The Wilderness Society ◆ Wilderness Workshop ◆ Rocky Mountain Wild ◆ Western Environmental Law Center ◆ Conservation Colorado ◆ San Juan Citizens Alliance ◆ Western Colorado Congress

November 14, 2016

Ruth Welch, State Director
BLM Colorado State Office□
2850 Youngfield Street
Lakewood, Colorado 80215-7093
Hand delivered

RE: Formal Protest of December 8, 2016 Oil and Gas Lease Sale

Dear Director Welch:

Please accept and fully consider this timely protest of BLM Colorado's fourth quarter oil and gas lease sale. This protest challenges BLM's Determination of NEPA Adequacy (DNA), DOI-BLM-CO-N040-2016-0044-DNA, and the agency's decision to proceed with the sale of new leases located in the Colorado River Valley and Grand Junction Field Offices, including parcels:

1. COC77994 (7584)
2. COC77995 (7585)
3. COC77996 (7586)
4. COC77997 (7587)
5. COC77998 (7588)
6. COC78000 (7598)
7. COC78001 (7599)
8. COC78010 (7600)
9. COC77989 (7602)
10. COC77987 (7603)
11. COC77988 (7604)
12. COC78002 (7611)
13. COC78003 (7612)
14. COC78004 (7613)
15. COC77990 (7614)
16. COC77991 (7615)
17. COC78005 (7616)
18. COC77992 (7617)
19. COC77993 (7618)
20. COC78006 (7620)
21. COC78007 (7622)
22. COC78008 (7625)
23. COC78009 (7626)
24. COC77981 (7629)
25. COC77999 (7917)

This protest is submitted on behalf of The Wilderness Society, Wilderness Workshop, Western Environmental Law Center, Conservation Colorado, Rocky Mountain Wild, San Juan Citizens Alliance, and Western Colorado Congress.

The undersigned groups previously submitted comments in February and June of 2016. In earlier comments we raised issues related to the appropriate level of analysis for these new proposed lease parcels, as well as issues related to specific values that must be considered and protected, and concerns about the adequacy of existing programmatic plans.

This protest underscores our concerns about BLM's decision not to undertake any site-specific analysis of proposed parcels, as well as BLM's failure to consider potential impacts of new oil and gas leasing on climate and the lack of existing analysis to support leasing these parcels. Our organizations are deeply invested in sound stewardship of our public lands. We ask that BLM not sell or issue the proposed parcels until an adequate analysis of potential impacts, including those related to climate, can be undertaken.

PROTESTING PARTIES

Wilderness Workshop ("WW") is a 501(c)(3) dedicated to preservation and conservation of the wilderness and natural resources of the White River National Forest and adjacent public lands, including the Colorado River Valley and the Grand Junction Field Offices. WW engages in research, education, legal advocacy and grassroots organizing to protect the ecological integrity of local landscapes and public lands. WW focuses on the monitoring and conservation of air and water quality, wildlife species and habitat, natural communities and lands of wilderness quality. WW was founded in 1967 and has approximately 800 members. Many of our members live, work, and recreate in and around, and otherwise use and enjoy lands managed by the BLM in the Colorado River Valley and Grand Junction Field Offices. All members have a great interest in the protection and enhancement of natural values in the area. WW has been closely monitoring proposals, developments, and management actions on local BLM lands for many years.

The Wilderness Society ("TWS") has a long-standing interest in the management of Bureau of Land Management lands in Colorado and engages frequently in the decision-making processes for land use planning and project proposals that could potentially affect wilderness-quality lands and other important natural resources managed by the BLM in Colorado. TWS members and staff enjoy a myriad of recreation opportunities on BLM-managed public lands, including hiking, biking, nature-viewing, photography, and the quiet contemplation in the solitude offered by wild places. Founded in 1935, our mission is to protect wilderness and inspire Americans to care for our wild places.

The **Western Environmental Law Center** ("WELC") uses the power of the law to defend and protect the American West's treasured landscapes, iconic wildlife and rural communities. WELC combines legal skills with sound conservation biology and environmental science to address major environmental issues in the West in the most strategic and effective manner. WELC works at the national, regional, state, and local levels; and in all three branches of government. WELC integrates national policies and regional perspective with the local knowledge of our 100+ partner groups to implement smart and appropriate place-based actions.

Western Colorado Congress ("WCC") is an alliance for community action empowering people to protect and enhance their quality of life in Western Colorado. We have been working for land conservation and the responsible use and development of our natural resources for 35 years. Our work is based in the local knowledge and experience of our members who live, work and play in western slope communities surrounded by public lands; WCC is here to empower their voices and concerns in regards to public land management.

Founded in 1986, **San Juan Citizens Alliance** ("SJCA") organizes people to protect our water and air, our lands, and the character of our rural communities in the San Juan Basin. SJCA focuses to ensure proper regulation and enforcement of the oil, gas, and coal industry and transitioning to a renewable energy economy. SJCA has been active in BLM and National Forest oil and gas issues in western Colorado since the 1980's, and comments regularly on multi-well drilling program, lease sale, and programmatic environmental review conducted in the region by the federal land management agencies. SJCA's members live, work, and recreate throughout the San Juan Basin and San Juan Mountains. SJCA's members' health, use and enjoyment of this region is directly impacted by the decisions made by federal agencies.

Conservation Colorado is a grassroots organization working to protect our air, land, water, and people. We have a long and successful history in Colorado of collaborating on the key environmental issues of the day, and establishing strategic partnerships to find conservation success at the state and federal levels. Our organization has a long history of working on public lands issues across Colorado, but specifically on BLM lands on Colorado's western slope. Among our thousands of members are those that live, work, recreate and enjoy the BLM lands of the Colorado River Valley and Grand Junction Field Offices for a wide variety of activities and have a vested interest in the management of those lands.

Rocky Mountain Wild ("RMW") is a non-profit environmental organization based in Denver, Colorado, that works to conserve and recover the native species and ecosystems of the Greater Southern Rockies using the best available science. RMW has a well-established history of participation in BLM planning and management activities. RMW works to save endangered species and preserve landscapes and critical ecosystems. It achieves these goals by working with biologists and landowners, utilizing GIS technology to promote understanding of complex land use issues, and monitoring government agencies whose actions affect endangered and threatened species. RMW's members and supporters include approximately 1,200 outdoor enthusiasts, wildlife conservationists, scientists, and concerned citizens across the country.

RMW's staff and members visit, recreate on, and use lands on or near the parcels proposed for leasing. Our staff and members enjoy various activities on or near land proposed for leasing, including viewing and studying rare and imperiled wildlife and native ecosystems, hiking, camping, taking photographs, and experiencing solitude. Our staff and members plan to return to the subject lands in the future to engage in these activities, and to observe and monitor rare and imperiled species and native ecosystems. We are collectively committed to ensuring that federal agencies properly manage rare and imperiled species and native ecosystems. Members and professional staff of RMW are conducting research and advocacy to protect the populations and habitat of rare and imperiled species discussed herein. Our members and staff value the important role that areas of high conservation value should play in safeguarding rare and imperiled species and natural communities, and other unique resources on public land.

Our members' interests in rare and imperiled species and ecosystems on BLM lands will be adversely affected if the sale of these parcels proceeds as proposed. Oil and gas leasing and subsequent mineral development on the protested parcels, if approved without response to public comments made under the National Environmental Policy Act ("NEPA"), consultation required by the Endangered Species Act ("ESA"), and appropriate safeguards to minimize negative impacts, is likely to result in a greatly increased risk of significant harm to rare and imperiled species and native ecosystems. As a result, BLM's decision to lease the protested parcels is not based on the best available science and will result in significant harm to rare and imperiled species and native ecosystems. The proposed leasing of the protested parcels will harm our members' interests in the continued use of these public lands, and the rare and imperiled species they support. Therefore protestors have legally recognizable interests that will be affected by the proposed action.

STATEMENT OF REASONS FOR PROTEST

I. BLM HAS FAILED TO TAKE THE HARD LOOK REQUIRED BY NEPA PRIOR TO ISSUING NEW OIL AND GAS LEASES.

The National Environmental Policy Act (NEPA) is our "basic national charter for the protection of the environment." 40 C.F.R. § 1500.1 NEPA achieves its purpose through "action forcing procedures. . . requir[ing] that agencies take a hard look at environmental consequences." Id.; *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 350 (1989) (citations omitted) (emphasis added). This includes the consideration of best available information and data, as well as disclosure of any inconsistencies with federal policies and plans. BLM must comply with its legal obligation to take a hard look at potential impacts. The following pages demonstrate how BLM has failed to comply with its obligations under NEPA.

Federal agencies must comply with NEPA before there are "any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented." 42 U.S.C. § 4332(C)(v); *see also* 40 C.F.R. §§ 1501.2, 1502.5(a).

The Tenth Circuit has held that site-specific analysis is required prior to issuing oil and gas leases where there is surface that is not protected by no-surface occupancy stipulations (NSOs) and where there is reasonable foreseeability of environmental impacts. *See e.g.*, *New Mexico ex rel. Richardson v. BLM*, 565 F.3d 683, 718 (10th Cir. 2009); *Pennaco Energy, Inc. v. United States DOI*, 377 F.3d 1147, 1160 (10th Cir. 2004). This is because oil and gas leases confer "the right to use so much of the leased lands as is necessary to explore for, drill for, mine, extract, remove and dispose of all the leased resource in a leasehold" and therefore would constitute an "irreversible and irretrievable commitment of resources." *New Mexico ex rel. Richardson*, 565 F.3d at 718; 40 C.F.R. § 3101.1-2; *see also Sierra Club v. Hodel*, 848 F.2d 1068, 1093 (10th Cir. 1988) (agencies are to perform hard look NEPA analysis "before committing themselves irretrievably to a given course of action so that the action can be shaped to account for environmental values").

Here, the BLM refused to perform site-specific analysis at the lease stage, and, once lease rights are conferred, BLM's authority will be limited to imposing mitigation measures consistent with the terms of the lease. Consequently, if BLM discovers significant impacts at the APD stage, it may no longer be able to prevent them. Because BLM is irretrievably committing resources at the lease sale stage, it must consider the impacts of its decision to lease parcels before it can confer public resources to a private developer in a lease.

NEPA further requires federal agencies to consider "any adverse environmental effects which cannot be avoided." 42 U.S.C. § 4332(C)(ii). In so doing, agencies must "identify and develop methods and procedures . . . which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decisionmaking along with economic and technical considerations." Id. § 4332(B).

To accomplish these purposes, NEPA requires that all federal agencies prepare a "detailed statement" regarding all "major federal actions significantly affecting the quality of the human environment." 42 U.S.C. § 4332(C). This statement, known as an Environmental Impact Statement ("EIS"), must, among other things, rigorously explore and objectively evaluate all reasonable alternatives, analyze all direct, indirect, and cumulative environmental impacts, and include a discussion of the means to mitigate adverse environmental impacts. 40 C.F.R. §§ 1502.14 and 1502.16. Any analysis must include consideration of connected, cumulative and similar actions. Id., at § 1508.25.

"Connected actions" are those which "[a]utomatically trigger other actions which may require environmental impact statements," or which "[c]annot or will not proceed unless other actions are taken previously or simultaneously, or that "[a]re interdependent parts of a larger action and depend on the larger action for their justification." Id. "Cumulative actions" are those "which when viewed with other proposed actions have cumulatively significant impacts and should therefore be discussed in the same impact statement." Id. "Similar actions" are defined as those which, when viewed with other reasonably foreseeable or proposed agency actions, have similarities that provide a basis for evaluating their environmental consequences together, such as common timing or geography. Id.

Direct effects include those that "are caused by the action and occur at the same time and place." 40 C.F.R. § 1508.8(a). Indirect effects include effects that "are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable." 40 C.F.R. § 1508.8(b). Cumulative effects are "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions." 40 C.F.R. § 1508.7. "Effects" are synonymous with "impacts." 40 C.F.R. § 1508.8.

Effects that must be considered include "ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative." 40 C.F.R. § 1508.8.

BLM's analysis must do more than merely identify impacts; it must also "evaluate the severity" of effects. *Robertson v. Methow Valley Citizens Council*, 490 U.S. 332, 352 (1989); 40 C.F.R. § 1502.16(a)-(b) (recognizing that agency must explain the "significance" of effects).

An agency may also prepare an EA to determine whether an EIS is necessary. 40 C.F.R. §§ 1501.3, 1508.9. An EA must include a discussion of alternatives and the environmental impacts of the action. 40 C.F.R. § 1508.9.

If an agency decides not to prepare an EIS, an EA must "provide sufficient evidence" to support a Finding of No Significant Impact ("FONSI"). 40 C.F.R. § 1508.9(a)(1). Such evidence must demonstrate that the action "will not have a significant effect on the human environment." 40 C.F.R. § 1508.13. An assessment of whether or not an impact is "significant" is based on a consideration of the "context and intensity" of the impact. 40 C.F.R. § 1508.27. "Context" refers to the scope of the proposed action, including the interests affected. 40 C.F.R. § 1508.27(a). "Intensity" refers to the severity of the impact and must be evaluated with a host of factors in mind, including but not limited to [u]nique characteristics of the geographic area[,]" "[t]he degree to which the possible effects on the human environment are highly uncertain or involve unique or unknown risks[,]" and "[w]hether the action threatens a violation of Federal, State, or local law or requirements imposed for the protection of the environment." 40 C.F.R. § 1508.27(b).

NEPA allows an agency to "tier" a site-specific environmental analysis for a project to a broader EIS for a program or plan under which the subsequent project is carried out. 40 C.F.R. § 1508.28. When an agency tiers a site-specific analysis to a broader EIS, "the subsequent statement or environmental assessment need only summarize the issues discussed in the broader statement and incorporate discussions from the broader statement by reference and shall concentrate on the issues specific to the subsequent action." 40 C.F.R. § 1502.20.

Here, though, BLM has not completed an EA to support issuing new leases but is instead relying on a Determination of NEPA Adequacy (DNA). DNAs, unlike EAs and EISs, are not NEPA documents. They do not analyze impacts, but rather determine the adequacy of existing NEPA documents. *See e.g., S. Utah Wilderness Alliance v. Norton*, 457 F. Supp. 2d 1253, 1261-62 (D. Utah 2006). In this case, BLM is relying on analysis undertaken in the Grand Junction and Colorado River Valley Field Office RMPs to support this leasing decision. As we stated in previous comments on this lease sale and as we discuss below, BLM's DNA cannot be used to support issuance of the proposed leases because existing analyses do not adequately consider potential impacts.

In March 2016, undersigned groups submitted scoping comments to BLM regarding the proposal to lease new parcels at the scheduled November sale (the sale was later rescheduled for December 8th and is the same lease sale at issue in this protest). The comments included a thorough lease-by-lease screen identifying important wildlife, wildland, and environmental values that could be impacted by issuance of the proposed parcels. The comments also included a list of recommended Best Management Practices (BMPs) for plants of concern. In addition the comments highlighted a number of issues that were not adequately addressed in applicable RMPs, including impacts related to climate change and potential impacts of oil and gas development on human health.[1] Our prior comments were submitted with the goal of helping inform BLM's site-specific analysis of the proposed lease sale.

There is no indication in the record that BLM did anything with our March 2016 scoping comments. The agency did not undertake any site-specific analysis of the proposed lease sale. Instead, last summer BLM released a draft DNA with no analysis at all. We commented on the draft DNA, raising concerns about the lack of analysis, values that had not been considered or protected, and about BLM's failure to address public comments received during scoping.[2]

A final DNA was then issued by BLM.[3] The final DNA acknowledged comments received during a 30-day public review period in June, but included no new analysis and still failed to acknowledge or

[1] *See* Scoping Comments on BLM's Proposed November 16, 2016 Oil and Gas Lease Sale from Wilderness Workshop, et al., to BLM Northwest Colorado District Office (March 10, 2016) and attachments (on file with BLM).

[2] *See* Comments on Draft DNAs for GJFO, CRVFO and TRFO November 2016 Lease Sale (DOI-BLM-CO-N040-2016-0044-DNA and DOI-BLM-CO-S010-2017-0001-DNA) from Wilderness Workshop, et al., to BLM (June 13, 2016) and Exhibits A-E (on file with BLM).

[3] U.S. Department of Interior, BLM, Colorado State Office, Grand Junction and Colorado River Valley Field Offices, December 2016 Oil and Gas Lease Sale Determination of NEPA Adequacy DOI-BLM-CO-N040-

respond to issues raised during scoping. The only discussion of specific values in the DNA is less than a page related to cultural resources.[4] Aside from that, the DNA includes no consideration of values or the adequacy of protections for those values. The document simply asserts that NEPA was done at the RMP level and leaves it at that.

Importantly, the RMP-level analyses already undertaken were broad—encompassing millions of acres—and intended to inform land management goals Field Office-wide. Because of the scale of an RMP analysis, it is coarse. BLM's proposed sale of new leases, however, is a discrete action that requires additional and more granular analysis. Some of the parcels the agency is proposing to sell are as small as 80-acres. Site-specific analysis is reasonable and appropriate before issuance of these new leases. Now is the opportunity to ensure that specific resources within the proposed leases are adequately considered and protected. *See New Mexico ex rel. Richardson*, 565 F.3d at 717 ("assessment of all 'reasonably foreseeable' impacts must occur at the earliest practicable point, and must take place before an 'irretrievable commitment of resources' is made"; where environmental impacts are reasonable foreseeable at the leasing stage, issuance of an oil and gas lease without an NSO stipulation constitutes an irretrievable commitment of resources).

Our review of proposed parcels and stipulations in the DNA shows that the proposed leases fail to adequately protect values identified in public comments. For example, after requesting GIS layers for proposed stipulations from BLM and comparing the stipulations to our own data on resource values, there are several gaps. Our GIS experts found that none of the proposed stipulations line up with the critical habitat for Parachute penstemon and DeBeque phacelia. Our review also found that there were no stipulations around Colorado Natural Heritage Program Potential Conservation Areas.[5]

After raising these concerns with field staff, we heard that stipulation mapping is not an exact science and that BLM does not have knowledge of each species' habitat or distribution for the entire field office. That may seem reasonable when considering broad land use decisions at the RMP stage, but it is not reasonable when BLM is contemplating issuance of new leases in defined areas—on the cusp of making an irretrievable commitment of publicly owned resources. 42 U.S.C. § 4332(2)(C)(v); *New Mexico ex rel. Richardson*, 565 F.3d at 717-18.

It also appears that leasing parcels COC77995 (7585), COC77996 (7586), COC77998 (7588), and COC77990 (7614) will impact the federally listed Colorado hookless cactus (Sclerocactus glaucus).[6] The failure to adequately analyze how leasing these parcels will impact this threatened

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2016-0044-DNA (July 2016), *available at* http://www.blm.gov/style/medialib/blm/co/programs/oil_and_gas/Lease_Sale/2016/november.Par.5323.File.dat/DNA_Dec16_GJFO_CRVFO_LeaseSale.pdf (last accessed 11/13/16).

[4] Interestingly, in the few sentences BLM dedicates to cultural resources in the GJFO and CRVFO, the agency admits that 82% of the proposed lease area has not been surveyed for cultural resources and that it found 74 eligible or potentially eligible sites in the small portion of the lease area that actually has been inventoried. *See* DOI-BLM-CO-N040-2016-0044-DNA (July 2016), at 7-8.

[5] *See* Exhibit E filed with June 13, 2016 Comments on Draft DNAs for GJFO, CRVFO and TRFO November 2016 Lease Sale (DOI-BLM-CO-N040-2016-0044-DNA and DOI-BLM-CO-S010-2017-0001-DNA) from Wilderness Workshop, et al. (on file with BLM).

[6] An additional parcel, number 7619, was considered for lease in the draft DNA, but appears to have been dropped from the sale by BLM. Parcel 7619 overlapped with Colorado hookless cactus habitat and raised the

species is concerning. In 2009, the Fish and Wildlife Service (FWS) issued a "Taxonomic Change of Sclerocactus Glaucus to Three Separate Species." 74 Fed. Reg. 47112, 47117 (Sept. 15, 2009). However, since then the FWS has failed to analyze whether these three new species require uplisting to endangered status based on the smaller populations and habitat. FWS has also failed to designate critical habitat for this species, which means the information provided by the Colorado Natural Heritage Program – and used in our GIS analysis of these parcels – may be the best information available to protect, conserve, and recover this listed species.

It is true that BLM proposed to include NSO stipulations on some parcels to protect some resources. However, those stipulations are not uniform, and our review of those stipulations suggests that they may not adequately protect the existing values. Despite the fact that we raised these concerns in comments, the DNA provides no explanation or analysis to support a determination that the resources will be adequately protected. And our communications with BLM, suggesting that the stipulation mapping they have undertaken is not an exact science, only underscore the problem.

By selling leases without more granular analysis than was conducted at the RMP-level, BLM runs the risk of irretrievably committing resources without adequate protections. There is no reason that BLM could not undertake actual analysis at the leasing stage to ensure a more thorough understanding of the on-the-ground resources. The agency has done so before and continues to do so in other places. It is just good policy. As it is, BLM's DNA fails to explicitly address our concerns and lacks specificity necessary to satisfy NEPA's hard look standard.

Requested Remedy: Before selling the proposed parcels, BLM must take the hard look required by NEPA. This includes undertaking site-specific NEPA that discloses and analyzes potential impacts to resources within the proposed lease parcels. Adequate analysis must also be accompanied by meaningful opportunities for public comment.

II. BLM'S DECISION TO IGNORE RELEVANT GUIDANCE UNDERSCORES NEPA VIOLATIONS ASSOCIATED WITH THE SALE OF THESE LEASES.

A. Instruction Memorandum 2010-117 does not allow BLM to use DNAs to sell the leases at issue.

BLM reformed its onshore oil and gas leasing program in 2010 to ensure leasing of federal mineral resources is conducted in a more environmentally responsible and transparent manner. BLM's new process for oil and gas leasing is set forth in Instruction Memorandum (IM) 2010-117 (May 17, 2010).[7] The process has three primary goals: (1) "create more certainty and predictability" in the leasing process; (2) "protect multiple-use values"; and (3) "provide for consideration of natural and cultural resources as well as meaningful public involvement." To achieve those goals, the reforms instituted a new lease parcel review and issuance process that provides for increased public participation and more thorough site-specific analysis.

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same concerns discussed here. We specifically addressed parcel 7619 in our previous comments, but we omitted discussion of that parcel here because it was not included in BLM's most recent notice.

[7] *Available at* http://www.blm.gov/wo/st/en/info/regulations/Instruction_Memos_and_Bulletins/national_instruction/2010/IM_2010-117.html (last accessed 11/13/16).

A critical component of the new leasing process is that BLM typically prepares Environmental Assessments (EAs) to analyze potential parcels for lease:

> Most parcels that the field office determines should be available for lease will require site-specific NEPA analysis. This analysis will typically take the form of an EA, which would be tiered, as appropriate, to the RMP/EIS or a MLP/EA or EIS, if one has been completed for any of the parcels.

IM 2010-117 at III(E); *see also* 42 U.S.C. § 4332(2)(C)(v); *New Mexico ex rel. Richardson*, 565 F.3d at 717-18.

BLM's new guidance also requires the agency to provide a 30-day public review and comment period for the EA and unsigned Finding of No Significant Impact (FONSI) before forwarding the leasing recommendation to the State Director. IM 2010-117 at III(E). BLM notes that the "process outlined in this IM—which includes site-specific parcel analysis and increased public participation—will help identify, address, and resolve most issues before the lease sale." Id. at III(H) (emphasis added).

For the December 2016 lease sale, however, BLM Colorado is relying on a DNA to approve the sale of new oil and gas leases. As discussed above, the DNA includes no analysis at all. BLM's rationale for relying on the DNA is that the Grand Junction and Colorado River Valley Field Offices recently completed RMP revisions. In addition to violating BLM's obligation to take a hard look, this practice reflects an inappropriate interpretation of IM 2010-117, and does not comply with the intent or spirit of the agency's leasing reforms.

RMPs do not provide the site-specific analysis envisioned by the leasing reforms, even if they have been recently revised. RMPs make broad decisions about resource allocations based on a broad analysis. The intention of the reforms is to take a closer look at specific parcels and resources prior to leasing them. As BLM Colorado's FAQ on oil and gas leasing states: "An EA augments the decisions made in an RMP with current on-the-ground information."[8] Site-specific information and analysis is critically important to reviewing lease parcels regardless of the age of the governing RMP. We note that BLM Wyoming is still preparing EAs for all of its lease sales, even in areas with recently-completed RMPs.[9]

This argument is reinforced by the agency's own comparison of oil and gas decisions made in RMPs to those made in Master Leasing Plans (MLPs). According to BLM, MLPs are a "**stepped-down leasing analysis**" that evaluates "in **greater detail** than the RMP the impacts of leasing and likely development" and identifies "**key issues** such as protection of air quality, watersheds, wilderness, wildlife, and nearby land uses" and "**leasing and higher-level development mitigation measures**

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[8] BLM Colorado, Oil and Gas Leasing Program "Frequently Asked Questions", http://www.blm.gov/co/st/en/BLM_Programs/oilandgas/Frequently_Asked_Questions_Leasing.html (last accessed 11/13/16).

[9] *See* BLM Wyoming, Oil and Gas Lease Sale information, http://www.blm.gov/wy/st/en/programs/energy/Oil_and_Gas/Leasing.html (note: BLM continues to process all lease sales through EAs rather than DNAs. For example, the Bighorn Basin RMP was completed in 2015 and yet BLM completes EAs to support leasing in that district).

to protect the environment."[10] These types of analyses are not incorporated into RMPs and must be considered at the leasing stage, which necessitates additional analysis.

BLM's guidance is clear that while existence of a Master Leasing Plan may allow for the agency to complete a DNA rather than an EA, no such exception exists for "new" RMPs. IM 2010-117 states that a DNA may be prepared for a proposed leasing action if the action is "adequately analyzed in an existing NEPA document, such as that prepared during the MLP process, and is in conformance with the approved RMP." Id., at III(E) (emphasis added). This provision clearly states BLM's intention that a DNA could be used where an MLP has been completed, but not simply where the action is in conformance with the approved RMP. Therefore, only where BLM has a robust MLP in place that was developed and is being implemented in compliance with IM 2010-117 and Chapter V of BLM's Handbook on Planning for Fluid Mineral Resources, a DNA may be appropriate for evaluating parcels for oil and gas lease sales rather than an EA.

Requested Remedy: BLM must complete EAs for oil and gas lease sales, in compliance with IM 2010-117 which directs that most parcels field offices determine should be available for lease will require site-specific NEPA analysis—typically an EA. BLM Colorado should set as a threshold for preparing a DNA rather than an EA that a robust MLP is in place that was developed and is being implemented in compliance with IM 2010-117 and Chapter V of BLM's Handbook on Planning for Fluid Mineral Resources. The Shale Ridges and Canyons MLP does not yet meet that threshold, but could in the future once BLM completes additional implementation-level planning for the MLP.

B. BLM failed to consider potential climate impacts of selling the new leases, despite clear guidance on how to examine those impacts.

BLM has never adequately considered the potential climate impacts of selling the proposed leases despite the fact that clear guidance exists to guide such analysis. Earlier this year, the Council on Environmental Quality (CEQ) released the long-awaited final guidance on considering greenhouse gas (GHG) emissions and the effects of climate change in NEPA reviews (hereafter, "Final Guidance").[11] The overarching goal of the guidance is to provide greater clarity and more consistency in how federal agencies address climate change in their NEPA reviews and to facilitate compliance with existing NEPA requirements.

The guidance recognizes that "[c]limate change is a fundamental environmental issue, and its effects fall squarely within NEPA's purview." The Final Guidance applies to all proposed federal agency actions, "including site-specific actions, certain funding of site-specific projects, rulemaking actions, permitting decisions, and land and resource management decisions." Id. at 9, 3.

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[10] BLM, Washington Office, Presentation on "Oil and Gas Leasing Reform," http://www.blm.gov/style/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/energy/leasing_reform.Par.54947.File.dat/Leasing_Reform_05-11-2011.pdf, at slide 8 (last accessed 11/13/16) (emphases in original).

[11] *See* CEQ, Memorandum for Heads of Departments and Agencies: "Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews," (Aug. 1, 2016), *available at* https://www.whitehouse.gov/sites/whitehouse.gov/files/documents/nepa_final_ghg_guidance.pdf (last accessed 11/13/16) (attached as Exhibit 1).

The Final Guidance underscores BLM's existing legal obligations to disclose and consider the foreseeable effects that, for example, oil and gas leasing and development has on climate change. In its Final Guidance, the CEQ recognized that:

> Climate change results from the incremental addition of GHG emissions from millions of individual sources, which collectively have a large impact on a global scale. CEQ recognizes that the totality of climate change impacts is not attributable to any single action, but are exacerbated by a series of actions including actions taken pursuant to decisions of the Federal Government. Therefore, a statement that emissions from a proposed Federal action represent only a small fraction of global emissions is essentially a statement about the nature of the climate change challenge, and is not an appropriate basis for deciding whether or to what extent to consider climate change impacts under NEPA. Moreover, these comparisons are also not an appropriate method for characterizing the potential impacts associated with a proposed action and its alternatives and mitigations because this approach does not reveal anything beyond the nature of the climate change challenge itself: the fact that diverse individual sources of emissions each make a relatively small addition to global atmospheric GHG concentrations that collectively have a large impact.

Id. at 10-11.

The guidance recognizes that identifying and analyzing the interactions between our changing climate and the environmental impacts from a proposed action can have a number of benefits, including identifying opportunities to reduce and mitigate GHG emissions, to improve environmental outcomes, and to help safeguard communities, infrastructure, and resources against the effects of climate change. Therefore, an analysis of climate change "should be similar to the analysis of other environmental impacts under NEPA." Id. at 2.

CEQ's Final Guidance also discusses the application of NEPA principles and practices to the analysis of GHG emissions and climate change, including: (1) that agencies quantify a proposed action's projected direct and indirect GHG emissions, taking into account available data and GHG quantification tools; (2) that agencies use projected GHG emissions as a proxy for assessing potential climate change effects when preparing a NEPA analysis; (3) where GHG emission tools, methodologies, or data inputs are not reasonably available, that agencies include a qualitative analysis in the NEPA document and explain the basis for determining that quantification is not reasonably available; (4) that agencies analyze foreseeable direct, indirect, and cumulative GHG emissions and climate effects; (5) that agencies consider reasonable alternatives and the short- and long-term effect and benefits in the alternatives and mitigation analysis; (6) that agencies consider alternatives that would make the actions and affected communities more resilient to the effects of a changing climate; and (7) that agencies assess the broad-scale effects of GHG emissions and climate change, either to inform programmatic decisions, or at both the programmatic and project-level. *See* id. at 4-6.

As a general approach, BLM should first assess and, wherever possible, quantify or estimate greenhouse gas (GHG) emissions by type and source by analyzing the direct operational impacts of their proposed actions. Assessment of direct emissions of GHG from on-site combustion sources is relatively straightforward. The indirect effects of a project may be more far-reaching and will require careful analysis. Within this category, agencies should evaluate, inter alia, GHG and GHG-precursor emissions associated with construction, electricity use, fossil fuel use, downstream combustion of fossil fuels extracted or refined by the project, water consumption, water pollution, waste disposal, transportation, the manufacture of building materials, and land conversion.

Climate change effects must be integrated into the NEPA analysis as part of the environmental baseline. Agencies are required under NEPA to "describe the environment of the areas to be affected or created by the alternatives under consideration." 40 C.F.R. § 1502.15. The current affected environment sets the "baseline" for the impacts analysis and comparison of alternatives. As the Ninth Circuit held, "without establishing the baseline conditions . . . there is simply no way to determine what effect the proposed [action] will have on the environment and, consequently, no way to comply with NEPA." *Half Moon Bay Fisherman's Marketing Ass'n v. Carlucci*, 857 F.2d 505, 510 (9th Cir. 1988). Excluding climate change effects from the environmental baseline ignores the reality that the impacts of proposed actions must be evaluated based on the already deteriorating, climate-impacted state of the resources, ecosystems, human communities, and structures that will be affected. Accordingly, existing and reasonably foreseeable climate change impacts must be included as part of the affected environment, assessed as part of the agency's hard look at impacts, and integrated into each of the alternatives, including the no action alternative. Simply acknowledging climate impacts as part of the affected environment is insufficient. Rather, agencies must incorporate that information into their hard look at impacts and comparison of alternatives.

BLM cannot make an informed decision about how much disturbance issuing new oil and gas leases will have on the region or what the degraded ecosystem can withstand under changing conditions without fully understanding the baseline and adequately assessing the action's direct, indirect, and cumulative effects. Direct effects are those "which are caused by the action and occur at the same time and place." 40 C.F.R. § 1508.8(a). Indirect effects are those "caused by the action, and later in time or further removed in distance, but still reasonably foreseeable." *S. Fork Band Council of W. Shoshone of Nev. v. U.S. Dep't of the Interior*, 588 F.3d 718, 725 (9th Cir. 2009) (quoting 40 C.F.R. § 1508.8(b)). Cumulative effects are the effects of the action in combination with "other past, present, and reasonably foreseeable future actions." *See Klamath-Siskiyou Wildlands Ctr. v. Bureau of Land Mgmt.*, 387 F.3d 989, 993 (9th Cir. 2004) (quoting 40 C.F.R. § 1508.7). As a result, NEPA requires agencies to assess the climate effects of direct emissions from a project, such as emissions from construction activities, the indirect environmental impacts, such as degraded air quality, and the long-term collective impacts caused by the project's development and continued activity.

The NEPA requirement to consider climate change has been repeatedly upheld by the courts. In *Center for Biological Diversity v. NHTSA*, the Ninth Circuit assessed an agency's NEPA analysis for a rule requiring automobile manufacturers to increase the fuel efficiency of their vehicles, thereby lowering average tailpipe emissions per mile driven. The Court stated that "[t]he impact of greenhouse gas emissions on climate change is precisely the kind of cumulative impacts analysis that NEPA requires agencies to conduct." *Ctr. for Biological Diversity*, 538 F.3d at 1217. 1223-25 (9th Cir. 2008). Likewise, in *Mid States Coalition for Progress v. Surface Transportation Board*, the Eighth Circuit held that NEPA requires an agency to disclose and analyze the impacts of future combustion of mined coal when deciding whether to approve a railroad line providing access to coal mining areas. 345 F.3d 520, 549-50 (8th Cir. 2003).

The CEQ guidance on considering climate change in NEPA analyses also provides that agencies should analyze reasonable alternatives that would mitigate both direct and indirect GHG emissions impacts, and the short- and long-term cumulative effects of climate change (e.g., enhanced energy efficiency, carbon sequestration, lower GHG-emitting technology). Final Guidance, at 13, 16.

BLM has never taken a hard look at the climate-related impacts of selling the proposed parcels in any existing analysis. The DNA that BLM is relying upon to support the sale of proposed leases contains no analysis of climate impacts at all. BLM claims that the Grand Junction and Colorado River Valley RMPs provide adequate analysis of potential climate impacts. BLM says that additional climate analysis, like calculating the social cost of carbon likely to result from development of the proposed leases, "would not be useful to the decisionmaker."[12] But this rationale fails because climate analyses in the underlying RMPs are inadequate and BLM has never actually considered the climate impacts of its oil and gas leasing activities on a programmatic scale.

The Colorado River Valley and Grand Junction RMPs never quantified or considered the full effects of oil and gas combustion emissions, and the costs that the full spectrum of oil and gas emissions impose on society. The RMPs also failed to quantify the scale of methane pollution from oil and gas emission sources, and underestimated by an order of magnitude the global warming potential of such emissions.

BLM excused the lack of analysis in the Colorado River Valley RMP/EIS by saying "[q]uantification of cumulative climate change impacts…is beyond the scope of this analysis." Colorado River Valley Proposed RMP at 4-56. BLM also stated, "It is not possible at this time to determine whether GHG emissions that would result from the project sources associated with the Proposed RMP would cause a significant impact" and that "it is not possible to determine the impact that GHG emissions from the Proposed RMP would have on global climate change." *Id.* at 4-52. These statements directly contravene the CEQ guidance; thus, supplemental climate analysis is necessary to support leasing under the Colorado River Valley RMP.

Similarly, the Grand Junction RMP/EIS lacks a full accounting of climate change impacts from decisions authorized under the RMP, including subsequent oil and gas leasing. The RMP states that "[t]he lack of scientific tools designed to predict climate change on regional or local scales limits the ability to quantify potential future impacts. Currently, the BLM does not have an established mechanism to accurately predict the effect of resource management-level decisions from this planning effort on global climate change." Grand Junction Proposed RMP at 6-15. Again, this statement directly contravenes the CEQ guidance and so supplemental climate analysis is necessary to support leasing under the Grand Junction RMP.

BLM is saying that site-specific analysis would not be useful prior to issuing the proposed leases and relying on RMPs that, by BLM's own admission, fail to assess all the impacts of new leasing. This approach could satisfy BLM's obligations under NEPA if there was a programmatic analysis that actually considered the cumulative impacts of BLM's leasing decisions, but BLM has never undertaken such a programmatic analysis of its oil and gas leasing program.

Several comments filed on the December 2016 lease sale raised concerns about cumulative impacts and asked BLM to undertake a programmatic analysis of its oil and gas leasing program to help resolve the lack of adequate analysis. BLM's response to those comments was simply: "The question whether BLM should prepare a programmatic analysis of GHG emissions and climate

[12] DOI-BLM-CO-N040-2016-0044-DNA (July 2016), at 165.

change impacts from federal fluid mineral leasing and development is outside the scope of the December 2016 leasing decision."[13] This response ignores the fact that continued leasing is part of a broader program for which the impacts have never been considered.

BLM's refusal to assess the impacts of selling these leases or the broader program is tantamount to a lease before you look, and that directly contravenes the intent of NEPA as well as relevant guidance issued under NEPA and other statutes. BLM has failed to take a hard look at the potential impacts of its decisions and, in so doing, appears to be overlooking the significant cumulative impacts associated with selling new oil and gas leases.

Requested Remedy: Because of the scale of the oil and gas leasing program and the nature of climate change, the appropriate way for BLM to consider impacts is at the nationwide, programmatic scale. Until BLM undertakes that broad, fact-based, hard look at the GHG pollution implications of oil and gas leasing, the agency should refrain from selling new leases. If BLM moves forward with leasing prior to completing programmatic analysis regarding climate change, BLM must at a minimum revise its analysis for this lease sale to include the following components before issuing these leases:

- Complete an EA or EIS to appropriately analyze climate change impacts and mitigation opportunities. This analysis must include methane emissions and social cost of carbon.
- Consider alternatives to mitigate GHG emissions and consider mitigation measures. Alternatives must allow the public and the decisionmaker to "compare the anticipated levels of GHG emissions from each alternative – including the no-action alternative – and mitigation actions. . . ."
- Evaluate direct/indirect impacts of GHG emissions, quantifying whenever possible.
- Evaluate end-use of fossil fuel extraction.
- Attach lease notices to preserve BLM's ability to impose mitigation or offsets at the APD stage, or to delay/disapprove development.

III. BLM'S FAILURE TO TAKE A HARD LOOK AT CLIMATE IMPACTS OF SELLING NEW LEASES IGNORES NATIONAL POLICY AND RECENT SCIENCE.

BLM has failed to internalize and consider national policy and science related to climate change. Some of this information is not new and the agency has ignored it. Some of this information is new and the agency has never considered it. Importantly, though, the agency's obligation to take a hard look necessitates consideration of relevant policy and science discussed below before selling the proposed leases.

National policy and statements addressing climate change have accelerated in recent years, as they should given the narrowing window of time to take meaningful action. Nonetheless, the federal government's recognition of climate change is not new. The Secretary of Interior stated, in Secretarial Order 3226, Evaluating Climate Change Impacts in Management Planning (January 19, 2001), that "[t]here is a consensus in the international community that global climate change is occurring and that it should be addressed in governmental decision making." Order 3226 established the responsibility of agencies to "consider and analyze potential climate change impacts when undertaking long-range planning exercises, when setting priorities for scientific research and

[13] DOI-BLM-CO-N040-2016-0044-DNA (July 2016), at 173.

investigations, when developing multi-year management plans, and/or when making major decisions regarding potential utilization of resources under the Department's purview."

In a 2007 report entitled *Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources*, the GAO concluded that the Department of the Interior had not provided specific guidance to implement Secretarial Order 3226, that officials were not even aware of Secretarial Order 3226, and that Secretarial Order 3226 had effectively been ignored.[14] This report led to Secretarial Order 3289, Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources (September 14, 2009), which reinstated the provisions of Order 3226, and recognized that "the realities of climate change require us to change how we manage land, water, fish and wildlife, and cultural heritage and tribal lands and resources we oversee," and acknowledged that the Department of the Interior is "responsible for helping protect the nation from the impacts of climate change." A month later, in Executive Order No. 13514, Federal Leadership in Environmental, Energy, and Economic Performance (Oct. 5, 2009), President Obama called on all federal agencies to "measure, report, and reduce their greenhouse gas emissions from direct and indirect activities." 74 Fed. Reg. 52,117 (Oct. 8, 2009). This directive was followed by Executive Order No. 13693, Planning for Federal Sustainability in the Next Decade (March 25, 2015), which reaffirmed the federal government's commitment to reducing GHG emissions. 80 Fed. Reg. 15,871 (March 25, 2015).

In 2009, the Environmental Protection Agency ("EPA") issued a finding that the changes in our climate caused by elevated concentrations of greenhouse gases in the atmosphere are reasonably anticipated to endanger the public health and welfare of current and future generations. EPA, Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act, 74 Fed. Reg. 66,496 (Dec. 15, 2009). The D.C. Circuit upheld this decision as supported by the vast body of scientific evidence on the subject. *See Coal. for Responsible Regulation, Inc. v. EPA.*, 684 F.3d 102, 120-22 (D.C. Cir. 2012).

Climate change has been intensively studied and acknowledged at the global, national, and regional scales. Climate change is being fueled by the human-caused release of greenhouse gas emissions, in particular carbon dioxide and methane. The Intergovernmental Panel on Climate Change ("IPCC") is a Nobel Prize-winning scientific body within the United Nations that reviews and assesses the most recent scientific, technical, and socio-economic information relevant to our understanding of climate change. In a 2014 report to policymakers, the IPCC provided a summary of our understanding of human-caused climate change. Among other things, the IPCC summarized:[15]

- Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.
- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

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[14] U.S. Government Accountability Office, Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources, GAO-07-863: (Aug 7, 2007), *available at* http://www.gao.gov/products/GAO-07-863 (last accessed 11/13/16).
[15] IPCC AR5, Summary for Policymakers (March 2014), *available at* http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf (attached as Exhibit 2) (last accessed 11/13/16).

- Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane, and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.
- In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate.
- Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive, and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.
- Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise.

Also in 2014, President Obama described climate change as an "urgent and growing threat . . . that will define the contours of this century more dramatically than any other."[16] That same year, the U.S. pledged to reduce its greenhouse gas ("GHG") emissions 26-28 percent below 2005 levels by 2020.[17] Since then, the President has also announced a new goal to cut methane emissions from the oil and gas sector by 40-45 percent below 2012 levels by 2025.[18]

In 2015, EPA acknowledged more recent scientific assessments that "highlight the urgency of addressing the rising concentrations of CO_2 in the atmosphere." 80 Fed. Reg. 64,661 (Oct. 23, 2015). President Obama also recognized, "ultimately, if we're going to prevent large parts of this Earth from becoming not only inhospitable but uninhabitable in our lifetimes, we're going to have to keep some fossil fuels in the ground rather than burn them and release more dangerous pollution into the sky."[19]

In his final State of the Union address earlier this year, President Obama again noted the federal government's commitment to fighting climate change, vowing "to accelerate the transition away from old, dirtier energy sources," and making a powerful promise "to change the way we manage

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[16] The White House, Remarks by the President at U.N. Climate Change Summit (Sept. 23, 2014), *available at* https://www.whitehouse.gov/the-press-office/2014/09/23/remarks-president-un-climate-change-summit (last accessed 11/13/16).
[17] U.S.-China Joint Announcement on Climate Change (Nov. 11, 2014), *available at* https://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change (last accessed 11/13/16) (attached as Exhibit 3).
[18] The White House, Climate Action Plan: Strategy to Reduce Methane Emissions (March 2014), *available at* https://www.whitehouse.gov/blog/2014/03/28/strategy-cut-methane-emissions (last accessed 11/13/16) (attached as Exhibit 4).
[19] The White House, Statement by the President on the Keystone XL Pipeline (Nov. 6, 2015), *available at* https://www.whitehouse.gov/the-press-office/2015/11/06/statement-president-keystone-xl-pipeline (last accessed 11/13/16) (attached as Exhibit 5).

our oil and coal resources so that they better reflect the costs they impose on taxpayers and our planet."[20]

The United States has also joined 194 other nations in recognizing "that climate change represents an urgent and potentially irreversible threat to human societies and the planet" and setting the goal of "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C."[21] The President ratified the Paris Agreement, along with China, on September 3, 2016.[22] The agreement entered into effect earlier this month.[23]

As discussed above, earlier this year the White House Council on Environmental Quality ("CEQ")—the federal agency tasked with managing the federal government's implementation of NEPA—recognized the unique nature of climate change and the challenges it imposed on NEPA compliance. *See* supra Section II.B. In so doing, CEQ issued guidance to help federal agencies adequately consider impacts of their decisions on climate.

Since the dawn of the industrial revolution a century ago, the average global temperature has risen some 1.6 degrees Fahrenheit. Most climatologists agree that, while the warming to date is already causing environmental problems, another 0.4 degree Fahrenheit rise in temperature, representing a global average atmospheric concentration of carbon dioxide ("CO_2") of 450 parts per million ("ppm"), could set in motion unprecedented changes in global climate and a significant increase in the severity of natural disasters—and could represent the point of no return.[24] In August 2016, the atmospheric concentration of CO_2 was approximately 402.25 ppm, up from 398.93 ppm the same month a year earlier.[25]

According to the National Oceanic and Atmospheric Administration ("NOAA"), "[t]he combined average temperature over global land and ocean surfaces for August 2016 was the highest for

[20] President Barack Obama, State of the Union (Jan. 12, 2016), *available at* https://www.whitehouse.gov/sotu (last accessed 11/13/16).

[21] United Nations Framework Convention on Climate Change, Conference of the Parties (Nov 30-Dec. 11, 2015), Adoption of the Paris Agreement, Art. 2, U.N. Doc. FCCC/CP/2015/L.9 (Dec. 12, 2015), *available at* http://unfccc.int/resource/docs/2015/cop21/eng/l09.pdf (accessed 11/13/16) ("Paris Agreement") (attached as Exhibit 6).

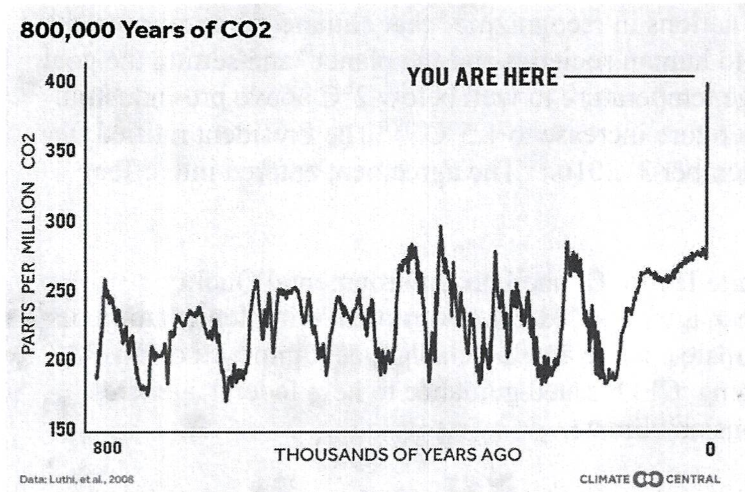
[22] The White House, President Obama: The United States Formally Enters the Paris Agreement (Sept. 3, 2016), *available at* https://www.whitehouse.gov/blog/2016/09/03/president-obama-united-states-formally-enters-paris-agreement (last accessed 11/13/16).

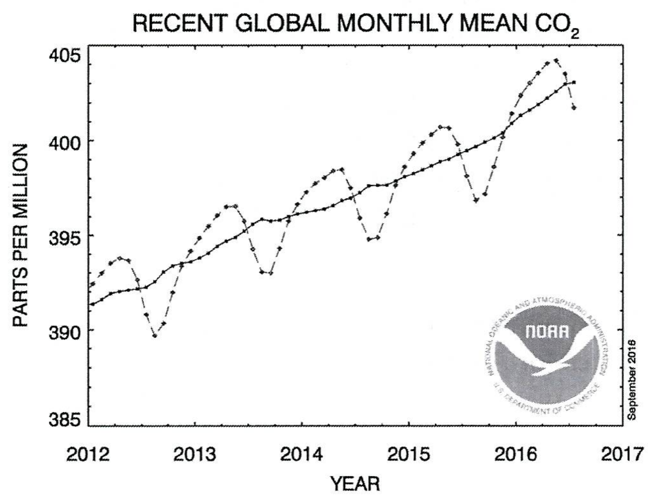
[23] Importantly, the President has recognized that "the Paris Agreement alone will not solve the climate crisis. Even if we meet every target embodied in the agreement, we'll only get to part of where we need to go." *See e.g,*. The White House, Office of the Press Secretary, Remarks by the President on the Paris Agreement (Oct. 5, 2016), *available at* https://www.whitehouse.gov/the-press-office/2016/10/05/remarks-president-paris-agreement (last accessed 11/13/16) (attached as Exhibit 7).

[24] *See* David Johnston, *Have We Passed the Point of No Return on Climate Change?*, Scientific American (April 2015), *available at* http://www.scientificamerican.com/article/have-we-passed-the-point-of-no-return-on-climate-change/ (last accessed 11/13/16) (attached as Exhibit 8).

[25] NOAA, Earth System Research Laboratory, Trends in Atmospheric Carbon Dioxide, *available at* http://www.esrl.noaa.gov/gmd/ccgg/trends/ (last accessed 11/13/16) (attached as Exhibit 9).

August in the 137-year period of record, marking the 16th consecutive month of record warmth for the globe."[26] The global climate crisis is happening and it is accelerating quickly.





The graphs show globally averaged historic and monthly mean carbon dioxide.

The IPCC has affirmed: "Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" causing "widespread impacts on human and natural systems."[27] This is consistent with the findings of the United States' 2014 Third National Climate Assessment, stating: "That the planet has warmed is 'unequivocal,' and is corroborated through multiple lines of evidence, as is the conclusion that the causes are very likely human in origin."[28] With particular regard to the Southwest Region—which includes Colorado, New Mexico,

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[26] NOAA, Global Analysis – August 2016, *available at* https://www.ncdc.noaa.gov/sotc/global/201608 (last accessed 11/13/16) (attached as Exhibit 10).
[27] IPCC AR5 Synthesis Report at 2 (attached as Exhibit 2).
[28] Jerry M. Melillo, et al., Climate Change Impacts in the United States: The Third National Climate Assessment (2014) at 61, *available at* http://nca2014.globalchange.gov (last accessed 11/13/16) (attached as Exhibit 11).

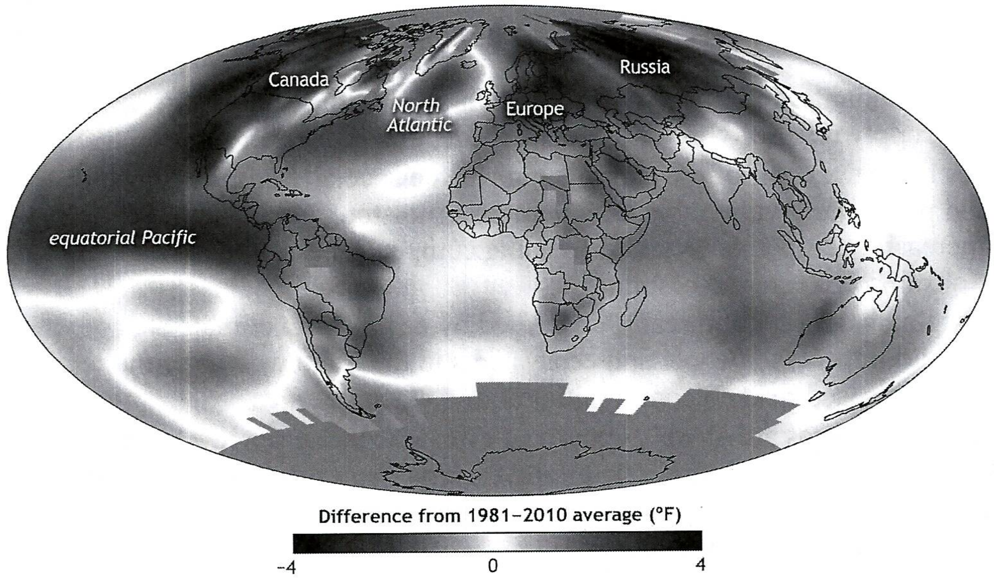
Utah, Arizona, Nevada, and California—the National Climate Assessment included in the following overview:[29]

- Snowpack and streamflow amounts are projected to decline in parts of the Southwest, decreasing surface water supply reliability for cities, agriculture, and ecosystems.
- The Southwest produces more than half of the nation's high-value specialty crops, which are irrigation-dependent and particularly vulnerable to extremes of moisture, cold, and heat. Reduced yields from increasing temperatures and increasing competition for scarce water supplies will displace jobs in some rural communities.
- Increased warming, drought, and insect outbreaks, all caused by or linked to climate change, have increased wildfires and impacts to people and ecosystems in the Southwest. Fire models project more wildfire and increased risks to communities across extensive areas.
- Flooding and erosion in coastal areas are already occurring even at existing sea levels and damaging some California coastal areas during storms and extreme high tides. Sea level rise is projected to increase as Earth continues to warm, resulting in major damage as wind-driven waves ride upon higher seas and reach farther inland.
- Projected regional temperature increases, combined with the way cities amplify heat, will pose increased threats and costs to public health in southwestern cities, which are home to more than 90% of the region's population. Disruptions to urban electricity and water supplies will exacerbate these health problems.

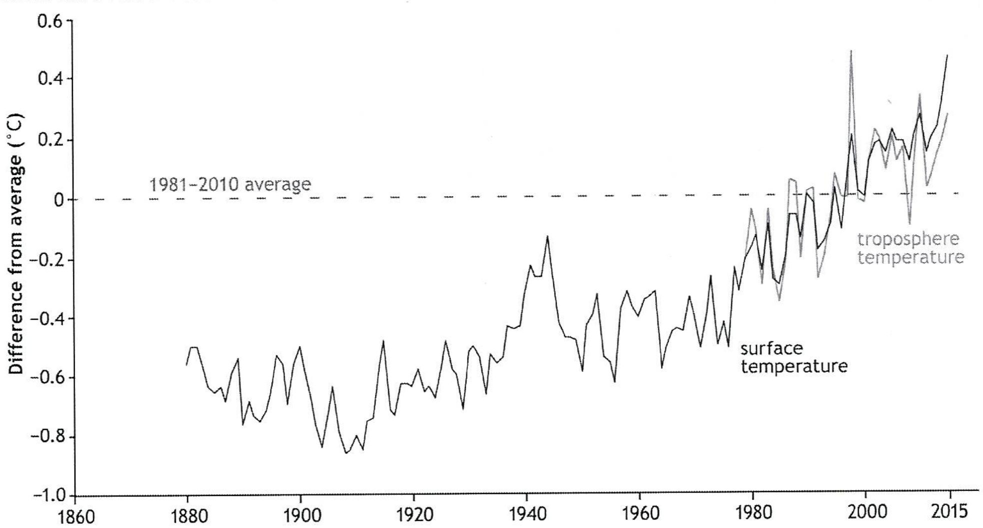
Immediate and substantial GHG reductions are required to avoid catastrophic impacts to people and communities. "Following the warmest year on record in 2014 according to most estimates, 2015 reached record warmth yet again, surpassing the previous record by more than 0.1°C."[30]

[29] *See* Third National Climate Assessment at 463-86 (attached as Exhibit 11).
[30] American Meteorological Society, State of the Climate in 2015, Vol.97, No.8 (Aug. 2016), at S7 (attached as Exhibit 12).

VERY FEW COOL SPOTS IN 2015



NEW HOTTEST YEAR ON RECORD



NOAA Climate.gov, adapted from State of the Climate 2015

As noted above, the Paris Agreement commits all signatories—including the United States—to a target holding long-term global average temperature "to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels."[31] As articulated by a team of international climate scientists, including Dr. James Hansen, in a 2013 report: "The widely accepted target of limiting human-made global warming to 2 degrees Celsius (3.6 degrees Fahrenheit) above preindustrial level is too high and would subject young people, future generations and nature to irreparable harm.... Observational data reveal that some climate extremes are already increasing in response to warming of several tenths of a degree in recent

[31] Paris Agreement at Art. 2 (attached as Exhibit 6).

decades; these extremes would likely be much enhanced with warming of 2°C or more."[32] "Runaway climate change—in which feedback loops drive ever-worsening climate change, regardless of human activities—are now seen as a risk even at 2°C of warming."[33] Indeed, the impacts of 2°C temperature rise have been "revised upwards, sufficiently so that 2°C now more appropriately represents the threshold between 'dangerous' and 'extremely dangerous' climate change."[34]

Although the Paris Agreement underscores the need for immediate action to avoid 'extremely dangerous' warming, meeting the voluntary commitments adopted in Paris alone will be insufficient to meet goal of limiting temperature change to between 1.5°C and 2.0°C above pre-industrial levels. In fact, the potential carbon emissions from *existing* fossil fuel reserves—the known belowground stock of extractable fossil fuels—considerably exceed both 2°C and 1.5°C of warming. "Estimated total fossil carbon reserves exceed this remaining [carbon budget] by a factor of 4 to 7."[35] "For the 2°C or 1.5°C limits, respectively 68% or 85% of reserves must remain in the ground."[36] The reserves in currently operating oil and gas fields alone, even with no coal, would take the world beyond 1.5°C.[37]

With specific regard to United States commitments under the Paris Agreement, the U.S. INDC set specific greenhouse gas emissions reduction target for 2025 of a 26% to 28% reduction below the 2005 emission levels, producing a range in 2005 net GHG emissions from 6,323 to 7,403 $MTCO_2e$.[38] The difference between this target and the estimated 2025 emissions without INDC policies results in an 'emissions gap' ranging from 896 to 2,121 $MTCO_2e$.[39]

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[32] James Hansen, *et al., Assessing "Dangerous Climate Change": Required Reduction of Carbon Emissions to Protect Young People, Future Generations and Nature,* 8 PLoS ONE 8 e81648 (2013) (attached as Exhibit 13).

[33] Greg Muttitt, *et al., The Sky's Limit: Why the Paris Climate Goals Require a Managed Decline of Fossil Fuel Production*, Oil Change International (Sept. 2016) at 6 (attached as Exhibit 14); *see also* David Spratt, *Climate Reality Check: After Paris, Counting the Cost* (March 2016) at 8 (attached as Exhibit 15) ("there is an unacceptable risk that before 2°C of warming, significant "long-term" feedbacks will be triggered, in which warming produces conditions that generate more warming, so that carbon sinks such as the oceans and forests become less efficient in storing carbon, and polar warming triggers the release of significant permafrost and clathrate carbon stores. Such an outcome could render ineffective human efforts to control the level of future warming to manageable proportions.").

[34] Kevin Anderson and Alice Bows, *Beyond 'Dangerous' Climate Change: Emission Scenarios for a New World*, Phil. Trans. R. Soc. (2011) (attached as Exhibit 16).

[35] IPCC AR5 Synthesis Report at 63 (attached as Exhibit 2).

[36] The Sky's Limit at 6 (attached as Exhibit 14); *see also* Kevin Anderson and Alice Bows, *Reframing the climate change challenge in light of post-2000 emission trends*, Phil. Trans. R. Soc. (2008) (attached as Exhibit 17) ("to provide a 93% mid-value probability of not exceeding 2°C, the concentration (of atmospheric greenhouse gases) would need to be stabilized at or below 350 parts per million carbon dioxide equivalent (ppm CO_2e)" compared to the current level of ~485 ppm CO_2e.).

[37] The Sky's Limit at 5, 17 (attached as Exhibit 14).

[38] Jeffery Greenblatt & Max Wei, Assessment of the climate commitments and additional mitigation policies of the Unites States, Nature Climate Change (Sept. 2016), *available at* http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate3125.html (last accessed 11/13/16) (attached as Exhibit 18).

[39] Greenblatt at 2 (attached as Exhibit 18); *see also* UNEP, The Emissions GAP Report (Nov. 2015) (attached as Exhibit 29).

Both the IPCC and National Climate Assessment recognize the dominant role of fossil fuels in driving climate change:

> While scientists continue to refine projections of the future, observations unequivocally show that climate is changing and that the warming of the past 50 years is primarily due to human-induced emissions of heat-trapping gases. These emissions come mainly from burning coal, oil, and gas, with additional contributions from forest clearing and some agricultural practices.[40]
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> CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% to the total GHG emission increase between 1970 and 2010, with a contribution of similar percentage over the 2000–2010 period (high confidence).[41]

As summarized in a recent report:

> The Paris Agreement aims to help the world avoid the worst effects of climate change and respond to its already substantial impacts. The basic climate science involved is simple: cumulative carbon dioxide (CO_2) emissions over time are the key determinant of how much global warming occurs. This gives us a finite carbon budget of how much may be emitted in total without surpassing dangerous temperature limits.[42]

According to the IPCC, as of 2011, the remaining carbon budget of cumulative CO_2 emissions from all anthropogenic sources must remain below 1,000 $GtCO_2$ to provide a 66% probability of limiting warming to 2°C above pre-industrial levels.[43] For years 2012-2014, approximately 107 $GtCO_2$ was emitted, averaging approximately 36 $GtCO_2$ per year, which left us at the start of 2016 with a carbon budget of only 850 $GtCO_2$.[44] These emissions were the highest in human history and 60% higher than in 1990 (the Kyoto Protocol reference year). Of course, the Paris Agreement's aim of limiting global warming to 1.5°C requires adherence to a more stringent carbon budget of only 400 $GtCO_2$ from 2011 onward, of which about 250 $GtCO_2$ remained at the start of 2016.[45] "With global annual emissions amounting to 36 $GtCO_2$ in 2015, scientists predict that at current rates global emissions will exceed the carbon budgets necessary to stay under the 1.5°C target by 2021 and the

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[40] Third National Climate Assessment at 2 (attached as Exhibit 11).
[41] IPCC AR5 Synthesis Report at 46 (attached as Exhibit 2).
[42] Greg Muttitt, et al., The Sky's Limit: Why the Paris Climate Goals Require a Managed Decline of Fossil Fuel Production, Oil Change International (Sept. 2016) at 6 (attached as Exhibit 14).
[43] IPCC AR5 Synthesis Report at 63-64 & Table 2.2 (attached as Exhibit 2). For an 80% probability of staying below 2°C, the budget from 2000 is 890 $GtCO_2$, with less than 430 $GtCO_2$ remaining. Malte Meinshausen et al., Greenhouse-gas emission targets for limiting global warming to 2°C, Nature (2009) at 1159 (attached as Exhibit 19).
[44] *See* Annual Global Carbon Emissions, *available at* https://www.co2.earth/global-co2-emissions (last accessed 11/13/16); *see also* C. Le Quéré, et al., Global Carbon Budget 2015, Earth Syst. Sci. Data (Dec. 2015) (attached as Exhibit 20).
[45] Dustin Mulvaney, et al., Over-Leased: How Production Horizons of Already Leased Federal Fossil Fuels Outlast Global Carbon Budgets, EcoShift Consulting (July 2016) (attached as Exhibit 21) at 2 (citing Joeri Rogelj, et al., Difference between carbon budget estimates unraveled, Nature Climate Change (2016) (attached as Exhibit 22).

2°C target by 2036.[46]

In order for the world to stay within a carbon budget consistent with Paris Agreement goals—"holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C"[47]—significant fossil fuel resources must remain in the ground. More specifically, to meet the target of 2°C, globally "a third of oil reserves, half of gas reserves and over 80 percent of current coal reserves should remain unused from 2010-2050."[48] Studies estimate that global coal, oil and gas resources considered currently economically recoverable contain potential greenhouse gas emissions of 4,196 $GtCO_2$,[49] with other estimates as high as 7,120 $GtCO_2$.[50]

Critically, the United States carbon quota—equivalent to 11% of the global carbon budget needed for a 50% chance of limiting warming to 2°C—allocates approximately 158 $GtCO_2$ to the United States as of 2011.[51] By way of comparison, federal and non-federal fossil fuel emissions together would produce between 697 and 1,070 $GtCO_2$.[52] Regarding just federal fossil fuel resources, the United States contains enough recoverable coal, oil and gas that, if extracted and burned, would result in as much as 492 $GtCO_2$, surpassing the entire global carbon budget for a 1.5°C target and nearly eclipsing the 2°C target—to say nothing of the United States 'share' of global emissions.[53] Unleased federal fossil fuels comprise 91% of these potential emissions, with already leased federal fossil fuels accounting for as much as 43 $GtCO_2$.[54]

In 2012, "the GHG emissions resulting from the extraction of fossil fuels from federal lands by private leaseholders totaled approximately 1,344 $MMTCO_2e$."[55] Between 2003 and 2014, approximately 25% of all United States and 3-4% of global fossil fuel greenhouse gas emissions are attributable to federal minerals leased and developed by the Department of the Interior.[56] Continued leasing and development of federal fossil fuel resources commits the world to 'extremely dangerous' warming well beyond the 2°C threshold. As one study put it, "the disparity between what resources and reserves exist and what can be emitted while avoiding a temperature rise greater

[46] Mulvaney at 2 (attached as Exhibit 21) (citing Oak Ridge National Laboratories, Carbon Dioxide Information Analysis Center (2015), available at: http://cdiac.ornl.gov/GCP/ (last accessed 11/13/16)).
[47] Paris Agreement Art. 2 (attached as Exhibit 6).
[48] Christophe McGlade & Paul Ekins, The geographical distribution of fossil fuels unused when limiting global warming to 2°C, Nature (Jan 2015) (attached as Exhibit 23).
[49] Michael Raupach, et al., Sharing a quota on cumulative carbon emissions, Nature Climate Change (Sept. 2014) (attached as Exhibit 24).
[50] IPCC AR5, Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014) at Table 7.2 (attached as Exhibit 25).
[51] Raupach at 875 (attached as Exhibit 24).
[52] Dustin Mulvaney, et al., The Potential Greenhouse Gas Emissions from U.S. Federal Fossil Fuels, EcoShift Consulting (Aug. 2015) at 16 (attached as Exhibit 26).
[53] Mulvaney (2015) at 16 (attached as Exhibit 26).
[54] Mulvaney (2015) at 16 (attached as Exhibit 26).
[55] Stratus Consulting, Greenhouse Gas Emissions from Fossil Energy Extracted from Federal Lands and Waters: An Update (Dec. 2014) at 9 (attached as Exhibit 27).
[56] *See* Energy Information Administration, Sales of Fossil Fuels Produced from Federal and Indian Lands, FY 2003 through FY 2014 (July 2015) (attached as Exhibit 28); *see also* Stratus Consulting (attached as Exhibit 27).

than the agreed 2°C limit is therefore stark."[57] In short, any new leasing of federal fossil fuel resources is inconsistent with a carbon budget that would seek to avoid catastrophic climate change.

The production horizons for already leased federal fossil fuel resources underscore how unwarranted any additional leasing is, and in turn how unreasonable new leasing is. Comparing these production horizons to dates at which carbon budgets would be exceeded if current emission levels continue:

- Federal crude oil already leased will continue producing for 34 years beyond the 1.5°C threshold and 19 years beyond the 2°C threshold;
- Federal natural gas already leased will continue producing 23 years beyond the 1.5°C threshold and 8 years beyond the 2°C threshold;
- Federal coal already leased will continue producing 20 years beyond the 1.5°C threshold and 5 years beyond the 2°C threshold.[58]

Simply put, the timeframe to avoid catastrophic climate change is short, and the management of our federal minerals is dangerously out of step with this reality. As noted above, the BLM has failed to consider any of this new information in its leasing decisions, and the agency has not taken a hard look at this information in any relevant analysis.

Choosing not to lease oil and gas parcels could be a very significant part of U.S. efforts to address climate change. If new leasing ceases and existing non-producing leases are not renewed, 12% of oil production could be avoided in 2025 and 65% could be avoided by 2040 while 6% of natural gas production could be avoided in 2025 and 59% could be avoided by 2040.[59] This avoided production would significantly reduce future U.S. emissions. Cessation of new and renewed leases for federal fossil fuel extraction could reduce CO_2 emissions by about 100 Mt per year by 2030.

The 100 Mt CO_2 emissions savings that could result from no leasing in 2030 compares favorably with EPA standards for light- and medium-vehicles that are expected to yield 200 Mt in CO2 savings in 2030, and with standards for heavy-duty vehicles that are expected to yield 70 Mt in CO2 savings in the same year. The 100 Mt CO_2 emissions reduction from leasing restrictions would be greater than either the emission reductions that the EPA expects to achieve through its existing regulation of oil and gas industry emissions or reductions the BLM expects to achieve from its proposed methane waste standards on oil and gas operations on federal land. Clearly, cessation of new and renewed leases could make an important contribution to U.S. climate change mitigation efforts.[60]

Here, BLM has failed to consider the impacts of climate change despite implications that selling new leases could have on national policy, and despite clear guidance requiring the agency to consider such impacts and describing how to undertake such consideration.

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[57] McGlade at 188 (attached as Exhibit 23).
[58] Mulvaney (2016) at 5 (attached as Exhibit 21).
[59] Peter Erickson and Michael Lazarus, *How Would Phasing Out U.S. Federal Leases for Fossil Fuel Extraction Affect CO2 Emissions and 2°C Goals?,* Stockholm Environmental Institute (2016) at 16, *available at* https://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-WP-2016-02-US-fossilfuel-leases.pdf (last accessed 11/13/16) (attached as Exhibit 30).
[60] Erickson (2016) at 27 (attached as Exhibit 30).

Requested Remedy: BLM must defer the sale of new oil and gas leases until the agency has undertaken a thorough hard look at potential climate impacts associated with its management of oil and gas. That analysis must consider national policies and recent science that BLM has never considered and that the agency has failed to internalize to date.

Conclusion: BLM has failed to take a hard look at the potential impacts of selling the proposed parcels. The agency has not undertaken the required site-specific analysis of individual parcels, and the agency has not considered the potential climate impacts of selling more oil and gas leases. BLM should consider remedies discussed above for the various problems plaguing this process. Until the problems discussed here are resolved, the agency should defer the sale of any new parcels.

Thank you,

Peter Hart, Staff Attorney
Wilderness Workshop□
PO Box 1442□
Carbondale, CO 81623□
www.wildernessworkshop.org□
970.963.3977
peter@wildernessworkshop.org

Juli Slivka, Planning Specialist
The Wilderness Society
1660 Wynkoop St. Ste. 850
Denver, CO 80202
www.wilderness.org
(303) 650-1179
juli_slivka@tws.org

Laura King, Staff Attorney
Western Environmental Law Center
103 Reeder's Alley
Helena, MT 59601

(406) 204-4852 (tel.)
king@westernlaw.org
www.westernlaw.org

Luke Schafer, West Slope Advocacy Director
Conservation Colorado
529 Yampa Ave□Craig, CO 81625
luke@conservationco.org
970-824-5241
www.conservationco.org

Matthew Sandler, Staff Attorney
Rocky Mountain Wild
1536 Wynkoop St., Suite 900
Denver, CO 80202
Phone: 303-579-5162
matt@rockymountainwild.org
www.rockymountainwild.org

Dave Reed, Executive Director
Western Colorado Congress
134 Nth 6th St
Grand Junction, CO
(970) 256-7650
dave@wccongress.org
www.wc**congress**.org

Jimbo Buickerood, Lands and Forest Protection Program Manager
San Juan Citizens Alliance
1309 East Third Avenue #5
PO Box 2461
Durango, CO 81302
970.259.3583 Ext. 2
jimbo@sanjuancitizens.org
sanjuancitizens.org

Exhibit 1

EXECUTIVE OFFICE OF THE PRESIDENT
COUNCIL ON ENVIRONMENTAL QUALITY
WASHINGTON, D.C. 20503

August 1, 2016

MEMORANDUM FOR HEADS OF FEDERAL DEPARTMENTS AND AGENCIES

FROM: CHRISTINA GOLDFUSS
COUNCIL ON ENVIRONMENTAL QUALITY

SUBJECT: Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews

I. INTRODUCTION

The Council on Environmental Quality (CEQ) issues this guidance to assist Federal agencies in their consideration of the effects of greenhouse gas (GHG) emissions[1] and climate change when evaluating proposed Federal actions in accordance with the National Environmental Policy Act (NEPA) and the CEQ Regulations Implementing the Procedural Provisions of NEPA (CEQ Regulations).[2] This guidance will facilitate compliance with existing NEPA requirements, thereby improving the efficiency and consistency of reviews of proposed Federal actions for agencies, decision makers, project proponents, and the public.[3] The guidance provides Federal agencies a common

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[1] For purposes of this guidance, CEQ defines GHGs in accordance with Section 19(m) of Exec. Order No. 13693, Planning for Federal Sustainability in the Next Decade, 80 Fed. Reg. 15869, 15882 (Mar. 25, 2015) (carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride, and sulfur hexafluoride). Also for purposes of this guidance, "emissions" includes release of stored GHGs as a result of land management activities affecting terrestrial GHG pools such as, but not limited to, carbon stocks in forests and soils, as well as actions that affect the future changes in carbon stocks. The common unit of measurement for GHGs is metric tons of CO_2 equivalent (mt CO_2-e).

[2] *See* 42 U.S.C. 4321 et seq.; 40 CFR Parts 1500–1508.

[3] This guidance is not a rule or regulation, and the recommendations it contains may not apply to a particular situation based upon the individual facts and circumstances. This guidance does not change or substitute for any law, regulation, or other legally binding

approach for assessing their proposed actions, while recognizing each agency's unique circumstances and authorities.[4]

Climate change is a fundamental environmental issue, and its effects fall squarely within NEPA's purview.[5] Climate change is a particularly complex challenge given its global nature and the inherent interrelationships among its sources, causation, mechanisms of action, and impacts. Analyzing a proposed action's GHG emissions and the effects of climate change relevant to a proposed action—particularly how climate change may change an action's environmental effects—can provide useful information to decision makers and the public.

CEQ is issuing the guidance to provide for greater clarity and more consistency in how agencies address climate change in the environmental impact assessment process. This guidance uses longstanding NEPA principles because such an analysis should be similar to the analysis of other environmental impacts under NEPA. The guidance is intended to assist agencies in disclosing and considering the reasonably foreseeable effects of proposed actions that are relevant to their decision-making processes. It confirms that agencies should provide the public and decision makers with explanations of the basis for agency determinations.

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requirement, and is not legally enforceable. The use of non-mandatory language such as "guidance," "recommend," "may," "should," and "can," is intended to describe CEQ policies and recommendations. The use of mandatory terminology such as "must" and "required" is intended to describe controlling requirements under the terms of NEPA and the CEQ regulations, but this document does not affect legally binding requirements.

[4] This guidance also addresses recommendations offered by a number of stakeholders. *See* President's State, Local, and Tribal Leaders Task Force on Climate Preparedness and Resilience, *Recommendations to the President* (November 2014), p. 20 (recommendation 2.7), *available at* www.whitehouse.gov/sites/default/files/docs/task_force_report_0.pdf; U.S. Government Accountability Office, *Future Federal Adaptation Efforts Could Better Support Local Infrastructure Decision Makers*, (Apr. 2013), *available at* http://www.gao.gov/assets/660/653741.pdf. Public comments on drafts of this guidance document are available at http://www.whitehouse.gov/administration/eop/ceq/initiatives/nepa/comments.

[5] NEPA recognizes "the profound impact of man's activity on the interrelations of all components of the natural environment." (42 U.S.C. 4331(a)). It was enacted to, *inter alia,* "promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man." (42 U.S.C. 4321).

Focused and effective consideration of climate change in NEPA reviews[6] will allow agencies to improve the quality of their decisions. Identifying important interactions between a changing climate and the environmental impacts from a proposed action can help Federal agencies and other decision makers identify practicable opportunities to reduce GHG emissions, improve environmental outcomes, and contribute to safeguarding communities and their infrastructure against the effects of extreme weather events and other climate-related impacts.

Agencies implement NEPA through one of three levels of NEPA analysis: a Categorical Exclusion (CE); an Environmental Assessment (EA); or an Environmental Impact Statement (EIS). This guidance is intended to help Federal agencies ensure their analysis of potential GHG emissions and effects of climate change in an EA or EIS is commensurate with the extent of the effects of the proposed action.[7] Agencies have discretion in how they tailor their individual NEPA reviews to accommodate the approach outlined in this guidance, consistent with the CEQ Regulations and their respective implementing procedures and policies.[8] CEQ does not expect that implementation of this guidance will require agencies to develop new NEPA implementing procedures. However, CEQ recommends that agencies review their NEPA procedures and propose any updates they deem necessary or appropriate to facilitate their consideration of GHG emissions and climate change.[9] CEQ will review agency

[6] The term "NEPA review" is used to include the analysis, process, and documentation required under NEPA. While this document focuses on NEPA reviews, agencies are encouraged to analyze GHG emissions and climate-resilient design issues early in the planning and development of proposed actions and projects under their substantive authorities.

[7] *See* 40 CFR 1502.2(b) (Impacts shall be discussed in proportion to their significance); 40 CFR 1502.15 (Data and analyses in a statement shall be commensurate with the importance of the impact…).

[8] *See* 40 CFR 1502.24 (Methodology and scientific accuracy).

[9] *See* 40 CFR 1507.3. Agency NEPA implementing procedures can be, but are not required to be, in the form of regulation. Section 1507.3 encourages agencies to publish explanatory guidance, and agencies also should consider whether any updates to explanatory guidance are necessary. Agencies should review their policies and implementing procedures and revise them as necessary to ensure full compliance with NEPA.

proposals for revising their NEPA procedures, including any revision of CEs, in light of this guidance.

As discussed in this guidance, when addressing climate change agencies should consider: (1) The potential effects of a proposed action on climate change as indicated by assessing GHG emissions (e.g., to include, where applicable, carbon sequestration);[10] and, (2) The effects of climate change on a proposed action and its environmental impacts.

This guidance explains the application of NEPA principles and practices to the analysis of GHG emissions and climate change, and

- Recommends that agencies quantify a proposed agency action's projected direct and indirect GHG emissions, taking into account available data and GHG quantification tools that are suitable for the proposed agency action;
- Recommends that agencies use projected GHG emissions (to include, where applicable, carbon sequestration implications associated with the proposed agency action) as a proxy for assessing potential climate change effects when preparing a NEPA analysis for a proposed agency action;
- Recommends that where agencies do not quantify a proposed agency action's projected GHG emissions because tools, methodologies, or data inputs are not reasonably available to support calculations for a quantitative analysis, agencies include a qualitative analysis in the NEPA document and explain the basis for determining that quantification is not reasonably available;

[10] Carbon sequestration is the long-term carbon storage in plants, soils, geologic formations, and oceans.

- Discusses methods to appropriately analyze reasonably foreseeable direct, indirect, and cumulative GHG emissions and climate effects;
- Guides the consideration of reasonable alternatives and recommends agencies consider the short- and long-term effects and benefits in the alternatives and mitigation analysis;
- Advises agencies to use available information when assessing the potential future state of the affected environment in a NEPA analysis, instead of undertaking new research, and provides examples of existing sources of scientific information;
- Counsels agencies to use the information developed during the NEPA review to consider alternatives that would make the actions and affected communities more resilient to the effects of a changing climate;
- Outlines special considerations for agencies analyzing biogenic carbon dioxide sources and carbon stocks associated with land and resource management actions under NEPA;
- Recommends that agencies select the appropriate level of NEPA review to assess the broad-scale effects of GHG emissions and climate change, either to inform programmatic (e.g., landscape-scale) decisions, or at both the programmatic and tiered project- or site-specific level, and to set forth a reasoned explanation for the agency's approach; and
- Counsels agencies that the "rule of reason" inherent in NEPA and the CEQ Regulations allows agencies to determine, based on their expertise and

experience, how to consider an environmental effect and prepare an analysis based on the available information.

II. BACKGROUND

A. NEPA

NEPA is designed to promote consideration of potential effects on the human environment[11] that would result from proposed Federal agency actions, and to provide the public and decision makers with useful information regarding reasonable alternatives[12] and mitigation measures to improve the environmental outcomes of Federal agency actions. NEPA ensures that the environmental effects of proposed actions are taken into account before decisions are made and informs the public of significant environmental effects of proposed Federal agency actions, promoting transparency and accountability concerning Federal actions that may significantly affect the quality of the human environment. NEPA reviews should identify measures to avoid, minimize, or mitigate adverse effects of Federal agency actions. Better analysis and decisions are the ultimate goal of the NEPA process.[13]

Inherent in NEPA and the CEQ Regulations is a "rule of reason" that allows agencies to determine, based on their expertise and experience, how to consider an environmental effect and prepare an analysis based on the available information. The usefulness of that information to the decision-making process and the public, and the

[11] 40 CFR 1508.14 ("'Human environment' shall be interpreted comprehensively to include the natural and physical environment and the relationship of people with that environment.").
[12] 40 CFR 1508.25(b) ("Alternatives, which include: (1) No action alternative. (2) Other reasonable courses of actions. (3) Mitigation measures (not in the proposed action).").
[13] 40 CFR 1500.1(c) ("Ultimately, of course, it is not better documents but better decisions that count. NEPA's purpose is not to generate paperwork—even excellent paperwork—but to foster excellent action. The NEPA process is intended to help public officials make decisions that are based on understanding of environmental consequences, and take actions that protect, restore, and enhance the environment.").

extent of the anticipated environmental consequences are important factors to consider when applying that "rule of reason."

B. Climate Change

Climate change science continues to expand and refine our understanding of the impacts of anthropogenic GHG emissions. CEQ's first Annual Report in 1970 referenced climate change, indicating that "[m]an may be changing his weather."[14] At that time, the mean level of atmospheric carbon dioxide (CO_2) had been measured as increasing to 325 parts per million (ppm) from an average of 280 ppm pre-Industrial levels.[15] Since 1970, the concentration of atmospheric carbon dioxide has increased to approximately 400 ppm (2015 globally averaged value).[16] Since the publication of CEQ's first Annual Report, it has been determined that human activities have caused the carbon dioxide content of the atmosphere of our planet to increase to its highest level in at least 800,000 years.[17]

It is now well established that rising global atmospheric GHG emission concentrations are significantly affecting the Earth's climate. These conclusions are built upon a scientific record that has been created with substantial contributions from the

[14] *See* CEQ, *Environmental Quality The First Annual Report*, p. 93 (August 1970); *available at* https://ceq.doe.gov/ceq_reports/annual_environmental_quality_reports.html.
[15] *See* USGCRP, *Climate Change Impacts in the United States The Third National Climate Assessment* (Jerry M. Melillo, Terese (T.C.) Richmond, & Gary W. Yohe eds., 2014) [hereinafter "Third National Climate Assessment"], *Appendix 3 Climate Science Supplement*, p. 739; EPA, April 2015: *Inventory of U.S. Greenhouse Emissions and Sinks 1990-2013, available at* https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf. *See also* Hartmann, D.L., A.M.G. Klein Tank, M. Rusticucci, et al., *2013 Observations Atmosphere and Surface. In Climate Change 2013 The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K., et al. (eds)]. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA. *Available at* http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter02_Final.pdf.
[16] *See* Ed Dlugokencky & Pieter Tans, National Oceanic and Atmospheric Administration/Earth System Research Laboratory, http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html.
[17] *See* http://earthobservatory.nasa.gov/Features/CarbonCycle; University of California Riverside, National Aeronautics and Space Administration (NASA), and Riverside Unified School District, *Down to Earth Climate Change*, http://globalclimate.ucr.edu/resources.html; USGCRP, *Third National Climate Assessment, Appendix 3 Climate Science Supplement*, p. 736 ("Although climate changes in the past have been caused by natural factors, human activities are now the dominant agents of change. Human activities are affecting climate through increasing atmospheric levels of heat-trapping gases and other substances, including particles.").

United States Global Change Research Program (USGCRP), which informs the United States' response to global climate change through coordinated Federal programs of research, education, communication, and decision support.[18] Studies have projected the effects of increasing GHGs on many resources normally discussed in the NEPA process, including water availability, ocean acidity, sea-level rise, ecosystem functions, energy production, agriculture and food security, air quality and human health.[19]

Based primarily on the scientific assessments of the USGCRP, the National Research Council, and the Intergovernmental Panel on Climate Change, in 2009 the Environmental Protection Agency (EPA) issued a finding that the changes in our climate caused by elevated concentrations of greenhouse gases in the atmosphere are reasonably anticipated to endanger the public health and public welfare of current and future generations.[20] In 2015, EPA acknowledged more recent scientific assessments that "highlight the urgency of addressing the rising concentration of CO_2 in the atmosphere," finding that certain groups are especially vulnerable to climate-related effects.[21] Broadly

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[18] *See* Global Change Research Act of 1990, Pub. L. 101–606, Sec. 103 (November 16, 1990). For additional information on the United States Global Change Research Program [hereinafter "USGCRP"], visit http://www.globalchange.gov. The USGCRP, formerly the Climate Change Science Program, coordinates and integrates the activities of 13 Federal agencies that conduct research on changes in the global environment and their implications for society. The USGCRP began as a Presidential initiative in 1989 and was codified in the Global Change Research Act of 1990 (Public Law 101–606). USGCRP-participating agencies are the Departments of Agriculture, Commerce, Defense, Energy, Interior, Health and Human Services, State, and Transportation; the U.S. Agency for International Development, the Environmental Protection Agency, NASA, the National Science Foundation, and the Smithsonian Institution.

[19] *See* USGCRP, *Third National Climate Assessment, available at* http://nca2014.globalchange.gov/system/files_force/downloads/low/NCA3_Climate_Change_Impacts_in_the_United%20States_LowRes.pdf?download=1; IPCC, *Climate Change 2014 Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (R.K. Pachauri, & L.A. Meyer eds., 2014), *available at* https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf; *see also* http://www.globalchange.gov; 40 CFR 1508.8 (effects include ecological, aesthetic, historic, cultural, economic, social, and health effects); USGCRP, *The Impacts of Climate Change on Human Health in the United States A Scientific Assessment, available at* https://health2016.globalchange.gov/.

[20] *See generally Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act*, 74 Fed. Reg. 66496 (Dec. 15, 2009). (For example, at 66497-98: "[t]he evidence concerning how human-induced climate change may alter extreme weather events also clearly supports a finding of endangerment, given the serious adverse impacts that can result from such events and the increase in risk, even if small, of the occurrence and intensity of events such as hurricanes and floods. Additionally, public health is expected to be adversely affected by an increase in the severity of coastal storm events due to rising sea levels").

[21] *See* EPA, *Final Rule for Carbon Pollution Emission Guidelines for Existing Stationary Sources Electric Utility Generating Units*, 80 Fed. Reg. 64661, 64677 (Oct. 23, 2015) ("Certain groups, including children, the elderly, and the poor, are most vulnerable to climate-related effects. Recent studies also find that certain communities, including low-income communities and some communities of color … are disproportionately affected by certain climate change related impacts—including heat waves, degraded air quality, and

stated, the effects of climate change observed to date and projected to occur in the future include more frequent and intense heat waves, longer fire seasons and more severe wildfires, degraded air quality, more heavy downpours and flooding, increased drought, greater sea-level rise, more intense storms, harm to water resources, harm to agriculture, ocean acidification, and harm to wildlife and ecosystems.[22]

III. CONSIDERING THE EFFECTS OF GHG EMISSIONS AND CLIMATE CHANGE

This guidance is applicable to all Federal actions subject to NEPA, including site-specific actions, certain funding of site-specific projects, rulemaking actions, permitting decisions, and land and resource management decisions.[23] This guidance does not – and cannot – expand the range of Federal agency actions that are subject to NEPA. Consistent with NEPA, Federal agencies should consider the extent to which a proposed action and its reasonable alternatives would contribute to climate change, through GHG emissions, and take into account the ways in which a changing climate may impact the proposed action and any alternative actions, change the action's environmental effects over the lifetime of those effects, and alter the overall environmental implications of such actions.

This guidance is intended to assist agencies in disclosing and considering the effects of GHG emissions and climate change along with the other reasonably foreseeable environmental effects of their proposed actions. This guidance does not establish any

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extreme weather events—which are associated with increased deaths, illnesses, and economic challenges. Studies also find that climate change poses particular threats to the health, well-being, and ways of life of indigenous peoples in the U.S.").

[22] *See* http://www.globalchange.gov/climate-change/impacts-society and Third National Climate Assessment, Chapters 3-15 (Sectors) and Chapters 16-25 (Regions), *available at* http://nca2014.globalchange.gov/downloads.

[23] *See* 40 CFR 1508.18.

particular quantity of GHG emissions as "significantly" affecting the quality of the human environment or give greater consideration to the effects of GHG emissions and climate change over other effects on the human environment.

A. GHG Emissions as a Proxy for the Climate Change Impacts of a Proposed Action

In light of the global scope of the impacts of GHG emissions, and the incremental contribution of each single action to global concentrations, CEQ recommends agencies use the projected GHG emissions associated with proposed actions as a proxy for assessing proposed actions' potential effects on climate change in NEPA analysis.[24] This approach, together with providing a qualitative summary discussion of the impacts of GHG emissions based on authoritative reports such as the USGCRP's National Climate Assessments and the Impacts of Climate Change on Human Health in the United States, a Scientific Assessment of the USGCRP, allows an agency to present the environmental and public health impacts of a proposed action in clear terms and with sufficient information to make a reasoned choice between no action and other alternatives and appropriate mitigation measures, and to ensure the professional and scientific integrity of the NEPA review.[25]

Climate change results from the incremental addition of GHG emissions from millions of individual sources,[26] which collectively have a large impact on a global scale.

[24] *See* 40 CFR 1502.16, 1508.9.
[25] *See* 40 CFR 1500.1, 1502.24 (requiring agencies to use high quality information and ensure the professional and scientific integrity of the discussions and analyses in environmental impact statements).
[26] Some sources emit GHGs in quantities that are orders of magnitude greater than others. *See* EPA, *Greenhouse Gas Reporting Program 2014 Reported Data*, Figure 2: Direct GHG Emissions Reported by Sector (2014), *available at* https://www.epa.gov/ghgreporting/ghgrp-2014-reported-data (amounts of GHG emissions by sector); *Final Rule for Carbon Pollution Emission Guidelines for Existing Stationary Sources Electric Utility Generating Units*, 80 Fed. Reg. 64661, 64663, 64689 (Oct. 23, 2015) (regulation of GHG emissions from fossil fuel-fired electricity generating power plants); *Oil and Natural Gas Sector Emission Standards for New, Reconstructed, and Modified Sources*, 81 Fed. Reg. 34824, 35830 (June 3, 2016 (regulation of GHG emissions from oil and gas sector).

CEQ recognizes that the totality of climate change impacts is not attributable to any single action, but are exacerbated by a series of actions including actions taken pursuant to decisions of the Federal Government. Therefore, a statement that emissions from a proposed Federal action represent only a small fraction of global emissions is essentially a statement about the nature of the climate change challenge, and is not an appropriate basis for deciding whether or to what extent to consider climate change impacts under NEPA. Moreover, these comparisons are also not an appropriate method for characterizing the potential impacts associated with a proposed action and its alternatives and mitigations because this approach does not reveal anything beyond the nature of the climate change challenge itself: the fact that diverse individual sources of emissions each make a relatively small addition to global atmospheric GHG concentrations that collectively have a large impact. When considering GHG emissions and their significance, agencies should use appropriate tools and methodologies for quantifying GHG emissions and comparing GHG quantities across alternative scenarios. Agencies should not limit themselves to calculating a proposed action's emissions as a percentage of sector, nationwide, or global emissions in deciding whether or to what extent to consider climate change impacts under NEPA.

1. GHG Emissions Quantification and Relevant Tools

This guidance recommends that agencies quantify a proposed agency action's projected direct and indirect GHG emissions. Agencies should be guided by the principle that the extent of the analysis should be commensurate with the quantity of projected GHG emissions and take into account available data and GHG quantification tools that are suitable for and commensurate with the proposed agency action.[27] The rule of reason and the concept of proportionality caution against providing an in-depth analysis of emissions regardless of the insignificance of the quantity of GHG emissions that would be caused by the proposed agency action.

Quantification tools are widely available, and are already in broad use in the Federal and private sectors, by state and local governments, and globally.[28] Such quantification tools and methodologies have been developed to assist institutions, organizations, agencies, and companies with different levels of technical sophistication, data availability, and GHG source profiles. When data inputs are reasonably available to support calculations, agencies should conduct GHG analysis and disclose quantitative estimates of GHG emissions in their NEPA reviews. These tools can provide estimates of GHG emissions, including emissions from fossil fuel combustion and estimates of GHG emissions and carbon sequestration for many of the sources and sinks potentially affected by proposed resource management actions.[29] When considering which tool(s) to employ, it is important to consider the proposed action's temporal scale, and the availability of input data.[30] Examples of the kinds of methodologies agencies might consider using are presented in CEQ's 2012 Guidance for Accounting and Reporting GHG Emissions for a wide variety of activities associated with Federal agency operations.[31] When an agency determines that quantifying GHG emissions would not be

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[27] *See* 40 CFR 1500.1(b) ("Most important, NEPA documents must concentrate on the issues that are truly significant to the action in question, rather than amassing needless detail."); 40 CFR 1502.2(b) (Impacts shall be discussed in proportion to their significance); 40 CFR 1502.15 (Data and analyses in a statement shall be commensurate with the importance of the impact…).
[28] *See* https://ceq.doe.gov/current_developments/GHG-accounting-tools.html.
[29] For example, USDA's COMET-Farm tool can be used to assess the carbon sequestration of existing agricultural activities along with the reduction in carbon sequestration (emissions) of project-level activities, http://cometfarm.nrel.colostate.edu/. Examples of other tools are available at https://ceq.doe.gov/current_developments/GHG-accounting-tools.html.
[30] *See* 40 CFR 1502.22.
[31] *See*
https://www.whitehouse.gov/sites/default/files/microsites/ceq/revised_federal_greenhouse_gas_accounting_and_reporting_guidance_

warranted because tools, methodologies, or data inputs are not reasonably available, the agency should provide a qualitative analysis and its rationale for determining that the quantitative analysis is not warranted. A qualitative analysis can rely on sector-specific descriptions of the GHG emissions of the category of Federal agency action that is the subject of the NEPA analysis.

When updating their NEPA procedures[32] and guidance, agencies should coordinate with CEQ to identify 1) the actions that normally warrant quantification of their GHG emissions, and consideration of the relative GHG emissions associated with alternative actions and 2) agency actions that normally do not warrant such quantification because tools, methodologies, or data inputs are not reasonably available. The determination of the potential significance of a proposed action remains subject to agency practice for the consideration of context and intensity, as set forth in the CEQ Regulations.[33]

2. The Scope of the Proposed Action

In order to assess effects, agencies should take account of the proposed action – including "connected" actions[34] – subject to reasonable limits based on feasibility and practicality. Activities that have a reasonably close causal relationship to the Federal action, such as those that may occur as a predicate for a proposed agency action or as a consequence of a proposed agency action, should be accounted for in the NEPA analysis.

060412.pdf. Federal agencies' Strategic Sustainability Performance Plans reflecting their annual GHG inventories and reports under Executive Order 13514 are available at https://www.performance.gov/node/3406/view?view=public#supporting-info.

[32] *See* 40 CFR 1507.3.

[33] 40 CFR 1508.27 ("'Significantly' as used in NEPA requires considerations of both context and intensity: (a) Context. This means that the significance of an action must be analyzed in several contexts such as society as a whole (human, national), the affected region, the affected interests, and the locality. . . . (b) Intensity. This refers to the severity of impact.").

[34] 40 CFR 1508.25(a) (Actions are connected if they: (i) Automatically trigger other actions which may require environmental impact statements; (ii) Cannot or will not proceed unless other actions are taken previously or simultaneously, or; (iii) Are interdependent parts of a larger action and depend on the larger action for their justification.).

For example, NEPA reviews for proposed resource extraction and development projects typically include the reasonably foreseeable effects of various phases in the process, such as clearing land for the project, building access roads, extraction, transport, refining, processing, using the resource, disassembly, disposal, and reclamation. Depending on the relationship between any of the phases, as well as the authority under which they may be carried out, agencies should use the analytical scope that best informs their decision making.

The agency should focus on significant potential effects and conduct an analysis that is proportionate to the environmental consequences of the proposed action.[35] Agencies can rely on basic NEPA principles to determine and explain the reasonable parameters of their analyses in order to disclose the reasonably foreseeable effects that may result from their proposed actions.[36]

3. Alternatives

Considering alternatives, including alternatives that mitigate GHG emissions, is fundamental to the NEPA process and accords with NEPA Sections 102(2)(C) and 102(2)(E).[37] The CEQ regulations emphasize that the alternatives analysis is the heart of the EIS under NEPA Section 102(2)(C).[38] NEPA Section 102(2)(E) provides an independent requirement for the consideration of alternatives in environmental documents.[39] NEPA calls upon agencies to use the NEPA process to "identify and assess the reasonable alternatives to proposed actions that will avoid or minimize adverse effects of these actions upon the quality of the human environment."[40] The requirement to

[35] *See* 40 CFR 1501.7(a)(3), 1502.2(b), and 1502.15.
[36] *See* 40 CFR 1502.16.
[37] 42 U.S.C. 4332(2)(C), 4332(2)(E); 40 CFR 1502.14, 1508.9(b).
[38] 40 CFR 1502.14.
[39] *See* 40 CFR 1500.2, 1508.9(b).
[40] 40 CFR 1500.2(c).

consider alternatives ensures that agencies account for approaches with no, or less, adverse environmental effects for a particular resource.

Consideration of alternatives also provides each agency decision maker the information needed to examine other possible approaches to a particular proposed action (including the no action alternative) that could alter the environmental impact or the balance of factors considered in making the decision. Agency decisions are aided when there are reasonable alternatives that allow for comparing GHG emissions and carbon sequestration potential, trade-offs with other environmental values, and the risk from – and resilience to – climate change inherent in a proposed action and its design.

Agencies must consider a range of reasonable alternatives consistent with the level of NEPA review (e.g., EA or EIS) and the purpose and need for the proposed action, as well as reasonable mitigation measures if not already included in the proposed action or alternatives.[41] Accordingly, a comparison of these alternatives based on GHG emissions and any potential mitigation measures can be useful to advance a reasoned choice among alternatives and mitigation actions. When conducting the analysis, an agency should compare the anticipated levels of GHG emissions from each alternative – including the no-action alternative – and mitigation actions to provide information to the public and enable the decision maker to make an informed choice.

Agencies should consider reasonable alternatives and mitigation measures to reduce action-related GHG emissions or increase carbon sequestration in the same fashion as they consider alternatives and mitigation measures for any other environmental effects. NEPA, the CEQ Regulations, and this guidance do not require the decision

[41] *See* 42 U.S.C. 4332(2)(C), 4332(2)(E), and 40 CFR 1502.14(f), 1508.9(b). The purpose and need for action usually reflects both the extent of the agency's statutory authority and its policies.

maker to select the alternative with the lowest net level of emissions. Rather, they allow for the careful consideration of emissions and mitigation measures along with all the other factors considered in making a final decision.

4. Direct and Indirect Effects

If the direct and indirect GHG emissions can be quantified based on available information, including reasonable projections and assumptions, agencies should consider and disclose the reasonably foreseeable direct and indirect emissions when analyzing the direct and indirect effects of the proposed action.[42] Agencies should disclose the information and any assumptions used in the analysis and explain any uncertainties.

To compare a project's estimated direct and indirect emissions with GHG emissions from the no-action alternative, agencies should draw on existing, timely, objective, and authoritative analyses, such as those by the Energy Information Administration, the Federal Energy Management Program, or Office of Fossil Energy of the Department of Energy.[43] In the absence of such analyses, agencies should use other available information. When such analyses or information for quantification is unavailable, or the complexity of comparing emissions from various sources would make quantification overly speculative, then the agency should quantify emissions to the extent that this information is available and explain the extent to which quantified emissions information is unavailable while providing a qualitative analysis of those emissions. As

[42] For example, where the proposed action involves fossil fuel extraction, direct emissions typically include GHGs emitted during the process of exploring for or extracting the fossil fuel. The indirect effects of such an action that are reasonably foreseeable at the time would vary with the circumstances of the proposed action. For actions such as a Federal lease sale of coal for energy production, the impacts associated with the end-use of the fossil fuel being extracted would be the reasonably foreseeable combustion of that coal.

[43] For a current example, see Office of Fossil Energy, Nat'l Energy Tech. Lab., U.S. Dep't of Energy, *Life Cycle Greenhouse Gas Perspective on Exporting Liquefied Natural Gas from the United States*, Pub. No. DOE/NETL-2014/1649 (2014), *available at* http://energy.gov/sites/prod/files/2014/05/f16/Life%20Cycle%20GHG%20Perspective%20Report.pdf.

with any NEPA analysis, the level of effort should be proportionate to the scale of the emissions relevant to the NEPA review.

5. Cumulative Effects

"Cumulative impact" is defined in the CEQ Regulations as the "impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions."[44] All GHG emissions contribute to cumulative climate change impacts. However, for most Federal agency actions CEQ does not expect that an EIS would be required based *solely* on the global significance of cumulative impacts of GHG emissions, as it would not be consistent with the rule of reason to require the preparation of an EIS for every Federal action that may cause GHG emissions regardless of the magnitude of those emissions.

Based on the agency identification and analysis of the direct and indirect effects of its proposed action, NEPA requires an agency to consider the cumulative impacts of its proposed action and reasonable alternatives.[45] As noted above, for the purposes of NEPA, the analysis of the effects of GHG emissions is essentially a cumulative effects analysis that is subsumed within the general analysis and discussion of climate change impacts. Therefore, direct and indirect effects analysis for GHG emissions will adequately address the cumulative impacts for climate change from the proposed action and its alternatives and a separate cumulative effects analysis for GHG emissions is not needed.

6. Short- and Long-Term Effects

[44] 40 CFR 1508.7.

[45] *See* 40 CFR 1502.16, 1508.7, 1508.8. *See also* CEQ Memorandum to Heads of Federal Agencies, *Guidance on the Consideration of Past Actions in Cumulative Effects Analysis*, June 24, 2005, *available at* https//ceq.doe.gov/nepa/regs/Guidance_on_CE.pdf.

When considering effects, agencies should take into account both the short- and long-term adverse and beneficial effects using a temporal scope that is grounded in the concept of reasonable foreseeability. Some proposed actions will have to consider effects at different stages to ensure the direct effects and reasonably foreseeable indirect effects are appropriately assessed; for example, the effects of construction are different from the effects of the operations and maintenance of a facility.

Biogenic GHG emissions and carbon stocks from some land or resource management activities, such as a prescribed burn of a forest or grassland conducted to limit loss of ecosystem function through wildfires or insect infestations, may result in short-term GHG emissions and loss of stored carbon, while in the longer term a restored, healthy ecosystem may provide long-term carbon sequestration. Therefore, the short- and long-term effects should be described in comparison to the no action alternative in the NEPA review.

7. Mitigation

Mitigation is an important component of the NEPA process that Federal agencies can use to avoid, minimize, and compensate for the adverse environmental effects associated with their actions. Mitigation, by definition, includes avoiding impacts, minimizing impacts by limiting them, rectifying the impact, reducing or eliminating the impacts over time, or compensating for them.[46] Consequently, agencies should consider reasonable mitigation measures and alternatives as provided for under existing CEQ Regulations and take into account relevant agency statutory authorities and policies. The NEPA process is also intended to provide useful advice and information to State, local

[46] *See* 40 CFR 1508.20, 1508.25 (Alternatives include mitigation measures not included in the proposed action).

and tribal governments and private parties so that the agencies can better coordinate with other agencies and organizations regarding the means to mitigate effects of their actions.[47] The NEPA process considers the effects of mitigation commitments made by project proponents or others and mitigation required under other relevant permitting and environmental review regimes.[48]

As Federal agencies evaluate potential mitigation of GHG emissions and the interaction of a proposed action with climate change, the agencies should also carefully evaluate the quality of that mitigation to ensure it is additional, verifiable, durable, enforceable, and will be implemented.[49] Agencies should consider the potential for mitigation measures to reduce or mitigate GHG emissions and climate change effects when those measures are reasonable and consistent with achieving the purpose and need for the proposed action. Such mitigation measures could include enhanced energy efficiency, lower GHG-emitting technology, carbon capture, carbon sequestration (e.g., forest, agricultural soils, and coastal habitat restoration), sustainable land management practices, and capturing or beneficially using GHG emissions such as methane.

Finally, the CEQ Regulations and guidance recognize the value of monitoring to ensure that mitigation is carried out as provided in a record of decision or finding of no significant impact.[50] The agency's final decision on the proposed action should identify those mitigation measures that the agency commits to take, recommends, or requires

[47] NEPA directs Federal agencies to make "advice and information useful in restoring, maintaining, and enhancing the quality of the environment" available to States, Tribes, counties, cities, institutions and individuals. NEPA Sec. 102(2)(G).
[48] *See* CEQ Memorandum to Heads of Federal Agencies, *Appropriate Use of Mitigation and Monitoring and Clarifying the Appropriate Use of Mitigated Findings of No Significant Impact,* 76 FR 3843 (Jan. 21, 2011) *available at* https://ceq.doe.gov/current_developments/docs/Mitigation_and_Monitoring_Guidance_14Jan2011.pdf.
[49] *See* Presidential Memorandum: *Mitigating Impacts on Natural Resources from Development and Encouraging Related Private Investment* (https://www.whitehouse.gov/the-press-office/2015/11/03/mitigating-impacts-natural-resources-development-and-encouraging-related) defining "durability" and addressing additionality.
[50] *See* 40 CFR 1505.2(c), 1505.3. *See also* CEQ Memorandum to Heads of Federal Agencies, *Appropriate Use of Mitigation and Monitoring and Clarifying the Appropriate Use of Mitigated Findings of No Significant Impact,* 76 FR 3843 (Jan. 21, 2011) *available at* https://ceq.doe.gov/current_developments/docs/Mitigation_and_Monitoring_Guidance_14Jan2011.pdf.

others to take. Monitoring is particularly appropriate to confirm the effectiveness of mitigation when that mitigation is adopted to reduce the impacts of a proposed action on affected resources already increasingly vulnerable due to climate change.

B. CONSIDERING THE EFFECTS OF CLIMATE CHANGE ON A PROPOSED ACTION AND ITS ENVIRONMENTAL IMPACTS

According to the USGCRP and others, GHGs already in the atmosphere will continue altering the climate system into the future, even with current or future emissions control efforts.[51] Therefore, a NEPA review should consider an action in the context of the future state of the environment. In addition, climate change adaptation and resilience — defined as adjustments to natural or human systems in response to actual or expected climate changes — are important considerations for agencies contemplating and planning actions with effects that will occur both at the time of implementation and into the future.[52]

1. Affected Environment

An agency should identify the affected environment to provide a basis for comparing the current and the future state of the environment as affected by the proposed action or its reasonable alternatives.[53] The current and projected future state of the environment without the proposed action (i.e., the no action alternative) represents the reasonably foreseeable affected environment, and this should be described based on

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[51] *See* Third National Climate Assessment, *Appendix 3 Climate Science Supplement* 753-754, *available at* http://s3.amazonaws.com/nca2014/low/NCA3_Full_Report_Appendix_3_Climate_Science_Supplement_LowRes.pdf?download=1.
[52] *See* Third National Climate Assessment, Chapter 28, "Adaptation" and Chapter 26, "Decision Support: Connecting Science, Risk Perception, and Decisions," *available at* http://www.globalchange.gov/nca3-downloads-materials; see also, Exec. Order No. 13653, 78 Fed. Reg. 66817 (Nov. 6, 2013) and Exec. Order No.13693, *Planning for Federal Sustainability in the Next Decade*, 80 Fed. Reg. 15869 (Mach 25, 2015) (defining "climate-resilient design").
[53] *See* 40 CFR 1502.15 (providing that environmental impact statements shall succinctly describe the environmental impacts on the area(s) to be affected or created by the alternatives under consideration).

authoritative climate change reports,[54] which often project at least two possible future scenarios.[55] The temporal bounds for the state of the environment are determined by the projected initiation of implementation and the expected life of the proposed action and its effects.[56] Agencies should remain aware of the evolving body of scientific information as more refined estimates of the impacts of climate change, both globally and at a localized level, become available.[57]

2. Impacts

The analysis of climate change impacts should focus on those aspects of the human environment that are impacted by both the proposed action and climate change. Climate change can make a resource, ecosystem, human community, or structure more susceptible to many types of impacts and lessen its resilience to other environmental impacts apart from climate change. This increase in vulnerability can exacerbate the effects of the proposed action. For example, a proposed action may require water from a stream that has diminishing quantities of available water because of decreased snow pack in the mountains, or add heat to a water body that is already warming due to increasing atmospheric temperatures. Such considerations are squarely within the scope of NEPA and can inform decisions on whether to proceed with, and how to design, the proposed action to eliminate or mitigate impacts exacerbated by climate change. They can also

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[54] *See, e.g.,* Third National Climate Assessment (Regional impacts chapters) *available at* http://www.globalchange.gov/nca3-downloads-materials.

[55] *See, e.g.,* Third National Climate Assessment (Regional impacts chapters, considering a low future global emissions scenario, and a high emissions scenario) *available at* http://www.globalchange.gov/nca3-downloads-materials.

[56] CEQ, *Considering Cumulative Effects Under the National Environmental Policy Act* (1997), https://ceq.doe.gov/publications/cumulative_effects html. Agencies should also consider their work under Exec. Order No. 13653, *Preparing the United States for the Impacts of Climate Change*, 78 Fed. Reg. 66817 (Nov. 6, 2013), that considers how capital investments will be affected by a changing climate over time.

[57] *See, e.g.,* http://nca2014.globalchange.gov/report/regions/coasts.

inform possible adaptation measures to address the impacts of climate change, ultimately enabling the selection of smarter, more resilient actions.

3. Available Assessments and Scenarios

In accordance with NEPA's rule of reason and standards for obtaining information regarding reasonably foreseeable effects on the human environment, agencies need not undertake new research or analysis of potential climate change impacts in the proposed action area, but may instead summarize and incorporate by reference the relevant scientific literature.[58] For example, agencies may summarize and incorporate by reference the relevant chapters of the most recent national climate assessments or reports from the USGCRP.[59] Particularly relevant to some proposed actions are the most current reports on climate change impacts on water resources, ecosystems, agriculture and forestry, health, coastlines, and ocean and arctic regions in the United States.[60] Agencies may recognize that scenarios or climate modeling information (including seasonal, inter-annual, long-term, and regional-scale projections) are widely used, but when relying on a single study or projection, agencies should consider their limitations and discuss them.[61]

4. Opportunities for Resilience and Adaptation

As called for under NEPA, the CEQ Regulations, and CEQ guidance, the NEPA review process should be integrated with agency planning at the earliest possible time that would allow for a meaningful analysis.[62] Information developed during early

[58] *See* 40 CFR 1502.21 (material may be incorporated by reference if it is reasonably available for inspection by potentially interested persons during public review and comment).
[59] *See* http://www.globalchange.gov/browse/reports.
[60] *See* Third National Climate Assessment, *Our Changing Climate*, *available at* http://nca2014.globalchange.gov/report. Agencies should consider the latest final assessments and reports when they are updated.
[61] *See* 40 CFR 1502.22. Agencies can consult www.data.gov/climate/portals for model data archives, visualization tools, and downscaling results.
[62] *See* 42 U.S.C. 4332 ("agencies of the Federal Government shall ... utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision-making"); 40 CFR 1501.2 ("Agencies shall integrate the NEPA process with other planning at the earliest possible time..."); *See also* CEQ Memorandum

planning processes that precede a NEPA review may be incorporated into the NEPA review. Decades of NEPA practice have shown that integrating environmental considerations with the planning process provides useful information that program and project planners can consider in the design of the proposed action, alternatives, and potential mitigation measures. For instance, agencies should take into account increased risks associated with development in floodplains, avoiding such development wherever there is a practicable alternative, as required by Executive Order 11988 and Executive Order 13690.[63] In addition, agencies should take into account their ongoing efforts to incorporate environmental justice principles into their programs, policies, and activities, including the environmental justice strategies required by Executive Order 12898, as amended, and consider whether the effects of climate change in association with the effects of the proposed action may result in a disproportionate effect on minority and low income communities.[64] Agencies also may consider co-benefits of the proposed action, alternatives, and potential mitigation measures for human health, economic and social stability, ecosystem services, or other benefit that increases climate change preparedness or resilience. Individual agency adaptation plans and interagency adaptation strategies, such as agency Climate Adaptation Plans, the National Fish, Wildlife and Plants Climate Adaptation Strategy, and the National Action Plan: Priorities for Managing Freshwater

for Heads of Federal Departments and Agencies, *Improving the Process for Preparing Efficient and Timely Environmental Reviews under the National Environmental Policy Act*, 77 Fed. Reg. 14473 (Mar. 12, 2012), *available at* https://ceq.doe.gov/current_developments/docs/Improving_NEPA_Efficiencies_06Mar2012.pdf.

[63] *See* Exec. Order No. 11988, "Floodplain Management," 42 Fed. Reg. 26951 (May 24, 1977), *available at* http://www.archives.gov/federal-register/codification/executive-order/11988.html; Exec. Order No. 13690, *Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input*, 80 Fed. Reg. 6425 (Jan. 30, 2015), *available at* https://www.gpo.gov/fdsys/pkg/FR-2015-02-04/pdf/2015-02379.pdf.

[64] *See* Exec. Order No. 12898, *Federal Actions to Address Environmental Justice in Minority and Low-Income Populations*, 59 Fed. Reg. 7629 (Feb. 16, 1994), *available at* https://ceq.doe.gov/nepa/regs/eos/ii-5.pdf; CEQ, *Environmental Justice Guidance Under the National Environmental Policy Act* (Dec. 1997), *available at* http://ceq.doe.gov/nepa/regs/ej/justice.pdf.

Resources in a Changing Climate, provide other good examples of the type of relevant and useful information that can be considered.[65]

Climate change effects on the environment and on the proposed project should be considered in the analysis of a project considered vulnerable to the effects of climate change such as increasing sea level, drought, high intensity precipitation events, increased fire risk, or ecological change. In such cases, a NEPA review will provide relevant information that agencies can use to consider in the initial project design, as well as alternatives with preferable overall environmental outcomes and improved resilience to climate impacts. For example, an agency considering a proposed long-term development of transportation infrastructure on a coastal barrier island should take into account climate change effects on the environment and, as applicable, consequences of rebuilding where sea level rise and more intense storms will shorten the projected life of the project and change its effects on the environment.[66] Given the length of time involved in present sea level projections, such considerations typically will not be relevant to short-term actions with short-term effects.

In addition, the particular impacts of climate change on vulnerable communities may be considered in the design of the action or the selection among alternatives to

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[65] *See* http://sustainability.performance.gov for agency sustainability plans, which contain agency adaptation plans. *See also* http://www.wildlifeadaptationstrategy.gov; http://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf; and https://www.epa.gov/greeningepa/climate-change-adaptation-plans

[66] *See* U.S. Department of Transportation, Gulf Coast Study, Phase 2, *Assessing Transportation Vulnerability to Climate Change Synthesis of Lessons Learned and Methods Applied*, FHWA-HEP-15-007 (Oct. 2014) (focusing on the Mobile, Alabama region), *available at* http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task6/fhwahep15007.pdf; U.S. Climate Change Science Program, Synthesis and Assessment Product 4.7, Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I (Mar. 2008) (focusing on a regional scale in the central Gulf Coast), *available at* https://downloads.globalchange.gov/sap/sap4-7/sap4-7-final-all.pdf. Information about the Gulf Coast Study is *available at http //www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study*. *See also* Third National Climate Assessment, Chapter 28, "Adaptation," at 675 (noting that Federal agencies in particular can facilitate climate adaptation by "ensuring the establishment of federal policies that allow for "flexible" adaptation efforts and take steps to avoid unintended consequences"), *available at* http://nca2014.globalchange.gov/report/response-strategies/adaptation#intro-section-2.

assess the impact, and potential for disproportionate impacts, on those communities.[67] For example, chemical facilities located near the coastline could have increased risk of spills or leakages due to sea level rise or increased storm surges, putting local communities and environmental resources at greater risk. Increased resilience could minimize such potential future effects. Finally, considering climate change preparedness and resilience can help ensure that agencies evaluate the potential for generating additional GHGs if a project has to be replaced, repaired, or modified, and minimize the risk of expending additional time and funds in the future.

C. Special Considerations for Biogenic Sources of Carbon

With regard to biogenic GHG emissions from land management actions – such as prescribed burning, timber stand improvements, fuel load reductions, scheduled harvesting, and livestock grazing – it is important to recognize that these land management actions involve GHG emissions and carbon sequestration that operate within the global carbon and nitrogen cycle, which may be affected by those actions. Similarly, some water management practices have GHG emission consequences (e.g., reservoir management practices can reduce methane releases, wetlands management practices can enhance carbon sequestration, and water conservation can improve energy efficiency).

Notably, it is possible that the net effect of ecosystem restoration actions resulting in short-term biogenic emissions may lead to long-term reductions of atmospheric GHG concentrations through increases in carbon stocks or reduced risks of future emissions. In the land and resource management context, how a proposed action affects a net carbon sink or source will depend on multiple factors such as the climatic region, the distribution

[67] For an example, *see* https://www.blm.gov/epl-front-office/projects/nepa/5251/42462/45213/NPR-A_FINAL_ROD_2-21-13.pdf.

of carbon across carbon pools in the project area, and the ongoing activities and trends. In addressing biogenic GHG emissions, resource management agencies should include a comparison of estimated net GHG emissions and carbon stock changes that are projected to occur with and without implementation of proposed land or resource management actions.[68] This analysis should take into account the GHG emissions, carbon sequestration potential, and the changes in carbon stocks that are relevant to decision making in light of the proposed actions and timeframes under consideration.

One example of agencies dealing with biogenic emissions and carbon sequestration arises when agencies consider proposed vegetation management practices that affect the risk of wildfire, insect and disease outbreak, or other disturbance. The public and the decision maker may benefit from consideration of the influence of a vegetation management action that affects the risk of wildfire on net GHG emissions and carbon stock changes. NEPA reviews should consider whether to include a comparison of net GHG emissions and carbon stock changes that are anticipated to occur, with and without implementation of the proposed vegetation management practice, to provide information that is useful to the decision maker and the public to distinguish between alternatives. The analysis would take into account the estimated GHG emissions (biogenic and fossil), carbon sequestration potential, and the net change in carbon stocks relevant in light of the proposed actions and timeframes under consideration. In such cases the agency should describe the basis for estimates used to project the probability or likelihood of occurrence or changes in the effects or severity of wildfire. Where such

[68] One example of a tool for such calculations is the Carbon On Line Estimator (COLE), which uses data based on USDA Forest Service Forest Inventory & Analysis and Resource Planning Assessment data and other ecological data. COLE began as a collaboration between the National Council for Air and Stream Improvement, Inc. (NCASI) and USDA Forest Service, Northern Research Station. It currently is maintained by NCASI. It is available at http://www.fs.usda.gov/ccrc/tools/cole.

tools, methodologies, or data are not yet available, the agency should provide a qualitative analysis and its rationale for determining that the quantitative analysis is not warranted. As with any other analysis, the rule of reason and proportionality should be applied to determine the extent of the analysis.

CEQ acknowledges that Federal land and resource management agencies are developing agency-specific principles and guidance for considering biological carbon in management and planning decisions.[69] Such guidance is expected to address the importance of considering biogenic carbon fluxes and storage within the context of other management objectives and ecosystem service goals, and integrating carbon considerations as part of a balanced and comprehensive program of sustainable management, climate change mitigation, and climate change adaptation.

IV. TRADITIONAL NEPA TOOLS AND PRACTICES

A. Scoping and Framing the NEPA Review

To effectuate integrated decision making, avoid duplication, and focus the NEPA review, the CEQ Regulations provide for scoping.[70] In scoping, the agency determines the issues that the NEPA review will address and identifies the impacts related to the proposed action that the analyses will consider.[71] An agency can use the scoping process to help it determine whether analysis is relevant and, if so, the extent of analysis

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[69] *See* Council on Climate Change Preparedness and Resilience, *Priority Agenda Enhancing the Climate Resilience of America's Natural Resources*, at 52 (Oct. 2014), *available at* http://www.whitehouse.gov/sites/default/files/docs/enhancing_climate_resilience_of_americas_natural_resources.pdf.

[70] *See* 40 CFR 1501.7 ("There shall be an early and open process for determining the scope of issues to be addressed and for identifying the significant issues related to a proposed action. This process shall be termed scoping."); *see also* CEQ Memorandum for Heads of Federal Departments and Agencies, *Improving the Process for Preparing Efficient and Timely Environmental Reviews under the National Environmental Policy Act*, March 6, 2012, *available at* https://ceq.doe.gov/current_developments/docs/Improving_NEPA_Efficiencies_06Mar2012.pdf (the CEQ Regulations explicitly require scoping for preparing an EIS, however, agencies can also take advantage of scoping whenever preparing an EA).

[71] *See* 40 CFR 1500.4(b), 1500.4(g), 1501.7.

appropriate for a proposed action.[72] When scoping for the climate change issues associated with the proposed agency action, the nature, location, timeframe, and type of the proposed action and the extent of its effects will help determine the degree to which to consider climate projections, including whether climate change considerations warrant emphasis, detailed analysis, and disclosure.

Consistent with this guidance, agencies may develop their own agency-specific practices and guidance for framing the NEPA review. Grounded on the principles of proportionality and the rule of reason, such aids can help an agency determine the extent to which an analysis of GHG emissions and climate change impacts should be explored in the decision-making process and will assist in the analysis of the no action and proposed alternatives and mitigation.[73] The agency should explain such a framing process and its application to the proposed action to the decision makers and the public during the NEPA review and in the EA or EIS document.

B. Frame of Reference

When discussing GHG emissions, as for all environmental impacts, it can be helpful to provide the decision maker and the public with a recognizable frame of reference for comparing alternatives and mitigation measures. Agencies should discuss relevant approved federal, regional, state, tribal, or local plans, policies, or laws for GHG emission reductions or climate adaptation to make clear whether a proposed project's

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[72] *See* 40 CFR 1501.7 (The agency preparing the NEPA analysis must use the scoping process to, among other things, determine the scope and identify the significant issues to be analyzed in depth) and CEQ, *Memorandum for General Counsels, NEPA Liaisons, and Participants in Scoping*, April 30, 1981, *available at* https://ceq.doe.gov/nepa/regs/scope/scoping.htm.

[73] *See, e.g.,* Matthew P. Thompson, Bruce G. Marcot, Frank R. Thompson, III, Steven McNulty, Larry A. Fisher, Michael C. Runge, David Cleaves, and Monica Tomosy, *The Science of Decisionmaking Applications for Sustainable Forest and Grassland Management in the National Forest System* (2013), *available at* http://www.fs.fed.us/rm/pubs_other/rmrs_2013_thompson_m004.pdf; U.S. Forest Service Comparative Risk Assessment Framework And Tools, *available at* www.fs.fed.us/psw/topics/fire_science/craft/craft; and Julien Martin, Michael C. Runge, James D. Nichols, Bruce C. Lubow, and William L. Kendall, *Structured decision making as a conceptual framework to identify thresholds for conservation and management* (2009), Ecological Applications 19:1079–1090, *available at* http://www.esajournals.org/doi/abs/10.1890/08-0255.1.

GHG emissions are consistent with such plans or laws.[74] For example, the Bureau of Land Management has discussed how agency actions in California, especially joint projects with the State, may or may not facilitate California reaching its emission reduction goals under the State's Assembly Bill 32 (Global Warming Solutions Act).[75] This approach helps frame the policy context for the agency decision based on its NEPA review.

C. Incorporation by Reference

Incorporation by reference is of great value in considering GHG emissions or where an agency is considering the implications of climate change for the proposed action and its environmental effects. Agencies should identify situations where prior studies or NEPA analyses are likely to cover emissions or adaptation issues, in whole or in part. When larger scale analyses have considered climate change impacts and GHG emissions, calculating GHG emissions and carbon stocks for a specific action may provide only limited information beyond the information already collected and considered in the larger scale analyses. The NEPA reviews for a specific action can incorporate by reference earlier programmatic studies or information such as management plans, inventories, assessments, and research that consider potential changes in carbon stocks, as well as any relevant programmatic NEPA reviews.[76]

Accordingly, agencies should use the scoping process to consider whether they should incorporate by reference GHG analyses from other programmatic studies, action

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[74] *See* 40 CFR 1502.16(c), 1506.2(d) (where an inconsistency exists, agencies should describe the extent to which the agency will reconcile its proposed action with the plan or law). *See also* Exec. Order No. 13693, 80 Fed. Reg. 15869 (Mar. 25, 2015) (establishing GHG emission and related goals for agency facilities and operations. Scope 1, 2, and 3 emissions are typically separate and distinct from analyses and information used in an EA or EIS.).
[75] *See, e.g.*, U.S. Bureau of Land Management, Desert Renewable Energy Conservation Plan Proposed Land Use Plan Amendment and Final Environmental Impact Statement, Vol. I, § I.3.3.2, at 12, *available at* http://drecp.org/finaldrecp/.
[76] *See* 40 CFR 1502.5, 1502.21.

specific NEPA reviews, or programmatic NEPA reviews to avoid duplication of effort. Furthermore, agencies should engage other agencies and stakeholders with expertise or an interest in related actions to participate in the scoping process to identify relevant GHG and adaptation analyses from other actions or programmatic NEPA documents.

D. Using Available Information

Agencies should make decisions using current scientific information and methodologies. CEQ does not expect agencies to fund and conduct original climate change research to support their NEPA analyses or for agencies to require project proponents to do so. Agencies should exercise their discretion to select and use the tools, methodologies, and scientific and research information that are of high quality and available to assess the impacts.[77]

Agencies should be aware of the ongoing efforts to address the impacts of climate change on human health and vulnerable communities.[78] Certain groups, including children, the elderly, and the poor, are more vulnerable to climate-related health effects, and may face barriers to engaging on issues that disproportionately affect them. CEQ recommends that agencies periodically engage their environmental justice experts, and the Federal Interagency Working Group on Environmental Justice,[79] to identify approaches to avoid or minimize impacts that may have disproportionately high and

[77] *See* 40 CFR 1502.24 (requiring agencies to ensure the professional and scientific integrity of the discussions and analyses in environmental impact statements).
[78] USGCRP, *The Impacts of Climate Change on Human Health in the United States A Scientific Assessment* (Apr. 2016), *available at* https://health2016.globalchange.gov/downloads.
[79] For more information on the Federal Interagency Working Group on Environmental Justice co-chaired by EPA and CEQ, *see* http://www.epa.gov/environmentaljustice/interagency/index.html.

adverse human health or environmental effects on minority and low-income populations.[80]

E. Programmatic or Broad-Based Studies and NEPA Reviews

Agency decisions can address different geographic scales that can range from the programmatic or landscape level to the site- or project-specific level. Agencies sometimes conduct analyses or studies that are not NEPA reviews at the national level or other broad scale level (e.g., landscape, regional, or watershed) to assess the status of one or more resources or to determine trends in changing environmental conditions.[81] In the context of long-range energy, transportation, and resource management strategies an agency may decide that it would be useful and efficient to provide an aggregate analysis of GHG emissions or climate change effects in a programmatic analysis and then incorporate by reference that analysis into future NEPA reviews.

A tiered, analytical decision-making approach using a programmatic NEPA review is used for many types of Federal actions[82] and can be particularly relevant to addressing proposed land, aquatic, and other resource management plans. Under such an approach, an agency conducts a broad-scale programmatic NEPA analysis for decisions such as establishing or revising USDA Forest Service land management plans, Bureau of Land Management resource management plans, or Natural Resources Conservation Service conservation programs. Subsequent NEPA analyses for proposed site-specific

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[80] *President's Memorandum for the Heads of All Departments and Agencies, Executive Order on Federal Actions to Address Environmental Justice in Minority and Low-Income Populations* (Feb. 11, 1994), *available at* https://ceq.doe.gov/nepa/regs/eos/ii-5.pdf; CEQ, *Environmental Justice Guidance Under the National Environmental Policy Act*, *available at* https://ceq.doe.gov/nepa/regs/ej/justice.pdf.

[81] Such a programmatic study is distinct from a programmatic NEPA review which is appropriate when the action under consideration is itself subject to NEPA requirements. *See* CEQ, *Memorandum for Heads of Federal Departments and Agencies, Effective Use of Programmatic NEPA Reviews*, Dec. 18, 2014, § I(A), p. 9, *available at* https://www.whitehouse.gov/sites/default/files/docs/effective_use_of_programmatic_nepa_reviews_final_dec2014_searchable.pdf (discussing non-NEPA types of programmatic analyses such as data collection, assessments, and research, which previous NEPA guidance described as joint inventories or planning studies).

[82] *See* 40 CFR 1502.20, 1508.28. A programmatic NEPA review may be appropriate when a decision is being made that is subject to NEPA, such as establishing formal plans, programs, and policies, and when considering a suite of similar projects.

decisions – such as proposed actions that implement land, aquatic, and other resource management plans – may be tiered from the broader programmatic analysis, drawing upon its basic framework analysis to avoid repeating analytical efforts for each tiered decision. Examples of project- or site-specific actions that may benefit from being able to tier to a programmatic NEPA review include: constructing transmission lines; conducting prescribed burns; approving grazing leases; granting rights-of-way; issuing leases for oil and gas drilling; authorizing construction of wind, solar or geothermal projects; and approving hard rock mineral extraction.

A programmatic NEPA review may also serve as an efficient mechanism in which to assess Federal agency efforts to adopt broad-scale sustainable practices for energy efficiency, GHG emissions avoidance and emissions reduction measures, petroleum product use reduction, and renewable energy use, as well as other sustainability practices.[83] While broad department- or agency-wide goals may be of a far larger scale than a particular program, policy, or proposed action, an analysis that informs how a particular action affects that broader goal can be of value.

F. Monetizing Costs and Benefits

NEPA does not require monetizing costs and benefits. Furthermore, the weighing of the merits and drawbacks of the various alternatives need not be displayed using a monetary cost-benefit analysis and should not be when there are important qualitative considerations.[84] When an agency determines that a monetized assessment of the impacts of greenhouse gas emissions or a monetary cost-benefit analysis is appropriate and

[83] *See* Exec. Order No. 13693, 80 Fed. Reg. 15869 (Mar. 25, 2015).
[84] *See* 40 CFR 1502.23.

relevant to the choice among different alternatives being considered, such analysis may be incorporated by reference[85] or appended to the NEPA document as an aid in evaluating the environmental consequences.[86] For example, a rulemaking could have useful information for the NEPA review in an associated regulatory impact analysis which could be incorporated by reference.[87] When using a monetary cost-benefit analysis, just as with tools to quantify emissions, the agency should disclose the assumptions, alternative inputs, and levels of uncertainty associated with such analysis. Finally, if an agency chooses to monetize some but not all impacts of an action, the agency providing this additional information should explain its rationale for doing so.[88]

V. CONCLUSION AND EFFECTIVE DATE

Agencies should apply this guidance to all new proposed agency actions when a NEPA review is initiated. Agencies should exercise judgment when considering whether to apply this guidance to the extent practicable to an on-going NEPA process. CEQ does not expect agencies to apply this guidance to concluded NEPA reviews and actions for

[85] *See* 40 CFR 1502.21 (material may be cited if it is reasonably available for inspection by potentially interested persons within the time allowed for public review and comment).

[86] When conducting a cost-benefit analysis, determining an appropriate method for preparing a cost-benefit analysis is a decision left to the agency's discretion, taking into account established practices for cost-benefit analysis with strong theoretical underpinnings (for example, see OMB Circular A-4 and references therein). For example, the Federal social cost of carbon (SCC) estimates the marginal damages associated with an increase in carbon dioxide emissions in a given year. Developed through an interagency process committed to ensuring that the SCC estimates reflect the best available science and methodologies and used to assess the social benefits of reducing carbon dioxide emissions across alternatives in rulemakings, it provides a harmonized, interagency metric that can give decision makers and the public useful information for their NEPA review. For current Federal estimates, *see* Interagency Working Group on Social Cost of Carbon, United States Government, *Technical Support Document Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866* (revised July 2015), *available at* https://www.whitehouse.gov/omb/oira/social-cost-of-carbon.

[87] For example, the regulatory impact analysis was used as a source of information and aligned with the NEPA review for Corporate Average Fuel Economy (CAFÉ) standards, *see* National Highway Traffic Safety Administration, Corporate Average Fuel Economy Standards, Passenger Cars and Light Trucks, Model Years 2017-2025, Final Environmental Impact Statement, Docket No. NHTSA-2011-0056 (July 2012), § 5.3.2, *available at* http://www.nhtsa.gov/Laws+&+Regulations/CAFE+-+Fuel+Economy/Environmental+Impact+Statement+for+CAFE+Standards,+2017-2025.

[88] For example, the information may be responsive to public comments or useful to the decision maker in further distinguishing between alternatives and mitigation measures. In all cases, the agency should ensure that its consideration of the information and other factors relevant to its decision is consistent with applicable statutory or other authorities, including requirements for the use of cost-benefit analysis.

which a final EIS or EA has been issued. Agencies should consider applying this guidance to projects in the EIS or EA preparation stage if this would inform the consideration of differences between alternatives or address comments raised through the public comment process with sufficient scientific basis that suggest the environmental analysis would be incomplete without application of the guidance, and the additional time and resources needed would be proportionate to the value of the information included.

# # #

Exhibit 2

Climate Change 2014
Synthesis Report
Summary for Policymakers

SPM

Introduction

This Synthesis Report is based on the reports of the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC), including relevant Special Reports. It provides an integrated view of climate change as the final part of the IPCC's Fifth Assessment Report (AR5).

This summary follows the structure of the longer report which addresses the following topics: Observed changes and their causes; Future climate change, risks and impacts; Future pathways for adaptation, mitigation and sustainable development; Adaptation and mitigation.

In the Synthesis Report, the certainty in key assessment findings is communicated as in the Working Group Reports and Special Reports. It is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from *very low* to *very high*) and, when possible, probabilistically with a quantified likelihood (from *exceptionally unlikely* to *virtually certain*)[1]. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

This report includes information relevant to Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

SPM 1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. *{1}*

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. *{1.1}*

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was *likely* the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (*medium confidence*). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C[2] over the period 1880 to 2012, when multiple independently produced datasets exist (Figure SPM.1a). *{1.1.1, Figure 1.1}*

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (Figure SPM.1a). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over

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[1] Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence. The summary terms for evidence are: limited, medium or robust. For agreement, they are low, medium or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. See for more details: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

[2] Ranges in square brackets or following '±' are expected to have a 90% likelihood of including the value that is being estimated, unless otherwise stated.

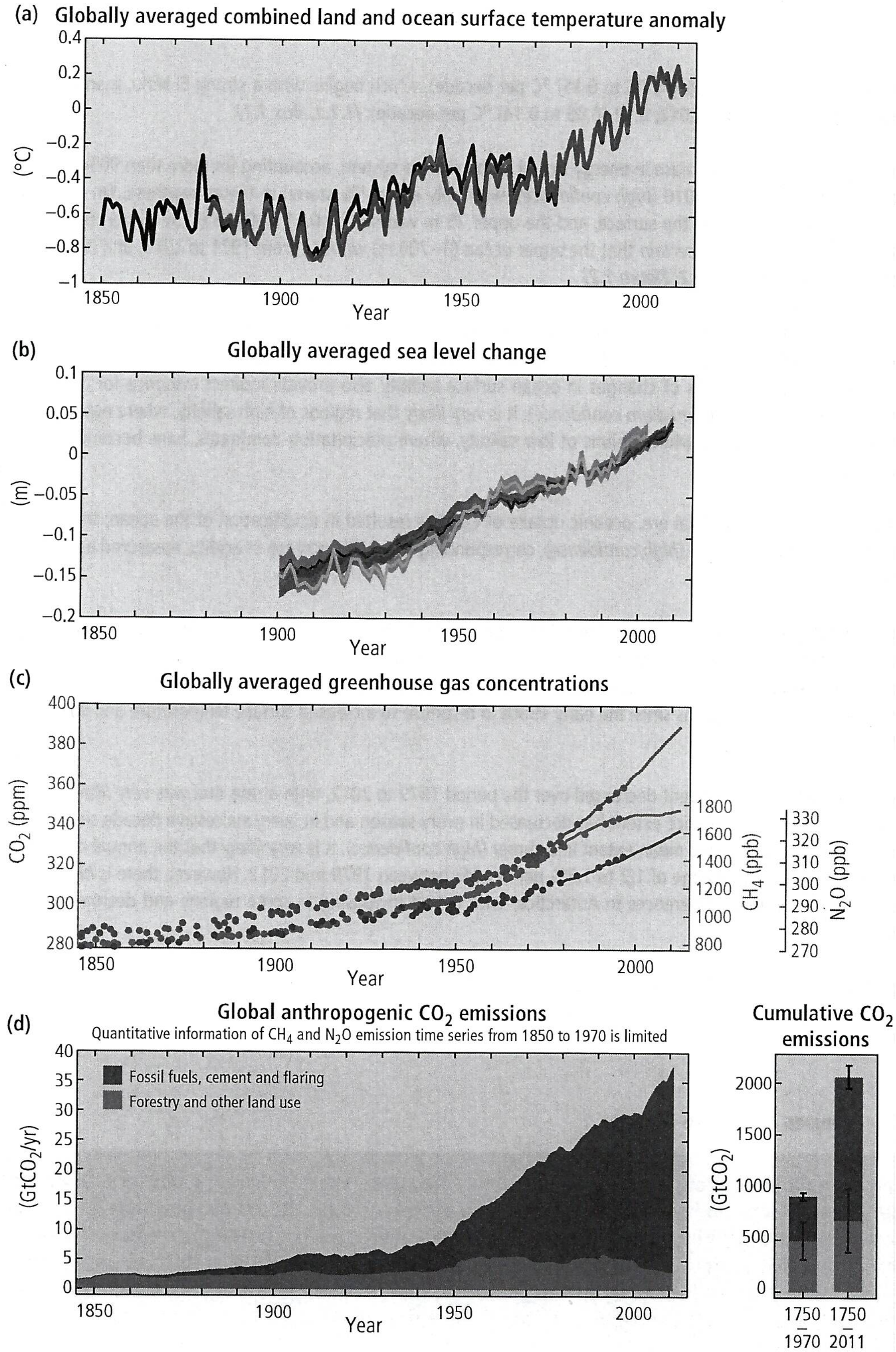

Figure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observations: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange) and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Indicators: **(d)** Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global effects of the accumulation of CH_4 and N_2O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM.2. *{Figures 1.1, 1.3, 1.5}* the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade). *{1.1.1, Box 1.1}*

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. *{1.1.2, Figure 1.2}*

Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes, area-averaged long-term positive or negative trends have *low confidence*. Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean (*medium confidence*). It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. *{1.1.1, 1.1.2}*

Since the beginning of the industrial era, oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. *{1.1.2}*

Over the period 1992 to 2011, the Greenland and Antarctic ice sheets have been losing mass (*high confidence*), *likely* at a larger rate over 2002 to 2011. Glaciers have continued to shrink almost worldwide (*high confidence*). Northern Hemisphere spring snow cover has continued to decrease in extent (*high confidence*). There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s in response to increased surface temperature and changing snow cover. *{1.1.3}*

The annual mean Arctic sea-ice extent decreased over the period 1979 to 2012, with a rate that was *very likely* in the range 3.5 to 4.1% per decade. Arctic sea-ice extent has decreased in every season and in every successive decade since 1979, with the most rapid decrease in decadal mean extent in summer (*high confidence*). It is *very likely* that the annual mean Antarctic sea-ice extent increased in the range of 1.2 to 1.8% per decade between 1979 and 2012. However, there is *high confidence* that there are strong regional differences in Antarctica, with extent increasing in some regions and decreasing in others. *{1.1.3, Figure 1.1}*

Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure SPM.1b). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). *{1.1.4, Figure 1.1}*

SPM 1.2 Causes of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. *{1.2, 1.3.1}*

Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Figure SPM.1c). Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. About 40% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*) (Figure SPM.1d). *{1.2.1, 1.2.2}*

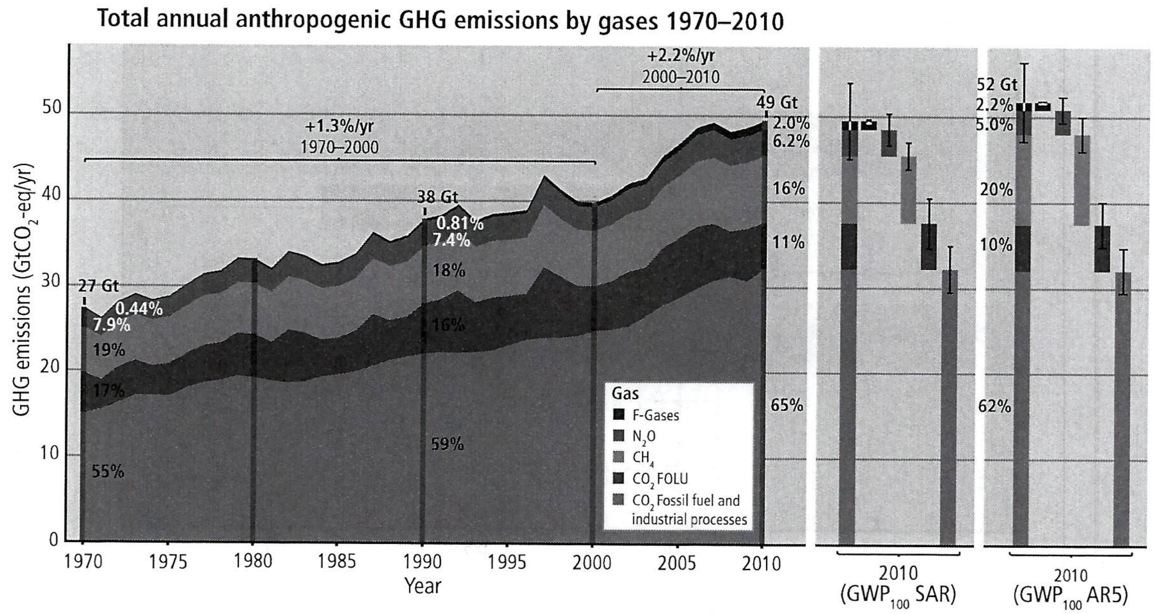

Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO_2-equivalent emissions in this report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the SAR (see Glossary). Using the most recent GWP_{100} values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 $GtCO_2$-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. *{Figure 1.6, Box 3.2}*

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010, despite a growing number of climate change mitigation policies. Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 $GtCO_2$-eq/yr [3]. Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000 to 2010 (*high confidence*) (Figure SPM.2). Globally, economic and population growth continued to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Increased use of coal has reversed the long-standing trend of gradual decarbonization (i.e., reducing the carbon intensity of energy) of the world's energy supply (*high confidence*). *{1.2.2}*

The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period (Figure SPM.3). Anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica[4]. Anthropogenic influences have *likely* affected the global water cycle since 1960 and contributed to the retreat of glaciers since the 1960s and to the increased surface melting of the Greenland ice sheet since 1993. Anthropogenic influences have *very likely* contributed to Arctic sea-ice loss since 1979 and have *very likely* made a substantial contribution to increases in global upper ocean heat content (0–700 m) and to global mean sea level rise observed since the 1970s. *{1.3, Figure 1.10}*

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[3] Greenhouse gas emissions are quantified as CO_2-equivalent ($GtCO_2$-eq) emissions using weightings based on the 100-year Global Warming Potentials, using IPCC Second Assessment Report values unless otherwise stated. *{Box 3.2}*

[4] For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations.

SPM

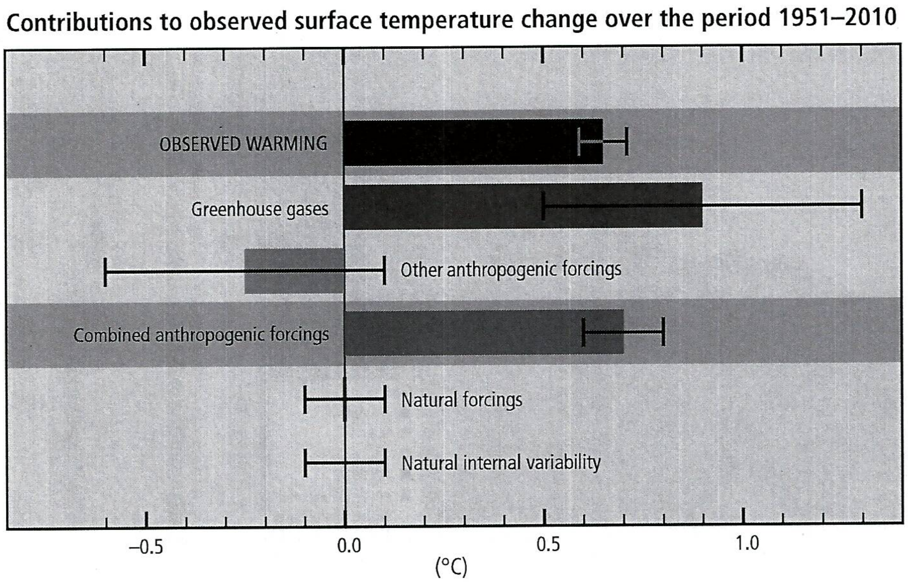

Figure SPM.3 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural forcings and natural internal climate variability (which is the element of climate variability that arises spontaneously within the climate system even in the absence of forcings). The observed surface temperature change is shown in black, with the 5 to 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution of an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the contributions from greenhouse gases and from other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a combined signal that is better constrained by observations. *{Figure 1.9}*

SPM 1.3 Impacts of climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. *{1.3.2}*

Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change (*high confidence*). Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure SPM.4). Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). Some impacts of ocean acidification on marine organisms have been attributed to human influence (*medium confidence*). *{1.3.2}*

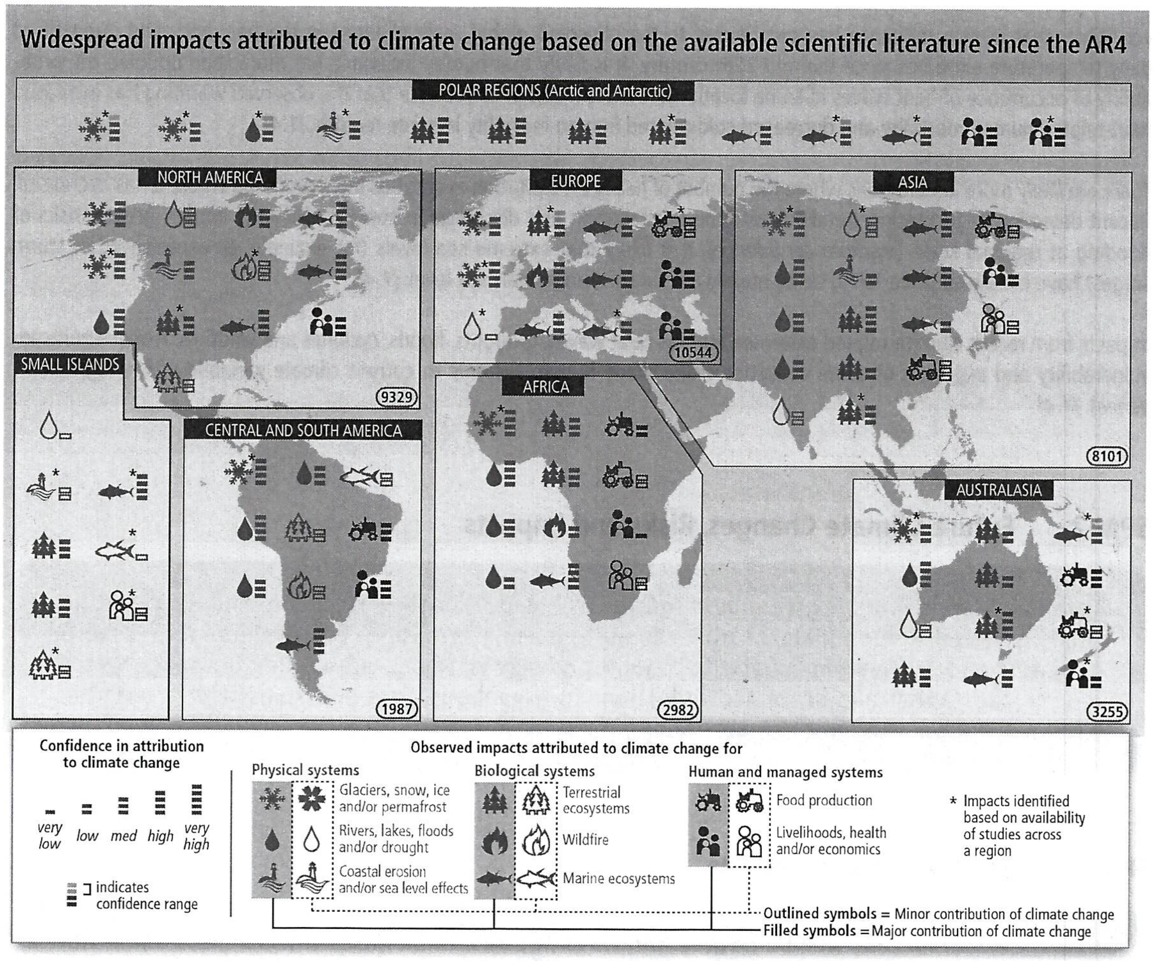

Figure SPM.4 | Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a growing knowledge base, but publications are still limited for many regions, systems and processes, highlighting gaps in data and studies. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries in WGII Table SPM.A1, grouping related regional-scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). These numbers provide an overall measure of the available scientific literature on climate change across regions; they do not indicate the number of publications supporting attribution of climate change impacts in each region. Studies for polar regions and small islands are grouped with neighbouring continental regions. The inclusion of publications for assessment of attribution followed IPCC scientific evidence criteria defined in WGII Chapter 18. Publications considered in the attribution analyses come from a broader range of literature assessed in the WGII AR5. See WGII Table SPM.A1 for descriptions of the attributed impacts. *{Figure 1.11}*

SPM 1.4 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions. *{1.4}*

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is

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very likely that human influence has contributed to the observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. There is *medium confidence* that the observed warming has increased heat-related human mortality and decreased cold-related human mortality in some regions. *{1.4}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*). It is *likely* that extreme sea levels (for example, as experienced in storm surges) have increased since 1970, being mainly a result of rising mean sea level. *{1.4}*

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). *{1.4}*

SPM 2. Future Climate Changes, Risks and Impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. *{2}*

SPM 2.1 Key drivers of future climate

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy. *{2.1}*

Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5 (Figure SPM.5a). RCP2.6 is representative of a scenario that aims to keep global warming *likely* below 2°C above pre-industrial temperatures. The RCPs are consistent with the wide range of scenarios in the literature as assessed by WGIII[5]. *{2.1, Box 2.2, 4.3}*

Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100 in both the RCPs and the wider set of mitigation scenarios analysed in WGIII (Figure SPM.5b). Any given level of warming is associated with a range of cumulative CO_2 emissions[6], and therefore, e.g., higher emissions in earlier decades imply lower emissions later. *{2.2.5, Table 2.2}*

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5 Roughly 300 baseline scenarios and 900 mitigation scenarios are categorized by CO_2-equivalent concentration (CO_2-eq) by 2100. The CO_2-eq includes the forcing due to all GHGs (including halogenated gases and tropospheric ozone), aerosols and albedo change.

6 Quantification of this range of CO_2 emissions requires taking into account non-CO_2 drivers.

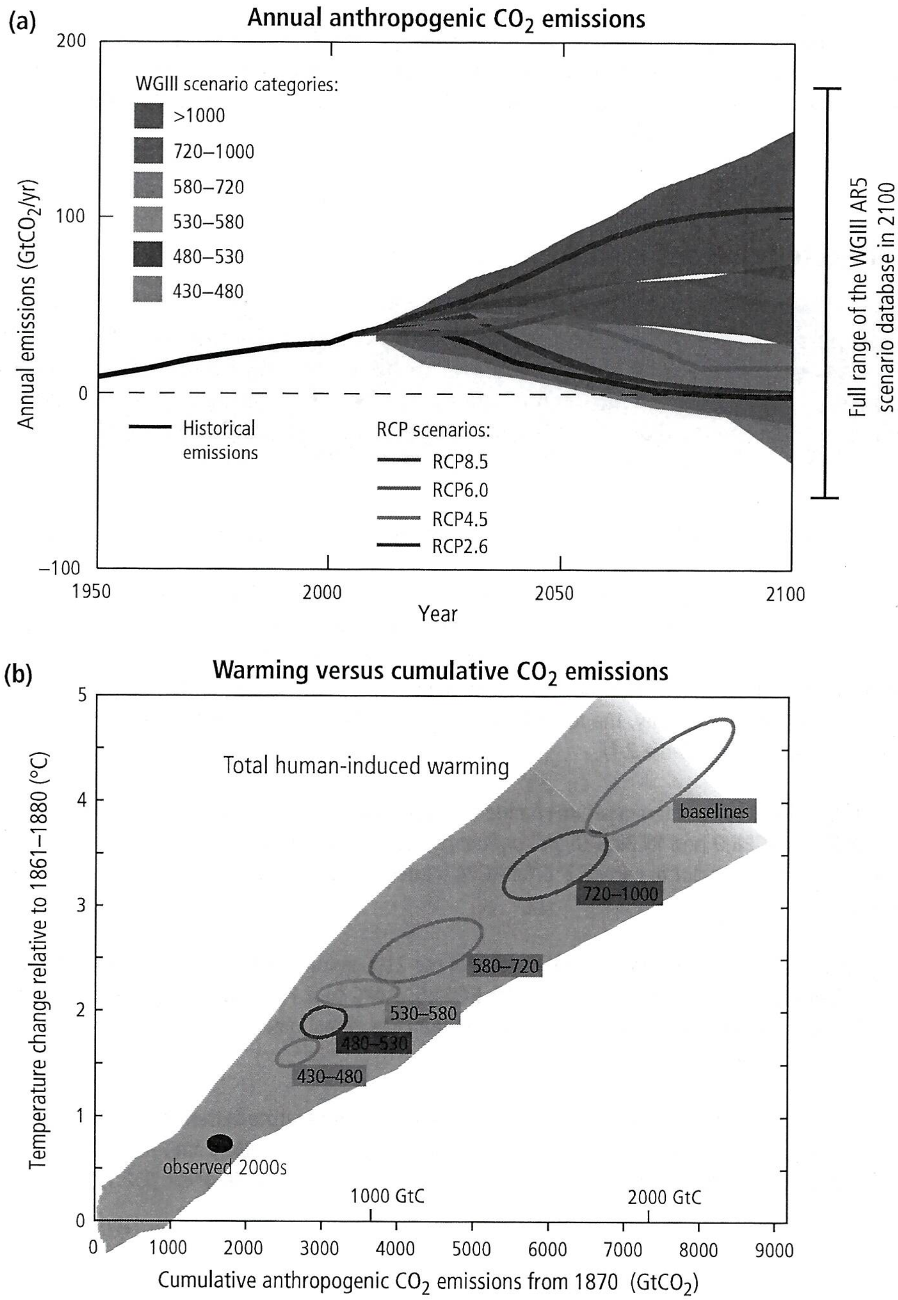

Figure SPM.5 | **(a)** Emissions of carbon dioxide (CO_2) alone in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used in WGIII (coloured areas show 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined on the basis of CO_2-eq concentration levels (in ppm) in 2100. The time series of other greenhouse gas emissions are shown in Box 2.2, Figure 1. **(b)** Global mean surface temperature increase at the time global CO_2 emissions reach a given net cumulative total, plotted as a function of that total, from various lines of evidence. Coloured plume shows the spread of past and future projections from a hierarchy of climate-carbon cycle models driven by historical emissions and the four RCPs over all times out to 2100, and fades with the decreasing number of available models. Ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in WGIII. The width of the ellipses in terms of temperature is caused by the impact of different scenarios for non-CO_2 climate drivers. The filled black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. *{Box 2.2, Figure 1; Figure 2.3}*

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Multi-model results show that limiting total human-induced warming to less than 2°C relative to the period 1861–1880 with a probability of >66%[7] would require cumulative CO_2 emissions from all anthropogenic sources since 1870 to remain below about 2900 $GtCO_2$ (with a range of 2550 to 3150 $GtCO_2$ depending on non-CO_2 drivers). About 1900 $GtCO_2$[8] had already been emitted by 2011. For additional context see Table 2.2. *{2.2.5}*

SPM 2.2 Projected changes in the climate system

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. *{2.2}*

The projected changes in Section SPM 2.2 are for 2081–2100 relative to 1986–2005, unless otherwise indicated.

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will *likely* be in the range 0.3°C to 0.7°C (*medium confidence*). This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH_4 and N_2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario. *{2.2.1, Table 2.1}*

Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to *likely* exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). *{2.2.1}*

The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is *likely* to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5[9]. The Arctic region will continue to warm more rapidly than the global mean (Figure SPM.6a, Figure SPM.7a). *{2.2.1, Figure 2.1, Figure 2.2, Table 2.1}*

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is *very likely* that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur. *{2.2.1}*

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7 Corresponding figures for limiting warming to 2°C with a probability of >50% and >33% are 3000 $GtCO_2$ (range of 2900 to 3200 $GtCO_2$) and 3300 $GtCO_2$ (range of 2950 to 3800 $GtCO_2$) respectively. Higher or lower temperature limits would imply larger or lower cumulative emissions respectively.

8 This corresponds to about two thirds of the 2900 $GtCO_2$ that would limit warming to less than 2°C with a probability of >66%; to about 63% of the total amount of 3000 $GtCO_2$ that would limit warming to less than 2°C with a probability of >50%; and to about 58% of the total amount of 3300 $GtCO_2$ that would limit warming to less than 2°C with a probability of >33%.

9 The period 1986–2005 is approximately 0.61 [0.55 to 0.67] °C warmer than 1850–1900. *{2.2.1}*

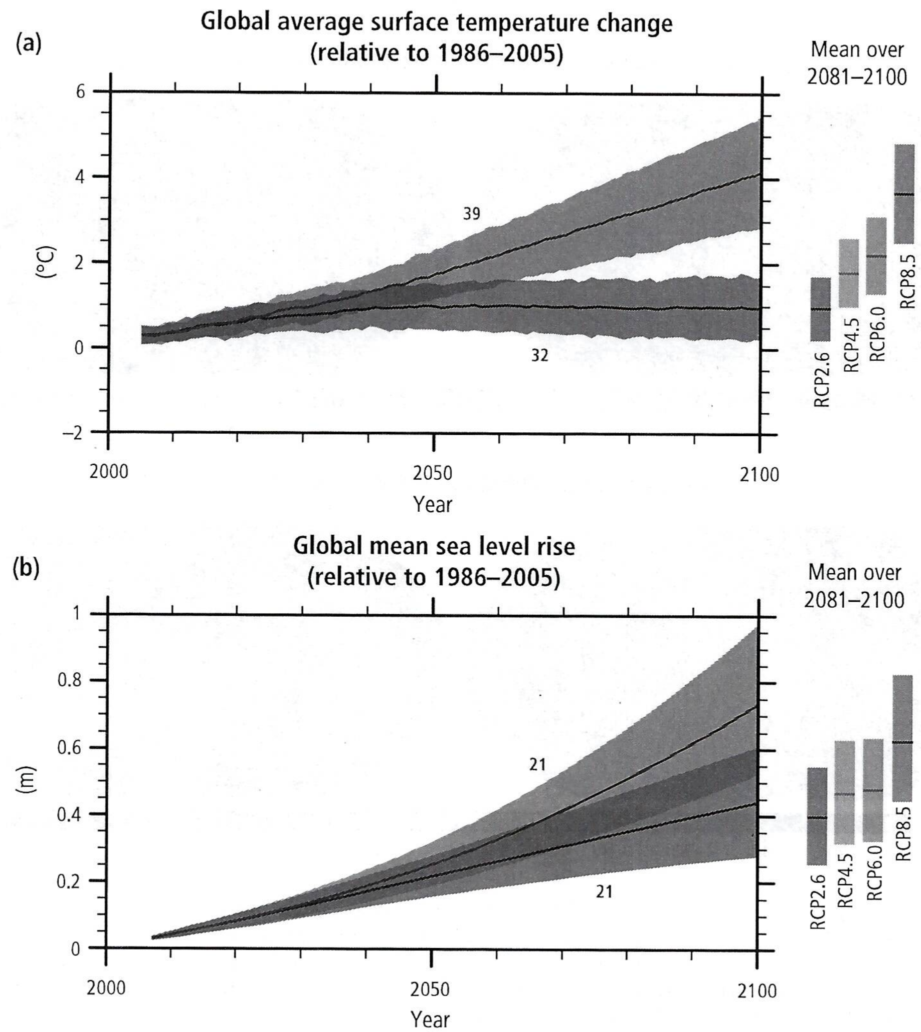

Figure SPM.6 | Global average surface temperature change **(a)** and global mean sea level rise[10] **(b)** from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars at the right hand side of each panel. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models used to calculate the multi-model mean is indicated. *{2.2, Figure 2.1}*

Changes in precipitation will not be uniform. The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure SPM.7b). Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent. *{2.2.2, Figure 2.2}*

The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere subtropical regions (Figure SPM.7a). *{2.2.3, Figure 2.2}*

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[10] Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

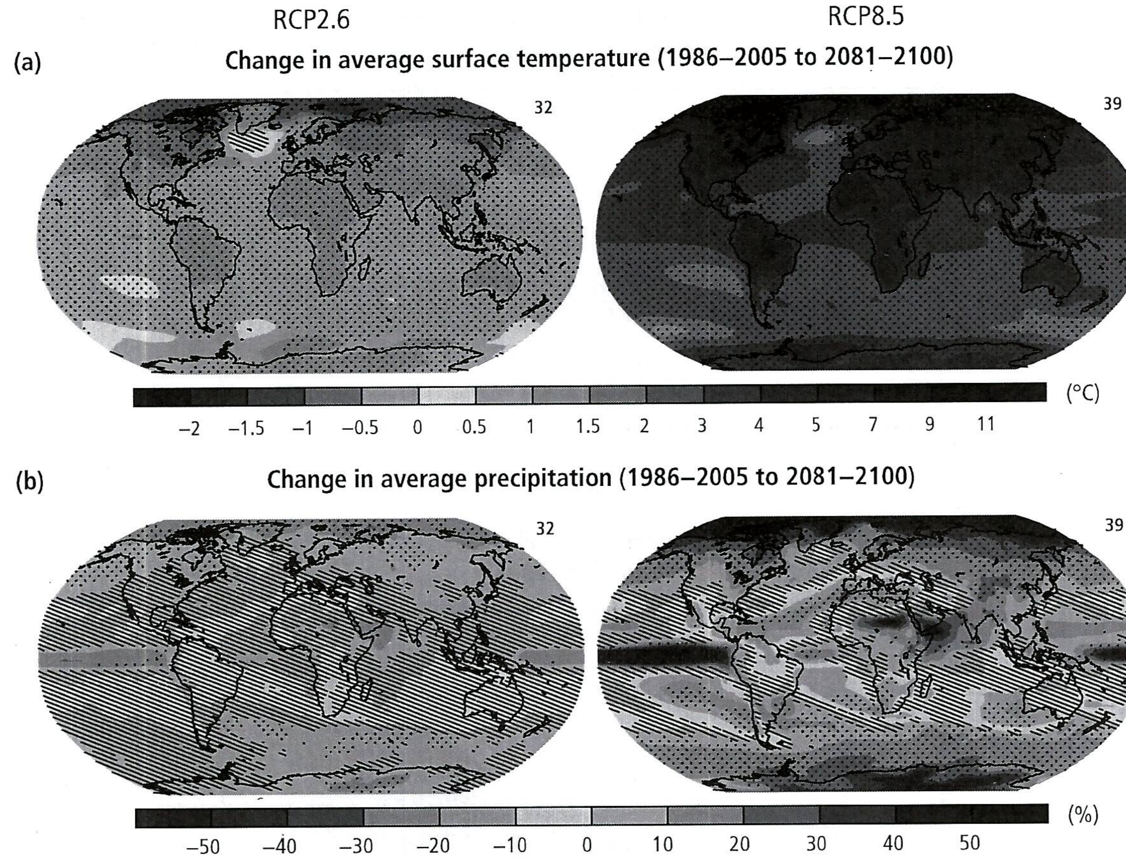

Figure SPM.7 | Change in average surface temperature **(a)** and change in average precipitation **(b)** based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (i.e., dots) shows regions where the projected change is large compared to natural internal variability and where at least 90% of models agree on the sign of change. Hatching (i.e., diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability. *{2.2, Figure 2.2}*

Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century, with a slow recovery after mid-century under RCP2.6. The decrease in surface ocean pH is in the range of 0.06 to 0.07 (15 to 17% increase in acidity) for RCP2.6, 0.14 to 0.15 (38 to 41%) for RCP4.5, 0.20 to 0.21 (58 to 62%) for RCP6.0 and 0.30 to 0.32 (100 to 109%) for RCP8.5. *{2.2.4, Figure 2.1}*

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. A nearly ice-free[11] Arctic Ocean in the summer sea-ice minimum in September before mid-century is *likely* for RCP8.5[12] (*medium confidence*). *{2.2.3, Figure 2.1}*

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with the area of permafrost near the surface (upper 3.5 m) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (*medium confidence*). *{2.2.3}*

The global glacier volume, excluding glaciers on the periphery of Antarctica (and excluding the Greenland and Antarctic ice sheets), is projected to decrease by 15 to 55% for RCP2.6 and by 35 to 85% for RCP8.5 (*medium confidence*). *{2.2.3}*

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[11] When sea-ice extent is less than one million km^2 for at least five consecutive years.

[12] Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979–2012 trend of the Arctic sea-ice extent.

There has been significant improvement in understanding and projection of sea level change since the AR4. Global mean sea level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, and of 0.45 to 0.82 m for RCP8.5 (*medium confidence*)[10] (Figure SPM.6b). Sea level rise will not be uniform across regions. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience a sea level change within ±20% of the global mean. *{2.2.3}*

SPM 2.3 Future risks and impacts caused by a changing climate

Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. *{2.3}*

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems, including their ability to adapt. Rising rates and magnitudes of warming and other changes in the climate system, accompanied by ocean acidification, increase the risk of severe, pervasive and in some cases irreversible detrimental impacts. Some risks are particularly relevant for individual regions (Figure SPM.8), while others are global. The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change, including ocean acidification. The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature (*medium confidence*). For risk assessment, it is important to evaluate the widest possible range of impacts, including low-probability outcomes with large consequences. *{1.5, 2.3, 2.4, 3.3, Box Introduction.1, Box 2.3, Box 2.4}*

A large fraction of species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). Most plant species cannot naturally shift their geographical ranges sufficiently fast to keep up with current and high projected rates of climate change in most landscapes; most small mammals and freshwater molluscs will not be able to keep up at the rates projected under RCP4.5 and above in flat landscapes in this century (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Marine organisms will face progressively lower oxygen levels and high rates and magnitudes of ocean acidification (*high confidence*), with associated risks exacerbated by rising ocean temperature extremes (*medium confidence*). Coral reefs and polar ecosystems are highly vulnerable. Coastal systems and low-lying areas are at risk from sea level rise, which will continue for centuries even if the global mean temperature is stabilized (*high confidence*). *{2.3, 2.4, Figure 2.5}*

Climate change is projected to undermine food security (Figure SPM.9). Due to projected climate change by the mid-21st century and beyond, global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*). For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit (*medium confidence*). Global temperature increases of ~4°C or more[13] above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally (*high confidence*). Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (*robust evidence, high agreement*), intensifying competition for water among sectors (*limited evidence, medium agreement*). *{2.3.1, 2.3.2}*

[13] Projected warming averaged over land is larger than global average warming for all RCP scenarios for the period 2081–2100 relative to 1986–2005. For regional projections, see Figure SPM.7. *{2.2}*

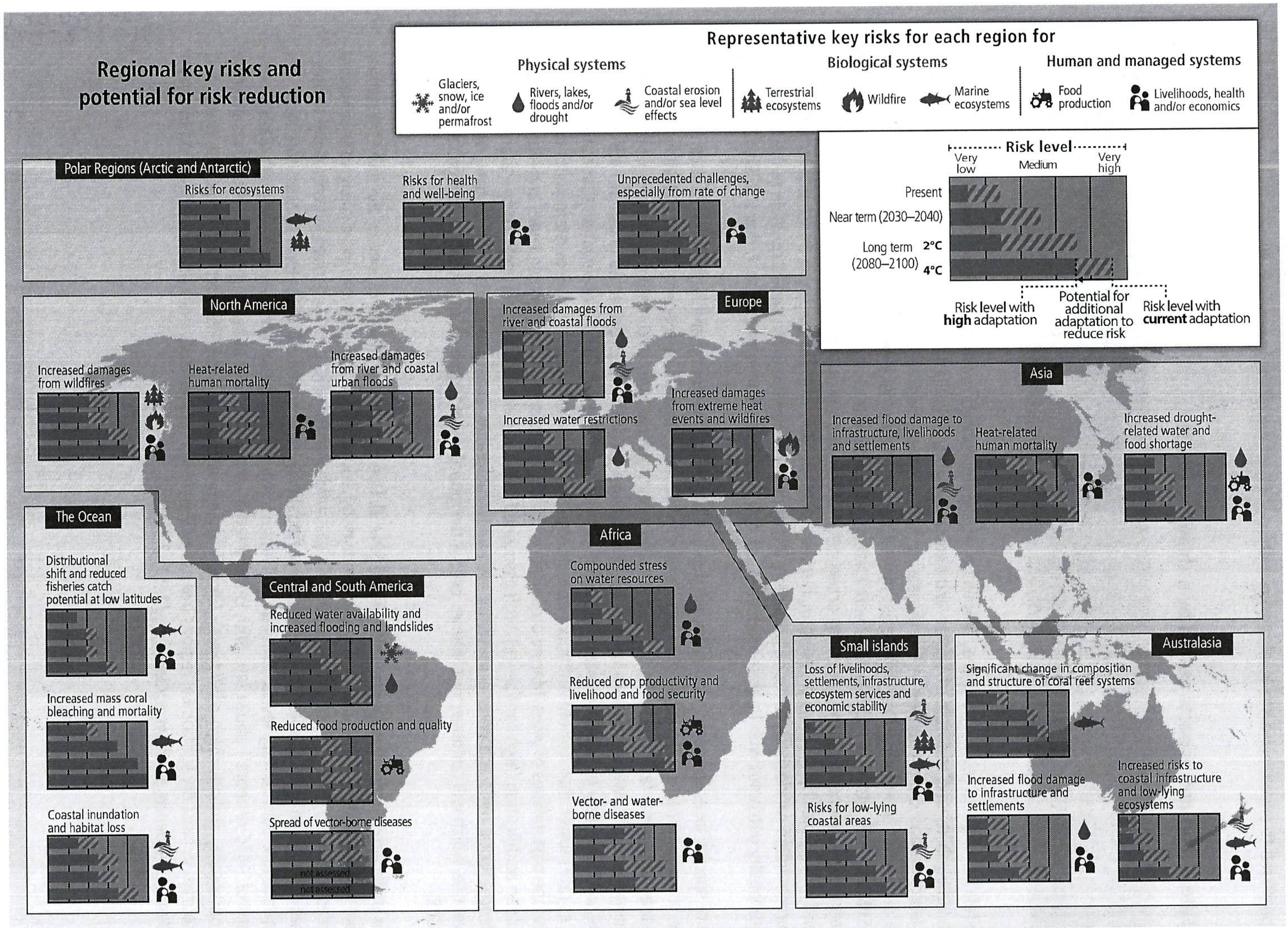

Figure SPM.8 | Representative key risks[14] for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each timeframe, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. *{Figure 2.4}*

[14] Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation.

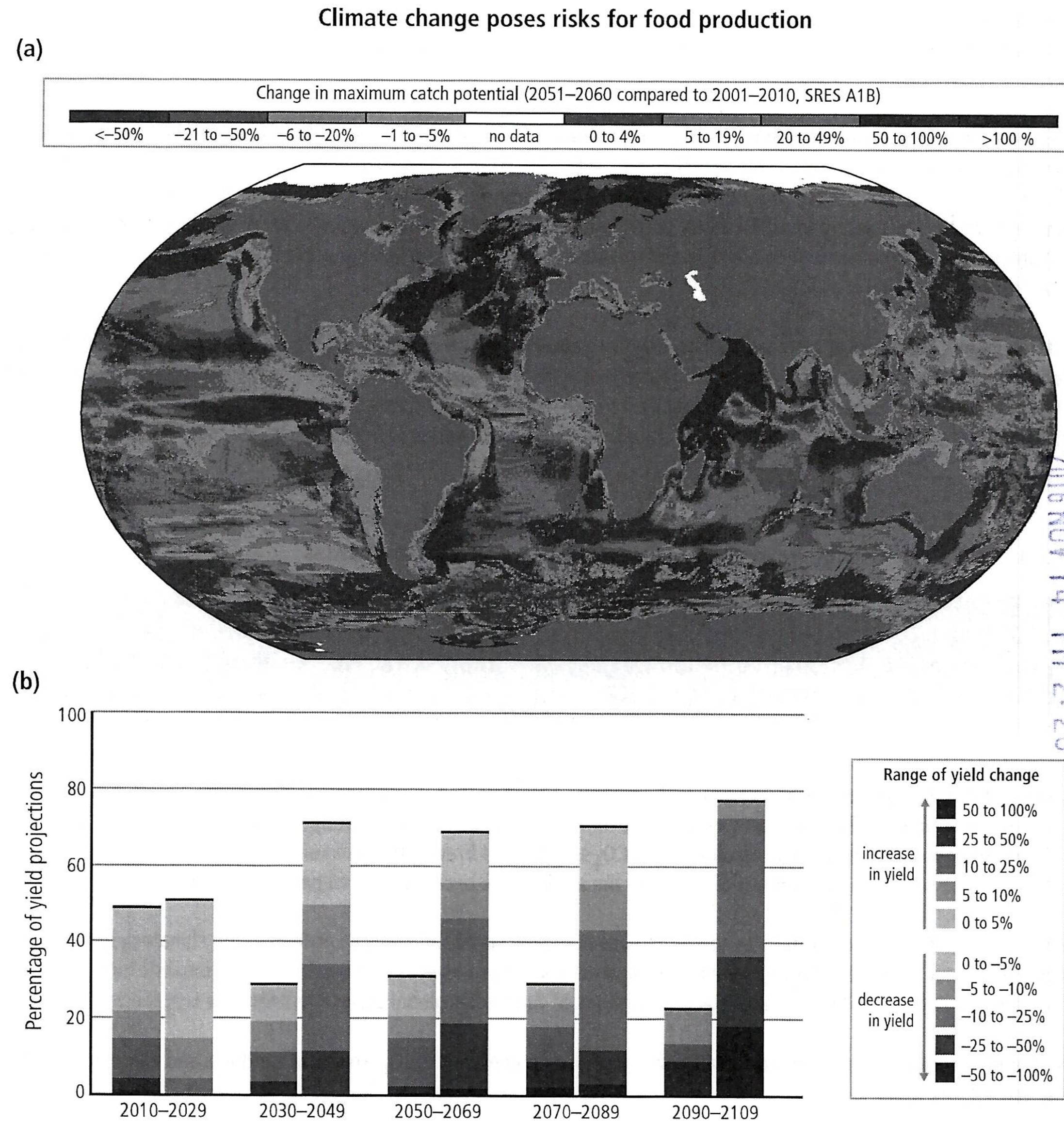

Figure SPM.9 | **(a)** Projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using ocean conditions based on a single climate model under a moderate to high warming scenario, without analysis of potential impacts of overfishing or ocean acidification. **(b)** Summary of projected changes in crop yields (mostly wheat, maize, rice and soy), due to climate change over the 21st century. Data for each timeframe sum to 100%, indicating the percentage of projections showing yield increases versus decreases. The figure includes projections (based on 1090 data points) for different emission scenarios, for tropical and temperate regions and for adaptation and no-adaptation cases combined. Changes in crop yields are relative to late 20th century levels. *{Figure 2.6a, Figure 2.7}*

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist (*very high confidence*). Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (*high confidence*). By 2100 for RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is expected to compromise common human activities, including growing food and working outdoors (*high confidence*). *{2.3.2}*

In urban areas climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges (*very high confidence*). These risks are amplified for those lacking essential infrastructure and services or living in exposed areas. *{2.3.2}*

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Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). {2.3.2}

Aggregate economic losses accelerate with increasing temperature (*limited evidence, high agreement*), but global economic impacts from climate change are currently difficult to estimate. From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). International dimensions such as trade and relations among states are also important for understanding the risks of climate change at regional scales. {2.3.2}

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Populations that lack the resources for planned migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Climate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). {2.3.2}

SPM 2.4 Climate change beyond 2100, irreversibility and abrupt changes

Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases. *{2.4}*

Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial timescale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. *{2.4, Figure 2.8}*

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales which will result in changes lasting hundreds to thousands of years after global surface temperature is stabilized. *{2.1, 2.4}*

There is *high confidence* that ocean acidification will increase for centuries if CO_2 emissions continue, and will strongly affect marine ecosystems. *{2.4}*

It is *virtually certain* that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions. The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment. *{2.4}*

Magnitudes and rates of climate change associated with medium- to high-emission scenarios pose an increased risk of abrupt and irreversible regional-scale change in the composition, structure and function of marine, terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). A reduction in permafrost extent is *virtually certain* with continued rise in global temperatures. *{2.4}*

SPM 3. Future Pathways for Adaptation, Mitigation and Sustainable Development

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development. *{3.2, 3.3, 3.4}*

SPM 3.1 Foundations of decision-making about climate change

Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty. *{3.1}*

Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions. Delaying mitigation shifts burdens from the present to the future, and insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development. Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. *{3.1, 3.5, Box 3.4}*

The design of climate policy is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. Methods of valuation from economic, social and ethical analysis are available to assist decision-making. These methods can take account of a wide range of possible impacts, including low-probability outcomes with large consequences. But they cannot identify a single best balance between mitigation, adaptation and residual climate impacts. *{3.1}*

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Effective mitigation will not be achieved if individual agents advance their own interests independently. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. *{3.1}*

SPM 3.2 Climate change risks reduced by mitigation and adaptation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts. *{3.2, 3.4}*

Mitigation and adaptation are complementary approaches for reducing risks of climate change impacts over different timescales (*high confidence*). Mitigation, in the near term and through the century, can substantially reduce climate change

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impacts in the latter decades of the 21st century and beyond. Benefits from adaptation can already be realized in addressing current risks, and can be realized in the future for addressing emerging risks. *{3.2, 4.5}*

Five Reasons For Concern (RFCs) aggregate climate change risks and illustrate the implications of warming and of adaptation limits for people, economies and ecosystems across sectors and regions. The five RFCs are associated with: (1) Unique and threatened systems, (2) Extreme weather events, (3) Distribution of impacts, (4) Global aggregate impacts, and (5) Large-scale singular events. In this report, the RFCs provide information relevant to Article 2 of UNFCCC. *{Box 2.4}*

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Figure SPM.10). In most scenarios without additional mitigation efforts (those with 2100 atmospheric concentrations

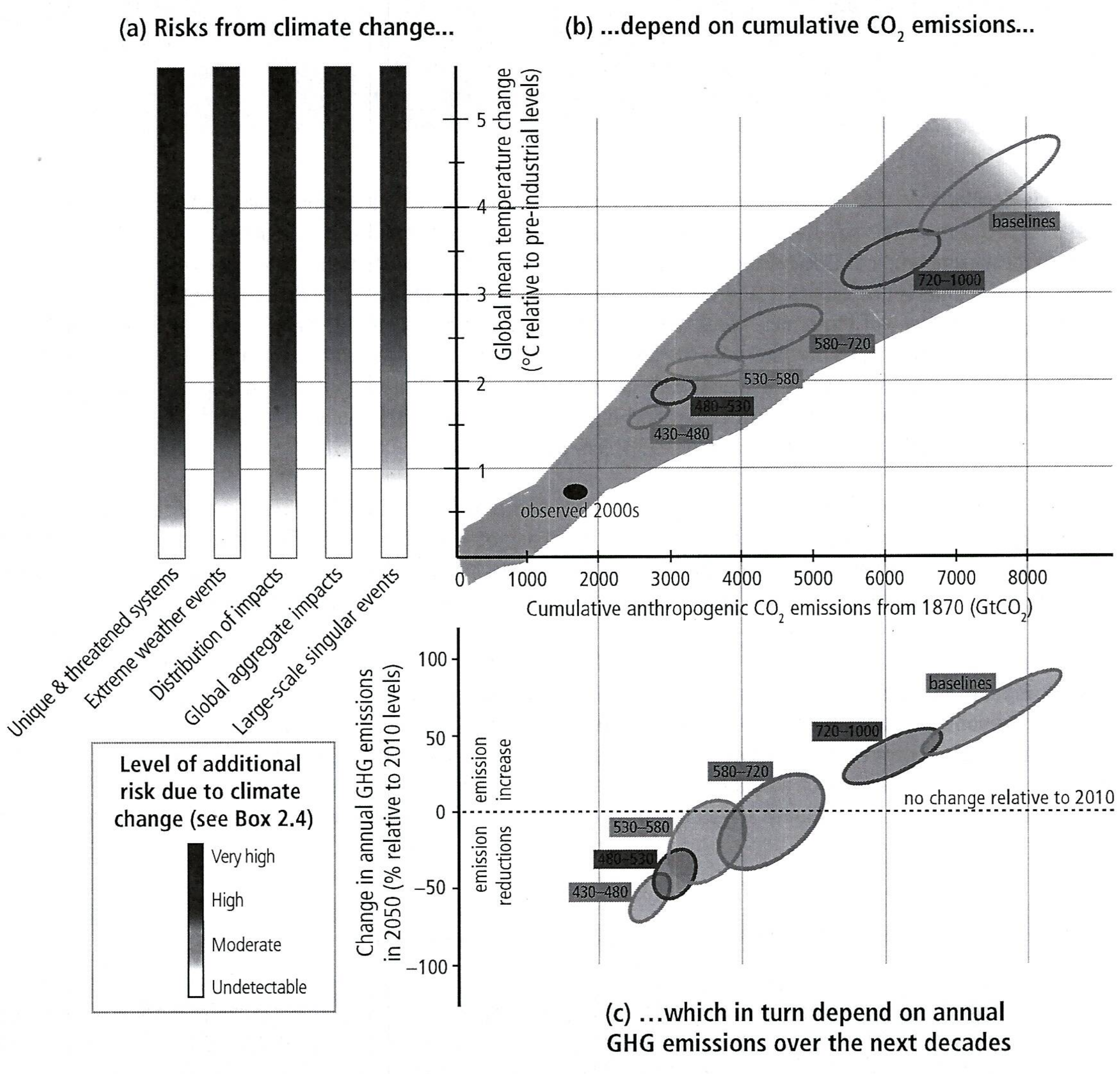

Figure SPM.10 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)** which would constrain annual GHG emissions over the next few decades **(c)**. **Panel a** reproduces the five Reasons For Concern *{Box 2.4}*. **Panel b** links temperature changes to cumulative CO_2 emissions (in $GtCO_2$) from 1870. They are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (pink plume) and on a simple climate model (median climate response in 2100), for the baselines and five mitigation scenario categories (six ellipses). Details are provided in Figure SPM.5. **Panel c** shows the relationship between the cumulative CO_2 emissions (in $GtCO_2$) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent $GtCO_2$-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel b, and are built with a similar method (see details in Figure SPM.5). *{Figure 3.1}*

>1000 ppm CO_2-eq), warming is *more likely than not* to exceed 4°C above pre-industrial levels by 2100 (Table SPM.1). The risks associated with temperatures at or above 4°C include substantial species extinction, global and regional food insecurity, consequential constraints on common human activities and limited potential for adaptation in some cases (*high confidence*). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels. *{2.3, Figure 2.5, 3.2, 3.4, Box 2.4, Table SPM.1}*

Substantial cuts in GHG emissions over the next few decades can substantially reduce risks of climate change by limiting warming in the second half of the 21st century and beyond. Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Limiting risks across RFCs would imply a limit for cumulative emissions of CO_2. Such a limit would require that global net emissions of CO_2 eventually decrease to zero and would constrain annual emissions over the next few decades (Figure SPM.10) (*high confidence*). But some risks from climate damages are unavoidable, even with mitigation and adaptation. *{2.2.5, 3.2, 3.4}*

Mitigation involves some level of co-benefits and risks, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change. Inertia in the economic and climate system and the possibility of irreversible impacts from climate change increase the benefits from near-term mitigation efforts (*high confidence*). Delays in additional mitigation or constraints on technological options increase the longer-term mitigation costs to hold climate change risks at a given level (Table SPM.2). *{3.2, 3.4}*

SPM 3.3 Characteristics of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness. *{3.3}*

Adaptation can contribute to the well-being of populations, the security of assets and the maintenance of ecosystem goods, functions and services now and in the future. Adaptation is place- and context-specific (*high confidence*). A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Integration of adaptation into planning, including policy design, and decision-making can promote synergies with development and disaster risk reduction. Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*robust evidence, high agreement*). *{3.3}*

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification and by providing information, policy and legal frameworks and financial support (*robust evidence*, *high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence*, *high agreement*). *{3.3}*

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts and expectations can benefit decision-making processes. Indigenous, local and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change, but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation. *{3.3}*

Constraints can interact to impede adaptation planning and implementation (*high confidence*). Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Another constraint includes insufficient research, monitoring, and observation and the finance to maintain them. *{3.3}*

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Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). Limits to adaptation emerge from the interaction among climate change and biophysical and/or socio-economic constraints. Further, poor planning or implementation, overemphasizing short-term outcomes or failing to sufficiently anticipate consequences can result in maladaptation, increasing the vulnerability or exposure of the target group in the future or the vulnerability of other people, places or sectors (*medium evidence, high agreement*). Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. *{3.3}*

Significant co-benefits, synergies and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use and biodiversity, but tools to understand and manage these interactions remain limited. Examples of actions with co-benefits include (i) improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging, climate-altering air pollutants; (ii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iii) sustainable agriculture and forestry; and (iv) protection of ecosystems for carbon storage and other ecosystem services. *{3.3}*

Transformations in economic, social, technological and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. Restricting adaptation responses to incremental changes to existing systems and structures, without considering transformational change, may increase costs and losses and miss opportunities. Planning and implementation of transformational adaptation could reflect strengthened, altered or aligned paradigms and may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications. Adaptation pathways are enhanced by iterative learning, deliberative processes and innovation. *{3.3}*

SPM 3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are *likely* to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales. *{3.4}*

Without additional efforts to reduce GHG emissions beyond those in place today, global emissions growth is expected to persist, driven by growth in global population and economic activities. Global mean surface temperature increases in 2100 in baseline scenarios—those without additional mitigation—range from 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range) (*high confidence*). *{3.4}*

Emissions scenarios leading to CO_2-equivalent concentrations in 2100 of about 450 ppm or lower are *likely* to maintain warming below 2°C over the 21st century relative to pre-industrial levels[15]. These scenarios are characterized by 40 to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010[16], and emissions levels near zero or below in 2100. Mitigation scenarios reaching concentration levels of about 500 ppm CO_2-eq by 2100 are *more likely than not* to limit temperature change to less than 2°C, unless they temporarily overshoot concentration levels of roughly 530 ppm CO_2-eq

[15] For comparison, the CO_2-eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm)

[16] This range differs from the range provided for a similar concentration category in the AR4 (50 to 85% lower than 2000 for CO_2 only). Reasons for this difference include that this report has assessed a substantially larger number of scenarios than in the AR4 and looks at all GHGs. In addition, a large proportion of the new scenarios include Carbon Dioxide Removal (CDR) technologies (see below). Other factors include the use of 2100 concentration levels instead of stabilization levels and the shift in reference year from 2000 to 2010.

before 2100, in which case they are *about as likely as not* to achieve that goal. In these 500 ppm CO_2-eq scenarios, global 2050 emissions levels are 25 to 55% lower than in 2010. Scenarios with higher emissions in 2050 are characterized by a greater reliance on Carbon Dioxide Removal (CDR) technologies beyond mid-century (and vice versa). Trajectories that are *likely* to limit warming to 3°C relative to pre-industrial levels reduce emissions less rapidly than those limiting warming to 2°C. A limited number of studies provide scenarios that are *more likely than not* to limit warming to 1.5°C by 2100; these scenarios are characterized by concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70% and 95% below 2010. For a comprehensive overview of the characteristics of emissions scenarios, their CO_2-equivalent concentrations and their likelihood to keep warming to below a range of temperature levels, see Figure SPM.11 and Table SPM.1. *{3.4}*

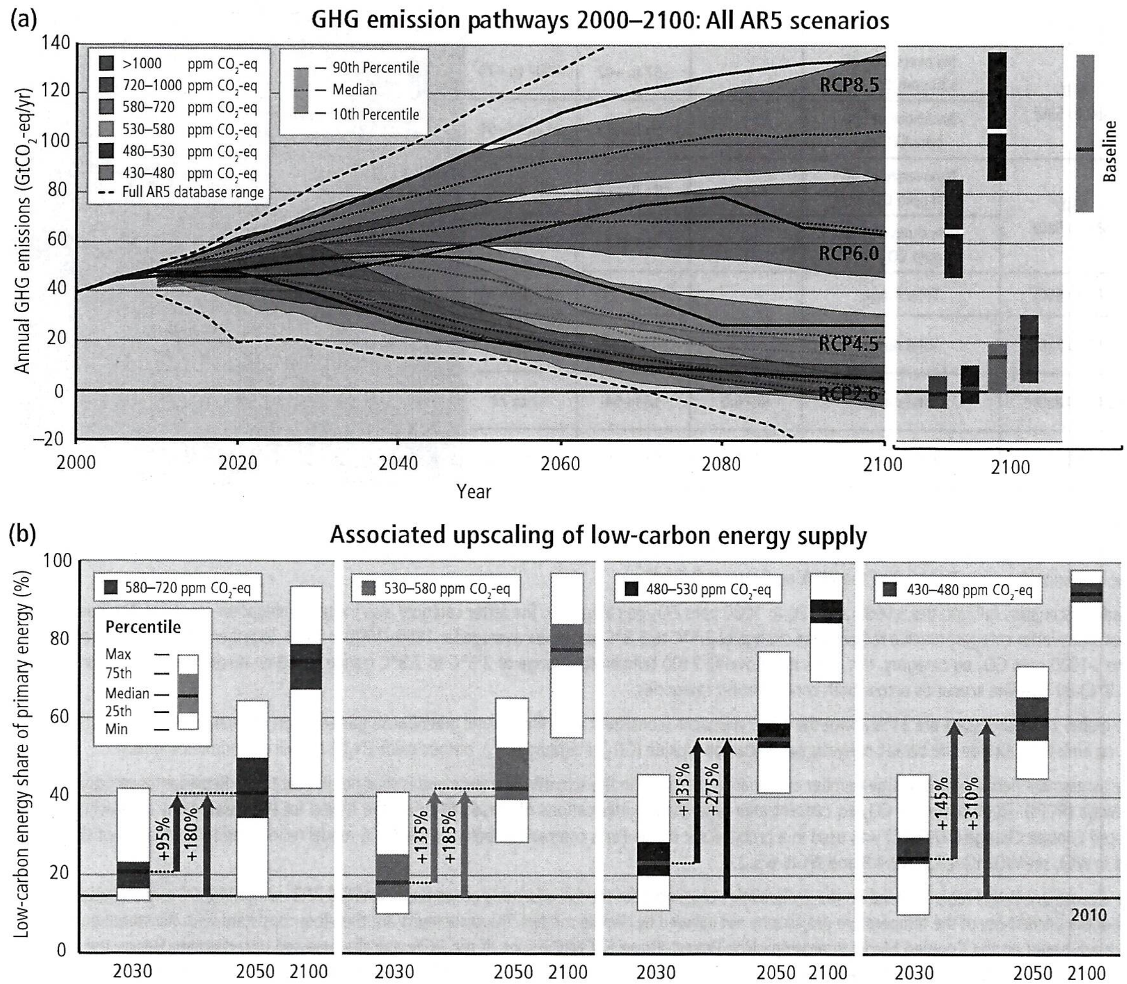

Figure SPM.11 | Global greenhouse gas emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels **(a)** and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios **(b)**. *{Figure 3.2}*

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Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown[a]. *{Table 3.1}*

<table>
<tr><th rowspan="2">CO_2-eq Concentrations in 2100 (ppm CO_2-eq)[f]

Category label (conc. range)</th><th rowspan="2">Subcategories</th><th rowspan="2">Relative position of the RCPs[d]</th><th colspan="2">Change in CO_2-eq emissions compared to 2010 (in %)[c]</th><th colspan="4">Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900)[d, e]</th></tr>
<tr><th>2050</th><th>2100</th><th>1.5°C</th><th>2°C</th><th>3°C</th><th>4°C</th></tr>
<tr><td><430</td><td colspan="8">Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq[j]</td></tr>
<tr><td>450
(430 to 480)</td><td>Total range[a, g]</td><td>RCP2.6</td><td>−72 to −41</td><td>−118 to −78</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500
(480 to 530)</td><td>No overshoot of 530 ppm CO_2-eq</td><td></td><td>−57 to −42</td><td>−107 to −73</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2-eq</td><td></td><td>−55 to −25</td><td>−114 to −90</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550
(530 to 580)</td><td>No overshoot of 580 ppm CO_2-eq</td><td></td><td>−47 to −19</td><td>−81 to −59</td><td rowspan="3">More unlikely than likely[i]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2-eq</td><td></td><td>−16 to 7</td><td>−183 to −86</td></tr>
<tr><td>(580 to 650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>−38 to 24</td><td>−134 to −50</td></tr>
<tr><td>(650 to 720)</td><td>Total range</td><td>−11 to 17</td><td>−54 to −21</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720 to 1000)[b]</td><td>Total range</td><td>RCP6.0</td><td>18 to 54</td><td>−7 to 72</td><td rowspan="2">Unlikely[h]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000[b]</td><td>Total range</td><td>RCP8.5</td><td>52 to 95</td><td>74 to 178</td><td>Unlikely[h]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

Notes:

[a] The 'total range' for the 430 to 480 ppm CO_2-eq concentrations scenarios corresponds to the range of the 10th to 90th percentile of the subcategory of these scenarios shown in Table 6.3 of the Working Group III Report.

[b] Baseline scenarios fall into the >1000 and 720 to 1000 ppm CO_2-eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5°C to 5.8°C above the average for 1850–1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO_2-eq category, this leads to an overall 2100 temperature range of 2.5°C to 7.8°C (range based on median climate response: 3.7°C to 4.8°C) for baseline scenarios across both concentration categories.

[c] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic greenhouse gas emission estimates presented in this report). CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases).

[d] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the Representative Concentration Pathways (RCPs). To evaluate the CO_2-eq concentration and climate implications of these scenarios, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) was used in a probabilistic mode. For a comparison between MAGICC model results and the outcomes of the models used in WGI, see WGI 12.4.1.2, 12.4.8 and WGIII 6.3.2.6.

[e] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII AR5 using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only *{WGIII 6.3}* and follow broadly the terms used by the WGI SPM for temperature projections: likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, and unlikely 0–33%. In addition the term more unlikely than likely 0–<50% is used.

[f] The CO_2-equivalent concentration (see Glossary) is calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC. The CO_2-equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm). This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i.e., 2.3 W/m^2, uncertainty range 1.1 to 3.3 W/m^2.

[g] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2-eq concentration.

[h] For scenarios in this category, no CMIP5 run or MAGICC realization stays below the respective temperature level. Still, an *unlikely* assignment is given to reflect uncertainties that may not be reflected by the current climate models.

[i] Scenarios in the 580 to 650 ppm CO_2-eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g., RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to stay below the 2°C temperature level, while the former are mostly assessed to have an *unlikely* probability of staying below this level.

[j] In these scenarios, global CO_2-eq emissions in 2050 are between 70 to 95% below 2010 emissions, and they are between 110 to 120% below 2010 emissions in 2100.

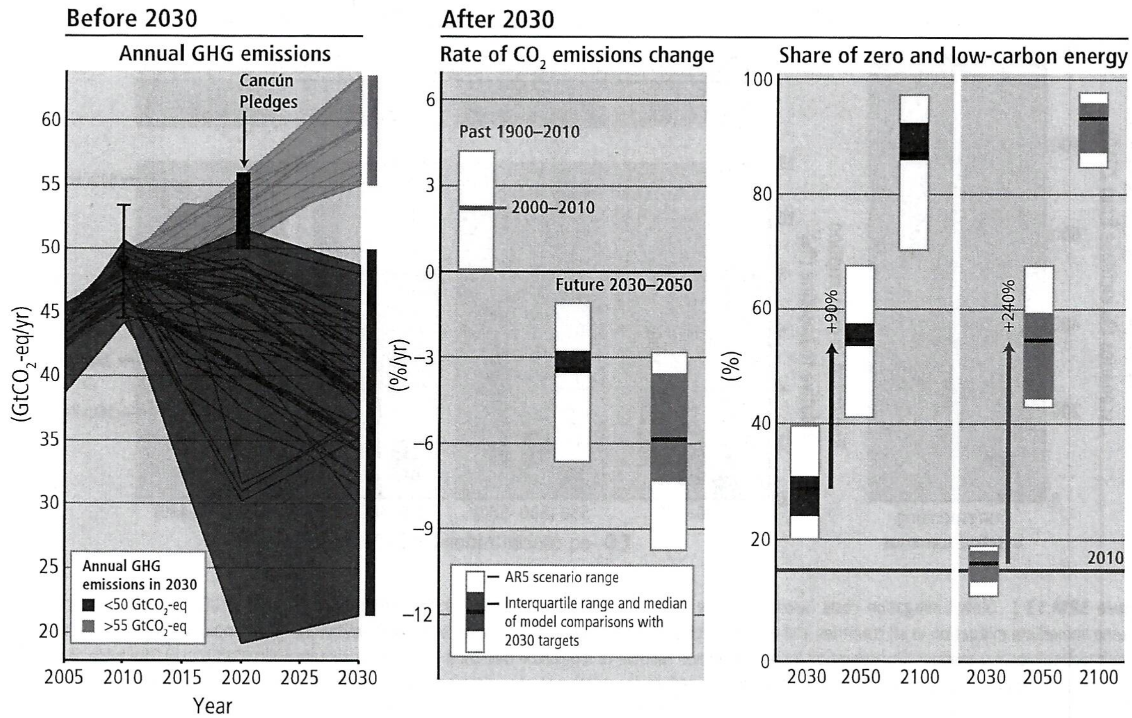

Figure SPM.12 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO_2) emissions reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C relative to pre-industrial levels (2100 CO_2-equivalent concentrations of 430 to 530 ppm). The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) leading to these 2030 levels. The black dot with whiskers gives historic GHG emission levels and associated uncertainties in 2010 as reported in Figure SPM.2. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emissions reduction rates for the period 2030–2050. It compares the median and interquartile range across scenarios from recent inter-model comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emissions change (sustained over a period of 20 years) and the average annual CO_2 emission change between 2000 and 2010 are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply upscaling from 2030 to 2050 subject to different 2030 GHG emissions levels. Zero- and low-carbon energy supply includes renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or bioenergy with CCS (BECCS). [Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$-eq/yr), scenarios with exogenous carbon price assumptions and scenarios with 2010 emissions significantly outside the historical range are excluded.] *{Figure 3.3}*

Mitigation scenarios reaching about 450 ppm CO_2-eq in 2100 (consistent with a *likely* chance to keep warming below 2°C relative to pre-industrial levels) typically involve temporary overshoot[17] of atmospheric concentrations, as do many scenarios reaching about 500 ppm CO_2-eq to about 550 ppm CO_2-eq in 2100 (Table SPM.1). Depending on the level of overshoot, overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century. The availability and scale of these and other CDR technologies and methods are uncertain and CDR technologies are, to varying degrees, associated with challenges and risks[18]. CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive (*high confidence*). *{3.4, Box 3.3}*

Reducing emissions of non-CO_2 agents can be an important element of mitigation strategies. All current GHG emissions and other forcing agents affect the rate and magnitude of climate change over the next few decades, although long-term warming is mainly driven by CO_2 emissions. Emissions of non-CO_2 forcers are often expressed as 'CO_2-equivalent emissions', but the choice of metric to calculate these emissions, and the implications for the emphasis and timing of abatement of the various climate forcers, depends on application and policy context and contains value judgments. *{3.4, Box 3.2}*

[17] In concentration 'overshoot' scenarios, concentrations peak during the century and then decline.

[18] CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. CDR methods may carry side effects and long-term consequences on a global scale.

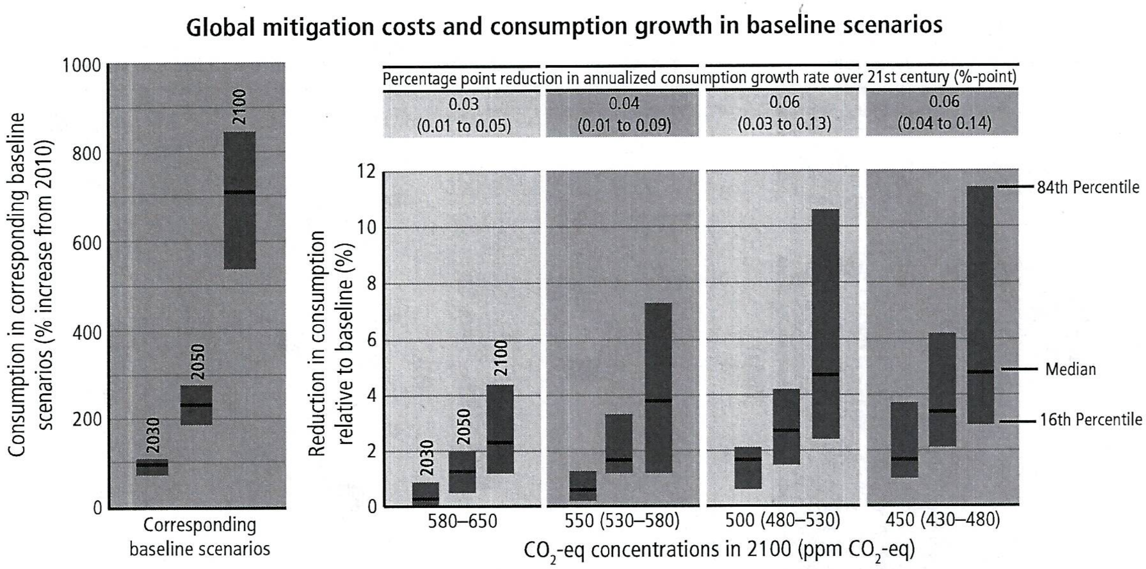

Figure SPM.13 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy (left panel). The table at the top shows percentage points of annualized consumption growth reductions relative to consumption growth in the baseline of 1.6 to 3% per year (e.g., if the reduction is 0.06 percentage points per year due to mitigation, and baseline growth is 2.0% per year, then the growth rate with mitigation would be 1.94% per year). Cost estimates shown in this table do not consider the benefits of reduced climate change or co-benefits and adverse side effects of mitigation. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. *{Figure 3.4}*

Delaying additional mitigation to 2030 will substantially increase the challenges associated with limiting warming over the 21st century to below 2°C relative to pre-industrial levels. It will require substantially higher rates of emissions reductions from 2030 to 2050; a much more rapid scale-up of low-carbon energy over this period; a larger reliance on CDR in the long term; and higher transitional and long-term economic impacts. Estimated global emissions levels in 2020 based on the Cancún Pledges are not consistent with cost-effective mitigation trajectories that are at least *about as likely as not* to limit warming to below 2°C relative to pre-industrial levels, but they do not preclude the option to meet this goal (*high confidence*) (Figure SPM.12, Table SPM.2). *{3.4}*

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation. Scenarios in which all countries of the world begin mitigation immediately, in which there is a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macro-economic mitigation costs (Figure SPM.13). Under these assumptions mitigation scenarios that are *likely* to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side effects of mitigation—of 1 to 4% (median: 1.7%) in 2030, 2 to 6% (median: 3.4%) in 2050 and 3 to 11% (median: 4.8%) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century (Figure SPM.13). These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6 and 3% per year (*high confidence*). *{3.4}*

In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS and their combination BECCS, nuclear, wind/solar), mitigation costs can increase substantially depending on the technology considered. Delaying additional mitigation increases mitigation costs in the medium to long term. Many models could not limit *likely* warming to below 2°C over the 21st century relative to pre-industrial levels if additional mitigation is considerably delayed. Many models could not limit *likely* warming to below 2°C if bioenergy, CCS and their combination (BECCS) are limited (*high confidence*) (Table SPM.2). *{3.4}*

Table SPM.2 | Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation [a] relative to cost-effective scenarios [b]. The increase in costs is given for the median estimate and the 16th to 84th percentile range of the scenarios (in parentheses) [c]. In addition, the sample size of each scenario set is provided in the coloured symbols. The colours of the symbols indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level. *{Table 3.2}*

	Mitigation cost increases in scenarios with limited availability of technologies [d] *[% increase in total discounted [e] mitigation costs (2015–2100) relative to default technology assumptions]*				Mitigation cost increases due to delayed additional mitigation until 2030 *[% increase in mitigation costs relative to immediate mitigation]*	
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy	medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%) [4]	7% (4 to 18%) [8]	6% (2 to 29%) [8]	64% (44 to 78%) [8]	44% (2 to 78%) [29]	37% (16 to 82%) [29]
500 (480 to 530)	not available (n.a.)	n.a.	n.a.	n.a.		
550 (530 to 580)	39% (18 to 78%) [11]	13% (2 to 23%) [10]	8% (5 to 15%) [10]	18% (4 to 66%) [12]	15% (3 to 32%)	16% (5 to 24%)
580 to 650	n.a.	n.a.	n.a.	n.a.		

Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)

- : all models successful
- : between 80 and 100% of models successful
- : between 50 and 80% of models successful
- : less than 50% of models successful

Notes:

[a] Delayed mitigation scenarios are associated with greenhouse gas emission of more than 55 $GtCO_2$-eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.

[b] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.

[c] The range is determined by the central scenarios encompassing the 16th to 84th percentile range of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2-eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2-eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.

[d] No CCS: carbon dioxide capture and storage is not included in these scenarios. Nuclear phase out: no addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations and industry was around 18 EJ/yr in 2008). EJ = Exajoule = 10^{18} Joule.

[e] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline gross domestic product (GDP, for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

Mitigation scenarios reaching about 450 or 500 ppm CO_2-eq by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts and sufficiency of resources and resilience of the energy system. *{4.4.2.2}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*). Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters (*high confidence*). The availability of CCS would reduce the adverse effects of mitigation on the value of fossil fuel assets (*medium confidence*). *{4.4.2.2}*

Solar Radiation Management (SRM) involves large-scale methods that seek to reduce the amount of absorbed solar energy in the climate system. SRM is untested and is not included in any of the mitigation scenarios. If it were deployed, SRM would

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entail numerous uncertainties, side effects, risks and shortcomings and has particular governance and ethical implications. SRM would not reduce ocean acidification. If it were terminated, there is *high confidence* that surface temperatures would rise very rapidly impacting ecosystems susceptible to rapid rates of change. *{Box 3.3}*

SPM 4. Adaptation and Mitigation

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives. *{4}*

SPM 4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices. *{4.1}*

Inertia in many aspects of the socio-economic system constrains adaptation and mitigation options (*medium evidence, high agreement*). Innovation and investments in environmentally sound infrastructure and technologies can reduce GHG emissions and enhance resilience to climate change (*very high confidence*). *{4.1}*

Vulnerability to climate change, GHG emissions and the capacity for adaptation and mitigation are strongly influenced by livelihoods, lifestyles, behaviour and culture (*medium evidence, medium agreement*). Also, the social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivize or depend on regionally appropriate changes in lifestyles or behaviours. *{4.1}*

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Improving institutions as well as coordination and cooperation in governance can help overcome regional constraints associated with mitigation, adaptation and disaster risk reduction (*very high confidence*). *{4.1}*

SPM 4.2 Response options for adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options. *{4.2}*

Adaptation experience is accumulating across regions in the public and private sectors and within communities. There is increasing recognition of the value of social (including local and indigenous), institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). *{1.6, 4.2, 4.4.2.1}*

The need for adaptation along with associated challenges is expected to increase with climate change (*very high confidence*). Adaptation options exist in all sectors and regions, with diverse potential and approaches depending on their context in vulnerability reduction, disaster risk management or proactive adaptation planning (Table SPM.3). Effective strategies and actions consider the potential for co-benefits and opportunities within wider strategic goals and development plans. *{4.2}*

Table SPM.3 | Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples are presented in no specific order and can be relevant to more than one category. *{Table 4.2}*

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalinisation; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other *ex situ* conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioural options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioural shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.

SPM

SPM 4.3 Response options for mitigation

Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors. *{4.3}*

Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors, with efforts in one sector affecting the need for mitigation in others (*medium confidence*). Mitigation measures intersect with other societal goals, creating the possibility of co-benefits or adverse side effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action. *{4.3}*

Emissions ranges for baseline scenarios and mitigation scenarios that limit CO_2-equivalent concentrations to low levels (about 450 ppm CO_2-eq, *likely* to limit warming to 2°C above pre-industrial levels) are shown for different sectors and gases in Figure SPM.14. Key measures to achieve such mitigation goals include decarbonizing (i.e., reducing the carbon intensity of) electricity generation (*medium evidence, high agreement*) as well as efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development (*robust evidence, high agreement*). In scenarios reaching 450 ppm CO_2-eq concentrations by 2100, global CO_2 emissions from the energy supply sector are projected to decline over the next decade and are characterized by reductions of 90% or more below 2010 levels between 2040 and 2070. In the majority of low-concentration stabilization scenarios (about 450 to about 500 ppm CO_2-eq, at least *about as likely as not* to limit warming to 2°C above pre-industrial levels), the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and carbon dioxide capture and storage (CCS) including bioenergy with carbon dioxide capture and storage (BECCS)) increases from the current share of approximately 30% to more than 80% by 2050, and fossil fuel power generation without CCS is phased out almost entirely by 2100. *{4.3}*

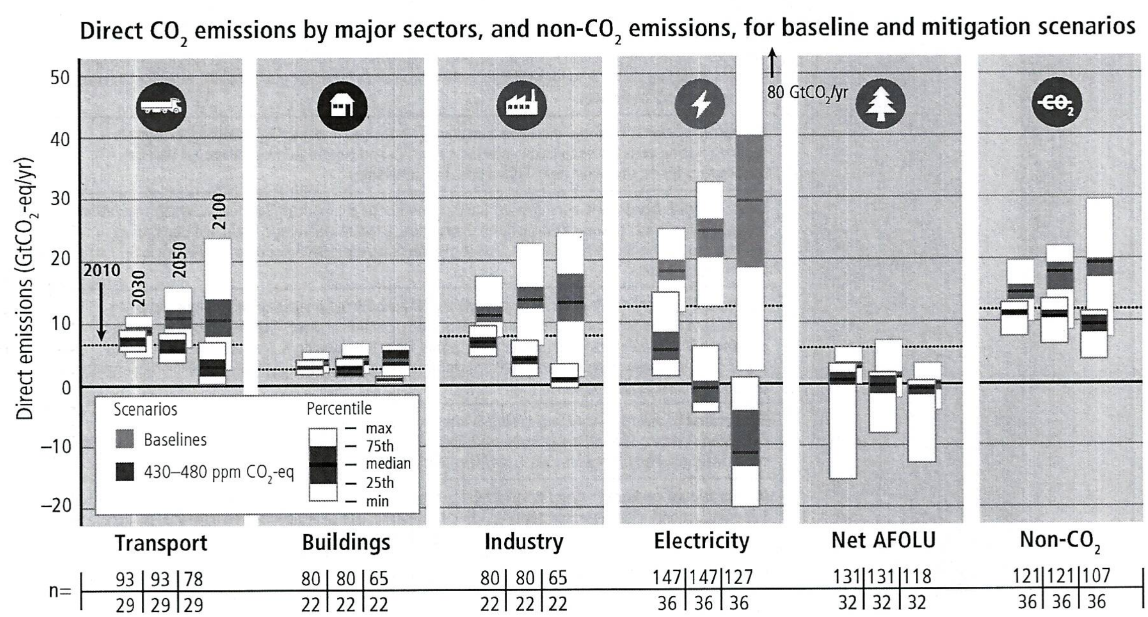

Figure SPM.14 | Carbon dioxide (CO_2) emissions by sector and total non-CO_2 greenhouse gases (Kyoto gases) across sectors in baseline (faded bars) and mitigation scenarios (solid colour bars) that reach about 450 (430 to 480) ppm CO_2-eq concentrations in 2100 (*likely* to limit warming to 2°C above pre-industrial levels). Mitigation in the end-use sectors leads also to indirect emissions reductions in the upstream energy supply sector. Direct emissions of the end-use sectors thus do not include the emission reduction potential at the supply-side due to, for example, reduced electricity demand. The numbers at the bottom of the graphs refer to the number of scenarios included in the range (upper row: baseline scenarios; lower row: mitigation scenarios), which differs across sectors and time due to different sectoral resolution and time horizon of models. Emissions ranges for mitigation scenarios include the full portfolio of mitigation options; many models cannot reach 450 ppm CO_2-eq concentration by 2100 in the absence of carbon dioxide capture and storage (CCS). Negative emissions in the electricity sector are due to the application of bioenergy with carbon dioxide capture and storage (BECCS). 'Net' agriculture, forestry and other land use (AFOLU) emissions consider afforestation, reforestation as well as deforestation activities. *{4.3, Figure 4.1}*

Near-term reductions in energy demand are an important element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits. The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions; and in agriculture, cropland management, grazing land management and restoration of organic soils (*medium evidence, high agreement*). *{4.3, Figures 4.1, 4.2, Table 4.3}*

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Emissions can be substantially lowered through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes. *{4.1, 4.3}*

SPM 4.4 Policy approaches for adaptation and mitigation, technology and finance

Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation. *{4.4}*

International cooperation is critical for effective mitigation, even though mitigation can also have local co-benefits. Adaptation focuses primarily on local to national scale outcomes, but its effectiveness can be enhanced through coordination across governance scales, including international cooperation: *{3.1, 4.4.1}*

- The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{4.4.1}*

- The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms and environmental effectiveness (*medium evidence, low agreement*). *{4.4.1}*

- Policy linkages among regional, national and sub-national climate policies offer potential climate change mitigation benefits (*medium evidence, medium agreement*). Potential advantages include lower mitigation costs, decreased emission leakage and increased market liquidity. *{4.4.1}*

- International cooperation for supporting adaptation planning and implementation has received less attention historically than mitigation but is increasing and has assisted in the creation of adaptation strategies, plans and actions at the national, sub-national and local level (*high confidence*). *{4.4.1}*

There has been a considerable increase in national and sub-national plans and strategies on both adaptation and mitigation since the AR4, with an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side effects (*high confidence*): *{4.4.2.1, 4.4.2.2}*

- National governments play key roles in adaptation planning and implementation (*robust evidence, high agreement*) through coordinating actions and providing frameworks and support. While local government and the private sector have different functions, which vary regionally, they are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). *{4.4.2.1}*

- Institutional dimensions of adaptation governance, including the integration of adaptation into planning and decision-making, play a key role in promoting the transition from planning to implementation of adaptation (*robust evidence,* *high agreement*). Examples of institutional approaches to adaptation involving multiple actors include economic options (e.g., insurance, public-private partnerships), laws and regulations (e.g., land-zoning laws) and national and government policies and programmes (e.g., economic diversification). *{4.2, 4.4.2.1, Table SPM.3}*

- In principle, mechanisms that set a carbon price, including cap and trade systems and carbon taxes, can achieve mitigation in a cost-effective way but have been implemented with diverse effects due in part to national circumstances as well as policy design. The short-run effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining (*limited evidence, medium agreement*). In some countries, tax-based policies specifically aimed at reducing GHG emissions—alongside technology and other policies—have helped to weaken the link between GHG emissions and GDP (*high confidence*). In addition, in a large group of countries, fuel taxes (although not necessarily designed for the purpose of mitigation) have had effects that are akin to sectoral carbon taxes. *{4.4.2.2}*

- Regulatory approaches and information measures are widely used and are often environmentally effective (*medium evidence, medium agreement*). Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programmes that can help consumers make better-informed decisions. *{4.4.2.2}*

- Sector-specific mitigation policies have been more widely used than economy-wide policies (*medium evidence, high agreement*). Sector-specific policies may be better suited to address sector-specific barriers or market failures and may be bundled in packages of complementary policies. Although theoretically more cost-effective, administrative and political barriers may make economy-wide policies harder to implement. Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions. *{4.4.2.2}*

- Economic instruments in the form of subsidies may be applied across sectors, and include a variety of policy designs, such as tax rebates or exemptions, grants, loans and credit lines. An increasing number and variety of renewable energy (RE) policies including subsidies—motivated by many factors—have driven escalated growth of RE technologies in recent years. At the same time, reducing subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). *{4.4.2.2}*

Co-benefits and adverse side effects of mitigation could affect achievement of other objectives such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development. The potential for co-benefits for energy end-use measures outweighs the potential for adverse side effects whereas the evidence suggests this may not be the case for all energy supply and agriculture, forestry and other land use (AFOLU) measures. Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side effects on energy access can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). Whether or not side effects materialize, and to what extent side effects materialize, will be case- and site-specific, and depend on local circumstances and the scale, scope and pace of implementation. Many co-benefits and adverse side effects have not been well-quantified. *{4.3, 4.4.2.2, Box 3.4}*

Technology policy (development, diffusion and transfer) complements other mitigation policies across all scales, from international to sub-national; many adaptation efforts also critically rely on diffusion and transfer of technologies and management practices (*high confidence*). Policies exist to address market failures in R&D, but the effective use of technologies can also depend on capacities to adopt technologies appropriate to local circumstances. *{4.4.3}*

Substantial reductions in emissions would require large changes in investment patterns (*high confidence*). For mitigation scenarios that stabilize concentrations (without overshoot) in the range of 430 to 530 ppm CO_2-eq by 2100[19], annual investments in low carbon electricity supply and energy efficiency in key sectors (transport, industry and buildings) are projected in the scenarios to rise by several hundred billion dollars per year before 2030. Within appropriate enabling environments, the private sector, along with the public sector, can play important roles in financing mitigation and adaptation (*medium evidence, high agreement*). *{4.4.4}*

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[19] This range comprises scenarios that reach 430 to 480 ppm CO_2-eq by 2100 (*likely* to limit warming to 2°C above pre-industrial levels) and scenarios that reach 480 to 530 ppm CO_2-eq by 2100 (without overshoot: *more likely than* not to limit warming to 2°C above pre-industrial levels).

Financial resources for adaptation have become available more slowly than for mitigation in both developed and developing countries. Limited evidence indicates that there is a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). There is a need for better assessment of global adaptation costs, funding and investment. Potential synergies between international finance for disaster risk management and adaptation have not yet been fully realized (*high confidence*). *{4.4.4}*

SPM 4.5 Trade-offs, synergies and interactions with sustainable development

Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (*medium confidence*). *{3.5, 4.5}*

Climate change exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor (*high confidence*). Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Delaying global mitigation actions may reduce options for climate-resilient pathways and adaptation in the future. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use and biodiversity (*medium evidence, high agreement*). *{3.1, 3.5, 4.5}*

Strategies and actions can be pursued now which will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being and effective environmental management. In some cases, economic diversification can be an important element of such strategies. The effectiveness of integrated responses can be enhanced by relevant tools, suitable governance structures and adequate institutional and human capacity (*medium confidence*). Integrated responses are especially relevant to energy planning and implementation; interactions among water, food, energy and biological carbon sequestration; and urban planning, which provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development (*medium confidence*). *{3.5, 4.4, 4.5}*

Exhibit 3

The White House

Office of the Press Secretary

For Immediate Release November 11, 2014

U.S.-China Joint Announcement on Climate Change

Beijing, China, 12 November 2014

1. The United States of America and the People's Republic of China have a critical role to play in combating global climate change, one of the greatest threats facing humanity. The seriousness of the challenge calls upon the two sides to work constructively together for the common good.

2. To this end, President Barack Obama and President Xi Jinping reaffirmed the importance of strengthening bilateral cooperation on climate change and will work together, and with other countries, to adopt a protocol, another legal instrument or an agreed outcome with legal force under the Convention applicable to all Parties at the United Nations Climate Conference in Paris in 2015. They are committed to reaching an ambitious 2015 agreement that reflects the principle of common but differentiated responsibilities and respective capabilities, in light of different national circumstances.

3. Today, the Presidents of the United States and China announced their respective post-2020 actions on climate change, recognizing that these actions are part of the longer range effort to transition to low-carbon economies, mindful of the global temperature goal of 2℃. The United States intends to achieve an economy-wide target of reducing its emissions by 26%-28% below its 2005 level in 2025 and to make best efforts to reduce its emissions by 28%. China intends to achieve the peaking of CO2 emissions around 2030 and to make best efforts to peak early and intends to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030. Both sides intend to continue to work to increase ambition over time.

4. The United States and China hope that by announcing these targets now, they can inject momentum into the global climate negotiations and inspire other countries to join in coming forward with ambitious actions as soon as possible, preferably by the first quarter of 2015. The two Presidents resolved to work closely together over the next year to address major impediments to reaching a successful global climate agreement in Paris.

5. The global scientific community has made clear that human activity is already changing the world's climate system. Accelerating climate change has caused serious impacts. Higher temperatures and extreme weather events are damaging food production, rising sea levels and more damaging storms are putting our coastal cities increasingly at risk and the impacts of climate change are already harming economies around the world, including those of the United States and China. These developments urgently require enhanced actions to tackle the challenge.

6. At the same time, economic evidence makes increasingly clear that smart action on climate change now can drive innovation, strengthen economic growth and bring broad benefits – from sustainable development to increased energy security, improved public health and a better quality of life. Tackling climate change will also strengthen national and international security.

7. Technological innovation is essential for reducing the cost of current mitigation technologies, leading to the invention and dissemination of new zero and low-carbon technologies and enhancing the capacity of countries to reduce their emissions. The United States and China are two of the world's largest investors in clean energy and already have a robust program of energy technology cooperation. The two sides have, among other things:

- established the U.S.-China Climate Change Working Group (CCWG), under which they have launched action initiatives on vehicles, smart grids, carbon capture, utilization and storage, energy efficiency, greenhouse gas data management, forests and industrial boilers;
- agreed to work together towards the global phase down of hydrofluorocarbons (HFCs), very potent greenhouse gases;

- created the U.S.-China Clean Energy Research Center, which facilitates collaborative work in carbon capture and storage technologies, energy efficiency in buildings, and clean vehicles; and
- agreed on a joint peer review of inefficient fossil fuel subsidies under the G-20.

8. The two sides intend to continue strengthening their policy dialogue and practical cooperation, including cooperation on advanced coal technologies, nuclear energy, shale gas and renewable energy, which will help optimize the energy mix and reduce emissions, including from coal, in both countries. To further support achieving their ambitious climate goals, today the two sides announced additional measures to strengthen and expand their cooperation, using the existing vehicles, in particular the U.S.-China Climate Change Working Group, the U.S.-China Clean Energy Research Center and the U.S.-China Strategic and Economic Dialogue. These include:

- **Expanding Joint Clean Energy Research and Development:** A renewed commitment to the U.S.-China Clean Energy Research Center, including continued funding for three existing tracks on building efficiency, clean vehicles and advanced coal technology and launching a new track on the energy-water nexus;
- **Advancing Major Carbon Capture, Utilization and Storage Demonstrations:** Establishment of a major new carbon storage project based in China through an international public-private consortium led by the United States and China to intensively study and monitor carbon storage using industrial CO2 and also work together on a new Enhanced Water Recovery (EWR) pilot project to produce fresh water from CO2 injection into deep saline aquifers;
- **Enhancing Cooperation on HFCs:** Building on the historic Sunnylands agreement between President Obama and President Xi regarding HFCs, highly potent greenhouse gases, the two sides will enhance bilateral cooperation to begin phasing-down the use of high global warming potential HFCs and work together in a multilateral context as agreed by the two Presidents at their meeting in St. Petersburg on 6 September 2013;
- **Launching a Climate-Smart/Low-Carbon Cities Initiative:** In response to growing urbanization and increasingly significant greenhouse gas emissions from cities and recognizing the potential for local leaders to undertake significant climate action, the United States and China will establish a new initiative on Climate-Smart/Low-Carbon Cities under the CCWG. As a first step, the United States and China will convene a Climate-Smart/ Low-Carbon Cities Summit where leading cities from both countries will share best practices, set new goals and celebrate city-level leadership in reducing carbon emissions and building resilience;
- **Promoting Trade in Green Goods:** Encouraging bilateral trade in sustainable environmental goods and clean energy technologies, including through a U.S. trade mission led by Secretaries Moniz and Pritzker in April 2015 that will focus on smart low-carbon cities and smart low-carbon growth technologies; and
- **Demonstrating Clean Energy on the Ground:** Additional pilot programs, feasibility studies and other collaborative projects in the areas of building efficiency, boiler efficiency, solar energy and smart grids.

Exhibit 4

THE WHITE HOUSE
WASHINGTON

CLIMATE ACTION PLAN
STRATEGY TO REDUCE METHANE EMISSIONS

MARCH 2014

CLIMATE ACTION PLAN - STRATEGY TO REDUCE METHANE EMISSIONS

EXECUTIVE SUMMARY

Reducing methane emissions is a powerful way to take action on climate change; and putting methane to use can support local economies with a source of clean energy that generates revenue, spurs investment, improves safety, and leads to cleaner air. That is why in his Climate Action Plan, President Obama directed the Administration to develop a comprehensive, interagency strategy to cut methane emissions.

This document lays out that strategy – summarizing the sources of methane and trends in emissions; setting forth a plan to reduce both domestic and international methane emissions through incentive-based programs and the Administration's existing authorities; and, outlining the Administration's efforts to improve measurement of these emissions. This strategy also highlights examples of technologies and industry-led best practices that are already helping to cut methane emissions.

Today, methane accounts for nearly 9 percent of domestic greenhouse gas emissions. And although U.S. methane emissions have decreased by 11 percent since 1990, they are projected to increase through 2030 if additional action is not taken. As a key element of the Climate Action Plan, this strategy outlines new actions to reduce methane emissions. These actions will improve public health and safety while providing more energy to power our communities, farms, factories, and power plants. These steps will also make an important contribution to meeting the Administration goal of reducing U.S. greenhouse gas emissions in the range of 17 percent below 2005 levels by 2020. While the elements of the strategy will be further fleshed out in the coming months, Administration estimates show that steps along these lines could deliver greenhouse gas emissions reductions up to 90 million metric tons in 2020.

Through partnerships with industry, both at home and abroad, we have already demonstrated the technology and best practices to deliver substantial reductions in methane emissions. These cost-effective steps can deliver multiple benefits:

- *Economic Benefits:* Methane is the primary component of natural gas, so the recovery of methane that would otherwise be emitted can be productively used for power generation, heating or manufacturing. In addition, projects to reduce methane emissions can put people to work and spur investment in local economies.

- *Climate Change Benefits:* Every ton of methane in the atmosphere has a global warming effect that is more than 20 times greater than a ton of carbon dioxide. Thus, methane reductions yield important climate benefits, particularly in the near term.

- *Public Health:* Actions to reduce methane also improve the quality of the air we breathe. Methane is a contributor to ground level ozone, so cutting methane emissions reduces smog, which is associated with higher rates of asthma attacks. Moreover, methane is often co-emitted with volatile organic compounds, some of which are hazardous air pollutants, and many measures can cost-effectively reduce both pollutants.

- *Safety:* Improved safety and reduced methane emissions go hand-in-hand, as in our natural gas transmission and distributions systems and coal mining industries.

Reducing Methane Emissions
The Administration is pursuing a targeted strategy that builds on progress to date and takes steps to further cut methane emissions from a number of key sources:

- **Landfills**: In the summer of 2014, the Environmental Protection Agency (EPA) will propose updated standards to reduce methane from new landfills and take public comment on whether to update standards for existing landfills. Through the Landfill Methane Outreach Program, EPA will further reduce methane emissions through voluntary programs – partnering with industry, state, and local leaders, many of whom are putting the methane waste to use powering their communities.

- **Coal Mines:** In April of 2014, the Interior Department's Bureau of Land Management (BLM) will release an Advanced Notice of Proposed Rulemaking (ANPRM) to gather public input on the development of a program for the capture and sale, or disposal, of waste mine methane on lands leased by the Federal government. In addition, EPA will continue to partner with industry through its voluntary program to reduce institutional, technical, regulatory, and financial barriers to beneficial methane recovery and use at coal mines.

- **Agriculture:** In June, in partnership with the dairy industry, the US Department of Agriculture (USDA), EPA and the Department of Energy (DOE) will jointly release a "Biogas Roadmap" outlining voluntary strategies to accelerate adoption of methane digesters and other cost-effective technologies to reduce U.S. dairy sector greenhouse gas emissions by 25 percent by 2020. USDA and EPA will also continue to support biodigester technology deployment by providing financial and technical assistance through voluntary programs.

- **Oil and Gas:** Building on the success of voluntary programs and targeted regulations in reducing methane emissions from the oil and gas sector, the Administration will take new actions to encourage additional cost-effective reductions. Key steps include:

    - In the spring of 2014, EPA will assess several potentially significant sources of methane and other emissions from the oil and gas sector. EPA will solicit input from independent experts through a series of technical white papers, and in the fall of 2014, EPA will determine how best to pursue further methane reductions from these sources. If EPA decides to develop additional regulations, it will complete those regulations by the end of 2016. Through the Natural Gas STAR program, EPA will work with the industry to expand voluntary efforts to reduce methane emissions.

- Later this year, the BLM will propose updated standards to reduce venting and flaring from oil and gas production on public lands.

- As part of the Quadrennial Energy Review, and through DOE-convened roundtables, the Administration will identify "downstream" methane reduction opportunities.

Beyond these actions to reduce domestic methane emissions, the United States is also helping partners around the world to reduce methane emissions, including through the Climate and Clean Air Coalition and the Global Methane Initiative.

Improving Methane Measurement
Methane emissions come from diverse sources and sectors of the economy, unevenly dispersed across the landscape. These characteristics complicate measurement and attribution and lead to significant uncertainties in estimates of current and projected methane emissions. Better data collection and measurement will improve our understanding of methane sources and trends, and enable more effective management of opportunities to reduce methane emissions. Key steps under the strategy to improve data quality include:

- Developing new measurement technologies, including lower-cost emissions sensing equipment.

- Addressing areas of higher uncertainty in bottom-up inventories through additional data collection, direct emission measurements, and research and analysis.

- Enhancing top-down modeling and monitoring based on direct measurement of atmospheric concentrations.

I. SOURCES AND TRENDS IN METHANE EMISSIONS

Methane has a global warming potential more than 20 times greater than that of carbon dioxide, per metric ton; on this basis, emissions of methane from human-related sources were equivalent to approximately 560 million metric tons of carbon dioxide pollution in 2012 – making up nearly 9 percent of all the greenhouse gases emitted as a result of human activity in the United States[1]. Since 1990, methane emissions in the United States have decreased by 11 percent, even as many activities that can produce methane have increased. However, methane emissions are projected to increase to a level equivalent to over 620 million tons of carbon dioxide pollution in 2030 absent additional action to reduce emissions. The main sources of human-related methane emissions are agriculture (36 percent), natural gas systems (23 percent), landfills (18 percent), coal mining (10 percent), petroleum systems (6 percent), and wastewater treatment (2 percent) [2].

II. REDUCING METHANE EMISSIONS

On June 25, 2013, the President issued a broad-based Climate Action Plan to cut the pollution that causes climate change and damages public health. The plan has three key pillars: cutting domestic greenhouse gas emissions, preparing the United States for the impacts of climate change, and continuing American leadership in international efforts to combat global climate change.

Low-cost technologies and best practices to recover methane and cut pollution are already widely available and used in key sectors. In addition to taking on climate change, reducing methane emissions has many other benefits. Recovered methane provides a local source of clean energy that can generate revenue and spur economic development. Reducing methane emissions can also improve safety and reduce local air pollution and odors. For example, landfill gas can be captured with collection systems and used for electricity generation or to provide fuel to a nearby factory. Methane recovered from coal mine degasification systems can be sold to natural gas pipelines or used on site for process heat. Methane generated from livestock manure can be captured through the use of biodigesters and used to generate electricity, avoiding fuel costs or providing a source of additional revenue. Methane that is vented or leaked from oil and natural gas production or processing facilities can be recovered through upgraded equipment and management practices that improve the company's bottom line.

This section outlines cost-effective opportunities to reduce methane emissions in four key sectors of our economy. It highlights new Administration actions to encourage voluntary emissions reductions and to set new standards where appropriate. The section also features key public-private sector initiatives that are cutting methane emissions or improving our understanding about specific sources of emissions. Finally, this section describes key U.S. efforts in helping

[1] Estimates of methane's potency as a greenhouse gas in this document use 100-year global warming potential values from the Second Assessment Report of the Intergovernmental Panel on Climate Change, as required by international reporting standards.

[2] These estimates are based on the Draft *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2012*, EPA, February 2014. The draft 2014 GHG Inventory (calculating emissions from 1990 through 2012) includes several updates to the methane numbers. As a result of the recalculations, in the draft 2014 Inventory, the total methane emissions estimate decreased by about 4 percent from the previous estimate.

international partners to reduce their methane emissions.

Reducing Emissions from Landfills

Municipal solid waste landfills are the third-largest source of human-related methane emissions in the United States, accounting for approximately 18 percent of methane emissions in 2012, equivalent to approximately 100 million metric tons of carbon dioxide pollution. Instead of allowing landfill gas to escape into the air, there is an opportunity to capture this gas and use it as a source of clean energy. In fact, standards and programs already in place have reduced landfill emission considerably, while creating jobs and improving public health. The Administration is committed to further reducing landfill emissions and tapping this important energy resource:

- **Updating Common Sense Rules to Reduce Landfill Emissions**: EPA will release a proposed update to its current standards for new municipal solid waste landfills in the summer of 2014, including assessing opportunities for further minimizing emissions when landfills are built or modified. Since there may be an even bigger opportunity for reducing methane emissions at existing landfills, EPA will also issue an Advanced Notice of Proposed Rulemaking (ANPRM) by June 2014 to engage industry and stakeholders on a range of approaches for cutting methane-rich landfill gases currently being emitted by existing facilities.

Case Study: Blue Ridge Renewable Energy Plant in Pennsylvania

In a true private-public partnership, landfill gas supplier IESI Blue Ridge Landfill, power purchaser Borough of Chambersburg and project developer PPL Renewable Energy (PPLRE) worked closely together to bring this 6.4-megawatt landfill gas electricity project online after only seven months of construction. In addition to designing, constructing, owning, and operating the LFG electricity plant at the landfill, PPLRE designed, permitted, and built the dedicated, 4-mile Express Generator Feeder from the plant to the Borough's Cree substation. Coming full circle, waste that Borough residents and businesses deposited in the landfill now supplies about 15 percent of its 11,000 customers' electric needs, plus the Borough was able to decrease the price of electricity those customers pay. In addition, the project generates 50,000 renewable energy credits annually toward meeting the state renewable energy goal.

- **Enhancing Landfill Gas-to-Energy Projects**: EPA will continue to work with municipalities and landfill owners to advance cost-effective voluntary energy recovery projects at landfills through the Landfill Methane Outreach Program.

- **Reducing Landfill Waste:** Through the U.S. Food Waste Challenge, the USDA and EPA are challenging producers, processors, manufacturers, retailers, communities, and other government agencies to help reduce, recover, or recycle food waste. Less waste in our landfills, means less methane emissions, a win-win.

Capturing Methane Emissions from Coal Mining

In 2012, 10 percent of human-related methane emissions came from the coal mining sector, equivalent to 56 million tons of carbon dioxide pollution. When recovered safely, coal mine methane can be a valuable, clean-burning source of energy. One of the most important co-benefits to reducing methane emissions at coal mines is increasing mine safety since uncontrolled methane emissions can cause fires and explosions. To further reduce coal mine methane emissions, the Department of Interior's BLM and the Environmental Protection Agency will take actions in two key areas:

- **Establishing a Program to Reduce Waste Coal Mine Emissions on Public Lands**: The BLM will release an Advanced Notice of Proposed Rulemaking (ANPRM) in April 2014, to solicit public input on the development of a program for the capture, sale, or disposal of waste mine methane from Federal coal leases and Federal leases for other solid minerals. The ANPRM will seek public input on preferred technology options for methane capture, whether the BLM should promote partnerships to capture or destroy waste mine methane, and how the agency could encourage cost-effective capture of methane from coal mines.

- **Overcoming Barriers to Reducing Coal Mining Emissions:** Since the Coalbed Methane Outreach Program's launch in 1994, the coal mining industry has nearly doubled its total methane recovery and use. Currently, over 20 mines have installed methane degasification systems. The EPA will continue to work with industry through this voluntary program to encourage recovery and beneficial use of methane by helping to overcome institutional, technical, regulatory, and financial barriers. The EPA will also continue to coordinate with the Department of Labor's Mine Safety and Health Administration to ensure that implementation of methane recovery projects at coal mines is consistent with all applicable safety standards and with the BLM's efforts to facilitate coalbed methane capture and use on Federal lands.

Reducing Emissions from Agriculture

Thirty six percent of human-related methane emissions come from the agricultural sector in the United States, equivalent to over 200 million tons of carbon pollution. This strategy addresses emissions from agriculture exclusively through voluntary actions, not through regulations. The most important voluntary opportunities are through manure management with anaerobic digestion and biogas utilization. Biogas systems are proven and effective technology to process organic waste and generate renewable energy. They can reduce the risk of potential air and water quality issues while providing additional revenue for the operation. Yet, there are still relatively few digesters in operation on farms across America. To encourage adoption of this technology, the Administration is committed to promoting additional, cost-effective actions to reduce methane emissions through voluntary partnerships and programs, including:

- **Developing a Biogas Roadmap**: This June, in partnership with the dairy industry, USDA, EPA and DOE will jointly release a Biogas Roadmap outlining voluntary strategies to accelerate the adoption of biogas systems and other cost-effective technologies to reduce greenhouse gas emissions. This work will support the U.S. dairy industry goal to reduce greenhouse gas emissions by 25 percent by the year 2020 for the entire value chain.

- **Enhancing Biogas System Deployment:** USDA will continue to support biogas system deployment by providing financial and technical assistance through the Natural Resources Conservation Service's Environmental Quality Incentive Program and Rural Development's Rural Energy for America Program, Bioenergy Program for Advanced Biofuels, and Biorefinery Assistance Program. The Natural Resources Conservation Service Conservation's Innovation Grants program is already catalyzing reductions in methane emissions through projects on rice cultivation and manure management. Through the AgSTAR program, EPA and USDA will continue working together to overcome barriers to expanding the use of agricultural biogas systems, and provide a forum for industry and other stakeholders to access information.

> **The Dairy Innovation Center "Dairy Power" Project**
>
> The Innovation Center for U.S. Dairy's "Dairy Power™ "project is focused on realizing the significant potential of anaerobic digester systems that can produce clean energy and value-added products, generate revenue for dairy producers and create jobs. The Dairy Power project report findings show a $3 billion market potential through the products and co-products developed by mature digester systems that process manure and commercial food waste, with additional value for potential nutrient trading markets, and renewable energy and low-carbon energy production incentives.

Reducing Methane Emissions from the Oil and Natural Gas Sectors

In 2012, 28 percent of methane emissions were attributed to the oil and natural gas sectors. Methane equivalent to 127 million tons of carbon dioxide pollution was emitted from production, processing, transmission, storage, and distribution of natural gas. Methane equivalent to 32 million tons of carbon dioxide pollution was emitted from production and refining, of oil. Within the natural gas industry, approximately 31 percent of this methane came from production sources, 15 percent from processing, 34 percent from the transmission and storage, and 20 percent from distribution. As our use of natural gas in manufacturing, transportation, and power generation increases – creating jobs, reducing costs, cutting carbon pollution, and reducing dependence on foreign oil in our nation – we must continue to build on progress in reducing methane emissions from this vital sector of our economy.

There are cost-effective technologies and best management practices to capture methane from venting and leaks across the entire oil and natural gas value chain. These range from equipment upgrades or replacements, to process or operational changes. Building on progress to date, the Administration will undertake new steps, including:

- **Working with States:** States are the primary regulators of many aspects of oil and gas production activities and the distribution of natural gas. DOE and EPA will continue to provide technical assistance in support of effective state policy actions to reduce emissions, and to encourage broader adoption of proven mitigation strategies.

- **Building on Common-Sense Federal Standards**: Since 2012, the EPA has taken a series of steps to address air pollution from the oil and gas sector. On April 17, 2012, the EPA issued final regulations to reduce the emissions of volatile organic compounds (VOCs), some of which are hazardous air pollutants, establishing, among other things, the first Federal air pollution standards for natural gas wells that are hydraulically fractured, along with requirements for other sources, such as compressors, that were not previously regulated at the Federal level. Although these regulations targeted VOCs, they also reduced methane emissions substantially. EPA estimates that when fully implemented in 2015, the 2012 rules will decrease methane equivalent to 33 million tons of carbon pollution per year. Going forward, the EPA will deploy a carefully selected combination of policy tools to maximize cost-effective methane and VOC reductions from the oil and gas sector.

During the spring of 2014, the EPA will release a series of white papers on several potentially significant sources of methane in the oil and gas sector and solicit input from independent experts. The papers will focus on technical issues, covering emissions and control technologies that target both VOC and methane —with particular focus on oil and co-producing wells, liquids unloading, leaks, pneumatic devices and compressors. The agency will use these technical documents to solidify its understanding of these potentially significant sources of methane. This robust technical understanding will allow the agency to fully evaluate the range of policy mechanisms that will cost-effectively cut methane waste and emissions. The EPA will make peer reviewer comments available this summer. This fall, the EPA will determine what if any regulatory authorities, including setting standards under section 111 of the Clean Air Act or issuing Control Techniques Guidelines under section 182 of the Act, the agency will apply to emissions from these sources. If the agency determines to follow a regulatory course of action, it will undertake a schedule that will ensure that both rulemaking and any ensuing regulatory requirements for the states are completed by the end of 2016.

- **Enhanced Partnerships and Stakeholder Engagement:** The Administration will work collaboratively with key stakeholders to reduce methane emissions from natural gas systems.

  - In coordination with the Executive Office of the President and other Federal agencies, Secretary of Energy Ernest Moniz hosted a roundtable discussion on March 19, 2014 with leaders from industry, state governments, academic researchers, non-governmental organizations, and labor. DOE will sponsor additional roundtable discussions with stakeholders, with the primary objective of accelerating the adoption of best practices for reducing methane emissions from natural gas systems. Through these DOE roundtables the Administration also aims to:
    - Promote a common understanding of methane emissions from natural gas systems and related abatement opportunities.
    - Develop strategies for cost-effectively reducing methane emissions from processing, transmission and storage and distribution segments of the supply chain.
    - Catalyze greater action and engagement by policymakers at all levels of government, and encourage industry to embrace a common vision, including through participation in existing voluntary programs.

  - EPA will take steps to bolster its voluntary Natural Gas STAR Program, which has already identified over 50 cost-effective technologies and practices that reduce or avoid methane emissions, by eliciting more robust industry commitments while enhancing transparency and accountability. In the spring of 2014, EPA will begin to engage the industry, states, and other key stakeholders on ways to enhance this program, and will formally launch the new partnership by the end of 2014.

- **Minimizing Venting and Flaring on Public Lands:** DOI's Office of Inspector General and the U.S. Government Accountability Office have both criticized BLM's outdated requirements governing venting and flaring for wasting Federal gas resources and associated royalties to the American taxpayer. To reduce the loss of natural gas through the venting or flaring of methane produced from Federal and Indian oil and gas leases, the BLM will develop a draft rule, known informally as Onshore Order 9, and anticipates releasing this proposed rule later this year. To aid in the development of the rule, DOI has begun outreach to tribes, industry and other stakeholders.

Reducing Downstream Emissions

Safety is a top priority for natural gas distribution companies and state regulators. Thirty-eight states have some form of accelerated infrastructure replacement cost recovery program in place. Many companies are working with their state regulators to accelerate the modernization, replacement and expansion of the nation's natural gas pipeline system. These efforts to enhance safety also put people to work and reduce methane emissions. Several cooperative efforts are also underway. A group of 13 American Gas Association members are working with the Environmental Defense Fund on a project to improve measurement of methane emissions from natural gas distribution systems. In addition, the Natural Gas Downstream Initiative, a group of natural gas utilities, is collaborating to address key technical and regulatory factors affecting methane emission reduction opportunities from natural gas distribution systems. Through the initiative, partners are working to identify and encourage programs that accelerate investments in infrastructure and promote outstanding operations, including modernizing their systems and utilizing next generation technologies. The initiative is focused on opportunities that can substantially reduce methane emissions and support safe, reliable and cost-effective service. Current partners include Consolidated Edison Company of New York, National Grid, Pacific Gas & Electric Company, Public Service Electric and Gas Company, and Xcel Energy.

- **Identifying Policy Recommendations for Reducing Emissions from Energy Infrastructure**: The first installment of the Quadrennial Energy Review (QER), to be released in January of 2015, will recommend actions that industry, and Federal and state governments can take to improve the performance of our energy transmission, storage and distributions systems. Building on the DOE roundtables, the QER will evaluate methane emissions abatement opportunities from the processing, transmission, storage and distribution segments of the natural gas supply chain. To help identify the most cost-effective mitigation options, DOE's Office of Energy Policy and Systems Analysis will work with the National Labs and EPA to evaluate technology cost estimates developed by NGOs and industry, and combine analysis with associated emissions data, recently updated by EPA.

- **Supporting Development of New Technologies to Reduce Emissions:** DOE will support the development of new technologies to enable more cost-effective emission reductions through several programs:

- In December 2013, the DOE made up to $8 billion in loan guarantee authority available for a wide array of advanced fossil energy projects under its Section 1703 loan guarantee program. Innovative technologies to reduce methane emissions from the coal mining and oil and gas sectors is one specific focus of this initiative, which will include regular solicitations for new loan applications.

- The 2015 Budget proposes a new $4.7 million DOE program to speed development of technologies for leak detection and monitoring, pipeline leak repair without having to evacuate gas from the pipelines, smart pipeline sensors, and compressor controls. The program will be aimed at accelerating the commercialization of advanced pipeline inspection technologies. For example smart sensors could be distributed within the pipeline network and provide real-time continuous tracking of gas volumes and pipeline internal conditions.

- **Continuing to Prioritize Pipeline Safety**: The Pipeline and Hazardous Materials Safety Administration (PHMSA) will continue monitoring natural gas pipeline systems for safety, including requiring pipeline operators to take steps to eliminate leaks and prevent accidental releases of methane. Through this effort PHMSA has conducted a survey to evaluate each states progress to replace old, high-risk cast iron pipelines in their systems with new technologies that reduce leakage and accidental releases of methane over time.

U.S. Leadership in Reducing Global Methane Emissions

Methane accounts for approximately 15 percent of global annual greenhouse gas emissions. The United States is the recognized global leader in helping partners around the world to reduce methane emissions, including through the following two key actions:

- **Spearheading Key Initiatives in the Climate and Clean Air Coalition:** As a founding partner of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) – which now includes nearly 40 country partners and key actors like the World Bank, UN Environment Programme, and World Health Assembly – the United States is helping to spearhead initiatives to across key sectors:

    - The CCAC Municipal Solid Waste Initiative is currently working with 26 cities in Africa, Asia and Latin America to develop sustainable municipal solid waste practices to reduce methane emissions from landfills and improve air quality, public health, and the environment. To scale-up and replicate these efforts, the initiative is helping to build the capacity of national governments; has created a global city network that promotes peer-to-peer learning and sharing of best practices; and is developing innovative, sustainable financing solutions.

    - The recently-launched CCAC Agriculture Initiative will promote improved manure management and rice cultivation practices through new global knowledge platforms, regional centers providing targeted assistance, and support to national and local early adopters of policies and technologies to catalyze large-scale practice change. This effort will not only reduce methane emissions and local pollution from the agriculture sector, it will also increase food security and productivity.

- The United States is working with international and corporate partners to launch the CCAC Oil and Gas Methane Partnership in 2014 with an initial group of oil and gas companies agreeing to systematically survey, report, and reduce methane emissions across a range of their participating operations. Participating companies will deploy proven and cost-effective technologies and practices across the largest sources of methane emissions in the oil and gas sector.

- Leveraging U.S. Technical Expertise through the Global Methane Initiative: Through the Global Methane Initiative (GMI), the United States leverages U.S. technical expertise to help partners around the world substantially reduce their methane emissions in five key sectors: agriculture; coal mines; municipal solid waste; oil and gas systems; and municipal wastewater. GMI is a public-private initiative with 43 partner countries, including all of the top 10 leading methane emitters, and over 1,000 members of the Project Network, including private sector, nongovernmental organizations, and multilateral organizations such as the World Bank, the Asian Development Bank, and the Inter-American Development Bank. GMI advances cost-effective, near-term methane recovery and use as a clean energy source, with a proven track record of helping to reduce methane emissions of over 220 million metric tons carbon dioxide since 2004, and identifying additional potential reductions that can be achieved cost-effectively. GMI has also developed a suite of tools and resources to help overcome barriers to methane capture and recovery and has built institutional capacity in Partner countries to ensure the long-term success of these efforts. These projects reduce greenhouse gas emissions in the near term and provide important environmental, safety, and economic co-benefits. The EPA is the lead agency from the U.S. Government and coordinates with the Department of State, Department of Energy, Department of Agriculture, USAID, and the Trade and Development Agency.

NGO-Industry Cooperative Research Initiative

In 2012, Environmental Defense Fund kicked off a series of studies — collaborating with more than 90 academic, research and industry partners — to better understand how much and from where methane is lost from the natural gas system today.

This project is investigating emissions from five key areas that make up the natural gas supply chain: production, gathering lines and processing facilities, long-distance pipelines and storage, local distribution and commercial trucks and refueling stations. The initiative includes 16 independent projects, all expected to be completed by the end of 2014.

III. IMPROVING MEASUREMENT OF METHANE SOURCES AND EMISSIONS

Our current understanding of methane sources and trends supports the steps to reduce emissions outlined in this strategy. At the same time, sharpening our ability to measure emissions will enable more targeted efforts in the future. For this reason, in addition to identifying technologies and best practices for reducing emissions, the Climate Action Plan also calls for an assessment of current methane emissions data. Unlike carbon dioxide, where emissions are easily estimated from well-tracked energy statistics, many sources of methane are more diffuse, not systematically tracked by statistics agencies, and thus considerably more uncertain.

<u>Methods for Measuring Methane Emissions</u>

The measurement and estimation of methane emissions currently occurs in two primary ways: through "bottom-up" greenhouse gas inventories, which focus on the specific source or activity causing the emissions, and through "top-down" methods that infer emissions from measurements of atmospheric methane concentrations. Each approach has different strengths, weaknesses, and uncertainties, and they play complementary roles. Bottom-up inventories provide the foundation for policy and programs and top-down approaches are utilized for independent validation and overall assessments of the efficacy of national and international efforts to reduce methane in the atmosphere.

Nationally, emissions are tracked by the EPA through a bottom-up inventory, the U.S. Greenhouse Gas Inventory (GHGI), a document all parties to the UN Framework Convention on Climate Change (UNFCCC) are required to produce. A suite of methods for such inventories are published by the Intergovernmental Panel on Climate Change and generally consist of statistical approaches involving activity factors (*e.g.*, number of gas wells, number of landfills), emissions factors (*e.g.*, methane emissions per gas well, methane emissions per landfill), and reductions data (*e.g.*, counts of devices or practices that reduce methane emissions, such as flares and anaerobic digesters). The quality of methane data for some sources in the GHGI can be highly variable, and consequently, emissions estimates for some sources entail considerable uncertainty.

The GHGI is also beginning to be supplemented by new data from the Greenhouse Gas Reporting Program (GHGRP), a congressionally mandated EPA program requiring large emitters of GHGs from many sectors to estimate and report their emissions to EPA. Methane data are now available for several important sectors (*i.e.*, landfills, petroleum and natural gas systems, underground coal mines, and industrial wastewater systems) and are generally consistent with the GHGI, although more analysis is planned.

In addition to estimating human-related emissions using bottom-up statistical approaches, aggregate emissions can be inferred using top-down atmospheric models and measured concentrations of methane in the atmosphere. Atmospheric methane concentrations are sampled in the United States, as well as globally, by a variety of instruments on towers, ships, and aircraft. The network is adequate to estimate average global emissions, but it lacks the density to quantify emissions in all regions or to systematically identify emissions sources.

In sum, bottom-up methods are necessary to characterize emissions sources with precision, which is critical for designing mitigation strategies. Top-down methods, while they cannot generally perform such attribution with high confidence, can help to validate bottom-up estimates using measured values and can help to identify emissions 'hot spots' for closer measurement.

<u>Key Actions to Improve Methane Emissions Measurement and Monitoring</u>

Administration efforts to improve U.S. methane measurement support two broad goals: 1) improving the bottom-up emissions data relevant for mitigation; and, 2) advancing the science and technology for monitoring and validating atmospheric concentrations. Within these broad goals, improvement opportunities exist across input data (*i.e.*, emissions factors, activity factors, and reductions data), atmospheric observations data, and the science needed to bridge between atmospheric observations and bottom-up emissions data (*i.e.*, monitoring and validation science). Federal agencies are already investing in related enhancements, and this strategy announces several critical new activities to further improve methane emissions measurement Examples of both include:

- **Encouraging the Development of Cost-Effective Measurement Technologies**: DOE's ARPA-E program is preparing a new methane program that will fund technologies to deliver an order-of-magnitude reduction on the cost of methane sensing, thus facilitating much wider deployment throughout all segments of natural gas systems.

- **Enhancing the US Greenhouse Gas Inventory**: EPA will continue to update and enhance the data published in its annual GHGI as new scientific evidence and data sources emerge. EPA will also continue to use the data collected through the GHGRP to improve the GHGI, particularly for the petroleum, natural gas, coal mining, and landfill sectors. This data will improve as additional reporting of inputs to emissions equations began in 2013 and, in 2015, EPA also plans to make ongoing improvements to the GHGRP regulatory requirements for petroleum and natural gas systems. In March 2014, EPA proposed revisions to GHGRP calculation methods, monitoring and data reporting requirements that would enhance the clarity and consistency of the reported data from petroleum and natural gas systems, such as for liquids unloading, completions and workovers, and compressors. The EPA will continue to review regulatory requirements to address potential gaps in coverage, improve methods, and help ensure high quality data reporting. DOE and USDA will also provide support to improve emissions factors. EPA efforts to improve the GHGI will promote transparency and stakeholder input by means of annual expert, public and international review periods.

- **Building our National Methane Monitoring Network:** National Oceanic and Atmospheric Administration (NOAA) scientists maintain a network of methane monitoring sites in the United States, including tall towers, periodic aircraft measurements, and surface measurements. NOAA has also conducted periodic aircraft-based methane measurements in six major U.S. oil and gas production regions. At its current funding level, this Carbon Observation and Analysis Program provides the minimum needed for climate modeling. To expand capabilities, the President's budget requests $8 million above current funding of $6.5 million for this program to:
    - Add 6 tall towers to the network, increasing the network to 14;
    - Enhance the measurement capabilities of all 14 towers;
    - Triple the frequency of aircraft-based observations.

- **Improving Local & Regional Emissions Modeling:** As part of DOE's ongoing unconventional gas program, DOE is funding two projects - one at Pennsylvania State University and one at Carnegie Mellon University - using tracer release methods and tower, automobile, aircraft monitoring, and other methods to measure and model methane emissions from the Marcellus region in Pennsylvania. A regional inventory of other methane sources including landfills, wetlands, water treatment facilities, and agriculture sources will also be obtained. The project is scheduled to begin in 2015 and end in 2017. Additionally, NASA's Jet Propulsion Laboratory JPL, is carrying out a Carbon in Arctic

Reservoirs Vulnerability Experiment, which includes regular monitoring of methane concentrations over Alaska's North Slope.

- **Improving Global Emissions Monitoring and Estimates:** EPA is collecting emissions reduction data through the Global Methane Initiative. EPA will also continue to update and publish detailed estimates and projections of global human-related non-CO_2 greenhouse gas emissions, and the mitigation potential from these sources. DOE's Atmospheric Radiation Measurement Climate Research Facility is making long-term methane flux measurements at multiple permanent locations around the world. NOAA runs the largest global network of GHG measurements and works closely with international partners and the World Meteorological Organization to ensure global measurements of GHG concentrations, including methane, are standardized. NOAA also consolidates data from this global network and releases the data to the public. Other Federal agencies (e.g. NASA and DOE) also contribute to these networks. NASA and the National Institute of Standards and Technology are helping to fund the Megacities Carbon Project, an international research effort to develop and demonstrate a scientifically robust capability to measure multi-year emission trends of CO_2, methane, and carbon monoxide attributed to individual megacities and selected major sectors in those cities. In addition, USDA's Forest Service is working with international partners, universities and the USAID on international efforts that monitor methane on sites in Mexico, Ecuador, Colombia, and Peru.

Exhibit 5

The White House
Office of the Press Secretary

For Immediate Release November 06, 2015

Statement by the President on the Keystone XL Pipeline

Roosevelt Room

11:58 A.M. EST

THE PRESIDENT: Good morning, everybody. Several years ago, the State Department began a review process for the proposed construction of a pipeline that would carry Canadian crude oil through our heartland to ports in the Gulf of Mexico and out into the world market.

This morning, Secretary Kerry informed me that, after extensive public outreach and consultation with other Cabinet agencies, the State Department has decided that the Keystone XL Pipeline would not serve the national interest of the United States. I agree with that decision.

This morning, I also had the opportunity to speak with Prime Minister Trudeau of Canada. And while he expressed his disappointment, given Canada's position on this issue, we both agreed that our close friendship on a whole range of issues, including energy and climate change, should provide the basis for even closer coordination between our countries going forward. And in the coming weeks, senior members of my team will be engaging with theirs in order to help deepen that cooperation.

Now, for years, the Keystone Pipeline has occupied what I, frankly, consider an overinflated role in our political discourse. It became a symbol too often used as a campaign cudgel by both parties rather than a serious policy matter. And all of this obscured the fact that this pipeline would neither be a silver bullet for the economy, as was promised by some, nor the express lane to climate disaster proclaimed by others.

To illustrate this, let me briefly comment on some of the reasons why the State Department rejected this pipeline.

First: The pipeline would not make a meaningful long-term contribution to our economy. So if Congress is serious about wanting to create jobs, this was not the way to do it. If they want to do it, what we should be doing is passing a bipartisan infrastructure plan that, in the short term, could create more than 30 times as many jobs per year as the pipeline would, and in the long run would benefit our economy and our workers for decades to come.

Our businesses created 268,000 new jobs last month. They've created 13.5 million new jobs over the past 68 straight months -- the longest streak on record. The unemployment rate fell to 5 percent. This Congress should pass a serious infrastructure plan, and keep those jobs coming. That would make a difference. The pipeline would not have made a serious impact on those numbers and on the American people's prospects for the future.

Second: The pipeline would not lower gas prices for American consumers. In fact, gas prices have already been falling -- steadily. The national average gas price is down about 77 cents over a year ago. It's down a dollar over two years ago. It's down $1.27 over three years ago. Today, in 41 states, drivers can find at least one gas station selling gas for less than two bucks a gallon. So while our politics have been consumed by a debate over whether or not this pipeline would create jobs and lower gas prices, we've gone ahead and created jobs and lowered gas prices.

Third: Shipping dirtier crude oil into our country would not increase America's energy security. What has increased America's energy security is our strategy over the past several years to reduce our reliance on dirty fossil fuels from unstable parts of the world. Three years ago, I set a goal to cut our oil imports in half by 2020. Between producing more oil here at home, and using less oil throughout our economy, we met that goal last year -- five years early. In fact, for the first time in two decades, the United States of America now produces more oil than we buy from other countries.

Now, the truth is, the United States will continue to rely on oil and gas as we transition -- as we must transition -- to a clean energy economy. That transition will take some time. But it's also going more quickly than many anticipated. Think about it. Since I took office, we've doubled the distance our cars will go on a gallon of gas by 2025; tripled the power we generate from the wind; multiplied the power we generate from the sun 20 times over. Our biggest and most successful businesses are going all-in on clean energy. And thanks in part to the investments we've made, there are already parts of America where clean power from the wind or the sun is finally cheaper than dirtier, conventional power.

The point is the old rules said we couldn't promote economic growth and protect our environment at the same time. The old rules said we couldn't transition to clean energy without squeezing businesses and consumers. But this is America, and we have come up with new ways and new technologies to break down the old rules, so that today, homegrown American energy is booming, energy prices are falling, and over the past decade, even as our economy has continued to grow, America has cut our total carbon pollution more than any other country on Earth.

Today, the United States of America is leading on climate change with our investments in clean energy and energy efficiency. America is leading on climate change with new rules on power plants that will protect our air so that our kids can breathe. America is leading on climate change by working with other big emitters like China to encourage and announce new commitments to reduce harmful greenhouse gas emissions. In part because of that American leadership, more than 150 nations representing nearly 90 percent of global emissions have put forward plans to cut pollution.

America is now a global leader when it comes to taking serious action to fight climate change. And frankly, approving this project would have undercut that global leadership. And that's the biggest risk we face -- not acting.

Today, we're continuing to lead by example. Because ultimately, if we're going to prevent large parts of this Earth from becoming not only inhospitable but uninhabitable in our lifetimes, we're going to have to keep some fossil fuels in the ground rather than burn them and release more dangerous pollution into the sky.

As long as I'm President of the United States, America is going to hold ourselves to the same high standards to which we hold the rest of the world. And three weeks from now, I look forward to joining my fellow world leaders in Paris, where we've got to come together around an ambitious framework to protect the one planet that we've got while we still can.

If we want to prevent the worst effects of climate change before it's too late, the time to act is now. Not later. Not someday. Right here, right now. And I'm optimistic about what we can accomplish together. I'm optimistic because our own country proves, every day -- one step at a time -- that not only do we have the power to combat this threat, we can do it while creating new jobs, while growing our economy, while saving money, while helping consumers, and most of all, leaving our kids a cleaner, safer planet at the same time.

That's what our own ingenuity and action can do. That's what we can accomplish. And America is prepared to show the rest of the world the way forward.

Thank you very much.

END
12:08 P.M. EST

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Council on Environmental Quality
National Security Council
See All
Initiatives
Lets Move
Joining Forces
Reach Higher
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Exhibit 6

United Nations

FCCC/CP/2015/L.9

Framework Convention on Climate Change

Distr.: Limited
12 December 2015

Original: English

Conference of the Parties
Twenty-first session
Paris, 30 November to 11 December 2015

Agenda item 4(b)
Durban Platform for Enhanced Action (decision 1/CP.17)
Adoption of a protocol, another legal instrument, or an agreed outcome with legal force under the Convention applicable to all Parties

ADOPTION OF THE PARIS AGREEMENT

Proposal by the President

Draft decision -/CP.21

The *Conference of the Parties*,

Recalling decision 1/CP.17 on the establishment of the Ad Hoc Working Group on the Durban Platform for Enhanced Action,

Also recalling Articles 2, 3 and 4 of the Convention,

Further recalling relevant decisions of the Conference of the Parties, including decisions 1/CP.16, 2/CP.18, 1/CP.19 and 1/CP.20,

Welcoming the adoption of United Nations General Assembly resolution A/RES/70/1, "Transforming our world: the 2030 Agenda for Sustainable Development", in particular its goal 13, and the adoption of the Addis Ababa Action Agenda of the third International Conference on Financing for Development and the adoption of the Sendai Framework for Disaster Risk Reduction,

Recognizing that climate change represents an urgent and potentially irreversible threat to human societies and the planet and thus requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response, with a view to accelerating the reduction of global greenhouse gas emissions,

Also recognizing that deep reductions in global emissions will be required in order to achieve the ultimate objective of the Convention and emphasizing the need for urgency in addressing climate change,

Acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Also acknowledging the specific needs and concerns of developing country Parties arising from the impact of the implementation of response measures and, in this regard, decisions 5/CP.7, 1/CP.10, 1/CP.16 and 8/CP.17,

Emphasizing with serious concern the urgent need to address the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C,

Also emphasizing that enhanced pre-2020 ambition can lay a solid foundation for enhanced post-2020 ambition,

Stressing the urgency of accelerating the implementation of the Convention and its Kyoto Protocol in order to enhance pre-2020 ambition,

Recognizing the urgent need to enhance the provision of finance, technology and capacity-building support by developed country Parties, in a predictable manner, to enable enhanced pre-2020 action by developing country Parties,

Emphasizing the enduring benefits of ambitious and early action, including major reductions in the cost of future mitigation and adaptation efforts,

Acknowledging the need to promote universal access to sustainable energy in developing countries, in particular in Africa, through the enhanced deployment of renewable energy,

Agreeing to uphold and promote regional and international cooperation in order to mobilize stronger and more ambitious climate action by all Parties and non-Party stakeholders, including civil society, the private sector, financial institutions, cities and other subnational authorities, local communities and indigenous peoples,

I. ADOPTION

1. *Decides* to adopt the Paris Agreement under the United Nations Framework Convention on Climate Change (hereinafter referred to as "the Agreement") as contained in the annex;

2. *Requests* the Secretary-General of the United Nations to be the Depositary of the Agreement and to have it open for signature in New York, United States of America, from 22 April 2016 to 21 April 2017;

3. *Invites* the Secretary-General to convene a high-level signature ceremony for the Agreement on 22 April 2016;

4. *Also invites* all Parties to the Convention to sign the Agreement at the ceremony to be convened by the Secretary-General, or at their earliest opportunity, and to deposit their respective instruments of ratification, acceptance, approval or accession, where appropriate, as soon as possible;

5. *Recognizes* that Parties to the Convention may provisionally apply all of the provisions of the Agreement pending its entry into force, and *requests* Parties to provide notification of any such provisional application to the Depositary;

6. *Notes* that the work of the Ad Hoc Working Group on the Durban Platform for Enhanced Action, in accordance with decision 1/CP.17, paragraph 4, has been completed;

7. *Decides* to establish the Ad Hoc Working Group on the Paris Agreement under the same arrangement, mutatis mutandis, as those concerning the election of officers to the Bureau of the Ad Hoc Working Group on the Durban Platform for Enhanced Action;[1]

8. *Also decides* that the Ad Hoc Working Group on the Paris Agreement shall prepare for the entry into force of the Agreement and for the convening of the first session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

9. *Further decides* to oversee the implementation of the work programme resulting from the relevant requests contained in this decision;

10. *Requests* the Ad Hoc Working Group on the Paris Agreement to report regularly to the Conference of the Parties on the progress of its work and to complete its work by the first session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

11. *Decides* that the Ad Hoc Working Group on the Paris Agreement shall hold its sessions starting in 2016 in conjunction with the sessions of the Convention subsidiary bodies and shall prepare draft decisions to be recommended through the Conference of the Parties to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session;

II. INTENDED NATIONALLY DETERMINED CONTRIBUTIONS

12. *Welcomes* the intended nationally determined contributions that have been communicated by Parties in accordance with decision 1/CP.19, paragraph 2(b);

13. *Reiterates* its invitation to all Parties that have not yet done so to communicate to the secretariat their intended nationally determined contributions towards achieving the objective of the Convention as set out in its Article 2 as soon as possible and well in advance of the twenty-second session of the Conference of the Parties (November 2016) and in a manner that facilitates the clarity, transparency and understanding of the intended nationally determined contributions;

14. *Requests* the secretariat to continue to publish the intended nationally determined contributions communicated by Parties on the UNFCCC website;

15. *Reiterates* its call to developed country Parties, the operating entities of the Financial Mechanism and any other organizations in a position to do so to provide support for the preparation and communication of the intended nationally determined contributions of Parties that may need such support;

16. *Takes note* of the synthesis report on the aggregate effect of intended nationally determined contributions communicated by Parties by 1 October 2015, contained in document FCCC/CP/2015/7;

17. *Notes* with concern that the estimated aggregate greenhouse gas emission levels in 2025 and 2030 resulting from the intended nationally determined contributions do not fall within least-cost 2 ˚C scenarios but rather lead to a projected level of 55 gigatonnes in 2030, and *also notes* that much greater emission reduction efforts will be required than those associated with the intended nationally determined contributions in order to hold the increase in the global average temperature to below 2 ˚C above pre-industrial levels by reducing emissions to 40 gigatonnes or to 1.5 ˚C above pre-industrial levels by reducing to a level to be identified in the special report referred to in paragraph 21 below;

[1] Endorsed by decision 2/CP.18, paragraph 2.

18. *Also notes, in this context,* the adaptation needs expressed by many developing country Parties in their intended nationally determined contributions;

19. *Requests* the secretariat to update the synthesis report referred to in paragraph 16 above so as to cover all the information in the intended nationally determined contributions communicated by Parties pursuant to decision 1/CP.20 by 4 April 2016 and to make it available by 2 May 2016;

20. *Decides* to convene a facilitative dialogue among Parties in 2018 to take stock of the collective efforts of Parties in relation to progress towards the long-term goal referred to in Article 4, paragraph 1, of the Agreement and to inform the preparation of nationally determined contributions pursuant to Article 4, paragraph 8, of the Agreement;

21. *Invites* the Intergovernmental Panel on Climate Change to provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways;

III. DECISIONS TO GIVE EFFECT TO THE AGREEMENT

MITIGATION

22. *Invites* Parties to communicate their first nationally determined contribution no later than when the Party submits its respective instrument of ratification, accession, or approval of the Paris Agreement. If a Party has communicated an intended nationally determined contribution prior to joining the Agreement, that Party shall be considered to have satisfied this provision unless that Party decides otherwise;

23. *Urges* those Parties whose intended nationally determined contribution pursuant to decision 1/CP.20 contains a time frame up to 2025 to communicate by 2020 a new nationally determined contribution and to do so every five years thereafter pursuant to Article 4, paragraph 9, of the Agreement;

24. *Requests* those Parties whose intended nationally determined contribution pursuant to decision 1/CP.20 contains a time frame up to 2030 to communicate or update by 2020 these contributions and to do so every five years thereafter pursuant to Article 4, paragraph 9, of the Agreement;

25. *Decides* that Parties shall submit to the secretariat their nationally determined contributions referred to in Article 4 of the Agreement at least 9 to 12 months in advance of the relevant meeting of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement with a view to facilitating the clarity, transparency and understanding of these contributions, including through a synthesis report prepared by the secretariat;

26. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop further guidance on features of the nationally determined contributions for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

27. *Agrees* that the information to be provided by Parties communicating their nationally determined contributions, in order to facilitate clarity, transparency and understanding, may include, as appropriate, inter alia, quantifiable information on the reference point (including, as appropriate, a base year), time frames and/or periods for implementation, scope and coverage, planning processes, assumptions and methodological approaches including those for estimating and accounting for anthropogenic greenhouse gas emissions and, as appropriate, removals, and how the Party considers that its nationally determined contribution is fair and ambitious, in the light of its national circumstances, and

how it contributes towards achieving the objective of the Convention as set out in its Article 2;

28. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop further guidance for the information to be provided by Parties in order to facilitate clarity, transparency and understanding of nationally determined contributions for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

29. *Also requests* the Subsidiary Body for Implementation to develop modalities and procedures for the operation and use of the public registry referred to in Article 4, paragraph 12, of the Agreement, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

30. *Further requests* the secretariat to make available an interim public registry in the first half of 2016 for the recording of nationally determined contributions submitted in accordance with Article 4 of the Agreement, pending the adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement of the modalities and procedures referred to in paragraph 29 above;

31. *Requests* the Ad Hoc Working Group on the Paris Agreement to elaborate, drawing from approaches established under the Convention and its related legal instruments as appropriate, guidance for accounting for Parties' nationally determined contributions, as referred to in Article 4, paragraph 13, of the Agreement, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session, which ensures that:

(a) Parties account for anthropogenic emissions and removals in accordance with common methodologies and metrics assessed by the Intergovernmental Panel on Climate Change and adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

(b) Parties ensure methodological consistency, including on baselines, between the communication and implementation of nationally determined contributions;

(c) Parties strive to include all categories of anthropogenic emissions or removals in their nationally determined contributions and, once a source, sink or activity is included, continue to include it;

(d) Parties shall provide an explanation of why any categories of anthropogenic emissions or removals are excluded;

32. *Decides* that Parties shall apply the guidance mentioned in paragraph 31 above to the second and subsequent nationally determined contributions and that Parties may elect to apply such guidance to their first nationally determined contribution;

33. *Also decides* that the Forum on the Impact of the Implementation of response measures, under the subsidiary bodies, shall continue, and shall serve the Agreement;

34. *Further decides* that the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation shall recommend, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session, the modalities, work programme and functions of the Forum on the Impact of the Implementation of response measures to address the effects of the implementation of response measures under the Agreement by enhancing cooperation amongst Parties on understanding the impacts of mitigation actions under the Agreement and the exchange of information, experiences, and best practices amongst Parties to raise their resilience to these impacts;

35. *Decides* that the guidance under paragraph 31 above shall ensure that double counting is avoided on the basis of a corresponding adjustment by both Parties for anthropogenic emissions by sources and/or removals by sinks covered by their nationally determined contributions under the Agreement;

36. *Invites* Parties to communicate, by 2020, to the secretariat mid-century, long-term low greenhouse gas emission development strategies in accordance with Article 4, paragraph 19, of the Agreement, and *requests* the secretariat to publish on the UNFCCC website Parties' low greenhouse gas emission development strategies as communicated;

37. *Requests* the Subsidiary Body for Scientific and Technological Advice to develop and recommend the guidance referred to under Article 6, paragraph 2, of the Agreement for adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session, including guidance to ensure that double counting is avoided on the basis of a corresponding adjustment by Parties for both anthropogenic emissions by sources and removals by sinks covered by their nationally determined contributions under the Agreement;

38. *Recommends* that the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement adopt rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Agreement on the basis of:

(a) Voluntary participation authorized by each Party involved;

(b) Real, measurable, and long-term benefits related to the mitigation of climate change;

(c) Specific scopes of activities;

(d) Reductions in emissions that are additional to any that would otherwise occur;

(e) Verification and certification of emission reductions resulting from mitigation activities by designated operational entities;

(f) Experience gained with and lessons learned from existing mechanisms and approaches adopted under the Convention and its related legal instruments;

39. *Requests* the Subsidiary Body for Scientific and Technological Advice to develop and recommend rules, modalities and procedures for the mechanism referred to in paragraph 38 above for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

40. *Also requests* the Subsidiary Body for Scientific and Technological Advice to undertake a work programme under the framework for non-market approaches to sustainable development referred to in Article 6, paragraph 8, of the Agreement, with the objective of considering how to enhance linkages and create synergy between, inter alia, mitigation, adaptation, finance, technology transfer and capacity-building, and how to facilitate the implementation and coordination of non-market approaches;

41. *Further requests* the Subsidiary Body for Scientific and Technological Advice to recommend a draft decision on the work programme referred to in paragraph 40 above, taking into account the views of Parties, for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

ADAPTATION

42. *Requests* the Adaptation Committee and the Least Developed Countries Expert Group to jointly develop modalities to recognize the adaptation efforts of developing

country Parties, as referred to in Article 7, paragraph 3, of the Agreement, and make recommendations for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

43. *Also requests* the Adaptation Committee, taking into account its mandate and its second three-year workplan, and with a view to preparing recommendations for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session:

(a) To review, in 2017, the work of adaptation-related institutional arrangements under the Convention, with a view to identifying ways to enhance the coherence of their work, as appropriate, in order to respond adequately to the needs of Parties;

(b) To consider methodologies for assessing adaptation needs with a view to assisting developing countries, without placing an undue burden on them;

44. *Invites* all relevant United Nations agencies and international, regional and national financial institutions to provide information to Parties through the secretariat on how their development assistance and climate finance programmes incorporate climate-proofing and climate resilience measures;

45. *Requests* Parties to strengthen regional cooperation on adaptation where appropriate and, where necessary, establish regional centres and networks, in particular in developing countries, taking into account decision 1/CP.16, paragraph 13;

46. *Also requests* the Adaptation Committee and the Least Developed Countries Expert Group, in collaboration with the Standing Committee on Finance and other relevant institutions, to develop methodologies, and make recommendations for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session on:

(a) Taking the necessary steps to facilitate the mobilization of support for adaptation in developing countries in the context of the limit to global average temperature increase referred to in Article 2 of the Agreement;

(b) Reviewing the adequacy and effectiveness of adaptation and support referred to in Article 7, paragraph 14(c), of the Agreement;

47. *Further requests* the Green Climate Fund to expedite support for the least developed countries and other developing country Parties for the formulation of national adaptation plans, consistent with decisions 1/CP.16 and 5/CP.17, and for the subsequent implementation of policies, projects and programmes identified by them;

LOSS AND DAMAGE

48. *Decides* on the continuation of the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts, following the review in 2016;

49. *Requests* the Executive Committee of the Warsaw International Mechanism to establish a clearinghouse for risk transfer that serves as a repository for information on insurance and risk transfer, in order to facilitate the efforts of Parties to develop and implement comprehensive risk management strategies;

50. *Also requests* the Executive Committee of the Warsaw International Mechanism to establish, according to its procedures and mandate, a task force to complement, draw upon the work of and involve, as appropriate, existing bodies and expert groups under the Convention including the Adaptation Committee and the Least Developed Countries Expert Group, as well as relevant organizations and expert bodies outside the Convention, to develop recommendations for integrated approaches to avert, minimize and address displacement related to the adverse impacts of climate change;

51. *Further requests* the Executive Committee of the Warsaw International Mechanism to initiate its work, at its next meeting, to operationalize the provisions referred to in paragraphs 49 and 50 above, and to report on progress thereon in its annual report;

52. *Agrees* that Article 8 of the Agreement does not involve or provide a basis for any liability or compensation;

FINANCE

53. *Decides* that, in the implementation of the Agreement, financial resources provided to developing countries should enhance the implementation of their policies, strategies, regulations and action plans and their climate change actions with respect to both mitigation and adaptation to contribute to the achievement of the purpose of the Agreement as defined in Article 2;

54. *Further decides* that, in accordance with Article 9, paragraph 3, of the Agreement, developed countries intend to continue their existing collective mobilization goal through 2025 in the context of meaningful mitigation actions and transparency on implementation; prior to 2025 the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall set a new collective quantified goal from a floor of USD 100 billion per year, taking into account the needs and priorities of developing countries;

55. *Recognizes* the importance of adequate and predictable financial resources, including for results-based payments, as appropriate, for the implementation of policy approaches and positive incentives for reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks; as well as alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests; while reaffirming the importance of non-carbon benefits associated with such approaches; encouraging the coordination of support from, inter alia, public and private, bilateral and multilateral sources, such as the Green Climate Fund, and alternative sources in accordance with relevant decisions by the Conference of the Parties;

56. *Decides* to initiate, at its twenty-second session, a process to identify the information to be provided by Parties, in accordance with Article 9, paragraph 5, of the Agreement with the view to providing a recommendation for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

57. *Also decides* to ensure that the provision of information in accordance with Article 9, paragraph 7 of the Agreement shall be undertaken in accordance with modalities, procedures and guidelines referred to in paragraph 96 below;

58. *Requests* Subsidiary Body for Scientific and Technological Advice to develop modalities for the accounting of financial resources provided and mobilized through public interventions in accordance with Article 9, paragraph 7, of the Agreement for consideration by the Conference of the Parties at its twenty-fourth session (November 2018), with the view to making a recommendation for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

59. *Decides* that the Green Climate Fund and the Global Environment Facility, the entities entrusted with the operation of the Financial Mechanism of the Convention, as well as the Least Developed Countries Fund and the Special Climate Change Fund, administered by the Global Environment Facility, shall serve the Agreement;

60. *Recognizes* that the Adaptation Fund may serve the Agreement, subject to relevant decisions by the Conference of the Parties serving as the meeting of the Parties to the Kyoto

Protocol and the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

61. *Invites* the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol to consider the issue referred to in paragraph 60 above and make a recommendation to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

62. *Recommends* that the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall provide guidance to the entities entrusted with the operation of the Financial Mechanism of the Convention on the policies, programme priorities and eligibility criteria related to the Agreement for transmission by the Conference of the Parties;

63. *Decides* that the guidance to the entities entrusted with the operations of the Financial Mechanism of the Convention in relevant decisions of the Conference of the Parties, including those agreed before adoption of the Agreement, shall apply mutatis mutandis;

64. *Also decides* that the Standing Committee on Finance shall serve the Agreement in line with its functions and responsibilities established under the Conference of the Parties;

65. *Urges* the institutions serving the Agreement to enhance the coordination and delivery of resources to support country-driven strategies through simplified and efficient application and approval procedures, and through continued readiness support to developing country Parties, including the least developed countries and small island developing States, as appropriate;

TECHNOLOGY DEVELOPMENT AND TRANSFER

66. *Takes note of* the interim report of the Technology Executive Committee on guidance on enhanced implementation of the results of technology needs assessments as referred to in document FCCC/SB/2015/INF.3;

67. *Decides* to strengthen the Technology Mechanism and requests the Technology Executive Committee and the Climate Technology Centre and Network, in supporting the implementation of the Agreement, to undertake further work relating to, inter alia:

(a) Technology research, development and demonstration;

(b) The development and enhancement of endogenous capacities and technologies;

68. *Requests* the Subsidiary Body for Scientific and Technological Advice to initiate, at its forty-fourth session (May 2016), the elaboration of the technology framework established under Article 10, paragraph 4, of the Agreement and to report on its findings to the Conference of the Parties, with a view to the Conference of the Parties making a recommendation on the framework to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session, taking into consideration that the framework should facilitate, inter alia:

(a) The undertaking and updating of technology needs assessments, as well as the *enhanced* implementation of their results, particularly technology action plans and project ideas, through the preparation of bankable projects;

(b) The provision of enhanced financial and technical support for the implementation of the results of the technology needs assessments;

(c) The assessment of technologies that are ready for transfer;

(d) The enhancement of enabling environments for and the addressing of barriers to the development and transfer of socially and environmentally sound technologies;

69. *Decides* that the Technology Executive Committee and the Climate Technology Centre and Network shall report to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, through the subsidiary bodies, on their activities to support the implementation of the Agreement;

70. *Also decides* to undertake a periodic assessment of the effectiveness of and the adequacy of the support provided to the Technology Mechanism in supporting the implementation of the Agreement on matters relating to technology development and transfer;

71. *Requests* the Subsidiary Body for Implementation to initiate, at its forty-fourth session , the elaboration of the scope of and modalities for the periodic assessment referred to in paragraph 70 above, taking into account the review of the Climate Technology Centre and Network as referred to in decision 2/CP.17, annex VII, paragraph 20 and the modalities for the global stocktake referred to in Article 14 of the Agreement, for consideration and adoption by the Conference of the Parties at its twenty-fifth session (November 2019);

CAPACITY-BUILDING

72. *Decides* to establish the Paris Committee on Capacity-building whose aim will be to address gaps and needs, both current and emerging, in implementing capacity-building in developing country Parties and further enhancing capacity-building efforts, including with regard to coherence and coordination in capacity-building activities under the Convention;

73. *Also decides* that the Paris Committee on Capacity-building will manage and oversee the work plan mentioned in paragraph 74 below;

74. *Further decides* to launch a work plan for the period 2016–2020 with the following activities:

(a) Assessing how to increase synergies through cooperation and avoid duplication among existing bodies established under the Convention that implement capacity-building activities, including through collaborating with institutions under and outside the Convention;

(b) Identifying capacity gaps and needs and recommending ways to address them;

(c) Promoting the development and dissemination of tools and methodologies for the implementation of capacity-building;

(d) Fostering global, regional, national and subnational cooperation;

(e) Identifying and collecting good practices, challenges, experiences, and lessons learned from work on capacity-building by bodies established under the Convention;

(f) Exploring how developing country Parties can take ownership of building and maintaining capacity over time and space;

(g) Identifying opportunities to strengthen capacity at the national, regional, and subnational level;

(h) Fostering dialogue, coordination, collaboration and coherence among relevant processes and initiatives under the Convention, including through exchanging information on capacity-building activities and strategies of bodies established under the Convention;

(i) Providing guidance to the secretariat on the maintenance and further development of the web-based capacity-building portal;

75. *Decides* that the Paris Committee on Capacity-building will annually focus on an area or theme related to enhanced technical exchange on capacity-building, with the purpose of maintaining up-to-date knowledge on the successes and challenges in building capacity effectively in a particular area;

76. *Requests* the Subsidiary Body for Implementation to organize annual in-session meetings of the Paris Committee on Capacity-building;

77. *Also requests* the Subsidiary Body for Implementation to develop the terms of reference for the Paris Committee on Capacity-building, in the context of the third comprehensive review of the implementation of the capacity-building framework, also taking into account paragraphs 75, 76, 77 and 78 above and paragraphs 82 and 83 below, with a view to recommending a draft decision on this matter for consideration and adoption by the Conference of the Parties at its twenty-second session;

78. *Invites* Parties to submit their views on the membership of the Paris Committee on Capacity-building by 9 March 2016;[2]

79. *Requests* the secretariat to compile the submissions referred to in paragraph 78 above into a miscellaneous document for consideration by the Subsidiary Body for Implementation at its forty-fourth session;

80. *Decides* that the inputs to the Paris Committee on Capacity-building will include, inter alia, submissions, the outcome of the third comprehensive review of the implementation of the capacity-building framework, the secretariat's annual synthesis report on the implementation of the framework for capacity-building in developing countries, the secretariat's compilation and synthesis report on capacity-building work of bodies established under the Convention and its Kyoto Protocol, and reports on the Durban Forum and the capacity-building portal;

81. *Requests* the Paris Committee on Capacity-building to prepare annual technical progress reports on its work, and to make these reports available at the sessions of the Subsidiary Body for Implementation coinciding with the sessions of the Conference of the Parties;

82. *Also requests* the Conference of the Parties at its twenty-fifth session (November 2019), to review the progress, need for extension, the effectiveness and enhancement of the Paris Committee on Capacity-building and to take any action it considers appropriate, with a view to making recommendations to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session on enhancing institutional arrangements for capacity-building consistent with Article 11, paragraph 5, of the Agreement;

83. *Calls upon* all Parties to ensure that education, training and public awareness, as reflected in Article 6 of the Convention and in Article 12 of the Agreement are adequately considered in their contribution to capacity-building;

84. *Invites* the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session to explore ways of enhancing the implementation of training, public awareness, public participation and public access to information so as to enhance actions under the Agreement;

[2] Parties should submit their views via the submissions portal at <http://www.unfccc.int/5900>.

TRANSPARENCY OF ACTION AND SUPPORT

85. *Decides* to establish a Capacity-building Initiative for Transparency in order to build institutional and technical capacity, both pre- and post-2020. This initiative will support developing country Parties, upon request, in meeting enhanced transparency requirements as defined in Article 13 of the Agreement in a timely manner;

86. *Also decides* that the Capacity-building Initiative for Transparency will aim:

(a) To strengthen national institutions for transparency-related activities in line with national priorities;

(b) To provide relevant tools, training and assistance for meeting the provisions stipulated in Article 13 of the Agreement;

(c) To assist in the improvement of transparency over time;

87. *Urges and requests* the Global Environment Facility to make arrangements to support the establishment and operation of the Capacity-building Initiative for Transparency as a priority reporting-related need, including through voluntary contributions to support developing countries in the sixth replenishment of the Global Environment Facility and future replenishment cycles, to complement existing support under the Global Environment Facility;

88. *Decides* to assess the implementation of the Capacity-building Initiative for Transparency in the context of the seventh review of the financial mechanism;

89. *Requests* that the Global Environment Facility, as an operating entity of the financial mechanism include in its annual report to the Conference of the Parties the progress of work in the design, development and implementation of the Capacity-building Initiative for Transparency referred to in paragraph 85 above starting in 2016;

90. *Decides* that, in accordance with Article 13, paragraph 2, of the Agreement, developing countries shall be provided flexibility in the implementation of the provisions of that Article, including in the scope, frequency and level of detail of reporting, and in the scope of review, and that the scope of review could provide for in-country reviews to be optional, while such flexibilities shall be reflected in the development of modalities, procedures and guidelines referred to in paragraph 92 below;

91. *Also decides* that all Parties, except for the least developed country Parties and small island developing States, shall submit the information referred to in Article 13, paragraphs 7, 8, 9 and 10, as appropriate, no less frequently than on a biennial basis, and that the least developed country Parties and small island developing States may submit this information at their discretion;

92. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop recommendations for modalities, procedures and guidelines in accordance with Article 13, paragraph 13, of the Agreement, and to define the year of their first and subsequent review and update, as appropriate, at regular intervals, for consideration by the Conference of the Parties, at its twenty-fourth session, with a view to forwarding them to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for adoption at its first session;

93. *Also requests* the Ad Hoc Working Group on the Paris Agreement in developing the recommendations for the modalities, procedures and guidelines referred to in paragraph 92 above to take into account, inter alia:

(a) The importance of facilitating improved reporting and transparency over time;

(b) The need to provide flexibility to those developing country Parties that need it in the light of their capacities;

(c) The need to promote transparency, accuracy, completeness, consistency, and comparability;

(d) The need to avoid duplication as well as undue burden on Parties and the secretariat;

(e) The need to ensure that Parties maintain at least the frequency and quality of reporting in accordance with their respective obligations under the Convention;

(f) The need to ensure that double counting is avoided;

(g) The need to ensure environmental integrity;

94. *Further requests* the Ad Hoc Working Group on the Paris Agreement, when developing the modalities, procedures and guidelines referred to in paragraph 92 above, to draw on the experiences from and take into account other on-going relevant processes under the Convention;

95. *Requests* the Ad Hoc Working Group on the Paris Agreement, when developing modalities, procedures and guidelines referred to in paragraph 92 above, to consider, inter alia:

(a) The types of flexibility available to those developing countries that need it on the basis of their capacities;

(b) The consistency between the methodology communicated in the nationally determined contribution and the methodology for reporting on progress made towards achieving individual Parties' respective nationally determined contribution;

(c) That Parties report information on adaptation action and planning including, if appropriate, their national adaptation plans, with a view to collectively exchanging information and sharing lessons learned;

(d) Support provided, enhancing delivery of support for both adaptation and mitigation through, inter alia, the common tabular formats for reporting support, and taking into account issues considered by the Subsidiary Body for Scientific and Technological Advice on methodologies for reporting on financial information, and enhancing the reporting by developing countries on support received, including the use, impact and estimated results thereof;

(e) Information in the biennial assessments and other reports of the Standing Committee on Finance and other relevant bodies under the Convention;

(f) Information on the social and economic impact of response measures;

96. *Also requests* the Ad Hoc Working Group on the Paris Agreement, when developing recommendations for modalities, procedures and guidelines referred to in paragraph 92 above, to enhance the transparency of support provided in accordance with Article 9 of the Agreement;

97. *Further requests* the Ad Hoc Working Group on the Paris Agreement to report on the progress of work on the modalities, procedures and guidelines referred to in paragraph 92 above to future sessions of the Conference of the Parties, and that this work be concluded no later than 2018;

98. *Decides* that the modalities, procedures and guidelines developed under paragraph 92 above, shall be applied upon the entry into force of the Paris Agreement;

99. *Also decides* that the modalities, procedures and guidelines of this transparency framework shall build upon and eventually supercede the measurement, reporting and verification system established by paragraphs 40 to 47 and 60 to 64 of decision 1/CP.16 and paragraph 12 to 62 of decision 2/CP.17 immediately following the submission of the final biennial reports and biennial update reports;

GLOBAL STOCKTAKE

100. *Requests* the Ad Hoc Working Group on the Paris Agreement to identify the sources of input for the global stocktake referred to in Article 14 of the Agreement and to report to the Conference of the Parties, with a view to the Conference of the Parties making a recommendation to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session, including, but not limited to:

(a) Information on:

(i) The overall effect of the nationally determined contributions communicated by Parties;

(ii) The state of adaptation efforts, support, experiences and priorities from the communications referred to in Article 7, paragraphs 10 and 11, of the Agreement, and reports referred to in Article 13, paragraph 7, of the Agreement;

(iii) The mobilization and provision of support;

(b) The latest reports of the Intergovernmental Panel on Climate Change;

(c) Reports of the subsidiary bodies;

101. *Also requests* the Subsidiary Body for Scientific and Technological Advice to provide advice on how the assessments of the Intergovernmental Panel on Climate Change can inform the global stocktake of the implementation of the Agreement pursuant to its Article 14 of the Agreement and to report on this matter to the Ad Hoc Working Group on the Paris Agreement at its second session;

102. *Further requests* the Ad Hoc Working Group on the Paris Agreement to develop modalities for the global stocktake referred to in Article 14 of the Agreement and to report to the Conference of the Parties, with a view to making a recommendation to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for consideration and adoption at its first session;

FACILITATING IMPLEMENTATION AND COMPLIANCE

103. *Decides* that the committee referred to in Article 15, paragraph 2, of the Agreement shall consist of 12 members with recognized competence in relevant scientific, technical, socio-economic or legal fields, to be elected by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on the basis of equitable geographical representation, with two members each from the five regional groups of the United Nations and one member each from the small island developing States and the least developed countries, while taking into account the goal of gender balance;

104. *Requests* the Ad Hoc Working Group on the Paris Agreement to develop the modalities and procedures for the effective operation of the committee referred to in Article 15, paragraph 2, of the Agreement, with a view to the Ad Hoc Working Group on the Paris Agreement completing its work on such modalities and procedures for consideration and adoption by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session;

FINAL CLAUSES

105. *Also requests* the secretariat, solely for the purposes of Article 21 of the Agreement, to make available on its website on the date of adoption of the Agreement as well as in the report of the Conference of the Parties at its twenty-first session, information on the most up-to-date total and per cent of greenhouse gas emissions communicated by Parties to the Convention in their national communications, greenhouse gas inventory reports, biennial reports or biennial update reports;

IV. ENHANCED ACTION PRIOR TO 2020

106. *Resolves* to ensure the highest possible mitigation efforts in the pre-2020 period, including by:

(a) Urging all Parties to the Kyoto Protocol that have not already done so to ratify and implement the Doha Amendment to the Kyoto Protocol;

(b) Urging all Parties that have not already done so to make and implement a mitigation pledge under the Cancun Agreements;

(c) Reiterating its resolve, as set out in decision 1/CP.19, paragraphs 3 and 4, to accelerate the full implementation of the decisions constituting the agreed outcome pursuant to decision 1/CP.13 and enhance ambition in the pre-2020 period in order to ensure the highest possible mitigation efforts under the Convention by all Parties;

(d) Inviting developing country Parties that have not submitted their first biennial update reports to do so as soon as possible;

(e) Urging all Parties to participate in the existing measurement, reporting and verification processes under the Cancun Agreements, in a timely manner, with a view to demonstrating progress made in the implementation of their mitigation pledges;

107. *Encourages* Parties to promote the voluntary cancellation by Party and non-Party stakeholders, without double counting of units issued under the Kyoto Protocol, including certified emission reductions that are valid for the second commitment period;

108. *Urges* host and purchasing Parties to report transparently on internationally transferred mitigation outcomes, including outcomes used to meet international pledges, and emission units issued under the Kyoto Protocol with a view to promoting environmental integrity and avoiding double counting;

109. *Recognizes* the social, economic and environmental value of voluntary mitigation actions and their co-benefits for adaptation, health and sustainable development;

110. *Resolves* to strengthen, in the period 2016–2020, the existing technical examination process on mitigation as defined in decision 1/CP.19, paragraph 5(a), and decision 1/CP.20, paragraph 19, taking into account the latest scientific knowledge, including by:

(a) Encouraging Parties, Convention bodies and international organizations to engage in this process, including, as appropriate, in cooperation with relevant non-Party stakeholders, to share their experiences and suggestions, including from regional events, and to cooperate in facilitating the implementation of policies, practices and actions identified during this process in accordance with national sustainable development priorities;

(b) Striving to improve, in consultation with Parties, access to and participation in this process by developing country Party and non-Party experts;

(c) Requesting the Technology Executive Committee and the Climate Technology Centre and Network in accordance with their respective mandates:

(i) To engage in the technical expert meetings and enhance their efforts to facilitate and support Parties in scaling up the implementation of policies, practices and actions identified during this process;

(ii) To provide regular updates during the technical expert meetings on the progress made in facilitating the implementation of policies, practices and actions previously identified during this process;

(iii) To include information on their activities under this process in their joint annual report to the Conference of the Parties;

(d) Encouraging Parties to make effective use of the Climate Technology Centre and Network to obtain assistance to develop economically, environmentally and socially viable project proposals in the high mitigation potential areas identified in this process;

111. *Encourages* the operating entities of the Financial Mechanism of the Convention to engage in the technical expert meetings and to inform participants of their contribution to facilitating progress in the implementation of policies, practices and actions identified during the technical examination process;

112. *Requests* the secretariat to organize the process referred to in paragraph 110 above and disseminate its results, including by:

(a) Organizing, in consultation with the Technology Executive Committee and relevant expert organizations, regular technical expert meetings focusing on specific policies, practices and actions representing best practices and with the potential to be scalable and replicable;

(b) Updating, on an annual basis, following the meetings referred to in paragraph 112(a) above and in time to serve as input to the summary for policymakers referred to in paragraph 112(c) below, a technical paper on the mitigation benefits and co-benefits of policies, practices and actions for enhancing mitigation ambition, as well as on options for supporting their implementation, information on which should be made available in a user-friendly online format;

(c) Preparing, in consultation with the champions referred to in paragraph 122 below, a summary for policymakers, with information on specific policies, practices and actions representing best practices and with the potential to be scalable and replicable, and on options to support their implementation, as well as on relevant collaborative initiatives, and publishing the summary at least two months in advance of each session of the Conference of the Parties as input for the high-level event referred to in paragraph 121 below;

113. *Decides* that the process referred to in paragraph 110 above should be organized jointly by the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice and should take place on an ongoing basis until 2020;

114. *Also decides* to conduct in 2017 an assessment of the process referred to in paragraph 110 above so as to improve its effectiveness;

115. *Resolves* to enhance the provision of urgent and adequate finance, technology and capacity-building support by developed country Parties in order to enhance the level of ambition of pre-2020 action by Parties, and in this regard *strongly urges* developed country Parties to scale up their level of financial support, with a concrete roadmap to achieve the goal of jointly providing USD 100 billion annually by 2020 for mitigation and adaptation while significantly increasing adaptation finance from current levels and to further provide appropriate technology and capacity-building support;

116. *Decides* to conduct a facilitative dialogue in conjunction with the twenty-second session of the Conference of the Parties to assess the progress in implementing decision 1/CP.19, paragraphs 3 and 4, and identify relevant opportunities to enhance the provision of financial resources, including for technology development and transfer and capacity-building support, with a view to identifying ways to enhance the ambition of mitigation efforts by all Parties, including identifying relevant opportunities to enhance the provision and mobilization of support and enabling environments;

117. *Acknowledges* with appreciation the results of the Lima-Paris Action Agenda, which build on the climate summit convened on 23 September 2014 by the Secretary-General of the United Nations;

118. *Welcomes* the efforts of non-Party stakeholders to scale up their climate actions, and *encourages* the registration of those actions in the Non-State Actor Zone for Climate Action platform;[3]

119. *Encourages* Parties to work closely with non-Party stakeholders to catalyse efforts to strengthen mitigation and adaptation action;

120. *Also encourages* non-Party stakeholders to increase their engagement in the processes referred to in paragraph 110 above and paragraph 125 below;

121. *Agrees* to convene, pursuant to decision 1/CP.20, paragraph 21, building on the Lima-Paris Action Agenda and in conjunction with each session of the Conference of the Parties during the period 2016–2020, a high-level event that:

(a) Further strengthens high-level engagement on the implementation of policy options and actions arising from the processes referred to in paragraph 110 above and paragraph below, drawing on the summary for policymakers referred to in paragraph 112(c) above;

(b) Provides an opportunity for announcing new or strengthened voluntary efforts, initiatives and coalitions, including the implementation of policies, practices and actions arising from the processes referred to in paragraph 110 above and paragraph 125 below and presented in the summary for policymakers referred to in paragraph 112(c) above;

(c) Takes stock of related progress and recognizes new or strengthened voluntary efforts, initiatives and coalitions;

(d) Provides meaningful and regular opportunities for the effective high-level engagement of dignitaries of Parties, international organizations, international cooperative initiatives and non-Party stakeholders;

122. *Decides* that two high-level champions shall be appointed to act on behalf of the President of the Conference of the Parties to facilitate through strengthened high-level engagement in the period 2016–2020 the successful execution of existing efforts and the scaling-up and introduction of new or strengthened voluntary efforts, initiatives and coalitions, including by:

(a) Working with the Executive Secretary and the current and incoming Presidents of the Conference of the Parties to coordinate the annual high-level event referred to in paragraph 121 above;

(b) Engaging with interested Parties and non-Party stakeholders, including to further the voluntary initiatives of the Lima-Paris Action Agenda;

[3] <http://climateaction.unfccc.int/>.

(c) Providing guidance to the secretariat on the organization of technical expert meetings referred to in paragraph 112(a) above and paragraph 130(a) below;

123. *Also decides* that the high-level champions referred to in paragraph 122 above should normally serve for a term of two years, with their terms overlapping for a full year to ensure continuity, such that:

(a) The President of the Conference of the Parties of the twenty-first session should appoint one champion, who should serve for one year from the date of the appointment until the last day of the Conference of the Parties at its twenty-second session;

(b) The President of the Conference of the Parties of the twenty-second session should appoint one champion who should serve for two years from the date of the appointment until the last day of the Conference of the Parties at its twenty-third session (November 2017);

(c) Thereafter, each subsequent President of the Conference of the Parties should appoint one champion who should serve for two years and succeed the previously appointed champion whose term has ended;

124. *Invites* all interested Parties and relevant organizations to provide support for the work of the champions referred to in paragraph 122 above;

125. *Decides* to launch, in the period 2016–2020, a technical examination process on adaptation;

126. *Also decides* that the technical examination process on adaptation referred to in paragraph 125 above will endeavour to identify concrete opportunities for strengthening resilience, reducing vulnerabilities and increasing the understanding and implementation of adaptation actions;

127. *Further decides* that the technical examination process referred to in paragraph 125 above should be organized jointly by the Subsidiary Body for Implementation and the Subsidiary Body for Scientific and Technological Advice, and conducted by the Adaptation Committee;

128. *Decides* that the process referred to in paragraph 125 above will be pursued by:

(a) Facilitating the sharing of good practices, experiences and lessons learned;

(b) Identifying actions that could significantly enhance the implementation of adaptation actions, including actions that could enhance economic diversification and have mitigation co-benefits;

(c) Promoting cooperative action on adaptation;

(d) Identifying opportunities to strengthen enabling environments and enhance the provision of support for adaptation in the context of specific policies, practices and actions;

129. *Also decides* that the technical examination process on adaptation referred to in paragraph 125 above will take into account the process, modalities, outputs, outcomes and lessons learned from the technical examination process on mitigation referred to in paragraph 110 above;

130. *Requests* the secretariat to support the technical examination process referred to in paragraph 125 above by:

(a) Organizing regular technical expert meetings focusing on specific policies, strategies and actions;

(b) Preparing annually, on the basis of the meetings referred to in paragraph 130(a) above and in time to serve as an input to the summary for policymakers referred to in paragraph 112(c) above, a technical paper on opportunities to enhance adaptation action, as well as options to support their implementation, information on which should be made available in a user-friendly online format;

131. *Decides* that in conducting the process referred to in paragraph 125 above, the Adaptation Committee will engage with and explore ways to take into account, synergize with and build on the existing arrangements for adaptation-related work programmes, bodies and institutions under the Convention so as to ensure coherence and maximum value;

132. *Also decides* to conduct, in conjunction with the assessment referred to in paragraph 120 above, an assessment of the process referred to in paragraph 125 above, so as to improve its effectiveness;

133. *Invites* Parties and observer organizations to submit information on the opportunities referred to in paragraph 126 above by 3 February 2016;

V. NON-PARTY STAKEHOLDERS

134. *Welcomes* the efforts of all non-Party stakeholders to address and respond to climate change, including those of civil society, the private sector, financial institutions, cities and other subnational authorities;

135. *Invites* the non-Party stakeholders referred to in paragraph 134 above to scale up their efforts and support actions to reduce emissions and/or to build resilience and decrease vulnerability to the adverse effects of climate change and demonstrate these efforts via the Non-State Actor Zone for Climate Action platform[4] referred to in paragraph 118 above;

136. *Recognizes* the need to strengthen knowledge, technologies, practices and efforts of local communities and indigenous peoples related to addressing and responding to climate change, and *establishes* a platform for the exchange of experiences and sharing of best practices on mitigation and adaptation in a holistic and integrated manner;

137. *Also recognizes* the important role of providing incentives for emission reduction activities, including tools such as domestic policies and carbon pricing;

VI. ADMINISTRATIVE AND BUDGETARY MATTERS

138. *Takes note* of the estimated budgetary implications of the activities to be undertaken by the secretariat referred to in this decision and requests that the actions of the secretariat called for in this decision be undertaken subject to the availability of financial resources;

139. *Emphasizes* the urgency of making additional resources available for the implementation of the relevant actions, including actions referred to in this decision, and the implementation of the work programme referred to in paragraph 9 above;

140. *Urges* Parties to make voluntary contributions for the timely implementation of this decision.

[4] <http://climateaction.unfccc.int/>.

Annex

PARIS AGREEMENT

The Parties to this Agreement,

Being Parties to the United Nations Framework Convention on Climate Change, hereinafter referred to as "the Convention",

Pursuant to the Durban Platform for Enhanced Action established by decision 1/CP.17 of the Conference of the Parties to the Convention at its seventeenth session,

In pursuit of the objective of the Convention, and being guided by its principles, including the principle of equity and common but differentiated responsibilities and respective capabilities, in the light of different national circumstances,

Recognizing the need for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge,

Also recognizing the specific needs and special circumstances of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change, as provided for in the Convention,

Taking full account of the specific needs and special situations of the least developed countries with regard to funding and transfer of technology,

Recognizing that Parties may be affected not only by climate change, but also by the impacts of the measures taken in response to it,

Emphasizing the intrinsic relationship that climate change actions, responses and impacts have with equitable access to sustainable development and eradication of poverty,

Recognizing the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change,

Taking into account the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities,

Acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples, local communities, migrants, children, persons with disabilities and people in vulnerable situations and the right to development, as well as gender equality, empowerment of women and intergenerational equity,

Recognizing the importance of the conservation and enhancement, as appropriate, of sinks and reservoirs of the greenhouse gases referred to in the Convention,

Noting the importance of ensuring the integrity of all ecosystems, including oceans, and the protection of biodiversity, recognized by some cultures as Mother Earth, and noting the importance for some of the concept of "climate justice", when taking action to address climate change,

Affirming the importance of education, training, public awareness, public participation, public access to information and cooperation at all levels on the matters addressed in this Agreement,

Recognizing the importance of the engagements of all levels of government and various actors, in accordance with respective national legislations of Parties, in addressing climate change,

Also recognizing that sustainable lifestyles and sustainable patterns of consumption and production, with developed country Parties taking the lead, play an important role in addressing climate change,

Have agreed as follows:

Article 1

For the purpose of this Agreement, the definitions contained in Article 1 of the Convention shall apply. In addition:

1. "Convention" means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992.
2. "Conference of the Parties" means the Conference of the Parties to the Convention.
3. "Party" means a Party to this Agreement.

Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:
   (a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
   (b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production;
   (c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.
2. This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Article 3

As nationally determined contributions to the global response to climate change, all Parties are to undertake and communicate ambitious efforts as defined in Articles 4, 7, 9, 10, 11 and 13 with the view to achieving the purpose of this Agreement as set out in Article 2. The efforts of all Parties will represent a progression over time, while recognizing the need to support developing country Parties for the effective implementation of this Agreement.

Article 4

1. In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.
2. Each Party shall prepare, communicate and maintain successive nationally determined contributions that it intends to achieve. Parties shall pursue domestic mitigation measures with the aim of achieving the objectives of such contributions.
3. Each Party's successive nationally determined contribution will represent a progression beyond the Party's then current nationally determined contribution and reflect its highest possible ambition, reflecting its common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.
4. Developed country Parties shall continue taking the lead by undertaking economy-wide absolute emission reduction targets. Developing country Parties should continue enhancing their mitigation efforts, and are encouraged to move over time towards economy-wide emission reduction or limitation targets in the light of different national circumstances.
5. Support shall be provided to developing country Parties for the implementation of this Article, in accordance with Articles 9, 10 and 11, recognizing that enhanced support for developing country Parties will allow for higher ambition in their actions.

6. The least developed countries and small island developing States may prepare and communicate strategies, plans and actions for low greenhouse gas emissions development reflecting their special circumstances.

7. Mitigation co-benefits resulting from Parties' adaptation actions and/or economic diversification plans can contribute to mitigation outcomes under this Article.

8. In communicating their nationally determined contributions, all Parties shall provide the information necessary for clarity, transparency and understanding in accordance with decision 1/CP.21 and any relevant decisions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

9. Each Party shall communicate a nationally determined contribution every five years in accordance with decision 1/CP.21 and any relevant decisions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement and be informed by the outcomes of the global stocktake referred to in Article 14.

10. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall consider common time frames for nationally determined contributions at its first session.

11. A Party may at any time adjust its existing nationally determined contribution with a view to enhancing its level of ambition, in accordance with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

12. Nationally determined contributions communicated by Parties shall be recorded in a public registry maintained by the secretariat.

13. Parties shall account for their nationally determined contributions. In accounting for anthropogenic emissions and removals corresponding to their nationally determined contributions, Parties shall promote environmental integrity, transparency, accuracy, completeness, comparability and consistency, and ensure the avoidance of double counting, in accordance with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

14. In the context of their nationally determined contributions, when recognizing and implementing mitigation actions with respect to anthropogenic emissions and removals, Parties should take into account, as appropriate, existing methods and guidance under the Convention, in the light of the provisions of paragraph 13 of this Article.

15. Parties shall take into consideration in the implementation of this Agreement the concerns of Parties with economies most affected by the impacts of response measures, particularly developing country Parties.

16. Parties, including regional economic integration organizations and their member States, that have reached an agreement to act jointly under paragraph 2 of this Article shall notify the secretariat of the terms of that agreement, including the emission level allocated to each Party within the relevant time period, when they communicate their nationally determined contributions. The secretariat shall in turn inform the Parties and signatories to the Convention of the terms of that agreement.

17. Each party to such an agreement shall be responsible for its emission level as set out in the agreement referred to in paragraph 16 above in accordance with paragraphs 13 and 14 of this Article and Articles 13 and 15.

18. If Parties acting jointly do so in the framework of, and together with, a regional economic integration organization which is itself a Party to this Agreement, each member State of that regional economic integration organization individually, and together with the regional economic integration organization, shall be responsible for its emission level as set out in the agreement communicated under paragraph 16 of this Article in accordance with paragraphs 13 and 14 of this Article and Articles 13 and 15.

19. All Parties should strive to formulate and communicate long-term low greenhouse gas emission development strategies, mindful of Article 2 taking into account their common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Article 5

1. Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d), of the Convention, including forests.

2. Parties are encouraged to take action to implement and support, including through results-based payments, the existing framework as set out in related guidance and decisions already agreed under the Convention for: policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon

stocks in developing countries; and alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivizing, as appropriate, non-carbon benefits associated with such approaches.

Article 6

1. Parties recognize that some Parties choose to pursue voluntary cooperation in the implementation of their nationally determined contributions to allow for higher ambition in their mitigation and adaptation actions and to promote sustainable development and environmental integrity.

2. Parties shall, where engaging on a voluntary basis in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards nationally determined contributions, promote sustainable development and ensure environmental integrity and transparency, including in governance, and shall apply robust accounting to ensure, inter alia, the avoidance of double counting, consistent with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

3. The use of internationally transferred mitigation outcomes to achieve nationally determined contributions under this Agreement shall be voluntary and authorized by participating Parties.

4. A mechanism to contribute to the mitigation of greenhouse gas emissions and support sustainable development is hereby established under the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement for use by Parties on a voluntary basis. It shall be supervised by a body designated by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, and shall aim:

   (a) To promote the mitigation of greenhouse gas emissions while fostering sustainable development;

   (b) To incentivize and facilitate participation in the mitigation of greenhouse gas emissions by public and private entities authorized by a Party;

   (c) To contribute to the reduction of emission levels in the host Party, which will benefit from mitigation activities resulting in emission reductions that can also be used by another Party to fulfil its nationally determined contribution; and

   (d) To deliver an overall mitigation in global emissions.

5. Emission reductions resulting from the mechanism referred to in paragraph 4 of this Article shall not be used to demonstrate achievement of the host Party's nationally determined contribution if used by another Party to demonstrate achievement of its nationally determined contribution.

6. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall ensure that a share of the proceeds from activities under the mechanism referred to in paragraph 4 of this Article is used to cover administrative expenses as well as to assist developing country Parties that are particularly vulnerable to the adverse effects of climate change to meet the costs of adaptation.

7. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall adopt rules, modalities and procedures for the mechanism referred to in paragraph 4 of this Article at its first session.

8. Parties recognize the importance of integrated, holistic and balanced non-market approaches being available to Parties to assist in the implementation of their nationally determined contributions, in the context of sustainable development and poverty eradication, in a coordinated and effective manner, including through, inter alia, mitigation, adaptation, finance, technology transfer and capacity-building, as appropriate. These approaches shall aim to:

   (a) Promote mitigation and adaptation ambition;

   (b) Enhance public and private participation in the implementation of nationally determined contributions; and

   (c) Enable opportunities for coordination across instruments and relevant institutional arrangements.

9. A framework for non-market approaches to sustainable development is hereby defined to promote the non-market approaches referred to in paragraph 8 of this Article.

Article 7

1. Parties hereby establish the global goal on adaptation of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change, with a view to contributing to sustainable development and ensuring an adequate adaptation response in the context of the temperature goal referred to in Article 2.

2. Parties recognize that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions, and that it is a key component of and makes a contribution to the long-term global response to climate change to protect people, livelihoods and ecosystems, taking into account the urgent and immediate needs of those developing country Parties that are particularly vulnerable to the adverse effects of climate change.

3. The adaptation efforts of developing country Parties shall be recognized, in accordance with the modalities to be adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session.

4. Parties recognize that the current need for adaptation is significant and that greater levels of mitigation can reduce the need for additional adaptation efforts, and that greater adaptation needs can involve greater adaptation costs.

5. Parties acknowledge that adaptation action should follow a country-driven, gender-responsive, participatory and fully transparent approach, taking into consideration vulnerable groups, communities and ecosystems, and should be based on and guided by the best available science and, as appropriate, traditional knowledge, knowledge of indigenous peoples and local knowledge systems, with a view to integrating adaptation into relevant socioeconomic and environmental policies and actions, where appropriate.

6. Parties recognize the importance of support for and international cooperation on adaptation efforts and the importance of taking into account the needs of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change.

7. Parties should strengthen their cooperation on enhancing action on adaptation, taking into account the Cancun Adaptation Framework, including with regard to:

   (a) Sharing information, good practices, experiences and lessons learned, including, as appropriate, as these relate to science, planning, policies and implementation in relation to adaptation actions;

   (b) Strengthening institutional arrangements, including those under the Convention that serve this Agreement, to support the synthesis of relevant information and knowledge, and the provision of technical support and guidance to Parties;

   (c) Strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making;

   (d) Assisting developing country Parties in identifying effective adaptation practices, adaptation needs, priorities, support provided and received for adaptation actions and efforts, and challenges and gaps, in a manner consistent with encouraging good practices;

   (e) Improving the effectiveness and durability of adaptation actions.

8. United Nations specialized organizations and agencies are encouraged to support the efforts of Parties to implement the actions referred to in paragraph 7 of this Article, taking into account the provisions of paragraph 5 of this Article.

9. Each Party shall, as appropriate, engage in adaptation planning processes and the implementation of actions, including the development or enhancement of relevant plans, policies and/or contributions, which may include:

   (a) The implementation of adaptation actions, undertakings and/or efforts;

   (b) The process to formulate and implement national adaptation plans;

   (c) The assessment of climate change impacts and vulnerability, with a view to formulating nationally determined prioritized actions, taking into account vulnerable people, places and ecosystems;

   (d) Monitoring and evaluating and learning from adaptation plans, policies, programmes and actions; and

   (e) Building the resilience of socioeconomic and ecological systems, including through economic diversification and sustainable management of natural resources.

10. Each Party should, as appropriate, submit and update periodically an adaptation communication, which may include its priorities, implementation and support needs, plans and actions, without creating any additional burden for developing country Parties.

11. The adaptation communication referred to in paragraph 10 of this Article shall be, as appropriate, submitted and updated periodically, as a component of or in conjunction with other communications or documents, including a national adaptation plan, a nationally determined contribution as referred to in Article 4, paragraph 2, and/or a national communication.

12. The adaptation communications referred to in paragraph 10 of this Article shall be recorded in a public registry maintained by the secretariat.

13. Continuous and enhanced international support shall be provided to developing country Parties for the implementation of paragraphs 7, 9, 10 and 11 of this Article, in accordance with the provisions of Articles 9, 10 and 11.

14. The global stocktake referred to in Article 14 shall, inter alia:

(a) Recognize adaptation efforts of developing country Parties;

(b) Enhance the implementation of adaptation action taking into account the adaptation communication referred to in paragraph 10 of this Article;

(c) Review the adequacy and effectiveness of adaptation and support provided for adaptation; and

(d) Review the overall progress made in achieving the global goal on adaptation referred to in paragraph 1 of this Article.

Article 8

1. Parties recognize the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage.

2. The Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts shall be subject to the authority and guidance of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement and may be enhanced and strengthened, as determined by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

3. Parties should enhance understanding, action and support, including through the Warsaw International Mechanism, as appropriate, on a cooperative and facilitative basis with respect to loss and damage associated with the adverse effects of climate change.

4. Accordingly, areas of cooperation and facilitation to enhance understanding, action and support may include:

(a) Early warning systems;

(b) Emergency preparedness;

(c) Slow onset events;

(d) Events that may involve irreversible and permanent loss and damage;

(e) Comprehensive risk assessment and management;

(f) Risk insurance facilities, climate risk pooling and other insurance solutions;

(g) Non-economic losses;

(h) Resilience of communities, livelihoods and ecosystems.

5. The Warsaw International Mechanism shall collaborate with existing bodies and expert groups under the Agreement, as well as relevant organizations and expert bodies outside the Agreement.

Article 9

1. Developed country Parties shall provide financial resources to assist developing country Parties with respect to both mitigation and adaptation in continuation of their existing obligations under the Convention.

2. Other Parties are encouraged to provide or continue to provide such support voluntarily.

3. As part of a global effort, developed country Parties should continue to take the lead in mobilizing climate finance from a wide variety of sources, instruments and channels, noting the significant role of public funds,

through a variety of actions, including supporting country-driven strategies, and taking into account the needs and priorities of developing country Parties. Such mobilization of climate finance should represent a progression beyond previous efforts.

4. The provision of scaled-up financial resources should aim to achieve a balance between adaptation and mitigation, taking into account country-driven strategies, and the priorities and needs of developing country Parties, especially those that are particularly vulnerable to the adverse effects of climate change and have significant capacity constraints, such as the least developed countries and small island developing States, considering the need for public and grant-based resources for adaptation.

5. Developed country Parties shall biennially communicate indicative quantitative and qualitative information related to paragraphs 1 and 3 of this Article, as applicable, including, as available, projected levels of public financial resources to be provided to developing country Parties. Other Parties providing resources are encouraged to communicate biennially such information on a voluntary basis.

6. The global stocktake referred to in Article 14 shall take into account the relevant information provided by developed country Parties and/or Agreement bodies on efforts related to climate finance.

7. Developed country Parties shall provide transparent and consistent information on support for developing country Parties provided and mobilized through public interventions biennially in accordance with the modalities, procedures and guidelines to be adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement, at its first session, as stipulated in Article 13, paragraph 13. Other Parties are encouraged to do so.

8. The Financial Mechanism of the Convention, including its operating entities, shall serve as the financial mechanism of this Agreement.

9. The institutions serving this Agreement, including the operating entities of the Financial Mechanism of the Convention, shall aim to ensure efficient access to financial resources through simplified approval procedures and enhanced readiness support for developing country Parties, in particular for the least developed countries and small island developing States, in the context of their national climate strategies and plans.

Article 10

1. Parties share a long-term vision on the importance of fully realizing technology development and transfer in order to improve resilience to climate change and to reduce greenhouse gas emissions.

2. Parties, noting the importance of technology for the implementation of mitigation and adaptation actions under this Agreement and recognizing existing technology deployment and dissemination efforts, shall strengthen cooperative action on technology development and transfer.

3. The Technology Mechanism established under the Convention shall serve this Agreement.

4. A technology framework is hereby established to provide overarching guidance for the work of the Technology Mechanism in promoting and facilitating enhanced action on technology development and transfer in order to support the implementation of this Agreement, in pursuit of the long-term vision referred to in paragraph 1 of this Article.

5. Accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development. Such effort shall be, as appropriate, supported, including by the Technology Mechanism and, through financial means, by the Financial Mechanism of the Convention, for collaborative approaches to research and development, and facilitating access to technology, in particular for early stages of the technology cycle, to developing country Parties.

6. Support, including financial support, shall be provided to developing country Parties for the implementation of this Article, including for strengthening cooperative action on technology development and transfer at different stages of the technology cycle, with a view to achieving a balance between support for mitigation and adaptation. The global stocktake referred to in Article 14 shall take into account available information on efforts related to support on technology development and transfer for developing country Parties.

Article 11

1. Capacity-building under this Agreement should enhance the capacity and ability of developing country Parties, in particular countries with the least capacity, such as the least developed countries, and those that are particularly vulnerable to the adverse effects of climate change, such as small island developing States, to take

effective climate change action, including, inter alia, to implement adaptation and mitigation actions, and should facilitate technology development, dissemination and deployment, access to climate finance, relevant aspects of education, training and public awareness, and the transparent, timely and accurate communication of information.

2. Capacity-building should be country-driven, based on and responsive to national needs, and foster country ownership of Parties, in particular, for developing country Parties, including at the national, subnational and local levels. Capacity-building should be guided by lessons learned, including those from capacity-building activities under the Convention, and should be an effective, iterative process that is participatory, cross-cutting and gender-responsive.

3. All Parties should cooperate to enhance the capacity of developing country Parties to implement this Agreement. Developed country Parties should enhance support for capacity-building actions in developing country Parties.

4. All Parties enhancing the capacity of developing country Parties to implement this Agreement, including through regional, bilateral and multilateral approaches, shall regularly communicate on these actions or measures on capacity-building. Developing country Parties should regularly communicate progress made on implementing capacity-building plans, policies, actions or measures to implement this Agreement.

5. Capacity-building activities shall be enhanced through appropriate institutional arrangements to support the implementation of this Agreement, including the appropriate institutional arrangements established under the Convention that serve this Agreement. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall, at its first session, consider and adopt a decision on the initial institutional arrangements for capacity-building.

Article 12

Parties shall cooperate in taking measures, as appropriate, to enhance climate change education, training, public awareness, public participation and public access to information, recognizing the importance of these steps with respect to enhancing actions under this Agreement.

Article 13

1. In order to build mutual trust and confidence and to promote effective implementation, an enhanced transparency framework for action and support, with built-in flexibility which takes into account Parties' different capacities and builds upon collective experience is hereby established.

2. The transparency framework shall provide flexibility in the implementation of the provisions of this Article to those developing country Parties that need it in the light of their capacities. The modalities, procedures and guidelines referred to in paragraph 13 of this Article shall reflect such flexibility.

3. The transparency framework shall build on and enhance the transparency arrangements under the Convention, recognizing the special circumstances of the least developed countries and small island developing States, and be implemented in a facilitative, non-intrusive, non-punitive manner, respectful of national sovereignty, and avoid placing undue burden on Parties.

4. The transparency arrangements under the Convention, including national communications, biennial reports and biennial update reports, international assessment and review and international consultation and analysis, shall form part of the experience drawn upon for the development of the modalities, procedures and guidelines under paragraph 13 of this Article.

5. The purpose of the framework for transparency of action is to provide a clear understanding of climate change action in the light of the objective of the Convention as set out in its Article 2, including clarity and tracking of progress towards achieving Parties' individual nationally determined contributions under Article 4, and Parties' adaptation actions under Article 7, including good practices, priorities, needs and gaps, to inform the global stocktake under Article 14.

6. The purpose of the framework for transparency of support is to provide clarity on support provided and received by relevant individual Parties in the context of climate change actions under Articles 4, 7, 9, 10 and 11, and, to the extent possible, to provide a full overview of aggregate financial support provided, to inform the global stocktake under Article 14.

7. Each Party shall regularly provide the following information:

(a) A national inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement;

(b) Information necessary to track progress made in implementing and achieving its nationally determined contribution under Article 4.

8. Each Party should also provide information related to climate change impacts and adaptation under Article 7, as appropriate.

9. Developed country Parties shall, and other Parties that provide support should, provide information on financial, technology transfer and capacity-building support provided to developing country Parties under Article 9, 10 and 11.

10. Developing country Parties should provide information on financial, technology transfer and capacity-building support needed and received under Articles 9, 10 and 11.

11. Information submitted by each Party under paragraphs 7 and 9 of this Article shall undergo a technical expert review, in accordance with decision 1/CP.21. For those developing country Parties that need it in the light of their capacities, the review process shall include assistance in identifying capacity-building needs. In addition, each Party shall participate in a facilitative, multilateral consideration of progress with respect to efforts under Article 9, and its respective implementation and achievement of its nationally determined contribution.

12. The technical expert review under this paragraph shall consist of a consideration of the Party's support provided, as relevant, and its implementation and achievement of its nationally determined contribution. The review shall also identify areas of improvement for the Party, and include a review of the consistency of the information with the modalities, procedures and guidelines referred to in paragraph 13 of this Article, taking into account the flexibility accorded to the Party under paragraph 2 of this Article. The review shall pay particular attention to the respective national capabilities and circumstances of developing country Parties.

13. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall, at its first session, building on experience from the arrangements related to transparency under the Convention, and elaborating on the provisions in this Article, adopt common modalities, procedures and guidelines, as appropriate, for the transparency of action and support.

14. Support shall be provided to developing countries for the implementation of this Article.

15. Support shall also be provided for the building of transparency-related capacity of developing country Parties on a continuous basis.

Article 14

1. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall periodically take stock of the implementation of this Agreement to assess the collective progress towards achieving the purpose of this Agreement and its long-term goals (referred to as the "global stocktake"). It shall do so in a comprehensive and facilitative manner, considering mitigation, adaptation and the means of implementation and support, and in the light of equity and the best available science.

2. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall undertake its first global stocktake in 2023 and every five years thereafter unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

3. The outcome of the global stocktake shall inform Parties in updating and enhancing, in a nationally determined manner, their actions and support in accordance with the relevant provisions of this Agreement, as well as in enhancing international cooperation for climate action.

Article 15

1. A mechanism to facilitate implementation of and promote compliance with the provisions of this Agreement is hereby established.

2. The mechanism referred to in paragraph 1 of this Article shall consist of a committee that shall be expert-based and facilitative in nature and function in a manner that is transparent, non-adversarial and non-punitive. The committee shall pay particular attention to the respective national capabilities and circumstances of Parties.

3. The committee shall operate under the modalities and procedures adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement at its first session and report annually to the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

Article 16

1. The Conference of the Parties, the supreme body of the Convention, shall serve as the meeting of the Parties to this Agreement.

2. Parties to the Convention that are not Parties to this Agreement may participate as observers in the proceedings of any session of the Conference of the Parties serving as the meeting of the Parties to this Agreement. When the Conference of the Parties serves as the meeting of the Parties to this Agreement, decisions under this Agreement shall be taken only by those that are Parties to this Agreement.

3. When the Conference of the Parties serves as the meeting of the Parties to this Agreement, any member of the Bureau of the Conference of the Parties representing a Party to the Convention but, at that time, not a Party to this Agreement, shall be replaced by an additional member to be elected by and from amongst the Parties to this Agreement.

4. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall keep under regular review the implementation of this Agreement and shall make, within its mandate, the decisions necessary to promote its effective implementation. It shall perform the functions assigned to it by this Agreement and shall:

    (a) Establish such subsidiary bodies as deemed necessary for the implementation of this Agreement; and

    (b) Exercise such other functions as may be required for the implementation of this Agreement.

5. The rules of procedure of the Conference of the Parties and the financial procedures applied under the Convention shall be applied mutatis mutandis under this Agreement, except as may be otherwise decided by consensus by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

6. The first session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall be convened by the secretariat in conjunction with the first session of the Conference of the Parties that is scheduled after the date of entry into force of this Agreement. Subsequent ordinary sessions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall be held in conjunction with ordinary sessions of the Conference of the Parties, unless otherwise decided by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

7. Extraordinary sessions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall be held at such other times as may be deemed necessary by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement or at the written request of any Party, provided that, within six months of the request being communicated to the Parties by the secretariat, it is supported by at least one third of the Parties.

8. The United Nations and its specialized agencies and the International Atomic Energy Agency, as well as any State member thereof or observers thereto not party to the Convention, may be represented at sessions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement as observers. Any body or agency, whether national or international, governmental or non-governmental, which is qualified in matters covered by this Agreement and which has informed the secretariat of its wish to be represented at a session of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement as an observer, may be so admitted unless at least one third of the Parties present object. The admission and participation of observers shall be subject to the rules of procedure referred to in paragraph 5 of this Article.

Article 17

1. The secretariat established by Article 8 of the Convention shall serve as the secretariat of this Agreement.

2. Article 8, paragraph 2, of the Convention on the functions of the secretariat, and Article 8, paragraph 3, of the Convention, on the arrangements made for the functioning of the secretariat, shall apply mutatis mutandis to this Agreement. The secretariat shall, in addition, exercise the functions assigned to it under this Agreement and by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

Article 18

1. The Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation established by Articles 9 and 10 of the Convention shall serve, respectively, as the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Agreement. The provisions of the Convention relating to the functioning of these two bodies shall apply mutatis mutandis to this Agreement. Sessions of the meetings of the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of this Agreement shall be held in conjunction with the meetings of, respectively, the Subsidiary Body for Scientific and Technological Advice and the Subsidiary Body for Implementation of the Convention.

2. Parties to the Convention that are not Parties to this Agreement may participate as observers in the proceedings of any session of the subsidiary bodies. When the subsidiary bodies serve as the subsidiary bodies of this Agreement, decisions under this Agreement shall be taken only by those that are Parties to this Agreement.

3. When the subsidiary bodies established by Articles 9 and 10 of the Convention exercise their functions with regard to matters concerning this Agreement, any member of the bureaux of those subsidiary bodies representing a Party to the Convention but, at that time, not a Party to this Agreement, shall be replaced by an additional member to be elected by and from amongst the Parties to this Agreement.

Article 19

1. Subsidiary bodies or other institutional arrangements established by or under the Convention, other than those referred to in this Agreement, shall serve this Agreement upon a decision of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement shall specify the functions to be exercised by such subsidiary bodies or arrangements.

2. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement may provide further guidance to such subsidiary bodies and institutional arrangements.

Article 20

1. This Agreement shall be open for signature and subject to ratification, acceptance or approval by States and regional economic integration organizations that are Parties to the Convention. It shall be open for signature at the United Nations Headquarters in New York from 22 April 2016 to 21 April 2017. Thereafter, this Agreement shall be open for accession from the day following the date on which it is closed for signature. Instruments of ratification, acceptance, approval or accession shall be deposited with the Depositary.

2. Any regional economic integration organization that becomes a Party to this Agreement without any of its member States being a Party shall be bound by all the obligations under this Agreement. In the case of regional economic integration organizations with one or more member States that are Parties to this Agreement, the organization and its member States shall decide on their respective responsibilities for the performance of their obligations under this Agreement. In such cases, the organization and the member States shall not be entitled to exercise rights under this Agreement concurrently.

3. In their instruments of ratification, acceptance, approval or accession, regional economic integration organizations shall declare the extent of their competence with respect to the matters governed by this Agreement. These organizations shall also inform the Depositary, who shall in turn inform the Parties, of any substantial modification in the extent of their competence.

Article 21

1. This Agreement shall enter into force on the thirtieth day after the date on which at least 55 Parties to the Convention accounting in total for at least an estimated 55 percent of the total global greenhouse gas emissions have deposited their instruments of ratification, acceptance, approval or accession.

2. Solely for the limited purpose of paragraph 1 of this Article, "total global greenhouse gas emissions" means the most up-to-date amount communicated on or before the date of adoption of this Agreement by the Parties to the Convention.

3. For each State or regional economic integration organization that ratifies, accepts or approves this Agreement or accedes thereto after the conditions set out in paragraph 1 of this Article for entry into force have been fulfilled,

this Agreement shall enter into force on the thirtieth day after the date of deposit by such State or regional economic integration organization of its instrument of ratification, acceptance, approval or accession.

4. For the purposes of paragraph 1 of this Article, any instrument deposited by a regional economic integration organization shall not be counted as additional to those deposited by its member States.

Article 22

The provisions of Article 15 of the Convention on the adoption of amendments to the Convention shall apply mutatis mutandis to this Agreement.

Article 23

1. The provisions of Article 16 of the Convention on the adoption and amendment of annexes to the Convention shall apply mutatis mutandis to this Agreement.

2. Annexes to this Agreement shall form an integral part thereof and, unless otherwise expressly provided for, a reference to this Agreement constitutes at the same time a reference to any annexes thereto. Such annexes shall be restricted to lists, forms and any other material of a descriptive nature that is of a scientific, technical, procedural or administrative character.

Article 24

The provisions of Article 14 of the Convention on settlement of disputes shall apply mutatis mutandis to this Agreement.

Article 25

1. Each Party shall have one vote, except as provided for paragraph 2 of this Article.

2. Regional economic integration organizations, in matters within their competence, shall exercise their right to vote with a number of votes equal to the number of their member States that are Parties to this Agreement. Such an organization shall not exercise its right to vote if any of its member States exercises its right, and vice versa.

Article 26

The Secretary-General of the United Nations shall be the Depositary of this Agreement.

Article 27

No reservations may be made to this Agreement.

Article 28

1. At any time after three years from the date on which this Agreement has entered into force for a Party, that Party may withdraw from this Agreement by giving written notification to the Depositary.

2. Any such withdrawal shall take effect upon expiry of one year from the date of receipt by the Depositary of the notification of withdrawal, or on such later date as may be specified in the notification of withdrawal.

3. Any Party that withdraws from the Convention shall be considered as also having withdrawn from this Agreement.

Article 29

The original of this Agreement, of which the Arabic, Chinese, English, French, Russian and Spanish texts are equally authentic, shall be deposited with the Secretary-General of the United Nations.

DONE at Paris this twelfth day of December two thousand and fifteen.

IN WITNESS WHEREOF, the undersigned, being duly authorized to that effect, have signed this Agreement.

Exhibit 7

The White House
Office of the Press Secretary

For Immediate Release October 05, 2016

Remarks by the President on the Paris Agreement

Rose Garden

EMAIL

**Please see below for a correction, marked with an asterisk.

3:30 P.M. EDT

THE PRESIDENT: Good afternoon, everybody. Today is a historic day in the fight to protect our planet for future generations.

Ten months ago, in Paris, I said before the world that we needed a strong global agreement to reduce carbon pollution and to set the world on a low-carbon course. The result was the Paris Agreement. Last month, the United States and China -- the world's two largest economies and largest emitters -- formally joined that agreement together. And today, the world has officially crossed the threshold for the Paris Agreement to take effect.

Today, the world meets the moment. And if we follow through on the commitments that this agreement embodies, history may well judge it as a turning point for our planet.

Of course, it took a long time to reach this day. One of the reasons I ran for this office was to make America a leader in this mission. And over the past eight years, we've done just that. In 2009, we salvaged a chaotic climate summit in Copenhagen, establishing the principle that all nations have a role to play in combating climate change. And at home, we led by example, with historic investments in growing industries like wind and solar that created a steady stream of new jobs. We set the first-ever nationwide standards to limit the amount of carbon pollution that power plants can dump into the air our children breathe. From the cars and trucks we drive to the homes and businesses in which we live and work, we've changed fundamentally the way we consume energy.

Now, keep in mind, the skeptics said these actions would kill jobs. And instead, we saw -- even as we were bringing down these carbon levels -- the longest streak of job creation in American history. We drove economic output to new highs. And we drove our carbon pollution to its lowest levels in two decades.

We continued to lead by example with our historic joint announcement with China two years ago, where we put forward even more ambitious climate targets. And that achievement encouraged dozens of other countries to set more ambitious climate targets of their own. And that, in turn, paved the way for our success in Paris -- the idea that no nation, not even one as powerful as ours, can solve this challenge alone. All of us have to solve it together.

Now, the Paris Agreement alone will not solve the climate crisis. Even if we meet every target embodied in the agreement, we'll only get to part of where we need to go. But make no mistake, this agreement will help delay or avoid some of the worst consequences of climate change. It will help other nations ratchet down their dangerous carbon emissions over time, and set bolder targets as technology advances, all under a strong system of transparency that allows each nation to evaluate the progress of all other nations. And by sending a signal that this is going to be our future -- a clean energy future -- it opens up the floodgates for businesses, and scientists, and engineers to unleash high-tech, low-carbon investment and innovation at a scale that we've never seen before. So this gives us the best possible shot to save the one planet we've got.

I know diplomacy *can be [isn't always] easy, and progress on the world stage can sometimes be slow. But together, with steady persistent effort, with strong, principled, American leadership, with optimism and faith and hope, we're proving that it is possible.

And I want to embarrass my Senior Advisor, Brian Deese -- who is standing right over there -- because he worked tirelessly to make this deal possible. He, and John Kerry, Gina McCarthy at the EPA, everybody on their teams have done an extraordinary job to get us to this point -- and America should be as proud of them as I am of them.

I also want to thank the people of every nation that has moved quickly to bring the Paris Agreement into force. I encourage folks who have not yet submitted their documentation to enter into this agreement to do so as soon as possible. And in the coming days, let's help finish additional agreements to limit aviation emissions, to phase down dangerous use of hydrofluorocarbons -- all of which will help build a world that is safer, and more prosperous, and more secure, and more free than the one that was left for us.

That's our most important mission, to make sure our kids and our grandkids have at least as beautiful a planet, and hopefully more beautiful, than the one that we have. And today, I'm a little more confident that we can get the job done.

So thank you very much, everybody.

END
3:35 P.M. EDT

Exhibit 8

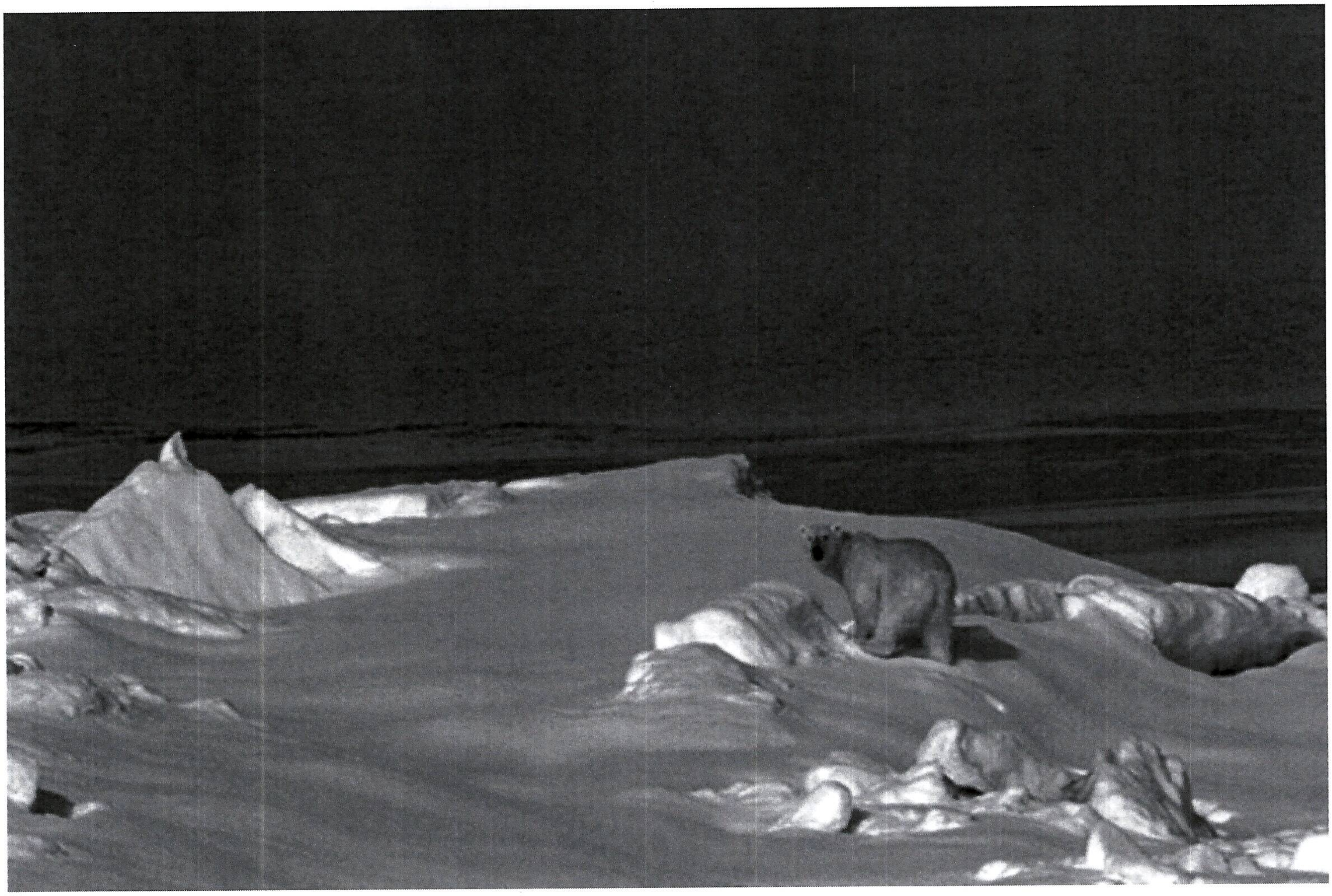
EARTHTALK

SUSTAINABILITY

Have We Passed the Point of No Return on Climate Change?

Greenhouse gas cuts must begin soon or it could be too late to halt global warming

By EarthTalk on April 13, 2015 23



If we don't get our carbon emissions in check soon, it could be too late for the polar bear and many other species impacted by global warming. *Credit: Gregory "Slobirdr" Smith, FlickrCC*

Dear EarthTalk: What is the best way to measure how close we are to the dreaded "point of no return" with climate change? In other words, when do we think we will have gone too far? — *David Johnston, via EarthTalk.org*

While we may not yet have reached the "point of no return"—when no amount of cutbacks on greenhouse gas emissions will save us from potentially catastrophic global warming—climate scientists warn we may be getting awfully close. Since the dawn of the Industrial Revolution a century ago, the average global temperature has risen some 1.6 degrees Fahrenheit. Most climatologists agree that, while the warming to date is already causing environmental problems, another 0.4 degree Fahrenheit rise in temperature, representing a global average atmospheric concentration of carbon dioxide (CO_2) of 450 parts per million (ppm), could set in motion unprecedented changes in global climate and a significant increase in the severity of natural disasters—and as such could represent the dreaded point of no return.

Currently the atmospheric concentration of CO_2 (the leading greenhouse gas) is approximately 398.55 parts per million (ppm). According to the National Oceanic and Atmospheric Administration (NOAA), the federal scientific agency tasked with monitoring the health of our oceans and atmosphere, the current average annual rate of increase of 1.92 ppm means we could reach the point of no return by 2042.

Environmental leaders point out that this doesn't give us much time to turn the tide. Greenpeace, a leading environmental advocacy group, says we have until around 2020 to significantly cut back on greenhouse gas output around the world—to the tune of a five percent annual reduction in emissions overall—if we are to avoid so-called "runaway" climate change. "The world is fast approaching a 'point of no return' beyond which extremely dangerous climate change impacts can become unavoidable," reports the group. "Within this time period, we will have to radically change our approach to energy production and consumption."

In a recent lecture at Georgetown University, World Bank president Jim Yong Kim reported that whether we are able to cut emissions enough to prevent catastrophe likely depends on the policies of the world's largest economies and the widespread adoption of so-called carbon pricing systems (such as emissions trading plans and carbon taxes). International negotiators meeting in Paris next December are already working to hammer out an agreement mandating that governments adopt these types of systems to facilitate emissions reductions. "A price on carbon is the single most important thing we have to get out of a Paris agreement," Kim stated. "It will unleash market forces."

While carbon pricing will be key to mitigating global warming, Greenpeace adds that stemming the tide of deforestation in the world's tropical rainforests and beyond and adapting our food systems to changing climatic conditions and increasingly limited resources will also be crucial to the health of the planet.

"Without additional mitigation, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally," reports the Intergovernmental Panel on Climate Change (IPCC), an international group of leading climate experts convened by the United Nations to review and assess the most recent scientific, technical and socioeconomic information on global warming. Indeed, there's no time like the present to start changing our ways.

CONTACTS: NOAA, www.noaa.gov; World Bank, www.worldbank.org; Greenpeace, www.greenpeace.org; IPCC, www.ipcc.ch.

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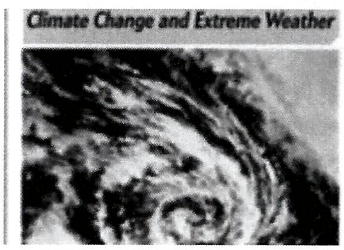

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Exhibit 9

RECENT MONTHLY MEAN CO_2 AT MAUNA LOA

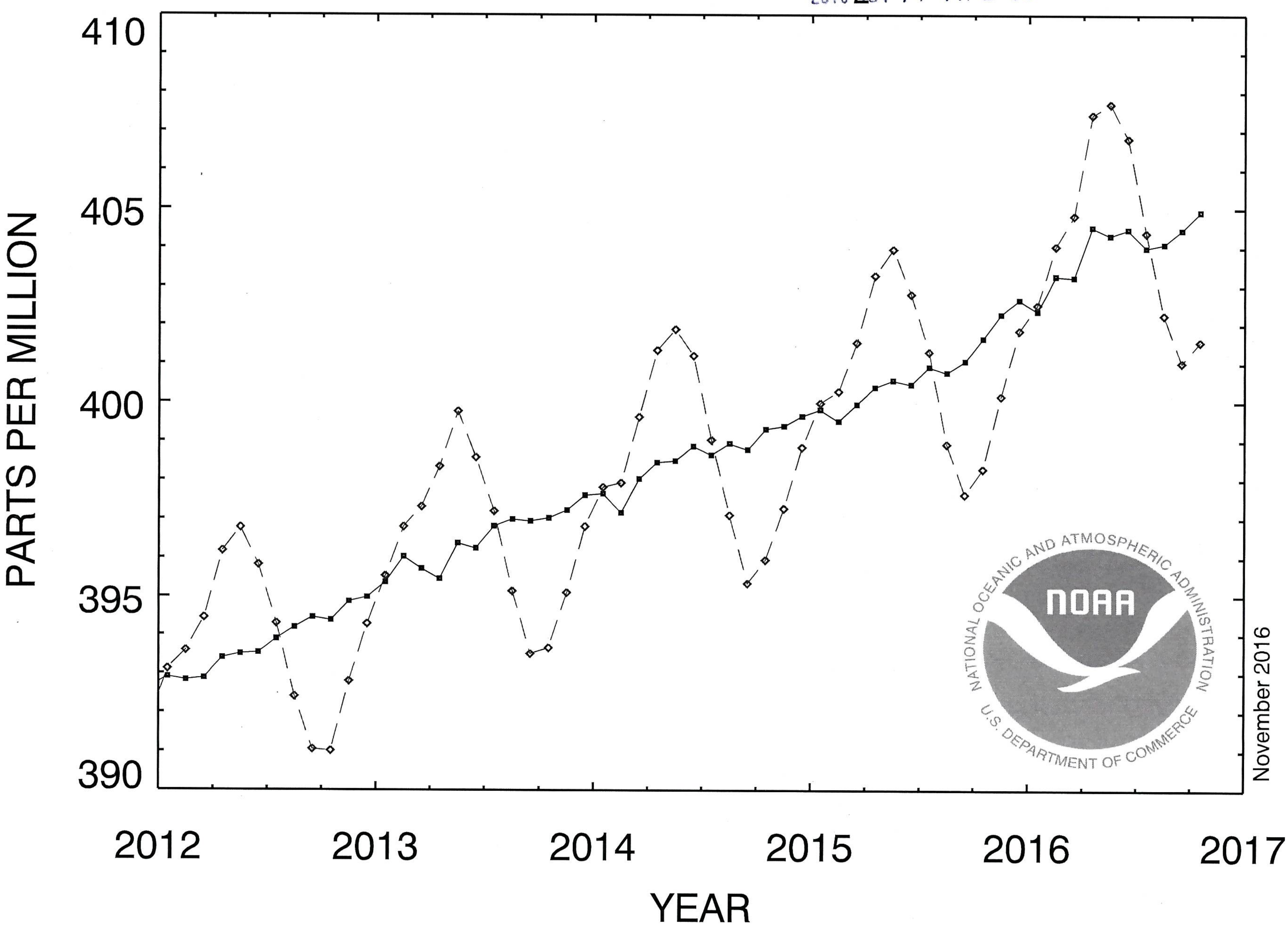


Exhibit 10

Global Analysis - August 2016

State of the Climate Reports | Summary Information | Monthly Climate Briefings | RSS Feed XML

Maps and Time Series

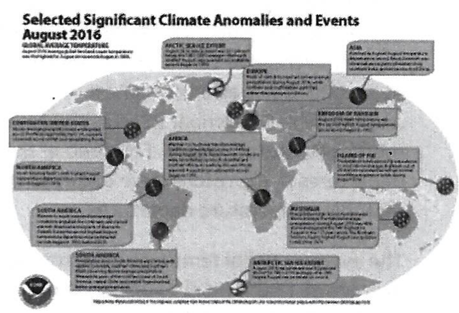
Temperature and Precipitation Maps

August 2016 | June - August 2016

Temperature Anomalies Time Series

August | June - August | Year-to-Date

Introduction | Temperatures | Precipitation | References



August 2016 Selected Climate Anomalies and Events Map

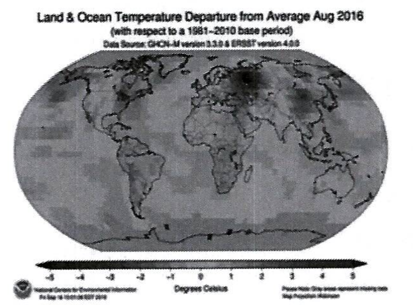
Introduction

Temperature anomalies and percentiles are shown on the gridded maps below. The anomaly map on the left is a product of a merged land surface temperature (Global Historical Climatology Network, GHCN) and sea surface temperature (ERSST.v4) anomaly analysis as described in Huang et al. (2016). Temperature anomalies for land and ocean are analyzed separately and then merged to form the global analysis. For more information, please visit NCEI's Global Surface Temperature Anomalies page. The percentile map on the right provides additional information by placing the temperature anomaly observed for a specific place and time period into historical perspective, showing how the most current month, season or year compares with the past.

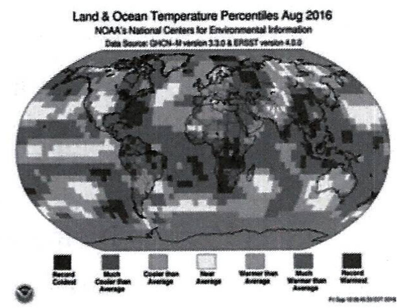
Supplemental August 2016 Information

In the atmosphere, 500-millibar height pressure anomalies correlate well with temperatures at the Earth's surface. The average position of the upper-level ridges of high pressure and troughs of low pressure—depicted by positive and negative 500-millibar height anomalies on the August 2016 and June–August 2016 maps—is generally reflected by areas of positive and negative temperature anomalies at the surface, respectively.

August



August 2016 Blended Land and Sea Surface Temperature Anomalies in degrees Celsius



August 2016 Blended Land and Sea Surface Temperature Percentiles

The combined average temperature over global land and ocean surfaces for August 2016 was the highest for August in the 137-year period of record, marking the 16th consecutive month of record warmth for the globe. The August 2016 temperature departure of 0.92°C (1.66°F) above the 20th century average of 15.6°C (60.1°F) surpassed the previous record set in 2015 by 0.05°C (0.09°F). August 2016 was also the highest monthly land and ocean temperature departure since April 2016 and tied with September 2015 as the eighth highest monthly temperature departure among all months (1,640) on record. Fourteen of the 15 highest monthly land and ocean temperature departures in the record have occurred since February 2015, with January 2007 among the 15 highest monthly temperature departures.

The average global temperature across land surfaces was 1.29°C (2.32°F) above the 20th century average of 13.8°C (56.9°F)—the highest August global land temperature on record, besting the previous record set in 2015 by 0.19°C (0.34°F). This was also the highest monthly global land temperature departure since April 2016.

Warmer- to much-warmer-than-average conditions were present across much of the world's land surface, with record warmth across the northeastern U.S., northern South America, central and southern Africa, and across parts of western Russia, southern India, China, Southeastern Asia and Indonesia, according to the Land & Ocean Temperature Percentiles map above. Near- to cooler-than-average conditions were observed across the central U.S., northern Mexico, Scandinavia, central and north-central Asia, and western Australia. No land areas experienced record cold temperatures during August 2016. According to NCEI's Global Regional analysis, five of the six continents had at least a top ten warm August, with Africa and Asia observing a record high average temperature for August since continental records began in 1910.

Select national information is highlighted below. Please note that different countries report anomalies with respect to different base periods. The information provided here is based directly upon these data:

- Spain had its fifth warmest August since 1961, with an average temperature of 25.2°C (77.4°F) or 1.3°C (2.3°F) above the 1981–2010 average.
- The Kingdom of Bahrain had its second highest mean August temperature since national records began in 1902, with a mean temperature of 36.4°C (97.5°F) or 2.4°C (4.3°F) above average. The nationally-averaged daytime (maximum) and nighttime (minimum) August temperatures were second highest and the highest on record, respectively, since 1946.
- The United Kingdom had a mean temperature of 15.5°C (59.9°F) during August 2016, which is

0.6°C (1.1°F) above the 1981–2010 average. This was the highest August temperature since 2013.

- According to El Centro Internacional para la Investigación del Fenómeno del Niño (CIIFEN), the average monthly temperature across much of South America was predominantly above normal, with temperature departures from average as high as 2.0°C (3.6°F) in eastern Brazil, western Argentina and on the border between Bolivia and Argentina.
- Ontario, Canada, experienced warmer-than-average temperatures during August 2016, with temperature departures ranging between 2°–3°C (3°–5°F).

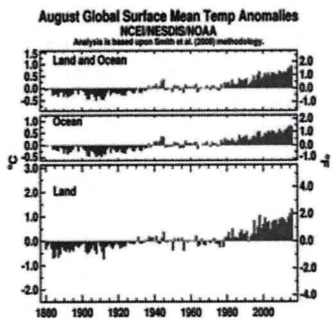
For the oceans, the August globally-averaged sea surface temperature was 0.77°C (1.39°F) above the 20th century average of 16.4°C (61.4°F), the second highest for August on record, behind 2015 by 0.02°C (0.04°F). August 2016 tied with June 2016 as the 11th highest temperature departure from average among all 1,640 months in the record.

Most of the world's oceans experienced warmer- to much-warmer-than-average temperatures during August 2016, with record warmth present across the northwestern Atlantic Ocean (along the U.S. East coast), the central southern Atlantic Ocean, and across parts of western Indian Ocean and the western and southeastern Pacific Ocean. Cooler-than-average conditions were limited to small areas across the north, central, and southern Pacific Ocean, the southern Atlantic Ocean (southeastern of Argentina), and southeastern Indian Ocean (off the southwestern coast of Australia).

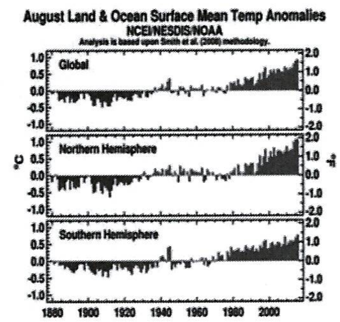
ENSO neutral conditions prevailed during August 2016 even though sea surface temperatures were below-average across the eastern tropical Pacific Ocean. According to NOAA's Climate Prediction Center, ENSO neutral (neither El Niño nor La Niña) is slightly favored, with a 55–60 percent chance, to continue during late Northern Hemisphere fall and winter 2016. This forecast focuses on the ocean surface temperatures between 5°N and 5°S latitude and 170°W to 120°W longitude, called the Niño 3.4 region.

AUGUST	ANOMALY		RANK (OUT OF 137 YEARS)		RECORDS		
	°C	°F			YEAR(S)	°C	°F
Global							
Land	+1.29 ± 0.22	+2.32 ± 0.40	Warmest	1st	2016	+1.29	+2.32
			Coolest	137th	1911	-0.43	-0.77
Ocean	+0.77 ± 0.14	+1.39 ± 0.25	Warmest	2nd	2015	+0.79	+1.42
			Coolest	136th	1907	-0.33	-0.59
Land and Ocean	+0.92 ± 0.16	+1.66 ± 0.29	Warmest	1st	2016	+0.92	+1.66
			Coolest	137th	1887, 1890, 1893, 1913	-0.33	-0.59
Northern Hemisphere							
Land	+1.28 ± 0.21	+2.30 ± 0.38	Warmest	1st	2016	+1.28	+2.30
			Coolest	137th	1875	-0.43	-0.77
Ocean	+0.92 ± 0.13	+1.66 ± 0.23	Warmest	3rd	2015	+1.03	+1.85
			Coolest	135th	1890, 1910	-0.44	-0.79
Land and Ocean	+1.06 ± 0.17	+1.91 ± 0.31	Warmest	1st	2016	+1.06	+1.91
			Coolest	137th	1890	-0.40	-0.72
Southern Hemisphere							
Land	+1.33 ± 0.17	+2.39 ± 0.31	Warmest	2nd	2009	+1.43	+2.57

			Coolest	136th	1924	-0.54	-0.97
Ocean	+0.66 ± 0.15	+1.19 ± 0.27	Warmest	1st	2016	+0.66	+1.19
			Coolest	137th	1909	-0.33	-0.59
Land and Ocean	+0.77 ± 0.14	+1.39 ± 0.25	Warmest	1st	2016	+0.77	+1.39
			Coolest	137th	1902, 1923	-0.31	-0.56



August Global Land and Ocean plot



August Global Hemisphere plot

The most current data can be accessed via the Global Surface Temperature Anomalies page.

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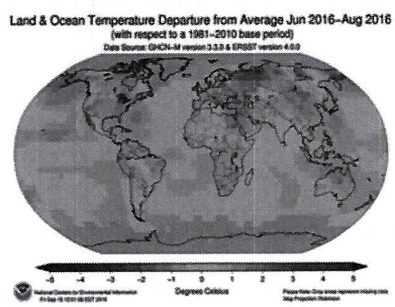
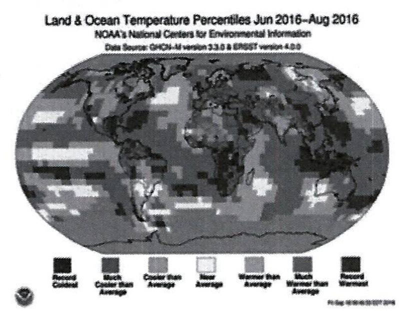
Seasonal (June–August)



June–August 2016 Blended Land and Sea Surface Temperature Anomalies in degrees Celsius



June–August 2016 Blended Land and Sea Surface Temperature Percentiles

The June–August seasonal global land and ocean temperature was 0.89°C (1.60°F) above the 20th century average of 15.6°C (60.1°F)—the highest temperature departure from average for June–August in the 1880–2016 record, surpassing the previous record set in 2015 by 0.04°C (0.07°F). June–August 2016 also marks the tenth highest three-month departure for any three-month period on record. The 10 highest three-month temperature departures in the record have all occurred since August–October 2015, when a strong El Niño episode was in place in the tropical Pacific Ocean.

The globally-averaged temperature across land surfaces for June–August was also the highest on record for June–August, at 1.21°C (2.18°F) above the 20th century average of 13.8°C (56.9°F). This surpasses the previous record set in 2015 by 0.11°C (0.20°F). Across the world's oceans, the June–August average sea surface temperature was 0.77°C (1.39°F) above the 20th century average of 16.4°C (61.5°F)—the highest for June–August on record, besting the previous record set in 2015 by only 0.01°C (0.02°F). This was also the tenth highest three-month ocean temperature departure from average for any three-month period on record. The ten highest three-month departures from average in the record have occurred since July–September 2015, when a strong El Niño episode was in place in the tropical Pacific Ocean.

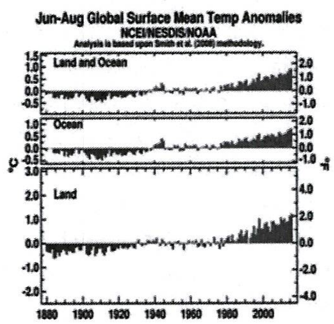
The three-month period was characterized by warmer- to much-warmer-than-average temperatures across much of the global land and ocean surfaces. Record warmth was scattered across parts of western and southern Atlantic Ocean, the Gulf of Mexico, western Alaska, northern South America, central and southern Africa, the Middle East, northwestern and Far East Russia, China, Indonesia, New Zealand and the oceans surrounding New Zealand. Meanwhile, very limited land and ocean areas experienced cooler-than-average conditions, including northeastern Russia and the southern Oceans. No land areas observed record cold temperatures for the June–August period, however, the only ocean area with record cold temperatures was east of the Drake Passage off the southern tip of South America. According to NCEI's Global Regional analysis, all six continents had at least a top seven warm June–August period, with Africa and Asia observing a record high average temperature for June–August and North America having its second warmest June–August period since continental records began in 1910.

Select national information is highlighted below. (Please note that different countries report anomalies with respect to different base periods. The information provided here is based directly upon these data):

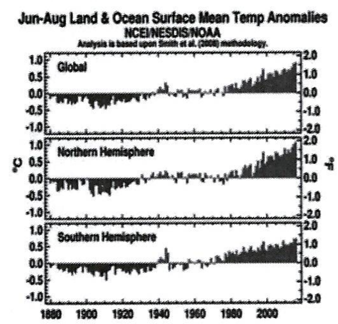
- Australia's mean temperature during June–August 2016 (Southern Hemisphere winter) was 0.91°C (1.64°F) above the 1961–1990 average—tying as the sixth highest June–August period. The region with the highest temperature departure was the Northern Territory with a temperature departure for the three-month period of 1.34°C (2.41°F) above average and the eighth highest since records began in 1910. Queensland, New South Wales, and Tasmania had a top ten June–August period. Nighttime (minimum) temperatures were unusually warm, resulting in the nation experiencing its fourth warmest June–August minimum temperature at 1.49°C (2.68°F) above average. All regions, with the exception of South Australia, had a top seven warm minimum temperature for the three-month period, with New South Wales tying 1973 as the highest minimum temperature on record.
- The United Kingdom had its warmest summer since 2013, with an average temperature for June–August 2016 of 14.9°C (58.8°F) or 0.6°C (1.1°F) above the 1981–2010 average.
- Most of Ireland experienced above average June–August conditions, with temperature departures ranging between -0.4°C (-0.7°F) to 1°C (1.8°F). The Dublin Airport had its warmest summer since 2006 with a temperature of 15.1°C (59.2°F) or 0.4°C (0.7°F) above average.

JUNE–AUGUST	ANOMALY		RANK (OUT OF 137 YEARS)		RECORDS		
	°C	°F			YEAR(S)	°C	°F
Global							
Land	+1.21 ± 0.18	+2.18 ± 0.32	Warmest	1st	2016	+1.21	+2.18
			Coolest	137th	1908	-0.42	-0.76
Ocean	+0.77 ± 0.15	+1.39 ± 0.27	Warmest	1st	2016	+0.77	+1.39
			Coolest	137th	1907, 1916	-0.31	-0.56
Land and Ocean	+0.89 ± 0.16	+1.60 ± 0.29	Warmest	1st	2016	+0.89	+1.60
			Coolest	137th	1892	-0.33	-0.59
Northern Hemisphere							
Land	+1.26 ± 0.17	+2.27 ± 0.31	Warmest	1st	2016	+1.26	+2.27
			Coolest	137th	1895	-0.41	-0.74
Ocean	+0.92 ± 0.14	+1.66 ± 0.25	Warmest	2nd	2015	+0.93	+1.67
			Coolest	136th	1890, 1912	-0.36	-0.65

Land and Ocean	+1.05 ± 0.17	+1.89 ± 0.31	Warmest	1st	2016	+1.05	+1.89
			Coolest	137th	1884	-0.37	-0.67
Southern Hemisphere							
Land	+1.06 ± 0.15	+1.91 ± 0.27	Warmest	2nd	2015	+1.14	+2.05
			Coolest	136th	1925	-0.51	-0.92
Ocean	+0.67 ± 0.16	+1.21 ± 0.29	Warmest	1st	2016	+0.67	+1.21
			Coolest	137th	1903, 1910, 1916	-0.30	-0.54
Land and Ocean	+0.73 ± 0.15	+1.31 ± 0.27	Warmest	1st	2016	+0.73	+1.31
			Coolest	137th	1922	-0.30	-0.54



June–August Global Land and Ocean plot



June–August Global Hemisphere plot

The most current data can be accessed via the Global Surface Temperature Anomalies page.

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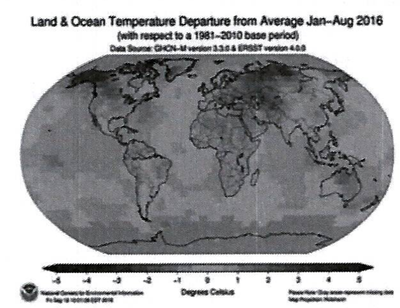
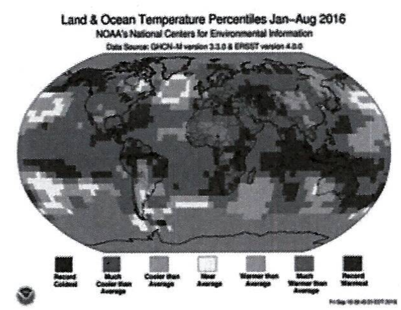
Year-to-date (January–August)



January–August 2016 Blended Land and Sea Surface Temperature Anomalies in degrees Celsius



January–August 2016 Blended Land and Sea Surface Temperature Percentiles

The first eight months of the year were characterized by much-warmer-than-average conditions across much of the globe's surface, resulting in the highest January–August period on record at 1.01°C (1.82°F) above the 20th century average of 14.0°C (57.3°F). This value exceeded the previous record set in 2015 by 0.16°C (0.29°F).

Much-warmer-than-average conditions engulfed the vast majority of the world's land surfaces, resulting in a record warm January–August period at 1.62°C (2.92°F) above the 20th century average of 9.0°C (48.1°F), besting the previous record set in 2015 by 0.33°C (0.59°F). Record warmth during the first eight months was present across Alaska, western Canada, northern South America, central and southern Africa, southern Europe, Indonesia, and across parts of Central America, the Caribbean, northern and central Asia and Australia. According to NCEI's Global Regional analysis, all six continents had at least a top three warm January–August period, with North America, Asia, and Oceania experiencing a record high average temperature for January–August since continental records began in 1910. No land areas experienced cooler-than-average conditions during January–August 2016.

Select national information is highlighted below. (Please note that different countries report anomalies with respect to different base periods. The information provided here is based directly upon these data):

- The January–August 2016 average temperature for New Zealand was the highest such period since national temperature records began in 1909, at 1.1°C (2.0°C) above the 1981–2010 average.

The average global sea surface temperature for the year-to-date was the highest for January–August in the 137-year period of record, at 0.79°C (1.42°F) above average, surpassing the previous record set in 2015 by 0.11°C (0.20°F). Record warm sea surface temperature during January–August 2016 was present across much of the Indian Ocean and Southwest Pacific Ocean, with scattered areas across the Atlantic Ocean and the tropical Pacific Ocean. The only ocean area with record cold temperatures was east of the Drake Passage off the southern tip of South America

JANUARY–AUGUST	ANOMALY		RANK (OUT OF 137 YEARS)		RECORDS		
	°C	°F			YEAR(S)	°C	°F
Global							
Land	+1.62 ± 0.16	+2.92 ± 0.29	Warmest	1st	2016	+1.62	+2.92
			Coolest	137th	1888	-0.57	-1.03
Ocean	+0.79 ± 0.18	+1.42 ± 0.32	Warmest	1st	2016	+0.79	+1.42
			Coolest	137th	1890, 1894, 1929	-0.28	-0.50
Land and Ocean	+1.01 ± 0.17	+1.82 ± 0.31	Warmest	1st	2016	+1.01	+1.82
			Coolest	137th	1905, 1910, 1917	-0.35	-0.63
Northern Hemisphere							
Land	+1.78 ± 0.18	+3.20 ± 0.32	Warmest	1st	2016	+1.78	+3.20
			Coolest	137th	1886, 1888	-0.61	-1.10
Ocean	+0.87 ± 0.17	+1.57 ± 0.31	Warmest	1st	2016	+0.87	+1.57
			Coolest	137th	1903	-0.30	-0.54
Land and Ocean	+1.22 ± 0.18	+2.20 ± 0.32	Warmest	1st	2016	+1.22	+2.20
			Coolest	137th	1895	-0.38	-0.68
Southern Hemisphere							
Land	+1.20 ± 0.15	+2.16 ± 0.27	Warmest	1st	2016	+1.20	+2.16
			Coolest	137th	1909	-0.53	-0.95
Ocean	+0.73 ± 0.18	+1.31 ± 0.32	Warmest	1st	2016	+0.73	+1.31
			Coolest	137th	1890, 1921, 1928	-0.27	-0.49
Land and Ocean	+0.81 ± 0.17	+1.46 ± 0.31	Warmest	1st	2016	+0.81	+1.46
			Coolest	137th	1890, 1898, 1917, 1925	-0.29	-0.52

The most current data can be accessed via the Global Surface Temperature Anomalies page.

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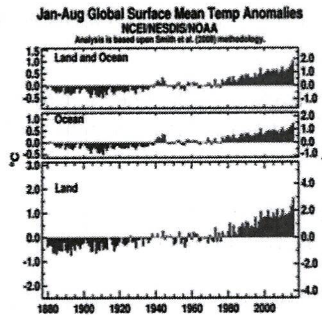
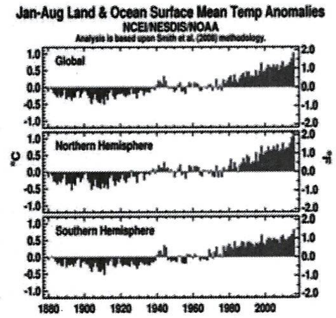


January–August Global Land and Ocean plot



January–August Global Hemisphere plot

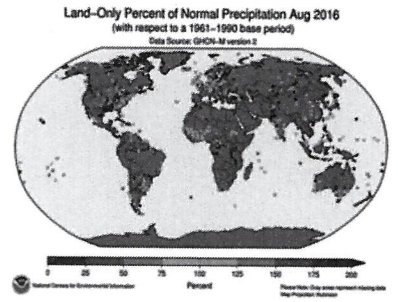
Precipitation

August

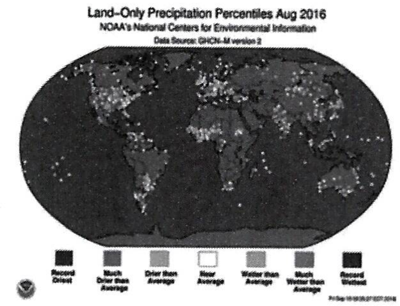
The maps below represent precipitation percent of normal (left, using a base period of 1961–1990) and precipitation percentiles (right, using the period of record) based on the GHCN dataset of land surface stations. As is typical, precipitation anomalies during August 2016 varied significantly around the world. August precipitation generally was drier than normal across parts of the western contiguous U.S., northern, northeastern and southern South America, central Europe, southern Africa, and central, eastern and southern Asia. Wetter than normal conditions were present across the contiguous U.S. Midwest and Lower Mississippi Valley, northern Mexico, southern Brazil, southern Argentina, the Scandinavia region, western Africa, northern Russia, northern Japan, northwestern India, and across parts of Australia.

Select national information is highlighted below. (Please note that different countries report anomalies with respect to different base periods. The information provided here is based directly upon these data):

- According to El Centro Internacional para la Investigación del Fenómeno del Niño (CIIFEN), precipitation was above normal in eastern Colombia and southern Chile, with 30–40% above-average precipitation. A stretch from the northeastern region of Bolivia to south-central Brazil received as much as 150% above-average precipitation. In contrast, Venezuela, central Chile, and central Argentina had rainfall deficits during the month.
- Drier-than-average conditions were present across much of Ireland during August 2016, with the exception of several stations across parts of the West, Southwest, and East that had near- to above-average precipitation. Belmullet, Co Mayo had its driest August in a decade at 55% of average, meanwhile Shannon Airport, Co Clare had its wettest August in seven years.
- Precipitation totals across the Island of Fiji were above- to much-above-average. According to Fiji's Meteorological Service, 18 out of 26 stations recorded twice their normal monthly precipitation total during August 2016, with five stations receiving triple the amount and four stations receiving as much as four times their monthly normal. The much needed precipitation helped provide relief from the dry conditions that plagued the region in the past months. The much-above-average amounts of precipitation received in several stations were not enough to set new rainfall records.



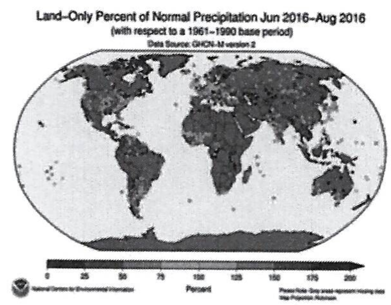
August 2016 Land-Only Precipitation Percent of Normal



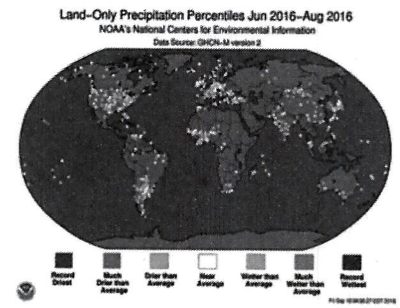
August 2016 Land-Only Precipitation Percentiles

Seasonal (June–August)

As is typical, precipitation anomalies during June–August 2016 varied significantly around the world. During June–August 2016, above-average precipitation was observed across much of the contiguous U.S. Midwest and Lower Mississippi Valley, Alaska, British Isles, central Europe, northern Argentina, Asia, and across Australia. Drier-than-average conditions were present across the western contiguous U.S., northern, northeastern, and southern South America, western Europe, and central Asia.



June – August 2016 Land-Only Precipitation Percent of Normal



June – August 2016 Land-Only Precipitation Percentiles

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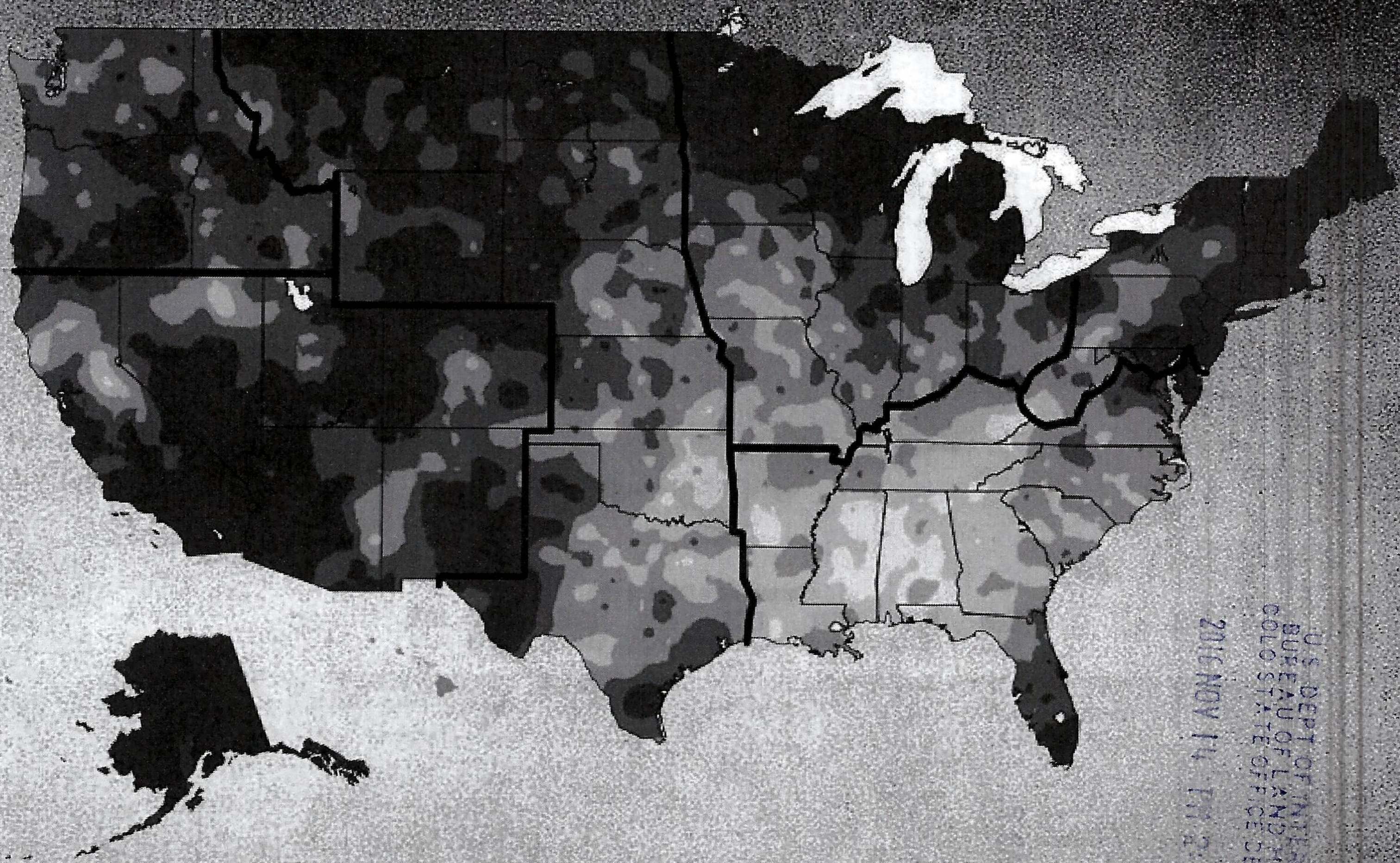
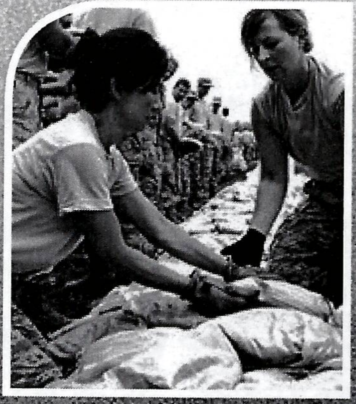
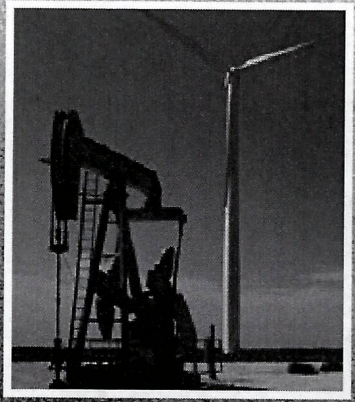
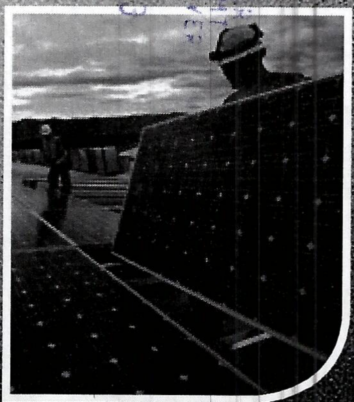
Exhibit 11

Climate Change Impacts in the United States







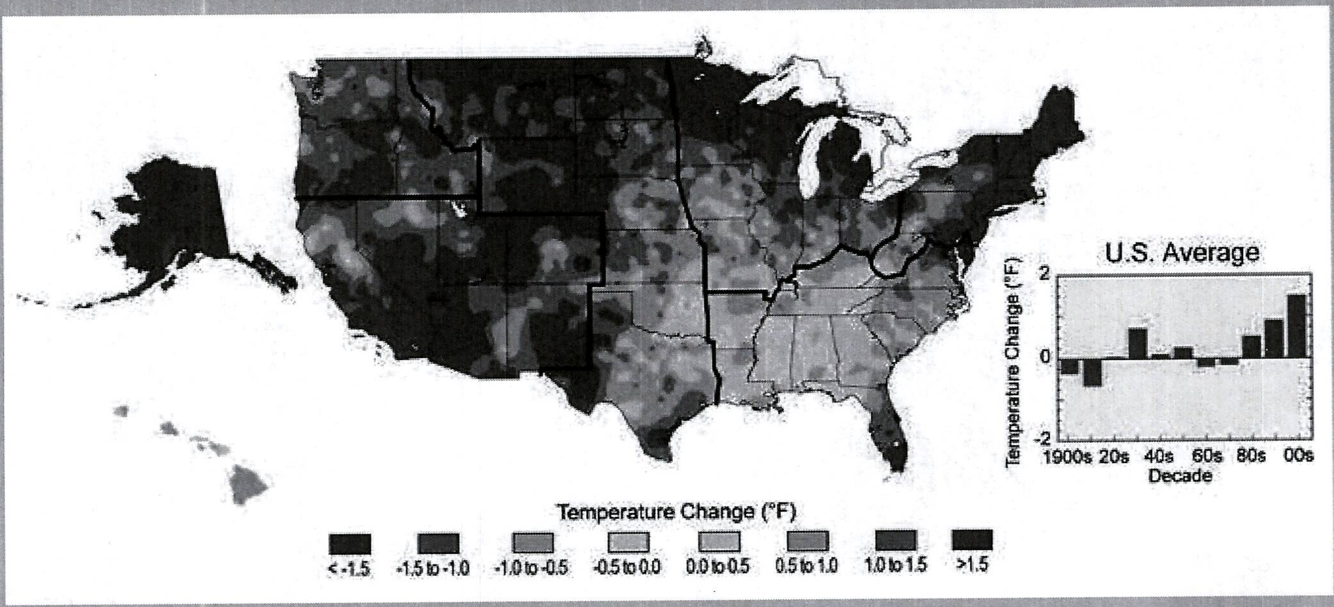


U.S. National Climate Assessment

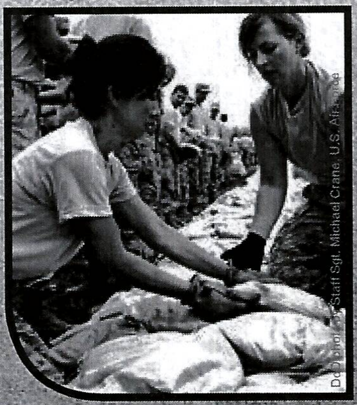
U.S. Global Change Research Program

Climate Change Impacts in the United States

Observed U.S. Temperature Change



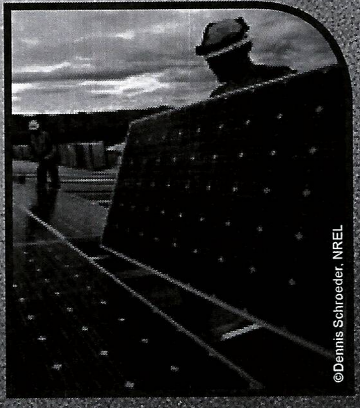
The colors on the map show temperature changes over the past 22 years (1991-2012) compared to the 1901-1960 average for the contiguous U.S., and to the 1951-1980 average for Alaska and Hawaii. The bars on the graph show the average temperature changes for the U.S. by decade for 1901-2012 (relative to the 1901-1960 average). The far right bar (2000s decade) includes 2011 and 2012. The period from 2001 to 2012 was warmer than any previous decade in every region. (Figure source: NOAA NCDC / CICS-NC).



Members of the National Guard lay sandbags to protect against Missouri River flooding.

Energy choices will affect the amount of future climate change.

Climate change is contributing to an increase in wildfires across the U.S. West.



Solar power use is increasing and is part of the solution to climate change.

Online at:
nca2014.globalchange.gov

First published May 2014. PDF revised October 2014. See errata (available at http://nca2014.globalchange.gov/downloads) for details.

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May 2014

Members of Congress:

On behalf of the National Science and Technology Council and the U.S. Global Change Research Program, we are pleased to transmit the report of the Third National Climate Assessment: *Climate Change Impacts in the United States*. As required by the Global Change Research Act of 1990, this report has collected, evaluated, and integrated observations and research on climate change in the United States. It focuses both on changes that are happening now and further changes that we can expect to see throughout this century.

This report is the result of a three-year analytical effort by a team of over 300 experts, overseen by a broadly constituted Federal Advisory Committee of 60 members. It was developed from information and analyses gathered in over 70 workshops and listening sessions held across the country. It was subjected to extensive review by the public and by scientific experts in and out of government, including a special panel of the National Research Council of the National Academy of Sciences. This process of unprecedented rigor and transparency was undertaken so that the findings of the National Climate Assessment would rest on the firmest possible base of expert judgment.

We gratefully acknowledge the authors, reviewers, and staff who have helped prepare this Third National Climate Assessment. Their work in assessing the rapid advances in our knowledge of climate science over the past several years has been outstanding. Their findings and key messages not only describe the current state of that science but also the current and future impacts of climate change on major U.S. regions and key sectors of the U.S. economy. This information establishes a strong base that government at all levels of U.S. society can use in responding to the twin challenges of changing our policies to mitigate further climate change and preparing for the consequences of the climate changes that can no longer be avoided. It is also an important scientific resource to empower communities, businesses, citizens, and decision makers with information they need to prepare for and build resilience to the impacts of climate change.

When President Obama launched his Climate Action Plan last year, he made clear that the essential information contained in this report would be used by the Executive Branch to underpin future policies and decisions to better understand and manage the risks of climate change. We strongly and respectfully urge others to do the same.

Sincerely,

Dr. John P. Holdren
Assistant to the President for Science and Technology
Director, Office of Science and Technology Policy
Executive Office of the President

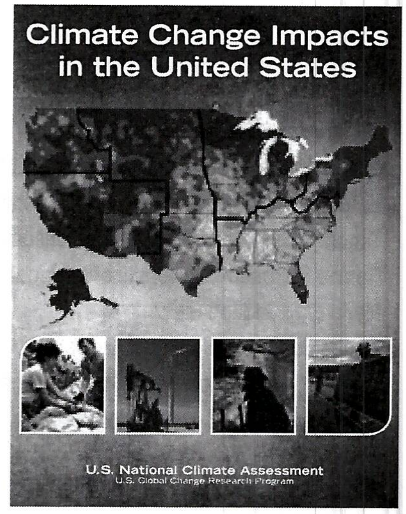
Dr. Kathryn D. Sullivan
Under Secretary for Oceans and Atmosphere
NOAA Administrator
U.S. Department of Commerce

About the NATIONAL CLIMATE ASSESSMENT

The National Climate Assessment assesses the science of climate change and its impacts across the United States, now and throughout this century. It documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision-making at all levels.

A team of more than 300 experts (see page 98), guided by a 60-member National Climate Assessment and Development Advisory Committee (listed on page vi) produced the full report – the largest and most diverse team to produce a U.S. climate assessment. Stakeholders involved in the development of the assessment included decision-makers from the public and private sectors, resource and environmental managers, researchers, representatives from businesses and non-governmental organizations, and the general public. More than 70 workshops and listening sessions were held, and thousands of public and expert comments on the draft report provided additional input to the process.

The assessment draws from a large body of scientific peer-reviewed research, technical input reports, and other publicly available sources; all sources meet the standards of the Information Quality Act. The report was extensively reviewed by the public and experts, including a panel of the National Academy of Sciences, the 13 Federal agencies of the U.S. Global Change Research Program, and the Federal Committee on Environment, Natural Resources, and Sustainability.



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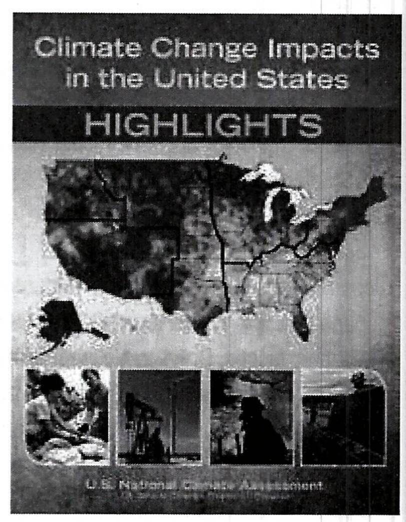
About the HIGHLIGHTS

The *Highlights* presents the major findings and selected highlights from *Climate Change Impacts in the United States*, the third National Climate Assessment.

The *Highlights* report is organized around the National Climate Assessment's 12 Report Findings, which take an overarching view of the entire report and its 30 chapters. All material in the *Highlights* report is drawn from the full report. The Key Messages from each of the 30 report chapters appear in boxes throughout this document.

A 20-page *Overview* booklet is available online.



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David Easterling, NCA Technical Support Unit Director, NOAA NCDC

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David Easterling, NCA Technical Support Unit Director, NOAA National Climatic Data Center (from March 2013)

Anne Waple, NCA Technical Support Unit Director, NOAA NCDC / UCAR (through February 2013)

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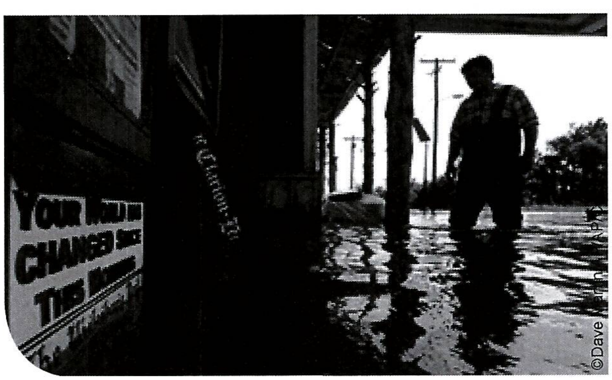
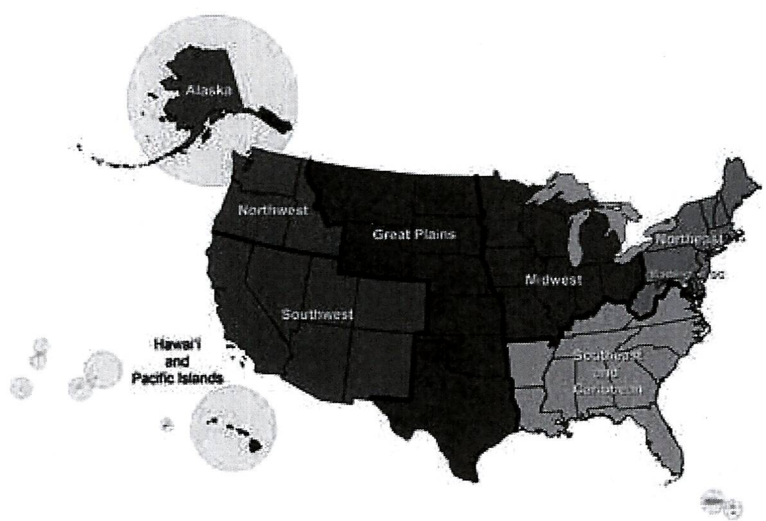




Alaska
Northwest
Great Plains
Midwest
Southwest
Hawai'i and Pacific Islands

CLIMATE CHANGE AND THE AMERICAN PEOPLE

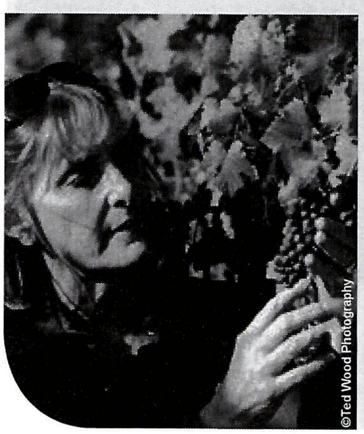
Climate change, once considered an issue for a distant future, has moved firmly into the present. Corn producers in Iowa, oyster growers in Washington State, and maple syrup producers in Vermont are all observing climate-related changes that are outside of recent experience. So, too, are coastal planners in Florida, water managers in the arid Southwest, city dwellers from Phoenix to New York, and Native Peoples on tribal lands from Louisiana to Alaska. This National Climate Assessment concludes that the evidence of human-induced climate change continues to strengthen and that impacts are increasing across the country.

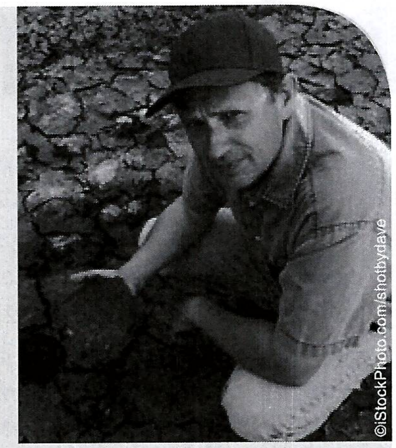
Americans are noticing changes all around them. Summers are longer and hotter, and extended periods of unusual heat last longer than any living American has ever experienced. Winters are generally shorter and warmer. Rain comes in heavier downpours. People are seeing changes in the length and severity of seasonal allergies, the plant varieties that thrive in their gardens, and the kinds of birds they see in any particular month in their neighborhoods.

Other changes are even more dramatic. Residents of some coastal cities see their streets flood more regularly during storms and high tides. Inland cities near large rivers also experience more flooding, especially in the Midwest and Northeast. Insurance rates are rising in some vulnerable locations, and insurance is no longer available in others. Hotter and drier weather and earlier snowmelt mean that wildfires in the West start earlier in the spring, last later into the fall, and burn more acreage. In Arctic Alaska, the summer sea ice that once protected the coasts has receded, and autumn storms now cause more erosion, threatening many communities with relocation.

Scientists who study climate change confirm that these observations are consistent with significant changes in Earth's climatic trends. Long-term, independent records from weather stations, satellites, ocean buoys, tide gauges, and many other data sources all confirm that our nation, like the rest of the world, is warming. Precipitation patterns are changing, sea level is rising, the oceans are becoming more acidic, and the frequency and intensity of some extreme weather events are increasing. Many lines of independent evidence demonstrate that the rapid warming of the past half-century is due primarily to human activities.

The observed warming and other climatic changes are triggering wide-ranging impacts in every region of our country and throughout our economy. Some of these changes can be beneficial over the short run, such as a longer growing season in some regions and a longer shipping season on the Great Lakes. But many more are detrimental, largely because our society and its infrastructure were designed for the climate that we have had, not the rapidly changing climate we now have and can expect in the future. In addition, climate change does not occur in isolation. Rather, it is superimposed on other stresses, which combine to create new challenges.





This National Climate Assessment collects, integrates, and assesses observations and research from around the country, helping us to see what is actually happening and understand what it means for our lives, our livelihoods, and our future. This report includes analyses of impacts on seven sectors – human health, water, energy, transportation, agriculture, forests, and ecosystems – and the interactions among sectors at the national level. This report also assesses key impacts on all U.S. regions: Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawai'i and the Pacific Islands, as well as the country's coastal areas, oceans, and marine resources.

Over recent decades, climate science has advanced significantly. Increased scrutiny has led to increased certainty that we are now seeing impacts associated with human-induced climate change. With each passing year, the accumulating evidence further expands our understanding and extends the record of observed trends in temperature, precipitation, sea level, ice mass, and many other variables recorded by a variety of measuring systems and analyzed by independent research groups from around the world. It is notable that as these data records have grown longer and climate models have become more comprehensive, earlier predictions have largely been confirmed. The only real surprises have been that some changes, such as sea level rise and Arctic sea ice decline, have outpaced earlier projections.

What is new over the last decade is that we know with increasing certainty that climate change is happening now. While scientists continue to refine projections of the future, observations unequivocally show that climate is changing and that the warming of the past 50 years is primarily due to human-induced emissions of heat-trapping gases. These emissions come mainly from burning coal, oil, and gas, with additional contributions from forest clearing and some agricultural practices.

Global climate is projected to continue to change over this century and beyond, but there is still time to act to limit the amount of change and the extent of damaging impacts.

This report documents the changes already observed and those projected for the future. It is important that these findings and response options be shared broadly to inform citizens and communities across our nation. Climate change presents a major challenge for society. This report advances our understanding of that challenge and the need for the American people to prepare for and respond to its far-reaching implications.

ABOUT THIS REPORT

This report assesses the science of climate change and its impacts across the United States, now and throughout this century. It integrates findings of the U.S. Global Change Research Program (USGCRP)[a] with the results of research and observations from across the U.S. and around the world, including reports from the U.S. National Research Council. This report documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision-making at all levels.

REPORT REQUIREMENTS, PRODUCTION, AND APPROVAL

The Global Change Research Act[1] requires that, every four years, the USGCRP prepare and submit to the President and Congress an assessment of the effects of global change in the United States. As part of this assessment, more than 70 workshops were held involving a wide range of stakeholders who identified issues and information for inclusion (see Appendix 1: Process). A team of more than 300 experts was involved in writing this report. Authors were appointed by the National Climate Assessment and Development Advisory Committee (NCADAC),[b] the federal advisory committee assembled for the purpose of conducting this assessment. The report was extensively reviewed and revised based on comments from the public and experts, including a panel of the National Academy of Sciences. The report was reviewed and approved by the USGCRP agencies and the federal Committee on Environment, Natural Resources, and Sustainability (CENRS). This report meets all federal requirements associated with the Information Quality Act (see Appendix 2: IQA), including those pertaining to public comment and transparency.

REPORT SOURCES

The report draws from a large body of scientific, peer-reviewed research, as well as a number of other publicly available sources. Author teams carefully reviewed these sources to ensure a reliable assessment of the state of scientific understanding. Each source of information was determined to meet the four parts of the IQA Guidance provided to authors: 1) utility, 2) transparency and traceability, 3) objectivity, and 4) integrity and security (see Appendix 2: IQA). Report authors made use of technical input reports produced by federal agencies and other interested parties in response to a request for information by the NCADAC;[2] other peer-reviewed scientific assessments (including those of the Intergovernmental Panel on Climate Change); the U.S. National Climate Assessment's 2009 report titled Global Climate Change Impacts in the United States;[3] the National Academy of Science's America's Climate Choices reports;[4] a variety of regional climate impact assessments, conference proceedings, and government statistics (such as population census and energy usage); and observational data. Case studies were also provided as illustrations of climate impacts and adaptation programs.

[a]The USGCRP is made up of 13 Federal departments and agencies that carry out research and support the nation's response to global change The USGCRP is overseen by the Subcommittee on Global Change Research (SGCR) of the National Science and Technology Council's Committee on Environment, Natural Resources and Sustainability (CENRS), which in turn is overseen by the White House Office of Science and Technology Policy (OSTP). The agencies within USGCRP are: the Department of Agriculture, the Department of Commerce (NOAA), the Department of Defense, the Department of Energy, the Department of Health and Human Services, the Department of the Interior, the Department of State, the Department of Transportation, the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation, the Smithsonian Institution, and the U.S. Agency for International Development.

[b]The NCADAC is a federal advisory committee sponsored by the National Oceanic and Atmospheric Administration under the requirements of the Federal Advisory Committee Act.

A GUIDE TO THE REPORT

The report has eight major sections, outlined below:

- **Overview and Report Findings:** gives a high-level perspective on the full National Climate Assessment and sets out the report's 12 key findings. The Overview synthesizes and summarizes the ideas that the authors consider to be of greatest importance to the American people.
- **Our Changing Climate:** presents recent advances in climate change science, which includes discussions of extreme weather events, observed and projected changes in temperature and precipitation, and the uncertainties associated with these projections. Substantial additional material related to this chapter can be found in the Appendices.
- **Sectors:** focuses on climate change impacts for seven societal and environmental sectors: human health, water, energy, transportation, agriculture, forests, and ecosystems and biodiversity; six additional chapters consider the interactions among sectors (such as energy, water, and land use) in the context of a changing climate.
- **Regions:** assesses key impacts on U.S. regions – Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, and Hawai'i and the U.S. affiliated Pacific Islands – as well as coastal areas, oceans, and marine resources.
- **Responses:** assesses the current state of responses to climate change, including adaptation, mitigation, and decision support activities.
- **Research Needs:** highlights major gaps in science and research to improve future assessments. New research is called for in climate science in support of assessments, climate impacts in regions and sectors, and adaptation, mitigation, and decision support.
- **Sustained Assessment Process:** describes an initial vision for and components of an ongoing, long-term assessment process.
- **Appendices:** Appendix 1 describes key aspects of the report process, with a focus on engagement; Appendix 2 describes the guidelines used in meeting the terms of the Federal Information Quality Act; Appendix 3 supplements the chapter on Our Changing Climate with an extended treatment of selected science issues; Appendix 4 provides answers to Frequently Asked Questions about climate change; Appendix 5 describes scenarios and models used in this assessment; and Appendix 6 describes possible topics for consideration in future assessments.

OVERARCHING PERSPECTIVES

Four overarching perspectives, derived from decades of observations, analysis, and experience, have helped to shape this report: 1) climate change is happening in the context of other ongoing changes across the U.S. and the globe; 2) climate change impacts can either be amplified or reduced by societal decisions; 3) climate change related impacts, vulnerabilities, and opportunities in the U.S. are linked to impacts and changes outside the United States, and vice versa; and 4) climate change can lead to dramatic tipping points in natural and social systems. These overarching perspectives are briefly discussed below.

Global Change Context

Climate change is one of a number of global changes affecting society, the environment, and the economy; others include population growth, land-use change, air and water pollution, and rising consumption of resources by a growing and wealthier global population. This perspective has implications for assessments of climate change impacts and the design of research questions at the national, regional, and local scales. This assessment explores some of the consequences of interacting factors by focusing on sets of crosscutting issues in a series of six chapters: Energy, Water, and Land Use; Biogeochemical Cycles; Indigenous Peoples, Lands, and Resources; Urban Systems, Infrastructure, and Vulnerability; Land Use and Land Cover Change; and Rural Communities. The assessment also includes discussions of how climate change impacts cascade through different sectors such as water and energy, and affect and are affected by land-use decisions. These and other interconnections greatly stress society's capacity to respond to climate-related crises that occur simultaneously or in rapid sequence.

Societal Choices

Because environmental, cultural, and socioeconomic systems are tightly coupled, climate change impacts can either be amplified or reduced by cultural and socioeconomic decisions. In many arenas, it is clear that societal decisions have substantial influence on the vulnerability of valued resources to climate change. For example, rapid population growth and development in coastal areas tends to amplify climate change related impacts. Recognition of these couplings, together with recognition of multiple sources of vulnerability, helps identify what information decision-makers need as they manage risks.

International Context

Climate change is a global phenomenon; the causes and the impacts involve energy-use, economic, and risk-management decisions across the globe. Impacts, vulnerabilities, and opportunities in the U.S. are related in complex and interactive ways with changes outside the United States, and vice versa. In order for U.S. concerns related to climate change to be addressed comprehensively, the international context must be considered. Foreign assistance, health, environmental quality objectives, and economic interests are all affected by climate changes experienced in other parts of the world. Although there is significantly more work to be done in this area, this report identifies some initial implications of global and international trends that can be more fully investigated in future assessments.

Thresholds, Tipping Points, and Surprises

While some climate changes will occur slowly and relatively gradually, others could be rapid and dramatic, leading to unexpected breaking points in natural and social systems. Although they have potentially large impacts, these breaking points or tipping points are difficult to predict, as there are many uncertainties about future conditions. These uncertainties and potential surprises come from a number of sources, including insufficient data associated with low probability/high consequence events, models that are not yet able to represent all the interactions of multiple stresses, incomplete understanding of physical climate mechanisms related to tipping points, and a multitude of issues associated with human behavior, risk management, and decision-making. Improving our ability to anticipate thresholds and tipping points can be helpful in developing effective climate change mitigation and adaptation strategies (Ch. 2: Our Changing Climate; Ch. 29: Research Needs; and Appendices 3 and 4).

RISK MANAGEMENT FRAMEWORK

Authors were asked to consider the science and information needs of decision-makers facing climate change risks to infrastructure, natural ecosystems, resources, communities, and other things of societal value. They were also asked to consider opportunities that climate change might present. For each region and sector, they were asked to assess a small number of key climate-related vulnerabilities of concern based on the risk (considering likelihood and consequence) of impacts. They were also asked to address the most important information needs of stakeholders, and to consider the decisions stakeholders are facing. The criteria provided for identifying key vulnerabilities in each sector or region included magnitude, timing, persistence/reversibility, scale, and distribution of impacts, likelihood whenever possible, importance of impacts (based on the perceptions of relevant parties), and the potential for adaptation. Authors were encouraged to think about these topics from both a quantitative and qualitative perspective and to consider the influence of multiple stresses whenever possible.

RESPONDING TO CLIMATE CHANGE

While the primary focus of this report is on the impacts of climate change in the United States, it also documents some of the actions society is taking or can take to respond. Responses to climate change fall into two broad categories. The first involves "mitigation" measures to reduce future climate change by reducing emissions of heat-trapping gases and particles, or increasing removal of carbon dioxide from the atmosphere. The second involves "adaptation" measures to improve society's ability to cope with or avoid harmful impacts and take advantage of beneficial ones, now and in the future. At this point, both of these response activities are necessary to limit the magnitude and impacts of global climate change on the United States.

More effective mitigation measures can reduce the amount of climate change, and therefore reduce the need for future adaptation. This report underscores the effects of mitigation measures by comparing impacts resulting from higher versus lower emissions scenarios. This shows that choices made about emissions in the next few decades will have far-reaching consequences for climate change impacts throughout this century. Lower emissions will reduce the rate and lessen the magnitude of climate change and its impacts. Higher emissions will do the opposite.

While the report demonstrates the importance of mitigation as an essential part of the nation's climate change strategy, it does not evaluate mitigation technologies or policies or undertake an analysis of the effectiveness of various approaches. The range of mitigation responses being studied includes, but is not limited to, policies and technologies that lead to more efficient production and use of energy, increased use of non-carbon-emitting energy sources such as wind and solar power, and carbon capture and storage.

Adaptation actions are complementary to mitigation actions. They are focused on moderating harmful impacts of current and future climate variability and change and taking advantage of possible opportunities. While this report assesses the current state of adaptation actions and planning across the country in a general way, the implementation of adaptive actions is still nascent. A comprehensive assessment of actions taken, and of their effectiveness, is not yet possible. This report documents some of the actions currently being pursued to address impacts such as increased urban heat extremes and air pollution, and describes the challenges decision-makers face in planning for and implementing adaptation responses.

TRACEABLE ACCOUNTS: PROCESS AND CONFIDENCE

The "traceable accounts" that accompany each chapter: 1) document the process the authors used to reach the conclusions in their key messages; 2) provide additional information to reviewers and other readers about the quality of the information used; 3) allow traceability to resources; and 4) provide the level of confidence the authors have in the main findings of the chapters. The authors have assessed a wide range of information in the scientific literature and various technical reports. In assessing confidence, they have considered the strength and consistency of the observed evidence, the skill, range, and consistency of model projections, and insights from peer-reviewed sources.

When it is considered scientifically justified to report the likelihood of particular impacts within the range of possible outcomes, this report takes a plain-language approach to expressing the expert judgment of the author team based on the best available evidence. For example, an outcome termed "likely" has at least a two-thirds chance of occurring; an outcome termed "very likely" has more than a 90% chance. Key sources of information used to develop these characterizations are referenced.

1 OVERVIEW AND REPORT FINDINGS

Climate change is already affecting the American people in far-reaching ways. Certain types of extreme weather events with links to climate change have become more frequent and/or intense, including prolonged periods of heat, heavy downpours, and, in some regions, floods and droughts. In addition, warming is causing sea level to rise and glaciers and Arctic sea ice to melt, and oceans are becoming more acidic as they absorb carbon dioxide. These and other aspects of climate change are disrupting people's lives and damaging some sectors of our economy.

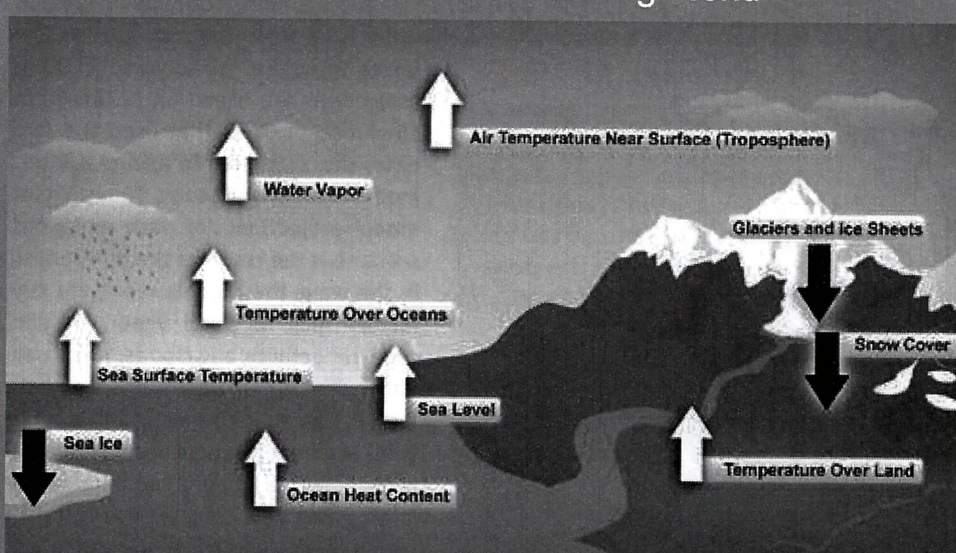
Coal-fired power plants emit heat-trapping carbon dioxide to the atmosphere.

Climate Change: Present and Future

Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans. Scientists and engineers from around the world have meticulously collected this evidence, using satellites and networks of weather balloons, thermometers, buoys, and other observing systems. Evidence of climate change is also visible in the observed and measured changes in location and behavior of species and functioning of ecosystems. Taken together, this evidence tells an unambiguous story: the planet is warming, and over the last half century, this warming has been driven primarily by human activity.

Multiple lines of independent evidence confirm that human activities are the primary cause of the global warming of the past 50 years. The burning of coal, oil, and gas, and clearing of forests have increased the concentration of carbon dioxide in the atmosphere by more than 40% since the Industrial Revolution, and it has been known for almost two centuries that this carbon dioxide traps heat. Methane and nitrous oxide emissions from agriculture and other human activities add to the atmospheric burden of heat-trapping gases. Data show that natural factors like the sun and volcanoes cannot have caused the warming observed over the past 50 years. Sensors on satellites have measured the sun's output with great accuracy and found no overall increase during the past half century. Large volcanic eruptions during this period, such as Mount Pinatubo in 1991, have exerted a short-term *cooling* influence. In fact, if not for human activities, global climate would actually have cooled slightly over the past 50 years. The pattern of temperature change through the layers of the atmosphere, with warming near the surface and cooling higher up in the stratosphere, further confirms that it is the buildup of heat-trapping gases (also known as "greenhouse gases") that has caused most of the Earth's warming over the past half century.

Ten Indicators of a Warming World

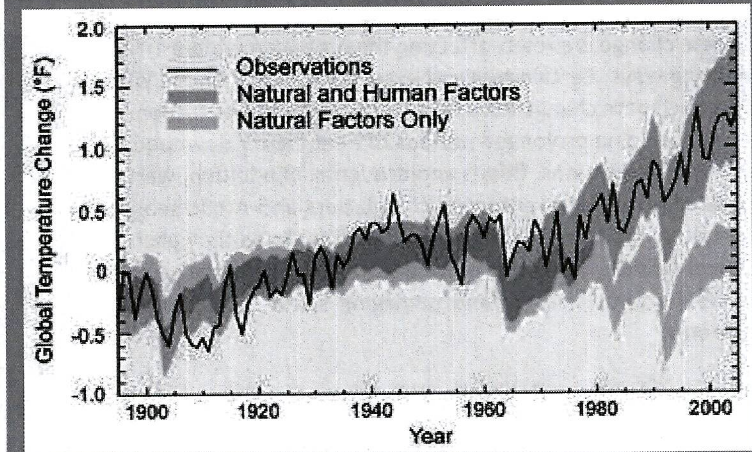


These are just some of the indicators measured globally over many decades that show that the Earth's climate is warming. White arrows indicate increasing trends; black arrows indicate decreasing trends. All the indicators expected to increase in a warming world are increasing, and all those expected to decrease in a warming world are decreasing. (Figure source: NOAA NCDC, based on data updated from Kennedy et al. 2010[3]).

Because human-induced warming is superimposed on a background of natural variations in climate, warming is not uniform over time. Short-term fluctuations in the long-term upward trend are thus natural and expected. For example, a recent slowing in the rate of surface air temperature rise appears to be related to cyclic changes in the oceans and in the sun's energy output, as well as a series of small volcanic eruptions and other factors. Nonetheless, global temperatures are still on the rise and are expected to rise further.

U.S. average temperature has increased by 1.3°F to 1.9°F since 1895, and most of this increase has occurred since 1970. The most recent decade was the nation's and the world's hottest on record, and 2012 was the hottest year on record in the continental United States. All U.S. regions have experienced warming in recent decades, but the extent of warming has not been uniform. In general, temperatures are rising more quickly in the north. Alaskans have experienced some of the largest increases in temperature between 1970 and the present. People living in the Southeast have experienced some of the smallest temperature increases over this period.

Separating Human and Natural Influences on Climate

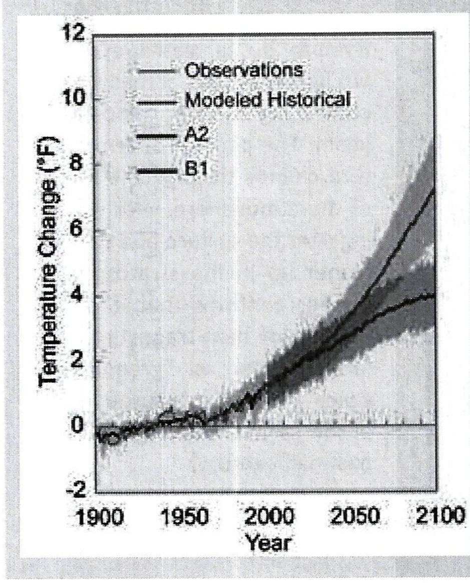


The green band shows how global average temperature would have changed over the last century due to natural forces alone, as simulated by climate models. The blue band shows model simulations of the effects of human and natural forces (including solar and volcanic activity) combined. The black line shows the actual observed global average temperatures. Only with the inclusion of human influences can models reproduce the observed temperature changes. (Figure source: adapted from Huber and Knutti 2012[b]).

Temperatures are projected to rise another 2°F to 4°F in most areas of the United States over the next few decades. Reductions in some short-lived human-induced emissions that contribute to warming, such as black carbon (soot) and methane, could reduce some of the projected warming over the next couple of decades, because, unlike carbon dioxide, these gases and particles have relatively short atmospheric lifetimes.

The amount of warming projected beyond the next few decades is directly linked to the cumulative global emissions of heat-trapping gases and particles. By the end of this century, a roughly 3°F to 5°F rise is projected under a lower emissions scenario, which would require substantial reductions in emissions (referred to as the "B1 scenario"), and a 5°F to 10°F rise for a higher emissions scenario assuming continued increases in emissions, predominantly from fossil fuel combustion (referred to as the "A2 scenario"). These projections are based on results from 16 climate models that used the two emissions scenarios in a formal inter-model comparison study. The range of model projections for each emissions scenario is the result of the differences in the ways the models represent key factors such as water vapor, ice and snow reflectivity, and clouds, which can either dampen or amplify the initial effect of human influences on temperature. The net effect of these feedbacks is expected to amplify warming. More information about the models and scenarios used in this report can be found in Appendix 5 of the full report.[1]

Projected Global Temperature Change



Different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature. The lines on the graph represent a central estimate of global average temperature rise (relative to the 1901-1960 average) for the two main scenarios used in this report. A2 assumes continued increases in emissions throughout this century, and B1 assumes significant emissions reductions, though not due explicitly to climate change policies. Shading indicates the range (5th to 95th percentile) of results from a suite of climate models. In both cases, temperatures are expected to rise, although the difference between lower and higher emissions pathways is substantial. (Figure source: NOAA NCDC / CICS-NC).

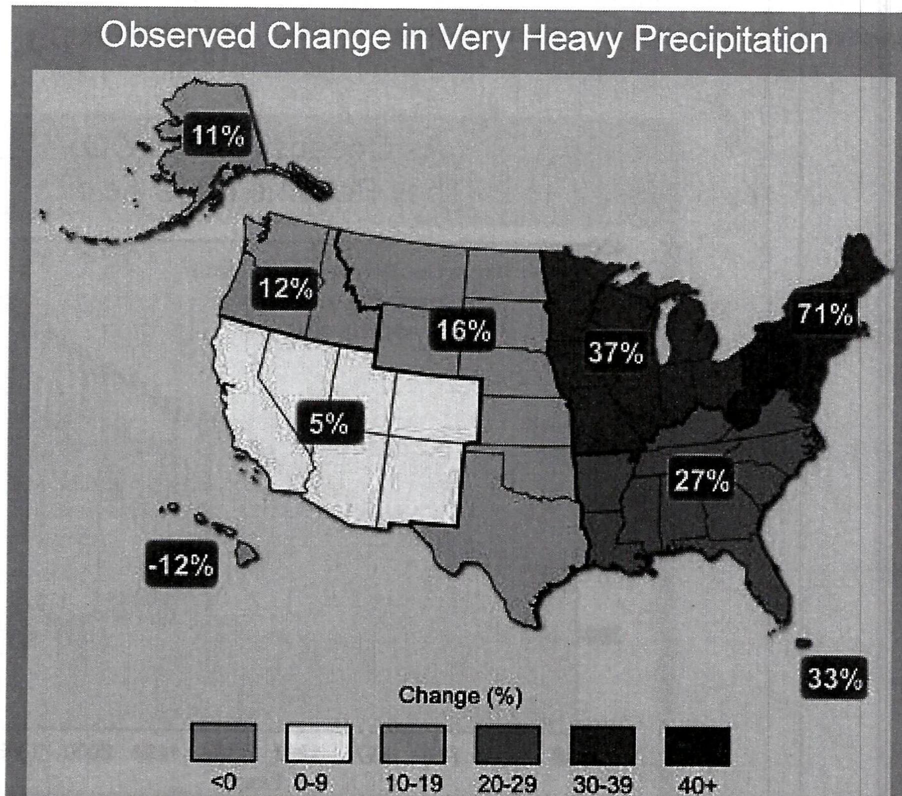
Prolonged periods of high temperatures and the persistence of high nighttime temperatures have increased in many locations (especially in urban areas) over the past half century. High nighttime temperatures have widespread impacts because people, livestock, and wildlife get no respite from the heat. In some regions, prolonged periods of high temperatures associated with droughts contribute to conditions that lead to larger wildfires and longer fire seasons. As expected in a warming climate, recent trends show that extreme heat is becoming more common, while extreme cold is becoming less common. Evidence indicates that the human influence on climate has already roughly doubled the probability of extreme heat events such as the record-breaking summer heat experienced in 2011 in Texas and Oklahoma. The incidence of record-breaking high temperatures is projected to rise.[2]

Human-induced climate change means much more than just hotter weather. Increases in ocean and freshwater temperatures, frost-free days, and heavy downpours have all been documented. Global sea level has risen, and there have been large reductions in snow-cover extent, glaciers, and sea ice. These changes and other climatic changes have affected and will continue to affect human health, water supply, agriculture, transportation, energy, coastal areas, and many other sectors of society, with increasingly adverse impacts on the American economy and quality of life.[3]

Some of the changes discussed in this report are common to many regions. For example, large increases in heavy precipitation have occurred in the Northeast, Midwest, and Great Plains, where heavy downpours have frequently led to runoff that exceeded the capacity of storm drains and levees, and caused flooding events and accelerated erosion. Other impacts, such as those associated with the rapid thawing of permafrost in Alaska, are unique to a particular U.S. region. Permafrost thawing is causing extensive damage to infrastructure in our nation's largest state.[4]

Some impacts that occur in one region ripple beyond that region. For example, the dramatic decline of summer sea ice in the Arctic – a loss of ice cover roughly equal to half the area of the continental United States – exacerbates global warming by reducing the reflectivity of Earth's surface and increasing the amount of heat absorbed. Similarly, smoke from wildfires in one location can contribute to poor air quality in faraway regions, and evidence suggests that particulate matter can affect atmospheric properties and therefore weather patterns. Major storms and the higher storm surges exacerbated by sea level rise that hit the Gulf Coast affect the entire country through their cascading effects on oil and gas production and distribution.[5]

Water expands as it warms, causing global sea levels to rise; melting of land-based ice also raises sea level by adding water to the oceans. Over the past century, global average sea level has risen by about 8 inches. Since 1992, the rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century, providing evidence of acceleration. Sea level rise, combined with coastal storms, has increased the risk of erosion, storm surge damage, and flooding for coastal communities, especially along the Gulf Coast, the Atlantic seaboard, and in Alaska. Coastal infrastructure, including roads, rail lines, energy infrastructure, airports, port facilities, and military bases, are increasingly at risk from sea level rise and damaging storm surges. Sea level is projected to rise by another 1 to 4 feet in this century, although the rise in sea level in specific regions is expected to vary from this global average for a number of reasons. A wider range of scenarios,

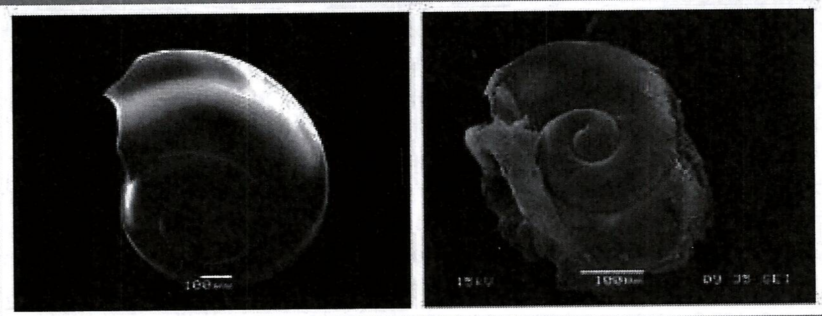


Percent changes in the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012 for each region. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events, particularly in the Northeast and Midwest. (Figure source: updated from Karl et al. 2009[c]).

from 8 inches to more than 6 feet by 2100, has been used in risk-based analyses in this report. In general, higher emissions scenarios that lead to more warming would be expected to lead to higher amounts of sea level rise. The stakes are high, as nearly five million Americans and hundreds of billions of dollars of property are located in areas that are less than four feet above the local high-tide level.[6]

In addition to causing changes in climate, increasing levels of carbon dioxide from the burning of fossil fuels and other human activities have a direct effect on the world's oceans. Carbon dioxide interacts with ocean water to form carbonic acid, increasing the ocean's acidity. Ocean surface waters have become 30% more acidic over the last 250 years as they have absorbed large amounts of carbon dioxide from the atmosphere. This ocean acidification makes water more corrosive, reducing the capacity of marine organisms with shells or skeletons made of calcium carbonate (such as corals, krill, oysters, clams, and crabs) to survive, grow, and reproduce, which in turn will affect the marine food chain.[7]

Shells Dissolve in Acidified Ocean Water

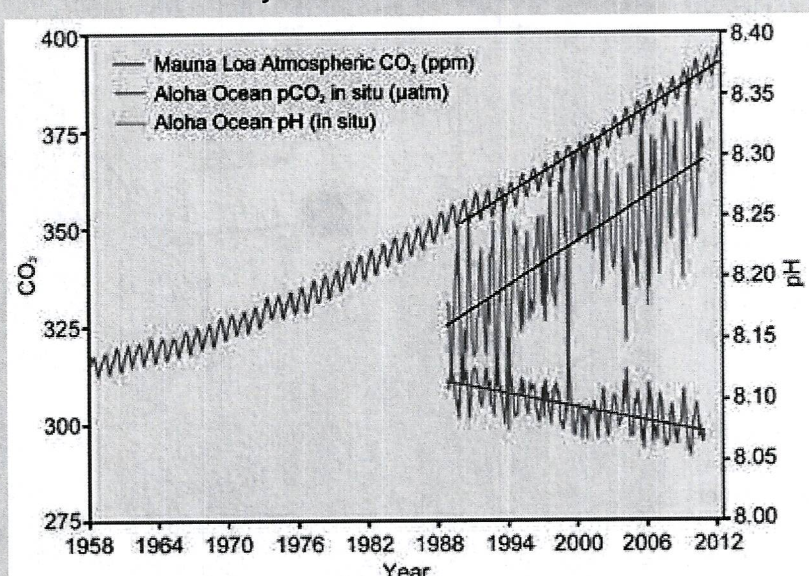


Pteropods, or "sea butterflies," are eaten by a variety of marine species ranging from tiny krill to salmon to whales. The photos show what happens to a pteropod's shell in seawater that is too acidic. On the left is a shell from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod in a region where the water is more acidic. (Figure source: (left) Bednaršek et al. 2012[e] (right) Nina Bednaršek).

Widespread Impacts

Impacts related to climate change are already evident in many regions and sectors and are expected to become increasingly disruptive across the nation throughout this century and beyond. Climate changes interact with other environmental and societal factors in ways that can either moderate or intensify these impacts.

As Oceans Absorb CO_2 They Become More Acidic



The correlation between rising levels of carbon dioxide in the atmosphere (red) with rising carbon dioxide levels (blue) and falling pH in the ocean (green). As carbon dioxide accumulates in the ocean, the water becomes more acidic (the pH declines). (Figure source: modified from Feely et al. 2009[d]).

Observed and projected climate change impacts vary across the regions of the United States. Selected impacts emphasized in the regional chapters are shown below, and many more are explored in detail in this report.

Northeast	Communities are affected by heat waves, more extreme precipitation events, and coastal flooding due to sea level rise and storm surge.
Southeast and Caribbean	Decreased water availability, exacerbated by population growth and land-use change, causes increased competition for water. There are increased risks associated with extreme events such as hurricanes.
Midwest	Longer growing seasons and rising carbon dioxide levels increase yields of some crops, although these benefits have already been offset in some instances by occurrence of extreme events such as heat waves, droughts, and floods.
Great Plains	Rising temperatures lead to increased demand for water and energy and impacts on agricultural practices.
Southwest	Drought and increased warming foster wildfires and increased competition for scarce water resources for people and ecosystems.
Northwest	Changes in the timing of streamflow related to earlier snowmelt reduce the supply of water in summer, causing far-reaching ecological and socioeconomic consequences.
Alaska	Rapidly receding summer sea ice, shrinking glaciers, and thawing permafrost cause damage to infrastructure and major changes to ecosystems. Impacts to Alaska Native communities increase.
Hawai'i and Pacific Islands	Increasingly constrained freshwater supplies, coupled with increased temperatures, stress both people and ecosystems and decrease food and water security.
Coasts	Coastal lifelines, such as water supply infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.
Oceans	The oceans are currently absorbing about a quarter of human-caused carbon dioxide emissions to the atmosphere and over 90% of the heat associated with global warming, leading to ocean acidification and the alteration of marine ecosystems.

Some climate changes currently have beneficial effects for specific sectors or regions. For example, current benefits of warming include longer growing seasons for agriculture and longer ice-free periods for shipping on the Great Lakes. At the same time, however, longer growing seasons, along with higher temperatures and carbon dioxide levels, can increase pollen production, intensifying and lengthening the allergy season. Longer ice-free periods on the Great Lakes can result in more lake-effect snowfalls.

Climate change can exacerbate respiratory and asthma-related conditions through increases in pollen, ground-level ozone, and wildfire smoke.

Sectors affected by climate changes include agriculture, water, human health, energy, transportation, forests, and ecosystems. Climate change poses a major challenge to U.S. agriculture because of the critical dependence of agricultural systems on climate. Climate change has the potential to both positively and negatively affect the location, timing, and productivity of crop, livestock, and fishery systems at local, national, and global scales. The United States produces nearly $330 billion per year in agricultural commodities. This productivity is vulnerable to direct impacts on crops and livestock from changing climate conditions and extreme weather events and indirect impacts through increasing pressures from pests and pathogens. Climate change will also alter the stability of food supplies and create new food security challenges for the United States as the world seeks to feed nine billion people by 2050. While the agriculture sector has proven to be adaptable to a range of stresses, as evidenced by continued growth in production and efficiency across the United States, climate change poses a new set of challenges.[8]

Certain groups of people are more vulnerable to the range of climate change related health impacts, including the elderly, children, the poor, and the sick.

Water quality and quantity are being affected by climate change. Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses. Water quality is also diminishing in many areas, particularly due to sediment and contaminant concentrations after heavy downpours. Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands. In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed with existing practices.[9]

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease water quality in many ways. Here, middle school students in Colorado test water quality.

Climate change affects human health in many ways. For example, increasingly frequent and intense heat events lead to more heat-related illnesses and deaths and, over time, worsen drought and wildfire risks, and intensify air pollution. Increasingly frequent extreme precipitation and associated flooding can lead to injuries and increases in waterborne disease. Rising sea surface temperatures have been linked with increasing levels and ranges of diseases. Rising sea levels intensify coastal flooding and storm surge, and thus exacerbate threats to public safety during storms. Certain groups of people are more vulnerable to the range of climate change related health impacts, including the elderly, children, the poor, and the sick. Others are vulnerable because of where they live, including those in floodplains, coastal zones, and some urban areas. Improving and properly supporting the public health infrastructure will be critical to managing the potential health impacts of climate change.[10]

Climate change also affects the living world, including people, through changes in ecosystems and biodiversity. Ecosystems provide a rich array of benefits and services to humanity, including habitat for fish and wildlife, drinking water storage and filtration, fertile soils for growing crops, buffering against a range of stressors including climate change impacts, and aesthetic and cultural values. These benefits are not always easy to quantify, but they support jobs, economic growth, health, and human well-being. Climate change driven disruptions to ecosystems have direct and indirect human impacts, including reduced water supply and quality, the loss of iconic species and landscapes, effects on food chains and the timing and success of species migrations, and the potential for extreme weather and climate events to destroy or degrade the ability of ecosystems to provide societal benefits.[11]

> The amount of future climate change will still largely be determined by choices society makes about emissions.

Human modifications of ecosystems and landscapes often increase their vulnerability to damage from extreme weather events, while simultaneously reducing their natural capacity to moderate the impacts of such events. For example, salt marshes, reefs, mangrove forests, and barrier islands defend coastal ecosystems and infrastructure, such as roads and buildings, against storm surges. The loss of these natural buffers due to coastal development, erosion, and sea level rise increases the risk of catastrophic damage during or after extreme weather events. Although floodplain wetlands are greatly reduced from their historical extent, those that remain still absorb floodwaters and reduce the effects of high flows on river-margin lands. Extreme weather events that produce sudden increases in water flow, often carrying debris and pollutants, can decrease the natural capacity of ecosystems to cleanse contaminants.[12]

The climate change impacts being felt in the regions and sectors of the United States are affected by global trends and economic decisions. In an increasingly interconnected world, U.S. vulnerability is linked to impacts in other nations. It is thus difficult to fully evaluate the impacts of climate change on the United States without considering consequences of climate change elsewhere.

Response Options

As the impacts of climate change are becoming more prevalent, Americans face choices. Especially because of past emissions of long-lived heat-trapping gases, some additional climate change and related impacts are now unavoidable. This is due to the long-lived nature of many of these gases, as well as the amount of heat absorbed and retained by the oceans and other responses within the climate system. The amount of future climate change, however, will still largely be determined by choices society makes about emissions. Lower emissions of heat-trapping gases and particles mean less future warming and less-severe impacts; higher emissions mean more warming and more severe impacts. Efforts to limit emissions or increase carbon uptake fall into a category of response options known as "mitigation," which refers to reducing the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing carbon dioxide from the atmosphere.[13]

The other major category of response options is known as "adaptation," and refers to actions to prepare for and adjust to new conditions, thereby reducing harm or taking advantage of new opportunities. Mitigation and adaptation actions are linked in multiple ways, including that effective mitigation reduces the need for adaptation in the future. Both are essential parts of a comprehensive climate change response strategy. The threat of irreversible impacts makes the timing of mitigation efforts particularly critical. This report includes chapters on Mitigation, Adaptation, and Decision Support that offer an overview of the options and activities being planned or implemented around the country as local, state, federal, and tribal governments, as well as businesses, organizations, and individuals begin to respond to climate change. These chapters conclude that while response actions are under development, current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.[14]

Large reductions in global emissions of heat-trapping gases, similar to the lower emissions scenario (B1) analyzed in this assessment, would reduce the risks of some of the worst impacts of climate change. Some targets called for in international climate negotiations to date would require even larger reductions than those outlined in the B1 scenario. Meanwhile, global emissions are still rising and are on a path to be even higher than the high emissions scenario (A2) analyzed in this report. The recent U.S. contribution to annual global emissions is about 18%, but the U.S. contribution to cumulative global emissions over the last century is much higher. Carbon dioxide lasts for a long time in the atmosphere, and it is the cumulative carbon emissions that determine the amount of global climate change. After decades of increases, U.S. CO_2 emissions from energy use (which account for 97% of total U.S. emissions) declined by around 9% between 2008 and 2012, largely due to a shift from coal to less CO_2-intensive natural gas for electricity production. Governmental actions in city, state, regional, and federal programs to promote energy efficiency have also contributed to reducing U.S. carbon emissions. Many, if not most of these programs are motivated by other policy objectives, but some are directed specifically at greenhouse gas emissions.

These U.S. actions and others that might be undertaken in the future are described in the Mitigation chapter of this report. Over the remainder of this century, aggressive and sustained greenhouse gas emission reductions by the United States and by other nations would be needed to reduce global emissions to a level consistent with the lower scenario (B1) analyzed in this assessment.[15]

With regard to adaptation, the pace and magnitude of observed and projected changes emphasize the need to be prepared for a wide variety and intensity of impacts. Because of the growing influence of human activities, the climate of the past is not a good basis for future planning. For example, building codes and landscaping ordinances could be updated to improve energy efficiency, conserve water supplies, protect against insects that spread disease (such as dengue fever), reduce susceptibility to heat stress, and improve protection against extreme events. The fact that climate change impacts are increasing points to the urgent need to develop and refine approaches that enable decision-making and increase flexibility and resilience in the face of ongoing and future impacts. Reducing non-climate-related stresses that contribute to existing vulnerabilities can also be an effective approach to climate change adaptation.[16]

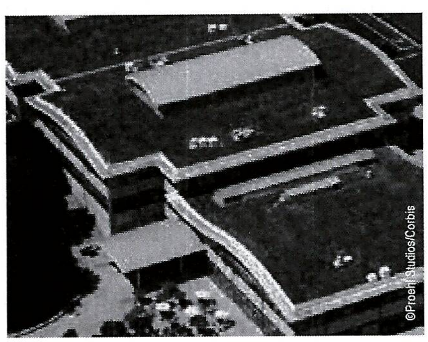
Adaptation can involve considering local, state, regional, national, and international jurisdictional objectives. For example, in managing water supplies to adapt to a changing climate, the implications of international treaties should be considered in the context of managing the Great Lakes, the Columbia River, and the Colorado River to deal with increased drought risk. Both "bottom up" community planning and "top down" national strategies may help regions deal with impacts such as increases in electrical brownouts, heat stress, floods, and wildfires.[17]

Proactively preparing for climate change can reduce impacts while also facilitating a more rapid and efficient response to changes as they happen. Such efforts are beginning at the federal, regional, state, tribal, and local levels, and in the corporate and non-governmental sectors, to build adaptive capacity and resilience to climate change impacts. Using scientific information to prepare for climate changes in advance can provide economic opportunities, and proactively managing the risks can reduce impacts and costs over time.[18]

There are a number of areas where improved scientific information or understanding would enhance the capacity to estimate future climate change impacts. For example, knowledge of the mechanisms controlling the rate of ice loss in Greenland and Antarctica is limited, making it difficult for scientists to narrow the range of expected future sea level rise. Improved understanding of ecological and social responses to climate change is needed, as is understanding of how ecological and social responses will interact.[19]

A sustained climate assessment process could more efficiently collect and synthesize the rapidly evolving science and help supply timely and relevant information to decision-makers. Results from all of these efforts could continue to deepen our understanding of the interactions of human and natural systems in the context of a changing climate, enabling society to effectively respond and prepare for our future.[20]

The cumulative weight of the scientific evidence contained in this report confirms that climate change is affecting the American people now, and that choices we make will affect our future and that of future generations.



Cities providing transportation options including bike lanes, buildings designed with energy saving features such as green roofs, and houses elevated to allow storm surges to pass underneath are among the many response options being pursued around the country.

Report Findings

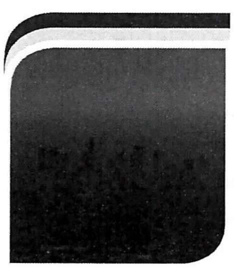
These findings distill important results that arise from this National Climate Assessment. They do not represent a full summary of all of the chapters' findings, but rather a synthesis of particularly noteworthy conclusions.

1. Global climate is changing and this is apparent across the United States in a wide range of observations. The global warming of the past 50 years is primarily due to human activities, predominantly the burning of fossil fuels.

Many independent lines of evidence confirm that human activities are affecting climate in unprecedented ways. U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The most recent decade was the warmest on record. Because human-induced warming is superimposed on a naturally varying climate, rising temperatures are not evenly distributed across the country or over time.[21]

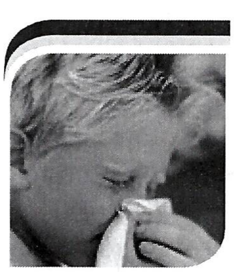
2. Some extreme weather and climate events have increased in recent decades, and new and stronger evidence confirms that some of these increases are related to human activities.

Changes in extreme weather events are the primary way that most people experience climate change. Human-induced climate change has already increased the number and strength of some of these extreme events. Over the last 50 years, much of the United States has seen an increase in prolonged periods of excessively high temperatures, more heavy downpours, and in some regions, more severe droughts.[22]



3. Human-induced climate change is projected to continue, and it will accelerate significantly if global emissions of heat-trapping gases continue to increase.

Heat-trapping gases already in the atmosphere have committed us to a hotter future with more climate-related impacts over the next few decades. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases that human activities emit globally, now and in the future.[23]



4. Impacts related to climate change are already evident in many sectors and are expected to become increasingly disruptive across the nation throughout this century and beyond.

Climate change is already affecting societies and the natural world. Climate change interacts with other environmental and societal factors in ways that can either moderate or intensify these impacts. The types and magnitudes of impacts vary across the nation and through time. Children, the elderly, the sick, and the poor are especially vulnerable. There is mounting evidence that harm to the nation will increase substantially in the future unless global emissions of heat-trapping gases are greatly reduced.[24]

5. Climate change threatens human health and well-being in many ways, including through more extreme weather events and wildfire, decreased air quality, and diseases transmitted by insects, food, and water.

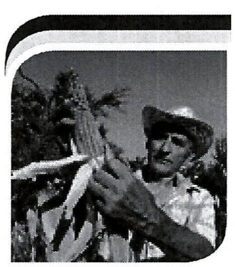
Climate change is increasing the risks of heat stress, respiratory stress from poor air quality, and the spread of waterborne diseases. Extreme weather events often lead to fatalities and a variety of health impacts on vulnerable populations, including impacts on mental health, such as anxiety and post-traumatic stress disorder. Large-scale changes in the environment due to climate change and extreme weather events are increasing the risk of the emergence or reemergence of health threats that are currently uncommon in the United States, such as dengue fever.[25]

6. Infrastructure is being damaged by sea level rise, heavy downpours, and extreme heat; damages are projected to increase with continued climate change.

Sea level rise, storm surge, and heavy downpours, in combination with the pattern of continued development in coastal areas, are increasing damage to U.S. infrastructure including roads, buildings, and industrial facilities, and are also increasing risks to ports and coastal military installations. Flooding along rivers, lakes, and in cities following heavy downpours, prolonged rains, and rapid melting of snowpack is exceeding the limits of flood protection infrastructure designed for historical conditions. Extreme heat is damaging transportation infrastructure such as roads, rail lines, and airport runways.[26]

7. Water quality and water supply reliability are jeopardized by climate change in a variety of ways that affect ecosystems and livelihoods.

Surface and groundwater supplies in some regions are already stressed by increasing demand for water as well as declining runoff and groundwater recharge. In some regions, particularly the southern part of the country and the Caribbean and Pacific Islands, climate change is increasing the likelihood of water shortages and competition for water among its many uses. Water quality is diminishing in many areas, particularly due to increasing sediment and contaminant concentrations after heavy downpours.[27]



8. Climate disruptions to agriculture have been increasing and are projected to become more severe over this century.

Some areas are already experiencing climate-related disruptions, particularly due to extreme weather events. While some U.S. regions and some types of agricultural production will be relatively resilient to climate change over the next 25 years or so, others will increasingly suffer from stresses due to extreme heat, drought, disease, and heavy downpours. From mid-century on, climate change is projected to have more negative impacts on crops and livestock across the country – a trend that could diminish the security of our food supply.[28]

9. Climate change poses particular threats to Indigenous Peoples' health, well-being, and ways of life.

Chronic stresses such as extreme poverty are being exacerbated by climate change impacts such as reduced access to traditional foods, decreased water quality, and increasing exposure to health and safety hazards. In parts of Alaska, Louisiana, the Pacific Islands, and other coastal locations, climate change impacts (through erosion and inundation) are so severe that some communities are already relocating from historical homelands to which their traditions and cultural identities are tied. Particularly in Alaska, the rapid pace of temperature rise, ice and snow melt, and permafrost thaw are significantly affecting critical infrastructure and traditional livelihoods.[29]

10. Ecosystems and the benefits they provide to society are being affected by climate change. The capacity of ecosystems to buffer the impacts of extreme events like fires, floods, and severe storms is being overwhelmed.

Climate change impacts on biodiversity are already being observed in alteration of the timing of critical biological events such as spring bud burst and substantial range shifts of many species. In the longer term, there is an increased risk of species extinction. These changes have social, cultural, and economic effects. Events such as droughts, floods, wildfires, and pest outbreaks associated with climate change (for example, bark beetles in the West) are already disrupting ecosystems. These changes limit the capacity of ecosystems, such as forests, barrier beaches, and wetlands, to continue to play important roles in reducing the impacts of these extreme events on infrastructure, human communities, and other valued resources.[30]

11. Ocean waters are becoming warmer and more acidic, broadly affecting ocean circulation, chemistry, ecosystems, and marine life.

More acidic waters inhibit the formation of shells, skeletons, and coral reefs. Warmer waters harm coral reefs and alter the distribution, abundance, and productivity of many marine species. The rising temperature and changing chemistry of ocean water combine with other stresses, such as overfishing and coastal and marine pollution, to alter marine-based food production and harm fishing communities.[31]

12. Planning for adaptation (to address and prepare for impacts) and mitigation (to reduce future climate change, for example by cutting emissions) is becoming more widespread, but current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.

Actions to reduce emissions, increase carbon uptake, adapt to a changing climate, and increase resilience to impacts that are unavoidable can improve public health, economic development, ecosystem protection, and quality of life.[32]

OVERVIEW AND REPORT FINDINGS

REFERENCES

Numbered references for the Overview indicate the chapters that provide supporting evidence for the reported conclusions.

1. Ch. 2.
2. Ch. 2, 3, 6, 9, 20.
3. Ch. 2, 3, 4, 5, 6, 9, 10, 12, 16, 20, 24, 25.
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18. Ch. 28.
19. Ch. 29, Appendix 6.
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21. Ch. 2, Appendices 3 and 4.
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31. Ch. 2, 12, 23, 24, 25.
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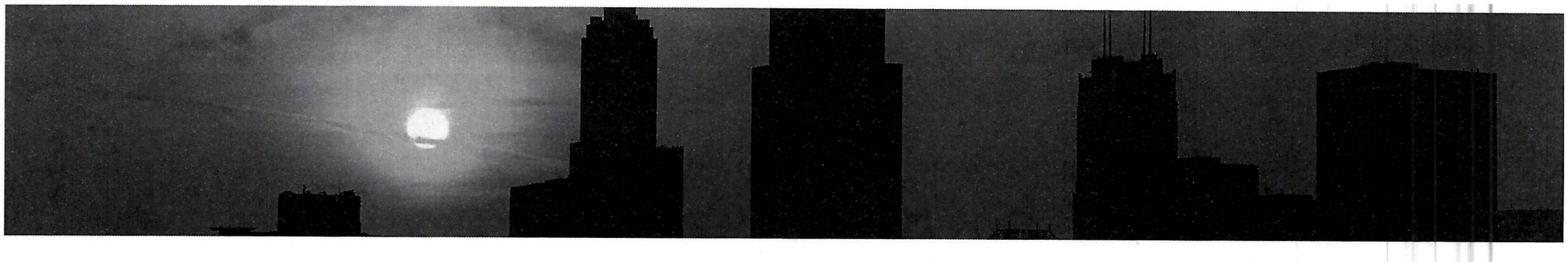

CHAPTER 2
OUR CHANGING CLIMATE

Convening Lead Authors
John Walsh, University of Alaska Fairbanks
Donald Wuebbles, University of Illinois

Lead Authors
Katharine Hayhoe, Texas Tech University
James Kossin, NOAA National Climatic Data Center
Kenneth Kunkel, CICS-NC, North Carolina State Univ., NOAA National Climatic Data Center
Graeme Stephens, NASA Jet Propulsion Laboratory
Peter Thorne, Nansen Environmental and Remote Sensing Center
Russell Vose, NOAA National Climatic Data Center
Michael Wehner, Lawrence Berkeley National Laboratory
Josh Willis, NASA Jet Propulsion Laboratory

Contributing Authors
David Anderson, NOAA National Climatic Data Center
Scott Doney, Woods Hole Oceanographic Institution
Richard Feely, NOAA Pacific Marine Environmental Laboratory
Paula Hennon, CICS-NC, North Carolina State Univ., NOAA National Climatic Data Center
Viatcheslav Kharin, Canadian Centre for Climate Modelling and Analysis, Environment Canada
Thomas Knutson, NOAA Geophysical Fluid Dynamics Laboratory
Felix Landerer, NASA Jet Propulsion Laboratory
Tim Lenton, Exeter University
John Kennedy, UK Meteorological Office
Richard Somerville, Scripps Institution of Oceanography, Univ. of California, San Diego

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On the Web: http://nca2014.globalchange.gov/report/our-changing-climate/introduction

First published May 2014. PDF revised October 2014. See errata (available at http://nca2014.globalchange.gov/downloads) for details.

INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

2 OUR CHANGING CLIMATE

Key Messages

1. Global climate is changing and this change is apparent across a wide range of observations. The global warming of the past 50 years is primarily due to human activities.
2. Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the Earth's climate is to those emissions.
3. U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The most recent decade was the nation's warmest on record. Temperatures in the United States are expected to continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, uniform or smooth across the country or over time.
4. The length of the frost-free season (and the corresponding growing season) has been increasing nationally since the 1980s, with the largest increases occurring in the western United States, affecting ecosystems and agriculture. Across the United States, the growing season is projected to continue to lengthen.
5. Average U.S. precipitation has increased since 1900, but some areas have had increases greater than the national average, and some areas have had decreases. More winter and spring precipitation is projected for the northern United States, and less for the Southwest, over this century.
6. Heavy downpours are increasing nationally, especially over the last three to five decades. Largest increases are in the Midwest and Northeast. Increases in the frequency and intensity of extreme precipitation events are projected for all U.S. regions.
7. There have been changes in some types of extreme weather events over the last several decades. Heat waves have become more frequent and intense, especially in the West. Cold waves have become less frequent and intense across the nation. There have been regional trends in floods and droughts. Droughts in the Southwest and heat waves everywhere are projected to become more intense, and cold waves less intense everywhere.
8. The intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (Category 4 and 5) hurricanes, have all increased since the early 1980s. The relative contributions of human and natural causes to these increases are still uncertain. Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm.
9. Winter storms have increased in frequency and intensity since the 1950s, and their tracks have shifted northward over the United States. Other trends in severe storms, including the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds, are uncertain and are being studied intensively.

Continued

Key Messages (Continued)

10. **Global sea level has risen by about 8 inches since reliable record keeping began in 1880. It is projected to rise another 1 to 4 feet by 2100.**

11. **Rising temperatures are reducing ice volume and surface extent on land, lakes, and sea. This loss of ice is expected to continue. The Arctic Ocean is expected to become essentially ice free in summer before mid-century.**

12. **The oceans are currently absorbing about a quarter of the carbon dioxide emitted to the atmosphere annually and are becoming more acidic as a result, leading to concerns about intensifying impacts on marine ecosystems.**

This chapter summarizes how climate is changing, why it is changing, and what is projected for the future. While the focus is on changes in the United States, the need to provide context sometimes requires a broader geographical perspective. Additional geographic detail is presented in the regional chapters of this report. Further details on the topics covered by this chapter are provided in the Climate Science Supplement and Frequently Asked Questions Appendices.

Since the second National Climate Assessment was published in 2009,[1] the climate has continued to change, with resulting effects on the United States. The trends described in the 2009 report have continued, and our understanding of the data and ability to model the many facets of the climate system have increased substantially. Several noteworthy advances are mentioned in the box below.

The 12 key messages presented above are repeated below, together with supporting evidence for those messages. The discussion of each key message begins with a summary of recent variations or trends, followed by projections of the corresponding changes for the future.

What's New?

- Continued warming and an increased understanding of the U.S. temperature record, as well as multiple other sources of evidence, have strengthened our confidence in the conclusions that the warming trend is clear and primarily the result of human activities. For the contiguous United States, the last decade was the warmest on record, and 2012 was the warmest year on record.
- Heavy precipitation and extreme heat events are increasing in a manner consistent with model projections; the risks of such extreme events will rise in the future.
- The sharp decline in summer Arctic sea ice has continued, is unprecedented, and is consistent with human-induced climate change. A new record for minimum area of Arctic sea ice was set in 2012.
- A longer and better-quality history of sea level rise has increased confidence that recent trends are unusual and human-induced. Limited knowledge of ice sheet dynamics leads to a broad range for projected sea level rise over this century.
- New approaches to building scenarios of the future have allowed for investigations of the implications of larger reductions in heat trapping gas emissions than examined previously.

Reference periods for graphs

Many of the graphs in this report illustrate historical changes and future trends in climate compared to some reference period, with the choice of this period determined by the purpose of the graph and the availability of data. The great majority of graphs are based on one of two reference periods. The period 1901-1960 is used for graphs that illustrate past changes in climate conditions, whether in observations or in model simulations. The choice of 1960 as the ending date of this period was based on past changes in human influences on the climate system. Human-induced forcing exhibited a slow rise during the early part of the last century but then accelerated after 1960.[2] Thus, these graphs highlight observed changes in climate during the period of rapid increase in human-caused forcing and also reveal how well climate models simulate these observed changes. The beginning date of 1901 was chosen because earlier historical observations are less reliable and because many climate model simulations begin in 1900 or 1901. The other commonly used reference period is 1971-2000, which is consistent with the World Meteorological Organization's recommended use of 30-year periods for climate statistics. This is used for graphs that illustrate projected future changes simulated by climate models. The purpose of these graphs is to show projected changes compared to a period that people have recently experienced and can remember; thus, the most recent available 30-year period was chosen (the historical period simulated by the CMIP3 models ends in 1999 or 2000).

Key Message 1: Observed Climate Change

Global climate is changing and this change is apparent across a wide range of observations. The global warming of the past 50 years is primarily due to human activities.

Climate is defined as long-term averages and variations in weather measured over a period of several decades. The Earth's climate system includes the land surface, atmosphere, oceans, and ice. Many aspects of the global climate are changing rapidly, and the primary drivers of that change are human in origin. Evidence for changes in the climate system abounds, from the top of the atmosphere to the depths of the oceans (Figure 2.1).[3] Scientists and engineers from around the world have compiled this evidence using satellites, weather balloons, thermometers at surface stations, and many other types of observing systems that monitor the Earth's weather and climate. The sum total of this evidence tells an unambiguous story: the planet is warming.

Ten Indicators of a Warming World

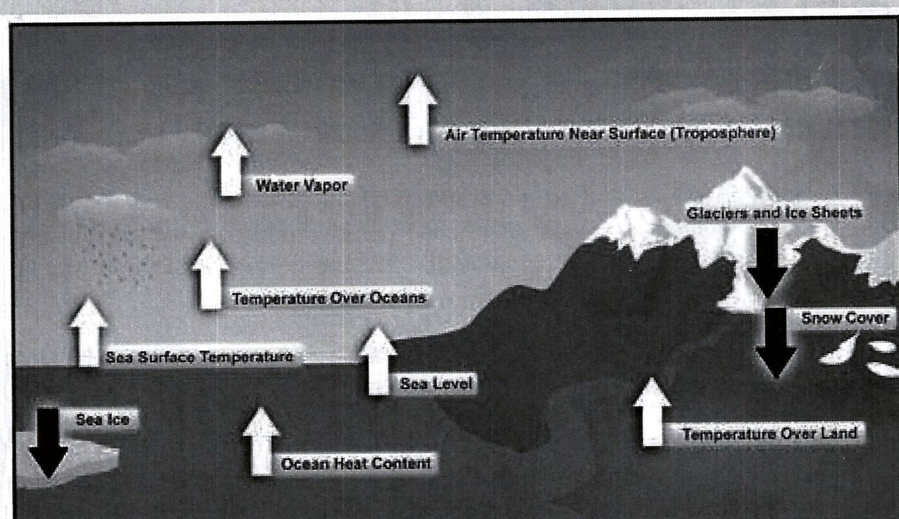


Figure 2.1. These are just some of the indicators measured globally over many decades that show that the Earth's climate is warming. White arrows indicate increasing trends, and black arrows indicate decreasing trends. All the indicators expected to increase in a warming world are, in fact, increasing, and all those expected to decrease in a warming world are decreasing. (Figure source: NOAA NCDC based on data updated from Kennedy et al. 2010[3]).

Temperatures at the surface, in the troposphere (the active weather layer extending up to about 5 to 10 miles above the ground), and in the oceans have all increased over recent decades (Figure 2.2). Consistent with our scientific understanding, the largest increases in temperature are occurring closer to the poles, especially in the Arctic. Snow and ice cover have decreased in most areas. Atmospheric water vapor is increasing in the lower atmosphere, because a warmer atmosphere can hold more water. Sea levels are also increasing (see Key Message 10). Changes in other climate-relevant indicators such as growing season length have been observed in many areas. Worldwide, the observed changes in average conditions have been accompanied by increasing trends in extremes of heat and heavy precipitation events, and decreases in extreme cold.[4]

Natural drivers of climate cannot explain the recent observed warming. Over the last five decades, natural factors (solar forcing and volcanoes) alone would actually have led to a slight cooling (see Figure 2.3).[5]

The majority of the warming at the global scale over the past 50 years can only be explained by the effects of human influences,[5,6,7] especially the emissions from burning fossil fuels (coal, oil, and natural gas) and from deforestation. The emissions from human influences that are affecting climate include heat-trapping gases such as carbon dioxide (CO_2), methane, and nitrous oxide, and particles such as black carbon (soot), which has a warming influence, and sulfates, which have an overall cooling influence (see Appendix 3: Climate Science Supplement for further discussion).[8,9] In addition to human-induced global climate change, local climate can also be affected by other human factors (such as crop irrigation) and natural variability (for example, Ashley et al. 2012; DeAngelis et al. 2010; Degu et al. 2011; Lo and Famiglietti 2013[10]).

The conclusion that human influences are the primary driver of recent climate change is based on multiple lines of independent evidence. The first line of evidence is our fundamental understanding of how certain gases trap heat, how the climate system responds to increases in these gases, and how other human and natural factors influence climate. The second line of evidence is from reconstructions of past climates using evidence such as tree rings, ice cores, and corals. These show that global surface temperatures over the last several decades are clearly unusual, with the last decade (2000-2009) warmer than any time in at least the last 1300 years and perhaps much longer.[11]

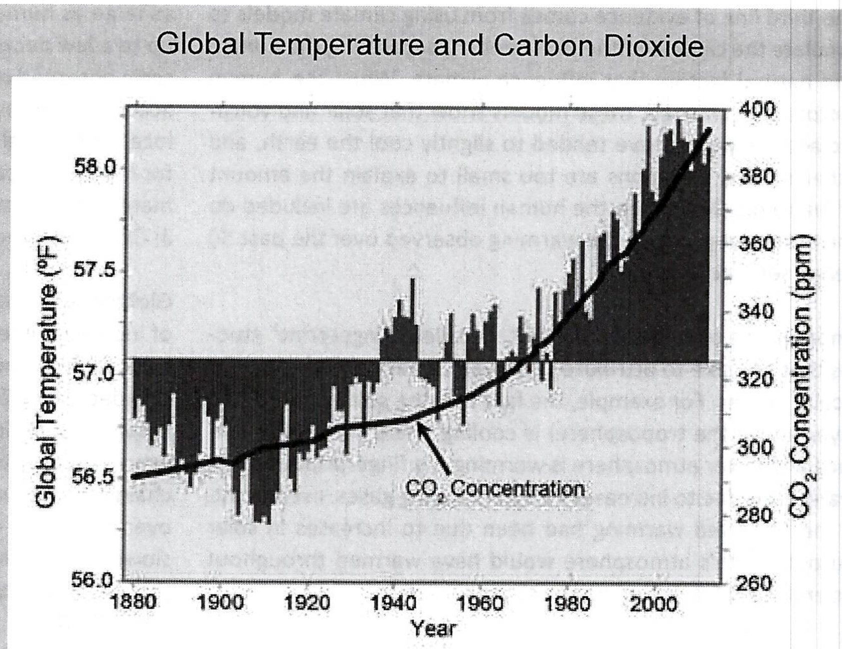


Figure 2.2. Global annual average temperature (as measured over both land and oceans) has increased by more than 1.5°F (0.8°C) since 1880 (through 2012). Red bars show temperatures above the long-term average, and blue bars indicate temperatures below the long-term average. The black line shows atmospheric carbon dioxide (CO_2) concentration in parts per million (ppm). While there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are due to natural processes, such as the effects of El Niños, La Niñas, and volcanic eruptions. (Figure source: updated from Karl et al. 2009[1]).

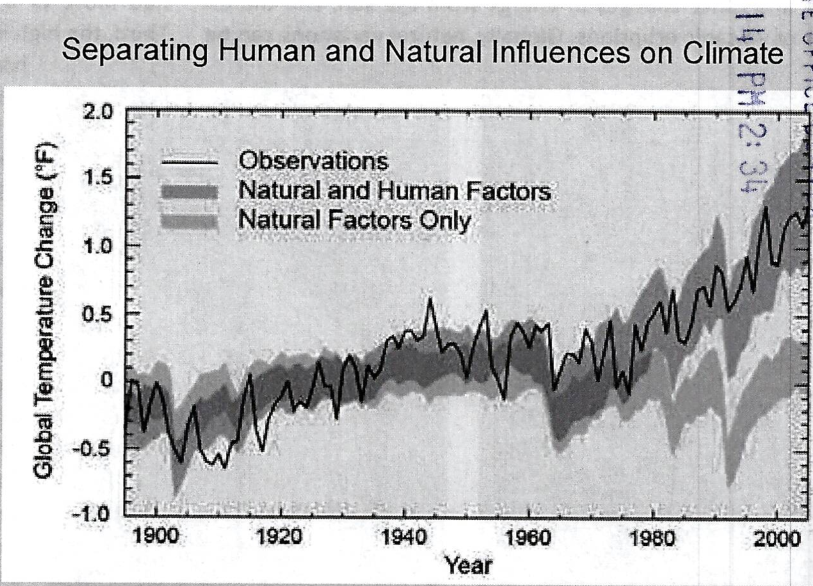


Figure 2.3. Observed global average changes (black line), model simulations using only changes in natural factors (solar and volcanic) in green, and model simulations with the addition of human-induced emissions (blue). Climate changes since 1950 cannot be explained by natural factors or variability, and can only be explained by human factors. (Figure source: adapted from Huber and Knutti[29]).

The third line of evidence comes from using climate models to simulate the climate of the past century, separating the human and natural factors that influence climate. When the human factors are removed, these models show that solar and volcanic activity would have tended to slightly cool the earth, and other natural variations are too small to explain the amount of warming. Only when the human influences are included do the models reproduce the warming observed over the past 50 years (see Figure 2.3).

Another line of evidence involves so-called "fingerprint" studies that are able to attribute observed climate changes to particular causes. For example, the fact that the stratosphere (the layer above the troposphere) is cooling while the Earth's surface and lower atmosphere is warming is a fingerprint that the warming is due to increases in heat-trapping gases. In contrast, if the observed warming had been due to increases in solar output, Earth's atmosphere would have warmed throughout its entire extent, including the stratosphere.[6]

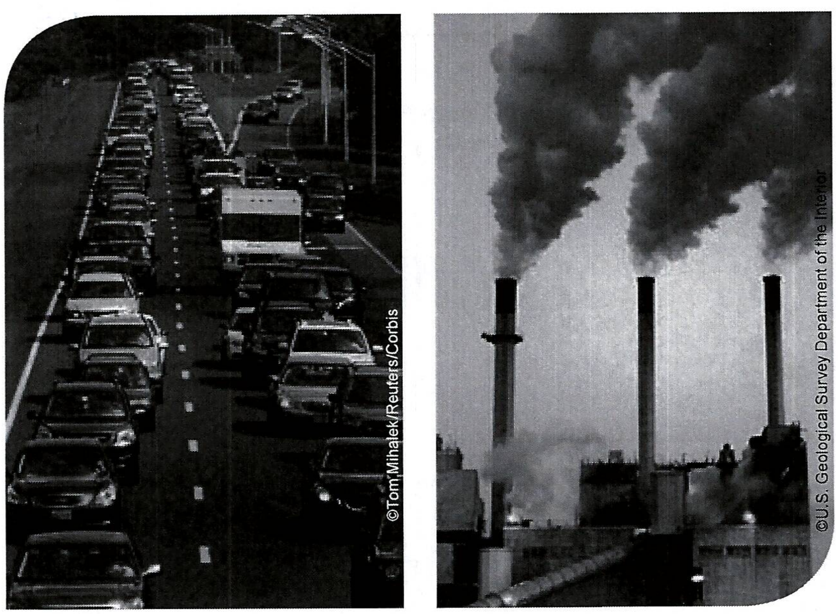
In addition to such temperature analyses, scientific attribution of observed changes to human influence extends to many other aspects of climate, such as changing patterns in precipitation,[12,13] increasing humidity,[14,15] changes in pressure,[16] and increasing ocean heat content.[17] Further discussion of how we know the recent changes in climate are caused by human activity is provided in Appendix 3: Climate Science Supplement.

Natural variations in climate include the effects of cycles such as El Niño, La Niña and other ocean cycles; the 11-year sunspot cycle and other changes in energy from the sun; and the effects of volcanic eruptions. Globally, natural variations can be as large as human-induced climate change over timescales of up to a few decades. However, changes in climate at the global scale observed over the past 50 years are far larger than can be accounted for by natural variability. Changes in climate at the local to regional scale can be influenced by natural variability for multiple decades.[18] This can affect the interpretation of climate trends observed regionally across the U.S. (see Appendix 3: Climate Science Supplement).

Globally averaged surface air temperature has slowed its rate of increase since the late 1990s. This is not in conflict with our basic understanding of global warming and its primary cause. The decade of 2000 to 2009 was still the warmest decade on record. In addition, global surface air temperature does not always increase steadily. This time period is too short to signify a change in the warming trend, as climate trends are measured over periods of decades, not years.[19,20,21,22] Such decade-long slowdowns or even reversals in trend have occurred before in the global instrumental record (for example, 1900-1910 and 1940-1950; see Figure 2.2), including three decade-long periods since 1970, each followed by a sharp temperature rise.[23] Nonetheless, satellite and ocean observations indicate that the Earth-atmosphere climate system has continued to gain heat energy.[24]

There are a number of possible contributions to the lower rate of increase over the last 15 years. First, the solar output during the latest 11-year solar cycle has been lower over the past 15 years than the past 60 years. Second, a series of mildly explosive volcanoes, which increased stratospheric particles, likely had more of a cooling effect than previously recognized.[25] Third, the high incidence of La Niña events in the last 15 years has played a role in the observed trends.[20,26] Recent analyses[27] suggest that more of the increase in heat energy during this period has been transferred to the deep ocean than previously. While this might temporarily slow the rate of increase in surface air temperature, ultimately it will prolong the effects of global warming because the oceans hold heat for longer than the atmosphere does.

Climate models are not intended to match the real-world timing of natural climate variations – instead, models have their own internal timing for such variations. Most modeling studies do not yet account for the observed changes in solar and volcanic forcing mentioned in the previous paragraph. Therefore, it is not surprising that the timing of such a slowdown in the rate of increase in the models would be different than that observed, although it is important to note that such periods *have* been simulated by climate models, with the deep oceans absorbing the extra heat during those decades.[28]



Oil used for transportation and coal used for electricity generation are the largest contributors to the rise in carbon dioxide that is the primary driver of observed changes in climate over recent decades.

Models used in the Assessment

This report uses various projections from models of the physical processes affecting the Earth's climate system, which are discussed further in Appendix 3: Climate Science Supplement. Three distinct sets of model simulations for past and projected changes in climate are used:

- Coupled Model Intercomparison Project, 3rd phase (CMIP3): global model analyses done for the Fourth Intergovernmental Panel on Climate Change (IPCC) assessment. Spatial resolutions typically vary from 125 to 187 miles (at mid-latitudes); approximately 25 representations of different models (not all are used in all studies). CMIP3 findings are the foundation for most of the impact analyses included in this assessment.
- Coupled Model Intercomparison Project, 5th phase (CMIP5): newer global model analyses done for the Fifth IPCC assessment generally based on improved formulations of the CMIP3 models. Spatial resolutions typically vary from 62 to 125 miles; about 30 representations of different models (not all are used in all studies); this new information was not available in time to serve as the foundation for the impacts analyses in this assessment, and information from CMIP5 is primarily provided for comparison purposes.
- North American Regional Climate Change Assessment Program (NARCCAP): six regional climate model analyses (and limited time-slice analyses from two global models) for the continental U.S. run at about 30-mile horizontal resolution. The analyses were done for past (1971-2000) and projected (2041-2070) time periods. Coarser resolution results from four of the CMIP3 models were used as the boundary conditions for the NARCCAP regional climate model studies, with each of the regional models doing analyses with boundary conditions from two of the CMIP3 models.

The scenarios for future human-related emissions of the relevant gases and particles used in these models are further discussed in Appendix 3: Climate Science Supplement. The emissions in these scenarios depend on various assumptions about changes in global population, economic and technological development, and choices in transportation and energy use.

Key Message 2: Future Climate Change

Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the Earth's climate is to those emissions.

A certain amount of continued warming of the planet is projected to occur as a result of human-induced emissions to date; another 0.5°F increase would be expected over the next few decades even if all emissions from human activities suddenly stopped,[30] although natural variability could still play an important role over this time period.[31] However, choices made now and in the next few decades will determine the amount of additional future warming. Beyond mid-century, lower levels of heat-trapping gases in scenarios with reduced emissions will lead to noticeably less future warming. Higher emissions levels will result in more warming, and thus more severe impacts on human society and the natural world.

Confidence in projections of future climate change has increased. The wider range of potential changes in global average temperature in the latest generation of climate model simulations[32] used in the Intergovernmental Panel on Climate Change's (IPCC) current assessment – versus those in the previous assessment[8] – is simply a result of considering more options for future human behavior. For example, one of the scenarios included in the IPCC's latest assessment assumes aggressive emissions reductions designed to limit the global temperature increase to 3.6°F (2°C) above pre-industrial levels.[33] This path would require rapid emissions reductions (more than 70% reduction in human-related emissions by 2050, and net negative emissions by 2100 – see the Appendix 3: Climate Science, Supplemental Message 5) sufficient to achieve heat-trapping gas concentrations well below those of any of the scenarios considered by the IPCC in its 2007 assessment. Such scenarios enable the investigation of climate impacts that would be avoided by deliberate, substantial reductions in heat-trapping gas emissions.

Projections of future changes in precipitation show small increases in the global average but substantial shifts in where and how precipitation falls. Generally, areas closest to the poles are projected to receive more precipitation, while the dry subtropics (the region just outside the tropics, between 23° and 35° on either side of the equator) expand toward the poles and receive less rain. Increases in tropical precipitation are projected during rainy seasons (such as monsoons), especially over the tropical Pacific. Certain regions, including the western U.S. (especially the Southwest[1]) and the Mediterranean, are presently dry and are expected to become drier. The widespread trend of increasing heavy downpours is expected to continue, with precipitation becoming less frequent but more intense.[34] The patterns of the projected changes of precipitation do not contain the spatial details that characterize observed precipitation, especially in mountainous terrain, because the projections are averages from multiple models and because the effective resolution of global climate models is roughly 100-200 miles.

Emissions Levels Determine Temperature Rises

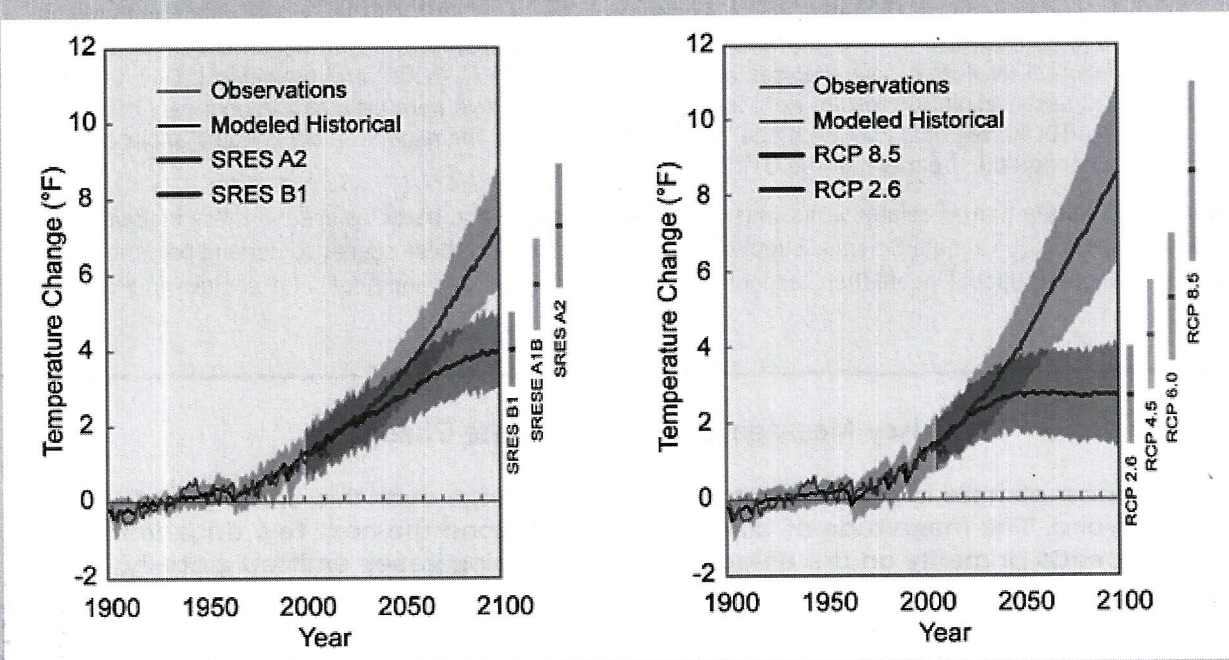


Figure 2.4. Different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature. In the figure, each line represents a central estimate of global average temperature rise (relative to the 1901-1960 average) for a specific emissions pathway. Shading indicates the range (5th to 95th percentile) of results from a suite of climate models. Projections in 2099 for additional emissions pathways are indicated by the bars to the right of each panel. In all cases, temperatures are expected to rise, although the difference between lower and higher emissions pathways is substantial. **(Left)** The panel shows the two main scenarios (SRES – Special Report on Emissions Scenarios) used in this report: A2 assumes continued increases in emissions throughout this century, and B1 assumes much slower increases in emissions beginning now and significant emissions reductions beginning around 2050, though not due explicitly to climate change policies. **(Right)** The panel shows newer analyses, which are results from the most recent generation of climate models (CMIP5) using the most recent emissions pathways (RCPs – Representative Concentration Pathways). Some of these new projections explicitly consider climate policies that would result in emissions reductions, which the SRES set did not.[35] The newest set includes both lower and higher pathways than did the previous set. The lowest emissions pathway shown here, RCP 2.6, assumes immediate and rapid reductions in emissions and would result in about 2.5°F of warming in this century. The highest pathway, RCP 8.5, roughly similar to a continuation of the current path of global emissions increases, is projected to lead to more than 8°F warming by 2100, with a high-end possibility of more than 11°F. (Data from CMIP3, CMIP5, and NOAA NCDC).

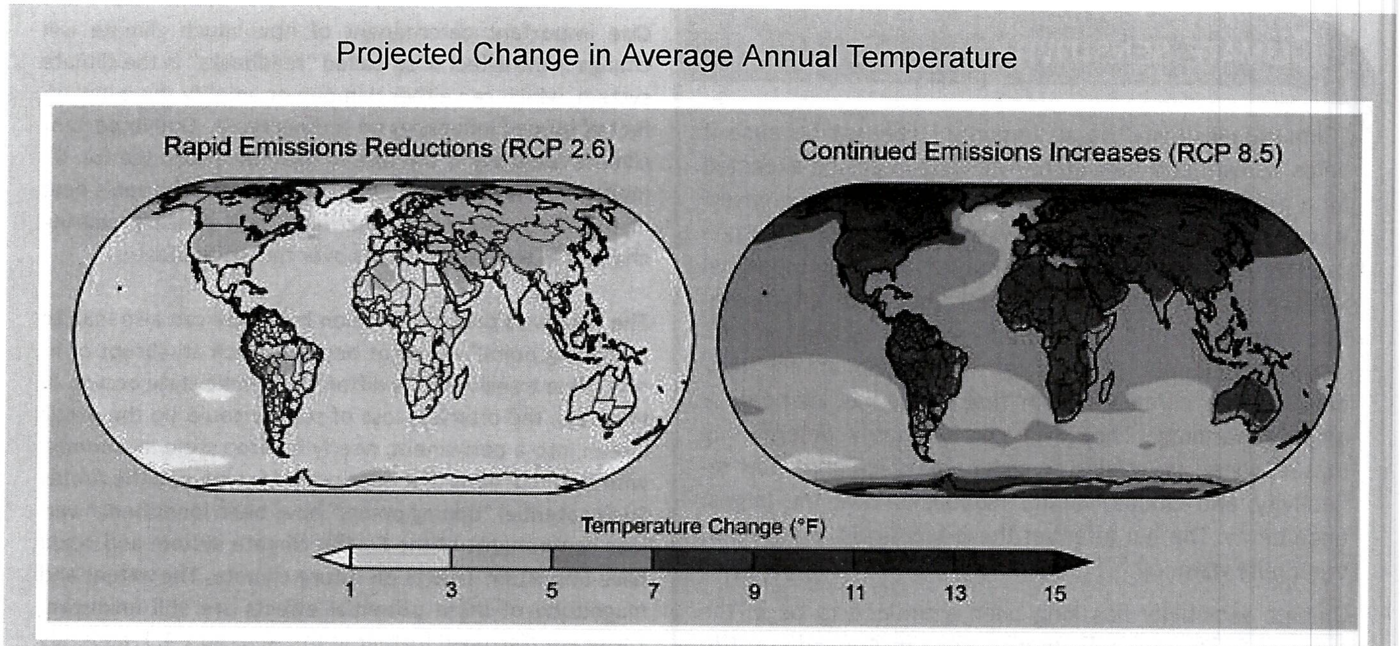


Figure 2.5. Projected change in average annual temperature over the period 2071-2099 (compared to the period 1970-1999) under a low scenario that assumes rapid reductions in emissions and concentrations of heat-trapping gases (RCP 2.6), and a higher scenario that assumes continued increases in emissions (RCP 8.5). (Figure source: NOAA NCDC / CICS-NC).

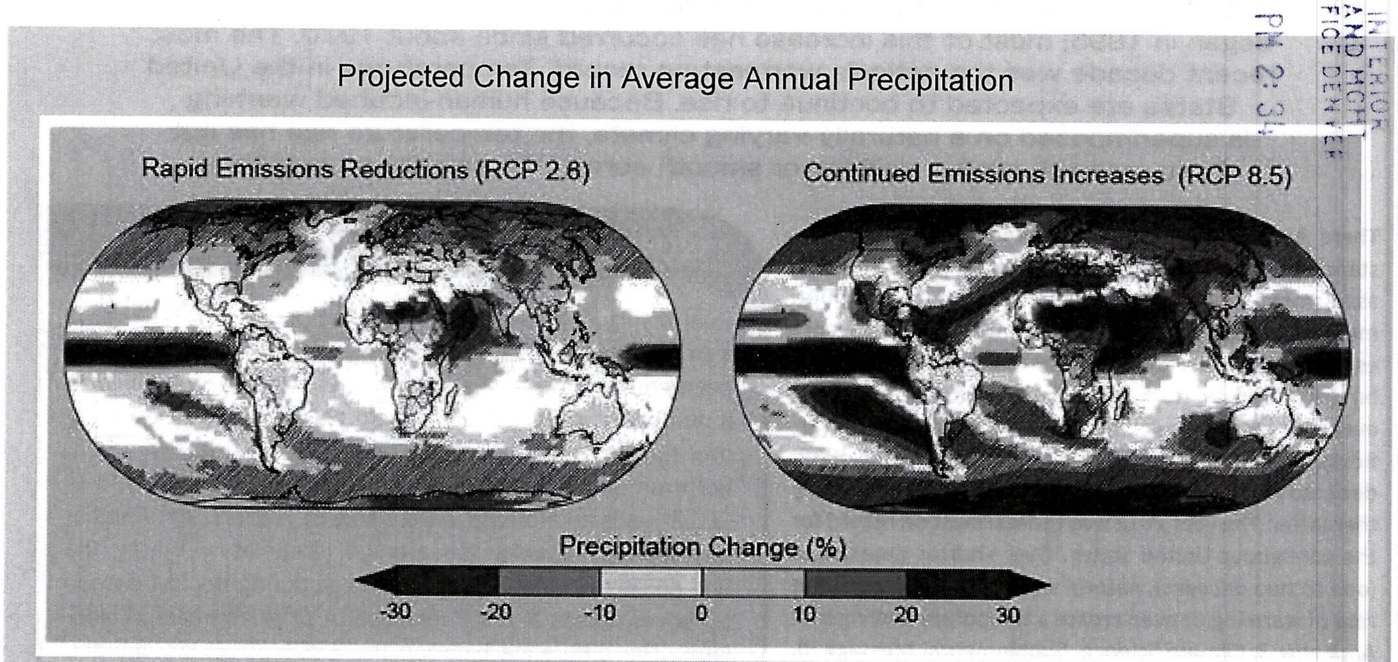


Figure 2.6. Projected change in average annual precipitation over the period 2071-2099 (compared to the period 1970-1999) under a low scenario that assumes rapid reductions in emissions and concentrations of heat-trapping gasses (RCP 2.6), and a higher scenario that assumes continued increases in emissions (RCP 8.5). Hatched areas indicate confidence that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. In general, northern parts of the U.S. (especially the Northeast and Alaska) are projected to receive more precipitation, while southern parts (especially the Southwest) are projected to receive less. (Figure source: NOAA NCDC / CICS-NC).

Climate Sensitivity

"Climate sensitivity" is an important concept because it helps us estimate how much warming might be expected for a given increase in the amount of heat-trapping gases. It is defined as the amount of warming expected if carbon dioxide (CO_2) concentrations doubled from pre-industrial levels and then remained constant until Earth's temperature reached a new equilibrium over timescales of centuries to millennia. Climate sensitivity accounts for feedbacks in the climate system that can either dampen or amplify warming. The feedbacks primarily determining that response are related to water vapor, ice and snow reflectivity, and clouds.[8] Cloud feedbacks have the largest uncertainty. The net effect of these feedbacks is expected to amplify warming.[8]

Climate sensitivity has long been estimated to be in the range of 2.7°F to 8.1°F. As discussed in Appendix 3: Climate Science Supplement, recent evidence lends further confidence in this range.

One important determinant of how much climate will change is the effect of so-called "feedbacks" in the climate system, which can either dampen or amplify the initial effect of human influences on temperature. One important climate feedback is the loss of summer Arctic sea ice, allowing absorption of substantially more of the sun's heat in the Arctic, increasing warming, and possibly causing changes in weather patterns over the United States.

The observed drastic reduction in sea ice can also lead to a "tipping point" – a point beyond which an abrupt or irreversible transition to a different climatic state occurs. In this case, the dramatic loss of sea ice could tip the Arctic Ocean into a permanent, nearly ice-free state in summer, with repercussions that may extend far beyond the Arctic. Such potential "tipping points" have been identified in various components of the Earth's climate system and could have important effects on future climate. The extent and magnitude of these potential effects are still unknown. These are discussed further in the Appendix 4: Frequently Asked Questions, under Question T.

Key Message 3: Recent U.S. Temperature Trends

U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The most recent decade was the nation's warmest on record. Temperatures in the United States are expected to continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, uniform or smooth across the country or over time.

There have been substantial advances in our understanding of the U.S. temperature record since the 2009 assessment (see Appendix 3: Climate Science, Supplemental Message 7 for more information). These advances confirm that the U.S. annually averaged temperature has increased by 1.3°F to 1.9°F since 1895.[1,36,37,38] However, this increase was not constant over time. In particular, temperatures generally rose until about 1940, declined slightly until about 1970, then increased rapidly thereafter. The year 2012 was the warmest on record for the contiguous United States. Over shorter time scales (one to two decades), natural variability can reduce the rate of warming or even create a temporary cooling (see Appendix 3: Climate Science, Supplemental Message 3). The cooling in mid-century that was especially prevalent over the eastern half of the U.S. may have stemmed partly from such natural variations and partly from human influences, in particular the cooling effects of sulfate particles from coal-burning power plants,[39] before these sulfur emissions were regulated to address health and acid rain concerns.

Quantifying U.S. Temperature Rise

Quantifying long-term increases of temperature in the U.S. in a single number is challenging because the increase has not been constant over time. The increase can be quantified in a number of ways, but all of them show significant warming over the U.S. since the instrumental record began in 1895. For example, fitting a linear trend over the period 1895 to 2012 yields an increase in the range of 1.3 to 1.9°F. Another approach, comparing the average temperature during the first decade of record with the average during the last decade of record, yields a 1.9°F increase. A third approach, calculating the difference between the 1901-1960 average and the past decade average yields a change of 1.5°F. Thus, the temperature increase cited in this assessment is described as 1.3°F to 1.9°F since 1895. Notably, however, the rate of rise in temperature over the past 4 to 5 decades has been greater than the rate over earlier decades.

Observed U.S. Temperature Change

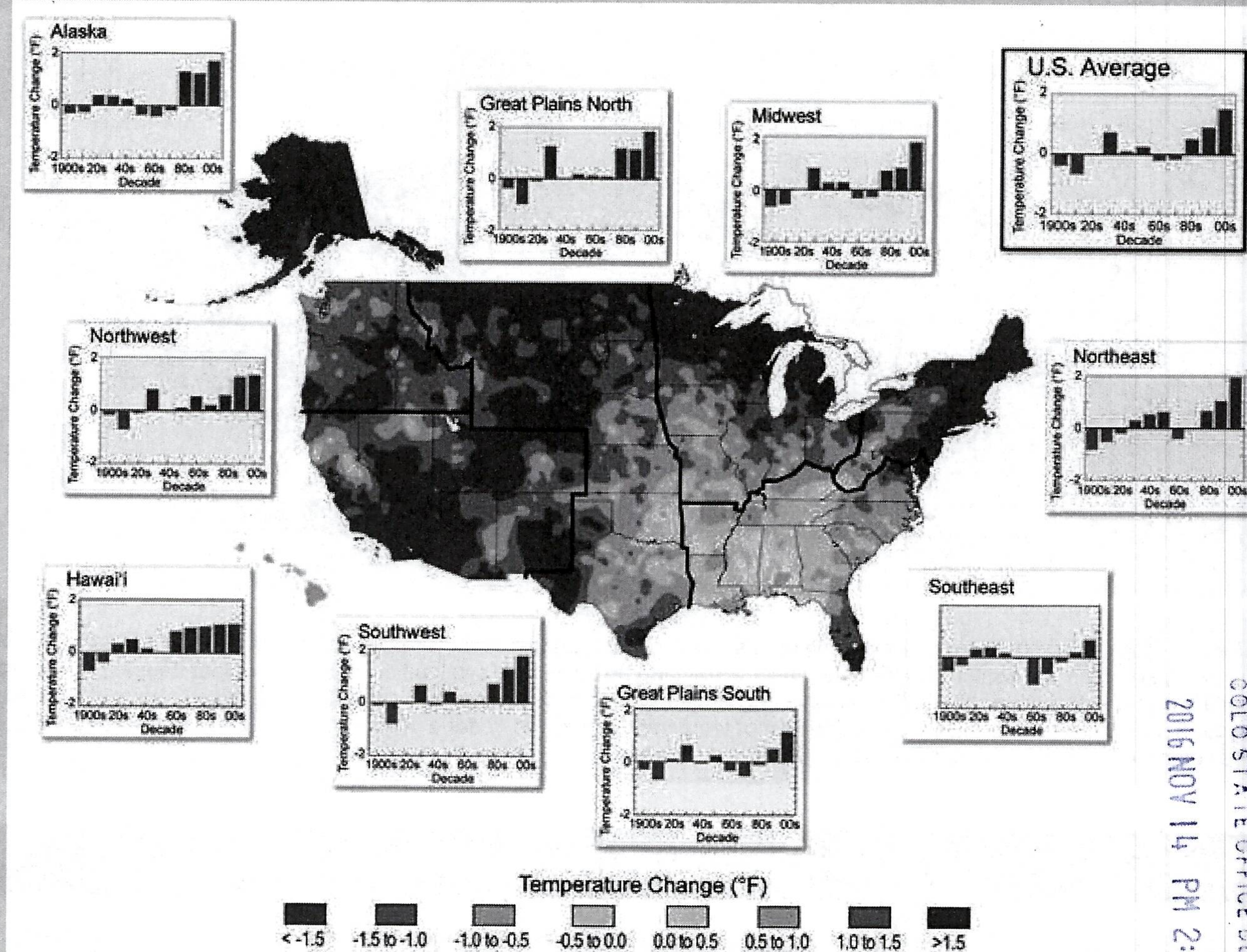


Figure 2.7. The colors on the map show temperature changes over the past 22 years (1991-2012) compared to the 1901-1960 average, and compared to the 1951-1980 average for Alaska and Hawai'i. The bars on the graphs show the average temperature changes by decade for 1901-2012 (relative to the 1901-1960 average) for each region. The far right bar in each graph (2000s decade) includes 2011 and 2012. The period from 2001 to 2012 was warmer than any previous decade in every region. (Figure source: NOAA NCDC / CICS-NC).

Since 1991, temperatures have averaged 1°F to 1.5°F higher than 1901-1960 over most of the United States, except for the Southeast, where the warming has been less than 1°F. On a seasonal basis, long-term warming has been greatest in winter and spring.

Warming is ultimately projected for all parts of the nation during this century. In the next few decades, this warming will be roughly 2°F to 4°F in most areas. By the end of the century, U.S. warming is projected to correspond closely to the level of global emissions: roughly 3°F to 5°F under lower emissions scenarios (B1 or RCP 4.5) involving substantial reductions in emissions, and 5°F to 10°F for higher emissions scenarios (A2 or RCP 8.5) that assume continued increases in emissions; the largest temperature increases are projected for the upper Midwest and Alaska.

Future human-induced warming depends on both past and future emissions of heat-trapping gases and changes in the amount of particle pollution. The amount of climate change (aside from natural variability) expected for the next two to three decades is a combination of the warming already built into the climate system by the past history of human emissions of heat-trapping gases, and the expected ongoing increases in emissions of those gases. However, the magnitude of temperature increases over the second half of this century, both in the U.S. and globally, will be primarily determined by the emissions produced now and over the next few decades, and there are substantial differences between higher, fossil-fuel intensive scenarios compared to scenarios in which emissions are reduced. The most recent model projections of climate change due to human activities expand the range of future scenarios considered (particularly at the lower end), but are entirely consistent with the older model results. This consistency increases our confidence in the projections.

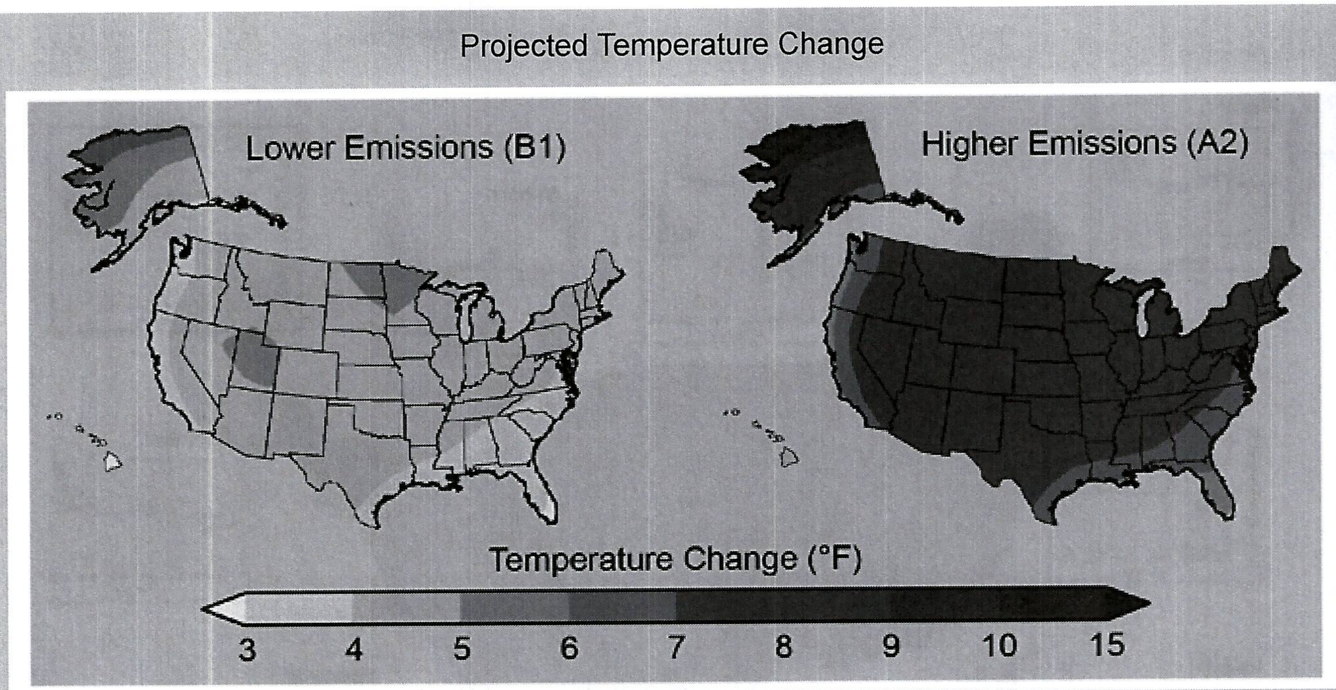


Figure 2.8. Maps show projected change in average surface air temperature in the later part of this century (2071-2099) relative to the later part of the last century (1970-1999) under a scenario that assumes substantial reductions in heat trapping gases (B1, left) and a higher emissions scenario that assumes continued increases in global emissions (A2, right). (See Appendix 3: Climate Science, Supplemental Message 5 for a discussion of temperature changes under a wider range of future scenarios for various periods of this century). (Figure source: NOAA NCDC / CICS-NC).

NEWER SIMULATIONS FOR PROJECTED TEMPERATURE (CMIP5 MODELS)

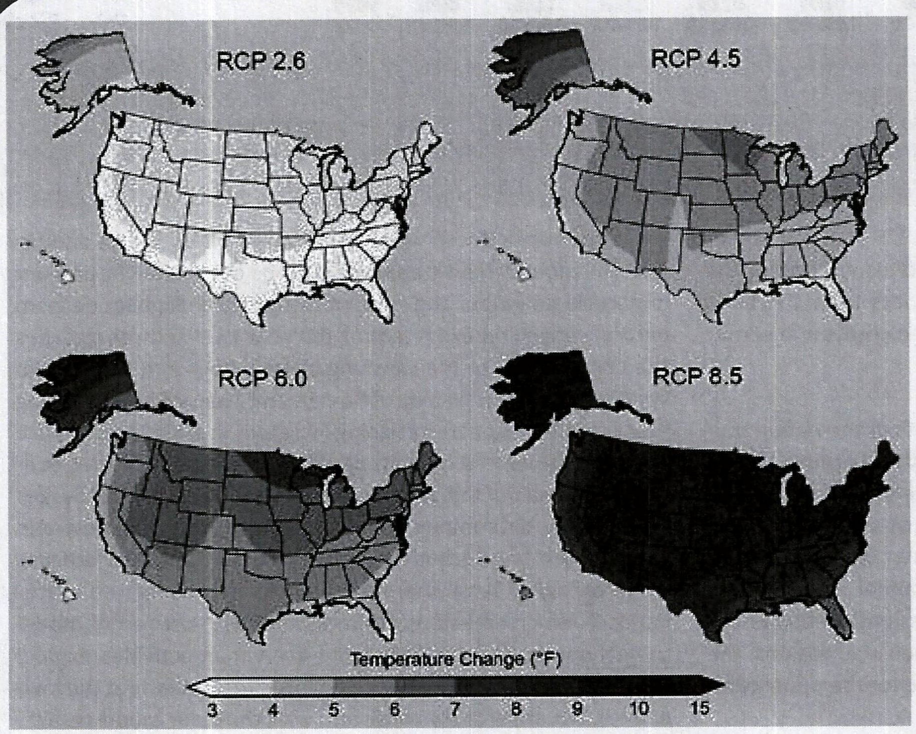


Figure 2.9. The largest uncertainty in projecting climate change beyond the next few decades is the level of heat-trapping gas emissions. The most recent model projections (CMIP5) take into account a wider range of options with regard to human behavior, including a lower scenario than has been considered before (RCP 2.6). This scenario assumes rapid reductions in emissions – more than 70% cuts from current levels by 2050 and further large decreases by 2100 – and the corresponding smaller amount of warming. On the higher end, the scenarios include one that assumes continued increases in emissions (RCP 8.5) and the corresponding greater amount of warming. Also shown are temperature changes for the intermediate scenarios RCP 4.5 (which is most similar to B1) and RCP 6.0 (which is most similar to A1B; see Appendix 3: Climate Science Supplement). Projections show change in average temperature in the later part of this century (2071-2099) relative to the late part of last century (1970-1999). (Figure source: NOAA NCDC / CICS-NC).

Key Message 4: Lengthening Frost-free Season

The length of the frost-free season (and the corresponding growing season) has been increasing nationally since the 1980s, with the largest increases occurring in the western United States, affecting ecosystems and agriculture. Across the United States, the growing season is projected to continue to lengthen.

The length of the frost-free season (and the corresponding growing season) is a major determinant of the types of plants and crops that do well in a particular region. The frost-free season length has been gradually increasing since the 1980s.[40] The last occurrence of 32°F in the spring has been occurring earlier in the year, and the first occurrence of 32°F in the fall has been happening later. During 1991-2011, the average frost-free season was about 10 days longer than during 1901-1960. These observed climate changes have been mirrored by changes in the biosphere, including increases in forest productivity[41,42] and satellite-derived estimates of the length of the growing season.[43] A longer growing season provides a longer period for plant growth and productivity and can slow the increase in atmospheric CO_2 concentrations through increased CO_2 uptake by living things and their environment.[44] The longer growing season can increase the growth of beneficial plants (such as crops and forests) as well as undesirable ones (such as ragweed).[45] In some cases where moisture is limited, the greater evaporation and loss of moisture through plant transpiration (release of water from plant leaves) associated with a longer growing season can mean less productivity because of increased drying[46] and earlier and longer fire seasons.

Observed Increase in Frost-Free Season Length

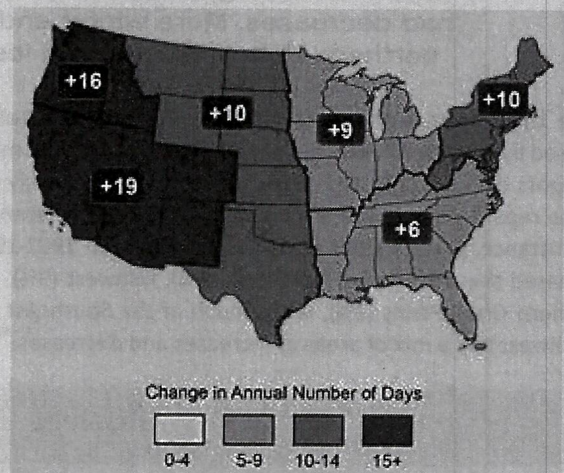


Figure 2.10. The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has increased in each U.S. region during 1991-2012 relative to 1901-1960. Increases in frost-free season length correspond to similar increases in growing season length. (Figure source: NOAA NCDC / CICS-NC).

The lengthening of the frost-free season has been somewhat greater in the western U.S. than the eastern United States,[1] increasing by 2 to 3 weeks in the Northwest and Southwest, 1 to 2 weeks in the Midwest, Great Plains, and Northeast, and slightly less than 1 week in the Southeast. These differences mirror the overall trend of more warming in the north and west and less warming in the Southeast.

Projected Changes in Frost-Free Season Length

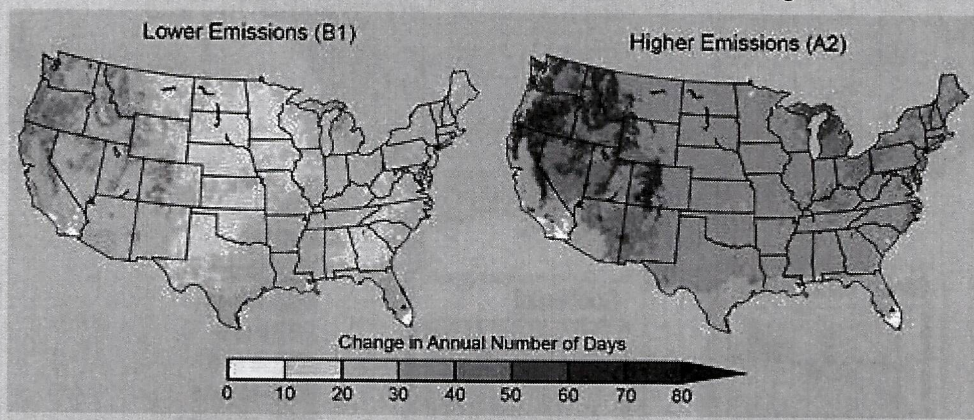


Figure 2.11. The maps show projected increases in frost-free season length for the last three decades of this century (2070-2099 as compared to 1971-2000) under two emissions scenarios, one in which heat-trapping gas emissions continue to grow (A2) and one in which emissions peak in 2050 (B1). Increases in the frost-free season correspond to similar increases in the growing season. White areas are projected to experience no freezes for 2070-2099, and gray areas are projected to experience more than 10 frost-free years during the same period. (Figure source: NOAA NCDC / CICS-NC).

In a future in which heat-trapping gas emissions continue to grow, increases of a month or more in the lengths of the frost-free and growing seasons are projected across most of the U.S. by the end of the century, with slightly smaller increases in the northern Great Plains. The largest increases in the frost-free season (more than 8 weeks) are projected for the western U.S., particularly in high elevation and coastal areas. The increases will be considerably smaller if heat-trapping gas emissions are reduced, although still substantial. These increases are projected to be much greater than the normal year-to-year variability experienced today. The projected changes also imply that the southern boundary of the seasonal freeze zone will move northward, with increasing frequencies of years without subfreezing temperatures in the most southern parts of the United States.

Key Message 5: U.S. Precipitation Change

Average U.S. precipitation has increased since 1900, but some areas have had increases greater than the national average, and some areas have had decreases. More winter and spring precipitation is projected for the northern United States, and less for the Southwest, over this century.

Since 1900, average annual precipitation over the U.S. has increased by roughly 5%. This increase reflects, in part, the major droughts of the 1930s and 1950s, which made the early half of the record drier. There are important regional differences. For instance, precipitation since 1991 (relative to 1901-1960) increased the most in the Northeast (8%), Midwest (9%), and southern Great Plains (8%), while much of the Southeast and Southwest had a mix of areas of increases and decreases.[47,48]

While significant trends in average precipitation have been detected, the fraction of these trends attributable to human activity is difficult to quantify at regional scales because the range of natural variability in precipitation is large. Projected changes are generally small for central portions of the United States. However, if emissions of heat-trapping gases continue their upward trend, certain global patterns of precipitation change are projected to emerge that will affect northern and

Observed U.S. Precipitation Change

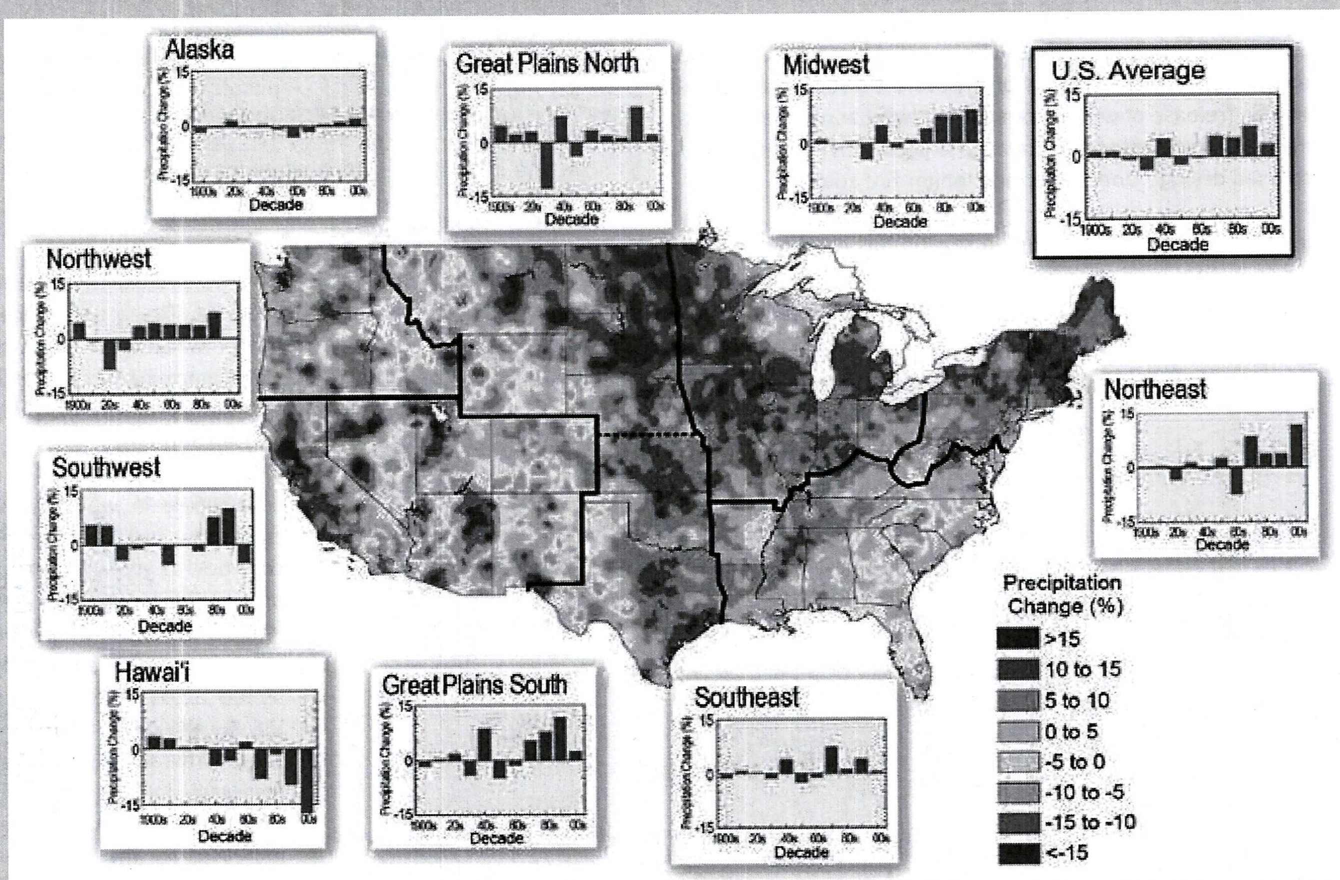


Figure 2.12. The colors on the map show annual total precipitation changes for 1991-2012 compared to the 1901-1960 average, and show wetter conditions in most areas. The bars on the graphs show average precipitation differences by decade for 1901-2012 (relative to the 1901-1960 average) for each region. The far right bar in each graph is for 2001-2012. (Figure source: adapted from Peterson et al. 2013[48]).

southwestern areas of the United States. The northern U.S. is projected to experience more precipitation in the winter and spring (except for the Northwest in the spring), while the Southwest is projected to experience less, particularly in the spring. The contrast between wet and dry areas will increase both in the U.S. and globally – in other words, the wet areas will get wetter and the dry areas will get drier. As discussed in the next section, there has been an increase in the amount of precipitation falling in heavy events[49] and this is projected to continue.

The projected changes in the northern U.S. are a consequence of both a warmer atmosphere (which can hold more moisture than a colder one) and associated changes in large-scale

Uncertainties in Regional Projections

On the global scale, climate model simulations show consistent projections of future conditions under a range of emissions scenarios. For temperature, all models show warming by late this century that is much larger than historical variations nearly everywhere. For precipitation, models are in complete agreement in showing decreases in precipitation in the subtropics and increases in precipitation at higher latitudes.

Models unequivocally project large and historically unprecedented future warming in every region of the U.S. under all of the scenarios used in this assessment. The amount of warming varies substantially between higher versus lower scenarios, and moderately from model to model, but the amount of projected warming is larger than the model-to-model range.

The contiguous U.S. straddles the transition zone between drier conditions in the sub-tropics (south) and wetter conditions at higher latitudes (north). Because the precise location of this zone varies somewhat among models, projected changes in precipitation in central areas of the U.S. range from small increases to small decreases. A clear direction of change only occurs in Alaska and the far north of the contiguous U.S. where increases are projected and in the far Southwest where decreases are projected.

Although this means that changes in overall precipitation are uncertain in many U.S. areas, there is a high degree of certainty that the heaviest precipitation events will increase everywhere, and by large amounts (Figure 2.13). This consistent model projection is well understood and is a direct outcome of the increase in atmospheric moisture caused by warming. There is also more certainty regarding dry spells. The annual maximum number of consecutive dry days is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States. Thus, both extreme wetness and extreme dryness are projected to increase in many areas.

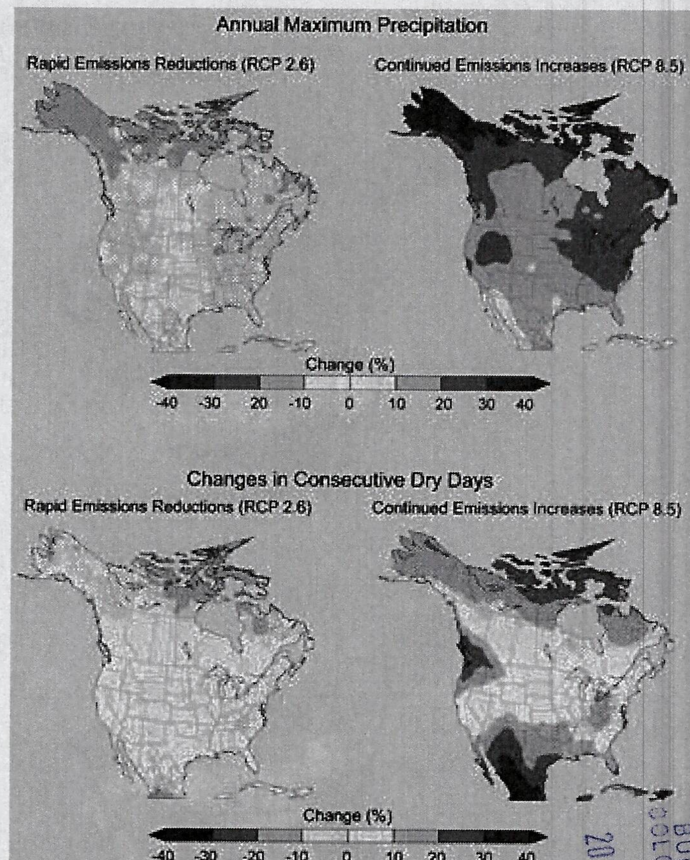


Figure 2.13. Top panels show simulated changes in the average amount of precipitation falling on the wettest day of the year for the period 2070-2099 as compared to 1971-2000 under a scenario that assumes rapid reductions in emissions (RCP 2.6) and one that assumes continued emissions increases (RCP 8.5). Bottom panels show simulated changes in the annual maximum number of consecutive dry days (days receiving less than 0.04 inches (1 mm) of precipitation) under the same two scenarios. Simulations are from CMIP5 models. Stippling indicates areas where changes are consistent among at least 80% of the models used in this analysis. (Figure source: NOAA NCDC / CICS-NC).

Modeling methods that downscale (generate higher spatial resolution) climate projections from coarser global model output can reduce the range of projections to the extent that they incorporate better representation of certain physical processes (such as the influence of topography and convection). However, a sizeable portion of the range is a result of the variations in large-scale patterns produced by the global models and so downscaling methods do not change this.

weather patterns (which affect where precipitation occurs). The projected reduction in Southwest precipitation is a result of changes in large-scale weather patterns, including the northward expansion of the belt of high pressure in the subtropics, which suppresses rainfall. Recent improvements in understanding these mechanisms of change increase confidence in these projections.[50] The patterns of the projected changes of precipitation resulting from human alterations of the climate are geographically smoother in these maps than what will actually be observed because: 1) the precise locations of natural increases and decreases differ from model to model, and averaging across models smooths these differences; and 2) the resolution of current climate models is too coarse to capture fine topographic details, especially in mountainous terrain. Hence, there is considerably more confidence in the large-scale patterns of change than in local details.

In general, a comparison of the various sources of climate model data used in this assessment provides a consistent picture of the large-scale projected precipitation changes

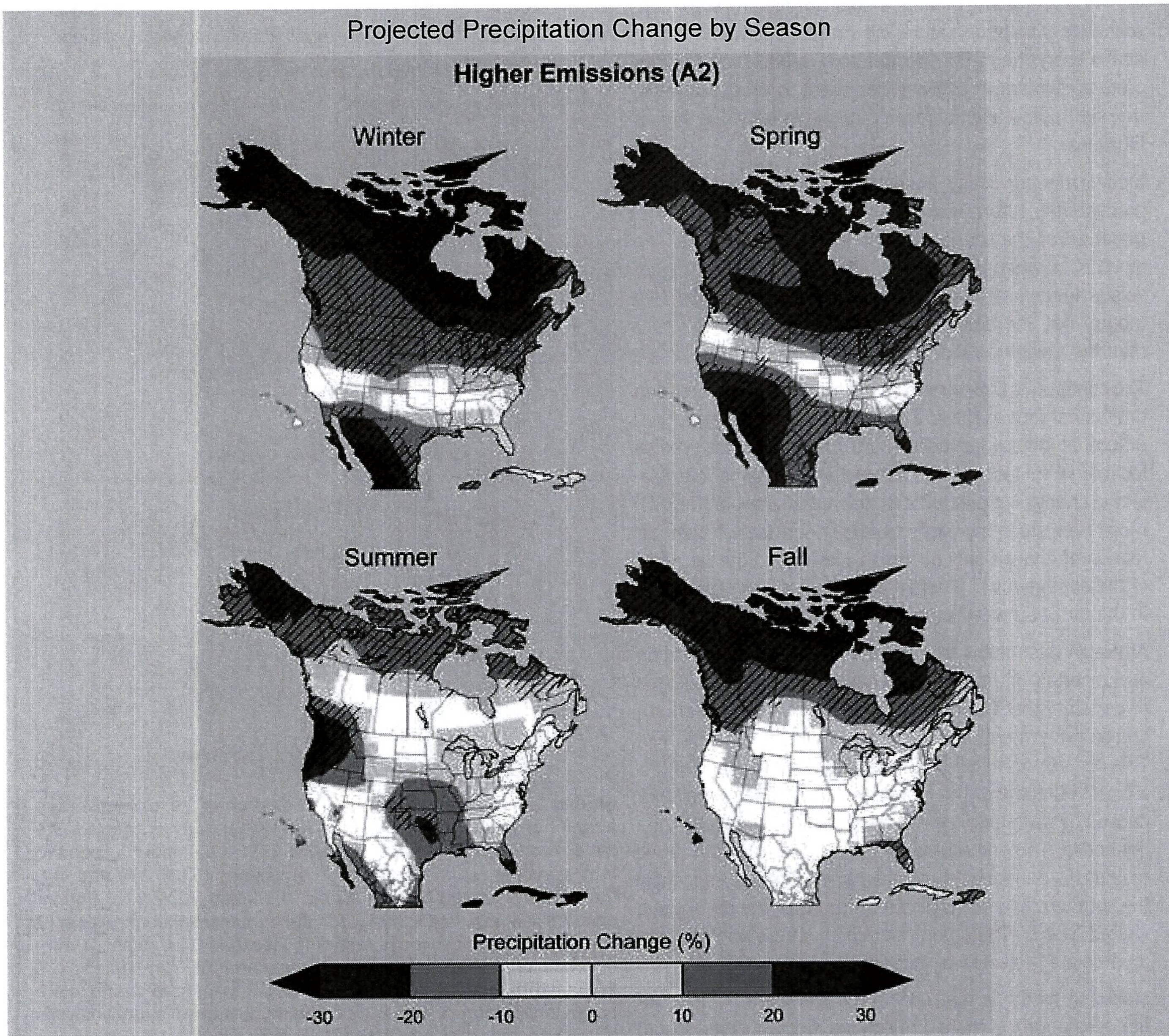


Figure 2.14. Projected change in seasonal precipitation for 2071-2099 (compared to 1970-1999) under an emissions scenario that assumes continued increases in emissions (A2). Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. In general, the northern part of the U.S. is projected to see more winter and spring precipitation, while the southwestern U.S. is projected to experience less precipitation in the spring. (Figure source: NOAA NCDC / CICS-NC).

across the United States (see "Models Used in the Assessment"). Multi-model average changes in all three of these sources show a general pattern of wetter future conditions in the north and drier conditions in the south. The regional suite generally shows conditions that are somewhat wetter overall in the wet areas and not as dry in the dry areas. The general pattern agreement among these three sources, with the wide variations in their spatial resolution, provides confidence that this pattern is robust and not sensitive to the limited spatial resolution of the models. The slightly different conditions in the North American NARCCAP regional analyses for the U.S. appear to arise partially or wholly from the choice of the four CMIP3 global climate models used to drive the regional simulations. These four global models, averaged together, project average changes that are 2% wetter than the average of the suite of global models used in CMIP3.

The patterns of precipitation change in the newer CMIP5 simulations are essentially the same as in the earlier CMIP3 and NARCCAP simulations used in impact analyses throughout this report, increasing confidence in our scientific understanding. The subtle differences between these two sets of projections are mostly due to the wider range of future scenarios considered in the more recent simulations. Thus, the overall picture remains the same: wetter conditions in the north and drier conditions in the Southwest in winter and spring. Drier conditions are projected for summer in most areas of the contiguous U.S. but, outside of the Northwest and south-central region, there is generally not high confidence that the changes will be large compared to natural variability. In all models and scenarios, a transition zone between drier (to the south) and wetter (to the north) shifts northward from the southern U.S. in winter to southern Canada in summer. Wetter conditions are projected for Alaska and northern Canada in all seasons.

Newer Simulations for Projected Precipitation Change (CMIP5 Models)

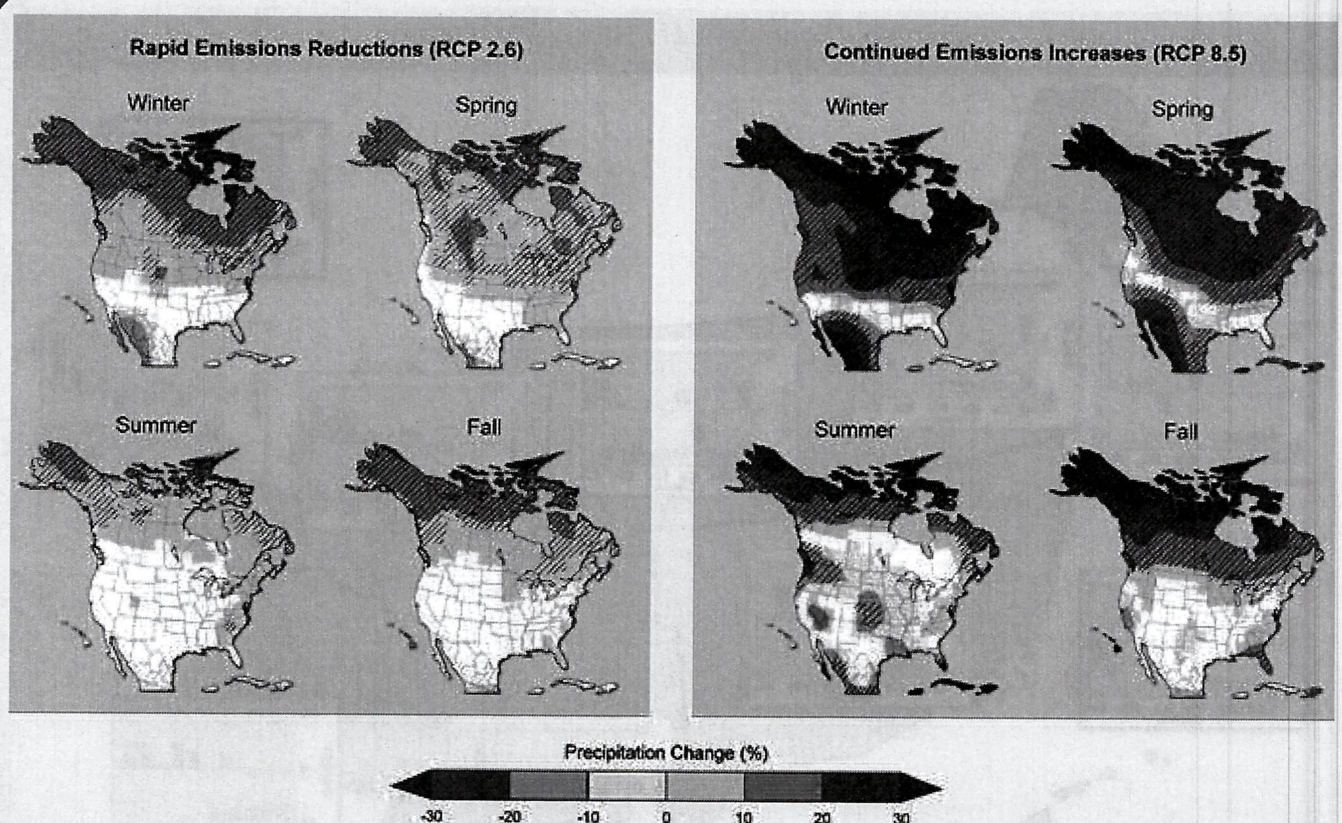


Figure 2.15. Seasonal precipitation change for 2071-2099 (compared to 1970-1999) as projected by recent simulations that include a wider range of scenarios. The maps on the left (RCP 2.6) assume rapid reductions in emissions – more than 70% cuts from current levels by 2050 – and a corresponding much smaller amount of warming and far less precipitation change. On the right, RCP 8.5 assumes continued increases in emissions, with associated large increases in warming and major precipitation changes. These would include, for example, large reductions in spring precipitation in the Southwest and large increases in the Northeast and Midwest. Rapid emissions reductions would be required for the more modest changes in the maps on the left. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. (Figure source: NOAA NCDC / CICS-NC).

Key Message 6: Heavy Downpours Increasing

Heavy downpours are increasing nationally, especially over the last three to five decades. Largest increases are in the Midwest and Northeast. Increases in the frequency and intensity of extreme precipitation events are projected for all U.S. regions.

Across most of the United States, the heaviest rainfall events have become heavier and more frequent. The amount of rain falling on the heaviest rain days has also increased over the past few decades. Since 1991, the amount of rain falling in very heavy precipitation events has been significantly above average. This increase has been greatest in the Northeast, Midwest, and upper Great Plains – more than 30% above the 1901-1960 average (see Figure 2.18). There has also been an increase in flooding events in the Midwest and Northeast where the largest increases in heavy rain amounts have occurred.

Observed U.S. Trend in Heavy Precipitation

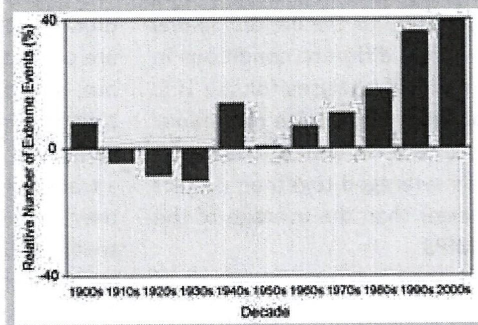


Figure 2.16: One measure of a heavy precipitation event is a 2-day precipitation total that is exceeded on average only once in a five-year period, also known as a once-in-five-year event. As this extreme precipitation index for 1901-2012 shows, the occurrence of such events has become much more common in recent decades. Changes are compared to the period 1901-1960, and do not include Alaska or Hawai'i. The 2000s decade (far right bar) includes 2001-2012. (Figure source: adapted from Kunkel et al. 2013[52]).

Observed Change in Very Heavy Precipitation

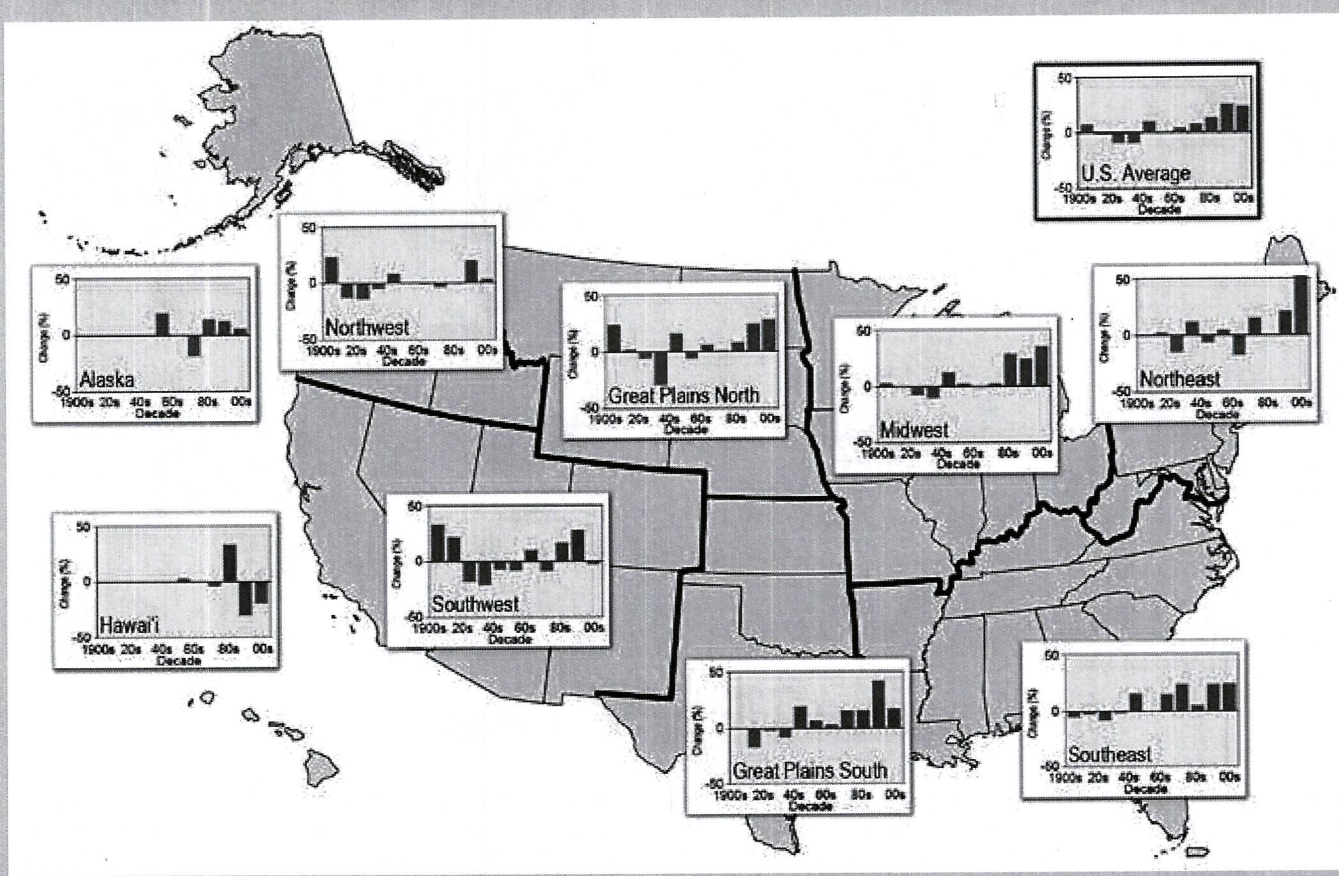


Figure 2.17. Percent changes in the annual amount of precipitation falling in very heavy events, defined as the heaviest 1% of all daily events from 1901 to 2012 for each region. The far right bar is for 2001-2012. In recent decades there have been increases nationally, with the largest increases in the Northeast, Great Plains, Midwest, and Southeast. Changes are compared to the 1901-1960 average for all regions except Alaska and Hawai'i, which are relative to the 1951-1980 average. (Figure source: NOAA NCDC / CICS-NC).

Warmer air can contain more water vapor than cooler air. Global analyses show that the amount of water vapor in the atmosphere has in fact increased over both land and oceans.[14,51] Climate change also alters dynamical characteristics of the atmosphere that in turn affect weather patterns and storms. In the mid-latitudes, where most of the continental U.S. is located, there is an upward trend in extreme precipitation in the vicinity of fronts associated with mid-latitude storms.[52] Locally, natural variations can also be important.[53]

Projections of future climate over the U.S. suggest that the recent trend towards increased heavy precipitation events will continue. This is projected to occur even in regions where total precipitation is projected to decrease, such as the Southwest.[52,54,55]

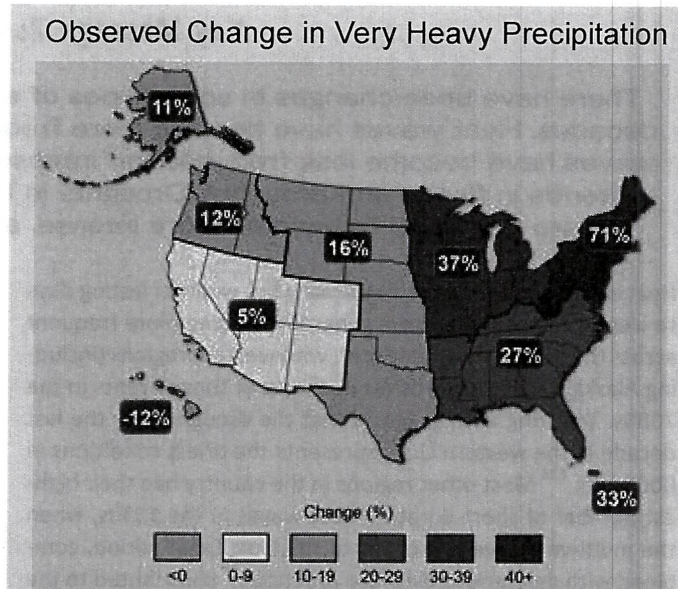


Figure 2.18. The map shows percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawai'i, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. (Figure source: updated from Karl et al. 2009[1]).

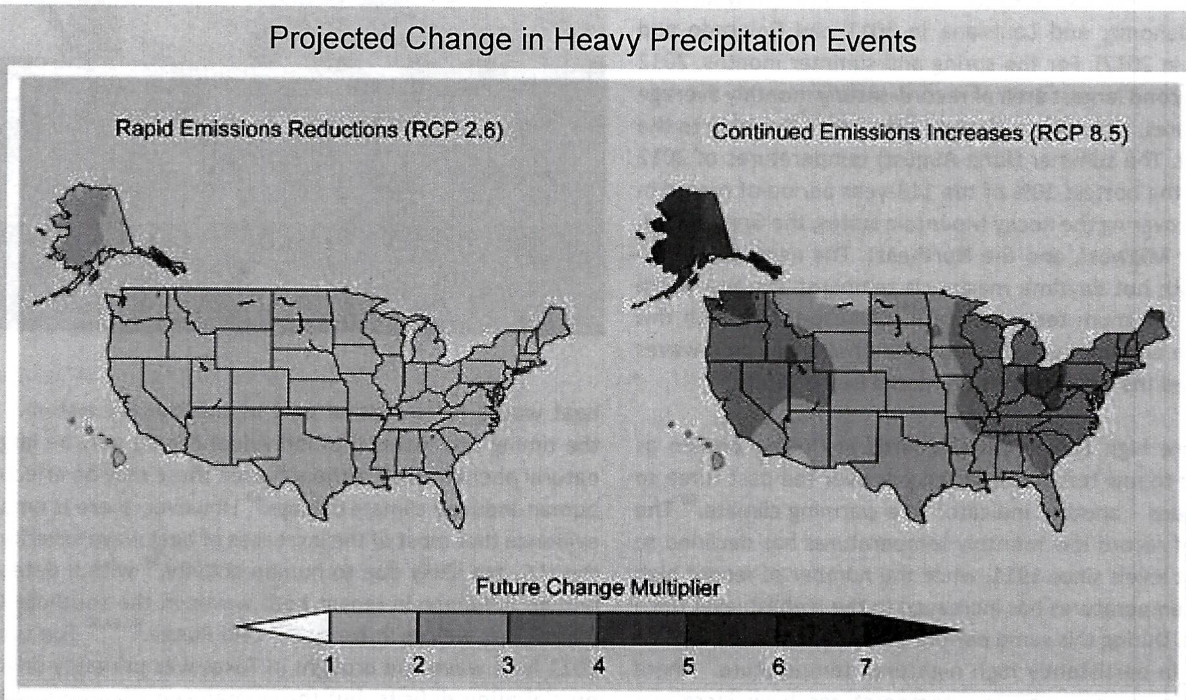


Figure 2.19. Maps show the increase in frequency of extreme daily precipitation events (a daily amount that now occurs once in 20 years) by the later part of this century (2081-2100) compared to the later part of last century (1981-2000). Such extreme events are projected to occur more frequently everywhere in the United States. Under the rapid emissions reduction scenario (RCP 2.6), these events would occur nearly twice as often. For the scenario assuming continued increases in emissions (RCP 8.5), these events would occur up to five times as often. (Figure source: NOAA NCDC / CICS-NC).

Key Message 7: Extreme Weather

There have been changes in some types of extreme weather events over the last several decades. Heat waves have become more frequent and intense, especially in the West. Cold waves have become less frequent and intense across the nation. There have been regional trends in floods and droughts. Droughts in the Southwest and heat waves everywhere are projected to become more intense, and cold waves less intense everywhere.

Heat waves are periods of abnormally hot weather lasting days to weeks.[48] Heat waves have generally become more frequent across the U.S. in recent decades, with western regions (including Alaska) setting records for numbers of these events in the 2000s. Tree ring data suggests that the drought over the last decade in the western U.S. represents the driest conditions in 800 years.[1,56] Most other regions in the country had their highest number of short-duration heat waves in the 1930s, when the multi-year severe drought of the Dust Bowl period, combined with deleterious land-use practices,[57] contributed to the intense summer heat through depletion of soil moisture and reduction of the moderating effects of evaporation.[58] However, the recent prolonged (multi-month) extreme heat has been unprecedented since the start of reliable instrumental records in 1895. The recent heat waves and droughts in Texas (2011) and the Midwest (2012) set records for highest monthly average temperatures, exceeding in some cases records set in the 1930s, including the highest monthly contiguous U.S. temperature on record (July 2012, breaking the July 1936 record) and the hottest summers on record in several states (New Mexico, Texas, Oklahoma, and Louisiana in 2011 and Colorado and Wyoming in 2012). For the spring and summer months, 2012 had the second largest area of record-setting monthly average temperatures, including a 26-state area from Wyoming to the East Coast. The summer (June-August) temperatures of 2012 ranked in the hottest 10% of the 118-year period of record in 28 states covering the Rocky Mountain states, the Great Plains, the Upper Midwest, and the Northeast. The new records included both hot daytime maximum temperatures and warm nighttime minimum temperatures.[59] Corresponding with this increase in extreme heat, the number of extreme cold waves has reached the lowest levels on record (since 1895).

Many more high temperature records are being broken as compared to low temperature records over the past three to four decades – another indicator of a warming climate.[60] The number of record low monthly temperatures has declined to the lowest levels since 1911, while the number of record high monthly temperatures has increased to the highest level since the 1930s. During this same period, there has been an increasing trend in persistently high nighttime temperature.[1] There are various reasons why low temperatures have increased more than high temperatures.[61]

In some areas, prolonged periods of record high temperatures associated with droughts contribute to dry conditions that are driving wildfires.[62] The meteorological situations that cause heat waves are a natural part of the climate system. Thus the timing and location of individual events may be largely a natural phenomenon, although even these may be affected by human-induced climate change.[63] However, there is emerging evidence that most of the increases of heat wave severity over the U.S. are likely due to human activity,[64] with a detectable human influence in recent heat waves in the southern Great Plains[1,65] as well as in Europe[7,62] and Russia.[60,66,67] The summer 2011 heat wave and drought in Texas was primarily driven by precipitation deficits, but the human contribution to climate change approximately doubled the probability that the heat was record-breaking.[68] So while an event such as this Texas heat wave and drought could be triggered by a naturally occurring event such as a deficit in precipitation, the chances for record-breaking temperature extremes has increased and will continue to increase as the global climate warms. Generally, the changes in climate are increasing the likelihood for these types of severe events.

The number of extremely hot days is projected to continue to increase over much of the United States, especially by late century. Summer temperatures are projected to continue rising, and a reduction of soil moisture, which exacerbates heat waves, is projected for much of the western and central U.S. in summer. Climate models project that the same summertime temperatures that ranked among the hottest 5% in 1950-1979 will occur at least 70% of the time by 2035-2064 in the U.S. if global emissions of heat-trapping gases continue to grow (as in the A2 scenario).[67] By the end of this century, what have previously been once-in-20-year extreme heat days (1-day events) are projected to occur every two or three years over most of the nation.[69,70] In other words, what now seems like an extremely hot day will become commonplace.

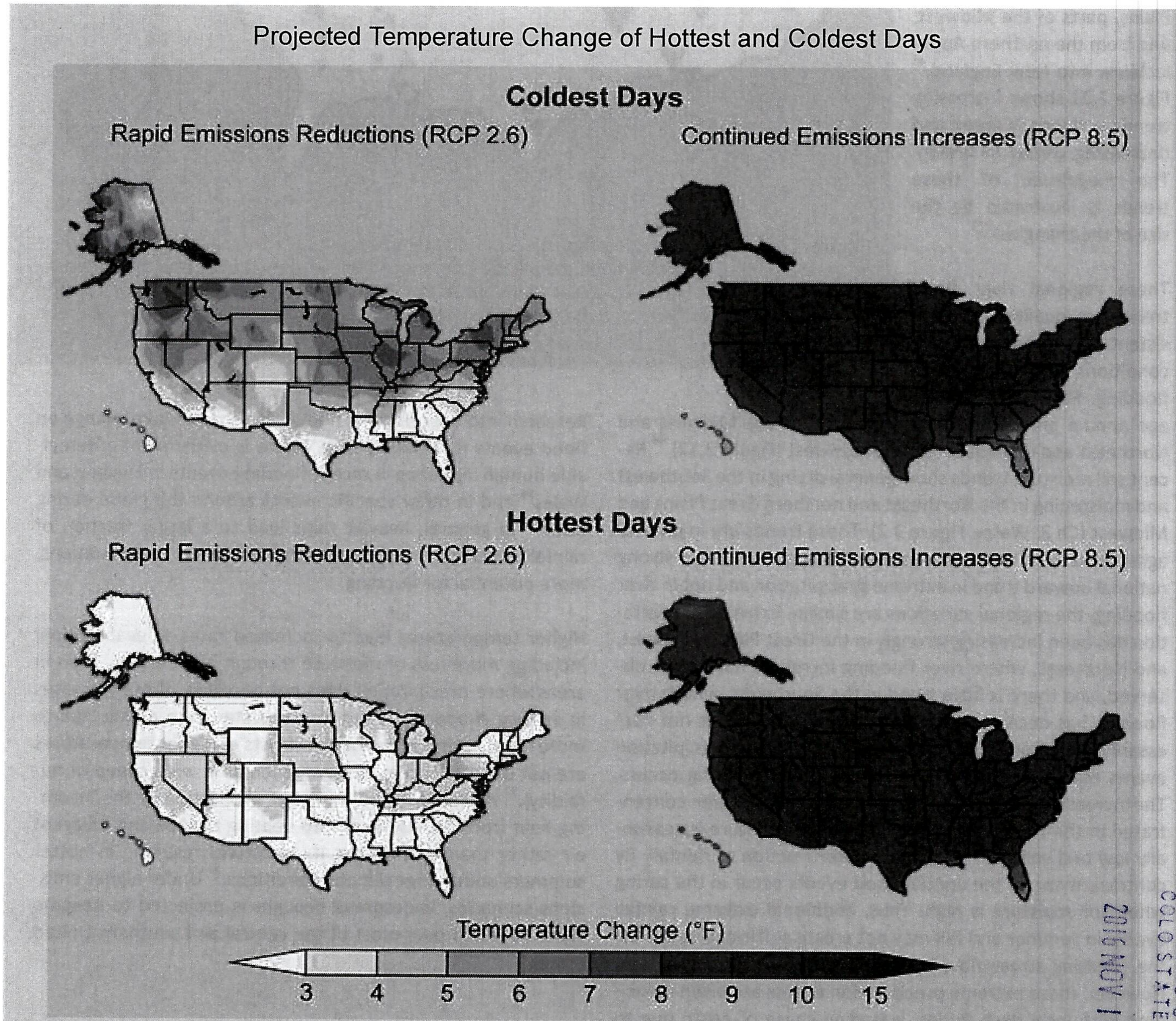


Figure 2.20. Change in surface air temperature at the end of this century (2081-2100) relative to the turn of the last century (1986-2005) on the coldest and hottest days under a scenario that assumes a rapid reduction in heat trapping gases (RCP 2.6) and a scenario that assumes continued increases in these gases (RCP 8.5). This figure shows estimated changes in the average temperature of the hottest and coldest days in each 20-year period. In other words, the hottest days will get even hotter, and the coldest days will be less cold. (Figure source: NOAA NCDC / CICS-NC).

There are significant trends in the magnitude of river flooding in many parts of the United States. When averaged over the entire nation, however, the increases and decreases cancel each other out and show no national level trend.[71] River flood magnitudes have decreased in the Southwest and increased in the eastern Great Plains, parts of the Midwest, and from the northern Appalachians into New England.[48] Figure 2.21 shows increasing trends in floods in green and decreasing trends in brown. The magnitude of these trends is illustrated by the size of the triangles.

These regional river flood trends are qualitatively consistent with trends in climate conditions associated with flooding. For example, average annual precipitation has increased in the Midwest and Northeast and decreased in the Southwest (Figure 2.12).[48] Recent soil moisture trends show general drying in the Southwest and moistening in the Northeast and northern Great Plains and Midwest (Ch 3: Water, Figure 3.2). These trends are in general agreement with the flood trends. Although there is a strong national upward trend in extreme precipitation and not in river flooding, the regional variations are similar. Extreme precipitation has been increasing strongly in the Great Plains, Midwest, and Northeast, where river flooding increases have been observed, and there is little trend in the Southwest, where river flooding has decreased. An exact correspondence is not necessarily expected since the seasonal timing of precipitation events makes a difference in whether river flooding occurs. The increase in extreme precipitation events has been concentrated in the summer and fall[52] when soil moisture is seasonally low and soils can absorb a greater fraction of rainfall. By contrast, many of the annual flood events occur in the spring when soil moisture is high. Thus, additional extreme rainfall events in summer and fall may not create sufficient runoff for the resulting streamflow to exceed spring flood magnitudes. However, these extreme precipitation events are often associated with local flash floods, a leading cause of death due to weather events (see "Flood Factors and Flood Types" in Ch. 3: Water).

Trends in Flood Magnitude

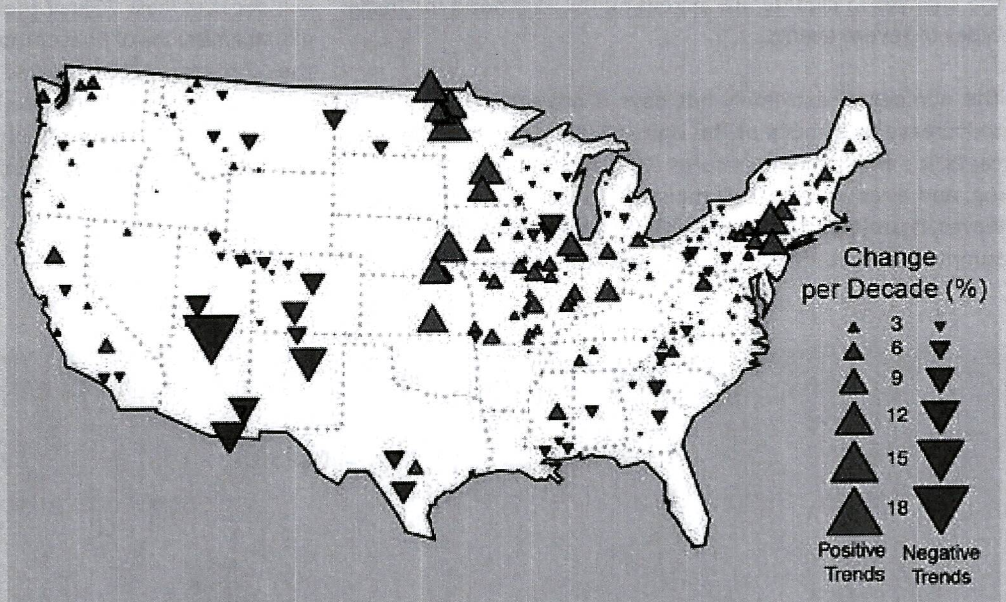


Figure 2.21. Trend magnitude (triangle size) and direction (green = increasing trend, brown = decreasing trend) of annual flood magnitude from the 1920s through 2008. Local areas can be affected by land-use change (such as dams). Most significant are the increasing trend for floods in the Midwest and Northeast and the decreasing trend in the Southwest. (Figure source: Peterson et al. 2013[48]).

Research into the effects of human-induced climate change on flood events is relatively new. There is evidence of a detectable human influence in recent flooding events in England and Wales[13] and in other specific events around the globe during 2011.[48] In general, heavier rains lead to a larger fraction of rainfall running off and, depending on the surface conditions, more potential for flooding.

Higher temperatures lead to increased rates of evaporation, including more loss of moisture through plant leaves. Even in areas where precipitation does not decrease, these increases in surface evaporation and loss of water from plants lead to more rapid drying of soils if the effects of higher temperatures are not offset by other changes (such as in wind speed or humidity).[72] As soil dries out, a larger proportion of the incoming heat from the sun goes into heating the soil and adjacent air rather than evaporating its moisture, resulting in hotter summers under drier climatic conditions.[73] Under higher emissions scenarios, widespread drought is projected to become more common over most of the central and southern United States.[56,74,75,76,77]

Projected Changes in Soil Moisture for the Western U.S.

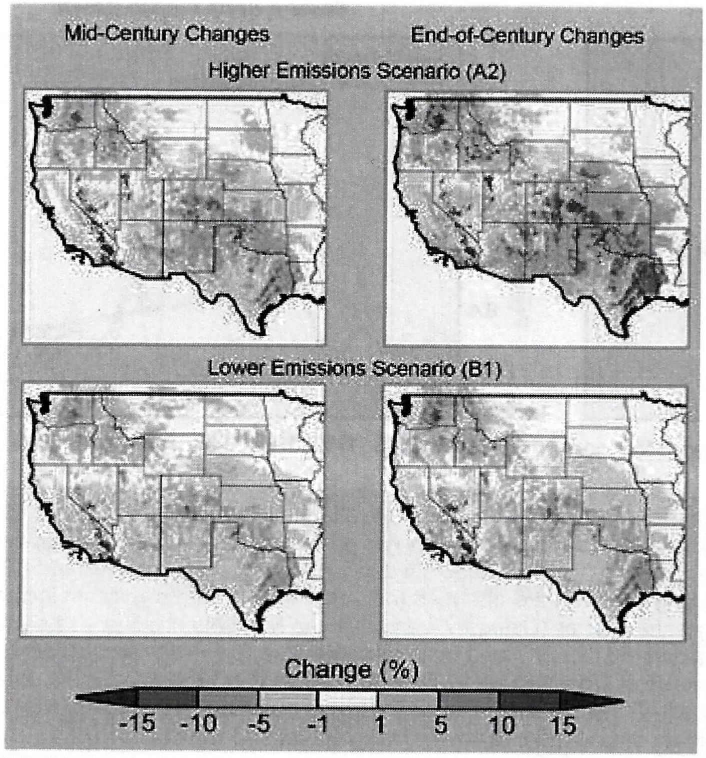


Figure 2.22. Average change in soil moisture compared to 1971-2000, as projected for the middle of this century (2041-2070) and late this century (2071-2100) under two emissions scenarios, a lower scenario (B1) and a higher scenario (A2).[75,77] The future drying of soils in most areas simulated by this sophisticated hydrologic model (Variable Infiltration Capacity or VIC model) is consistent with the future drought increases using the simpler Palmer Drought Severity Index (PDSI) metric. Only the western U.S. is displayed because model simulations were only run for this area. (Figure source: NOAA NCDC / CICS-NC).

Key Message 8: Changes in Hurricanes

The intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (Category 4 and 5) hurricanes, have all increased since the early 1980s. The relative contributions of human and natural causes to these increases are still uncertain. Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm.

There has been a substantial increase in most measures of Atlantic hurricane activity since the early 1980s, the period during which high-quality satellite data are available.[78,79] These include measures of intensity, frequency, and duration as well as the number of strongest (Category 4 and 5) storms. The ability to assess longer-term trends in hurricane activity is limited by the quality of available data. The historic record of Atlantic hurricanes dates back to the mid-1800s, and indicates other decades of high activity. However, there is considerable uncertainty in the record prior to the satellite era (early 1970s), and the further back in time one goes, the more uncertain the record becomes.[79]

The recent increases in activity are linked, in part, to higher sea surface temperatures in the region that Atlantic hurricanes form in and move through. Numerous factors have been shown to influence these local sea surface temperatures, including natural variability, human-induced emissions of heat-trapping gases, and particulate pollution. Quantifying the relative contributions of natural and human-caused factors is an active focus of research. Some studies suggest that natural variability, which includes the Atlantic Multidecadal Oscillation, is the dominant cause of the warming trend in the Atlantic since the 1970s,[80,81] while others argue that human-caused heat-trapping gases and particulate pollution are more important.[82]

Hurricane development, however, is influenced by more than just sea surface temperature. How hurricanes develop also depends on how the local atmosphere responds to changes in local sea surface temperatures, and this atmospheric response depends critically on the *cause* of the change.[83] For example, the atmosphere responds differently when local sea surface temperatures increase due to a local decrease of particulate pollution that allows more sunlight through to warm the ocean, versus when sea surface temperatures increase more uniformly around the world due to increased amounts of human-caused heat-trapping gases.[80,84] So the link between hurricanes and ocean temperatures is complex. Improving our

Observed Trends in Hurricane Power Dissipation

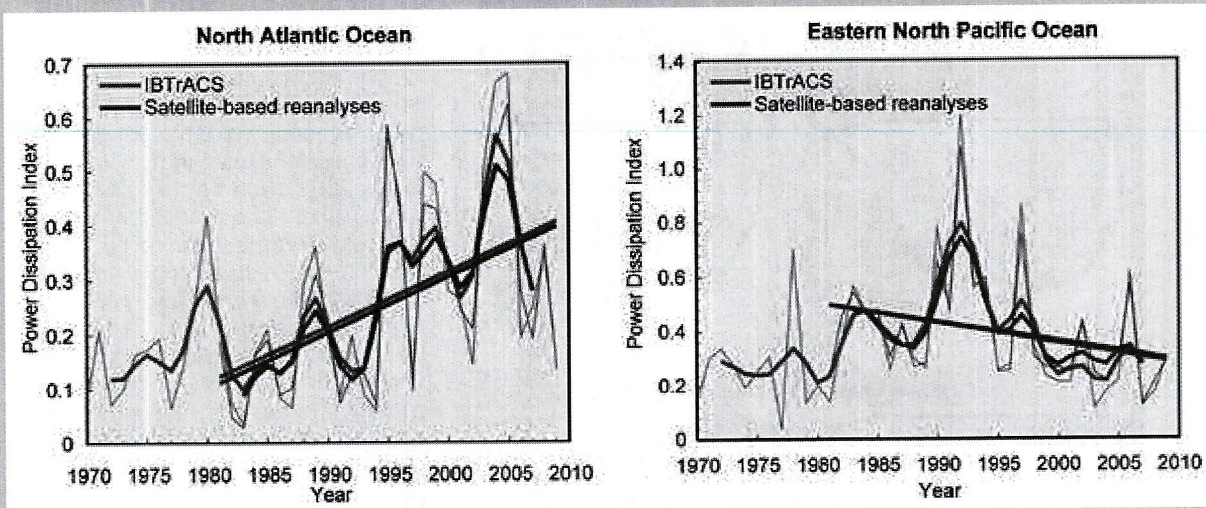
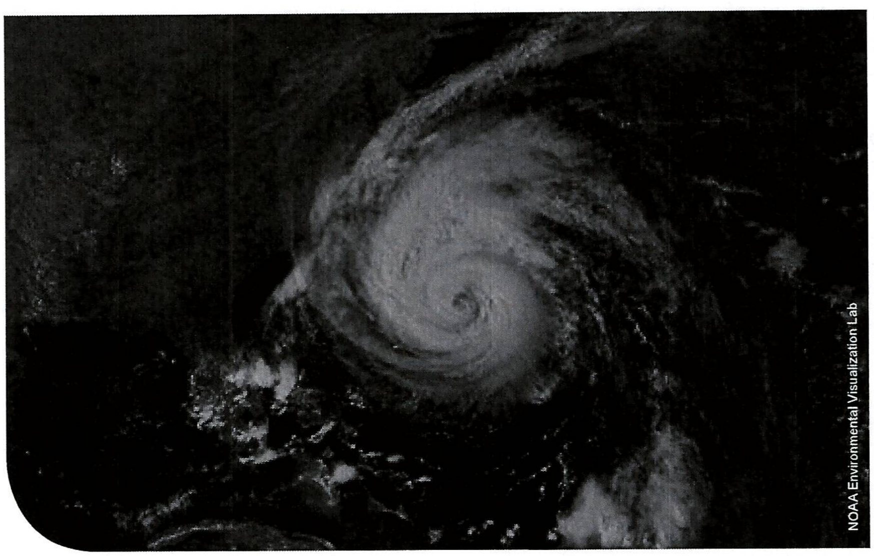


Figure 2.23. Recent variations of the Power Dissipation Index (PDI) in the North Atlantic and eastern North Pacific Oceans. PDI is an aggregate of storm intensity, frequency, and duration and provides a measure of total hurricane power over a hurricane season. There is a strong upward trend in Atlantic PDI, and a downward trend in the eastern North Pacific, both of which are well-supported by the reanalysis. Separate analyses (not shown) indicate a significant increase in the strength and in the number of the strongest hurricanes (Category 4 and 5) in the North Atlantic over this same time period. The PDI is calculated from historical data (IBTrACS[92]) and from reanalyses using satellite data (UW/NCDC & ADT-HURSAT[93,94]). IBTrACS is the International Best Track Archive for Climate Stewardship, UW/NCDC is the University of Wisconsin/NOAA National Climatic Data Center satellite-derived hurricane intensity dataset, and ADT-HURSAT is the Advanced Dvorak Technique–Hurricane Satellite dataset (Figure source: adapted from Kossin et al. 2007[93]).

understanding of the relationships between warming tropical oceans and tropical cyclones is another active area of research.

Changes in the average length and positions of Atlantic storm tracks are also associated with regional climate variability.[85] The locations and frequency of storms striking land have been argued to vary in opposing ways than basin-wide frequency. For example, fewer storms have been observed to strike land during warmer years even though overall activity is higher than average,[86] which may help to explain the lack of any clear trend in landfall frequency along the U.S. eastern and Gulf coasts.[87,88] Climate models also project changes in hurricane tracks and where they strike land.[89] The specific characteristics of the changes are being actively studied.

Other measures of Atlantic storm activity are projected to change as well.[87,90,91] By late this century, models, on average, project a slight decrease in the annual number of tropical cyclones, but an increase in the number of the strongest (Category 4 and 5) hurricanes. These projected changes are based on an average of projections from a number of individual models, and they represent the most likely outcome. There is some uncertainty in this as the individual models do not always agree on the amount of projected change, and some models may project an increase where others project a decrease. The models are in better agreement when projecting changes in hurricane precipitation – almost all existing studies project greater rainfall rates in hurricanes in a warmer climate, with projected increases of about 20% averaged near the center of hurricanes.



North Atlantic hurricanes have increased in intensity, frequency, and duration since the early 1980s.

Key Message 9: Changes in Storms

Winter storms have increased in frequency and intensity since the 1950s, and their tracks have shifted northward over the United States. Other trends in severe storms, including the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds, are uncertain and are being studied intensively.

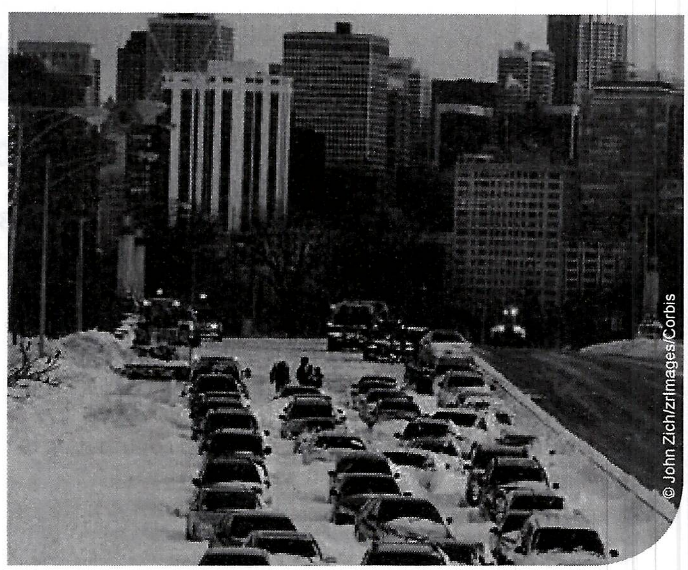
Trends in the occurrences of storms, ranging from severe thunderstorms to winter storms to hurricanes, are subject to much greater uncertainties than trends in temperature and variables that are directly related to temperature (such as snow and ice cover, ocean heat content, and sea level). Recognizing that the impacts of changes in the frequency and intensity of these storms can easily exceed the impacts of changes in average temperature or precipitation, climate scientists are actively researching the connections between climate change and severe storms. There has been a sizeable upward trend in the number of storms causing large financial and other losses.[95] However, there are societal contributions to this trend, such as increases in population and wealth.[52]

Severe Convective Storms

Tornadoes and other severe thunderstorm phenomena frequently cause as much annual property damage in the U.S. as do hurricanes, and often cause more deaths. Recent research has yielded insights into the connections between global warming and the factors that cause tornadoes and severe thunderstorms (such as atmospheric instability and increases in wind speed with altitude[96]). Although these relationships are still being explored, a recent study suggests a projected increase in the frequency of conditions favorable for severe thunderstorms.[97]

Winter Storms

For the entire Northern Hemisphere, there is evidence of an increase in both storm frequency and intensity during the cold season since 1950,[98] with storm tracks having shifted slightly towards the poles.[99,100] Extremely heavy snowstorms increased in number during the last century in northern and eastern parts of the United States, but have been less frequent since 2000.[52,101] Total seasonal snowfall has generally decreased in southern and some western areas,[102] increased in the northern Great Plains and Great Lakes region,[102,103] and not changed in other areas, such as the Sierra Nevada, although snow is melting earlier in the year and more precipitation is falling as rain versus snow.[104] Very snowy winters have generally been decreasing in frequency in most regions over the last 10 to 20 years, although the Northeast has been seeing a normal number of such winters.[105] Heavier-than-normal snowfalls recently observed in the Midwest and Northeast U.S. in some years, with little snow in other years, are consistent with indications of increased blocking (a large scale pressure pattern with little or no movement) of the wintertime circulation of the Northern Hemisphere.[106] However, conclusions about trends in blocking have been found to depend on the method of analysis,[107] so the assessment and attribution of trends in blocking remains an active research area. Overall snow cover has decreased in the Northern Hemisphere, due in part to higher temperatures that shorten the time snow spends on the ground.[108]



Variation of Storm Frequency and Intensity during the Cold Season (November – March)

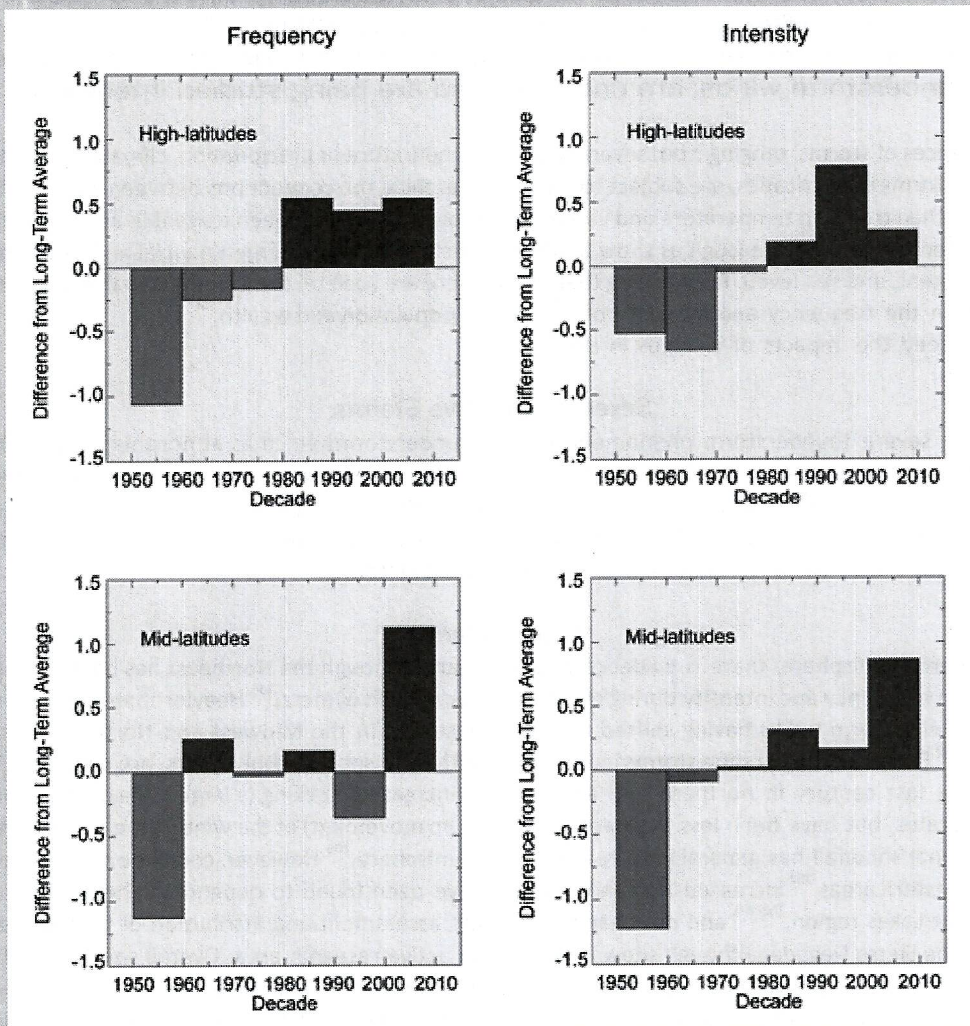


Figure 2.24. Variation of winter storm frequency and intensity during the cold season (November-March) for high latitudes (60-90°N) and mid-latitudes (30-60°N) of the Northern Hemisphere over the period 1949-2010. The bar for each decade represents the difference from the long-term average. Storm frequencies have increased in middle and high latitudes, and storm intensities have increased in middle latitudes. (Figure source: updated from CCSP 2008[109]).

Key Message 10: Sea Level Rise

Global sea level has risen by about 8 inches since reliable record keeping began in 1880. It is projected to rise another 1 to 4 feet by 2100.

The oceans are absorbing over 90% of the increased atmospheric heat associated with emissions from human activity.[110] Like mercury in a thermometer, water expands as it warms up (this is referred to as "thermal expansion") causing sea levels to rise. Melting of glaciers and ice sheets is also contributing to sea level rise at increasing rates.[111]

Since the late 1800s, tide gauges throughout the world have shown that global sea level has risen by about 8 inches. A new data set (Figure 2.25) shows that this recent rise is much greater than at any time in at least the past 2000 years.[112] Since 1992, the rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century, providing evidence of additional acceleration.[113]

Projecting future rates of sea level rise is challenging. Even the most sophisticated climate models, which explicitly represent Earth's physical processes, cannot simulate rapid changes in ice sheet dynamics, and thus are likely to underestimate future sea level rise. In recent years, "semi-empirical" methods have been developed to project future rates of sea level rise based on a simple statistical relationship between past rates of globally averaged temperature change and sea level rise. These models suggest a range of additional sea level rise from about 2 feet to as much as 6 feet by 2100, depending on emissions scenario.[114,115,116,117] It is not clear, however, whether these statistical relationships will hold in the future, or that they fully explain historical behavior.[118] Regardless of the amount of change by 2100, however, sea level rise is expected to continue well beyond this century as a result of both past and future emissions from human activities.

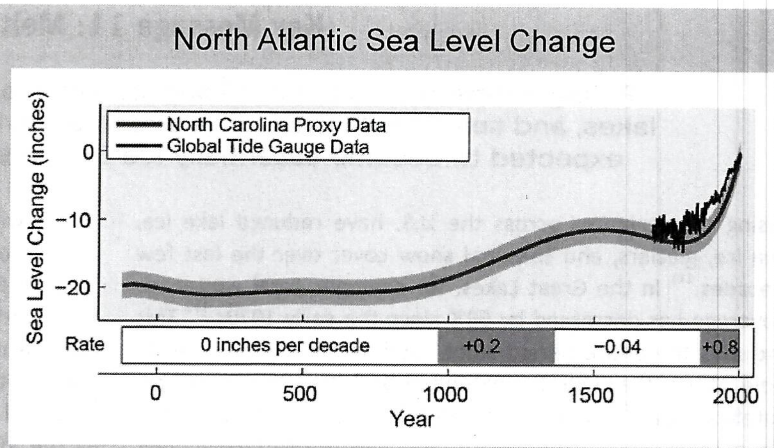


Figure 2.25. Sea level change in the North Atlantic Ocean relative to the year 2000 based on data collected from North Carolina[112] (red line, pink band shows the uncertainty range) compared with a reconstruction of global sea level rise based on tide gauge data from 1750 to present[127] (blue line). (Figure source: Adapted from Kemp et al. 2011[112]).

Scientists are working to narrow the range of sea level rise projections for this century. Recent projections show that for even the lowest emissions scenarios, thermal expansion of ocean waters[119] and the melting of small mountain glaciers[120] will result in 11 inches of sea level rise by 2100, even without any contribution from the ice sheets in Greenland and Antarctica. This suggests that about 1 foot of global sea level rise by 2100 is probably a realistic low end. On the high end, recent work suggests that 4 feet is plausible.[22,115,121] In the context of risk-based analysis, some decision makers may wish to use a wider range of scenarios, from 8 inches to 6.6 feet by 2100.[122,123] In particular, the high end of these scenarios may be useful for decision makers with a low tolerance for risk (see Figure 2.26 on global sea level rise).[122,123] Although scientists cannot yet assign likelihood to any particular scenario, in general, higher emissions scenarios that lead to more warming would be expected to lead to higher amounts of sea level rise.

Nearly 5 million people in the U.S. live within 4 feet of the local high-tide level (also known as mean higher high water). In the next several decades, storm surges and high tides could combine with sea level rise and land subsidence to further increase flooding in many of these regions.[124] Sea level rise will not stop in 2100 because the oceans take a very long time to respond to warmer conditions at the Earth's surface. Ocean waters will therefore continue to warm and sea level will continue to rise for many centuries at rates equal to or higher than that of the current century.[125] In fact, recent research has suggested that even present day carbon dioxide levels are sufficient to cause Greenland to melt completely over the next several thousand years.[126]

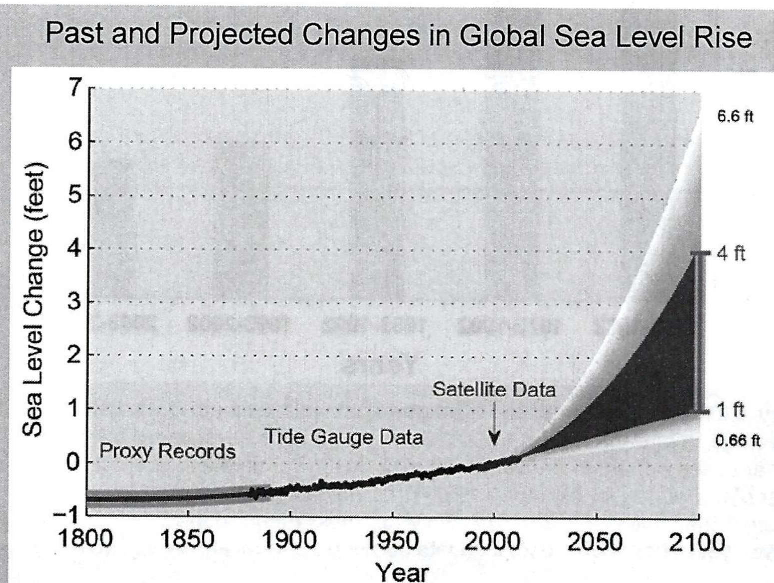


Figure 2.26. Estimated, observed, and possible future amounts of global sea level rise from 1800 to 2100, relative to the year 2000. Estimates from proxy data[112] (for example, based on sediment records) are shown in red (1800-1890, pink band shows uncertainty), tide gauge data are shown in blue for 1880-2009,[113] and satellite observations are shown in green from 1993 to 2012.[128] The future scenarios range from 0.66 feet to 6.6 feet in 2100.[123] These scenarios are not based on climate model simulations, but rather reflect the range of possible scenarios based on other scientific studies. The orange line at right shows the currently projected range of sea level rise of 1 to 4 feet by 2100, which falls within the larger risk-based scenario range. The large projected range reflects uncertainty about how glaciers and ice sheets will react to the warming ocean, the warming atmosphere, and changing winds and currents. As seen in the observations, there are year-to-year variations in the trend. (Figure source: Adapted from Parris et al. 2012,[123] with contributions from NASA Jet Propulsion Laboratory).

Key Message 11: Melting Ice

Rising temperatures are reducing ice volume and surface extent on land, lakes, and sea. This loss of ice is expected to continue. The Arctic Ocean is expected to become essentially ice free in summer before mid-century.

Rising temperatures across the U.S. have reduced lake ice, sea ice, glaciers, and seasonal snow cover over the last few decades.[111] In the Great Lakes, for example, total winter ice coverage has decreased by 63% since the early 1970s.[172] This includes the entire period since satellite data became available. When the record is extended back to 1963 using pre-satellite data,[129] the overall trend is less negative because the Great Lakes region experienced several extremely cold winters in the 1970s.

Sea ice in the Arctic has also decreased dramatically since the late 1970s, particularly in summer and autumn. Since the satellite record began in 1978, minimum Arctic sea ice extent (which occurs in early to mid-September) has decreased by more than 40%.[131] This decline is unprecedented in the historical record, and the reduction of ice volume and thickness is even greater. Ice thickness decreased by more than 50% from 1958-1976 to 2003-2008,[132] and the percentage of the March ice cover made up of thicker ice (ice that has survived a summer melt season) decreased from 75% in the mid-1980s to 45% in 2011.[133] Recent analyses indicate a decrease of 36% in autumn sea ice volume over the past decade.[134] The 2012 sea ice minimum broke the preceding record (set in 2007) by more than 200,000 square miles. Ice loss increases Arctic warming by replacing white, reflective ice with dark water that absorbs more energy from the sun. More open water can also increase snowfall over northern land areas[135] and increase the north-south meanders of the jet stream, consistent with the occurrence of unusually cold and snowy winters at mid-latitudes in several recent years.[106,135] Significant uncertainties remain at this time in interpreting the effect of Arctic ice changes on mid-latitudes.[107]

The loss of sea ice has been greater in summer than in winter. The Bering Sea, for example, has sea ice only in the winter-spring portion of the year, and shows no trend in surface area covered by ice over the past 30 years. However, seasonal ice in the Bering Sea and elsewhere in the Arctic is thin and susceptible to rapid melt during the following summer.

The seasonal pattern of observed loss of Arctic sea ice is generally consistent with simulations by global climate models, in which the extent of sea ice decreases more rapidly in summer than in winter. However, the models tend to underestimate the amount of decrease since 2007. Projections by these models indicate that the Arctic Ocean is expected to become essentially ice-free in summer before mid-century under scenarios that assume continued growth in global emissions, although sea ice would still form in winter.[136,137] Models that best match historical trends project a nearly sea ice-free Arctic in summer by the 2030s,[138] and extrapolation of the present observed trend suggests an even earlier ice-free Arctic in summer.[139] However, even during a long-term decrease, occasional temporary increases in Arctic summer sea ice can be expected over timescales of a decade or so because of natural variability.[140] The projected reduction of winter sea ice is only about 10% by 2030,[141] indicating that the Arctic will shift to a more seasonal sea ice pattern. While this ice will be thinner, it will cover much of the same area now covered by sea ice in winter.

While the Arctic is an ocean surrounded by continents, Antarctica is a continent surrounded by ocean. Nearly all of the sea ice in the Antarctic melts each summer, and changes there are more complicated than in the Arctic. While Arctic sea ice has

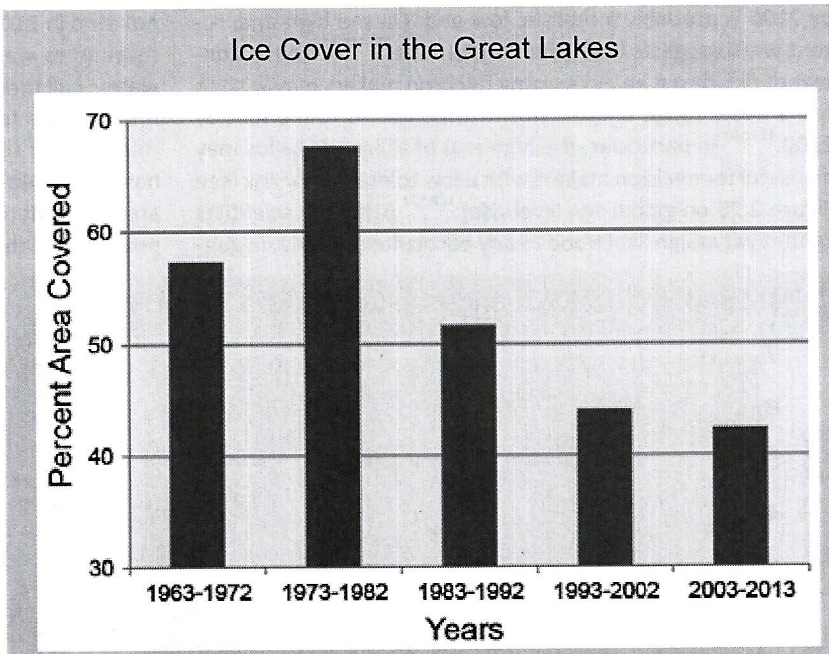


Figure 2.27. Bars show decade averages of annual maximum Great Lakes ice coverage from the winter of 1962-1963, when reliable coverage of the entire Great Lakes began, to the winter of 2012-2013. Bar labels indicate the end year of the winter; for example, 1963-1972 indicates the winter of 1962-1963 through the winter of 1971-1972. Only the most recent period includes the eleven years from 2003 to 2013. (Data updated from Bai and Wang, 2012[130]).

Decline in Arctic Sea Ice Extent

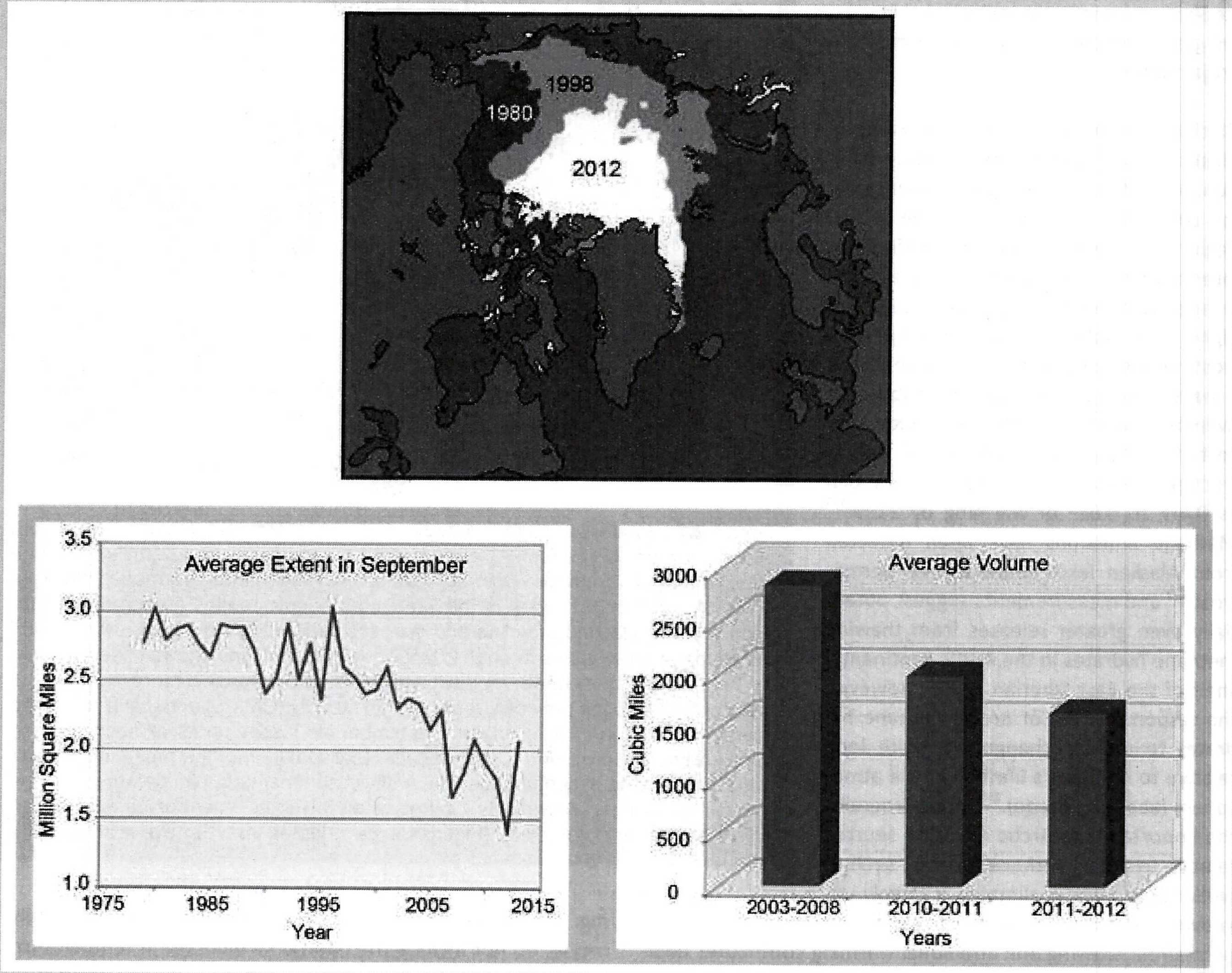


Figure 2.28. Summer Arctic sea ice has declined dramatically since satellites began measuring it in 1979. The extent of sea ice in September 2012, shown in white in the top figure, was more than 40% below the median for 1979-2000. The graph on the bottom left shows annual variations in September Arctic sea ice extent for 1979-2013. It is also notable that the ice has become much thinner in recent years, so its total volume (bottom right) has declined even more rapidly than the extent.[111] (Figure and data from National Snow and Ice Data Center).

been strongly decreasing, there has been a slight increase in sea ice in Antarctica.[142] Explanations for this include changes in winds that directly affect ice drift as well as the properties of the surrounding ocean,[143] and that winds around Antarctica may have been affected by stratospheric ozone depletion.[144]

Snow cover on land has decreased over the past several decades,[145] especially in late spring.[146] Each of five recent years (2008-2012) has set a new record for minimum snow extent in June in Eurasia, as did three of those five years in North America.

The surface of the Greenland Ice Sheet has been experiencing summer melting over increasingly large areas during the past several decades. In the decade of the 2000s, the daily melt area summed over the warm season was double the corresponding amounts of the 1970s,[147] culminating in summer surface melt that was far greater (97% of the Greenland Ice Sheet area) in 2012 than in any year since the satellite record began in 1979. More importantly, the rate of mass loss from the Greenland Ice Sheet's marine-terminating outlet glaciers has accelerated in recent decades, leading to predictions that the proportion of global sea level rise coming from Greenland will continue to increase.[148] Glaciers terminating on ice shelves and on land are also losing mass, but the rate of loss has not accelerated over the past decade.[149] As discussed in Key Message 10, the dynamics of the Greenland Ice Sheet are generally not included in present global climate models and sea level rise projections.

Glaciers are retreating and/or thinning in Alaska and in the lower 48 states. In addition, permafrost temperatures are increasing over Alaska and much of the Arctic. Regions of discontinuous permafrost in interior Alaska (where annual average soil temperatures are already close to 32°F) are highly vulnerable to thaw. Thawing permafrost releases carbon dioxide and methane – heat-trapping gases that contribute to even more warming. Recent estimates suggest that the potential release of carbon from permafrost soils could add as much as 0.4ºF to 0.6ºF of warming by 2100.[150] Methane emissions have been detected from Alaskan lakes underlain by permafrost,[151] and measurements suggest potentially even greater releases from thawing methane hydrates in the Arctic continental shelf of the East Siberian Sea.[152] However, the response times of Arctic methane hydrates to climate change are quite long relative to methane's lifetime in the atmosphere (about a decade).[153] More generally, the importance of Arctic methane sources relative to other methane sources, such as wetlands in warmer climates, is largely unknown. The potential for a self-reinforcing feedback between permafrost thawing and additional warming contributes additional uncertainty to the high end of the range of future warming. The projections of future climate shown throughout this report do not include the additional increase in temperature associated with this thawing.

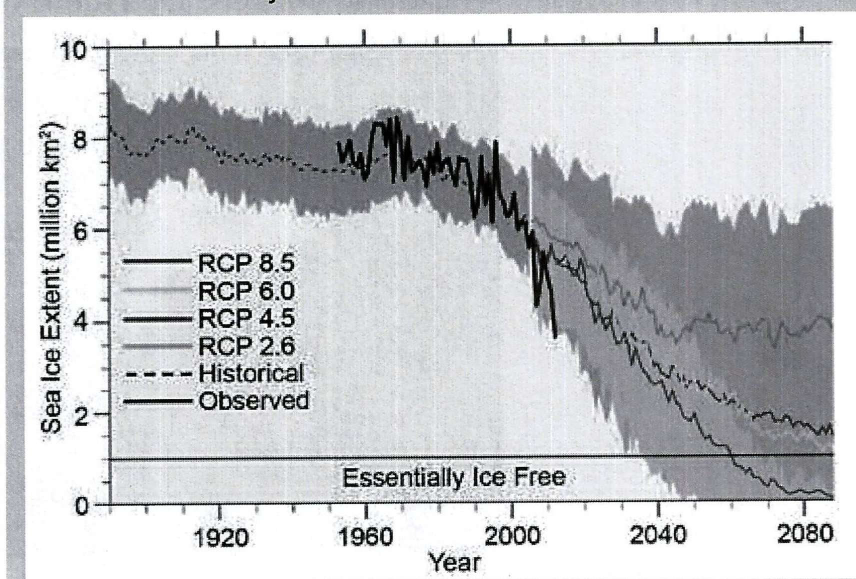


Figure 2.29. Model simulations of Arctic sea ice extent for September (1900-2100) based on observed concentrations of heat-trapping gases and particles (through 2005) and four scenarios. Colored lines for RCP scenarios are model averages (CMIP5) and lighter shades of the line colors denote ranges among models for each scenario. Dotted gray line and gray shading denotes average and range of the historical simulations through 2005. The thick black line shows observed data for 1953-2012. These newer model (CMIP5) simulations project more rapid sea ice loss compared to the previous generation of models (CMIP3) under similar forcing scenarios, although the simulated September ice losses under all scenarios still lag the observed loss of the past decade. Extrapolation of the present observed trend suggests an essentially ice-free Arctic in summer before mid-century.[139] The Arctic is considered essentially ice-free when the areal extent of ice is less than one million square kilometers. (Figure source: adapted from Stroeve et al. 2012[136]).

Key Message 12: Ocean Acidification

The oceans are currently absorbing about a quarter of the carbon dioxide emitted to the atmosphere annually and are becoming more acidic as a result, leading to concerns about intensifying impacts on marine ecosystems.

As human-induced emissions of carbon dioxide (CO_2) build up in the atmosphere, excess CO_2 is dissolving into the oceans where it reacts with seawater to form carbonic acid, lowering ocean pH levels ("acidification") and threatening a number of marine ecosystems.[154] Currently, the oceans absorbs about a quarter of the CO_2 humans produce every year.[155] Over the last 250 years, the oceans have absorbed 560 billion tons of CO_2, increasing the acidity of surface waters by 30%.[156,157,158] Although the average oceanic pH can vary on interglacial timescales,[156] the current observed rate of change is roughly 50 times faster than known historical change.[159,160] Regional factors such as coastal upwelling,[161] changes in discharge rates from rivers and glaciers,[162] sea ice loss,[163] and urbanization[164] have created "ocean acidification hotspots" where changes are occurring at even faster rates.

The acidification of the oceans has already caused a suppression of carbonate ion concentrations that are critical for marine calcifying animals such as corals, zooplankton, and shellfish. Many of these animals form the foundation of the marine food web. Today, more than a billion people worldwide rely on food from the ocean as their primary source of protein. Ocean acidification puts this important resource at risk.

Observations have shown that the northeastern Pacific Ocean, including the Arctic and sub-Arctic seas, is particularly susceptible to significant shifts in pH and calcium carbonate saturation levels. Recent analyses show that large areas of the oceans along the U.S. west coast,[157,165] the Bering Sea, and the western Arctic Ocean[158,166] will become difficult for calcifying animals within the next 50 years. In particular, animals that form calcium carbonate shells, including corals, crabs, clams, oysters, and tiny free-swimming snails called pteropods, could be particularly vulnerable, especially during the larval stage.[167,168,169]

Projections indicate that in higher emissions pathways, such as SRES A2 or RCP 8.5, current pH could be reduced from the current level of 8.1 to as low as 7.8 by the end of the century.[158] Such large changes in ocean pH have probably not been experienced on the planet for the past 100 million years, and it is unclear whether and how quickly ocean life could adapt to such rapid acidification.[159]

As Oceans Absorb CO_2, They Become More Acidic

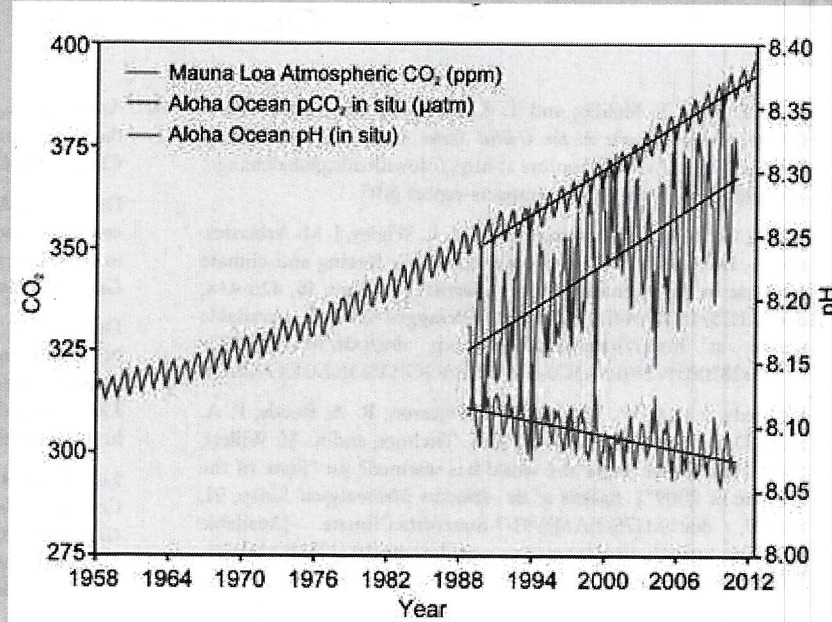


Figure 2.30. The correlation between rising levels of CO_2 in the atmosphere (red) at Mauna Loa and rising CO_2 levels (blue) and falling pH (green) in the nearby ocean at Station Aloha. As CO_2 accumulates in the ocean, the water becomes more acidic (the pH declines). (Figure source: modified from Feely et al. 2009[157]).

Shells Dissolve in Acidified Ocean Water

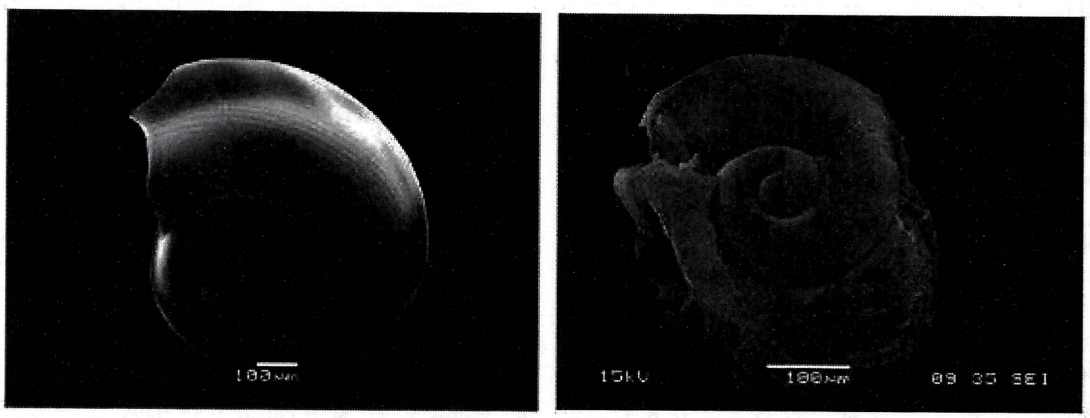


Figure 2.31. Pteropods, or "sea butterflies," are free-swimming sea snails about the size of a small pea. Pteropods are eaten by marine species ranging in size from tiny krill to whales and are an important source of food for North Pacific juvenile salmon. The photos above show what happens to a pteropod's shell in seawater that is too acidic. The left panel shows a shell collected from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod collected in a region where the water is more acidic (Photo credits: (left) Bednaršek et al. 2012;[168] (right) Nina Bednaršek).

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages
Development of the key messages involved discussions of the lead authors and accompanying analyses conducted via one in-person meeting plus multiple teleconferences and email exchanges from February thru September 2012. The authors reviewed 80 technical inputs provided by the public, as well as other published literature, and applied their professional judgment.

Key message development also involved the findings from four special workshops that related to the latest scientific understanding of climate extremes. Each workshop had a different theme related to climate extremes, had approximately 30 attendees (the CMIP5 meeting had more than 100), and the workshops resulted in a paper.[55] The first workshop was held in July 2011, titled Monitoring Changes in Extreme Storm Statistics: State of Knowledge.[52] The second was held in November 2011, titled Forum on Trends and Causes of Observed Changes in Heatwaves, Coldwaves, Floods, and Drought.[48] The third was held in January 2012, titled Forum on Trends in Extreme Winds, Waves, and Extratropical Storms along the Coasts.[98] The fourth, the CMIP5 results workshop, was held in March 2012 in Hawai'i, and resulted in an analysis of CMIP5 results relative to climate extremes in the United States.[55]

The Chapter Author Team's discussions were supported by targeted consultation with additional experts. Professional expertise and judgment led to determining "key vulnerabilities." A consensus-based approach was used for final key message selection.

Key message #1 Traceable Account

Global climate is changing and this change is apparent across a wide range of observations. The global warming of the past 50 years is primarily due to human activities.

Description of evidence base
The key message and supporting text summarizes extensive evidence documented in the climate science literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Evidence for changes in global climate arises from multiple analyses of data from in-situ, satellite, and other records undertaken by many groups over several decades.[3] Changes in the mean state have been accompanied by changes in the frequency and nature of extreme events.[4] A substantial body of analysis comparing the observed changes to a broad range of climate simulations consistently points to the necessity of invoking human-caused changes to adequately explain the observed climate system behavior.[5,7] The influence of human impacts on the climate system has also been observed in a number of individual climate variables.[6,12,13,14,15,16,17] A discussion of the slowdown in temperature increase with associated references (for example, Balmaseda et al. 2013; Easterling and Wehner 2009[19,27]) is included in the chapter.

The Climate Science Supplement Appendix provides further discussion of types of emissions or heat-trapping gases and particles, and future projections of human-related emissions. Supplemental Message 4 of the Appendix provides further details on attribution of observed climate changes to human influence.

New information and remaining uncertainties
Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to simulate and attribute such changes using climate models. Innovative new approaches to climate data analysis, continued improvements in climate modeling, and instigation and maintenance of reference quality observation networks such as the U.S. Climate Reference Network (http://www.ncdc.noaa.gov/crn/) all have the potential to reduce uncertainties.

Assessment of confidence based on evidence
There is **very high** confidence that global climate is changing and this change is apparent across a wide range of observations, given the evidence base and remaining uncertainties. All observational evidence is consistent with a warming climate since the late 1800s.

There is **very high** confidence that the global climate change of the past 50 years is primarily due to human activities, given the evidence base and remaining uncertainties. Recent changes have been consistently attributed in large part to human factors across a very broad range of climate system characteristics.

KEY MESSAGE #2 TRACEABLE ACCOUNT

Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the Earth's climate is to those emissions.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Evidence of continued global warming is based on past observations of climate change and our knowledge of the climate system's response to heat-trapping gases. Models have projected increased temperature under a number of different scenarios.[8,32,33]

That the planet has warmed is "unequivocal,"[8] and is corroborated though multiple lines of evidence, as is the conclusion that the causes are very likely human in origin (see also Appendices 3 and 4). The evidence for future warming is based on fundamental understanding of the behavior of heat-trapping gases in the atmosphere. Model simulations provide bounds on the estimates of this warming.

New information and remaining uncertainties

The trends described in the 2009 report[1] have continued, and our understanding of the data and ability to model the many facets of the climate system have increased substantially.

There are several major sources of uncertainty in making projections of climate change. The relative importance of these changes over time.

In the next few decades, the effects of natural variability will be an important source of uncertainty for climate change projections.

Uncertainty in future human emissions becomes the largest source of uncertainty by the end of this century.

Uncertainty in how sensitive the climate is to increased concentrations of heat-trapping gases is especially important beyond the next few decades. Recent evidence lends further confidence about climate sensitivity (see Appendix 3: Climate Science Supplement).

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Uncertainty in natural climate drivers, for example how much solar output will change over this century, also affects the accuracy of projections.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **very high** that the global climate is projected to continue to change over this century and beyond.

The statement on the magnitude of the effect also has **very high** confidence.

KEY MESSAGE #3 TRACEABLE ACCOUNT

U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The most recent decade was the nation's warmest on record. Temperatures in the United States are expected to continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, uniform or smooth across the country or over time.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Evidence for the long-term increase in temperature is based on analysis of daily maximum and minimum temperature observations from the U.S. Cooperative Observer Network (http://www.nws.noaa.gov/om/coop/). With the increasing understanding of U.S. temperature measurements, a temperature increase has been observed, and temperature is projected to continue rising.[36,37,38] Observations show that the last decade was the warmest in over a century. A number of climate model simulations were performed to assess past, and to forecast future, changes in climate; temperatures are generally projected to increase across the United States.

The section entitled "Quantifying U.S. Temperature Rise" explains the rational for using the range 1.3°F to 1.9°F in the key message.

All peer-reviewed studies to date satisfying the assessment process agree that the U.S. has warmed over the past century and in the past several decades. Climate model simulations consistently project future warming and bracket the range of plausible increases.

New information and remaining uncertainties

Since the 2009 National Climate Assessment,[1] there have been substantial advances in our understanding of the U.S. temperature record (Appendix 3: Climate Science, Supplemental Message 7).[36,37,38]

A potential uncertainty is the sensitivity of temperature trends to adjustments that account for historical changes in station location, temperature instrumentation, observing practice, and siting conditions. However, quality analyses of these uncertainties have not found any major issues of concern affecting the conclusions made in the key message (Appendix 3: Climate Science, Supplemental Message 7). (for example, Williams et al. 2012[38]).

While numerous studies (for example, Fall et al. 2011; Vose et al. 2012; Williams et al. 2012[37,38]) verify the efficacy of the adjustments, the information base can be improved in the future through continued refinements to the adjustment approach. Model biases are subject to changes in physical effects on climate; for example, model biases can be affected by snow cover and hence are subject to change as a warming climate changes snow cover.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **very high** in the key message. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, uniform or smooth across the country or over time.

KEY MESSAGE #4 TRACEABLE ACCOUNT

The length of the frost-free season (and the corresponding growing season) has been increasing nationally since the 1980s, with the largest increases occurring in the western United States, affecting ecosystems and agriculture. Across the United States, the growing season is projected to continue to lengthen.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Nearly all studies to date published in the peer-reviewed literature (for example, Dragoni et al. 2011; EPA 2012; Jeong et al. 2011[40,41,43]) agree that the frost-free and growing seasons have lengthened. This is most apparent in the western United States. Peer-reviewed studies also indicate that continued lengthening will occur if concentrations of heat-trapping gases continue to rise. The magnitude of future changes based on model simulations is large in the context of historical variations.

Evidence that the length of the frost-free season is lengthening is based on extensive analysis of daily minimum temperature observations from the U.S. Cooperative Observer Network. The geographic variations in increasing number of frost-free days are similar to the regional variations in mean temperature. Separate analysis of surface data also indicates a trend towards an earlier onset of spring.[40,41,43,45]

New information and remaining uncertainties

A key issue (uncertainty) is the potential effect on observed trends of climate monitoring station inhomogeneities (differences), particularly those arising from instrumentation changes. A second key issue is the extent to which observed regional variations (more lengthening in the west/less in the east) will persist into the future.

Local temperature biases in climate models contribute to the uncertainty in projections.

Viable avenues to improving the information base are to investigate the sensitivity of observed trends to potential biases introduced by station inhomogeneities and to investigate the causes of observed regional variations.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **very high** that the length of the frost-free season (also referred to as the growing season) has been increasing nationally since the 1980s, with the largest increases occurring in the western U.S, affecting ecosystems, gardening, and agriculture. Given the evidence base, confidence is **very high** that across the U.S., the growing season is projected to continue to lengthen.

KEY MESSAGE #5 TRACEABLE ACCOUNT

Average U.S. precipitation has increased since 1900, but some areas have had increases greater than the national average, and some areas have had decreases. More winter and spring precipitation is projected for the northern United States, and less for the Southwest, over this century.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Evidence of long-term change in precipitation is based on analysis (for example, Kunkel et al. 2013[170]) of daily observations from the U.S. Cooperative Observer Network. Published work shows the regional differences in precipitation.[47,48] Evidence of future change is based on our knowledge of the climate system's response to heat-trapping gases and an understanding of the regional mechanisms behind the projected changes (for example, IPCC 2007[8]).

New information and remaining uncertainties

A key issue (uncertainty) is the sensitivity of observed precipitation trends to historical changes in station location, rain gauges, and observing practice. A second key issue is the ability of climate models to simulate precipitation. This is one of the more challenging aspects of modeling of the climate system, because precipitation involves not only large-scale processes that are well-resolved by models but small-scale process, such as convection, that must be parameterized in the current generation of global and regional climate models. However, our understanding of the physical basis for these changes has solidified and the newest set of climate model simulations (CMIP5) continues to show high-latitude increases and subtropical decreases in precipitation. For most of the contiguous U.S., studies[171] indicate that the models currently do not detect a robust anthropogenic influence to observed changes, suggesting that observed changes are principally of natural origins. Thus, confident projections of precipitation changes are limited to the northern and southern areas of the contiguous U.S. that are part of the global pattern of observed and robust projected changes that can be related to anthropogenic forcing. Furthermore, for the first time in the U.S. National Climate Assessment, a confidence statement is made that some projected precipitation changes are deemed small. It is incorrect to attempt to validate or invalidate climate model simulations of observed trends in these regions and/or seasons, as such simulations are not designed to forecast the precise timing of natural variations.

Shifts in precipitation patterns due to changes in other sources of air pollution, such as sulfate aerosols, are uncertain and are an active research topic.

Viable avenues to improving the information base are to investigate the sensitivity of observed trends to potential biases introduced by station changes, and to investigate the causes of observed regional variations.

A number of peer-reviewed studies (for example, McRoberts and Nielsen-Gammon 2011; Peterson et al. 2013[47,48]) document precipitation increases at the national scale as well as regional-scale increases and decreases. The variation in magnitude and pattern of future changes from climate model simulations is large relative to observed (and modeled) historical variations.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **high** that average U.S. precipitation has increased since 1900, with some areas having had increases greater than the national average, and some areas having had decreases.

Confidence is **high,** given the evidence base and uncertainties, that more winter and spring precipitation is projected for the northern U.S., and less for the Southwest, over this century in the higher emissions scenarios. Confidence is **medium** that human-induced precipitation changes will be small compared to natural variations in all seasons over large portions of the U.S. in the lower emissions scenarios. Confidence is **medium** that human-induced precipitation changes will be small compared to natural variations in the summer and fall over large portions of the U.S. in the higher emissions scenarios.

KEY MESSAGE #6 TRACEABLE ACCOUNT

Heavy downpours are increasing nationally, especially over the last three to five decades. Largest increases are in the Midwest and Northeast. Increases in the frequency and intensity of extreme precipitation events are projected for all U.S. regions.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Evidence that extreme precipitation is increasing is based primarily on analysis[52,55,170] of hourly and daily precipitation observations from the U.S. Cooperative Observer Network, and is supported by observed increases in atmospheric water vapor.[75] Recent publications have projected an increase in extreme precipitation events,[52,137] with some areas getting larger increases[1] and some getting decreases.[54,55]

Nearly all studies to date published in the peer-reviewed literature agree that extreme precipitation event number and intensity have risen, when averaged over the United States. The pattern of change for the wettest day of the year is projected to roughly follow that of the average precipitation, with both increases and decreases across the U.S. Extreme hydrologic events are projected to increase over most of the U.S.

New information and remaining uncertainties

A key issue (uncertainty) is the ability of climate models to simulate precipitation. This is one of the more challenging aspects of modeling of the climate system because precipitation involves not only large-scale processes that are well-resolved by models but also small-scale process, such as convection, that must be parameterized in the current generation of global and regional climate models.

Viable avenues to improving the information base are to perform some long, very high-resolution simulations of this century's climate under different emissions scenarios.

Assessment of confidence based on evidence

Given the evidence base and uncertainties, confidence is **high** that heavy downpours are increasing in most regions of the U.S., with especially large increases in the Midwest and Northeast.

Confidence is **high** that further increases in the frequency and intensity of extreme precipitation events are projected for most U.S. areas, given the evidence base and uncertainties.

KEY MESSAGE #7 TRACEABLE ACCOUNT

There have been changes in some types of extreme weather events over the last several decades. Heat waves have become more frequent and intense, especially in the West. Cold waves have become less frequent and intense across the nation. There have been regional trends in floods and droughts. Droughts in the Southwest and heat waves everywhere are projected to become more intense, and cold waves less intense everywhere.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Analysis of U.S. temperature records indicates that record cold events are becoming progressively less frequent relative to record high events.[60,170] There is evidence for the corresponding trends in a global framework.[7,66] A number of publications have explored the increasing trend of heat waves.[7,62,69] Additionally, heat waves observed in the southern Great Plains,[1] Europe,[7,62] and Russia[60,66,67] have now been shown to have a higher probability of having occurred because of human-induced climate change.

Some parts of the U.S. have been seeing changing trends for floods and droughts over the last 50 years, with some evidence for human influence.[13,48,62] In the areas of increased flooding in parts of the Great Plains, Midwest, and Northeast, increases in both total precipitation and extreme precipitation have been observed and may be contributing to the flooding increases. However, when averaging over the entire contiguous U.S., there is no overall trend in flood magnitudes.[71] A number of publications project drought as becoming a more normal condition over much of the southern and central U.S. (most recent references: Dai 2012; Hoerling et al. 2012; Wehner et al. 2011[75,76]).

Analyses of U.S. daily temperature records indicate that low records are being broken at a much smaller rate than high records, and at the smallest rate in the historical record.[60,170] However, in certain localized regions, natural variations can be as large or larger than the human induced change.

New information and remaining uncertainties

The key uncertainty regarding projections of future drought is how soil moisture responds to precipitation changes and potential evaporation increases. Most studies indicate that many parts of the U.S. will experience drier soil conditions but the amount of that drying is uncertain.

Natural variability is also an uncertainty affecting projections of extreme event occurrences in shorter timescales (several years to decades), but the changes due to human influence become larger relative to natural variability as the timescale lengthens. Stakeholders should view the occurrence of extreme events in the context of increasing probabilities due to climate change.

Continuation of long term temperature and precipitation observations is critical to monitoring trends in extreme weather events.

Assessment of confidence based on evidence

Given the evidence base and uncertainties, confidence is **high** for the entire key message.

Heat waves have become more frequent and intense, and confidence is **high** that heat waves everywhere are projected to become more intense in the future.

Confidence is **high** that cold waves have become less frequent and intense across the nation.

Confidence is **high** that there have been regional trends in floods and droughts.

Confidence is **high** that droughts in the Southwest are projected to become more intense.

Key message #8 Traceable Account

The intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (Category 4 and 5) hurricanes, have all increased since the early 1980s. The relative contributions of human and natural causes to these increases are still uncertain. Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm.

Description of evidence base
The key message and supporting text summarize extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Recent studies suggest that the most intense Atlantic hurricanes have become stronger since the early 1980s.[93] While this is still the subject of active research, this trend is projected to continue.[90,91]

New information and remaining uncertainties
Detecting trends in Atlantic and eastern North Pacific hurricane activity is challenged by a lack of consistent historical data and limited understanding of all of the complex interactions between the atmosphere and ocean that influence hurricanes.[87,88]

While the best analyses to date[87,91] suggest an increase in intensity and in the number of the most intense hurricanes over this century, there remain significant uncertainties.

Assessment of confidence based on evidence
Given the evidence base and remaining uncertainties:

High confidence that the intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (Category 4 and 5) hurricanes, have increased substantially since the early 1980s.

Low confidence in relative contributions of human and natural causes in the increases.

Medium confidence that hurricane intensity and rainfall rates are projected to increase as the climate continues to warm.

Key message #9 Traceable Account

Winter storms have increased in frequency and intensity since the 1950s, and their tracks have shifted northward over the United States. Other trends in severe storms, including the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds, are uncertain and are being studied intensively.

Description of evidence base
The key message and supporting text summarize extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Current work[98] has provided evidence of the increase in frequency and intensity of winter storms, with the storm tracks shifting poleward,[99,100] but some areas have experienced a decrease in winter storm frequency.[1] Although there are some indications of increased blocking (a large-scale pressure pattern with little or no movement) of the wintertime circulation of the Northern Hemisphere,[106] the assessment and attribution of trends in blocking remain an active research area.[107] Some recent research has provided insight into the connection of global warming to tornadoes and severe thunderstorms.[96]

New information and remaining uncertainties
Winter storms and other types of severe storms have greater uncertainties in their recent trends and projections, compared to hurricanes (Key Message 8). The text for this key message explicitly acknowledges the state of knowledge, pointing out "what we don't know." There has been a sizeable upward trend in the number of storm events causing large financial and other losses.[95]

Assessment of confidence based on evidence
Given the evidence base and remaining uncertainties:

Confidence is **medium** that winter storms have increased slightly in frequency and intensity, and that their tracks have shifted northward over the U.S.

Confidence is **low** on other trends in severe storms, including the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds.

KEY MESSAGE #10 TRACEABLE ACCOUNT

Global sea level has risen by about 8 inches since reliable record keeping began in 1880. It is projected to rise another 1 to 4 feet by 2100.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

Nearly all studies to date published in the peer-reviewed literature agree that global sea level has risen during the past century, and that it will continue to rise over the next century.

Tide gauges throughout the world have documented rising sea levels during the last 130 years. This rise has been further confirmed over the past 20 years by satellite observations, which are highly accurate and have nearly global coverage. Recent studies have shown current sea level rise rates are increasing[112,123] and project that future sea level rise over the rest of this century will be faster than that of the last 100 years (Appendix 3: Climate Science, Supplemental Message 12).[123]

New information and remaining uncertainties

The key issue in predicting future rates of global sea level rise is to understand and predict how ice sheets in Greenland and Antarctica will react to a warming climate. Current projections of global sea level rise do not account for the complicated behavior of these giant ice slabs as they interact with the atmosphere, the ocean and the land. Lack of knowledge about the ice sheets and their behavior is the primary reason that projections of global sea level rise includes such a wide range of plausible future conditions.

Early efforts at semi-empirical models suggested much higher rates of sea level rise (as much as 6 feet by 2100).[115,117] More recent work suggests that a high end of 3 to 4 feet is more plausible.[115,116,121] It is not clear, however, whether these statistical relationships will hold in the future or that they are appropriate in modeling past behavior, thus calling their reliability into question.[118] Some decision-makers may wish to consider a broader range of scenarios such as 8 inches or 6.6 feet by 2100 in the context of risk-based analysis.[122,123]

Assessment of confidence based on evidence

Given the evidence and uncertainties, confidence is **very high** that global sea level has risen during the past century, and that it will continue to rise over this century, with **medium** confidence that global sea level rise will be in the range of 1 to 4 feet by 2100.

KEY MESSAGE #11 TRACEABLE ACCOUNT

Rising temperatures are reducing ice volume and surface extent on land, lakes, and sea. This loss of ice is expected to continue. The Arctic Ocean is expected to become essentially ice free in summer before mid-century.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

There have been a number of publications reporting decreases in ice on land[147] and glacier recession. Evidence that winter lake ice and summer sea ice are rapidly declining is based on satellite data and is incontrovertible.[111,172]

Nearly all studies to date published in the peer-reviewed literature agree that summer Arctic sea ice extent is rapidly declining,[131] with even greater reductions in ice thickness[132,133] and volume,[134] and that if heat-trapping gas concentrations continue to rise, an essentially ice-free Arctic ocean will be realized sometime during this century (for example, Stroeve et al. 2012[136]). September 2012 had the lowest levels of Arctic ice in recorded history. Great Lakes ice should follow a similar trajectory. Glaciers will generally retreat, except for a small percentage of glaciers that experience dynamical surging.[111] Snow cover on land has decreased over the past several decades.[145] The rate of permafrost degradation is complicated by changes in snow cover and vegetation.

New information and remaining uncertainties

The rate of sea ice loss through this century is a key issue (uncertainty), which stems from a combination of large differences in projections between different climate models, natural climate variability and uncertainty about future rates of fossil fuel emissions. This uncertainty is illustrated in Figure 2.29, showing the CMIP5-based projections (adapted from Stroeve et al. 2012[136]).

Viable avenues to improving the information base are determining the primary causes of the range of different climate model projections and determining which climate models exhibit the best ability to reproduce the observed rate of sea-ice loss.

Assessment of confidence based on evidence

Given the evidence base and uncertainties, confidence is **very high** that rising temperatures are reducing ice volume and extent on land, lakes, and sea, and that this loss of ice is expected to continue.

Confidence is **very high** that the Arctic Ocean is projected to become virtually ice-free in summer by mid-century.

KEY MESSAGE #12 TRACEABLE ACCOUNT

The oceans are currently absorbing about a quarter of the carbon dioxide emitted to the atmosphere annually and are becoming more acidic as a result, leading to concerns about intensifying impacts on marine ecosystems.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the climate science peer-reviewed literature. Technical Input reports (82) on a wide range of topics were also reviewed; they were received as part of the Federal Register Notice solicitation for public input.

The oceans currently absorb a quarter of the CO_2 the caused by human activities.[155] Publications have shown that this absorption causes the ocean to become more acidic (for example, Doney et al. 2009[154]). Recent publications demonstrate the adverse effects further acidification will have on marine life.[158,165,169]

New information and remaining uncertainties

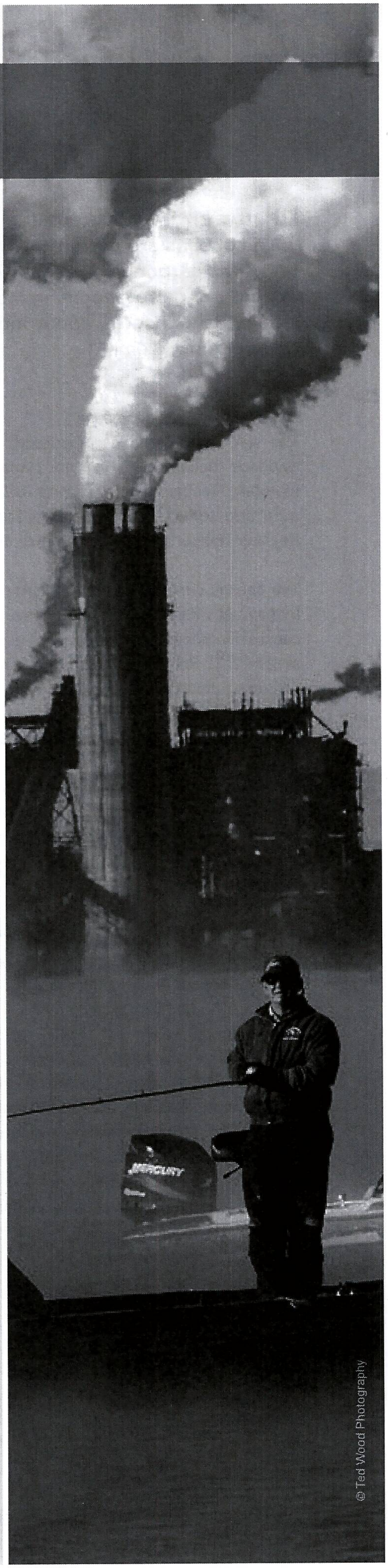
Absorption of CO_2 of human origin, reduced pH, and lower calcium carbonate ($CaCO_3$) saturation in surface waters, where the bulk of oceanic production occurs, are well verified from models, hydrographic surveys, and time series data.[158] The key issue (uncertainty) is how future levels of ocean acidity will affect marine ecosystems.

Assessment of confidence based on evidence

Given the evidence base and uncertainties, confidence is **very high** that oceans are absorbing about a quarter of emitted CO_2.

Very high for trend of ocean acidification; **low-to-medium** for intensifying impacts on marine ecosystems. Our present understanding of projected ocean acidification impacts on marine organisms stems largely from short-term laboratory and mesocosm experiments, although there are also examples based on actual ocean observations; consequently, the response of individual organisms, populations, and communities of species to more realistic, gradual changes still has large uncertainties.

SECTORS



Cherry farmers in Michigan, insurance agents in Florida, and water managers in Arizona are among the millions of Americans already living with – and adapting to – a range of climate change impacts. Higher temperatures, rising sea levels, and more extreme precipitation events are altering the work of first responders, city planners, engineers, and others, influencing economic sectors from coast to coast. Agriculture, energy, transportation, and more, are all affected by climate change in concrete ways. American communities are contending with these changes now, and will be doing so increasingly in the future.

Sectors of our economy do not exist in isolation. Forest management activities, for example, affect and are affected by water supply, changing ecosystems, impacts to biological diversity, and energy availability. Water supply and energy use are completely intertwined, since water is used to generate energy, and energy is required to pump, treat, and deliver water – which means that irrigation-dependent farmers and urban dwellers are linked as well. Human health is affected by water supply, agricultural practices, transportation systems, energy availability, and land use, among other factors – touching the lives of patients, nurses, county health administrators, and many others. Human social systems and communities are directly affected by extreme weather events and changes in natural resources such as water availability and quality; they are also affected both directly and indirectly by ecosystem health.

This report addresses some of these topics individually, focusing on the climate-related risks and opportunities that occur within individual sectors, while others take a cross-sector approach. Single-sector chapters focus on:

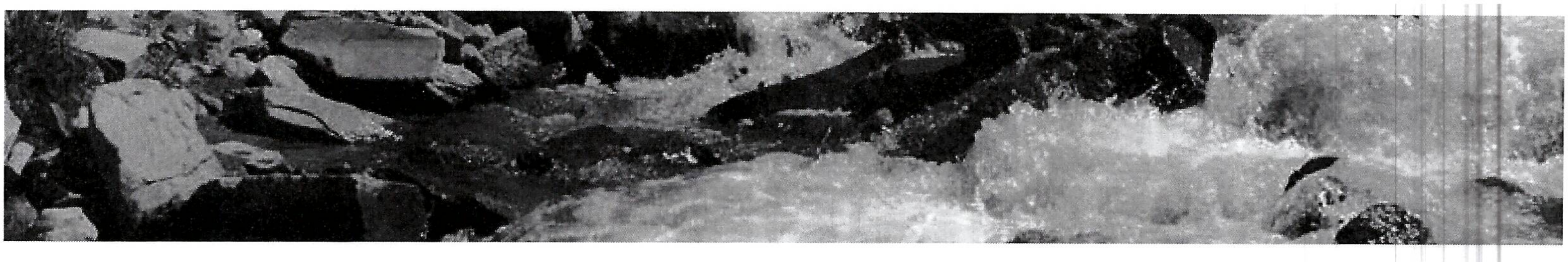
- Water resources
- Energy production and use
- Transportation
- Agriculture
- Forests
- Human health
- Ecosystems and biodiversity

Six crosscutting chapters address how climate change interacts with multiple sectors. These cover the following topics:

- Energy, water, and land use
- Urban infrastructure and vulnerability
- Indigenous peoples, lands, and resources
- Land use and land cover
- Rural communities
- Biogeochemical cycles

A common theme is that these sectors are interconnected in many ways. These intricate connections mean that changes in one sector are often amplified or reduced through links to other sectors. Another theme is how decisions can influence a cascade of events that affect individual and national vulnerability and/or resiliency to climate change across multiple sectors. This "systems approach" helps to reveal, for example, how adaptation and mitigation strategies are part of dynamic and interrelated systems. In this way, for example, adaptation plans for future coastal infrastructure are connected with the kinds of mitigation strategies that are – or are not – put into place today, since the amount of future sea level rise will differ according to various societal decisions about current and future emissions. These chapters also address the importance of underlying vulnerabilities and the ways they may influence risks associated with climate change.

The chapters in the following section assess risks in the selected sectors, and include both observations of existing impacts associated with climate change, as well as projected impacts over the next several decades and beyond.



Climate Change Impacts in the United States

CHAPTER 3
WATER RESOURCES

Convening Lead Authors

Aris Georgakakos, Georgia Institute of Technology

Paul Fleming, Seattle Public Utilities

Lead Authors

Michael Dettinger, U.S. Geological Survey

Christa Peters-Lidard, National Aeronautics and Space Administration

Terese (T.C.) Richmond, Van Ness Feldman, LLP

Ken Reckhow, Duke University

Kathleen White, U.S. Army Corps of Engineers

David Yates, University Corporation for Atmospheric Research

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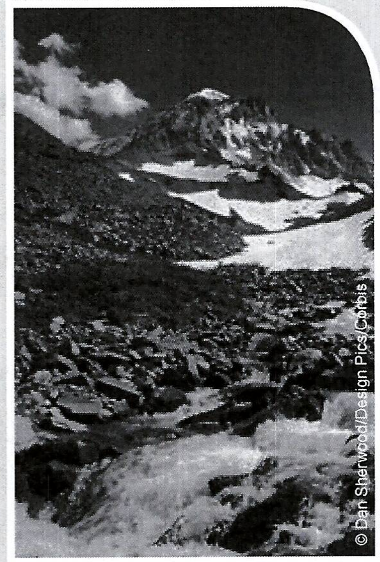
On the Web: http://nca2014.globalchange.gov/report/sectors/water

INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

3 WATER RESOURCES

Key Messages



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Climate Change Impacts on the Water Cycle

1. **Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.**

2. **Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.**

3. **Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.**

4. **Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.**

5. **Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.**

6. **Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.**

Climate Change Impacts on Water Resources Use and Managment

7. **Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.**

8. **Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.**

9. **Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the United States.**

Adaptation and Institutional Responses

10. **In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.**

11. **Increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts. Many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.**

This chapter contains three main sections: climate change impacts on the water cycle, climate change impacts on water resources use and management, and adaptation and institutional responses. Key messages for each section are summarized above.

The cycle of life is intricately joined with the cycle of water.

—Jacques-Yves Cousteau

Climate Change Impacts on the Water Cycle

Water cycles constantly from the atmosphere to the land and the oceans (through precipitation and runoff) and back to the atmosphere (through evaporation and the release of water from plant leaves), setting the stage for all life to exist. The water cycle is dynamic and naturally variable, and societies and ecosystems are accustomed to functioning within this variability. However, climate change is altering the water cycle in multiple ways over different time scales and geographic areas, presenting unfamiliar risks and opportunities.

Key Message 1: Changing Rain, Snow, and Runoff

Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.

Annual average precipitation over the continental U.S. as a whole increased by close to two inches (0.16 inches per decade) between 1895 and 2011.[1,2] In recent decades, annual average precipitation increases have been observed across the Midwest, Great Plains, the Northeast, and Alaska, while decreases have been observed in Hawai'i and parts of the Southeast and Southwest (Ch. 2: Our Changing Climate, Figure 2.12). Average annual precipitation is projected to increase across the northern U.S., and decrease in the southern U.S., especially the Southwest. (Ch. 2: Our Changing Climate, Figures 2.14 and 2.15).[3]

The number and intensity of very heavy precipitation events (defined as the heaviest 1% of all daily events from 1901 to 2012) have been increasing significantly across most of the United States. The amount of precipitation falling in the heaviest daily events has also increased in most areas of the United States (Ch. 2: Our Changing Climate, Figure 2.17). For example, from 1950 to 2007, daily precipitation totals with 2-, 5-, and 10-year average recurrence periods increased in the Northeast and western Great Lakes.[4] Very heavy precipitation events are projected to increase everywhere (Ch. 2: Our Changing Climate, Figure 2.19).[5] Heavy precipitation events that historically occurred once in 20 years are projected to occur as frequently as every 5 to 15 years by late this century.[6] The number and magnitude of the heaviest precipitation events is projected to increase everywhere in the United States (Ch. 2: Our Changing Climate, Figure 2.13).

Dry spells are also projected to increase in length in most regions, especially in the southern and northwestern portions of the contiguous United States (Ch. 2: Our Changing Climate, Figure 2.13). Projected changes in total average annual precipitation are generally small in many areas, but both wet and dry extremes (heavy precipitation events

Projected Changes in Snow, Runoff, and Soil Moisture

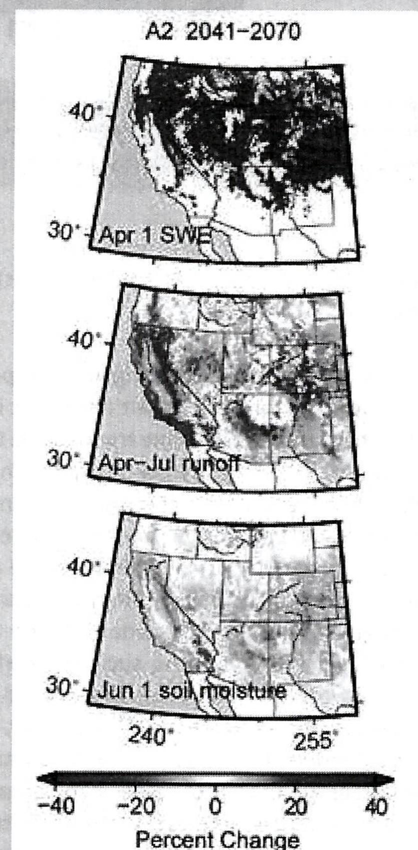

Figure 3.1. These projections, assuming continued increases in heat-trapping gas emissions (A2 scenario; Ch. 2: Our Changing Climate), illustrate: a) major losses in the water content of the snowpack that fills western rivers (snow water equivalent, or SWE); b) significant reductions in runoff in California, Arizona, and the central Rocky Mountains; and c) reductions in soil moisture across the Southwest. The changes shown are for mid-century (2041-2070) as percentage changes from 1971-2000 conditions (Figure source: Cayan et al. 2013[18]).

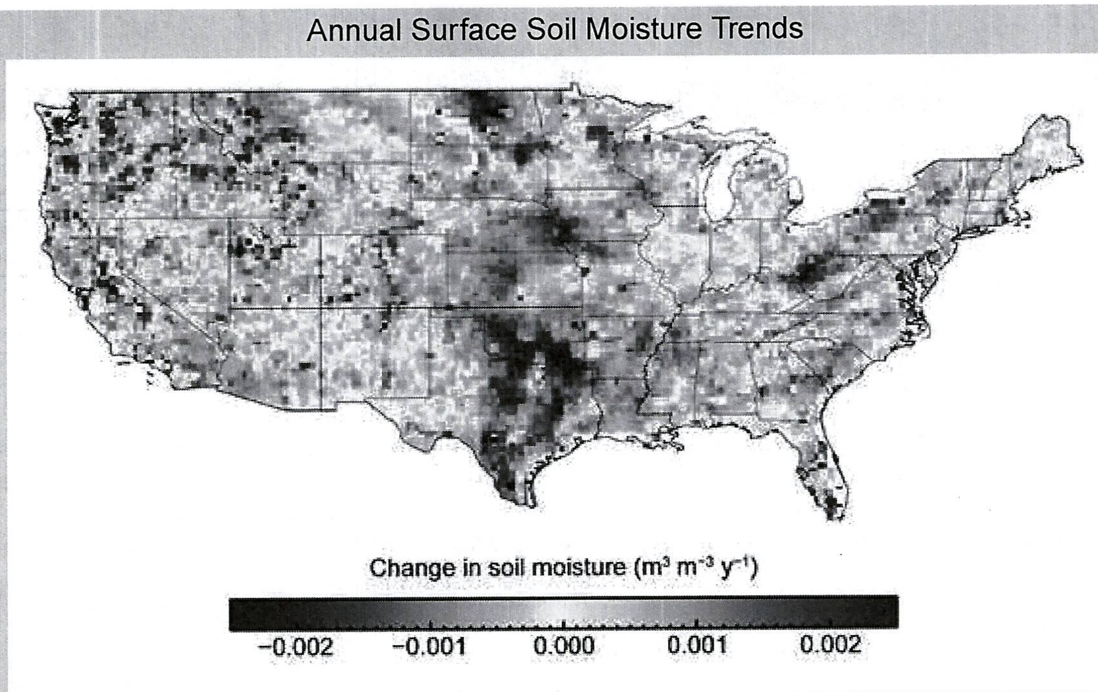

Figure 3.2. Changes in annual surface soil moisture per year over the period 1988 to 2010 based on multi-satellite datasets. Surface soil moisture exhibits wetting trends in the Northeast, Florida, upper Midwest, and Northwest, and drying trends almost everywhere else. (Images provided by W. Dorigo[35]).

and length of dry spells) are projected to increase substantially almost everywhere.

The timing of peak river levels has changed in response to warming trends. Snowpack and snowmelt-fed rivers in much of the western U.S. have earlier peak flow trends since the middle of the last century, including the past decade (Ch. 2: Our Changing Climate).[7,8] This is related to declines in spring snowpack, earlier snowmelt-fed streamflow, and larger percentages of precipitation falling as rain instead of snow. These changes have taken place in the midst of considerable year-to-year variability and long-term natural fluctuations of the western U.S. climate, as well as other influences, such as the effects of dust and soot on snowpacks.[7,9] There are both natural and human influences on the observed trends.[10,11] However, in studies specifically designed to differentiate between natural and human-induced causes, up to 60% of these changes have been attributed to human-induced climate warming,[10] but only among variables that are more responsive to warming than to precipitation variability, such as the effect of air temperature on snowpack.[12]

Other historical changes related to peak river-flow have been observed in the northern Great Plains, Midwest, and Northeast,[13,14] along with striking reductions in lake ice cover (Ch. 2: Our Changing Climate).[15,16]

Permafrost is thawing in many parts of Alaska, a trend that not only affects habitats and infrastructure but also mobilizes subsurface water and reroutes surface water in ways not previously witnessed.[17] Nationally, all of these trends are projected to become even more pronounced as the climate continues to warm (Figure 3.1).

Evapotranspiration (ET – the evaporation of moisture from soil, on plants and trees, and from water bodies; and transpiration, the use and release of water from plants), is the second largest component of the water cycle after precipitation. ET responds to temperature, solar energy, winds, atmospheric humidity, and moisture availability at the land surface and regulates amounts of soil moisture, groundwater recharge, and runoff.[19] Transpiration comprises between 80% and 90% of total ET on land (Ch. 6: Agriculture).[20] In snowy settings, sublimation of snow and ice (loss of snow and ice directly into water vapor without passing through a liquid stage) can increase these returns of water to the atmosphere, sometimes in significant amounts.[21] These interactions complicate estimation and projection of regional losses of water from the land surface to the atmosphere.

Globally-averaged ET increased between 1982 and 1997 but stopped increasing, or has decreased, since about 1998.[22] In North America, the observed ET decreases occurred in water-rich rather than water-limited areas. Factors contributing to these ET decreases are thought to include decreasing wind

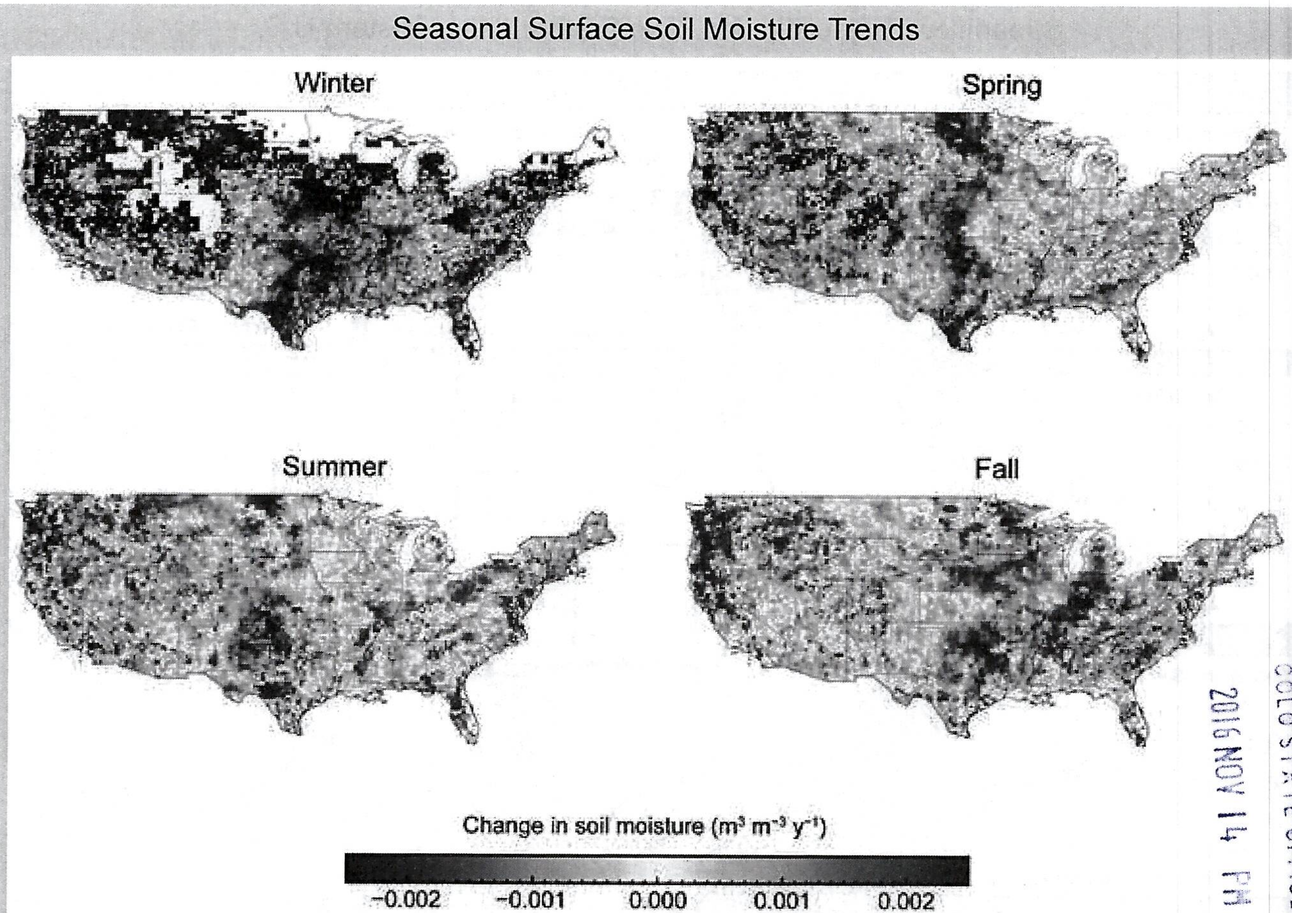

Figure 3.3. Changes in seasonal surface soil moisture per year over the period 1988 to 2010 based on multi-satellite datasets.[35] Seasonal drying is observed in central and lower Midwest and Southeast for most seasons (with the exception of the Southeast summer), and in most of the Southwest and West (with the exception of the Northwest) for spring and summer. Soil moisture in the upper Midwest, Northwest, and most of the Northeast is increasing in most seasons. (Images provided by W. Dorigo).

speed,[23,24] decreasing solar energy at the land surface due to increasing cloud cover and concentration of small particles (aerosols),[25] increasing humidity,[23] and declining soil moisture (Figure 3.2).[26]

Evapotranspiration projections vary by region,[27,28,29,30] but the atmospheric potential for ET is expected to increase; actual ET will be affected by regional soil moisture changes. Much more research is needed to confidently identify historical trends, causes, and implications for future ET trends.[31] This represents a critical uncertainty in projecting the impacts of climate change on regional water cycles.

Soil moisture plays a major role in the water cycle, regulating the exchange of water, energy, and carbon between the land surface and the atmosphere,[22] the production of runoff, and the recharge of groundwater aquifers. Soil moisture is projected to decline with higher temperatures and attendant increases in the potential for ET in much of the country, especially in the Great Plains,[29] Southwest,[18,32,33] and Southeast.[28,34]

Runoff and streamflow at regional scales declined during the last half-century in the Northwest.[36] Runoff and streamflow increased in the Mississippi Basin and Northeast, with no clear trends in much of the rest of the continental U.S.,[37] although a declining trend is emerging in annual runoff in the Colorado River Basin.[38] These changes need to be considered in the context of tree-ring studies in California's Central Valley, the Colorado River and Wind River basins, and the southeastern U.S. that indicate that these regions have experienced prolonged, even drier and wetter conditions at various times in the past two thousand years.[8,39,40] Human-caused climate change, when superimposed on past natural variability, may amplify these past extreme conditions. Projected changes in runoff for eight basins in the Northwest, northern Great Plains, and Southwest are illustrated in Figure 3.4.

Basins in the southwestern U.S. and southern Rockies (for example, the Rio Grande and Colorado River basins) are projected to experience gradual runoff declines during this century. Basins in the Northwest to north-central U.S. (for example, the

Streamflow Projections for River Basins in the Western U.S.

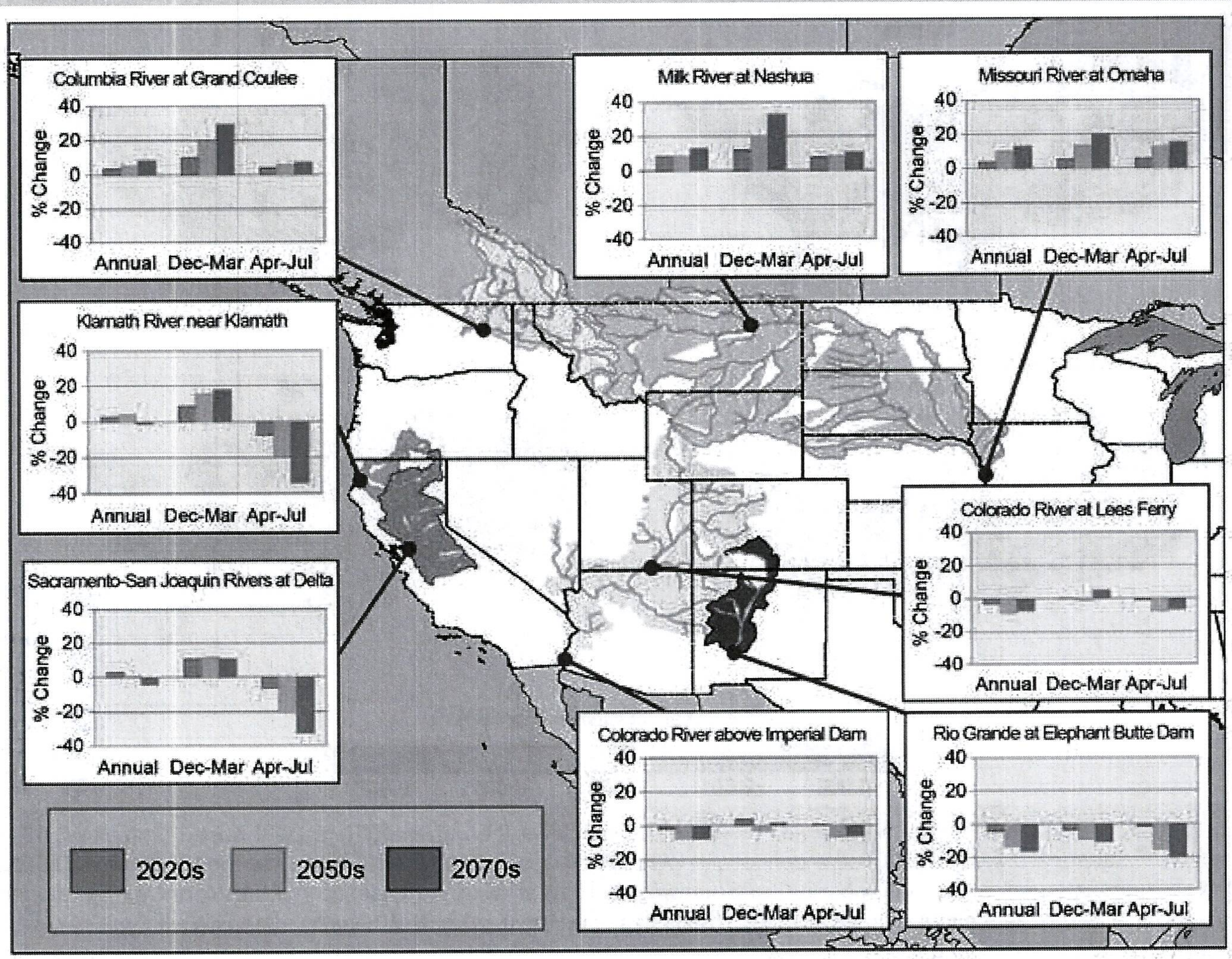

Figure 3.4. Annual and seasonal streamflow projections based on the B1 (with substantial emissions reductions), A1B (with gradual reductions from current emission trends beginning around mid-century), and A2 (with continuation of current rising emissions trends) CMIP3 scenarios for eight river basins in the western United States. The panels show percentage changes in average runoff, with projected increases above the zero line and decreases below. Projections are for annual, cool, and warm seasons, for three future decades (2020s, 2050s, and 2070s) relative to the 1990s. (Source: U.S. Department of the Interior – Bureau of Reclamation 2011;[41] Data provided by L. Brekke, S. Gangopadhyay, and T. Pruitt)

Columbia and the Missouri River basins) are projected to experience little change through the middle of this century, and increases by late this century.

Projected changes in runoff differ by season, with cool season runoff increasing over the west coast basins from California to Washington and over the north-central U.S. (for example, the San Joaquin, Sacramento, Klamath, Missouri, and Columbia River basins). Basins in the southwestern U.S. and southern Rockies are projected to see little change to slight decreases in the winter months.

Warm season runoff is projected to decrease substantially over a region spanning southern Oregon, the southwestern U.S., and southern Rockies (for example, the Klamath, Sacramento, San Joaquin, Rio Grande, and the Colorado River basins), and change little or increase slightly north of this region (for example, the Columbia and Missouri River basins).

In most of these western basins, these projected streamflow changes are outside the range of historical variability, especially by the 2050s and 2070s. The projected streamflow changes and associated uncertainties have water management implications (discussed below).

Key Message 2: Droughts Intensify

Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

Annual runoff and related river-flow are projected to decline in the Southwest[42,43] and Southeast,[34] and to increase in the Northeast, Alaska, Northwest, and upper Midwest regions,[42,43,44,45] broadly mirroring projected precipitation patterns.[46] Observational studies[47] have shown that decadal fluctuations in average temperature (up to 1.5°F) and precipitation changes of 10% have occurred in most areas of the U.S. during the last century. Fluctuations in river-flow indicate that effects of temperature are dominated by fluctuations in precipitation. Nevertheless, as warming affects water cycle processes, the amount of runoff generated by a given amount of precipitation is generally expected to decline.[37]

Droughts occur on time scales ranging from season-to-season to multiple years and even multiple decades. There has been no universal trend in the overall extent of drought across the continental U.S. since 1900. However, in the Southwest, widespread drought in the past decade has reflected both precipitation deficits and higher temperatures[8] in ways that resemble projected changes.[48] Long-term (multi-seasonal) drought conditions are also projected to increase in parts of the Southeast and possibly in Hawai'i and the Pacific Islands (Ch. 23: Hawai'i and Pacific Islands). Except in the few areas where increases in summer precipitation compensate, summer droughts (Ch. 2: Our Changing Climate) are expected to intensify almost everywhere in the continental U.S.[49] due to longer periods of dry weather and more extreme heat,[33] leading to more moisture loss from plants and earlier soil moisture depletion in basins where snowmelt shifts to earlier in the year.[50,51] Basins watered by glacial melt in the Sierra Nevada, Glacier National Park, and Alaska may experience increased summer river-flow in the next few decades, until the amounts of glacial ice become too small to contribute to river-flow.[52,53]

Key Message 3: Increased Risk of Flooding in Many Parts of the U.S.

Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.

There are various types of floods (see "Flood Factors and Flood Types"), some of which are projected to increase with continued climate change. Floods that are closely tied to heavy precipitation events, such as flash floods and urban floods, as well as coastal floods related to sea level rise and the resulting increase in storm surge height and inland impacts, are expected to increase. Other types of floods result from a more complex set of causes. For example, river floods are basin specific and dependent not only on precipitation but also on pre-existing soil moisture conditions, topography, and other factors, including important human-caused changes to watersheds and river courses across the United States.[54,55,56,57]

Significant changes in annual precipitation (Ch. 2: Our Changing Climate) and soil moisture (Figures 3.2 and 3.3), among other factors, are expected to affect annual flood magnitudes (Figure 3.5) in many regions.[58] River floods have been increasing in the Northeast and Midwest, and decreasing in the Southwest and Southeast.[56,57,58,59] These decreases are not surprising, as short duration very heavy precipitation events often occur during the summer and autumn when rivers are generally low. However, these very heavy precipitation events can and do lead to flash floods, often exacerbated in urban areas by the effect of impervious surfaces on runoff.

Heavy rainfall events are projected to increase, which is expected to increase the potential for flash flooding. Land cover, flow and water-supply management, soil moisture, and channel conditions are also important influences on flood generation[55] and must be considered in projections of future flood risks. Region-specific storm mechanisms and seasonality also affect flood peaks.[57] Because of this, and limited capacity to project future very heavy events with confidence, evaluations of the relative changes in various storm mechanisms may be useful.[57,60,61] Warming is likely to directly affect flooding in many mountain settings, as catchment areas receive increasingly more precipitation as rain rather than snow, or more rain falling on existing snowpack.[62] In some such settings, river flooding may increase as a result – even where precipitation and overall river flows decline (Ch. 2: Our Changing Climate).

Trends in Flood Magnitude

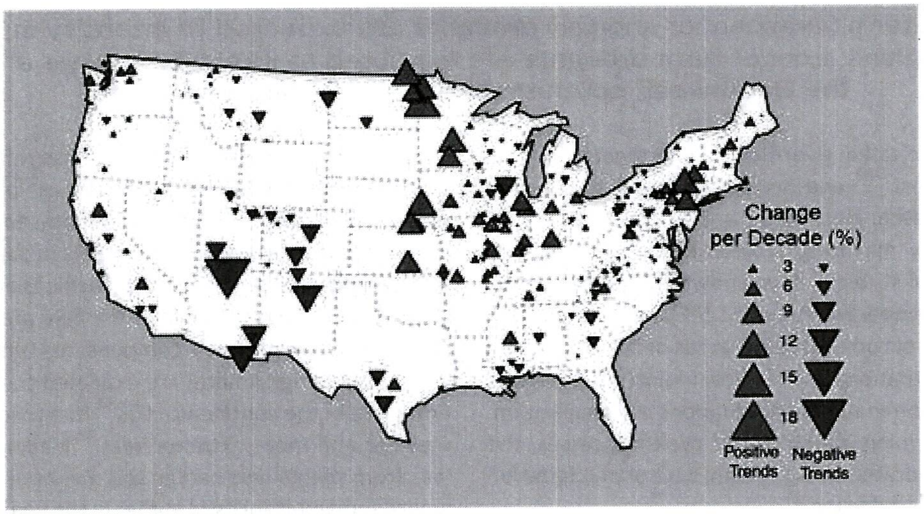

Figure 3.5. Trend magnitude (triangle size) and direction (green = increasing trend, brown = decreasing trend) of annual flood magnitude from the 1920s through 2008. Flooding in local areas can be affected by multiple factors, including land-use change, dams, and diversions of water for use. Most significant are increasing trends for floods in Midwest and Northeast, and a decreasing trend in the Southwest. (Figure source: Peterson et al. 2013[63]).

Key Message 4: Groundwater Availability

Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.

Groundwater is the only perennial source of fresh water in many regions and provides a buffer against climate extremes. As such, it is essential to water supplies, food security, and ecosystems. Though groundwater occurs in most areas of the U.S., the capacity of aquifers to store water varies depending on the geology of the region. (Figure 3.6b illustrates the importance of groundwater aquifers.) In large regions of the Southwest, Great Plains, Midwest, Florida, and some other coastal areas, groundwater is the primary water supply. Groundwater aquifers in these areas are susceptible to the combined stresses of climate and water-use changes. For example, during the 2006–2009 California drought, when the source of irrigation shifted from surface water to predominantly groundwater, groundwater storage in California's Central Valley declined by an amount roughly equivalent to the storage capacity of Lake Mead, the largest reservoir in the United States.[64]

Climate change impacts on groundwater storage are expected to vary from place to place and aquifer to aquifer. Although precise responses of groundwater storage and flow to climate change are not well understood nor readily generalizable, recent and ongoing studies[65,66,67,68] provide insights on various underlying mechanisms:

1) Precipitation is the key driver of aquifer recharge in water-limited environments (like arid regions), while evapotranspiration (ET) is the key driver in energy-limited environments (like swamps or marshlands).

2) Climate change impacts on aquifer recharge depend on several factors, including basin geology, frequency and intensity of high-rainfall periods that drive recharge, seasonal timing of recharge events, and strength of groundwater-surface water interaction.

3) Changes in recharge rates are amplified relative to changes in total precipitation, with greater amplification for drier areas.

With these insights in mind, it is clear that certain groundwater-dependent regions are projected to incur significant climate change related challenges. In some portions of the country, groundwater provides nearly 100% of the water supply (Figure 3.6b). Seasonal soil moisture changes are a key aquifer recharge driver and may provide an early indication of general aquifer recharge trends. Thus, the observed regional reductions in seasonal soil moisture for winter and spring (Figure 3.3) portend adverse recharge impacts for several U.S. regions, especially the Great Plains, Southwest, and Southeast.

Despite their critical national importance as water supply sources (see Figure 3.6), aquifers are not generally monitored

Principal U.S. Groundwater Aquifers and Use

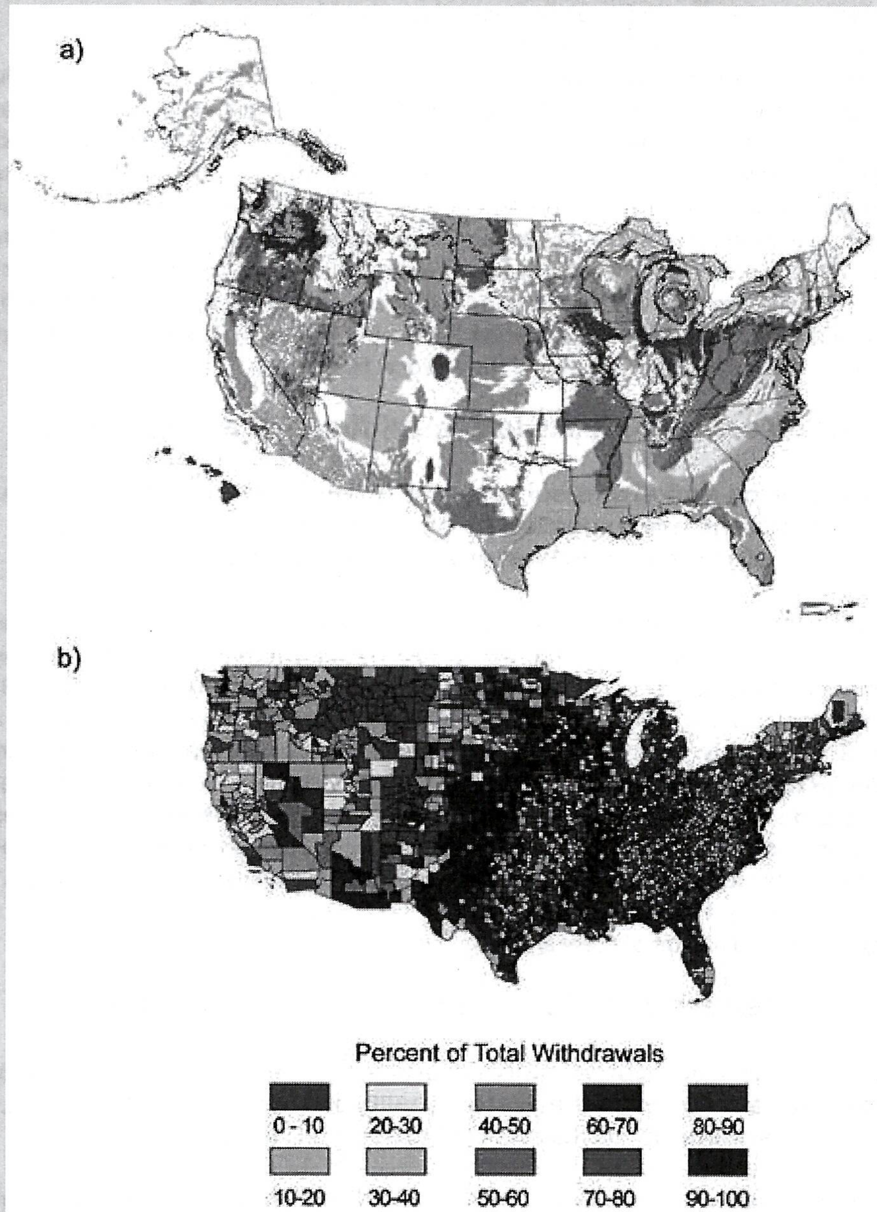

Figure 3.6. (**a**) Groundwater aquifers are found throughout the U.S., but they vary widely in terms of ability to store and recharge water. The colors on this map illustrate aquifer location and geology: blue colors indicate unconsolidated sand and gravel; yellow is semi-consolidated sand; green is sandstone; blue or purple is sandstone and carbonate-rock; browns are carbonate-rock; red is igneous and metamorphic rock; and white is other aquifer types. (Figure source: USGS). (**b**) Ratio of groundwater withdrawals to total water withdrawals from all surface and groundwater sources by county. The map illustrates that aquifers are the main (and often exclusive) water supply source for many U.S. regions, especially in the Great Plains, Misssissippi Valley, east central U.S., Great Lakes region, Florida, and other coastal areas. Groundwater aquifers in these regions are prone to impacts due to combined climate and water-use change. (Data from USGS 2005).

in ways that allow for clear identification of climatic influences on groundwater recharge, storage, flows, and discharge. Nearly all monitoring is focused in areas and aquifers where variations are dominated by groundwater pumping, which largely masks climatic influences,[69] highlighting the need for a national framework for groundwater monitoring.[70]

Generally, impacts of changing demands on groundwater systems, whether due directly to climate changes or indirectly through changes in land use or surface-water availability and management, are likely to have the most immediate effects on groundwater availability;[67,71] changes in recharge and storage may be more subtle and take longer to emerge. Groundwater models have only recently begun to include detailed representations of groundwater recharge and interactions with surface-water and land-surface processes,[50] with few projections of groundwater responses to climate change.[68,72] However, surface water declines have already resulted in larger groundwater withdrawals in some areas (for example, in the Central Valley of California and in the Southeast) and may be aggravated by climate change challenges.[73] In many mountainous areas of the U.S., groundwater recharge is disproportionately generated from snowmelt infiltration, suggesting that the loss of snowpack will affect recharge rates and patterns.[50,51,66,74] Models do not yet include dynamic representations of the groundwater reservoir and its connections to streams, the soil-vegetation system, and the atmosphere, limiting the understanding of the potential climate change impacts on groundwater and groundwater-reliant systems.[75]

As the risk of drought increases, groundwater can play a key role in enabling adaptation to climate variability and change. For example, groundwater can be augmented by surface water during times of high flow through aquifer recharge strategies, such as infiltration basins and injection wells. In addition, management strategies can be implemented that use surface water for irrigation and water supply during wet periods, and groundwater during drought, although these approaches face practical limitations within current management and institutional frameworks.[71,76]

Key Message 5: Risks to Coastal Aquifers and Wetlands

Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.

With more than 50% of the nation's population concentrated near coasts (Chapter 25: Coasts),[77] coastal aquifers and wetlands are precious resources. These aquifers and wetlands, which are extremely important from a biological/biodiversity perspective (see Ch. 8: Ecosystems; Ch. 25: Coasts), may be particularly at risk due to the combined effects of inland droughts and floods, increased surface water impoundments and diversions, increased groundwater withdrawals, and accelerating sea level rise and greater storm surges.[78,79] Estuaries are particularly vulnerable to changes in freshwater inflow and sea level rise by changing salinity and habitat of these areas.

Several coastal areas, including the Delaware, Susquehanna, and Potomac River deltas on the Northeast seaboard, most of Florida, the Apalachicola and Mobile River deltas and bays, the Mississippi River delta in Louisiana, and the delta of the Sacramento-San Joaquin rivers in northern California, are particularly vulnerable due to the combined effects of climate change and other human-caused stresses. In response, some coastal communities are among the nation's most proactive in adaptation planning (Chapter 25: Coasts).

Key Message 6: Water Quality Risks to Lakes and Rivers

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.

Water temperature has been increasing in some rivers.[80] The length of the season that lakes and reservoirs are thermally stratified (with separate density layers) is increasing with increased air and water temperatures.[81,82] In some cases, seasonal mixing may be eliminated in shallow lakes, decreasing dissolved oxygen and leading to excess concentrations of nutrients (nitrogen and phosphorous), heavy metals (such as mercury), and other toxins in lake waters.[81,82]

Lower and more persistent low flows under drought conditions as well as higher flows during floods can worsen water quality. Increasing precipitation intensity, along with the effects of wildfires and fertilizer use, are increasing sediment, nutrient, and contaminant loads in surface waters used by downstream water users[84] and ecosystems. Mineral weathering products, like calcium, magnesium, sodium, and silicon and nitrogen loads[85] have been increasing with higher streamflows.[86] Changing land cover, flood frequencies, and flood magnitudes are expected to increase mobilization of sediments in large river basins.[87]

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease water quality in many ways. Here, middle school students in Colorado learn about water quality.

Changes in sediment transport are expected to vary regionally and by land-use type, with potentially large increases in some areas,[88] resulting in alterations to reservoir storage and river channels, affecting flooding, navigation, water supply, and dredging. Increased frequency and duration of droughts, and associated low water levels, increase nutrient concentrations and residence times in streams, potentially increasing the likelihood of harmful algal blooms and low oxygen conditions.[89] Concerns over such impacts and their potential link to climate change are rising for many U.S. regions including the Great Lakes,[90] Chesapeake Bay,[91] and the Gulf of Mexico.[85,86] Strategies aiming to reduce sediment, nutrient, and contaminant loads at the source remain the most effective management responses.[92]

Observed Changes in Lake Stratification and Ice Covered Area

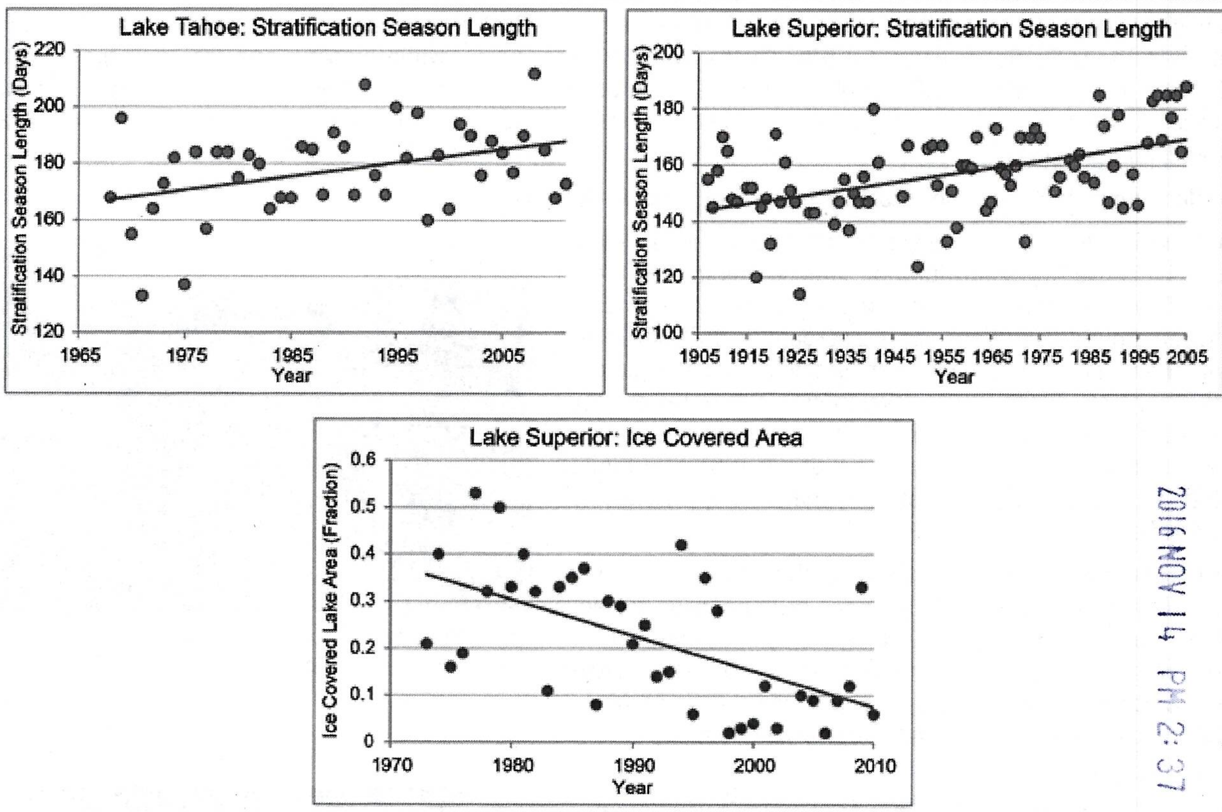

Figure 3.7. The length of the season in which differences in lake temperatures with depth cause stratification (separate density layers) is increasing in many lakes. In this case, measurements show stratification has been increasing in Lake Tahoe (top left) since the 1960s and in Lake Superior (top right) since the early 1900s in response to increasing air and surface water temperatures (see also Ch. 18: Midwest). In Lake Tahoe, because of its large size (relative to inflow) and resulting long water-residence times, other influences on stratification have been largely overwhelmed, and warming air and water temperatures have caused progressive declines in near-surface density, leading to longer stratification seasons (by an average of 20 days), decreasing the opportunities for deep lake mixing, reducing oxygen levels, and causing impacts to many species and numerous aspects of aquatic ecosytems.[83] Similar effects are observed in Lake Superior,[16] where the stratification season is lengthening (top right) and annual ice-covered area is declining (bottom); both observed changes are consistent with increasing air and water temperatures.

Relationship between Historical and Projected Water Cycle Changes

Natural climate variations occur on essentially all time scales from days to millennia, and the water cycle varies in much the same way. Observations of changes in the water cycle over time include responses to natural hydroclimatic variability as well as other, more local, human influences (like dam building or land-use changes), or combinations of these influences with human-caused climate change. Some recent studies have attributed specific observed changes in the water cycle to human-induced climate change (for example, Barnett et al. 2008[10]). For many other water cycle variables and impacts, the observed and projected responses are consistent with those expected by human-induced climate change and other human influences. Research aiming to formally attribute these responses to their underlying causes is ongoing.

Flood Factors and Flood Types

A flood is defined as any high flow, overflow, or inundation by water that causes or threatens damage.[93] Floods are caused or amplified by both weather- and human-related factors. Major weather factors include heavy or prolonged precipitation, snowmelt, thunderstorms, storm surges from hurricanes, and ice or debris jams. Human factors include structural failures of dams and levees, inadequate drainage, and land cover alterations (such as pavement or deforestation) that reduce the capacity of the land surface to absorb water. Increasingly, humanity is also adding to weather-related factors, as human-induced warming increases heavy downpours, causes more extensive storm surges due to sea level rise, and leads to more rapid spring snowmelt.

Worldwide, from 1980 to 2009, floods caused more than 500,000 deaths and affected more than 2.8 billion people.[94] In the U.S., floods caused 4,586 deaths from 1959 to 2005[95] while property and crop damage averaged nearly $8 billion per year (in 2011 dollars) over 1981 through 2011.[93] The risks from future floods are significant, given expanded development in coastal areas and floodplains, unabated urbanization, land-use changes, and human-induced climate change.[94]

Major flood types include flash, urban, riverine, and coastal flooding:

Flash floods occur in small and steep watersheds and waterways and can be caused by short-duration intense precipitation, dam or levee failure, or collapse of debris and ice jams. Snow cover and frozen ground conditions can exacerbate flash flooding during winter and early spring by increasing the fraction of precipitation that runs off. Flash floods develop within minutes or hours of the causative event, and can result in severe damage and loss of life due to high water velocity, heavy debris load, and limited warning. Most flood-related deaths in the U.S. are associated with flash floods.

Flash Flooding: Cave Creek, Arizona (Photo credit: Tom McGuire).

Urban flooding can be caused by short-duration very heavy precipitation. Urbanization creates large areas of impervious surfaces (such as roads, pavement, parking lots, and buildings) and increases immediate runoff. Stormwater drainage removes excess surface water as quickly as possible, but heavy downpours can exceed the capacity of drains and cause urban flooding.

Flash floods and urban flooding are directly linked to heavy precipitation and are expected to increase as a result of projected increases in heavy precipitation events. In mountainous watersheds, such increases may be partially offset in winter and spring due to projected snowpack reduction.

Riverine Flooding: In many regions, infrastructure is currently vulnerable to flooding, as demonstrated in these photos. Left: The Fort Calhoun Nuclear Power Plant in eastern Nebraska was surrounded by a Missouri River flood on June 8, 2011, that also affected Louisiana, Mississippi, Missouri, Illinois, Kentucky, Tennessee, and Arkansas (photo credit: Larry Geiger). Right: The R.M. Clayton sewage treatment plant in Atlanta, Georgia, September 23, 2009, was engulfed by floodwaters forcing it to shut down and resulting in the discharge of raw sewage into the Chattahoochee River (photo credit: Reuters/David Tulis). Flooding also disrupts road and rail transportation, and inland navigation.

Riverine flooding occurs when surface water drains from a watershed into a stream or a river exceeds channel capacity, overflows the

Continued

Flood factors and flood types (continued)

banks, and inundates adjacent low lying areas. Riverine flooding is commonly associated with large watersheds and rivers, while flash and urban flooding occurs in smaller natural or urban watersheds. Because heavy precipitation is often localized, riverine flooding typically results from multiple heavy precipitation events over periods of several days, weeks, or even months. In large basins, existing soil moisture conditions and evapotranspiration rates also influence the onset and severity of flooding, as runoff increases with wetter soil and/or lower evapotranspiration conditions. Snow cover and frozen ground conditions can also exacerbate riverine flooding during winter and spring by increasing runoff associated with rain-on-snow events and by snowmelt, although these effects may diminish in the long term as snow accumulation decreases due to warming. Since riverine flooding depends on precipitation as well as many other factors, projections about changes in frequency or intensity are more uncertain than with flash and urban flooding.

Coastal flooding is predominantly caused by storm surges that accompany hurricanes and other storms. Low storm pressure creates strong winds that create and push large sea water domes, often many miles across, toward the shore. The approaching domes can raise the water surface above normal tide levels (storm surge) by more than 25 feet, depending on various storm and shoreline factors. Inundation, battering waves, and floating debris associated with storm surge can cause deaths, widespread infrastructure damage (to buildings, roads, bridges, marinas, piers, boardwalks, and sea walls), and severe beach erosion. Storm-related rainfall can also cause inland flooding (flash, urban, or riverine) if, after landfall, the storm moves slowly or stalls over an area. Inland flooding can occur close to the shore or hundreds of miles away and is responsible for more than half of the deaths associated with tropical storms.[93] Climate change affects coastal flooding through sea level rise and storm surge, increases in heavy rainfall during hurricanes and other storms, and related increases in flooding in coastal rivers.

Hurricane Sandy coastal flooding in Mantoloking, N.J. (Photo credit: New Jersey National Guard/Scott Anema).

In some locations, early warning systems have helped reduce deaths, although property damage remains considerable (Ch. 28: Adaptation). Further improvements can be made by more effective communication strategies and better land-use planning.[94]

Climate Change Impacts on Water Resource Uses and Management

People use water for many different purposes and benefits. Our water use falls into five main categories: 1) municipal use, which includes domestic water for drinking and bathing; 2) agricultural use, which includes irrigation and cattle operations; 3) industrial use, which includes electricity production from coal- or gas-fired power plants that require water to keep the machinery cool; 4) providing ecosystem benefits, such as supporting the water needs of plants and animals we depend on; and 5) recreational uses, such as boating and fishing.

Water is supplied for these many uses from two main sources:

- freshwater withdrawals (from streams, rivers, lakes, and aquifers), which supply water for municipal, industrial, agricultural, and recirculating thermoelectric plant cooling water supply;
- instream surface water flows, which support hydropower production, once-through thermoelectric plant cooling, navigation, recreation, and healthy ecosystems.

Key Message 7: Changes to Water Demand and Use

Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.

Climate change, acting concurrently with demographic, land-use, energy generation and use, and socioeconomic changes, is challenging existing water management practices by affecting water availability and demand and by exacerbating competition among uses and users (see Ch. 4: Energy; Ch. 6: Agriculture; Ch. 10: Energy, Water, and Land; Ch. 12: Indigenous Peoples; and Ch. 13: Land Use & Land Cover Change). In some regions, these current and expected impacts are hastening efficiency improvements in water withdrawal and use, the deployment of more proactive water management and adaptation approaches, and the reassessment of the water infrastructure and institutional responses.[1]

Water Withdrawals

Total freshwater withdrawals (including water that is withdrawn and consumed as well as water that returns to the original source) and consumptive uses have leveled off nationally since 1980 at 350 billion gallons of withdrawn water and 100 billion gallons of consumptive water per day, despite the addition of 68 million people from 1980 to 2005 (Figure 3.8).[96] Irrigation and all electric power plant cooling withdrawals account for approximately 77% of total withdrawals, municipal and industrial for 20%, and livestock and aquaculture for 3%. Most thermoelectric withdrawals are returned back to rivers after cooling, while most irrigation withdrawals are consumed by the processes of evapotranspiration and plant growth. Thus, consumptive water use is dominated by irrigation (81%) followed distantly by municipal and industrial (8%) and the remaining water uses (5%). See Figure 3.9.

Water sector withdrawals and uses vary significantly by region. There is a notable east-west water use pattern, with the largest regional withdrawals occurring in western states (where the climate is drier) for agricultural irrigation (Figure 3.10a,d). In the east, water withdrawals mainly serve municipal, industrial, and thermoelectric uses (Figure 3.10a,b,c). Irrigation is also dominant along the Mississippi Valley, in Florida, and in southeastern Texas. Groundwater withdrawals are especially intense in parts of the Southwest, Southeast, Northwest, and

U.S. Freshwater Withdrawal, Consumptive Use, and Population Trends

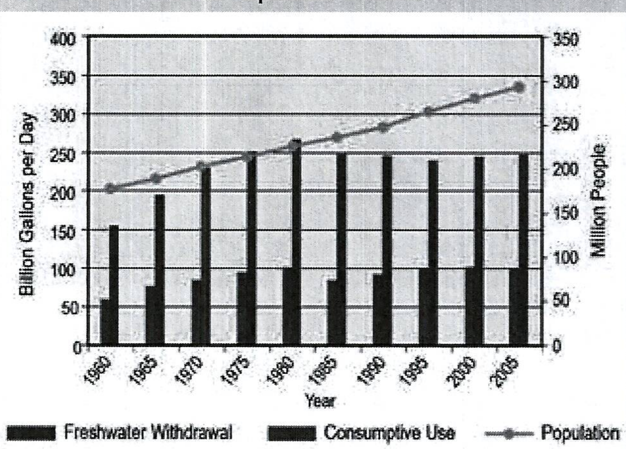

Figure 3.8. Trends in total freshwater withdrawal (equal to the sum of consumptive use and return flows to rivers) and population in the contiguous United States. This graph illustrates the remarkable change in the relationship between water use and population growth since about 1980. Reductions in per capita water withdrawals are directly related to increases in irrigation efficiency for agriculture, more efficient cooling processes in electrical generation, and, in many areas, price signals, more efficient indoor plumbing fixtures and appliances, and reductions in exterior landscape watering, in addition to shifts in land-use patterns in some areas.[97] Efficiency improvements have offset the demands of a growing population and have resulted in more flexibility in meeting water demand. In some cases these improvements have also reduced the flexibility to scale back water use in times of drought because some inefficiencies have already been removed from the system. With drought stress projected to increase in many U.S. regions, drought vulnerability is also expected to rise.[1]

Freshwater Withdrawals by Sector

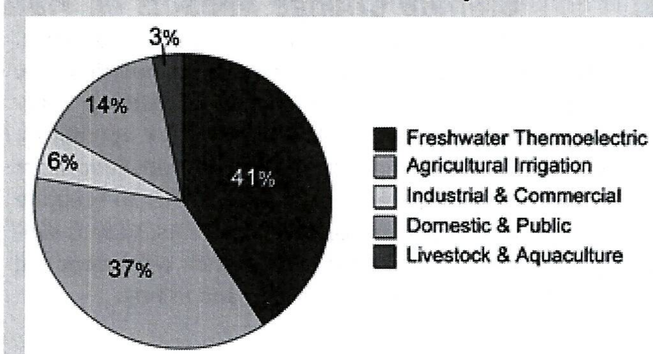

Figure 3.9. Total water withdrawals (groundwater and surface water) in the U.S. are dominated by agriculture and energy production, though the primary use of water for thermoelectric production is for cooling, where water is often returned to lakes and rivers after use (return flows). (Data from Kenny et al. 2009[96])

U.S. Water Withdrawal Distribution

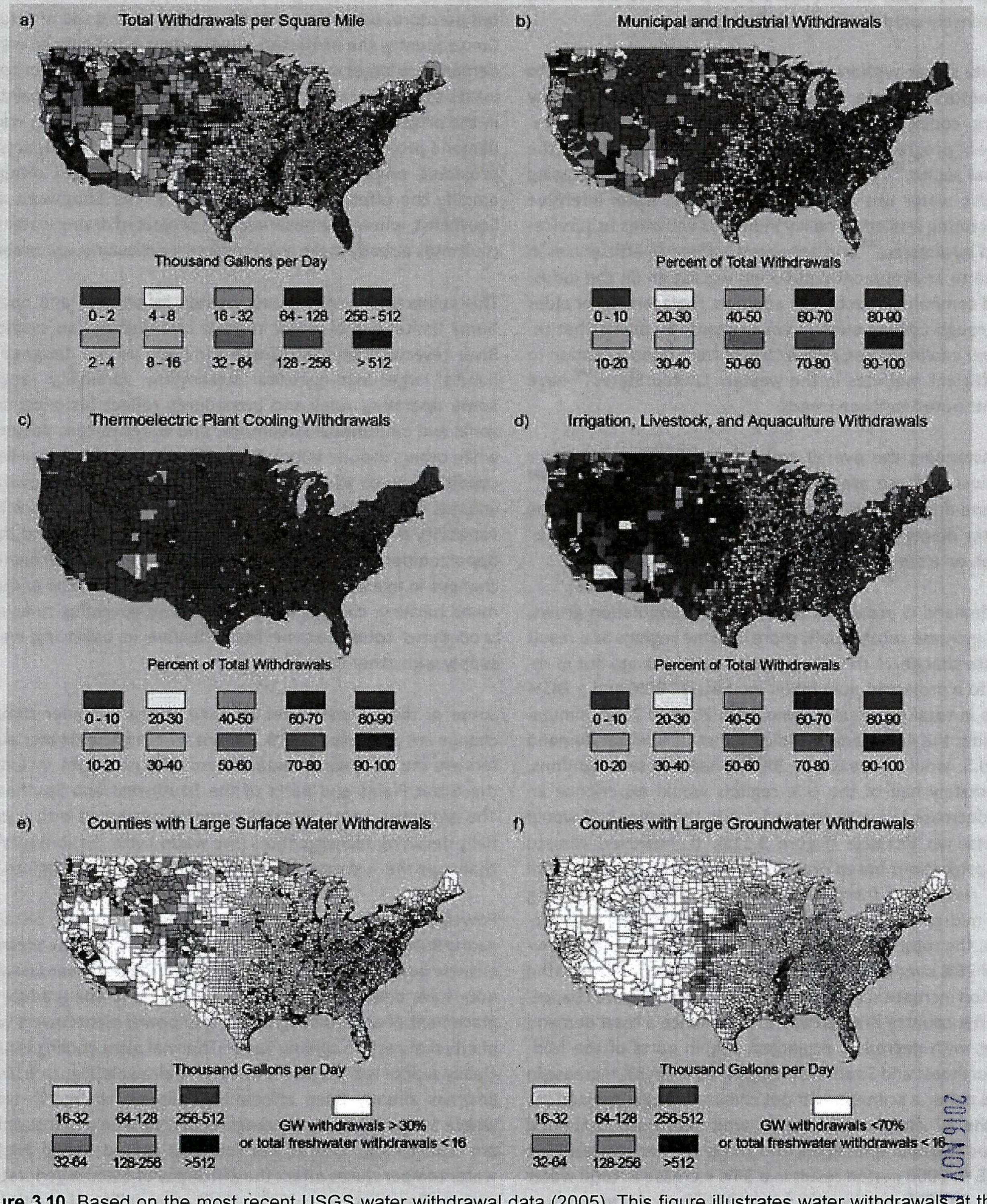

Figure 3.10. Based on the most recent USGS water withdrawal data (2005). This figure illustrates water withdrawals at the U.S. county level: (a) total withdrawals (surface and groundwater) in thousands of gallons per day per square mile; (b) municipal and industrial (including golf course irrigation) withdrawals as percent of total; (c) irrigation, livestock, and aquaculture withdrawals as percent of total; (d) thermoelectric plant cooling withdrawals as percent of total; (e) counties with large surface water withdrawals; and (f) counties with large groundwater withdrawals. The largest withdrawals occur in the drier western states for crop irrigation. In the east, water withdrawals mainly serve municipal, industrial, and thermoelectric uses. Groundwater withdrawals are intense in parts of the Southwest and Northwest, the Great Plains, Mississippi Valley, Florida and South Georgia, and near the Great Lakes (Figure source: Georgia Water Resources Institute, Georgia Institute of Technology; Data from Kenny et al. 2009;[96] USGS 2013[98]).

Great Plains, the Mississippi Valley, Florida and South Georgia, and near the Great Lakes (Figure 3.10f). Surface waters are most intensely used in all other U.S. regions.

Per capita water withdrawal and use are decreasing due to many factors.[99] These include demand management, new plumbing codes, water-efficient appliances, efficiency improvement programs, and pricing strategies, especially in the municipal sector.[100] Other factors contributing to decreasing per capita water use include changes from water-intensive manufacturing and other heavy industrial activities to service-oriented businesses,[101] and enhanced water-use efficiencies in response to environmental pollution legislation (in the industrial and commercial sector). In addition, replacement of older once-through-cooling electric power plants by plants that recycle their cooling water, and switching from flood irrigation to more efficient methods in the western United States[102] have also contributed to these trends.

Notwithstanding the overall national trends, regional water withdrawal and use are strongly correlated with climate;[103] hotter and drier regions tend to have higher per capita usage, and water demand is affected by both temperature and precipitation on a seasonal basis (see also Ch. 28: Adaptation).

Water demand is projected to increase as population grows, and will increase substantially more in some regions as a result of climate change. In the absence of climate change but in response to a projected population increase of 80% and a 245% increase in total personal income from 2005 to 2060, simulations under the A1B scenario indicate that total water demand in the U.S. would increase by 3%.[99] Under these conditions, approximately half of the U.S. regions would experience an overall decrease in water demand, while the other half would experience an increase (Figure 3.11a). If, however, climate change projections based on the A1B emissions scenario (with gradual reductions from current emission trends beginning around mid-century) and three climate models are also factored in, the total water demand is projected to rise by an average of 26% over the same period (Figure 3.11b).[99] Under the population increase scenario that also includes climate change, 90% of the country is projected to experience a total demand increase, with decreases projected only in parts of the Midwest, Northeast and Southeast. Compared to an 8% increase in demand under a scenario without climate change, projections under the A2 emissions scenario (which assumes continued increases in global emissions) and three climate models over the 2005 to 2060 period result in a 34% increase in total water demand. By 2090, total water demand is projected to increase by 42% over 2005 levels under the A1B scenario and 82% under the higher A2 emissions scenario.

Crop irrigation and landscape watering needs are directly affected by climate change, especially by projected changes in temperature, potential evapotranspiration, and soil moisture. Consequently, the projected climate change impacts on water demand are larger in the western states, where irrigation dominates total water withdrawals (see Figure 3.10). Uncertainties in the projections of these climate variables also affect water demand projections.[99] However, it is clear that the impacts of projected population, socioeconomic, and climate changes amplify the effects on water demand in the Southwest and Southeast, where the observed and projected drying water cycle trends already make these regions particularly vulnerable.

This vulnerability will be exacerbated by physical and operational limitations of water storage and distribution systems. River reservoirs and associated dams are usually designed to handle larger-than-historical streamflow variability ranges. Some operating rules and procedures reflect historical seasonal and interannual streamflow and water release patterns, while others include information about current and near-term conditions, such as snowpack depth and expected snowmelt volume. Climate change threatens to alter both the streamflow variability that these structures must accommodate and their opportunities to recover after doing so (due to permanent changes in average streamflow). Thus, as streamflow and demand patterns change, historically based operating rules and procedures could become less effective in balancing water supply with other uses.[104]

Some of the highest water demand increases under climate change are projected in U.S. regions where groundwater aquifers are the main water supply source (Figure 3.11b), including the Great Plains and parts of the Southwest and Southeast. The projected water demand increases combined with potentially declining recharge rates (see water cycle section) further challenge the sustainability of the aquifers in these regions.

Power plant cooling is a critical national water use, because nearly 90% of the U.S. electrical energy is produced by thermoelectric power plants.[105] Freshwater withdrawals per kilowatt hour have been falling in recent years due to the gradual replacement of once-through cooling of power plant towers with plants that recycle cooling water. Thermal plant cooling is principally supported by surface water withdrawals (Figure 3.10e,f) and has already been affected by climate change in areas where temperatures are increasing and surface water supplies are diminishing, such as the southern United States. Higher water temperatures affect the efficiency of electric generation and cooling processes. It also limits the ability of utilities to discharge heated water to streams from once-through cooled power systems due to regulatory requirements and concerns about how the release of warmer water into rivers and streams affects ecosystems and biodiversity (see Ch. 4: Energy).[106]

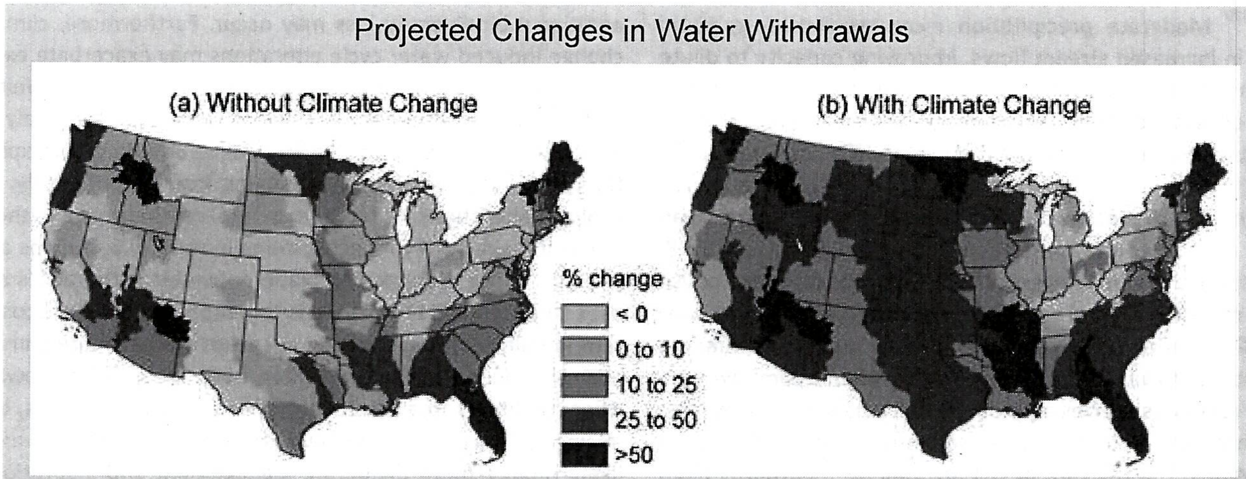

Figure 3.11. The effects of climate change, primarily associated with increasing temperatures and potential evapotranspiration, are projected to significantly increase water demand across most of the United States. Maps show percent change from 2005 to 2060 in projected demand for water assuming (a) change in population and socioeconomic conditions based on the underlying A1B emissions scenario, but with no change in climate, and (b) combined changes in population, socioeconomic conditions, and climate according to the A1B emissions scenario (gradual reductions from current emission trends beginning around mid-century). (Figure source: Brown et al. 2013[99]).

Instream Water Uses

Hydropower contributes 7% of electricity generation nationwide, but provides up to 70% in the Northwest and 20% in California, Alaska, and the Northeast.[107] Climate change is expected to affect hydropower directly through changes in runoff (average, extremes, and seasonality), and indirectly through increased competition with other water uses. Based on runoff projections, hydropower is expected to decline in the southern U.S. (especially the Southwest) and increase in the Northeast and Midwest (though actual gains or losses will depend on facility size and changes in runoff volume and timing). Where non-power water demands are expected to increase (as in the southern U.S.), hydropower generation, dependable capacity, and ancillary services are likely to decrease. Many hydropower facilities nationwide, especially in the Southeast, Southwest, and the Great Plains, are expected to face water availability constraints.[108] While some hydropower facilities may face water-related limitations, these could be offset to some degree by the use of more efficient turbines as well as innovative new hydropower technologies.

Inland navigation, most notably in the Great Lakes and the Missouri, Mississippi, and Ohio River systems, is particularly important for agricultural commodities (transported from the Midwest to the Gulf Coast and on to global food markets), coal, and iron ore.[1,109] Navigation is affected by ice cover and by floods and droughts. Seasonal ice cover on the Great Lakes has been decreasing[16] which may allow increased shipping.[110] However, lake level declines are also possible in the long term, decreasing vessel draft and cargo capacity. Future lake levels may also depend on non-climate factors and are uncertain both in direction and magnitude (see Ch. 2: Our Changing Climate; Ch. 5: Transportation; and Ch. 18: Midwest). Similarly, although the river ice cover period has been decreasing[53] (extending the inland navigation season), seasonal ice cover changes[111,112] could impede lock operations.[112] Intensified floods are likely to hinder shipping by causing waterway closures and damaging or destroying ports and locks. Droughts have already been shown to decrease reliability of flows or channel depth, adversely impacting navigation (Ch. 5: Transportation). Both floods and droughts can disrupt rail and road traffic and increase shipping costs[113] and result in commodity price volatility (Ch. 19: Great Plains).

Recreational activities associated with water resources, including boating, fishing, swimming, skiing, camping, and wildlife watching, are strong regional and national economic drivers.[114] Recreation is sensitive to weather and climate,[115] and climate change impacts to recreation can be difficult to project.[116] Rising temperatures affect extent of snowcover and mountain snowpack, with impacts on skiing[117] and snowmobiling.[118] As the climate warms, changes in precipitation and runoff are expected to result in both beneficial (in some regions) and adverse impacts[115] to water sports, with potential for considerable economic dislocation and job losses.[118]

Changing climate conditions are projected to affect water and wastewater treatment and disposal in ways that depend on system-specific and interacting attributes. For example, elevated stream temperatures, combined with lower flows, may require wastewater facilities to increase treatment to meet stream water quality standards.[119] More intense precipitation and floods, combined with escalating urbanization and associated increasing impermeable surfaces, may amplify the likelihood of contaminated overland flow or combined sewer overflows.[120] Moderate precipitation increases, however, could result in increased stream flows, improving capacity to dilute contaminants in some regions. Sea level rise and more frequent coastal flooding could damage wastewater utility infrastructure and reduce treatment efficiency (Ch. 25: Coasts).[121]

Changes in streamflow temperature and flow regimes can affect aquatic ecosystem structure and function (see Ch. 8: Ecosystems). Water temperature directly regulates the physiology, metabolism, and energy of individual aquatic organisms, as well as entire ecosystems. Streamflow quantity influences the extent of available aquatic habitats, and streamflow variability regulates species abundance and persistence. Flow also influences water temperature, sediment, and nutrient concentrations.[122] If the rate of climate change[123] outpaces plant and animal species' ability to adjust to temperature change, additional biodiversity loss may occur. Furthermore, climate change induced water cycle alterations may exacerbate existing ecosystem vulnerability, especially in the western United States[124] where droughts and water shortages are likely to increase. But areas projected to receive additional precipitation, such as the northern Great Plains, may benefit. Lastly, hydrologic alterations due to human interventions have without doubt impaired riverine ecosystems in most U.S. regions and globally.[125] The projected escalation of water withdrawals and uses (see Figure 3.11) threatens to deepen and widen ecosystem impairment, especially in southern states where climate change induced water cycle alterations are pointing toward drier conditions (see Ch. 8: Ecosystems). In these regions, balancing socioeconomic and environmental objectives will most likely require more deliberate management and institutional responses.

Major Water Resource Vulnerabilities and Challenges

Many U.S. regions are expected to face increased drought and flood vulnerabilities and exacerbated water management challenges. This section highlights regions where such issues are expected to be particularly intense.

Key Message 8: Drought is Affecting Water Supplies

Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.

Many southwestern and western watersheds, including the Colorado, Rio Grande,[38,43,126] and Sacramento-San Joaquin,[127,128] have recently experienced drier conditions. Even larger runoff reductions (about 10% to 20%) are projected over some of these watersheds in the next 50 years.[48,129] Increasing evaporative losses, declining runoff and groundwater recharge, and changing groundwater pumpage are expected to affect surface and groundwater supplies[65,66,67,71] and increase the risk of water shortages for many water uses. Changes in streamflow timing will exacerbate a growing mismatch between supply and demand (because peak flows are occurring earlier in the spring, while demand is highest in mid-summer) and will present challenges for the management of reservoirs, aquifers, and other water infrastructure.[130] Rising stream temperatures and longer low flow periods may make electric power plant cooling water withdrawals unreliable, and may affect aquatic and riparian ecosystems by degrading habitats and favoring invasive, non-native species.[131]

Key Message 9: Flood Effects on People and Communities

Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the U.S.

Flooding affects critical water, wastewater, power, transportation, and communications infrastructure in ways that are difficult to foresee and can result in interconnected and cascading failures (see "Flood Factors and Flood Types"). Very heavy precipitation events have intensified in recent decades in most U.S. regions, and this trend is projected to continue (Ch. 2: Our Changing Climate). Increasing heavy precipitation is an important contributing factor, but flood magnitude changes also depend on specific watershed conditions (including soil moisture, impervious area, and other human-caused alterations).

Projected changes in flood frequency based on climate projections and hydrologic models have recently begun to emerge (for example, Das et al. 2012;[60] Brekke et al. 2009;[132] Raff et al. 2009;[133] Shaw and Riha 2011;[134] Walker et al. 2011[135]), and suggest that flood frequency and severity increases may occur in the Northeast and Midwest (Ch. 16: Northeast; Ch. 18: Midwest). Flooding and sea water intrusion from sea level rise and increasing storm surge threaten New York, Boston, Philadelphia, Virginia Beach, Wilmington, Charleston, Miami, Tampa, Naples, Mobile, Houston, New Orleans, and many other cities on U.S. coasts (Chapter 25: Coasts).

The devastating toll of large floods (human life, property, environment, and infrastructure) suggests that proactive management measures could minimize changing future flood risks and consequences (Ch. 28: Adaptation). In coastal areas, sea level rise may act in parallel with inland climate changes to intensify water-use impacts and challenges (Ch. 12: Indigenous Peoples; Ch. 17: Southeast).[136] Increasing flooding risk, both coastal and inland, could also exacerbate human health risks associated with failure of critical infrastructure,[137,138] and an increase in both waterborne diseases (Ch. 9: Human Health)[139] and air-borne diseases.[140]

Changes in land use, land cover, development, and population distribution can all affect flood frequency and intensity. The nature and extent of these projected changes results in increased uncertainty and decreased accuracy of flood forecasting in both the short term[133] and long term.[141] This lack of certainty could hinder effective preparedness (such as evacuation planning) and the effectiveness of structural and non-structural flood risk reduction measures. However, many climate change projections are robust (Ch. 2: Our Changing Climate), and the long lead time needed for the planning, design, and construction of critical infrastructure that provides resilience to floods means that consideration of long-term changes is needed.

Effective climate change adaptation planning requires an integrated approach[45,118,142] that addresses public health and safety issues (Ch. 28: Adaptation).[143] Though numerous flood risk reduction measures are possible, including levees, land-use zoning, flood insurance, and restoration of natural flood-plain retention capacity,[144] economic and institutional conditions may constrain implementation. The effective use of these measures would require significant investment in many cases,[145] as well as updating policies and methods to account for climate change[42,146] in the planning, design, operation, and maintenance of flood risk reduction infrastructure.[132,147]

Adaptation and Institutional Responses

Key Message 10: Water Resources Management

In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.

Water managers and planners strive to balance water supply and demand across all water uses and users. The management process involves complex tradeoffs among water-use benefits, consequences, and risks. By altering water availability and demand, climate change is likely to present additional management challenges. One example is in the Sacramento-San Joaquin River Delta, where flooding, sea water intrusion, and changing needs for environmental, municipal, and agricultural water uses have created significant management challenges. This California Bay-Delta experience suggests that managing risks and sharing benefits requires re-assessment of very complex ecosystems, infrastructure systems, water rights, stakeholder preferences, and reservoir operation strategies – as well as significant investments. All of these considerations are subject to large uncertainties.[54,148] To some extent, all U.S. regions are susceptible, but the Southeast and Southwest are highly vulnerable because climate change is projected to reduce water availability, increase demand, and exacerbate shortages (see "Water Management").

Recent assessments illustrate water management challenges facing California,[127,129,149,150] the Southwest,[130,151] Southeast (Ch. 17: Southeast),[136,152] Northwest,[153] Great Plains,[154] and Great Lakes.[155] A number of these assessments demonstrate that while expanding supplies and storage may still be possible in some regions, effective climate adaptation strategies can benefit from innovative management strategies. These strategies can include domestic water conservation programs that use pricing incentives to curb use; more flexible, risk-based, better-informed, and adaptive operating rules for reservoirs; the integrated use of combined surface and groundwater resources; and better monitoring and assessment of statewide water use.[129,149,156,157] Water management and planning would benefit from better coordination among public sectors at the national, state, and local levels (including regional partnerships and agreements), and the private sector, with participation of all relevant stakeholders in well-informed, fair, and equitable decision-making processes. Better coordination among hydrologists and atmospheric scientists, and among these scientists and the professional water management community, is also needed to facilitate more effective translation of knowledge from science to practice (Ch. 26: Decision Support; Ch. 28: Adaptation).[158]

WATER CHALLENGES IN A SOUTHEAST RIVER BASIN

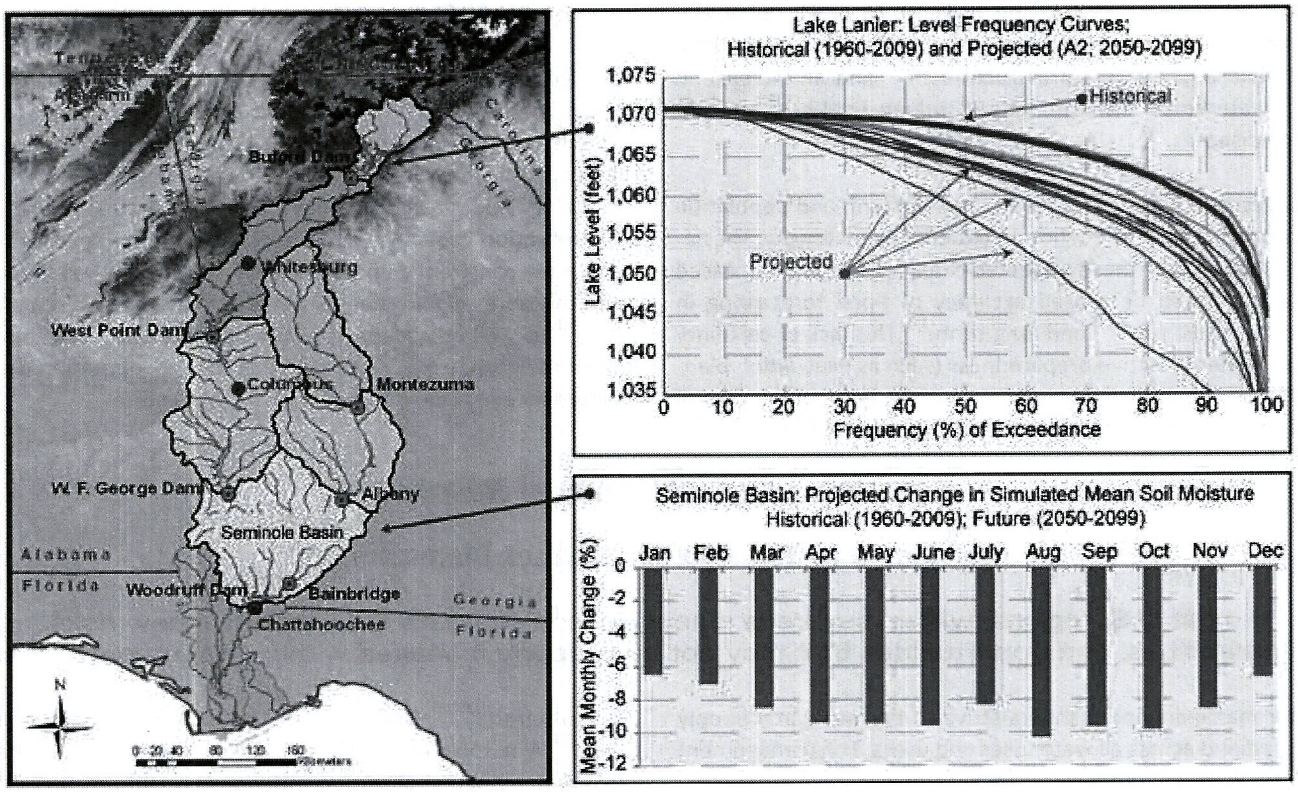

Figure 3.12. The Apalachicola-Chattahoochee-Flint (ACF) River Basin supports many water uses and users, including municipal, industrial, and agricultural water supply; flood management; hydroelectric and thermoelectric energy generation; recreation; navigation; fisheries; and a rich diversity of environmental and ecological resources. In recent decades, water demands have risen rapidly in the Upper Chattahoochee River (due to urban growth) and Lower Chattahoochee and Flint Rivers (due to expansion of irrigated agriculture). At the same time, basin precipitation, soil moisture, and runoff are declining, creating challenging water sharing tradeoffs for the basin stakeholders.[159] The historical water demand and supply trends are expected to continue in the coming decades. Climate assessments for 50 historical (1960-2009) and future years (2050-2099) based on a scenario of continued increases in emissions (A2) for the Seminole and all other ACF sub-basins[152] show that soil moisture is projected to continue to decline in all months, especially during the crop growing season from April to October (bottom right). Mean monthly runoff decreases (up to 20%, not shown) are also projected throughout the year and especially during the wet season from November to May. The projected soil moisture and runoff shifts are even more significant in the extreme values of the respective distributions. In addition to reduced supplies, these projections imply higher water demands in the agricultural and other sectors, exacerbating management challenges. These challenges are reflected in the projected response of Lake Lanier, the main ACF regulation project, the levels of which are projected (for 2050-2099) to be lower, by as much as 15 feet, than its historical (1960-2009) levels, particularly during droughts (top right). Recognizing these critical management challenges, the ACF stakeholders are earnestly working to develop a sustainable and equitable management plan that balances economic, ecological, and social values.[160] (Figure source: Georgia Water Resources Institute, Georgia Institute of Technology.[152]).

Key Message 11: Adaptation Opportunities and Challenges

Increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts. Many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.

Climate adaptation involves both addressing the risks and leveraging the opportunities that may arise as a result of the climate impacts on the water cycle and water resources. Efforts to increase resiliency and enhance adaptive capacity may create opportunities for a wide-ranging public discussion of water demands, improved collaboration around water use, increased public support for scientific and economic information, and the deployment of new technologies supporting adaptation. In addition, adaptation can promote the achievement of multiple water resource objectives through improved infrastructure planning, integrated regulation, and planning and management approaches at regional, watershed, or ecosystem scales. Pursuing these opportunities may require assessing how current institutional approaches support adaptation in light of the anticipated impacts of climate change.[161]

Climate change will stress the nation's aging water infrastructure to varying degrees by location and over time. Much of the country's current drainage infrastructure is already overwhelmed during heavy precipitation and high runoff events, an impact that is projected to be exacerbated as a result of climate change, land-use change, and other factors. Large percentage increases in combined sewage overflow volumes, associated with increased intensity of precipitation events, have been projected for selected watersheds by the end of this century in the absence of adaptive measures.[106,162] Infrastructure planning, especially for the long planning and operation horizons often associated with water resources infrastructure, can be improved by incorporating climate change as a factor in new design standards and in asset management and rehabilitation of critical and aging facilities, emphasizing flexibility, redundancy, and resiliency.[106,132,163]

Adaptation strategies for water infrastructure include structural and non-structural approaches. These may include changes in system operations and/or demand management changes, adopting water conserving plumbing codes, and improving flood forecasts, telecommunications, and early warning systems[164] that focus on both adapting physical structures and innovative management.[106,132,165] Such strategies could take advantage of conventional ("gray") infrastructure upgrades (like raising flood control levees); adjustments to reservoir operating rules; new demand management and incentive strategies; land-use management that enhances adaptive capacity; protection and restoration at the scale of river basins, watersheds, and ecosystems; hybrid strategies that blend "green" infrastructure with gray infrastructure; and pricing strategies.[1,106,132,166,167] Green infrastructure approaches that are increasingly being implemented by municipalities across the country include green roofs, rain gardens, roadside plantings, porous pavement, and rainwater harvesting (Ch. 28: Adaptation). These techniques typically utilize soils and vegetation in the built environment to absorb runoff close to where it falls, limiting flooding and sewer backups.[168] There are numerous non-infrastructure related adaptation strategies, some of which could include promoting drought-resistant crops, flood insurance reform, and building densely developed areas away from highly vulnerable areas.

In addition to physical adaptation, capacity-building activities can build knowledge and enhance communication and collaboration within and across sectors.[1,167,169] In particular, building networks, partnerships, and support systems has been identified as a major asset in building adaptive capacity (Ch. 26: Decision Support; Ch. 28: Adaptation).[170]

In addition to stressing the physical infrastructure of water systems, future impacts of climate change may reveal the weaknesses in existing water law regimes to accommodate novel and dynamic water management conditions. The basic paradigms of environmental and natural resources law are preservation and restoration, both of which are based on the assumption that natural systems fluctuate within an unchanging envelope of variability ("stationarity").[171] However, climate change is now projected to affect water supplies during the multi-decade lifetime of major water infrastructure projects in wide-ranging and pervasive ways.[132] Under these circumstances, stationarity will no longer be reliable as the central assumption in water-resource risk assessment and planning.[42,171] For example, in the future, water rights administrators may find it necessary to develop more flexible water rights systems conditioned to address the uncertain impacts of climate change.[172] Agencies and courts may seek added flexibility in regulations and laws to achieve the highest and best uses of limited water resources and to enhance water management capacity in the context of new and dynamic conditions.[132,173]

In the past few years, many federal, state, and local agencies and tribal governments have begun to address climate change adaptation, integrating it into existing decision-making, planning, or infrastructure-improvement processes (Ch. 28: Adaptation).[43,174] Drinking water utilities are increasingly utilizing climate information to prepare assessments of their supplies,[175] and utility associations and alliances, such as the Water Research Foundation and Water Utility Climate Alliance, have undertaken original research to better understand the implications of climate change on behalf of some of the largest municipal water utilities in the United States.[119,156,176]

The economic, social, and environmental implications of climate change induced water cycle changes are very significant, as is the cost of inaction. Adaptation responses need to address considerable uncertainties in the short-, medium-, and long-term; be proactive, integrated, and iterative; and be developed through well-informed stakeholder decision processes functioning within a flexible institutional and legal environment.

3: WATER RESOURCES

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages:

The chapter author team engaged in multiple technical discussions via teleconferences from March – June 2012. These discussions followed a thorough review of the literature, which included an inter-agency prepared foundational document,[1] over 500 technical inputs provided by the public, as well as other published literature. The author team met in Seattle, Washington, in May 2012 for expert deliberation of draft key messages by the authors wherein each message was defended before the entire author team before this key message was selected for inclusion in the Chapter. These discussions were supported by targeted consultation with additional experts by the lead author of each message, and they were based on criteria that help define "key vulnerabilities." Key messages were further refined following input from the NCADAC report integration team and authors of Ch. 2: Our Changing Climate.

Key Message #1 Traceable Account

Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] Ch. 2: Our Changing Climate, Ch. 20: Southwest, other technical input reports,[2] and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications describe precipitation trends (Ch. 2: Our Changing Climate)[4,7,8,34] and river-flow trends.[13,41] As discussed in Chapter 2, the majority of projections available from climate models (for example, Orlowsky and Seneviratne 2012;[3] Kharin et al. 2013[5]) indicate small projected changes in total average annual precipitation in many areas, while heavy precipitation[6] and the length of dry spells are projected to increase across the entire country. Projected precipitation responses (such as changing extremes) to increasing greenhouse gases are robust in a wide variety of models and depictions of climate.

The broad observed trends of precipitation and river-flow increases have been identified by many long-term National Weather Service (NWS)/National Climatic Data Center (NCDC) weather monitoring networks, USGS streamflow monitoring networks, and analyses of records therefrom (Ch. 2: Our Changing Climate;[34,36,37]). Ensembles of climate models[3,42](see also Ch. 2: Our Changing Climate, Ch. 20: Southwest) are the basis for the reported projections.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings from the 2009 National Climate Assessment.[177]

Observed trends: Precipitation trends are generally embedded amidst large year-to-year natural variations and thus trends may be difficult to detect, may differ from site to site, and may be reflections of multi-decadal variations rather than external (human) forcings. Consequently, careful analyses of longest-term records from many stations across the country and addressing multiple potential explanations are required and are cornerstones of the evidentiary studies described above.

Efforts are underway to continually improve the stability, placement, and numbers of weather observations needed to document trends; scientists also regularly search for other previously unanalyzed data sources for use in testing these findings.

Projected trends: The complexity of physical processes that result in precipitation and runoff reduces abilities to represent or predict them as accurately as would be desired and with the spatial and temporal resolution required for many applications; however, as noted, the trends at the scale depicted in this message are very robust among a wide variety of climate models and projections, which lends confidence that the projections are appropriate lessons from current climate (and streamflow) models. Nonetheless, other influences not included in the climate change projections might influence future patterns of precipitation and runoff, including changes in land cover, water use (by humans and vegetation), and streamflow management.

Climate models used to make projections of future trends are continually increasing in number, resolution, and in the number of additional external and internal influences that might be confounding current projections. For example, much more of all three of these directions for improvement are already evident in projection archives for the next IPCC assessment.

Assessment of confidence based on evidence

Observed trends have been demonstrated by a broad range of methods over the past 20+ years based on best available data; projected precipitation and river-flow responses to greenhouse gas increases are robust across large majorities of available climate (and hydrologic) models from scientific teams around the world.

Confidence is therefore judged to be **high** that annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions.

Confidence is **high** that very heavy precipitation events have increased nationally and are projected to increase in all regions.

Confidence is **high** that the length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous United States.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

KEY MESSAGE #2 TRACEABLE ACCOUNT

Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] Ch. 16: Northeast, Ch 17: Southeast, Ch. 2: Our Changing Climate, Ch. 18: Midwest, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 21: Northwest, Ch. 23: Hawai'i and Pacific Islands, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Projected drought trends derive directly from climate models in some studies (for example, Hoerling et al. 2012;[8] Wehner et al. 2011;[30] Gao et al. 2012;[32] Gao et al. 2011;[33]), from hydrologic models responding to projected climate trends in others (for example, Georgakakos and Zhang 2011;[38] Cayan et al. 2010;[48]), from considerations of the interactions between precipitation deficits and either warmer or cooler temperatures in historical (observed) droughts,[48] and from combinations of these approaches (for example, Trenberth et al. 2004[49]) in still other studies.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings from the 2009 National Climate Assessment.[177]

Warmer temperatures are robustly projected by essentially all climate models, with what are generally expected to be directly attendant increases in the potentials for greater evapotranspiration, or ET (although it is possible that current estimates of future ET are overly influenced by temperatures at the expense of other climate variables, like wind speed, humidity, net surface radiation, and soil moisture that might change in ways that could partly ameliorate rising ET demands). As a consequence, there is a widespread expectation that more water from precipitation will be evaporated or transpired in the warmer future, so that except in regions where precipitation increases more than ET increases, less overall water will remain on the landscape and droughts will intensify and become more common. Another widespread expectation is that precipitation variability will increase, which may result in larger swings in moisture availability, with swings towards the deficit side resulting in increased frequencies and intensities of drought conditions on seasonal time scales to times scales of multiple decades. An important remaining uncertainty, discussed in the supporting text for Key Message #1, is the extent to which the types of models used to project future droughts may be influencing results with a notable recent tendency for studies with more complete, more resolved land-surface models, as well as climate models, to yield more moderate projected changes.

Other uncertainties derive from the possibility that changes in other variables or influences of CO_2-fertilization and/or land cover change may also partly ameliorate drought intensification. Furthermore in many parts of the country, El Niño-Southern Oscillation (and other oceanic) influences on droughts and floods are large, and can overwhelm climate change effects during the next few decades. At present, however, the future of these oceanic climate influences remains uncertain.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties:

Confidence is judged to be **medium-high** that short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Confidence is **high** that longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.

Key Message #3 Traceable Account

Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] Ch. 16: Northeast, Ch 17: Southeast, Ch. 2: Our Changing Climate, Ch. 18: Midwest, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 21: Northwest, Ch. 23: Hawai'i and Pacific Islands, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

The principal observational bases for the key message are careful national-scale flood-trend analyses[58] based on annual peak-flow records from a selection of 200 USGS streamflow gaging stations measuring flows from catchments that are minimally influenced by upstream water uses, diversions, impoundments, or land-use changes with more than 85 years of records, and analyses of two other subsets of USGS gages with long records (including gages both impacted by human activities and less so), including one analysis of 50 gages nationwide[56] and a second analysis of 572 gages in the eastern United States.[57] There is some correspondence among regions with significant changes in annual precipitation (Ch. 2: Our Changing Climate) and soil moisture (Figures 3.2 and 3.3), and annual flood magnitudes (Figure 3.5).[58]

Projections of future flood-frequency changes result from detailed hydrologic models (for example, Das et al. 2012;[60] Raff et al. 2009;[133] Walker et al. 2011[135]) of rivers that simulate responses to projected precipitation and temperature changes from climate models; such simulations have only recently begun to emerge in the peer-reviewed literature.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings from the 2009 National Climate Assessment.[177]

Large uncertainties remain in efforts to detect flood-statistic changes attributable to climate change, because a wide range of local factors (such as dams, land-use changes, river channelization) also affect flood regimes and can mask, or proxy for, climate change induced alterations. Furthermore, it is especially difficult to detect any kinds of trends in what are, by definition, rare and extreme events. Finally, the response of floods to climate changes are expected to be fairly idiosyncratic from basin to basin, because of the strong influences of within-storm variations and local, basin-scale topographic, soil and vegetation, and river network characteristics that influence the size and extent of flooding associated with any given storm or season.[54,55,56,57]

Large uncertainties still exist as to how well climate models can represent and project future extremes of precipitation. This has – until recently – limited attempts to make specific projections of future flood frequencies by using climate model outputs directly or as direct inputs to hydrologic models. However, precipitation extremes are expected to intensify as the atmosphere warms, and many floods result from larger portions of catchment areas receiving rain as snowlines recede upward. As rain runs off more quickly than snowfall this results in increased flood potential; furthermore, occasional rain-on-snow events exacerbates this effect. This trend is broadly expected to increase in frequency under general warming trends, particularly in mountainous catchments.[62] Rising sea levels and projected increase in hurricane-associated storm intensity and rainfall rates provide first-principles bases for expecting intensified flood regimes in coastal settings (see Ch. 2: Our Changing Climate).

Assessment of confidence based on evidence

Future changes in flood frequencies and intensities will depend on a complex combination of local to regional climatic influences, and the details of complex surface-hydrologic conditions in each catchment (for example, topography, land cover, and upstream management). Consequently, flood frequency changes may be neither simple nor regionally homogeneous, and basin by basin projections may need to be developed. Early results now appearing in the literature have most often projected intensifications of flood regimes, in large part as responses to projections of more intense storms and increasingly rainy (rather than snowy) storms in previously snow-dominated settings. Confidence in current estimates of future changes in flood frequencies and intensities is overall judged to be **low**.

Key Message #4 Traceable Account

Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] regional chapters of the NCA, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Several recent studies[65,66,67,68,71,72] have evaluated the potential impacts of changes in groundwater use and recharge under scenarios including climate change, and generally they have illustrated the common-sense conclusion that changes in pumpage can have immediate and significant effects in the nation's aquifers. This has certainly been the historical experience in most aquifers that have seen significant development; pumpage variations usually tend to yield more immediate and often larger changes on many aquifers than do historical climate variations on time scales from years to decades. Meanwhile, for aquifers in the Southwest, there is a growing literature of geochemical studies that fingerprint various properties of groundwater and that are demonstrating that most western groundwater derives preferentially from snowmelt, rather than rainfall or other sources.[50,51,66,74] This finding suggests that much western recharge may be at risk of changes and disruptions from projected losses of snowpack, but as yet provides relatively little indication whether the net effects will be recharge declines, increases, or simply spatial redistribution.

New information and remaining uncertainties

The precise responses of groundwater storage and flow to climate change are not well understood, but recent and ongoing studies provide insights on underlying mechanisms.[65,66,67] The observations and modeling evidence to make projections of future responses of groundwater recharge and discharge to climate change are thus far very limited, primarily because of limitations in data availability and in the models themselves. New forms and networks of observations and new modeling approaches and tools are needed to provide projections of the likely influences of climate changes on groundwater recharge and discharge. Despite the uncertainties about the specifics of climate change impacts on groundwater, impacts of reduced groundwater supply and quality would likely be detrimental to the nation.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is judged to be **high** that climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge, reducing groundwater availability in some areas.

KEY MESSAGE #5 TRACEABLE ACCOUNT

Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.

Description of evidence base

This message has a strong theoretical and observational basis, including considerable historical experience with seawater intrusion into many of the nation's coastal aquifers and wetlands under the influence of heavy pumpage, some experience with the influences of droughts and storms on seawater intrusion, and experience with seepage of seawater into shallow coastal aquifers under storm and storm surge conditions that lead to coastal inundations with seawater. The likely influences of sea level rise on seawater intrusion into coastal (and island) aquifers and wetlands are somewhat less certain, as discussed below, although it is projected that sea level rise may increase opportunities for saltwater intrusion (see Ch. 25: Coasts).

New information and remaining uncertainties

There are few published studies describing the kinds of groundwater quality and flow modeling that are necessary to assess the real-world potentials for sea level rise to affect seawater intrusion.[78] Studies in the literature and historical experience demonstrate the detrimental impacts of alterations to the water budgets of the freshwater lenses in coastal aquifers and wetlands around the world (most often by groundwater development), but few evaluate the impacts of sea level rise alone. More studies with real-world aquifer geometries and development regimes are needed to reduce the current uncertainty of the potential interactions of sea level rise and seawater intrusion.

Assessment of confidence based on evidence

Confidence is **high** that sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.

KEY MESSAGE #6 TRACEABLE ACCOUNT

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] Ch. 8: Ecosystems, Ch. 15: Biogeochemical Cycles, and over 500 technical inputs on a wide range of topics that were reviewed as part of the Federal Register Notice solicitation for public input.

Thermal stratification of deep lakes and reservoirs has been observed to increase with increased air and water temperatures,[1,81,82] and may be eliminated in shallow lakes. Increased stratification reduces mixing, resulting in reduced oxygen in bottom waters. Deeper set-up of vertical thermal stratification in lakes and reservoirs may reduce or eliminate a bottom cold water zone; this, coupled with lower oxygen concentration, results in a degraded aquatic ecosystem.

Major precipitation events and resultant water flows increase watershed pollutant scour and thus increase pollutant loads.[84] Fluxes of mineral weathering products (for example, calcium, magnesium, sodium, and silicon) have also been shown to increase in response to higher discharge.[86] In the Mississippi drainage basin, increased precipitation has resulted in increased nitrogen loads contributing to hypoxia in the Gulf of Mexico.[85] Models predict and observations confirm that continued warming will have increasingly negative effects on lake water quality and ecosystem health.[81]

Future re-mobilization of sediment stored in large river basins will be influenced by changes in flood frequencies and magnitudes, as well as on vegetation changes in the context of climate and other anthropogenic factors.[87] Model projections suggest that changes in sediment delivery will vary regionally and by land-use type, but on average could increase by 25% to 55%.[88]

New information and remaining uncertainties

It is unclear whether increasing floods and droughts cancel each other out with respect to long-term pollutant loads.

It is also uncertain whether the absolute temperature differential with depth will remain constant, even with overall lake and reservoir water temperature increases. Further, it is uncertain if greater mixing with depth will eliminate thermal stratification in shallow, previously stratified lakes. Although recent studies of Lake Tahoe provide an example of longer stratification seasons,[83] lakes in other settings and with other geometries may not exhibit the same response.

Many factors influence stream water temperature, including air temperature, forest canopy cover, and ratio of baseflow to streamflow.

Assessment of confidence based on evidence

Given the evidence base, confidence is **medium** that increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and pollutant loads.

KEY MESSAGE #7 TRACEABLE ACCOUNT

Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] Ch. 2: Our Changing Climate, Ch. 17: Southeast, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 23: Hawai'i and Pacific Islands, and many technical inputs on a wide range of topics that were received and reviewed as part of the Federal Register Notice solicitation for public input.

Observed Trends: Historical water withdrawals by sector (for example, municipal, industrial, agricultural, and thermoelectric) have been monitored and documented by USGS for over 40 years and represent a credible database to assess water-use trends, efficiencies, and underlying drivers. Water-use drivers principally include population, personal income, electricity consumption, irrigated area, mean annual temperature, growing season precipitation, and growing season potential evapotranspiration.[99] Water-use efficiencies are also affected by many non-climate factors, including demand management, plumbing codes, water efficient appliances, efficiency improvement programs, and pricing strategies;[100] changes from water intensive manufacturing and other heavy industrial activities to service-oriented businesses,[101] and enhanced water-use efficiencies in response to environmental pollution legislation; replacement of older once-through-cooling electric power plants by plants that recycle their cooling water; and switching from flood irrigation to more efficient methods in the western United States.[102]

Projected Trends and Consequences: Future projections have been carried out with and without climate change to first assess the water demand impacts of projected population and socioeconomic increases, and subsequently combine them with climate change induced impacts. The main findings are that in the absence of climate change total water withdrawals in the U.S. will increase by 3% in the coming 50 years,[99] with approximately half of the U.S. experiencing a total water demand decrease and half an increase. If, however, climate change projections are also factored in, the demand for total water withdrawals is projected to rise by an average of 26%,[99] with more than 90% of the U.S. projected to experience a total demand increase, and decreases projected only in parts of the Midwest, Northeast, and Southeast. When coupled with the observed and projected drying water cycle trends (see key messages in "Climate Change Impacts on the Water Cycle" section), the water demand impacts of projected population, socioeconomic, and climate changes intensify and compound in the Southwest and Southeast, rendering these regions particularly vulnerable in the coming decades.

New information and remaining uncertainties

The studies of water demand in response to climate change and other stressors are very recent and constitute new information on their own merit.[99] In addition, for the first time, these studies make it possible to piece together the regional implications of climate change induced water cycle alterations in combination with projected changes in water demand. Such integrated assessments also constitute new information and knowledge building.

Demand projections include various uncertain assumptions which become increasingly important in longer term (multi-decadal) projections. Because irrigation demand is the largest water demand component most sensitive to climate change, the most important climate-related uncertainties are precipitation and potential evapotranspiration over the growing season. Non-climatic uncertainties relate to future population distribution, socioeconomic changes, and water-use efficiency improvements.

Assessment of confidence based on evidence

Considering that (a) droughts are projected to intensify in large areas of the Southwest, Great Plains, and the Southeast, and (b) that these same regions have experienced and are projected to experience continuing population and demand increases, confidence that these regions will become increasingly vulnerable to climate change is judged to be **high**.

KEY MESSAGE #8 TRACEABLE ACCOUNT

Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] Ch. 2: Our Changing Climate, Ch. 17: Southeast, Ch. 19: Great Plains, Ch. 20: Southwest, Ch. 23: Hawai'i and Pacific Islands, and over 500 technical inputs on a wide range of topics that were received and reviewed as part of the Federal Register Notice solicitation for public input.

Observed Trends: Observations suggest that the water cycle in the Southwest, Great Plains, and Southeast has been changing toward drier conditions (Ch. 17: Southeast).[130,151,152] Furthermore, paleoclimate tree-ring reconstructions indicate that drought in previous centuries has been more intense and of longer duration than the most extreme drought of the 20th and 21st centuries.[40]

Projected Trends and Consequences: Global Climate Model (GCM) projections indicate that this trend is likely to persist, with runoff reductions (in the range of 10% to 20% over the next 50 years) and intensifying droughts.[48]

The drying water cycle is expected to affect all human and ecological water uses, especially in the Southwest. Decreasing precipitation, rising temperatures, and drying soils are projected to increase irrigation and outdoor watering demand (which account for nearly 90% of consumptive water use) by as much as 34% by 2060 under the A2 emissions scenario.[99] Decreasing runoff and groundwater recharge are expected to reduce surface and groundwater supplies,[66] increasing the annual risk of water shortages from 25% to 50% by 2060.[130] Changes in streamflow timing will increase the mismatch of supply and demand. Earlier and declining streamflow and rising demands will make it more difficult to manage reservoirs, aquifers, and other water infrastructure.[130]

Such impacts and consequences have been identified for several southwestern and western river basins including the Colorado,[38] Rio Grande,[126] and Sacramento-San Joaquin.[127,128,129]

New information and remaining uncertainties

The drying climate trend observed in the Southwest and Southeast in the last decades is consistent across all water cycle variables (precipitation, temperature, snow cover, runoff, streamflow, reservoir levels, and soil moisture) and is not debatable. The debate is over whether this trend is part of a multi-decadal climate cycle and whether it will reverse direction at some future time. However, the rate of change and the comparative GCM assessment results with and without historical CO_2 forcing (Ch. 2: Our Changing Climate) support the view that the observed trends are due to both factors acting concurrently.

GCMs continue to be uncertain with respect to precipitation, but they are very consistent with respect to temperature. Runoff, streamflow, and soil moisture depend on both variables and are thus less susceptible to GCM precipitation uncertainty. The observed trends and the general GCM agreement that the southern states will continue to experience streamflow and soil moisture reductions[34,41] provides confidence that these projections are robust.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **high** that changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. Confidence is **high** that these trends are expected to continue, increasing the likelihood of water shortages for many uses.

KEY MESSAGE #9 TRACEABLE ACCOUNT

Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the U.S.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] Ch. 2: Our Changing Climate, Ch. 21: Northwest, Ch. 19: Great Plains, Ch. 18: Midwest, Ch. 16: Northeast, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Observed Trends: Very heavy precipitation events have intensified in recent decades in most U.S. regions, and this trend is projected to continue (Ch. 2: Our Changing Climate). Increasing heavy precipitation is an important contributing factor for floods, but flood magnitude changes also depend on specific watershed conditions (including soil moisture, impervious area, and other human-caused alterations). There is, however, some correspondence among regions with significant changes in annual precipitation (Ch. 2: Our Changing Climate), soil moisture (Figures 3.2 and 3.3), and annual flood magnitudes (Figure 3.5).[58]

Flooding and seawater intrusion from sea level rise and increasing storm surge threaten New York, Boston, Philadelphia, Virginia Beach, Wilmington, Charleston, Miami, Tampa, Naples, Mobile, Houston, New Orleans, and many other coastal cities (Chapter 25: Coasts).

Projected Trends: Projections of future flood-frequency changes result from detailed hydrologic[60,133,135] and hydraulic models of rivers that simulate responses to projected precipitation and temperature changes from climate models.

Consequences: Floods already affect human health and safety and result in substantial economic, ecological, and infrastructure damages. Many cities are located along coasts and, in some of these cities (including New York, Boston, Miami, Savannah, and New Orleans), sea level rise is expected to exacerbate coastal flooding issues by backing up flood flows and impeding flood-management responses (see Ch. 16: Northeast and Ch. 25: Coasts).[136]

Projected changes in flood frequency and severity can bring new challenges in flood risk management. For urban areas in particular, flooding impacts critical infrastructure in ways that are difficult to foresee and can result in interconnected and cascading failures (for example, failure of electrical generating lines can cause pump failure, additional flooding, and failure of evacuation services). Increasing likelihood of flooding also brings with it human health risks associated with failure of critical infrastructure (Ch. 11: Urban),[137] from waterborne disease that can persist well beyond the occurrence of very heavy precipitation (Ch. 9: Human Health),[139] from water outages associated with infrastructure failures that cause decreased sanitary conditions,[138] and from ecosystem changes that can affect airborne diseases (Ch. 8: Ecosystems).[140]

New information and remaining uncertainties

Large uncertainties still exist as to how well climate models can represent and project future precipitation extremes. However, precipitation extremes are expected to intensify as the atmosphere warms, and many floods result from larger portions of catchment areas receiving rain as snowlines recede upward. As rain runs off more quickly than snowfall, this results in increased flood potential; furthermore occasional rain-on-snow events exacerbate this effect. This trend is broadly expected to increase in frequency under general warming trends, particularly in mountainous catchments.[62]

Assessment of confidence based on evidence

Future changes in flood frequencies and intensities will depend on a complex combination of local to regional climatic influences and on the details of complex surface-hydrologic conditions in each catchment (for example, topography, land cover, and upstream managements). Consequently, flood frequency changes may be neither simple nor regionally homogeneous, and basin by basin projections may need to be developed. Nonetheless, early results now appearing in the literature have most often projected intensifications of flood regimes, in large part as responses to projections of more intense storms and more rainfall runoff from previously snowbound catchments and settings.

Therefore, confidence is judged to be **medium** that increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the U.S.

KEY MESSAGE #10 TRACEABLE ACCOUNT

In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document,[1] other chapters of the NCA, and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

Observed and Projected Trends: Many U.S. regions are facing critical water management and planning challenges. Recent assessments illustrate water management challenges facing California,[127,128,129,149] the Southwest,[130,151] Southeast (Ch. 17: Southeast),[136,152] Northwest,[153] Great Plains,[154] and Great Lakes.[155]

The Sacramento-San Joaquin Bay Delta is already threatened by flooding, seawater intrusion, and changing needs for environmental, municipal, and agricultural water uses. Managing these risks and uses requires reassessment of a very complex system of water rights, levees, stakeholder consensus processes, reservoir system operations, and significant investments, all of which are subject to large uncertainties.[54,148] Given the projected climate changes in the Sacramento-San Joaquin Bay Delta, adherence to historical management and planning practices may not be a long-term viable option,[128,129] but the supporting science is not yet fully actionable,[42] and a flexible legal and policy framework embracing change and uncertainty is lacking.

The Apalachicola-Chattahoochee-Flint (ACF) River basin in Georgia, Alabama, and Florida supports a wide range of water uses and the regional economy, creating challenging water-sharing tradeoffs for the basin stakeholders. Climate change presents new stresses and uncertainties.[152] ACF stakeholders are working to develop a management plan that balances economic, ecological, and social values.[160]

New information and remaining uncertainties

Changes in climate, water demand, land use, and demography combine to challenge water management in unprecedented ways. This is happening with a very high degree of certainty in most U.S. regions. Regardless of its underlying causes, climate change poses difficult challenges for water management because it invalidates stationarity – the perception that climate varies around a predictable mean based on the experience of the last century – and increases hydrologic variability and uncertainty. These conditions suggest that past management practices will become increasingly ineffective and that water management can benefit by the adoption of iterative, risk-based, and adaptive approaches.

Assessment of confidence based on evidence

The water resources literature is unanimous that water management should rely less on historical practices and responses and more on robust, risk-based, and adaptive decision approaches.

Therefore confidence is **very high** that in most U.S. regions, water resources managers and planners will face new risks, vulnerabilities, and opportunities that may not be properly managed with existing practices.

Key message #11 Traceable Account

Increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts. Many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.

Description of evidence base

The key message and supporting chapter text summarizes extensive evidence documented in the inter-agency prepared foundational document[1] and over 500 technical inputs on a wide range of topics that were received as part of the Federal Register Notice solicitation for public input.

There are many examples of adaptive strategies for water infrastructure[106,132,164,165] as well as strategies for demand management, land-use and watershed management, and use of "green" infrastructure.[1,106,132,166,167]

Building adaptive capacity ultimately increases the ability to develop and implement adaptation strategies and is considered a no-regrets strategy.[1,169] Building networks, partnerships, and support systems has been identified as a major asset in building adaptive capacity (Ch. 26: Decision Support; Ch. 28: Adaptation).[170]

Water utility associations have undertaken original research to better understand the implications of climate change on behalf of some of the largest municipal water utilities in the United States.[119,156,176]

Challenges include "stationarity" no longer being reliable as the central assumption in water-resource planning,[171] considerable uncertainties, insufficient actionable science ready for practical application, the challenges of stakeholder engagement, and a lack of agreement on "post-stationarity" paradigms on which to base water laws, regulations, and policies.[42] Water administrators may find it necessary to develop more flexible water rights and regulations.[132,172,173]

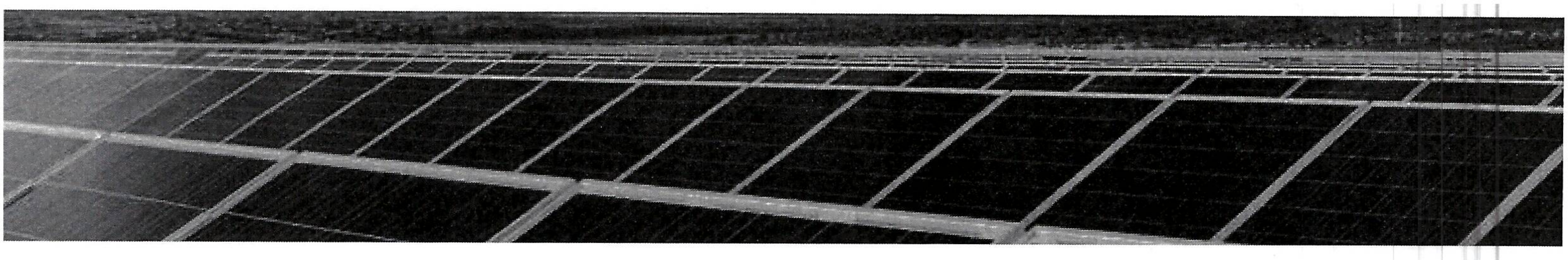
New information and remaining uncertainties

Jurisdictions at the state and local levels are addressing climate change related legal and institutional issues on an individual basis. An ongoing assessment of these efforts may show more practical applications.

Assessment of confidence based on evidence

Confidence is **very high** that increasing resilience and enhancing adaptive capacity provide opportunities to strengthen water resources management and plan for climate change impacts.

Confidence is **very high** that many institutional, scientific, economic, and political barriers present challenges to implementing adaptive strategies.



Climate Change Impacts in the United States

CHAPTER 4
ENERGY SUPPLY AND USE

Convening Lead Authors

Jan Dell, ConocoPhillips

Susan Tierney, Analysis Group Consultants

Lead Authors

Guido Franco, California Energy Commission

Richard G. Newell, Duke University

Rich Richels, Electric Power Research Institute

John Weyant, Stanford University

Thomas J. Wilbanks, Oak Ridge National Laboratory

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INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

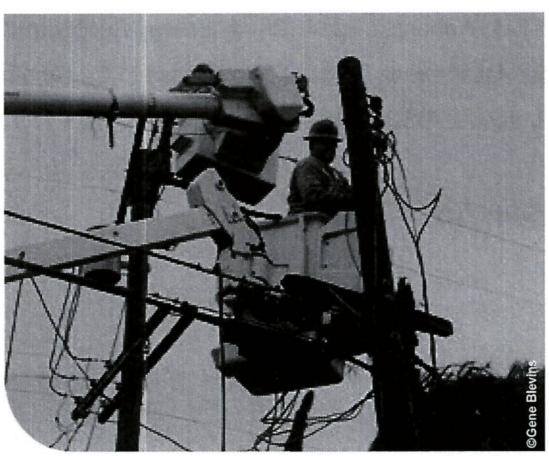
4 ENERGY SUPPLY AND USE

Key Messages

1. **Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of certain types of extreme weather events are expected to change.**
2. **Higher summer temperatures will increase electricity use, causing higher summer peak loads, while warmer winters will decrease energy demands for heating. Net electricity use is projected to increase.**
3. **Changes in water availability, both episodic and long-lasting, will constrain different forms of energy production.**
4. **In the longer term, sea level rise, extreme storm surge events, and high tides will affect coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.**
5. **As new investments in energy technologies occur, future energy systems will differ from today's in uncertain ways. Depending on the character of changes in the energy mix, climate change will introduce new risks as well as opportunities.**

The U.S. energy supply system is diverse and robust in its ability to provide a secure supply of energy with only occasional interruptions. However, projected impacts of climate change will increase energy use in the summer and pose additional risks to reliable energy supply. Extreme weather events and water shortages are already interrupting energy supply, and impacts are expected to increase in the future. Most vulnerabilities and risks to energy supply and use are unique to local situations; others are national in scope.

In addition to being vulnerable to the effects of climate change, electricity generation is a major source of the heat-trapping gases that contribute to climate change. Therefore, regulatory or policy efforts aimed at reducing emissions would also affect the energy supply system. See Ch. 10: Energy, Water, and Land, Key Message 2; and Ch. 27: Mitigation for more on this topic. This chapter focuses on impacts of climate change to the energy sector.



Energy infrastructure around the country has been compromised by extreme weather events.

The impacts of climate change in other countries will also affect U.S. energy systems through global and regional cross-border markets and policies. Increased energy demand within global markets due to industrialization, population growth, and other factors will influence U.S. energy costs through competition for imported and exported energy products. The physical impacts of climate change on future energy systems in the 25- to 100-year timeframe will depend on how those energy systems evolve. That evolution will be driven by multiple factors, including technology innovations and carbon emission constraints.

Adaptation actions can allow energy infrastructure to adjust more readily to climate change. Many investments toward adaptation provide short-term benefits because they address current vulnerabilities as well as future risks, and thus entail "no regrets." Such actions can include a focus on increased efficiency of energy use as well as improvements in the reliability of production and transmission of energy. The general concept of adaptation is presented in Chapter 28: Adaptation.

Key Message 1: Disruptions from Extreme Weather

Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of certain types of extreme weather events are expected to change.

Much of America's energy infrastructure is vulnerable to extreme weather events. Because so many components of U.S. energy supplies – like coal, oil, and electricity – move from one area to another, extreme weather events affecting energy infrastructure in one place can lead to supply consequences elsewhere.

Climate change has begun to affect the frequency, intensity, and length of certain types of extreme weather events.[1,2,3] What is considered an extreme weather or climate event varies from place to place. Observed changes across most of the U.S. include increased frequency and intensity of extreme precipitation events, sustained summer heat, and in some regions, droughts and winter storms. The frequency of cold waves has decreased (Ch. 2: Our Changing Climate).

Projected climate changes include increases in various types of extreme weather events, particularly heat waves, wildfire, longer and more intense drought, more frequent and intense very heavy precipitation events, and extreme coastal high water due to heavy-precipitation storm events coupled with sea level rise. Extreme coastal high water will increasingly disrupt infrastructure services in some locations.[4] The frequency of cold waves is expected to continue decreasing. Disruptions in services in one infrastructure system (such as energy) will lead to disruptions in one or more other infrastructures (such as communications and transportation) that depend on other affected systems. Infrastructure exposed to extreme weather and also stressed by age or by demand that exceeds designed levels is particularly vulnerable (see Ch. 11: Urban).

Like much of the nation's infrastructure affected by major weather events with estimated economic damages greater than $1 billion,[5,6] U.S. energy facilities and systems, especially those located in coastal areas, are vulnerable to extreme weather events. Wind and storm surge damage by hurricanes already causes significant infrastructure losses on the Gulf Coast.

In 2005, damage to oil and gas production and delivery infrastructure by Hurricanes Katrina and Rita affected natural gas, oil, and electricity markets in most parts of the United States.[4,7] Market impacts were felt as far away as New York and New England,[8,9] highlighting the significant indirect economic impacts of climate-related events that go well beyond the direct damages to energy infrastructure.

Paths of Hurricanes Katrina and Rita Relative to Oil and Gas Production Facilities

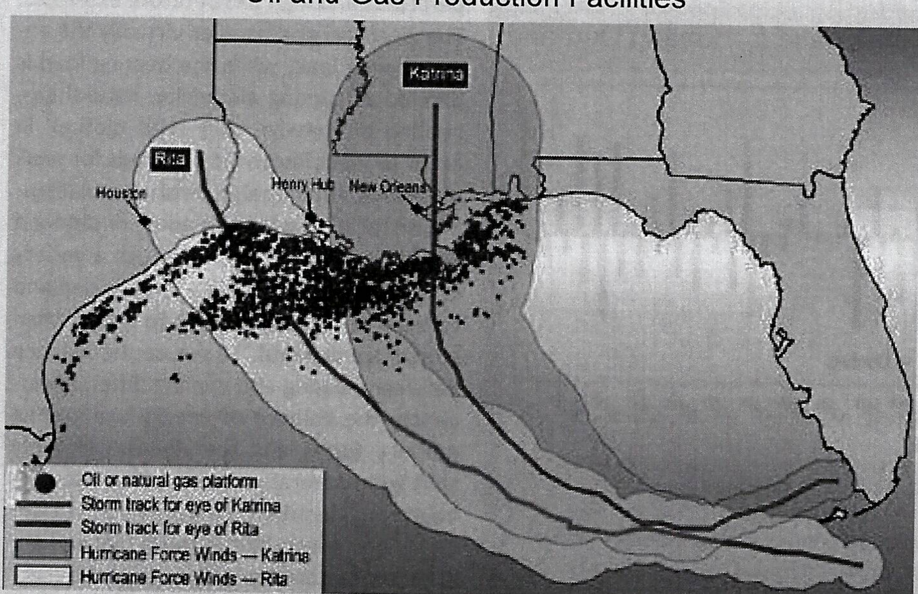


Figure 4.1. A substantial portion of U.S. energy facilities is located on the Gulf Coast as well as offshore in the Gulf of Mexico, where they are particularly vulnerable to hurricanes and other storms and sea level rise. (Figure source: U.S. Government Accountability Office 2006).

Various aspects of climate change will affect and disrupt energy distribution and energy production systems. It is projected that wildfires will affect extensive portions of California's electricity transmission grid.[10] Extreme storm surge events at high tides are expected to increase,[11] raising the risk of inundating energy facilities such as power plants, refineries, pipelines, and transmission and distribution networks. Rail transportation lines that carry coal to power plants, which produced 42% of U.S. electricity in 2011, often follow riverbeds. More intense rainstorms can lead to river flooding that degrades or washes out nearby railroads and roadbeds, and increases in rainstorm intensity have been observed and are projected to continue.

By learning from previous events, offshore operations can be made more resilient to the impacts of hurricanes. During Hurricane Isaac in August 2012, the U.S. Bureau of Safety and Environmental Enforcement reported that oil and gas production was safely shut down and restarted within days of the event.[12]

The geographical diversification of energy sources away from hurricane-prone areas such as the Gulf of Mexico has reduced vulnerability to hurricanes. The U.S. Energy Information Administration (EIA) reports that the percentage of natural gas production from the Gulf of Mexico shifted from 20% in 2005 to 7% in 2012.[13] This is due to the development of shale gas production in other parts of the United States.

Key Message 2: Climate Change and Seasonal Energy Demands

Higher summer temperatures will increase electricity use, causing higher summer peak loads, while warmer winters will decrease energy demands for heating. Net electricity use is projected to increase.

Over the last 20 years, annual average temperatures typically have been higher than the long-term average; nationally, temperatures were above average during 12 of the last 14 summers (Ch. 2: Our Changing Climate).[2] These increased temperatures are already affecting the demand for energy needed to cool buildings in the United States.

Average temperatures have increased in recent decades. In response, the Energy Information Administration began using 10-year average weather data instead of 30-year average weather data in order to estimate energy demands for heating and cooling purposes. The shorter period is more consistent with the observed trend of warmer winters and summers,[14] but is still not necessarily optimal for anticipating near-term temperatures.[17]

While recognizing that many factors besides climate change affect energy demand (including population changes, economic conditions, energy prices, consumer behavior, conservation programs, and changes in energy-using equipment), increases in temperature will result in increased energy use for cooling and decreased energy use for heating. These impacts differ among regions of the country and indicate a shift from predominantly heating to predominantly cooling in some regions with moderate climates. For example, in the Northwest, energy demand for cooling is projected to increase over the next century due to population growth, increased cooling degree days, and increased use of air conditioners as people adapt to higher temperatures.[19] Population growth is also expected to increase energy demand for heating. However, the projected increase in energy demand for heating is about half as much when the effects of a warming climate are considered along with population growth.[19]

Increase in Cooling Demand and Decrease in Heating Demand

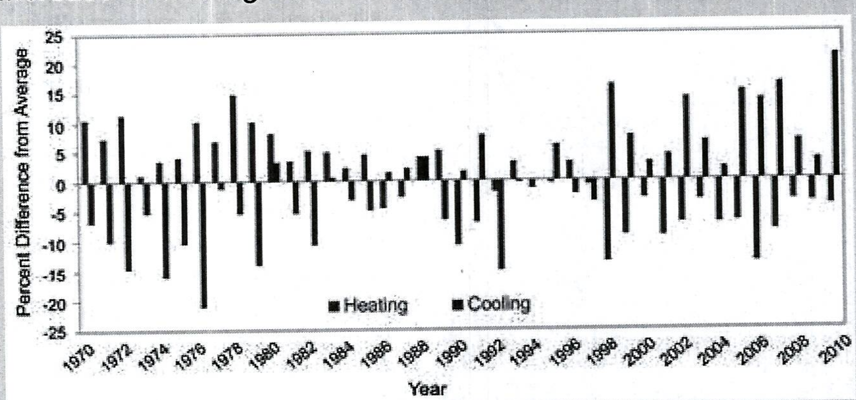


Figure 4.2. The amount of energy needed to cool (or warm) buildings is proportional to cooling (or heating) degree days. The figure shows increases in population-weighted cooling degree days, which result in increased air conditioning use, and decreases in population-weighted heating degree days, meaning less energy required to heat buildings in winter, compared to the average for 1970-2000. Cooling degree days are defined as the number of degrees that a day's average temperature is above 65°F, while heating degree days are the number of degrees a day's average temperature is below 65°F. As shown, the increase in cooling needs is greater than the decrease in heating needs (Data from NOAA NCDC 2012[16]).

Demands for electricity for cooling are expected to increase in every U.S. region as a result of increases in average temperatures and high temperature extremes. The electrical grid handles virtually the entire cooling load, while the heating load is distributed among electricity, natural gas, heating oil, passive solar, and biofuel. In order to meet increased demands for peak electricity, additional generation and distribution facilities will be needed, or demand will have to be managed through a variety of mechanisms. Electricity at peak demand typically is more expensive to supply than at average demand.[21] Because the balance between heating and cooling differs by location, the balance of energy use among delivery forms and fuel types will likely shift from natural gas and fuel oil used for heating to electricity used for air conditioning. In hotter conditions, more fuel and energy are required to generate and deliver electricity, so increases in air conditioning use and shifts from heating to cooling in regions with moderate climates will increase primary energy demands.[4]

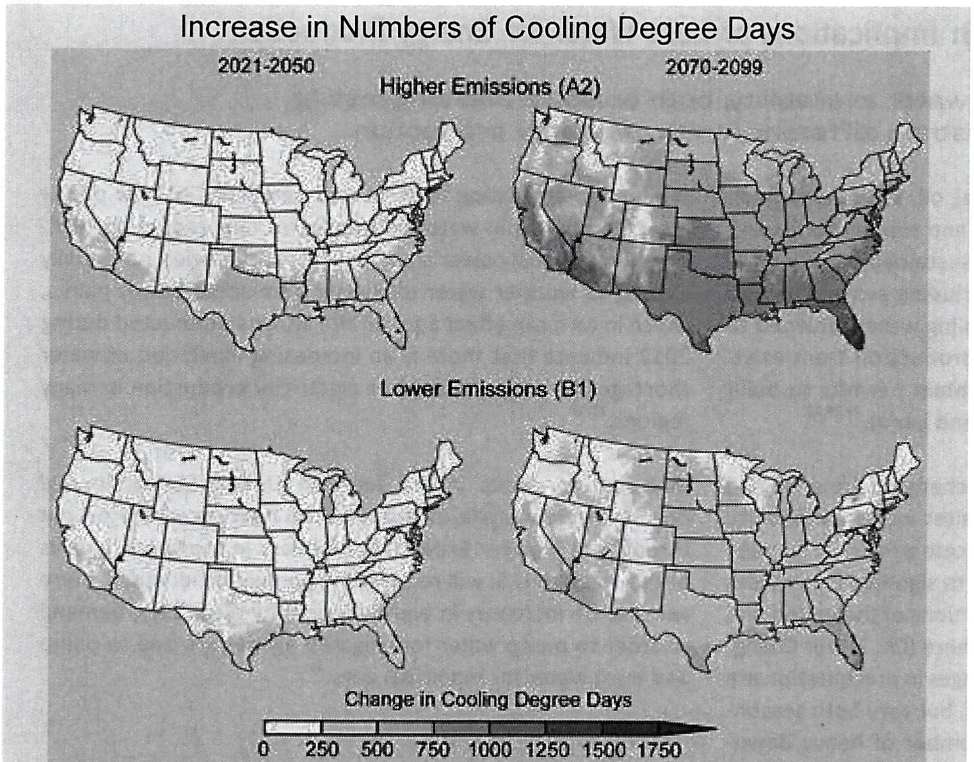


Figure 4.3. These maps show projected average changes in cooling degree days for two future time periods: 2021-2050 and 2070-2099 (as compared to the period 1971-2000). The top panel assumes climate change associated with continued increases in emissions of heat-trapping gases (A2), while the bottom panel assumes significant reductions (B1). The projections show significant regional variations, with the greatest increases in the southern United States by the end of this century under the higher emissions scenario. Furthermore, population projections suggest continued shifts toward areas that require air conditioning in the summer, thereby increasing the impact of temperature changes on increased energy demand.[18] (Figure source: NOAA NCDC / CICS-NC).

Table 4.1. Hotter and longer summers will increase the amount of electricity necessary to run air conditioning, especially in the Southeast and Southwest. Warmer winters will decrease the amount of natural gas required to heat buildings, especially in the Northeast, Midwest, and Northwest. Table information is adapted from multi-model means from 8 NARCCAP regional climate simulations for the higher emissions scenario (A2) considered in this report and is weighted by population. (Source: adapted from Regional Climate Trends and Scenarios reports[20])

Changing Energy Use for Heating and Cooling Will Vary by Region

	Consequences: Challenges and Opportunities	
Region	**Cooling**	**Heating**
Physical Impacts - High Likelihood	**Hotter and Longer Summers** Number of additional extreme hot days (> 95°F) and % increase in cooling degree days per year in 2041-2070 above 1971-2000 level	**Warmer Winters** Number of fewer extreme cold days (< 10°F) and % decrease in heating degree days per year in 2041-2070 below 1971-2000 level
Northeast	+10 days, +77%	-12 days, -17%
Southeast	+23 days, +43%	-2 days, -19%
Midwest	+14 days, +64%	-14 days, -15%
Great Plains	+22 days, +37%	-4 days, -18%
Southwest	+20 days, +44%	-3 days, -20%
Northwest	+5 days, +89%	-7 days, -15%
Alaska	Not studied	Not studied
Pacific Islands	Not studied	Not studied

Climate-related temperature shifts are expected to cause a net increase in residential electricity use.[21,22] Increased electricity demands for cooling will exceed electricity savings resulting from lower energy demands for heating. One study examining state-level energy consumption, weather data, and high emission scenarios (A2 and A1FI; Appendix 3: Climate Science Supplement) found a net increase of 11% in residential energy demand.[23] Another study reported annual increases in net energy expenditures for cooling and heating of about 10% ($26 billion in 1990 U.S. dollars) by the end of this century for 4.5°F of warming, and 22% ($57 billion in 1990 dollars) for overall warming of about 9°F.[24] New energy-efficient technology could help to offset growth in demand.

Several studies suggest that if substantial reductions in emissions of heat-trapping gases were required, the electricity generating sector would switch to using alternative (non-fossil) fuel sources first, given the multiple options available to generate electricity from sources that do not emit heat-trapping gases, such as wind and solar power. Under these circumstances, electricity would displace direct use of fossil fuels for some applications, such as heating, to reduce overall emissions of heat-trapping gases.[25,26] The implications for peak electricity demand could be significant. In California, for example, the estimated increase in use of electricity for space heating would shift the peak in electricity demand from summer to winter.[27] In addition, the fact that electricity from wind and solar is highly variable and may not be available when needed has the potential to decrease the reliability of the electricity system. However, some initial studies suggest that a well-designed electricity system with high penetration of renewable sources of energy should not decrease reliability (for example, Hand et al. 2012[28]).

Key Message 3: Implications of Less Water for Energy Production

Changes in water availability, both episodic and long-lasting, will constrain different forms of energy production.

Producing energy from fossil fuels (coal, oil, and natural gas), nuclear power, biofuels, hydropower, and some solar power systems often requires adequate and sustainable supplies of water. Issues relatableted to water, including availability and restrictions on the temperature of cooling water returned to streams, already pose challenges to production from existing power plants and the ability to obtain permits to build new facilities (Ch. 10: Energy, Water, and Land).[21,29,30]

In the future, long-term precipitation changes, drought, and reduced snowpack are projected to alter water availability (Ch. 3: Water). Recent climate data indicate a national average increase in annual precipitation, owing to significant increases across the central and northeastern portions of the nation and a mix of increases and decreases elsewhere (Ch. 2: Our Changing Climate, Figure 2.12). Projected changes in precipitation are small in most areas of the United States, but vary both seasonally and regionally (Figure 4.4). The number of heavy downpours has generally increased and is projected to increase for all regions (Ch 2: Our Changing Climate, Figures 2.16, 2.17, 2.18, and 2.19).

Different analyses of observed changes in dry spell length do not show clear trends,[31] but longer dry spells are projected in southern regions and the Northwest (Ch. 2: Our Changing Climate, Figure 2.13) as a result of projected large-scale changes in circulation patterns.

Regional or seasonal water constraints, particularly in the Southwest and Southeast, will result from chronic or seasonal drought, growing populations, and increasing demand for water for various uses (Ch. 2: Our Changing Climate; Ch. 10: Energy, Water, and Land).[29,32] Reduced availability of water for cooling, for hydropower, or for absorbing warm water discharges into water bodies without exceeding temperature limits, will continue to constrain power production at existing facilities and permitting of new power plants. Increases in water temperatures may reduce the efficiency of thermal power plant cooling technologies, potentially leading to warmer water discharge from some power plants, which in turn can affect aquatic life. Studies conducted during 2012 indicate that there is an increasing likelihood of water shortages limiting power plant electricity production in many regions.[21,33]

Hydropower plants in the western United States depend on the seasonal cycle of snowmelt to provide steady output throughout the year. Expected reductions in snowpack in parts of the western U.S. will reduce hydropower production. There will also be increases in energy (primarily electricity) demand in order to pump water for irrigated agriculture and to pump and treat water for municipal uses.[21]

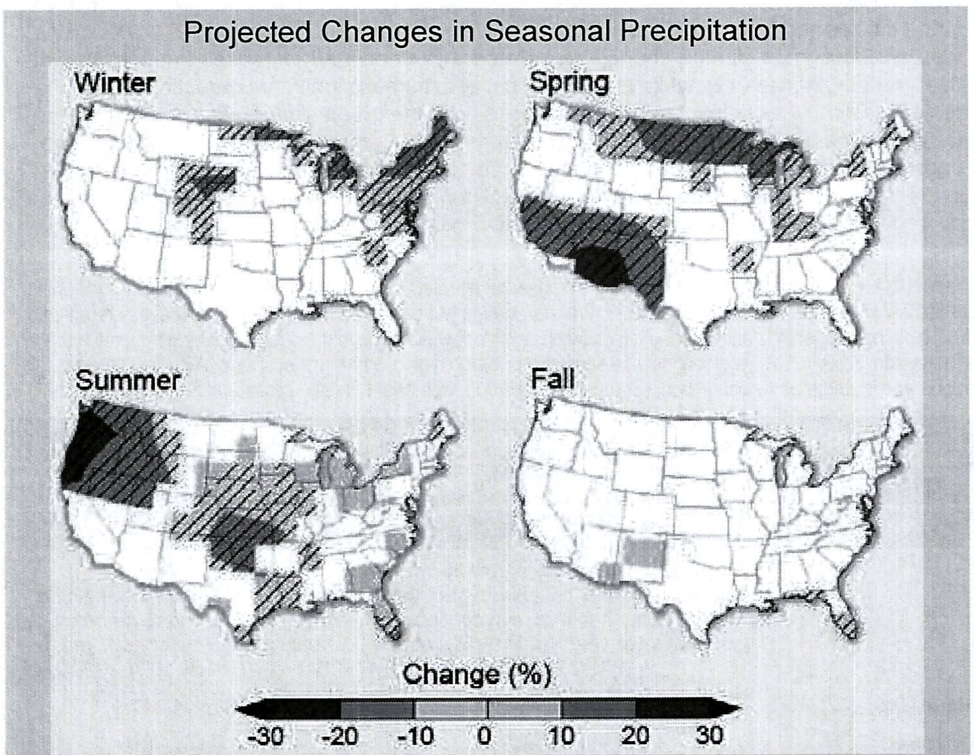


Figure 4.4. Climate change affects precipitation patterns as well as temperature patterns. The maps show projected changes in average precipitation by season for 2041–2070 compared to 1971–1999, assuming emissions of heat-trapping gases continue to rise (A2 scenario). Note significantly drier conditions in the Southwest in spring and Northwest in summer, as well as significantly more precipitation (some of which could fall as snow) projected for northern areas in winter and spring. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. (Figure source: NOAA NCDC / CICS-NC).

The Electric Power Research Institute's (EPRI) scenario-based technical projections of water demand in 2030 find that one-quarter of existing power generation facilities (about 240,000 megawatts) nationwide are in counties that face some type of water sustainability issue.[34] Many regions face water sustainability concerns, with the most significant water-related stresses in the Southeast, Southwest, and Great Plains regions (Ch. 3: Water).[34]

Key Message 4: Sea Level Rise and Infrastructure Damage

In the longer term, sea level rise, extreme storm surge events, and high tides will affect coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.

Significant portions of the nation's energy production and delivery infrastructure are in low-lying coastal areas; these facilities include oil and natural gas production and delivery facilities, refineries, power plants, and transmission lines.

Global sea level has risen by about 8 inches since reliable record keeping began in 1880, affecting countries throughout the world, including the United States. The rate of rise increased in recent decades and is not expected to slow. Global average sea level is projected to rise 1 to 4 feet by 2100 and is expected to continue to rise well beyond this century (Ch. 2: Our Changing Climate). Sea level change at any particular location can deviate substantially from this global average (Ch. 2: Our Changing Climate).[35]

Rising sea levels, combined with normal and potentially more intense coastal storms, an increase in very heavy precipitation events, and local land subsidence, threaten coastal energy equipment as a result of inundation, flooding, and erosion. This can be compounded in areas that are projected to receive more precipitation. In particular, sea level rise and coastal storms pose a danger to the dense network of Outer Continental Shelf marine and coastal facilities in the central Gulf Coast region.[36] Many of California's power plants are at risk from rising sea levels, which result in more extensive coastal storm flooding, especially in the low-lying San Francisco Bay area (Figure 4.5). Power plants and energy infrastructure in coastal areas throughout the United States face similar risks.

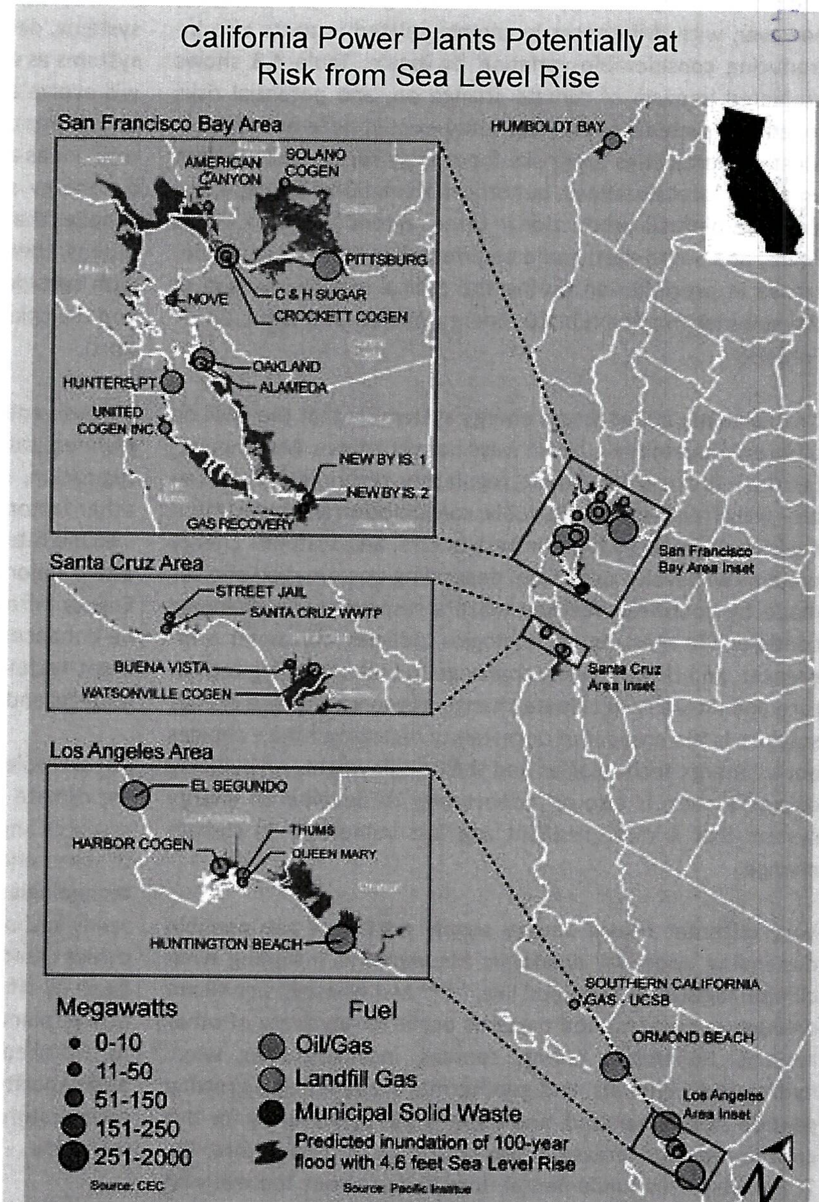


Figure 4.5. Rising sea levels will combine with storm surges and high tides to threaten power-generating facilities located in California coastal communities and around the San Francisco Bay. Sea level rise and more intense heavy precipitation events increase the risk of coastal flooding and damages to infrastructure (Ch. 3: Water). (Figure source: Sathaye et al. 2011[37]).

Key Message 5: Future Energy Systems

As new investments in energy technologies occur, future energy systems will differ from today's in uncertain ways. Depending on the character of changes in the energy mix, climate change will introduce new risks as well as opportunities.

Countless aspects of the U.S. economy today are supported by reliable, affordable, and accessible energy supplies. Electricity and other forms of energy are necessary for telecommunications, water and sewer systems, banking, public safety, and more. Today's energy systems vary significantly by region, however, with differences in climate-related impacts also introducing considerable variation by locale. Table 4.3 shows projected impacts of climate change on, and potential risks to, energy systems as they currently exist in different regions. Most vulnerabilities and risks for energy supply and use are unique to local situations, but others are national in scope. For example, biofuels production in three regions (Midwest, Great Plains, and Southwest) could be affected by the projected decrease in precipitation during the critical growing season in the summer months (Ch. 10: Energy, Water, and Land; Ch. 7: Forests).

One certainty about future energy systems is that they will be different than today's, but in ways not yet known. Many uncertainties – financial, economic, regulatory, technological, and so on – will affect private and public consumption and investment decisions on energy fuels, infrastructure, and systems. Energy systems will evolve over time, depending upon myriad choices made by countless decision-makers responding to changing conditions in markets, technologies, policies, consumer preferences, and climate. A key challenge to understanding the nature and intensity of climate change impacts on future energy systems is the amount of uncertainty regarding future choices about energy technologies and their deployment. An evolving energy system is also an opportunity to develop an energy system that is more resilient and less vulnerable to climate change.

Very different future energy supply portfolios are possible depending upon key economic assumptions, including what climate legislation may look like,[14,25,34] and whether significant changes in consumption patterns occur for a variety of other reasons. Renewable energy sources, including solar, wind, hydropower, biofuels, and geothermal are meeting a growing portion of U.S. demand, and there is the opportunity for this contribution to increase in the future (Ch. 6: Agriculture; Ch. 7: Forests). This fundamental uncertainty about the evolving character of energy systems contributes another layer of complexity to understanding how climate change will affect energy systems.

As they consider actions to enhance the resiliency of energy systems, decision-makers confront issues with current energy systems as well as possible future configurations. The systems will evolve and will be more resilient over time if actions tied to features of today's systems do not make future systems less resilient as a result. For example, if moving toward biomass as an energy source involves more water-consumptive energy supplies that could be constrained by drier future climate conditions, then decisions about energy choices should be made with consideration of potential changes in climate conditions and the risks these changes present (See Ch. 26: Decision Support).

Because energy systems in the United States are not centrally planned, they tend to reflect energy decisions shaped by law, regulation, other policies, and economic, technological, and other factors in markets. Trends in use patterns may continue into the future; this is an opportunity to increase resilience but also a major uncertainty for energy utilities and policy makers. Energy infrastructure tends to be long-lived, so resiliency can be enhanced by more deliberate applications of risk-management techniques and information about anticipated climate impacts and trends.[38]

For example, risk-management approaches informed by evolving climate conditions could be used to project the value of research and development on, or investments in, construction of dikes and barriers for coastal facilities or for dry-cooling technologies for power plants in regions where water is already in short supply. Solar and wind electricity generation facilities could be sited in areas that are initially more expensive (such as offshore areas) but less subject to large reductions in power plant output resulting from climatic changes. Targets for installed reserve margins for electric generating capacity and capacity of power lines can be established using certain temperature expectations, but adjusted as conditions unfold over time.

A range of climate change impacts will affect future energy production. This table shows possible ways to anticipate and respond to these changes. Innovations in technologies may provide additional opportunities and benefits to these and other adaptation actions. Behavioral change by consumers can also promote resiliency.

Table 4.2 summarizes actions that can be taken to increase the ease with which energy systems can adjust to climate change. Many of these adaptation investments entail "no regrets" actions, providing short-term benefits because they address current vulnerabilities as well as future risks.

Possible Climate Resilience and Adaptation Actions in Energy Sector				
	Key Challenges Addressed			
Possible Actions	**Extreme Weather Events**	**Increase in Peak Energy Loads**	**Water Constraints on Energy Production**	**Sea Level Rise**
Supply: System and Operational Planning				
Diversifying supply chains	X	X	X	X
Strengthening and coordinating emergency response plans	X	X	X	
Providing remote/protected emergency-response coordination centers	X			
Developing flood-management plans or improving stormwater management	X			X
Developing drought-management plans for reduced cooling flows			X	
Developing hydropower management plans/policies addressing extremes			X	
Supply: Existing Equipment Modifications				
Hardening/building redundancy into facilities	X	X		
Elevating water-sensitive equipment or redesigning elevation of intake structures	X			X
Building coastal barriers, dikes, or levees	X			X
Improving reliability of grid systems through back-up power supply, intelligent controls, and distributed generation	X	X	X	
Insulating equipment for temperature extremes	X			
References to technical studies with case studies on many of these topics may be found in Wilbanks et al. 2012.[4]				
Implementing dry (air-cooled) or low-water hybrid (or recirculating) cooling systems for power plants			X	
Adding technologies/systems to pre-cool water discharges			X	
Using non-fresh water supplies: municipal effluent, brackish or seawater			X	
Relocating vulnerable facilities	X		X	X
Supply: New Equipment				
Adding peak generation, power storage capacity, and distributed generation	X	X	X	X
Adding back-up power supply for grid interruptions	X	X	X	
Increasing transmission capacity within and between regions	X	X	X	X
Use: Reduce Energy Demand				
Improving building energy, cooling-system and manufacturing efficiencies, and demand-response capabilities (for example, smart grid)	X	X		
Setting higher ambient temperatures in buildings	X	X		
Improving irrigation and water distribution/reuse efficiency		X	X	
Allowing flexible work schedules to transfer energy use to off-peak hours		X		

Table 4.3. Increased temperatures, changing precipitation patterns, and sea level rise will affect many sectors and regions, including energy production, agriculture yields, and infrastructure damage. Changes are also projected to affect hydropower, solar photovoltaic, and wind power, but the projected impacts are not well defined at this time.

Energy Supply: Summary of National and Regional Impacts, Challenges, and Opportunities							
Consequences[a]: Challenges and Opportunities							
	Fuel Extraction, Production and Refining		**Fuel Distribution Transport/ Pipelines**	**Electricity Generation**			**Electricity Distribution**
	Hydrocarbons[b]	**Biofuels**		**Thermal Power Generation[c]**			
Physical Impacts – High Likelihood	Increased Ambient Temperature of Air and Water	Increased Extremes in Water Availability	Coastal Erosion and Sea Level Rise	Increased Ambient Temperature of Air and Water	Increased Extremes in Water Availability	Coastal Erosion and Sea Level Rise	Hot Summer Periods
National Trend Summary[f] Consequence	Decreased Production and Refining Capacity	Decreased Agricultural Yields	Damage to Facilities	Reduced Plant Efficiency and Cooling Capacity	Interruptions to Cooling Systems	Damage to Facilities	Reduced Capacity/Damage to Lines
Key Indicator (2071-2099 vs. 1971-2000)	**Mean Annual Temperature[d]**	**Summer Precipitation[d]**	**Sea level Rise[e] (2100)**	**Mean Annual Temperature[d]**	**Summer Precipitation[d]**	**Sea Level Rise[e] (2100)**	**# Days>90°F[f,g] (2055)**
Northeast	+4°F to 9°F	-5% to +6%		+4°F to 9°F	-5% to +6%		+13 days
Southeast	+3°F to 8°F	-22% to +10%		+3°F to 8°F	-22% to +10%		+31 days
Midwest	+4°F to 10°F	-22% to +7%		+4°F to 10°F	-22% to +7%		+19 days
Great Plains	+3°F to 9°F	-27% to +5%		+3°F to 9°F	-27% to +5%		+20 days
Southwest	+4°F to 9°F	-13% to +3%	1.6–3.9 ft (0.5–1.2m)	+4°F to 9°F	-13% to +3%	1.6–3.9 ft. (0.5–1.2m)	+24 days
Northwest	+3°F to 8°F	-34% to -4%		+3°F to 8°F	-34% to -4%		+4 days
Alaska	+4°F to 9°F	+10% to +25%		+4°F to 9°F	+10% to +25%		No Projection
Pacific Islands	+2°F to 5°F	Range from little change to increases		+2°F to 5°F	Range from little change to increases		No Projection

Notes
a) Excludes extreme weather events.
b) Hydrocarbons include coal, oil, and gas including shales.
c) Thermal power generation includes power plants fired from nuclear, coal, gas, oil, biomass fuels, solar thermal, and geothermal energy.
d) CMIP3 15 GCM Models: 2070–2099 Combined Interquartile Ranges of SRES B1 and A2 (versus 1971–2000), incorporating uncertainties from both differences in model climate sensitivity and differences between B1 and A2 in emissions trajectories
e) Range of sea level rise for 2100 is the Low Intermediate to High Intermediate Scenario from "Sea Level Change Scenarios for the U.S. National Climate Assessment."[35] Range is similar to the 1 to 4 feet of sea level rise projected in Ch. 2: Our Changing Climate, Key Message 10. There will be regional variations in sea level rise, and this category of impacts does not apply for the Midwest region.
f) 2055 NARCCAP
g) References: [4,25]

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages:
The author team met bi-weekly by teleconference during the months of March through July 2012. Early in the development of key messages and a chapter outline, the authors reviewed all of the four dozen relevant technical input reports that were received in response to the Federal Register solicitation for public input. Selected authors participated in a U.S. Department of Energy (DOE) sponsored workshop on Energy Supply and Use, December 29-30, 2011, in Washington, D.C. The workshop was organized specifically to inform a DOE technical input report and this National Climate Assessment and to engage stakeholders in this process. The authors selected key messages based on the risk and likelihood of impacts, associated consequences, and available evidence. Relevance to decision support within the energy sector was also an important criterion.

The U.S. maintains extensive data on energy supply and use. The Energy Information Administration (EIA) of the U.S. Department of Energy is a primary organization in this activity, and data with quality control, quality assurance, and expert review are available through EIA Web pages (for example, EIA 2012, EIA 2013[39]).

Key message #1 Traceable Account

Extreme weather events are affecting energy production and delivery facilities, causing supply disruptions of varying lengths and magnitudes and affecting other infrastructure that depends on energy supply. The frequency and intensity of certain types of extreme weather events are expected to change.

Description of evidence base
A series of NCA workshops reviewed potential influences of climate change thus far on the frequency and intensity of certain types of extreme events.[3] Numerous past extreme events demonstrate damage to energy facilities and infrastructure. Data assembled and reviewed by the Federal Government summarize typical costs associated with damage to energy facilities by extreme events.[5] State and regional reports as well as data provided by public utilities document specific examples.[4,9,10,26]

Damage to Gulf Coast energy facilities and infrastructure by Hurricanes Katrina and Rita in 2005 provides excellent examples to support this key message.[8,9] Wildfire also damages transmission grids.[10]

The authors benefited from Agency-sponsored technical input reports summarizing relevant data and information on energy supply and use as well as urban systems and infrastructure.[4,21,25] A number of other technical input reports were relevant as well. These were reviewed carefully, particularly with regard to the identification of key messages.

New information and remaining uncertainties
The information provided through a series of NCA workshops provided new (and current) evidence for influences of climate change on the frequency and intensity of extreme events. The summaries from those workshops provide succinct evidence that certain extreme events that damage energy facilities and infrastructure can be expected to increase in number and intensity with climate change (for example, Peterson et al. 2012[3]). Documentation of damage to energy facilities and infrastructure continues to accumulate, increasing confidence in this key message.[5,14]

The regional and local character of extreme events varies substantially, and this variability is a source of significant uncertainty regarding the impacts of climate change and consequences in terms of damage to energy facilities by extreme events. Additionally, damage to energy infrastructure in a specific location can have far-reaching consequences for energy production and distribution, and synthesis of such indirect consequences for production and distribution does not yet support detailed projections.

Assessment of confidence based on evidence
High. There is high consensus with moderate evidence that extreme weather events associated with climate change will increase disruptions of energy infrastructure and services in some locations.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

KEY MESSAGE #2 TRACEABLE ACCOUNT

Higher summer temperatures will increase electricity use, causing higher summer peak loads, while warmer winters will decrease energy demands for heating. Net electricity use is projected to increase.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the energy supply and use technical input.[4] Global climate models simulate increases in summer temperatures, and the NCA climate scenarios[2,20] describe this aspect of climate change projections for use in preparing this report (Ch. 2: Our Changing Climate). Data used by Kunkel et al.[2] and Census Bureau population data, synthesized by the EIA,[15] were the basis for calculating population-weighted heating and cooling degree-days over the historic period as well as projections assuming SRES B1 and A2 scenarios.

The NCA climate scenarios[2] project an increase in the number of cooling days and decrease in heating days, with peak electricity demand in some regions shifting from winter to summer[27] and shifting to electricity needs for cooling instead of fossil fuels for heating.[25,26,27]

New information and remaining uncertainties

While there is little uncertainty that peak electricity demands will increase with warming by climate change, substantial regional variability is expected. Climate change projections do not provide sufficient spatial and temporal detail to fully analyze these consequences. Socioeconomic factors including population changes, economic conditions, and energy prices, as well as technological developments in electricity generation and industrial equipment, will have a strong bearing on electricity demands, specific to each region of the country.

Assessment of confidence based on evidence

High. Assuming specific climate change scenarios, the consequences for heating and cooling buildings are reasonably predictable, especially for the residential sector. With a shift to higher summer demands for electricity, peak demands for electricity can be confidently expected to increase.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Changes in water availability, both episodic and long-lasting, will constrain different forms of energy production.

Description of evidence base

Climate scenarios prepared for the NCA[2] describe decreases in precipitation under the SRES A2 scenario, with the largest decreases across the Northwest and Southwest in the spring and summer.

Technical input reports (for example, Wilbanks et al.[4,21]) summarize data and studies show that changes in water availability will affect energy production,[33] and more specifically, that water shortages will constrain electricity production (Ch. 2: Our Changing Climate).[29,32] The impacts of drought in Texas during 2011 are an example of the consequences of water shortages for energy production as well as other uses (Ch. 10: Energy, Water, and Land). Electric utility industry reports document potential consequences for operation of generating facilities.[34] A number of power plants across the country have experienced interruptions due to water shortages.

New information and remaining uncertainties

An increasing number of documented incidents of interruptions in energy production due to water shortages provide strong evidence that decreased precipitation or drought will have consequences for energy production.[21]

There is little uncertainty that water shortages due to climate change will affect energy production. But uncertainty about changes in precipitation and moisture regimes simulated by global climate models is significantly higher than for simulated warming. Additionally, climate change simulations lack the spatial and temporal detail required to analyze the consequences for water availability at finer scales (for example, local and regional). Finer-scale projections would be relevant to decisions about changes in energy facilities to reduce risk or adapt to water shortages associated with climate change.

Assessment of confidence based on evidence

High. The evidence is compelling that insufficient water availability with climate change will affect energy production; however, simulations of climate change lack the detail needed to provide more specific information for decision support.

KEY MESSAGE #4 TRACEABLE ACCOUNT

In the longer term, sea level rise, extreme storm surge events, and high tides will affect coastal facilities and infrastructure on which many energy systems, markets, and consumers depend.

Description of evidence base

The sea level change scenario report prepared for the NCA (see also Ch. 2: Our Changing Climate)[35] provides further information about sea level change. Extreme surge events at high tides are expected to increase,[11] raising the risk of inundating energy facilities such as power plants, refineries, pipelines, and transmission and distribution networks (for example, Sathaye et al. 2013[10]) Data available through the EIA (for example, EIA 2010[15] provide high-quality information about the locations and distribution of energy facilities.

A substantial portion of the nation's energy facilities and infrastructure are located along coasts or offshore, and sea level rise will affect these facilities (Ch. 25: Coasts; Ch. 17: Southeast; Ch. 5: Transportation).[4,10,21,36]

New information and remaining uncertainties

Projections of sea level change are relatively uncertain compared to other aspects of climate change. More importantly, there will be substantial regional and local variability in sea level change, and facilities in locations exposed to more frequent and intense extreme wind and precipitation events will be at higher risk. Data and analyses to understand regional and local sea level change are improving, but substantial uncertainty remains and decision support for adaptation is challenged by these limitations.

Assessment of confidence based on evidence

High. There is high confidence that increases in global mean sea level, extreme surge events, and high tides will affect coastal energy facilities; however, regional and local details are less certain.

KEY MESSAGE #5 TRACEABLE ACCOUNT

As new investments in energy technologies occur, future energy systems will differ from today's in uncertain ways. Depending on the character of changes in the energy mix, climate change will introduce new risks as well as opportunities.

Description of evidence base

A number of studies describe U.S. energy system configurations in terms of supply and use assuming different scenarios of climate change, including SRES B1 and A2.[14,25,34] A technical input report to the NCA by DOE[4,21] provides details and updates earlier studies. The potential role of biofuels is described within chapters 6 and 7 of this report (Ch. 6: Agriculture; Ch. 7: Forests).

New information and remaining uncertainties

Understanding of options for future energy supply and use within the U.S. improves, as the EIA and other organizations update data and information about U.S. energy systems as well as projections of the mix of primary energy under various assumptions about demographic, economic, and other factors. With additional data and better models, alternative energy mixes can be explored with respect to climate change adaptation and mitigation. But numerous factors that are very difficult to predict – financial, economic, regulatory, technological – affect the deployment of actual facilities and infrastructure.

Assessment of confidence based on evidence

High. Given the evidence about climate change impacts and remaining uncertainties associated with the future configuration of energy systems and infrastructure, there is high confidence that U.S. energy systems will evolve in ways that affect risk with respect to climate change and options for adaptation or mitigation.

Climate Change Impacts in the United States

CHAPTER 5 TRANSPORTATION

Convening Lead Authors

Henry G. Schwartz, HGS Consulting, LLC

Michael Meyer, Parsons Brinckerhoff

Lead Authors

Cynthia J. Burbank, Parsons Brinckerhoff

Michael Kuby, Arizona State University

Clinton Oster, Indiana University

John Posey, East-West Gateway Council of Governments

Edmond J. Russo, U.S. Army Corps of Engineers

Arthur Rypinski, U.S. Department of Transportation

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INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

5 TRANSPORTATION

Key Messages

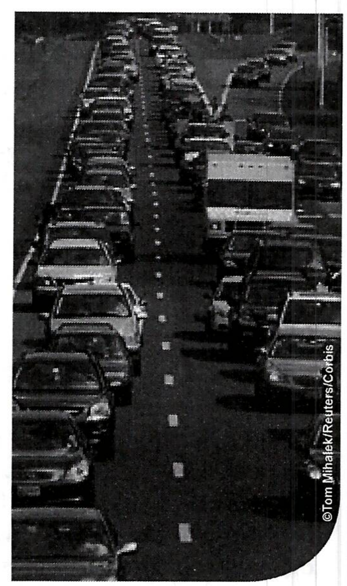
1. **The impacts from sea level rise and storm surge, extreme weather events, higher temperatures and heat waves, precipitation changes, Arctic warming, and other climatic conditions are affecting the reliability and capacity of the U.S. transportation system in many ways.**
2. **Sea level rise, coupled with storm surge, will continue to increase the risk of major coastal impacts on transportation infrastructure, including both temporary and permanent flooding of airports, ports and harbors, roads, rail lines, tunnels, and bridges.**
3. **Extreme weather events currently disrupt transportation networks in all areas of the country; projections indicate that such disruptions will increase.**
4. **Climate change impacts will increase the total costs to the nation's transportation systems and their users, but these impacts can be reduced through rerouting, mode change, and a wide range of adaptive actions.**

The U.S. economy depends on the personal and freight mobility provided by the country's transportation system. Essential products and services like energy, food, manufacturing, and trade all depend in interrelated ways on the reliable functioning of these transportation components. Disruptions to transportation systems, therefore, can cause large economic and personal losses.[1] The national transportation system is composed of four main components that are increasingly vulnerable to climate change impacts:

- fixed node infrastructure, such as ports, airports, and rail terminals;
- fixed route infrastructure, such as roads, bridges, pedestrian/bicycle trails and lanes, locks, canals/channels, light rail, subways, freight and commuter railways, and pipelines, with mixed public and private ownership and management;
- vehicles, such as cars, transit buses, and trucks; transit and railcars and locomotives; ships and barges; and aircraft – many privately owned; and
- the people, institutions, laws, policies, and information systems that convert infrastructure and vehicles into working transportation networks.

Besides being affected by climate changes, transportation systems also contribute to changes in the climate through emissions. In 2010, the U.S. transportation sector accounted for 27% of total U.S. greenhouse gas emissions, with cars and trucks accounting for 65% of that total.[2] Petroleum accounts for 93% of the nation's transportation energy use.[2] This means that policies and behavioral changes aimed at reducing greenhouse gas emissions will have significant implications for the various components of the transportation sector.

Weather events influence the daily and seasonal operation of transport systems.[3,4,5] Transportation systems are already experiencing costly climate change related impacts. Many inland states – for example, Vermont, Tennessee, Iowa, and Missouri – have experienced severe precipitation events, hail, and flooding during the past three years, damaging roads, bridges, and rail systems and the vehicles that use them. Over the coming decades, all regions and modes of transportation will be affected by increasing temperatures, more extreme weather events, and changes in precipitation. Concentrated transportation impacts are likely in Alaska and along seacoasts.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Climate trends affect the design of transport infrastructure, which is expensive and designed for long life (typically 50 to 100 years). The estimated value of U.S. transportation facilities in 2010 was $4.1 trillion.[6] As climatic conditions shift, portions of this infrastructure will increasingly be subject to climatic stresses that will reduce the reliability and capacity of transportation systems.[7] Transportation systems are also vulnerable to interruptions in fuel and electricity supply, as well as communications disruptions – which are also subject to climatic stresses.[7,8] For example, power outages resulting from Hurricane Katrina shut down three major petroleum pipelines for two days, and the systems operated at reduced capacities for two weeks.[9]

Climate change will affect transportation systems directly, through infrastructure damage, and indirectly, through changes in trade flows, agriculture, energy use, and settlement patterns. If, for instance, corn cultivation shifts northward in response to rising temperatures, U.S. agricultural products may flow to markets from different origins by different routes.[10] If policy measures and technological changes reduce greenhouse gas emissions by affecting fuel types, there will likely be significant impacts on the transportation of energy supplies (such as pipelines and coal trains) and on the cost of transportation to freight and passenger users.[11]

Shifts in demographic trends, land-use patterns, and advances in transportation technology over the next few decades will have profound impacts on how the nation's transportation system functions, its design, and its spatial extent. As transportation officials shape the future transportation system to address new demands, future climate conditions should be considered as part of the planning and decision-making process.

Disruptions to transportation system capacity and reliability can be partially offset by adaptations. Transportation systems *as networks* may use alternative routes around damaged elements or shift traffic to undamaged modes. Other adaptation actions include new infrastructure designs for future climate conditions, asset management programs, at-risk asset protection, operational changes, and abandoning/relocating infrastructure assets that would be too expensive to protect.[12] As new and rehabilitated transportation systems are developed, climate change impacts should be routinely incorporated into the planning for these systems.

There will be challenges in adapting transportation systems to climate related changes, particularly when factoring in projected growth in the transportation sector. A National Surface Transportation Policy and Revenue Commission in 2007 forecast the following annual average growth rates: average annual tonnage growth rates of 2.1% for trucks, 1.9% for rail, and 1.2% for waterborne transportation, and an average annual passenger vehicle miles traveled growth rate of 1.82% through 2035 and 1.72% through 2055.[13]

Key Message 1: Reliability and Capacity at Risk

The impacts from sea level rise and storm surge, extreme weather events, higher temperatures and heat waves, precipitation changes, Arctic warming, and other climatic conditions are affecting the reliability and capacity of the U.S. transportation system in many ways.

Global climate change has both gradual and extreme event implications. A gradually warming climate will accelerate asphalt deterioration and cause buckling of pavements and rail lines.[14] Streamflows based on increasingly more frequent and intense rainfall instead of slower snowmelt could increase the likelihood of bridge damage from faster-flowing streams.[15] However, less snow in some areas will reduce snow removal costs and extend construction seasons. Shifts in agricultural production patterns will necessitate changes in transportation routes and modes.[16]

Climate models project that extreme heat and heat waves will become more intense, longer lasting, and more frequent (Ch. 2: Our Changing Climate). By 2080-2100, average temperatures are expected to increase by 3°F to 6°F for the continental United States, assuming emissions reductions from current trends (B1 scenario), while continued increases in emissions (A2 scenario) would lead to an increase in average temperatures ranging from 5°F in Florida to 9°F in the upper Midwest.[17]

The impact on transportation systems not designed for such extreme temperatures would be severe. At higher temperatures, expansion joints on bridges and highways are stressed and some asphalt pavements deteriorate more rapidly.[18] Rail

Thawing Alaska

Permafrost – soil saturated with frozen water – is a key feature of the Alaskan landscape. *Frozen* permafrost is a suitable base for transportation infrastructure such as roads and airfields. In rapidly warming Alaska, however, as permafrost thaws into mud, road shoulders slump, highway cuts slide, and runways sink. Alaska currently spends an extra $10 million per year repairing permafrost damage.[25]

A recent study, which examined potential climate damage to Alaskan public infrastructure using results from three different climate models,[26] considered 253 airports, 853 bridges, 131 harbors, 819 miles of railroad, 4,576 miles of paved road, and 5,000 miles of unpaved road that could be affected by climate change. The present value of additional public infrastructure costs due to climate change impacts was estimated at $5.6 to $7.6 billion through 2080, or 10% to 12% of total public infrastructure costs in Alaska. These costs might be reduced by 40% with strong adaptation actions.[26]

track stresses and track buckling will increase.[14,19] High air temperatures can affect aircraft performance; lift-off limits at hot-weather and high-altitude airports will reduce aircraft operations.[20]

Construction crews may have to operate on altered time schedules to avoid the heat of the day, with greater safety risks for workers.[21] The construction season may lengthen in many localities. Similarly, higher temperatures (and precipitation changes) are likely to affect transit ridership, bicycling, and walking.[14,22]

Climate change is most pronounced at high northern latitudes. Alaska has experienced a 3°F rise in average temperatures since 1949,[23] double the rest of the country. Winter temperatures have risen by 6°F.[23] On the North Slope, sea ice formerly provided protection to the shoreline against strong fall/winter winds and storms (see Ch. 12: Indigenous Peoples). Retreating ice reduces this protection, eroding the shoreline and endangering coastal villages. Thawing permafrost is causing pavement, runway, rail, and pipeline displacements, creating problems for operation and maintenance, and requiring reconstruction of key facilities.

Arctic warming is also projected to allow the seasonal opening of the Northwest Passage to freight shipment.[24] Global climate projections to 2100 show extensive open water areas during the summer around the Arctic basin. Retreat of Arctic sea ice has been observed in all seasons over the past five decades, with the most prominent retreat in summer.[24] This has allowed a limited number of freighters, cruise ships, and smaller vessels to traverse the Northwest Passage for several years.

Possible Future Flood Depths in Mobile, AL with Rising Sea Level

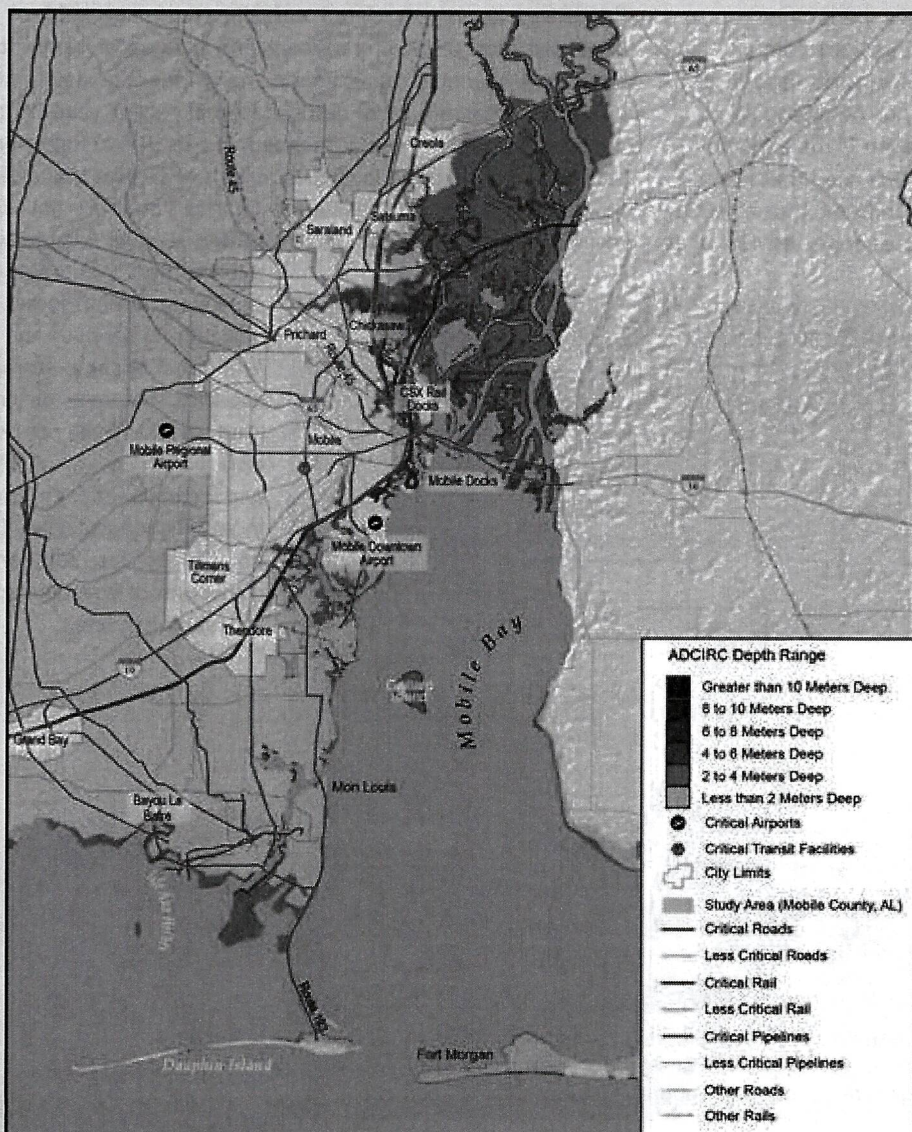

Figure 5.1. Many coastal areas in the United States, including the Gulf Coast, are especially vulnerable to sea level rise impacts on transportation systems.[11,27,28] This is particularly true when one considers the interaction among sea level rise, wave action, and local geology.[29] This map shows that many parts of Mobile, Alabama, including critical roads, rail lines, and pipelines, would be exposed to storm surge under a scenario of a 30-inch sea level rise combined with a storm similar to Hurricane Katrina. Not all roads would be flooded if they merely run through low areas since some are built above flood levels. A 30-inch sea level rise scenario is within the range projected for global sea level rise (Ch. 2: Our Changing Climate, Key Message 10). (Figure source: U.S. Department of Transportation 2012[30]).

Key Message 2: Coastal Impacts

Sea level rise, coupled with storm surge, will continue to increase the risk of major coastal impacts on transportation infrastructure, including both temporary and permanent flooding of airports, ports and harbors, roads, rail lines, tunnels, and bridges.

The transportation impacts of rising global sea level, which is expected to continue to rise by an additional 1 to 4 feet by 2100 (see also Ch. 2: Our Changing Climate, Key Message 10),[31] will vary widely by location and geography. When sea level rise is coupled with intense storms, the resulting storm surges will be greater, extend farther inland, and cause more extensive damage. Relative sea level rise will be greater along some coasts (such as Louisiana, Texas, and parts of the Chesapeake Bay), and this will have significant effects on transportation infrastructure, even without the coupling with storms, due to regional land subsidence (land sinking or settling) (Ch. 25: Coasts). Ports and harbors will need to be reconfigured to accommodate higher seas. Many of the nation's largest ports are along the Gulf Coast, which is especially vulnerable due to a combination of sea level rise, storm surges, erosion, and land subsidence.[11] Two additional impacts for ports include 1) as sea level rises, bridge clearance may not be adequate to allow safe passage of large vessels; 2) even if the elevation of port facilities is adequate, any main access road that is not elevated will become more frequently inundated, thus affecting port operations. In 2011, the United States imported 45% of all oil consumed, and 56% of those imports passed through Gulf Coast ports.[32]

More frequent disruptions and damage to roads, tracks, runways, and navigation channels are projected in coastal areas beyond the Gulf Coast. Thirteen of the nation's 47 largest airports have at least one runway with an elevation within 12 feet of current sea levels.[33] Most ocean-going ports are in low-lying coastal areas, including three of the most important for imports and exports: Los Angeles/Long Beach (which handles 31% of the U.S. port container movements) and the Port of South Louisiana and the Port of Galveston/Houston (which combined handle 25% of the tonnage handled by U.S. ports).[34] Extreme floods and storms associated with climate change will lead to increased movement of sediment and buildup of sandy formations in channels. For example, many federally maintained navigation channels have deteriorated in recent years to dimensions less than those authorized, in part due to floods and storms, which resulted in reduced levels of service that affect navigation safety and reliability.[35] Channels that are not well maintained and have less sedimentation storage volume will thus be more vulnerable to significant, abrupt losses in navigation service levels. Additional channel storage capacity that may be created by sea level rise will also increase water depths and increase sedimentation in some channels. (See Ch. 25: Coasts for additional discussion of coastal transportation impacts.)

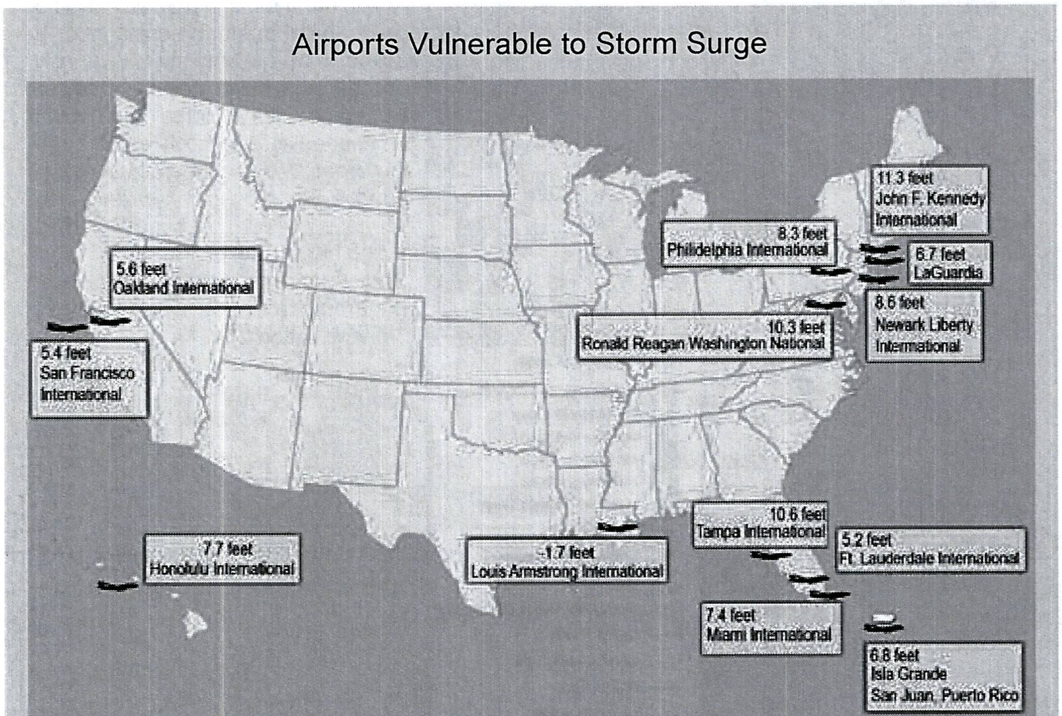

Figure 5.2. Thirteen of the nation's 47 largest airports have at least one runway with an elevation within the reach of moderate to high storm surge. Sea level rise will pose a threat to low-lying infrastructure, such as the airports shown here. (Data from Federal Aviation Administration 2012[33]).

Key Message 3: Weather Disruptions

Extreme weather events currently disrupt transportation networks in all areas of the country; projections indicate that such disruptions will increase.

Changes in precipitation patterns, particularly more extreme precipitation events and drought, will affect transportation systems across the country. Delays caused by severe storms disrupt almost all types of transportation. Storm drainage systems for highways, tunnels, airports, and city streets could prove inadequate, resulting in localized flooding. Bridge piers are subject to scour as runoff increases stream and river flows, potentially weakening bridge foundations. Severe storms will disrupt highway traffic, leading to more accidents and delays. More airline traffic will be delayed or canceled.

Infrastructure around the country has been compromised by extreme weather events such as heavy downpours. Road and bridge damage are among the infrastructure failures that have occurred during these extreme events.

Inland waterways may well experience greater floods, with high flow velocities that are unsafe for navigation and that cause channels to shut down intermittently. Numerous studies indicate increasing severity and frequency of flooding throughout much of the Mississippi and Missouri River Basins.[36] Increases in flood risk reflect both changing precipitation and changing land-use patterns.[37] In the Upper Mississippi/Missouri Rivers, there have been two 300- to 500-year floods over the past 20 years.[38] Drought increases the probability of wildfires, which affect visibility severely enough to close roads and airports. Drought can lower vessel drafts on navigable rivers and associated lock and dam pools. On the other hand, less ice formation on navigable waterways has the potential to increase seasonal windows for passage of navigation.

Gulf Coast Transportation Hubs at Risk

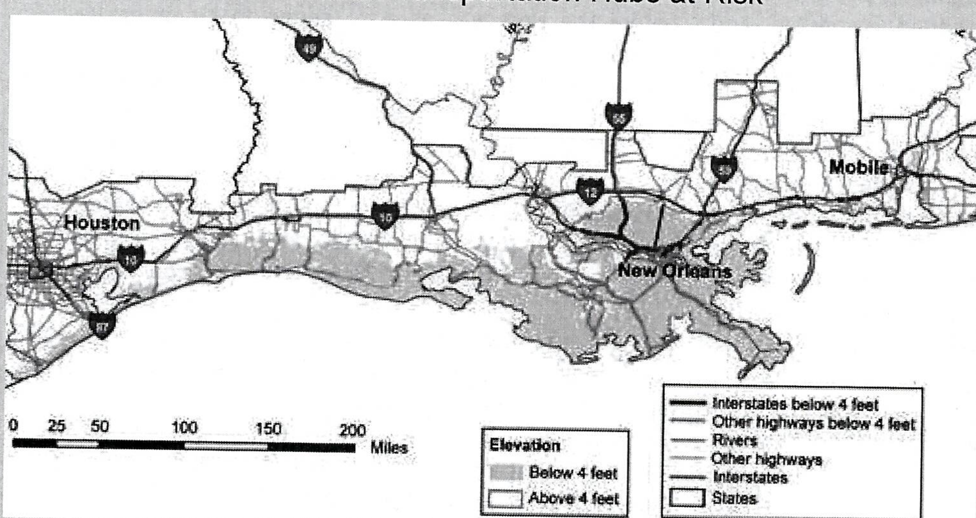

Figure 5.3. Within this century, 2,400 miles of major roadway are projected to be inundated by sea level rise in the Gulf Coast region. The map shows roadways at risk in the event of a sea level rise of about 4 feet, which is within the range of projections for this region in this century (see also Ch. 2: Our Changing Climate, Key Message 10). In total, 24% of interstate highway miles and 28% of secondary road miles in the Gulf Coast region are at elevations below 4 feet. (Figure source: Kafalenos et al. 2008[39]).

The frequency of the strongest hurricanes (Category 4 and 5) in the Atlantic is expected to increase (see Ch. 2: Our Changing Climate, Key Message 8). As hurricanes approach landfall, they create storm surge, which carries water farther inland. The resulting flooding, wind damage, and bridge destruction disrupts virtually all transportation systems in the affected area. Many of the nation's military installations are in areas that are vulnerable to extreme weather events, such as naval bases located in hurricane-prone zones.

Hurricane Sandy

On October 29, 2012, Hurricane Sandy dealt the transportation systems of New Jersey and New York and environs a massive blow (See also Ch.16: Northeast, "Hurricane Vulnerability"; Ch. 11: Urban "Hurricane Sandy"). The damages from Sandy are indicative of what powerful tropical storms and higher sea levels could bring on a more frequent basis in the future and were very much in line with vulnerability assessments conducted over the past four years.[40,41,42] All tunnels and most bridges leading into New York City were closed during the storm. Storm tides of up to 14 feet[43] flooded the Queens Midtown, Holland, and Carey (Brooklyn Battery) tunnels, which remained closed for at least one week (two weeks for the Carey Tunnel) while floodwaters were being pumped out and power restored. The three major airports (Kennedy, Newark, and LaGuardia) flooded, with LaGuardia absorbing the worst impact and closing for three days.[44]

Hurricane Sandy Causes Flooding in New York City Subway Stations

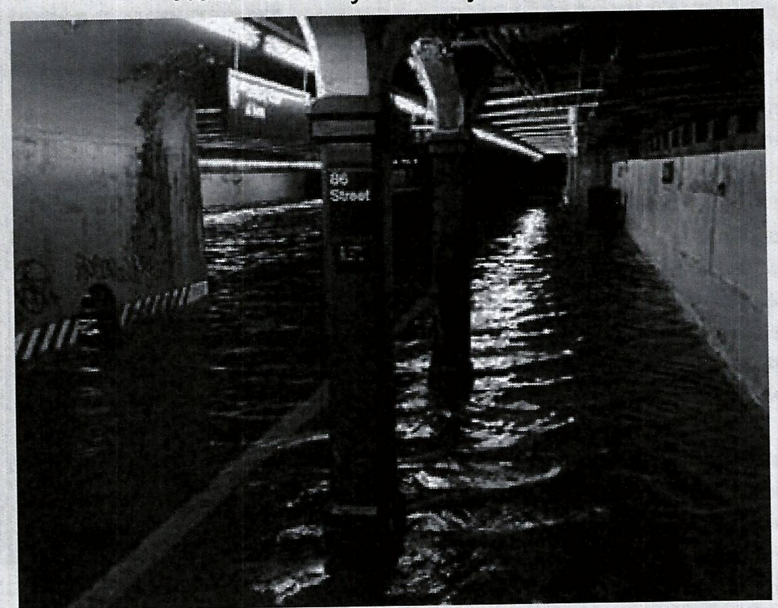

Figure 5.4. The nation's busiest subway system sustained the worst damage in its 108 years of operation on October 29, 2012, as a result of Hurricane Sandy. Millions of people were left without service for at least one week after the storm, as the Metropolitan Transportation Authority rapidly worked to repair extensive flood damage (Photo credit: William Vantuono, Railway Age Magazine, 2012[46]).

Almost 7.5 million passengers per day ride the New York City subways and buses.[45] Much of the New York City subway system below 34th Street was flooded, including all seven tunnels under the East River to Brooklyn and Queens. In addition to removing the floodwaters, all electrical signaling and power systems (the third rails) had to be cleaned, inspected, and repaired. Service on most Lower Manhattan subways was suspended for at least one week,[46] as was the PATH system to New Jersey.[47] Commuter rail service to New Jersey, Long Island, and northern suburbs, with more than 500,000 passengers per day,[45] was similarly affected for days or weeks with flooded tunnels, downed trees and large debris on tracks, and loss of electrical power.[48] In addition, miles of local roads, streets, underpasses, parking garages, and bridges flooded and/or were badly damaged in the region, and an estimated 230,000 parked vehicles[49] sustained water damage. Flooded roadways prevented the New York Fire Department from responding to a fire that destroyed more than 100 homes in Brooklyn's Breezy Point neighborhood.[50]

Hurricane Sandy's storm surge produced nearly four feet of floodwaters throughout the Port of New York and New Jersey, damaging electrical systems, highways, rail track, and port cargo; displacing hundreds of shipping containers; and causing ships to run aground.[51] Floating debris, wrecks, and obstructions in the channel had to be cleared before the Port was able to reopen to incoming vessels within a week.[52] Pleasure boats were damaged at marinas throughout the region. On a positive note, the vulnerability analyses prepared by the metropolitan New York authorities and referenced above provided a framework for efforts to control the damage and restore service more rapidly. Noteworthy are the efforts of the Metropolitan Transportation Authority to protect vital electrical systems and restore subway service to much of New York within four days.

The impacts of this extraordinary storm on one of the nation's most important transportation nodes were felt across the country. Airline schedules throughout the United States and internationally were snarled; Amtrak rail service along the East Coast and as far away as Buffalo and Montreal was curtailed; and freight shipments in and out of the hurricane impact zone were delayed. The resultant direct costs to the community and indirect costs to the economy will undoubtedly rise into the tens of billions of dollars (See also Ch. 11: Urban, "Hurricane Sandy").

Table 5.1 relates to overall national expectations based on Angel and Kunkel 2010[54] and as postulated by chapter authors. This kind of matrix is likely to be most valuable and accurate if used at the state/regional/local levels. (Source: Matrix format adapted from McLaughlin et al. 2011[53]).

Illustrative Risks of Climate-related Impacts

Magnitude of Consequences		Likelihood of Occurrence: Low	Medium	High	Virtually Certain
	High	Subway and tunnel flooding	Increased widespread flooding of transportation facilities	Major localized flooding disrupts transportation systems	Inundation of coastal assets due to storm surge
	Medium	Increased rock/mud slides blocking road and rail facilities	Train derailment due to rail buckling	Increased disruption of barge traffic due to flooding	Short-term road flooding and blocked culverts due to extreme events
	Low	Lower visibility from wildfires due to drought conditions	Northward shift of agricultural production places more demand and stress on roads and systems not prepared for higher volumes	Pavement heaving and reduced pavement life due to high temperatures	Inundation of local roads due to sea level rise
	Positive (beneficial)	Reduced flight cancellations due to fewer blizzards	Reduced maintenance costs for highways and airports due to warmer winters	Reduced Great Lakes freezing, leading to longer shipping season	Longer seasonal opening of Northwest Passage

Risks and Consequences

Risk is a function of both likelihood of impact and the consequences of that impact. Table 5.1 is an illustrative application of a risk matrix adapted from the Port Authority of New York and New Jersey. As shown, different types of climate-related incidents/events can have associated with them a likelihood of occurrence and a magnitude of the consequences if the incident does occur.

In assessing consequences, the intensity of system use, as well as the existence or lack of alternative routes, must be taken into account. Disabling a transportation facility can have ripple effects across a network, with trunk (main) lines and hubs having the most widespread impacts.[53] Any comprehensive assessment of the consequences of climate change would need to encompass the broad array of factors that influence the nation's transportation system, and consider changes in population, society, technology, prices, regulation, and the economy that eventually affect transportation system performance.[55] For example, the trend in recent years in the U.S. economy of adopting just-in-time logistics increases the vulnerability of businesses to day-to-day disruptions caused by weather and flooding.

Key Message 4: Costs and Adaptation Options

Climate change impacts will increase the total costs to the nation's transportation systems and their users, but these impacts can be reduced through rerouting, mode change, and a wide range of adaptive actions.

Adaptation strategies can be employed to reduce the impact of climate change related events and the resulting consequences (see Ch. 28: Adaptation). Consideration of adaptation strategies in the transportation sector is especially important in the following five areas:

- **Transportation and land-use planning:** deciding what infrastructure to build and where to build it, as well as planning for vulnerable areas of the community and impacts on specific population groups.
- **Vulnerability and risk assessment**: identifying existing vulnerable facilities and systems, together with the expected consequences.
- **New infrastructure design**: adapting new infrastructure designs that anticipate changing environmental and operational conditions.
- **Asset management**: adapting existing infrastructure and operations that respond to current and anticipated conditions, including changed maintenance practices and retrofits.
- **Emergency response:** anticipating expected disruptions from extreme weather events, and developing emergency response capability.

Adaptation takes place at multiple levels, from individual households and private businesses to federal, state, and local governments. The impacts associated with climate change are not new, since flooding, storm surge, and extreme heat have long been challenges. What *is* new is the changing frequency, intensity, and location/geography of impacts and hazards.

Responding effectively to present and future environmental challenges enhances the resilience of communities. Examples

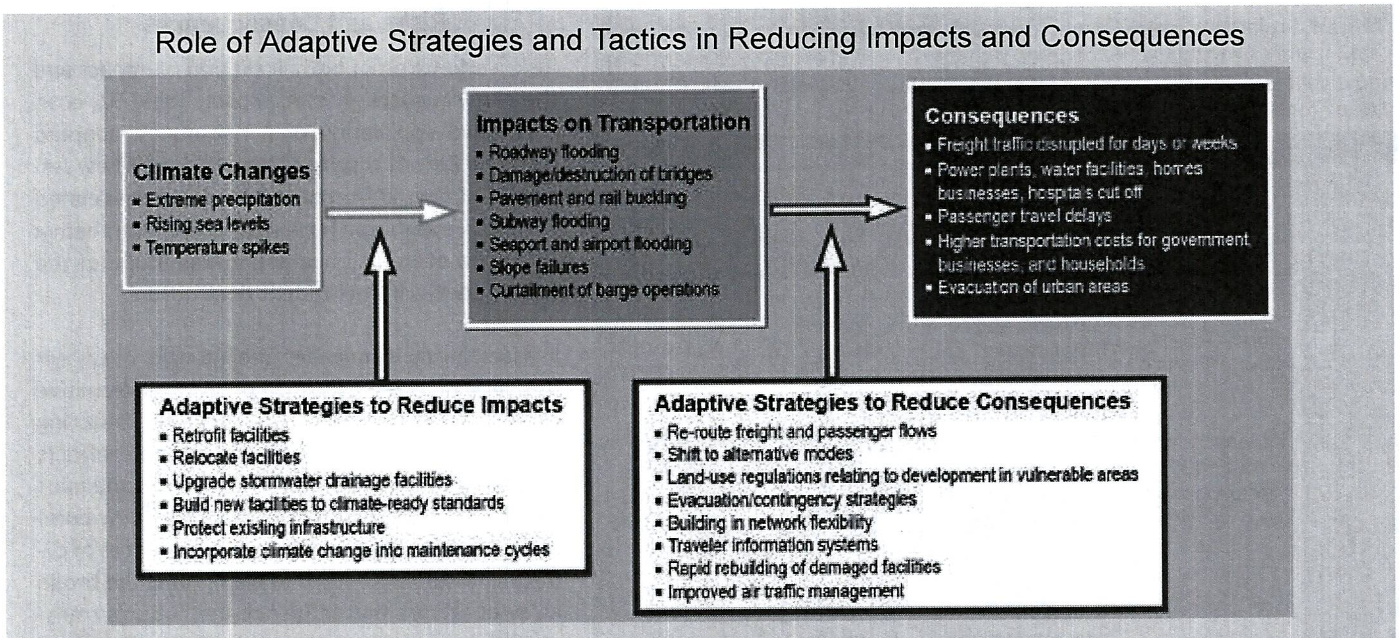

Figure 5.5. Many projected climate change impacts and resulting consequences on transportation systems can be reduced through a combination of infrastructure modifications, improved information systems, and policy changes.

include improvements in storm water management, coastal zone management, and coastal evacuation plans.

At the national level, the transportation network has some capability to adjust to climate-related disruptions due to the presence of network redundancy – multiple routes are often possible for long-distance travel, and more than one mode of transportation may be used for travel. However, in some cases, only one major route connects major destinations, such as Interstate 5 between Seattle and San Francisco; movements along such links are particularly vulnerable to disruption.

Disruptions to the nation's inland water system from floods or droughts can, and has, totally disrupted barge traffic. Severe droughts throughout the upper Midwest in 2012 reduced flows in the Missouri and Mississippi Rivers to near record low levels, disrupting barge traffic. While alternative modes, such as rail and truck, may alleviate some of these disruptions, it is impractical to shift major product shipments such as Midwest grain to other modes of transportation – at least in the near term.[57]

While extreme weather events will continue to cause flight cancellations and delays, many weather delays from non-extreme events are compounded by existing inadequacies in the current national air traffic management system.[58] Improvements in the air traffic system, such as those anticipated in the FAA's NextGEN (www.faa.gov/nextgen/), should reduce weather-related delays.

At the state and local level, there is less resilience to be gained by alternative routing, and impacts may be more intense. For example, significant local and regional disruption and economic costs could result from the flooding of assets as diverse as New York's subways, Iowa's roads, San Francisco's airports, and Vermont's bridges.

Climate change is one of many factors, and an increasingly important one, that many state, regional, and local agencies are considering as they plan for new and rehabilitated facilities. By incorporating climate change routinely into the planning process, governments can reduce the vulnerability to climate change impacts and take actions that enhance the resilience

Winter Storm-Related Closures of I-5 and I-90 in Washington State, 2007-2008

In December 2007, heavy rainfall west of I-5, combined with melting snow from the mountains, created extremely high floodwaters in western Washington State. Six-hour rainfall amounts were near a 100-year event for areas in Southwest Washington. High winds, heavy rains, mudslides, and falling trees made travel unsafe on highways. Downed power lines blocked roads, and, in many urban areas, rainwater overwhelmed drainage systems and flooded roadways.

The combined economic impact in the I-5 and I-90 corridors was estimated at almost $75 million, of which some $47 million was associated with the I-5 disruption and $28 million with the I-90 corridor. Estimated highway damage from the winter storm was $18 million for state routes and another $39 million for city and county roads.[56]

Planning for Climate Change

Charlotte County exemplifies how local governments can incorporate aspects of climate change into transportation planning. The Metropolitan Planning Organization in Charlotte County-Punta Gorda, Florida conducted long-range scenario planning that integrated climate change projections.[65] A "smart growth" scenario that concentrated growth in urban centers was compared with a "resilient growth" scenario that steered development away from areas vulnerable to sea level rise. Planners evaluated the scenarios based on projected transportation performance outcomes and selected a preferred scenario reflecting aspects of each alternative.

of the transportation system to adverse weather conditions. Governments at various levels are already taking action, as described below.

Land-use planning can reduce risk by avoiding new development in flood-prone areas, conserving open space to enhance drainage, and relocating or abandoning structures or roads that have experienced repeated flooding. The National Flood Insurance Program encourages buyouts of repetitive loss structures and preservation of open space by reducing flood insurance rates for communities that adopt these practices.

An important step in devising an adaptation plan is to assess vulnerabilities (Ch. 26: Decision Support; Ch. 28: Adaptation). The Federal Highway Administration funded pilot projects in five coastal states to test a conceptual framework for evaluating risk.[59] The framework identifies transportation assets, evaluates the likelihood of impact on specific assets, and assesses the seriousness of such impacts.

Several state and local governments have conducted additional vulnerability assessments that identify potential impacts to transportation systems, especially in coastal areas. Detailed assessment work has been undertaken by New York City,[40,42,60] California,[61] Massachusetts,[62] Washington,[63] Florida, and Boston.[64]

Non-coastal states and regions have also begun to produce vulnerability assessments. Midwestern states, including Wisconsin[66] Iowa,[67] and Michigan,[68] have addressed increasing risk of flooded roadways and other impacts.

Transit systems are already implementing measures that reduce vulnerability to climate impacts, including rail buckling. Portland, Oregon's transit agency has been installing expansion joints at vulnerable locations, improving reliability of rail

Tropical Storm Irene Devastates Vermont Transportation in August 2011

In August of 2011, Vermont was inundated with rain and massive flooding from Tropical Storm Irene (see also Ch.16: Northeast, "Hurricane Vulnerability"), closing down 146 segments of the state road system along with more than 200 bridges, and costing an estimated $175 to $200 million to rebuild state highways and bridges. An additional 2,000 or more municipal roads and nearly 1,000 culverts were damaged, and more than 200 miles of state-owned rail required repair.[75]

The volume of water was unprecedented, as was the power of the water in the rivers running through the state. Culverts and bridges were affected and slope stability was threatened as a result of the immense amount and power of water and subsequent flooding.

Tropical Storm Impact on Vermont Road

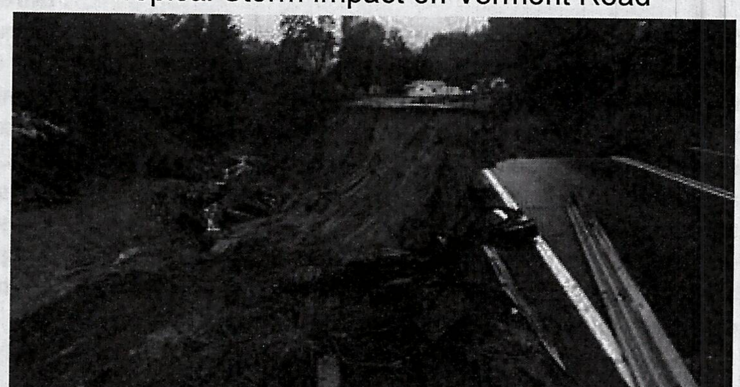

Figure 5.6. Vermont Route 131, outside Cavendish, a week after Tropical Storm Irene unleashed severe precipitation and flooding that damaged many Vermont roads, bridges, and rail lines. (Photo credit: Vermont Agency of Transportation).

When asked about the lessons learned, the Vermont Agency of Transportation (VTrans) indicated the importance of good maintenance of riverbeds as well as roads. VTrans is working with the Vermont Agency of Natural Resources, looking upstream and downstream at the structure of the rivers, recognizing that risk reduction may involve managing rivers as much as changing bridges or roadways.

Rich Tetreault of VTrans emphasized that "Certainly we will be looking to right-size the bridges and culverts that need to be replaced … Knowing that we do not have the funds to begin wholesale rebuilding of the entire highway network to withstand future flooding, we will also enhance our ability to respond" when future flooding occurs.[74]

Storm surge on top of rising sea levels have damaged roads and other coastal infrastructure.

service.[14] In New York, ventilation grates are being elevated to reduce the risk of flooding.[40]

Transportation agencies are incorporating climate change into ongoing design activities. For example, the Alaska Department of Transportation (DOT) spends more than $10 million annually on shoreline protection, relocations, and permafrost protection for roadways (see "Thawing Alaska").[25] In May 2011, the California Department of Transportation (Caltrans) issued guidance to their staff on whether and how to incorporate sea level rise into new project designs.[69]

States have begun to integrate climate impacts into Transportation Asset Management, a systematic process for monitoring the conditions of roads and transit facilities.[18,70] Maryland is working to prioritize assets taking sea level rise and increased storm intensity into account and is developing a tool to track assets and assess vulnerability.[71] Florida DOT continually monitors conditions on roads and bridges and is developing a statewide inventory and action plan for high-risk bridges.[72] Among inland states, Michigan DOT has identified a wide range of operational and asset management changes to adjust to climate change.[68] Planting street trees has been shown to reduce the urban heat island effect and reduce heat stress on pavement.[73]

Effective stormwater and stream/river management can reduce the risk of flooding for transportation infrastructure. Following Tropical Storm Irene, Vermont state agencies are working on stream and river management to reduce conditions that exacerbate flooding impacts on transportation.[74]

Effective asset management requires significant data and monitoring of transportation assets. Improved weather and road-condition information systems enable transportation system managers to anticipate and detect problems better and faster – enabling them to close systems if needed, alert motorists, and dispatch maintenance and snow-removal crews. As Michigan DOT has noted, an increase in lake-effect snows means that existing models used for snow and ice removal procedures are no longer reliable, requiring better monitoring and new models, as well as better roadway condition detection systems.[68]

Similarly, regular maintenance and cleaning of urban levee and culvert systems reduces the risk of roads and rails being inundated by flooding.

Extreme weather, such as hurricanes or intense storms, stresses transportation at precisely the time when smooth operation is critical. Effective evacuation planning, including early warning systems, coordination across jurisdictional boundaries, and creating multiple evacuation routes builds preparedness. Identifying areas with high concentrations of vulnerable and special-needs populations (including elderly, disabled, and transit-dependent groups) enhances readiness, as does identifying assets such as school buses or other transit vehicles that can be deployed for households that do not own vehicles.

5: TRANSPORTATION

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages
In developing key messages, the chapter author team engaged, via teleconference, in multiple technical discussions from January through May 2012 as they reviewed numerous peer reviewed publications. Technical input reports (21) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input. The author team's review included a foundational Technical Input Report for the National Climate Assessment, "Climate Impacts and U.S. Transportation."[57] Other published literature and professional judgment were also considered as the chapter key messages were developed. The chapter author team met in St. Louis, MO, in April 2012 for expert deliberation and finalization of key messages.

Key Message #1 Traceable Account

The impacts from sea level rise and storm surge, extreme weather events, higher temperatures and heat waves, precipitation changes, Arctic warming, and other climatic conditions are affecting the reliability and capacity of the U.S. transportation system in many ways.

Description of evidence base
Climate impacts in the form of sea level rise, changing frequency of extreme weather events, heat waves, precipitation changes, Arctic warming, and other climatic conditions are documented in Ch. 2: Our Changing Climate of this report.

Climate can be described as the frequency distribution of weather over time. Existing weather conditions, flooding, and storm surge demonstrably affect U.S. transportation systems. By changing the frequency of these weather conditions, climate change will inevitably affect the reliability and capacity of U.S. transportations systems. This view is supported by multiple studies of the impacts of weather and climate change on particular transportation systems or particular regions.

An aggregate summary of impacts of climate change on U.S. transportation can be found in NRC 2008.[7] A paper commissioned for NRC 2008 considers specific impacts of various forms of climate change on infrastructure, for example, possible future constraints on infrastructure.[12] The effects of climate on transit systems are summarized in Hodges 2011.[14] The impact of heat and other climate effects on rail systems are described by Hodges 2011 and Rossetti 2002.[14,19]

Future impacts of sea level rise and other climatic effects on transportation systems in the Gulf Coast were examined by CCSP 2008.[11] The impacts of climate change on New York State, including its transportation system, were undertaken by Rosenzweig et al. 2011.[60] Impacts of sea level rise on transportation infrastructure for the mid-Atlantic were also discussed in CCSP 2009 SAP 4.1, Ch. 7.[27]

Weather impacts on road systems are discussed in "Climate Impacts and U.S. Transportation"[57] and numerous other sources. Weather impacts on aviation operations are discussed in Kulesa 200320 and numerous other sources.

In addition, the key message and supporting text summarize extensive evidence documented in "Climate Impacts and U.S. Transportation."[57]

Additional peer-reviewed publications discuss the fact that Arctic warming is affecting existing Alaskan transportation infrastructure today, and is projected to allow the seasonal opening of the Northwest Passage to freight shipment.[24]

New information and remaining uncertainties
Recent changes in global sea level rise estimates documented in this report (Ch.2: Our Changing Climate, Key Message 10) have not been incorporated into existing regional studies of coastal areas. In addition, recent research by USGS on the interaction between sea level rise, wave action, and local geology have been incorporated in only a few studies.[29]

Specific estimates of climate change impacts on transportation are acutely sensitive to regional projections of climate change and, in particular, to the scale, timing, and type of predicted precipitation. New (CMIP5-based) regional climate projections will therefore affect most existing specific estimates of climate change impacts on transportation. Transportation planning in the face of uncertainties about regional-scale climate impacts presents particular challenges.

Impacts of climate on transportation system operations, including safety and congestion, both on road systems and in aviation, have been little studied to date.

Future characteristics of society, such as land-use patterns, demographics, and the use of information technology to alter transportation patterns, and possible changes to the very nature of future transportation systems themselves all create uncertainty in evaluating climate impacts on the nation's transportation networks. These societal changes will probably occur gradually, however, allowing the transportation systems to adapt. Adaptation can significantly ameliorate impacts on the transportation sector; however, evaluation of adaptation costs and strategies for the transportation sector is at a relatively early stage.

Assessment of confidence based on evidence

Confidence is **high** that transportation systems will be affected by climate change, given current climate projections, particularly regarding sea level rise and extreme weather events.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

KEY MESSAGE #2 TRACEABLE ACCOUNT

Sea level rise, coupled with storm surge, will continue to increase the risk of major coastal impacts on transportation infrastructure, including both temporary and permanent flooding of airports, ports and harbors, roads, rail lines, tunnels, and bridges.

Description of evidence base

Estimates of global sea level rise are documented in Ch. 2: Our Changing Climate, Key Message 10 of this report.

The prospective impact of sea level rise and storm surge on transportation systems is illustrated by the impact of recent hurricanes on U.S. coastlines. In addition, research on impacts of sea level rise and storm surge on transportation assets in particular regions of the United States demonstrate the potential for major coastal impacts (for example, CCSP 2008, Rosenzweig et al. 2011, and Suarez et al. 2005[11,28,60]). Note that most existing literature on storm surge and sea level rise impacts on transportation systems is based on a global sea level rise of less than one meter (about 3 feet). The most recent projections include a potentially greater rise in global sea level (Ch. 2: Our Changing Climate, Key Message 10).

In addition, the key message and supporting text summarize extensive evidence documented in "Climate Impacts and U.S. Transportation."[57]

New information and remaining uncertainties

As noted above, new estimates of global sea level rise have overtaken most of the existing literature on transportation and sea level rise in the United States. In addition, it is not clear that the existing transportation literature reflects recent USGS work on interactions between sea level rise, wave action, and local geology.[29]

New global sea level rise estimates will enable the development of new regional estimates, as well as revision of regional coastal erosion and flood modeling. Such smaller scale estimates are important because transportation and other infrastructure impacts must necessarily be studied in a local context.

Generally speaking, modeling of sea level rise impacts using existing USGS National Elevation Dataset (NED) data has well-understood limitations. Since NED data is freely and easily available, it is often used for preliminary modeling. More accurate and more recent elevation data may be captured via LIDAR campaigns, and this data collection effort will be necessary for accurate understanding of regional and local sea level rise and storm surge impacts.[27]

Accurate understanding of transportation impacts is specific to particular infrastructure elements, so detailed inventories of local and regional infrastructure must be combined with detailed and accurate elevation data and the best available predictions of local sea level rise and storm surge. Therefore, national assessments of sea level rise must be built on detailed local and regional assessments.

Improved modeling is needed on the interactions among sea level rise, storm surge, tidal movement, and wave action to get a better understanding of the dynamics of the phenomena.

Assessment of confidence based on evidence

The authors have **high** confidence sea levels are rising and storm surge on top of these higher sea levels pose risks to coastal transportation infrastructure.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Extreme weather events currently disrupt transportation networks in all areas of the country; projections indicate that such disruptions will increase.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in "Climate Impacts and U.S. Transportation."[57]

Specific regional climate impacts can be identified in each NCA region of the country. Specific climate impacts on transportation by region include:

In Alaska, rising temperatures cause permafrost to melt, causing damage to roadbeds, airfields, pipelines, and other transportation infrastructure.[25]

In the Northeast, the Chesapeake region is likely to experience particularly severe local sea level rise due to geologic subsidence,[27] and increased precipitation generally (see Ch. 2: Our Changing Climate, Key Message 5, and Ch.16: Northeast), along with an increased incidence of extreme weather events. The presence of large populations with associated transportation systems in coastal areas increases the potential impacts of sea level rise, storm surge, and precipitation-induced flooding.

The Southeast is subject to the interacting effects of sea level rise, increased precipitation, and other extreme events. The Southeast includes Virginia, so it shares the threat of regional sea level rise in the Chesapeake. In Louisiana, climate change poses a significant threat to transportation infrastructure of national significance.[11]

Midwest transportation infrastructure is subject to changing water levels on the Great Lakes.[54] Barge traffic disruptions, due to flooding or drought on the Mississippi/Missouri/Ohio river system, might be induced by changes in precipitation patterns.

A major concern in the Southwest is that declining precipitation (see Ch. 2: Our Changing Climate, Key Message 5) may induce changes in the economy and society that will affect the transportation systems that serve this region. In the Southwest, rail and highway systems may be exposed to increased heat damage from the higher temperatures. San Francisco Bay, which encompasses two major airports and numerous key transportation links, is at risk for sea level rise and storm surge.[61]

Much of the economy of the Northwest is built around electricity and irrigation from a network of dams. The performance of this system may be affected by changing precipitation patterns, with potential consequences for agriculture and industry, and, consequently for transportation systems. In addition, the Seattle area may be affected by sea level rise.[63]

Many relevant and recent climate data and models predict more intense precipitation events in much of the U.S., especially the Great Plains, Midwest, Northeast, and Southeast, with decreased precipitation in parts of the Southwest and Southeast (see Ch. 2: Our Changing Climate, Key Message 5).

New information and remaining uncertainties

Recent data clearly show – and climate models further substantiate – an increase in the intensity of precipitation events throughout much of the U.S.

There is a need for a better definition of the magnitude of increased storm intensity so that accurate return frequency curves can be established.

New regional climate model data from CMIP5 will have a significant impact on regional impact assessments.

Climate and impact data desired by transportation planners may be different from the projections generated by regional climate models. This presents a number of challenges:

Regional scale transportation impacts are often determined by flood risk and by water flows in rivers and streams. Flooding is, of course, linked to precipitation, but the linkage between precipitation and hydrology is very complex. Precipitation, as projected by climate models, is often difficult to convert into predictions of future flooding, which is what infrastructure designers need.

Similarly, an ice storm would be an extreme event for a transportation planner, but the frequency of ice storms has not yet been derived from climate models. More generally, improved methods of deriving the frequency of infrastructure-affecting weather events from regional climate models may be helpful in assessing climate impacts on transportation systems.

There are uncertainties associated with the correlation between a warming climate and increased hurricane intensity.

In regions likely to see decreased precipitation, especially those areas subject to drought, stronger correlations to fire threat and lowered water levels in major waterways are needed as projections of climate models.

Planning tools and models can present a step-by-step process for connecting the risk of impact with specific planning strategies such as assessing the vulnerability of existing and proposed infrastructure and then identifying key adaptation practices to address the risk.

Assessment of confidence based on evidence
Given the evidence base and remaining uncertainties, confidence is **high** that extreme weather events will affect transportation in all areas of the country.

KEY MESSAGE #4 TRACEABLE ACCOUNT

Climate change impacts will increase the total costs to the nation's transportation systems and their users, but these impacts can be reduced through rerouting, mode change, and a wide range of adaptive actions.

Description of evidence base
The economic cost of climate change to the transportation sector has been little studied. However, there is substantial evidence that costs will be significant. A recent study of climate change in New York indicated that a storm surge severe enough to flood Manhattan tunnels might cost as much as $100 billion.[60] The actual experience of Hurricane Sandy, where multiple tunnels were flooded, attests to the scale of the costs and disruption that attend an event of this magnitude (See also Ch. 11: Urban; Box on Hurricane Sandy). A study of the risk to specific infrastructure elements in Alaska[26] estimated the net present value of the extra cost from climate change at $2 to $4 billion through 2030, and $4 to $8 billion through 2080.

The indirect evidence for significant costs from climate change impacts begin with the consequences of recent hurricanes, particularly on the Eastern seaboard, where Hurricane Irene, a rather minor storm, produced unexpectedly heavy infrastructure damage from heavy rains.[75] The economic cost of infrastructure damage is often greater than the cost of repairing or replacing infrastructure.

In addition, a recent study of on-road congestion estimates the annual cost of highway congestion at about $100 billion,[5] and the Federal Highway Administration estimates that weather accounts for about 15% of total delay.[4] Similarly, a recent study of aviation congestion indicates that the annual cost of airline delay is about $33 billion[3] and that weather accounts for more than a third of airline delays. There is a strong circumstantial case to be made that increased frequency of extreme events (as defined by climate scientists) will produce increased traffic and aviation delays. Given the scale of current costs, even small changes in delay can have substantial economic costs.

There is little published material on transportation adaptation costs and benefits in the literature, in part because "adaptation" is an abstraction (see Ch. 28: Adaptation). Climate change is statistical weather, and manifests itself as a change in the frequency of events that would still occur (but with lower frequency) in the absence of climate change. Transportation agencies decide to protect (or not) specific pieces of infrastructure based on a range of considerations, including age and condition, extent of current and future usage, and cost of protection, as well as changing weather patterns. The authors, however, are aware, that transportation systems have always been required to adapt to changing conditions, and that, in general, it is almost always far less expensive to protect useful infrastructure than to wait for it to collapse. This professional experience, based on examination of multitudes of individual engineering studies, is the basis for the conclusion in this report (for example, Caltrans Climate Change Workshop 2011, CCSP 2008, and Meyer 2008[11,12,69]).

There are numerous examples of actions taken by state and local governments to enhance resilience and reduce climate impact costs on transportation, including land-use planning to discourage development in vulnerable areas, establishment of design guidelines to reduce vulnerability to sea level rise, use of effective stormwater management techniques, and coordinated emergency response systems.[7,69]

New information and remaining uncertainties
There is relatively little information on the costs of climate change in the transportation sector, and less on the benefits of adaptation. Much of the available research is focused on the costs of replacing assets that are affected by extreme weather events, with far less effort devoted to both longer-term impacts of climate change on transportation systems (such as inundation of coastal roads due to sea level rise) and to the broader effects of disrupted facilities on network operations or on the community, for example, rerouting of traffic around bottlenecks or evacuation of sensitive populations from vulnerable areas.

Calculating climate impact and adaptation costs and benefits is an exceptionally complex problem, particularly at high levels of aggregation, since both costs and benefits accrue based on a multitude of location-specific events. In addition, all of the methodological issues that are confronted by any long-term forecasting exercise are present. The forecasting problem may be more manageable at the local and regional scales at which most transportation decisions are usually made.

Assessment of confidence based on evidence
The authors have **high** confidence that climate impacts will be costly to the transportation sector, but are far less confident in assessing the exact magnitude of costs, based on the available evidence and their experience. The authors also have **high** confidence, based upon their experience, that costs may be significantly reduced by adaptation action, though, as noted, the magnitude of such potential reductions on a national scale would be difficult to determine.

Climate Change Impacts in the United States

CHAPTER 6
AGRICULTURE

Convening Lead Authors

Jerry Hatfield, U.S. Department of Agriculture

Gene Takle, Iowa State University

Lead Authors

Richard Grotjahn, University of California, Davis

Patrick Holden, Waterborne Environmental, Inc.

R. Cesar Izaurralde, Pacific Northwest National Laboratory

Terry Mader, University of Nebraska, Lincoln

Elizabeth Marshall, U.S. Department of Agriculture

Contributing Authors

Diana Liverman, University of Arizona

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INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

6 AGRICULTURE

Key Messages

1. **Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops and livestock.**
2. **Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.**
3. **Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.**
4. **The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.**
5. **Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.**
6. **Climate change effects on agriculture will have consequences for food security, both in the U.S. and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.**

The United States produces nearly $330 billion per year in agricultural commodities, with contributions from livestock accounting for roughly half of that value (Figure 6.1).[1] Production of all commodities will be vulnerable to direct impacts (from changes in crop and livestock development and yield due to changing climate conditions and extreme weather events) and indirect impacts (through increasing pressures from pests and pathogens that will benefit from a changing climate). The agricultural sector continually adapts to climate change through changes in crop rotations, planting times, genetic selection, fertilizer management, pest management, water management, and shifts in areas of crop production. These have proven to be effective strategies to allow previous agricultural production to increase, as evidenced by the continued growth in production and efficiency across the United States.

Climate change poses a major challenge to U.S. agriculture because of the critical dependence of the agricultural system on climate and because of the complex role agriculture plays in rural and national social and economic systems (Figure 6.2). Climate change has the potential to both positively and negatively affect the location, timing, and productivity of crop, livestock, and fishery systems at local, national, and global scales. It will also alter the stability of food supplies and create new food security challenges for the United States as the world seeks to feed nine billion people by 2050. U.S. agriculture exists as part of the global economy and agricultural exports have outpaced imports as part of the overall balance of trade. However, climate change will affect the quantity of produce available for export and import as well as prices (Figure 6.3).

The cumulative impacts of climate change will ultimately depend on changing global market conditions as well as responses to local climate stressors, including farmers adjusting planting patterns in response to altered crop yields and crop species, seed producers investing in drought-tolerant varieties, and nations restricting trade to protect food security. Adaptive actions in the areas of consumption, production, education, and research involve seizing opportunities to avoid economic damages and decline in food quality, minimize threats posed by climate stress, and in some cases increase profitability.

Key Message 1: Increasing Impacts on Agriculture

Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops and livestock.

Impacts on Crop Production

Producers have many available strategies for adapting to the average temperature and precipitation changes projected (Ch. 2: Our Changing Climate)[2] for the next 25 years. These strategies include continued technological advancements, expansion of irrigated acreage, regional shifts in crop acreage and crop species, other adjustments in inputs and outputs, and changes in livestock management practices in response to changing climate patterns.[3,4] However, crop production projections often fail to consider the indirect impacts from weeds, insects, and diseases that accompany changes in both average trends and extreme events, which can increase losses significantly.[2,5] By mid-century, when temperature increases are projected to be between 1.8°F and 5.4°F and precipitation extremes are further intensified, yields of major U.S. crops and farm profits are expected to decline.[6,7] There have already been detectable impacts on production due to increasing temperatures.[8] Over time, climate change is expected to increase the annual variation in crop and livestock production because of its effects on weather patterns and because of increases in some types of extreme weather events.[9,10] Overall implications for production are for increased uncertainty in production totals, which affects both domestic and international markets and food prices. Recent analysis suggests that climate change has an outsized influence on year-to-year swings in corn prices in the United States.[11]

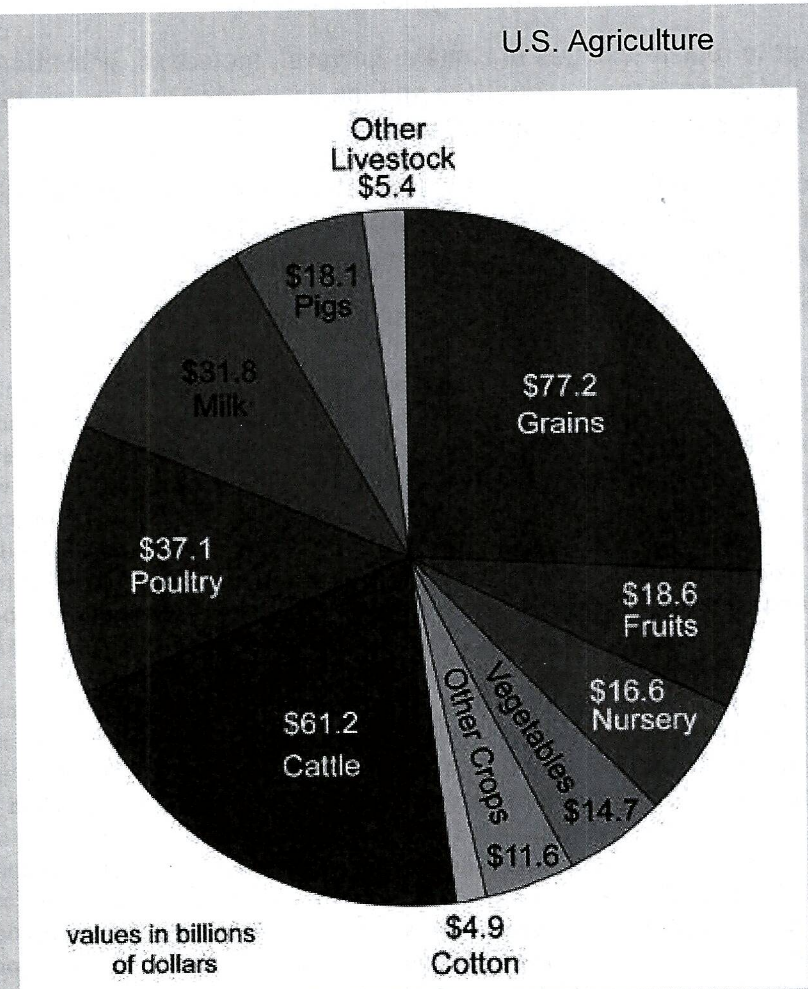

Figure 6.1. U.S. agriculture includes 300 different commodities with a nearly equal division between crop and livestock products. This chart shows a breakdown of the monetary value of U.S. agriculture products by category. (Data from 2007 Census of Agriculture, USDA National Agricultural Statistics Service 2008[12]).

Agricultural Distribution

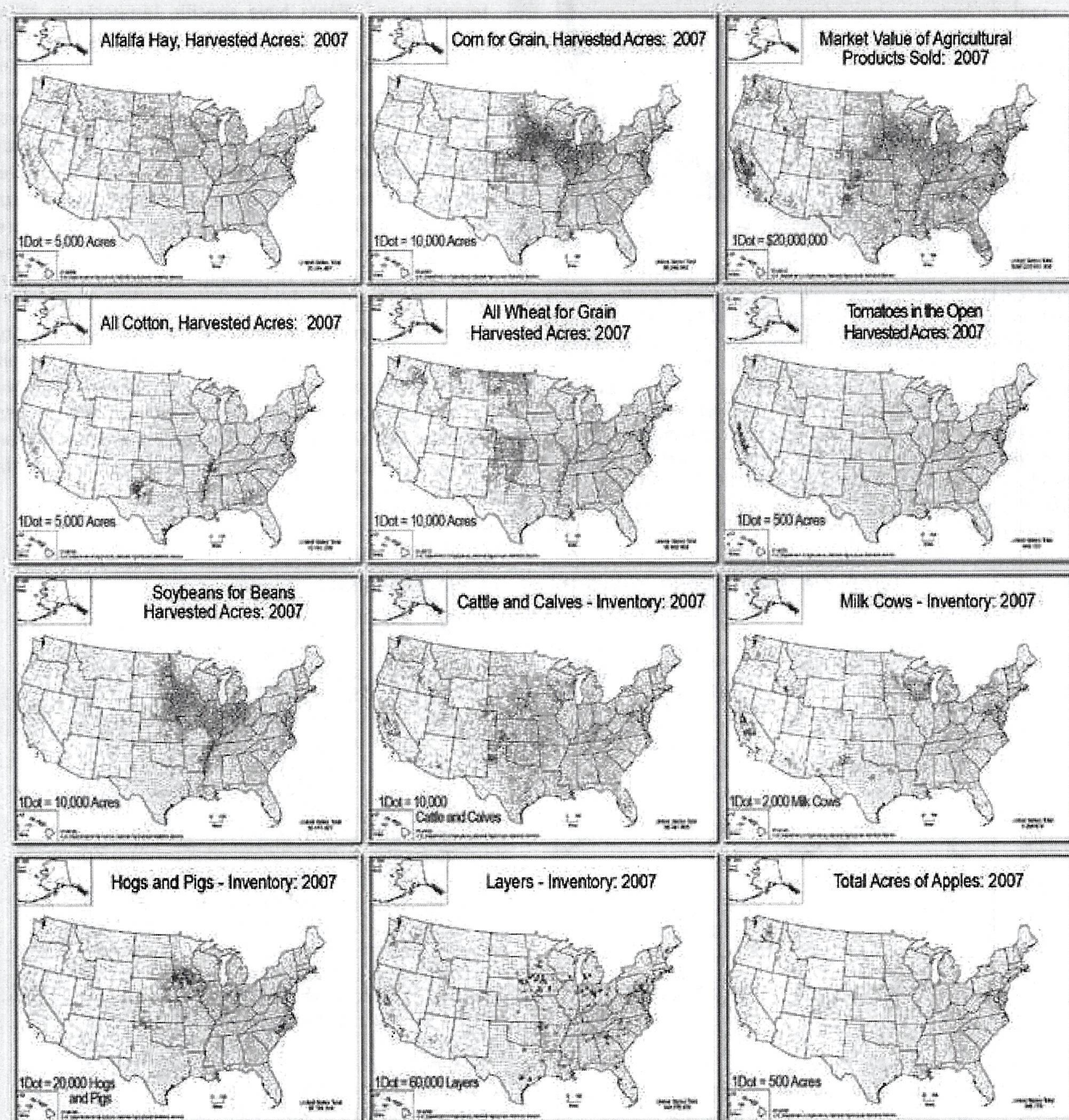

Figure 6.2. Agricultural activity is distributed across the U.S. with market value and crop types varying by region. In 2010, the total market value was nearly $330 billion. Wide variability in climate, commodities, and practices across the U.S. will likely result in differing responses, both in terms of yield and management. (Figure source: USDA National Agricultural Statistics Service 2008[13]).

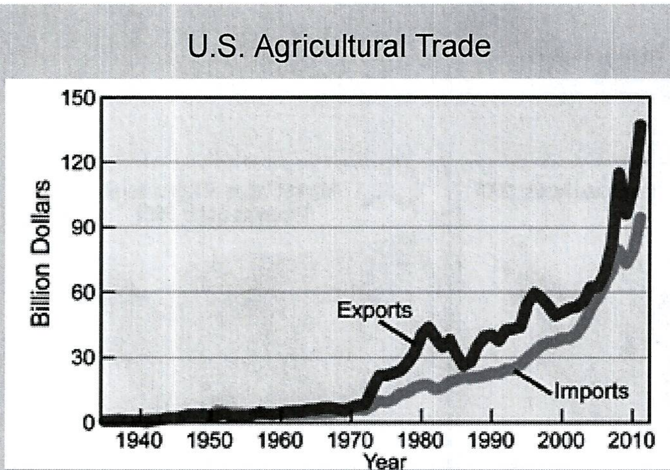

Figure 6.3. U.S. agriculture exists in the context of global markets. Climate is among the important factors that affect these markets. For example, the increase in U.S. food exports in the 1970s is attributed to a combination of rising incomes in other nations, changes in national currency values and farm policies, and poor harvests in many nations in which climate was a factor. Through seasonal weather impacts on harvests and other impacts, climate change will continue to be a factor in global markets. The graph shows U.S. imports and exports for 1935-2011 in adjusted dollar values. (Data from USDA Economic Research Service 2012[14]).

Plant response to climate change is dictated by complex interactions among carbon dioxide (CO_2), temperature, solar radiation, and precipitation. Each crop species has a temperature range for growth, along with an optimum temperature.[9] Plants have specific temperature tolerances, and can only be grown in areas where their temperature thresholds are not exceeded. As temperatures increase over this century, crop production areas may shift to follow the temperature range for optimal growth and yield of grain or fruit. Temperature effects on crop production are only one component; production over years in a given location is more affected by available soil water during the growing season than by temperature, and increased variation in seasonal precipitation, coupled with shifting patterns of precipitation within the season, will create more variation in soil water availability.[9,15] The use of a model to evaluate the effect of changing temperatures in the absence of changes in water availability reveals that crops in California's Central Valley will respond differently to projected temperature increases, as illustrated in Figure 6.4. This example demonstrates one of the methods available for studying the potential effects of climate change on agriculture.

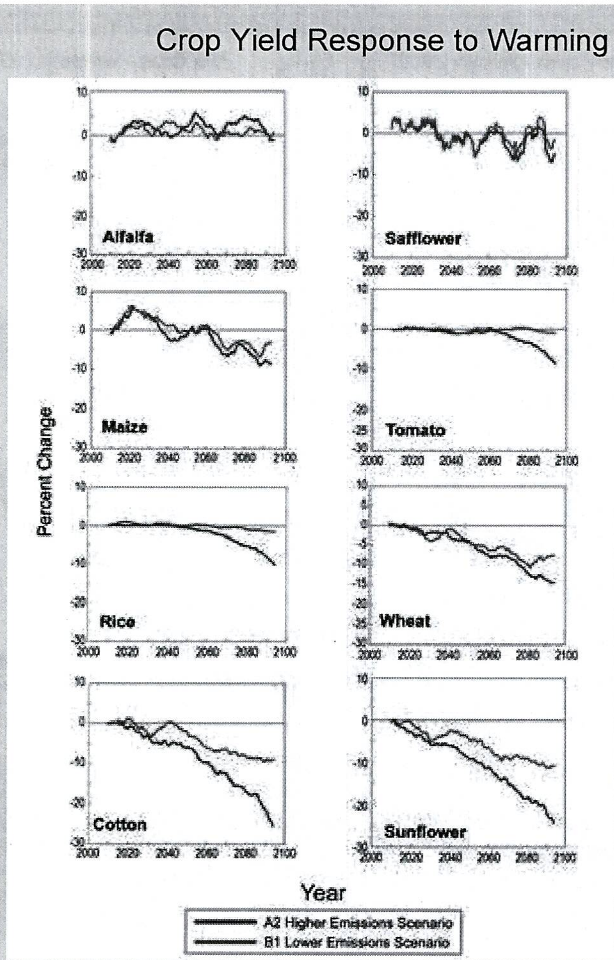

Figure 6.4. Changes in climate through this century will affect crops differently because individual species respond differently to warming. This figure is an example of the potential impacts on different crops within the same geographic region. Crop yield responses for eight crops in the Central Valley of California are projected under two emissions scenarios, one in which heat-trapping gas emissions are substantially reduced (B1) and another in which these emissions continue to grow (A2). This analysis assumes adequate water supplies (soil moisture) and nutrients are maintained while temperatures increase. The lines show five-year moving averages for the period from 2010 to 2094, with the yield changes shown as differences from the year 2009. Yield response varies among crops, with cotton, maize, wheat, and sunflower showing yield declines early in the period. Alfalfa and safflower showed no yield declines during the period. Rice and tomato do not show a yield response until the latter half of the period, with the higher emissions scenario resulting in a larger yield response. (Figure source: adapted from Lee et al. 2011[16]).

One critical period in which temperatures are a major factor is the pollination stage; pollen release is related to development of fruit, grain, or fiber. Exposure to high temperatures during this period can greatly reduce crop yields and increase the risk of total crop failure. Plants exposed to high nighttime temperatures during the grain, fiber, or fruit production period experience lower productivity and reduced quality.[15] These effects have already begun to occur; high nighttime temperatures affected corn yields in 2010 and 2012 across the Corn Belt. With the number of nights with hot temperatures projected to increase as much as 30%, yield reductions will become more prevalent.[9]

Projected Changes in Key Climate Variables Affecting Agricultural Productivity

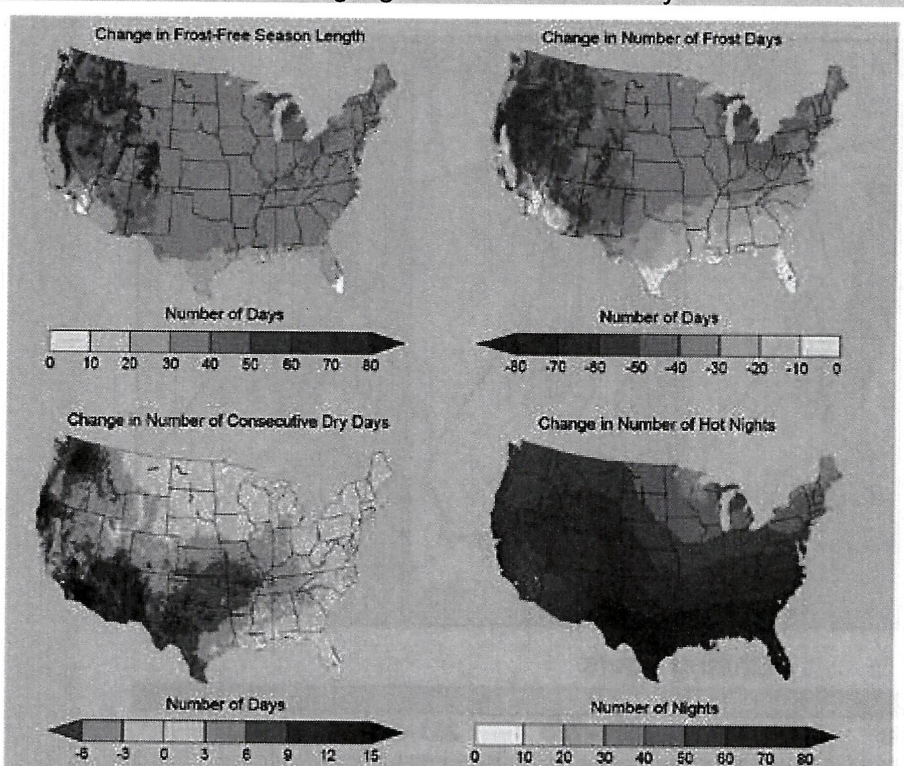

Figure 6.5. Many climate variables affect agriculture. The maps above show projected changes in key climate variables affecting agricultural productivity for the end of the century (2070-2099) compared to 1971-2000. Changes in climate parameters critical to agriculture show lengthening of the frost-free or growing season and reductions in the number of frost days (days with minimum temperatures below freezing), under an emissions scenario that assumes continued increases in heat-trapping gases (A2). Changes in these two variables are not identical, with the length of the growing season increasing across most of the United States and more variation in the change in the number of frost days. Warmer-season crops, such as melons, would grow better in warmer areas, while other crops, such as cereals, would grow more quickly, meaning less time for the grain itself to mature, reducing productivity.[9] Taking advantage of the increasing length of the growing season and changing planting dates could allow planting of more diverse crop rotations, which can be an effective adaptation strategy. On the frost-free map, white areas are projected to experience no freezes for 2070-2099, and gray areas are projected to experience more than 10 frost-free years during the same period. In the lower left graph, consecutive dry days are defined as the annual maximum number of consecutive days with less than 0.01 inches of precipitation. In the lower right graph, hot nights are defined as nights with a minimum temperature higher than 98% of the minimum temperatures between 1971 and 2000. (Figure source: NOAA NCDC / CICS-NC).

Temperature and precipitation changes will include an increase in both the number of consecutive dry days (days with less than 0.01 inches of precipitation) and the number of hot nights (Figure 6.5). The western and southern parts of the nation show the greatest projected increases in consecutive dry days, while the number of hot nights is projected to increase throughout the U.S. These increases in consecutive dry days and hot nights will have negative impacts on crop and animal production. High nighttime temperatures during the grain-filling period (the period between the fertilization of the ovule and the production of a mature seed in a plant) increase the rate of grain-filling and decrease the length of the grain-filling period, resulting in reduced grain yields. Exposure to multiple hot nights increases the degree of stress imposed on animals resulting in reduced rates of meat, milk, and egg production.[17]

Though changes in temperature, CO_2 concentrations, and solar radiation may benefit plant growth rates, this does not equate to increased production. Increasing temperatures cause cultivated plants to grow and mature more quickly. But because the soil may not be able to supply nutrients at required rates for faster growing plants, plants may be smaller, reducing grain, forage, fruit, or fiber production. Reduction in solar radiation in agricultural areas due to increased clouds and humidity in the last 60 years[18] is projected to continue[19] and may partially offset the acceleration of plant growth due to higher temperatures and CO_2 levels, depending on the crop. In vegetables, exposure to temperatures in the range of 1.8°F to 7.2°F above optimal moderately reduces yield, and exposure to temperatures more than 9°F to 12.6°F above optimal often leads to severe if not total production losses. Selective breeding and genetic engineering for both plants and animals provides some opportunity for adapting to climate change; however, development of new varieties in perennial specialty crops commonly requires 15 to 30 years or more, greatly limiting adaptive opportunity, unless varieties could be introduced from other areas. Additionally, perennial crops require time to reach their production potential.

A warmer climate will affect growing conditions, and the lack of cold temperatures may threaten perennial crop production (Figure 6.6). Perennial specialty crops have a winter chilling requirement (typically expressed as hours when temperatures are between 32°F and 50°F) ranging from 200 to 2,000 cumulative hours. Yields decline if the chilling requirement is not completely satisfied, because flower emergence and viability is low.[20] Projections show that chilling requirements for fruit and nut trees in California will not be met by the middle to the end of this century.[21] For most of the Northeast, a 400-hour chilling requirement for apples is projected to continue to be met during this century, but crops with prolonged chilling re-

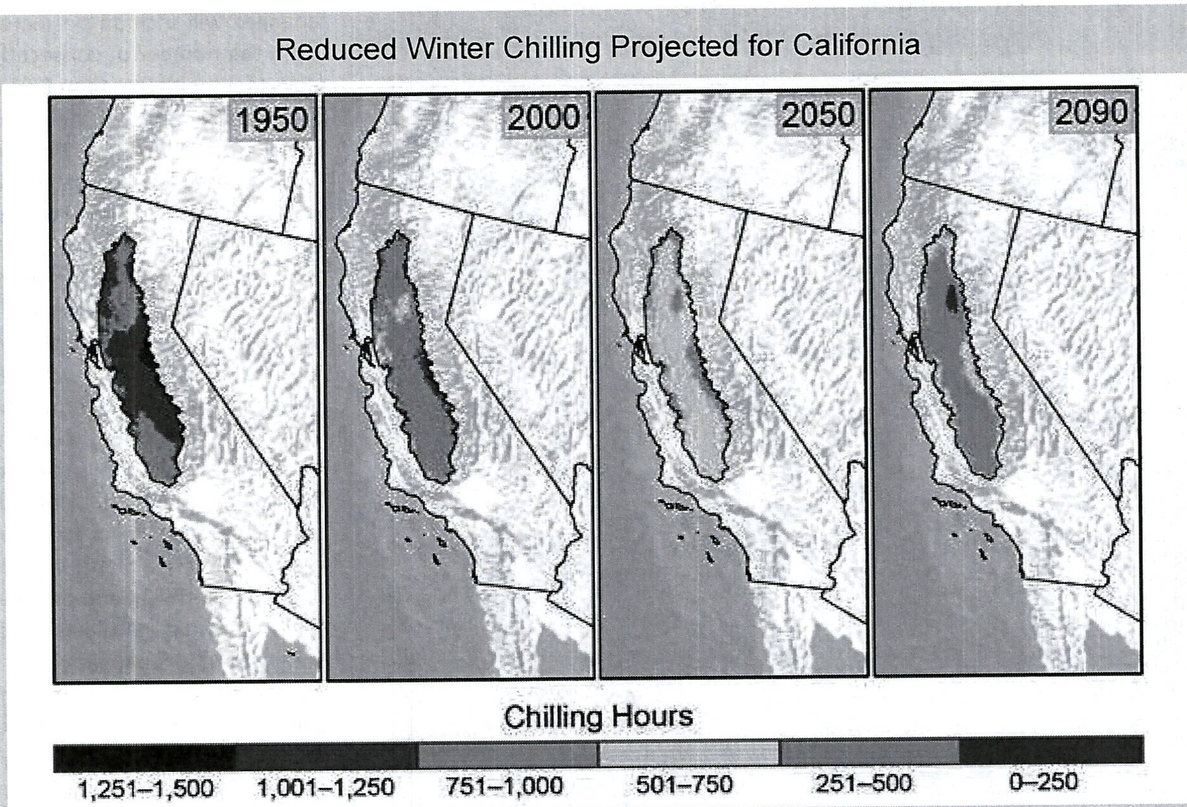

Figure 6.6. Many perennial plants (such as fruit trees and grape vines) require exposure to particular numbers of chilling hours (hours in which the temperatures are between 32°F and 50°F over the winter). This number varies among species, and many trees require chilling hours before flowering and fruit production can occur. With rising temperatures, chilling hours will be reduced. One example of this change is shown here for California's Central Valley, assuming that observed climate trends in that area continue through 2050 and 2090. Under such a scenario, a rapid decrease in the number of chilling hours is projected to occur.

By 2000, the number of chilling hours in some regions was 30% lower than in 1950. Based on the A2 emissions scenario that assumes continued increases in heat-trapping gases relative to 1950, the number of chilling hours is projected to decline by 30% to 60% by 2050 and by up to 80% by 2100. These are very conservative estimates of the reductions in chilling hours because climate models project not just simple continuations of observed trends (as assumed here), but temperature trends rising at an increasing rate.[21] To adapt to these kinds of changes, trees with a lower chilling requirement would have to be planted and reach productive age.

Various trees and grape vines differ in their chilling requirements, with grapes requiring 90 hours, peaches 225, apples 400, and cherries more than 1,000.[21] Increasing temperatures are likely to shift grape production for premium wines to different regions, but with a higher risk of extremely hot conditions that are detrimental to such varieties.[24] The area capable of consistently producing grapes required for the highest-quality wines is projected to decline by more than 50% by late this century.[24] (Figure source: adapted from Luedeling et al. 2009[21]).

quirements, such as plums and cherries (with chilling requirements of more than 700 hours), could be negatively affected, particularly in southern parts of the Northeast.[21,22] Warmer winters can lead to early bud burst or bloom of some perennial plants, resulting in frost damage when cold conditions occur in late spring[15], as was the case with cherries in Michigan in 2012, leading to an economic impact of $220 million (Andresen 2012, personal communication).[23]

The effects of elevated CO_2 on grain and fruit yield and quality are mixed. Some experiments have documented that elevated CO_2 concentrations can increase plant growth while increasing water use efficiency.[25,26] The magnitude of CO_2 growth stimulation in the absence of other stressors has been extensively analyzed for crop and tree species[27,28] and is relatively well understood; however, the interaction with changing temperature, ozone, and water and nutrient constraints creates uncertainty in the magnitude of these responses.[29] In plants such as soybean and alfalfa, elevated CO_2 has been associated with reduced nitrogen and protein content, causing a reduction in grain and forage quality and reducing the ability of pasture and rangeland to support grazing livestock.[30] The growth stimulation effect of increased atmospheric CO_2 concentrations has a disproportionately positive impact on several weed species. This effect will contribute to increased risk of crop loss due to weed pressure.[28,31]

The advantage of increased water-use efficiency due to elevated CO_2 in areas with limited soil water supply may be offset by other impacts from climate change. Rising average temperatures, for instance, will increase crop water demand, increasing the rate of water use by the crop. Rising temperatures coupled with more extreme wet and dry events, or seasonal shifts in precipitation, will affect both crop water demand and plant production.

Impacts on Animal Production from Temperature Extremes

Animal agriculture is a major component of the U.S. agriculture system (Figure 6.1). Changing climatic conditions affect animal agriculture in four primary ways: 1) feed-grain production, availability, and price; 2) pastures and forage crop production and quality; 3) animal health, growth, and reproduction; and 4) disease and pest distributions.[32] The optimal environmental conditions for livestock production include temperatures and other conditions for which animals do not need to significantly alter behavior or physiological functions to maintain relatively constant core body temperature.

Optimum animal core body temperature is often maintained within a 4°F to 5°F range, while deviations from this range can cause animals to become stressed. This can disrupt performance, production, and fertility, limiting the animals' ability to produce meat, milk, or eggs. In many species, deviations in core body temperature in excess of 4°F to 5°F cause significant reductions in productive performance, while deviations of 9°F to 12.6°F often result in death.[33] For cattle that breed during spring and summer, exposure to high temperatures reduces conception rates. Livestock and dairy production are more affected by the number of days of extreme heat than by increases in average temperature.[34] Elevated humidity exacerbates the impact of high temperatures on animal health and performance.

Animals respond to extreme temperature events (hot or cold) by altering their metabolic rates and behavior. Increases in extreme temperature events may become more likely for animals, placing them under conditions where their efficiency in meat, milk, or egg production is affected. Projected increases in extreme heat events (Ch. 2: Our Changing Climate, Key Message 7) will further increase the stress on animals, leading to the potential for greater impacts on production.[34] Meat animals are managed for a high rate of weight gain (high metabolic rate), which increases their potential risk when exposed to high temperature conditions. Exposure to heat stress disrupts metabolic functions in animals and alters their internal temperature when exposure occurs. Exposure to high temperature events can be costly to producers, as was the case in 2011, when heat-related production losses exceeded $1 billion.[35]

Livestock production systems that provide partial or total shelter to reduce thermal environmental challenges can reduce the risk and vulnerability associated with extreme heat. In general, livestock such as poultry and swine are managed in housed systems where airflow can be controlled and housing temperature modified to minimize or buffer against adverse environmental conditions. However, management and energy costs associated with increased temperature regulation will increase for confined production enterprises and may require modification of shelter and increased water use for cooling.

Key Message 2: Weeds, Diseases, and Pests

Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.

Weeds, insects, and diseases already have large negative impacts on agricultural production, and climate change has the potential to increase these impacts. Current estimates of losses in global crop production show that weeds cause the largest losses (34%), followed by insects (18%), and diseases (16%).[36] Further increases in temperature and changes in precipitation patterns will induce new conditions that will affect insect populations, incidence of pathogens, and the geographic distribution of insects and diseases.[15,37] Increasing CO_2 boosts weed growth, adding to the potential for increased competition between crops and weeds.[38] Several weed species benefit more than crops from higher temperatures and CO_2 levels.[28,31]

One concern involves the northward spread of invasive weeds like privet and kudzu, which are already present in the southern states.[39] Changing climate and changing trade patterns are likely to increase both the risks posed by, and the sources of, invasive species.[40] Controlling weeds costs the U.S. more than $11 billion a year, with most of that spent on herbicides. Both herbicide use and costs are expected to increase as temperatures and CO_2 levels rise.[41] Also, the most widely used herbicide in the United States, glyphosate (also known as RoundUp™ and other brand names), loses its efficacy on weeds grown at CO_2 levels projected to occur in the coming decades.[42] Higher concentrations of the chemical and more frequent sprayings thus will be needed, increasing economic and environmental costs associated with chemical use.

Climate change effects on land-use patterns have the potential to create interactions among climate, diseases, and crops.[37,43] How climate change affects crop diseases depends upon the effect that a combination of climate changes has on both the host and the pathogen. One example of the complexity of the interactions among climate, host, and pathogen is aflatoxin (*Aspergillus flavus*). Temperature and moisture availability are crucial for the production of this toxin, and both pre-harvest and post-harvest conditions are critical in understanding the impacts of climate change. High temperatures and drought stress increase aflatoxin production and at the same time reduce the growth of host plants. The toxin's impacts are augmented by the presence of insects, creating a potential for climate-toxin-insect-plant interactions that further affect crop production.[44] Earlier spring and warmer winter conditions are also expected to increase the survival and proliferation of disease-causing agents and parasites.

Insects are directly affected by temperature and synchronize their development and reproduction with warm periods and are dormant during cold periods.[45] Higher winter temperatures increase insect populations due to overwinter survival and, coupled with higher summer temperatures, increase reproductive rates and allow for multiple generations each year.[46] An example of this has been observed in the European corn borer (*Ostrinia nubialis)* which produces one generation in the northern Corn Belt and two or more generations in the southern Corn Belt.[47] Changes in the number of reproductive generations coupled with the shift in ranges of insects will alter insect pressure in a given region.

Superimposed on these climate change related impacts on weed and insect proliferation will be ongoing land-use and land-cover changes (Ch. 13: Land Use & Land Cover Change). For example, northward movement of non-migratory butterflies in Europe and changes in the range of insects were associated with land-use patterns and climate change.[48]

Livestock production faces additional climate change related impacts that can affect disease prevalence and range. Regional warming and changes in rainfall distribution have the potential to change the distributions of diseases that are sensitive to temperature and moisture, such as anthrax, blackleg, and hemorrhagic septicemia, and lead to increased incidence of ketosis, mastitis, and lameness in dairy cows.[33,49]

These observations illustrate some of the interactions among climate change, land-use patterns, and insect populations. Weeds, insects, and diseases thus cause a range of direct and indirect effects on plants and animals from climate change, although there are no simple models to predict the potential interactions. Given the economic impact of these pests and the potential implications for food security, research is critical to further understand these dynamics.

Key Message 3: Extreme Precipitation and Soil Erosion

Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.

Several processes act to degrade soils, including erosion, compaction, acidification, salinization, toxification, and net loss of organic matter (Ch. 15: Biogeochemical Cycles). Several of these processes, particularly erosion, will be directly affected by climate change. Rainfall's erosive power is expected to increase as a result of increases in rainfall amount in northern portions of the United States (see Ch. 2: Our Changing Climate), accompanied by further increases in precipitation intensity.[50] Projected increases in rainfall intensity that include more extreme events will increase soil erosion in the absence of conservation practices.[51,52]

Soil and water are essential resources for agricultural production, and both are subject to new conditions as climate changes. Precipitation and temperature affect the *potential* amount of water available, but the *actual* amount of available water also depends on soil type, soil water holding capacity, and the rate at which water filters through the soil (Figure 6.7 and 6.8). Such soil characteristics, however, are sensitive to changing climate conditions; changes in soil carbon content and soil loss will be affected by direct climate effects through changes in soil temperature, soil water availability, and the amount of organic matter input from plants.[53]

It is All About the Water!

Soil is a critical component of agricultural systems, and the changing climate affects the amount, distribution, and intensity of precipitation. Soil erosion occurs when the rate of precipitation exceeds the ability of the soil to maintain an adequate infiltration rate. When this occurs, runoff from fields moves water and soil from the field into nearby water bodies.

Figure 6.7

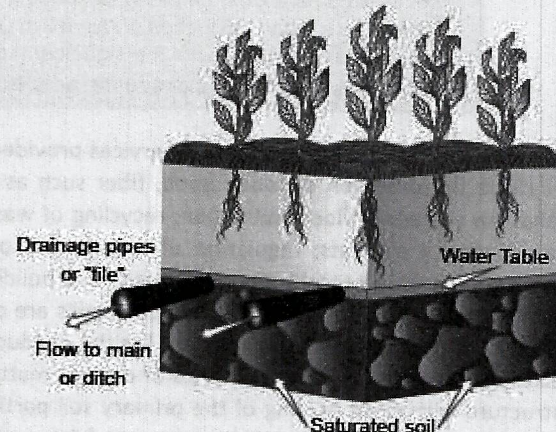

Figure 6.8

Water and soil that are lost from the field are no longer available to support crop growth. The increasing intensity of storms and the shifting of rainfall patterns toward more spring precipitation in the Midwest may lead to more scenes similar to this one (Figure 6.7). An analysis of the rainfall patterns across Iowa has shown there has not been an increase in total annual precipitation; however, there has been a large increase in the number of days with heavy rainfall (Figure 6.9). The increase in spring precipitation is evidenced by a decrease of three days in the number of workable days in the April to May period during 2001 through 2011 in Iowa compared to the period 1980-2000.[15] To offset this increased precipitation, producers have been installing subsurface drainage to remove more water from the fields at a cost of $500 per acre (Figure 6.8). These are elaborate systems designed to move water from the landscape to allow agricultural operations to occur in the spring. Water erosion and runoff is only one portion of the spectrum of extreme precipitation. Wind erosion could increase in areas with persistent drought because of the reduction in vegetative cover. (Photo credit (left): USDA Natural Resources Conservation Service; Figure source (right): NOAA NCDC / CICS-NC).

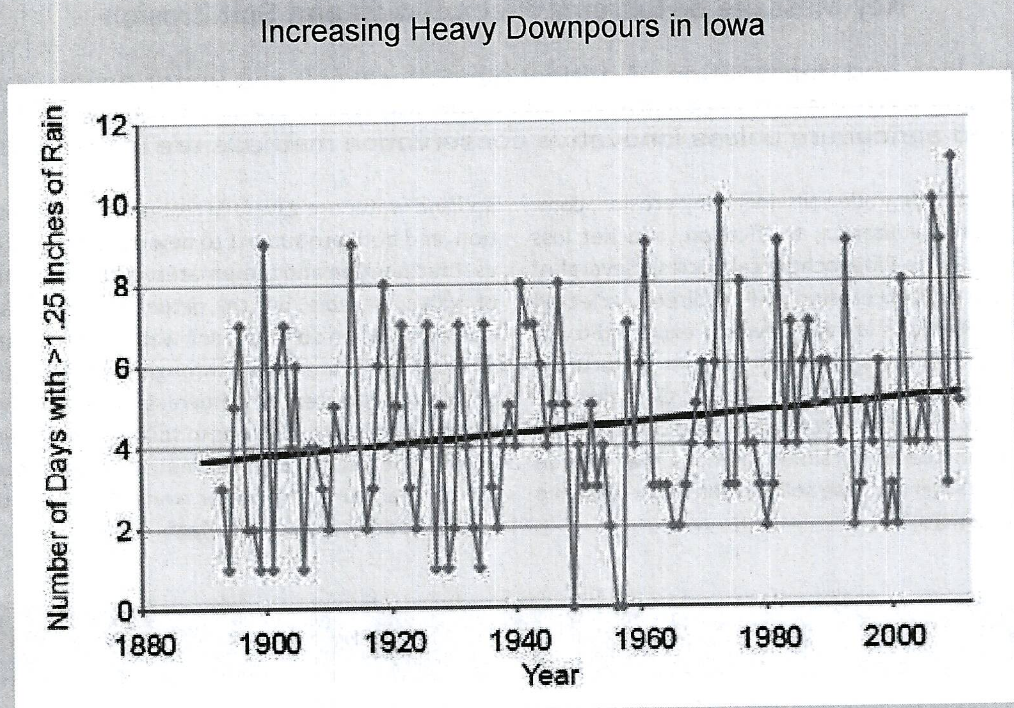

Figure 6.9. Iowa is the nation's top corn and soybean producing state. These crops are planted in the spring. Heavy rain can delay planting and create problems in obtaining a good stand of plants, both of which can reduce crop productivity. In Iowa soils with even modest slopes, rainfall of more than 1.25 inches in a single day leads to runoff that causes soil erosion and loss of nutrients and, under some circumstances, can lead to flooding. The figure shows the number of days per year during which more than 1.25 inches of rain fell in Des Moines, Iowa. Recent frequent occurrences of such events are consistent with the significant upward trend of heavy precipitation events documented in the Midwest.[51,55] (Figure source: adapted from Takle 2011[56]).

A few of the many important ecosystem services provided by soils include the provision of food, wood, fiber such as cotton, and raw materials; flood mitigation; recycling of wastes; biological control of pests; regulation of carbon and other heat-trapping gases; physical support for roads and buildings; and cultural and aesthetic values.[54] Productive soils are characterized by levels of nutrients necessary for the production of healthy plants, moderately high levels of organic matter, a soil structure with good binding of the primary soil particles, moderate pH levels, thickness sufficient to store adequate water for plants, a healthy microbial community, and the absence of elements or compounds in concentrations that are toxic for plant, animal, and microbial life.

Changes in production practices can have more effect than climate change on soil erosion; however, changes in climate will exacerbate the effects of management practices that do not protect the soil surface from the forces of rainfall. Erosion is managed through maintenance of cover on the soil surface to reduce the effect of rainfall intensity. Studies have shown that a reduction in projected crop biomass (and hence the amount of crop residue that remains on the surface over the winter) will increase soil loss.[57,58] Expected increases in soil erosion under climate change also will lead to increased off-site, non-point-source pollution. Soil conservation practices will therefore be an important element of agricultural adaptation to climate change.[59]

Rising temperatures and CO_2 and shifting precipitation patterns will alter crop-water requirements, crop-water availability, crop productivity, and costs of water access across the agricultural landscape. Higher temperatures are projected to increase both evaporative losses from land and water surfaces and transpiration losses (through plant leaves) from non-crop land cover, potentially reducing annual runoff and streamflow for a given amount of precipitation. The resulting shift in crop health will, in turn, drive changes in cropland allocations and production systems.

Key Message 4: Heat and Drought Damage

The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.

Climate change projections suggest an increase in extreme heat, severe drought, and heavy precipitation.[60] Extreme climate conditions, such as dry spells, sustained droughts, and heat waves all have large effects on crops and livestock. The timing of extreme events will be critical because they may occur at sensitive stages in the life cycles of agricultural crops or reproductive stages for animals, diseases, and insects. Extreme events at vulnerable times could result in major impacts on growth or productivity, such as hot-temperature extreme weather events on corn during pollination. By the end of this century, the occurrence of very hot nights and the duration of periods lacking agriculturally significant rainfall are projected to increase. Recent studies suggest that increased average temperatures and drier conditions will amplify future drought severity and temperature extremes.[6,61,62] Crops and livestock will be at increased risk of exposure to extreme heat events. Projected increases in the occurrence of extreme heat events will expose production systems to conditions exceeding maximum thresholds for given species more frequently. Goats, sheep, beef cattle, and dairy cattle are the livestock species most widely managed in extensive outdoor facilities. Within physiological limits, animals can adapt to and cope with gradual thermal changes, though shifts in thermoregulation may result in a loss of productivity.[63] Lack of prior conditioning to rapidly changing or adverse weather events, however, often results in catastrophic deaths in domestic livestock and losses of productivity in surviving animals.[34]

Key Message 5: Rate of Adaptation

Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.

There is emerging evidence about the economic impacts of climate change on agriculture and the potential for adaptive strategies.[64] Much of the economic literature suggests that in the short term, producers will continue to adapt to weather changes and shocks as they always have, with changes in the timing of field operations, shifts in crops grown, and changing tillage or irrigation practices.[64] In the longer term, however, existing adaptive technologies will likely not be sufficient to buffer the impacts of climate change without significant impacts to domestic producers, consumers, or both. New strategies for building long-term resilience include both new technologies and new institutions to facilitate appropriate, informed producer response to a changing climate. Furthermore, there are both public and private costs to adjusting agricultural production and infrastructure in a manner that enables adaptation.[2] Limits to public investment and constraints on private investment could slow the speed of adaptation, yet potential constraints and limits are not well understood or integrated into economic impact assessments. The economic implications of changing biotic pressures on crops and livestock, and on the agricultural system as a whole, are not well understood, either in the short or long term.[15] Adaptation may also be limited by the availability of inputs (such as land or water), changing prices of other inputs with climate change (such as energy and fertilizer), and by the environmental implications of intensifying or expanding agricultural production.

Adaptation strategies currently used by U.S. farmers to cope with weather and climate changes include changing selection of crops, the timing of field operations, and the increasing use of pesticides to control increased pressure from pests. Technological innovation increases the tools available to farmers in some agricultural sectors. Diversifying crop rotations, integrating livestock with crop production systems, improving soil quality, minimizing off-farm flows of nutrients and pesticides, and other practices typically associated with sustainable agriculture also increase the resiliency of the agricultural system to productivity impacts of climate change.[65,66] In the Midwest, there have been shifts in the distribution of crops and land-use change partially related to the increased demand for biofuels[67] (see also Ch. 10: Energy, Water, and Land for more discussion on biofuels). In California's Central Valley, an adaptation plan consisting of integrated changes in crop mix, irrigation methods, fertilization practices, tillage practices, and land management may be an effective approach to managing climate risk.[68] These practices are available to all agricultural regions of the United States as potential adaptation strategies.

Based on projected climate change impacts in some areas of the United States, agricultural systems may have to undergo more transformative changes to remain productive and profitable in the long term.[65] Research and development of sustainable natural resource management strategies inform adaptation options for U.S. agriculture. More transformative adaptive strategies, such as conversion to integrated crop-livestock farming, may reduce environmental impacts, improve profitability and sustainability, and enhance ecological resilience to climate change in U.S. livestock production systems.[69]

There are many possible responses to climate change that will allow agriculture to adapt over the next 25 years; however, potential constraints to adaptation must be recognized and addressed. In addition to regional constraints on the availability of critical basic resources such as land and water, there are potential constraints related to farm financing and credit availability in the U.S. and elsewhere. Research suggests that such constraints may be significant, especially for small family farms with little available capital.[22,64,70] In addition to the technical and financial ability to adapt to changing average conditions, farm resilience to climate change is also a function of financial capacity to withstand increasing variability in production and returns, including catastrophic loss.[71] As climate change intensifies, "climate risk" from more frequent and intense weather events will add to the existing risks commonly managed by producers, such as those related to production, marketing, finances, regulation, and personal health and safety factors.[72] The role of innovative management techniques and government policies as well as research and insurance programs will have a substantial impact on the degree to which the agricultural sector increases climate resilience in the longer term.

Modern agriculture has continually adapted to many changing factors, both within and outside of agricultural systems. As a result, agriculture in the U.S. over the past century has steadily increased productivity and integration into world markets. Although agriculture has a long history of successful adaptation to climate variability, the accelerating pace of climate change and the intensity of projected climate change represent new and unprecedented challenges to the sustainability of U.S. agriculture. In the short term, existing and evolving adaptation strategies will provide substantial adaptive capacity, protecting domestic producers and consumers from many of the impacts of climate change, except possibly the occurrence of protracted extreme events. In the longer term, adaptation will be more difficult and costly because the physiological limits of plant and animal species will be exceeded more frequently, and the productivity of crop and livestock systems will become more variable.

Key Message 6: Food Security

Climate change effects on agriculture will have consequences for food security, both in the U.S. and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.

Climate change impacts on agriculture will have consequences for food security both in the U.S. and globally. Food security includes four components: availability, stability, access, and utilization of food.[73] Following this definition, in 2011, 14.9% of U.S. households did not have secure food supplies at some point during the year, with 5.7% of U.S. households experiencing very low food security.[74] Food security is affected by a variety of supply and demand-side pressures, including economic conditions, globalization of markets, safety and quality of food, land-use change, demographic change, and disease and poverty.[75,76]

Within the complex global food system, climate change is expected to affect food security in multiple ways.[77] In addition to altering agricultural yields, projected rising temperatures, changing weather patterns, and increases in frequency of extreme weather events will affect distribution of food- and water-borne diseases as well as food trade and distribution.[78] This means that U.S. food security depends not only on how climate change affects crop yields at the local and national level, but also on how climate change and changes in extreme events affect food processing, storage, transportation, and retailing, through the disruption of transportation as well as the ability of consumers to purchase food. And because about one-fifth of all food consumed in the U.S. is imported, our food supply and security can be significantly affected by climate variations and changes in other parts of the world. The import share has increased over the last two decades, and the U.S. now imports 13% of grains, 20% of vegetables (much higher in winter months), almost 40% of fruit, 85% of fish and shellfish, and almost all tropical products such as coffee, tea, and bananas (Figure 6.3).[79] Climate extremes in regions that supply these products to the U.S. can cause sharp reductions in production and increases in prices.

In an increasingly globalized food system with volatile food prices, climate events abroad may affect food security in the U.S. while climate events in the U.S. may affect food security globally. The globalized food system can buffer the local impacts of weather events on food security, but can also increase the global vulnerability of food security by transmitting price shocks globally.[80]

The connections of U.S. agriculture and food security to global conditions are clearly illustrated by the recent food price spikes in 2008 and 2011 that highlighted the complex connections of climate, land use, demand, and markets. The doubling of the United Nations Food and Agriculture Organization (FAO) food price index over just a few months in 2010 was caused partly by weather conditions in food-exporting countries such as Australia, Russia, and the United States, but was also driven by increased demand for meat and dairy in Asia, increased energy costs and demand for biofuels, and commodity speculation in financial markets.[81]

Adapting food systems to limit the impacts of climate extremes and changes involves strategies to maintain supply and manage demand as well as an understanding of how other regions of the world adapt their food systems in ways that might affect U.S. agricultural competitiveness, imports, and prices. Supplies can be maintained through adaptations such as reducing waste in the food system, making food distribution systems more resilient to climate risks, protecting food quality and safety in higher temperatures, and policies to ensure food access for disadvantaged populations and during extreme events (Ch. 28 Adaptation).[15,75,76,80,81]

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SUPPLEMENTAL MATERIAL

TRACEABLE ACCOUNTS

Process for Developing Key Messages

A central component of the process was the development of a foundational technical input report (TIR), "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation".[15] A public session conducted as part of the Tri-Societies (https://www.acsmeetings.org/home) meeting held in San Antonio, Texas, on Oct. 16-19, 2011, provided input to this report.

The report team engaged in multiple technical discussions via teleconference, which included careful review of the foundational TIR[15] and of approximately 56 additional technical inputs provided by the public, as well as other published literature and professional judgment. Discussions were followed by expert deliberation of draft key messages by the authors and targeted consultation with additional experts by the lead author of each message.

Key message #1 Traceable Account

Climate disruptions to agricultural production have increased in the past 40 years and are projected to increase over the next 25 years. By mid-century and beyond, these impacts will be increasingly negative on most crops and livestock.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation.[15] Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Evidence that climate change has had and will have impacts on crops and livestock is based on numerous studies and is incontrovertible.[6,7,8]

The literature strongly suggests that carbon dioxide, temperature, and precipitation affect livestock and crop production. Plants have an optimal temperature range to which they are adapted, and regional crop growth will be affected by shifts in that region's temperatures relative to each crop's optimal range. Large shifts in temperature can significantly affect seasonal biomass growth, while changes in the timing and intensity of extreme temperature effects are expected to negatively affect crop development during critical windows such as pollination. Crop production will also be affected by changing patterns of seasonal precipitation; extreme precipitation events are expected to occur more frequently and negatively affect production levels. Livestock production is directly affected by extreme temperature as the animal makes metabolic adjustments to cope with heat stress.[15] Further, production costs in confined systems markedly increase when climate regulation is necessary.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture,[82] which informed the 2009 National Climate Assessment.[83]

There is insufficient understanding of the effects on crop production of rising carbon dioxide, changing temperatures and more variable precipitation patterns.[9] The combined effects on plant water demand and soil water availability will be critical to understanding regional crop response. The role of increasing minimum temperatures on water demand and growth and senescence rates of plants is an important factor. There is insufficient understanding of how prolonged exposure of livestock to high or cold temperatures affects metabolism and reproductive variables.[26] For grazing animals, climate conditions during the growing season are critical in determining feed availability and quality on rangeland and pastureland.[69]

The information base can be enhanced by evaluating crop growth and livestock production models. This evaluation would further the understanding of the interactions of climate variables and the biological system. Better understanding of projected changes in precipitation will narrow uncertainty about future yield reductions.[9,69]

Assessment of confidence based on evidence

There are a range of controlled environment and field studies that provide the evidence for these findings. Confidence in this key message is therefore judged to be **high**.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key message #2 Traceable Account

Many agricultural regions will experience declines in crop and livestock production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation".[15] Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications describe the direct effects of climate on the ecological systems within which crop and livestock operations occur. Many weeds respond more strongly to CO_2 than do crops, and it is believed that the range of many diseases and pests (for both crop and livestock) will expand under warming conditions.[28,31,40] Pests may have increased overwinter survival and fit more generations into a single year, which may also facilitate faster evolution of pesticide resistance. Changing patterns of pressure from weeds, other pests, and disease can affect crop and livestock production in ways that may be costly or challenging to address.[9,15]

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture,[82] which informed the 2009 National Climate Assessment.[83]

In addition to extant species already in the U.S., exotic weeds, diseases, and pests have particular significance in that: 1) they can often be invasive (that is, arrive without normal biological/ecological controls) and highly damaging; 2) with increasing international trade, there are numerous high-threat, high-impact species that will arrive on commodities from areas where some species even now are barely known to modern science, but which have the potential to emerge under a changed climate regime to pose significant risk of establishment in the U.S. and economic loss; and 3) can take advantage of "disturbances," where climate variability acts as an additional ecological disturbance. Improved models and observational data related to how many agricultural regions will experience declines in animal and plant production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses will need to be developed.

A key issue is the extent of the interaction between components of the natural biological system (for example, pests) and the economic biological system (for example, crop or animal). For insects, increased populations are a factor; however, their effect on the plant may be dependent upon the phenological stage of the plant when the insect is at specific phenological stages.[15]

To enhance our understanding of these issues will require a concerted effort to begin to quantify the interactions of pests and the economic crop or livestock system and how each system and their interactions are affected by climate.[15]

Assessment of confidence based on evidence

The scientific literature is beginning to emerge; however, there are still some unknowns about the effects of biotic stresses, and there may well be emergent "surprises" resulting from departures from past ecological equilibria. Confidence is therefore judged to be **medium** that many agricultural regions will experience declines in animal and plant production from increased stress due to weeds, diseases, insect pests, and other climate change induced stresses.

Key message #3 Traceable Account

Current loss and degradation of critical agricultural soil and water assets due to increasing extremes in precipitation will continue to challenge both rainfed and irrigated agriculture unless innovative conservation methods are implemented.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation."[15] Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Soil erosion is affected by rainfall intensity and there is evidence of increasing intensity in rainfall events even where the annual mean is reduced.[53] Unprotected soil surfaces will have increased erosion and require more intense conservation practices.[58,59] Shifts in seasonality and type of precipitation will affect both timing and impact of water availability for both rainfed and irrigated agriculture. Evidence is strong that in the future there will be more precipitation globally, and that rain events will be more intense, even if separated by longer periods without rain.[6]

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture,[82] which informed the 2009 National Climate Assessment.[83] Both rainfed and irrigated agriculture will increasingly be challenged, based on improved models and observational data related to the effects of increasing precipitation extremes on loss and degradation of critical agricultural soil and water assets.[51,52]

Precipitation shifts are the most difficult to project, and uncertainty in regional projections increases with time into the future.[61] To improve these projections will require enhanced understanding of shifts in timing, intensity, and magnitude of precipitation events. In the northern U.S., more frequent and severe winter and spring storms are projected, while there is a projected reduction in precipitation in the Southwest (see Ch. 2: Our Changing Climate).

Assessment of confidence based on evidence

The precipitation forecasts are the limiting factor in these assessments; the evidence of the impact of precipitation extremes on soil water availability and soil erosion is well established. Confidence in this key message is therefore judged to be **high**.

KEY MESSAGE #4 TRACEABLE ACCOUNT

The rising incidence of weather extremes will have increasingly negative impacts on crop and livestock productivity because critical thresholds are already being exceeded.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Agriculture TIR, "Climate Change and Agriculture in the United States: An Assessment of Effects and Potential for Adaptation".[15] Additional Technical Input Reports (56) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Numerous peer-reviewed publications[6,61,62] provide evidence that the occurrence of extreme events is increasing, and exposure of plants or animals to temperatures and soil water conditions (drought, water-logging, flood) outside of the biological range for the given species will cause stress and reduce production.[6,61,62] The direct effects of an extreme event will depend upon the timing of the event relative to the growth stage of the biological system.

New information and remaining uncertainties

Important new evidence (cited above) confirmed many of the findings in the past Synthesis and Assessment Product on agriculture, [82] which informed the 2009 National Climate Assessment.[83]

One key area of uncertainty is the timing of extreme events during the phenological stage of the plant or the growth stage of the animal. For example, plants are more sensitive to extreme high temperatures during the pollination stage compared to vegetative growth stages.[9] A parallel example for animals is relatively strong sensitivity to high temperatures during the conception phase.[34] Milk and egg production are also vulnerable to temperature extremes. The effects of extreme combinations of weather variables must be considered, such as elevated humidity in concert with high temperatures.[34]

Other key uncertainties include inadequate precision in simulations of the timing of extreme events relative to short time periods of crop vulnerability, and temperatures close to key thresholds such as freezing.[22] The uncertainty is amplified by the rarity of extreme events; this rarity means there are infrequent opportunities to study the impact of extreme events. In general, a shift of the distribution of temperatures can increase the frequency of threshold exceedance.[15]

The information base can be enhanced by improving the forecast of extreme events, given that the effect of extreme events on plants or animals is known.[3,61]

Assessment of confidence based on evidence

There is **high** confidence in the effects of extreme temperature events on crops and livestock, and the agreement in the literature is good.

KEY MESSAGE #5 TRACEABLE ACCOUNT

Agriculture has been able to adapt to recent changes in climate; however, increased innovation will be needed to ensure the rate of adaptation of agriculture and the associated socioeconomic system can keep pace with climate change over the next 25 years.

Description of evidence base

There is emerging evidence about the economic impacts of climate change on agriculture and the potential for adaptive strategies.[64] In the case of crop production, much of the economic literature suggests that in the short term, producers will continue to adapt to weather changes and shocks as they always have, with changes in the timing of field operations, shifts in crops grown, and changing tillage or irrigation practices.[64] In the longer term, however, existing adaptive technologies will likely not be sufficient to buffer the impacts of climate change without significant impacts to domestic producers, consumers, or both.

New strategies for building long-term resilience include both new technologies and new institutions to facilitate appropriate, informed producer response to a changing climate. Furthermore, there are both public and private costs to adjusting agricultural production and infrastructure in a manner that enables adaptation.[2]

New information and remaining uncertainties

Limits to public investment and constraints on private investment could slow the speed of adaptation, yet potential constraints and limits are not well-understood or integrated into economic impact assessments. The economic implications of changing biotic pressures on crops and livestock, and on the agricultural system as a whole, are not well-understood, either in the short or long term.[15] Adaptation may also be limited by availability of inputs (such as land or water), changing prices of other inputs with climate change (such as energy and fertilizer), and by the environmental implications of intensifying or expanding agricultural production.

It is difficult to fully represent the complex interactions of the entire socio-ecological system within which agriculture operates, to assess the relative effectiveness and feasibility of adaptation strategies at various levels. Economic impact assessments require improved understanding of adaptation capacity and agricultural resilience at the system level, including the agri-ecosystem impacts related to diseases and pests. Economic impact assessments also require improved understanding of adaptation opportunities, economic resilience, and constraints to adaptation at the producer level.[2,64] The economic value of ecological services, such as pollination services, is particularly difficult to quantify and incorporate into economic impact efforts.[15]

Assessment of confidence based on evidence

Emerging evidence about adaptation of agricultural systems to changing climate is beginning to be developed. The complex interactions among all of the system components present a limitation to a complete understanding, but do provide a comprehensive framework for the assessment of agricultural responses to climate change. Given the overall and remaining uncertainty, there is **medium** confidence in this message.

KEY MESSAGE #6 TRACEABLE ACCOUNT

Climate change effects on agriculture will have consequences for food security, both in the U.S. and globally, through changes in crop yields and food prices and effects on food processing, storage, transportation, and retailing. Adaptation measures can help delay and reduce some of these impacts.

Description of evidence base

The relationships among agricultural productivity, climate change, and food security have been documented through ongoing investigations by the Food and Agriculture Organization,[81,84] as well as the U.S. Department of Agriculture,[85] and the National Research Council.[77] There are many factors that affect food security, and agricultural yields are only one of them. Climate change is also expected to affect distribution of food- and waterborne diseases, and food trade and distribution.[78]

New information and remaining uncertainties

The components of food security derive from the intersection of political, physical, economic, and social factors. In many ways the impact of climate change on crop yields is the least complex of the factors that affect the four components of food security (availability, stability, access, and utilization). As the globalized food system is subject to conflicting pressures across scales, one approach to reducing risk is a "cross-scale problem-driven" approach to food security.[76] This and other approaches to understanding and responding to the complexities of the global food system need additional research. Climate change will have a direct impact on crop and livestock production by increasing the variability in production levels from year to year, with varying effects across different regions. Climate change will also affect the distribution of food supplies as a result of disruptions in transportation routes. Addressing food security will require integration of multiple factors, including the direct and indirect impacts of climate change.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainty, there is **high** confidence that climate change impacts will have consequences for food security both in the U.S. and globally through changes in crop yields and food prices, and **very high** confidence that other related factors, including food processing, storage, transportation, and retailing will also be affected by climate change. There is **high** confidence that adaptation measures will help delay and reduce some of these impacts.

Climate Change Impacts in the United States

CHAPTER 7
FORESTS

Convening Lead Authors

Linda A. Joyce, U.S. Forest Service

Steven W. Running, University of Montana

Lead Authors

David D. Breshears, University of Arizona

Virginia H. Dale, Oak Ridge National Laboratory

Robert W. Malmsheimer, SUNY Environmental Science and Forestry

R. Neil Sampson, Vision Forestry, LLC

Brent Sohngen, Ohio State University

Christopher W. Woodall, U.S. Forest Service

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On the Web: http://nca2014.globalchange.gov/report/sectors/forests

INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

7 FORESTS

Key Messages

1. **Climate change is increasing the vulnerability of many forests to ecosystem changes and tree mortality through fire, insect infestations, drought, and disease outbreaks.**
2. **U.S. forests and associated wood products currently absorb and store the equivalent of about 16% of all carbon dioxide (CO_2) emitted by fossil fuel burning in the U.S. each year. Climate change, combined with current societal trends in land use and forest management, is projected to reduce this rate of forest CO_2 uptake.**
3. **Bioenergy could emerge as a new market for wood and could aid in the restoration of forests killed by drought, insects, and fire.**
4. **Forest management responses to climate change will be influenced by the changing nature of private forestland ownership, globalization of forestry markets, emerging markets for bioenergy, and U.S. climate change policy.**

Forests occur within urban areas, at the interface between urban and rural areas (wildland-urban interface), and in rural areas. Urban forests contribute to clean air, cooling buildings, aesthetics, and recreation in parks. Development in the wildland-urban interface is increasing because of the appeal of owning homes near or in the woods. In rural areas, market factors drive land uses among commercial forestry and land uses such as agriculture. Across this spectrum, forests provide recreational opportunities, cultural resources, and social values such as aesthetics.[1]

Economic factors have historically influenced both the overall area and use of private forestland. Private entities (such as corporations, family forest owners, and tribes) own 56% of the forestlands in the United States. The remaining 44% of forests are on public lands: federal (33%), state (9%), and county and municipal government (2%).[2] Market factors can influence management objectives for public lands, but societal values also influence objectives by identifying benefits such as environmental services not ordinarily provided through markets, like watershed protection and wildlife habitat. Different challenges and opportunities exist for public and for private forest management decisions, especially when climate-related issues are considered on a national scale. For example, public forests typically carry higher levels of forest biomass, are more remote, and tend not to be as intensively managed as private forestlands.[1]

Forests provide opportunities to reduce future climate change by capturing and storing carbon, as well as by providing resources for bioenergy production (the use of forest-derived plant-based materials for energy production). The total amount of carbon stored in U.S. forest ecosystems and wood products (such as lumber and pulpwood) equals roughly 25 years of U.S. heat-trapping gas emissions at current rates of emission, providing an important national "sink" that could grow or shrink depending on the extent of climate change, forest management practices, policy decisions, and other factors.[3,4] For example, in 2011, U.S. forest ecosystems and the associated wood products industry captured and stored roughly 16% of all carbon dioxide emitted by fossil fuel burning in the United States.[3]

Management choices for public, private, and tribal forests all involve similar issues. For example, increases in wildfire, disease, drought, and extreme events are projected for some regions (see also Ch. 16: Northeast; Ch. 20: Southwest; Ch. 21: Northwest, Key Message 3; and Ch. 22: Alaska). At the same time, there is growing awareness that forests may play an expanded role in carbon management. Urban expansion fragments forests and may limit forest management options. Addressing climate change effects on forestlands requires considering the interactions among land-use practices, energy options, and climate change.[5]

Key Message 1: Increasing Forest Disturbances

Climate change is increasing the vulnerability of many forests to ecosystem changes and tree mortality through fire, insect infestations, drought, and disease outbreaks.

Insect and pathogen outbreaks, invasive species, wildfires, and extreme events such as droughts, high winds, ice storms, hurricanes, and landslides induced by storms[8] are all disturbances that affect U.S. forests and their management (Figure 7.1). These disturbances are part of forest dynamics, are often interrelated, and can be amplified by underlying trends – for example, decades of rising average temperatures can increase damage to forests when a drought occurs.[9] Disturbances that affect large portions of forest ecosystems occur relatively infrequently and in response to climate extremes. Changes in climate in the absence of extreme climate events (and the forest disturbances they trigger) may result in increased forest productivity, but extreme climate events can potentially overturn such patterns.[10]

Factors affecting tree death – such as drought, physiological water stress, higher temperatures, and/or pests and pathogens – are often interrelated, which means that isolating a single cause of mortality is rare.[11,12,13] However, in western forests there have been recent large-scale die-off events due to one or more of these factors,[14,15,16] and rates of tree mortality are well correlated with both rising temperatures and associated increases in evaporative water demand.[17] In eastern forests, tree mortality at large spatial scales was more sensitive

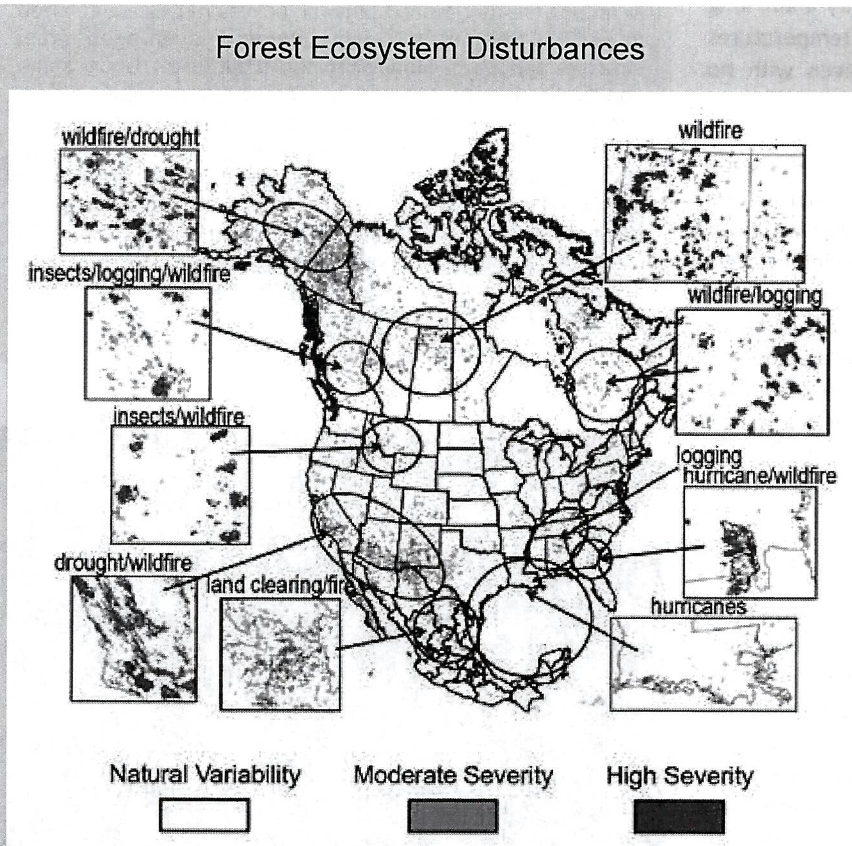
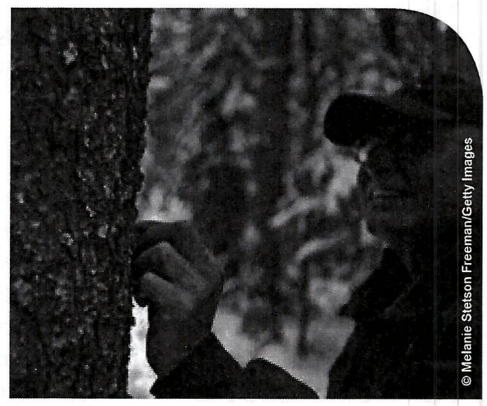


Figure 7.1. An example of the variability and distribution of major ecosystem disturbance types in North America, compiled from 2005 to 2009. Forest disturbance varies by topography, vegetation, weather patterns, climate gradients, and proximity to human settlement. Severity is mapped as a percent change in a satellite-derived Disturbance Index. White areas represent natural annual variability, orange represents moderate severity, and red represents high severity.[6] Fire dominates much of the western forest ecosystems, and storms affect the Gulf Coast. Insect damage is widespread but currently concentrated in western regions, and timber harvest is predominant in the Southeast. (Figure source: modified from Goetz et al. 2012;[7] Copyright 2012 American Geophysical Union).



A Montana saw mill owner inspects a lodgepole pine covered in pitch tubes that show the tree trying, unsuccessfully, to defend itself against the bark beetle. The bark beetle is killing lodgepole pines throughout the western U.S.

Warmer winters allow more insects to survive the cold season, and a longer summer allows some insects to complete two life cycles in a year instead of one. Drought stress reduces trees' ability to defend against boring insects. Above, beetle-killed trees in Rocky Mountain National Park in Colorado.

to forest structure (age, tree size, and species composition) and air pollutants than climate over recent decades. Nonetheless, mortality of some eastern tree groups is related to rising temperature[18] and is expected to increase as climate warms.[19]

Future disturbance rates in forests will depend on changes in the frequency of extreme events as well as the underlying changes in average climate conditions.[9,20] Of particular concern is the potential for increased forest disturbance as the result of drought accompanied with warmer temperatures, which can cause both wildfire and tree death. Temperatures have generally been increasing and are projected to increase in the future (see Ch. 2: Our Changing Climate). Therefore, although it is difficult to predict trends in future extreme events,[21] there is a high degree of confidence that future droughts will be accompanied by generally warmer conditions. Trees die faster when drought is accompanied by higher temperatures, so short droughts can trigger mortality if temperatures are higher.[22] Short droughts occur more frequently than long droughts. Consequently, a direct effect of rising temperatures may be substantially greater tree mortality even with no change in drought frequency.[22]

Given strong relationships between climate and fire, even when modified by land use and management, such as fuel treatments (Figure 7.2), projected climate changes suggest that western forests in the United States will be increasingly affected by large and intense fires that occur more frequently.[16,23,24,25] These impacts are compounded by a legacy of fire suppression that has resulted in many U.S. forests becoming increasingly dense.[26] Eastern forests are less likely to experience immediate increases in wildfire, unless a point is reached at which rising temperatures combine with seasonal dry periods, more protracted drought, and/or insect outbreaks to trigger wildfires – conditions that have been seen in Florida (see Ch. 17: Southeast).

Rising temperatures and CO_2 levels can increase growth or alter migration of some tree species;[1,27] however, the relationship between rising temperature and mortality is complex. For example, most functional groups show a decrease in mortality with higher summer temperatures (with the exception of northern groups), whereas warmer winters are correlated with higher mortality for some functional groups.[18] Tree mortality is often the result of a combination of many factors; thus increases in pollutants, droughts, and wildfires will increase the probability of a tree dying (Figure 7.3). Under projected climate conditions, rising temperatures could work together with forest stand characteristics and these other stressors to increase mortality. Recent die-offs have been more severe than projected.[11,14] As temperatures increase to levels projected for mid-century and beyond, eastern forests may be at risk of die-off.[19] New evidence indicates that most tree species can endure only limited abnormal water stress, reinforcing the idea that trees in wetter as well as semiarid forests are vulnerable to drought-induced mortality under warming climates.[28]

Effectiveness of Forest Management in Reducing Wildfire Risk

Figure 7.2. Forest management that selectively removes trees to reduce fire risk, among other objectives (a practice referred to as "fuel treatments"), can maintain uneven-aged forest structure and create small openings in the forest. Under some conditions, this practice can help prevent large wildfires from spreading. Photo shows the effectiveness of fuel treatments in Arizona's 2002 Rodeo-Chediski fire, which burned more than 400 square miles – at the time the worst fire in state history. Unburned area (left) had been managed with a treatment that removed commercial timber, thinned non-commercial-sized trees, and followed with prescribed fire in 1999. The right side of the photo shows burned area on the untreated slope below Limestone Ridge. (Photo credit: Jim Youtz, U.S. Forest Service).

Climate change is contributing to increases in wildfires across the western U.S. and Alaska.

Forest Vulnerability to Changing Climate

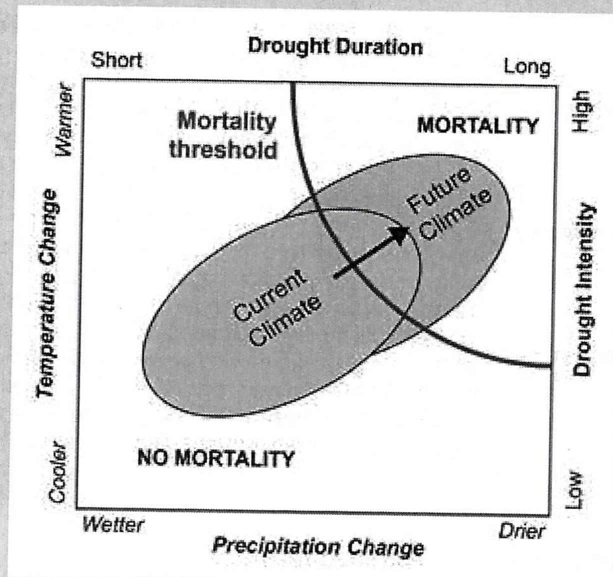


Figure 7.3. The figure shows a conceptual climate envelope analysis of forest vulnerability under current and projected future ranges of variability in climate parameters (temperature and precipitation, or alternatively drought duration and intensity). Climate models project increasing temperatures across the U.S. in coming decades, but a range of increasing or decreasing precipitation depending on region. Episodic droughts (where evaporation far exceeds precipitation) are also expected to increase in duration and/or intensity (see Ch. 2: Our Changing Climate). The overall result will be increased vulnerability of forests to periodic widespread regional mortality events resulting from trees exceeding their physiological stress thresholds.[11] (Figure source: Allen et al. 2010[11]).

Large-scale die-off and wildfire disturbance events could have potential impacts occurring at local and regional scales for timber production, flooding and erosion risks, other changes in water budgets, biogeochemical changes including carbon storage, and aesthetics.[29,30,31] Rising disturbance rates can increase harvested wood output and potentially lower prices; however, higher disturbance rates could make future forest investments more risky (Figure 7.4). Western forests could also lose substantial amounts of carbon storage capacity. For example, an increase in wildfires, insect outbreaks, and droughts that are severe enough to alter soil moisture and nutrient contents can result in changes in tree density or species composition.[10]

Key Message 2: Changing Carbon Uptake

U.S. forests and associated wood products currently absorb and store the equivalent of about 16% of all carbon dioxide (CO_2) emitted by fossil fuel burning in the U.S. each year. Climate change, combined with current societal trends in land use and forest management, is projected to reduce this rate of forest CO_2 uptake.

Climate-related Effects on Trees and Forest Productivity

Forests within the United States grow across a wide range of latitudes and altitudes and occupy all but the driest regions. Current forest cover has been shaped by climate, soils, topography, disturbance frequency, and human activity. Forest growth appears to be slowly accelerating (less than 1% per decade) in regions where tree growth is limited by low temperatures and short growing seasons that are gradually being altered by climate change (for species shifts, see Ch. 8: Ecosystems).[32] Forest carbon storage appears to be increasing both globally and within the United States.[33] Continental-scale satellite measurements document a lengthening growing season in the last thirty years, yet earlier spring growth may be negated by mid-summer drought.[34]

By the end of the century, snowmelt may occur a month earlier, but forest drought stress could increase by two months in the Rocky Mountain forests.[35] In the eastern United States, elevated CO_2 and temperature may increase forest growth and potentially carbon storage if sufficient water is available.[1,31,36] Despite recent increases in forest growth, future net forest carbon storage is expected to decline due to accelerating mortality and disturbance.

Forests can be a Source – or a Sink – for Carbon

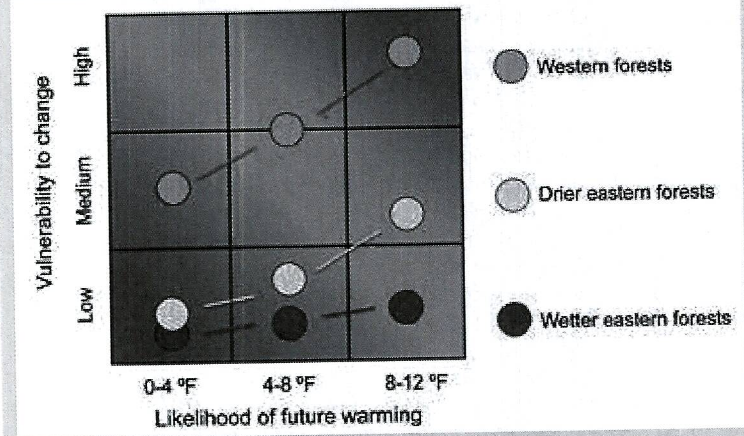


Figure 7.4. Relative vulnerability of different forest regions to climate change is illustrated in this conceptual risk analysis diagram. Forest carbon exchange is the difference between carbon captured in photosynthesis and carbon released by respiration of vegetation and soils. Both photosynthesis and respiration are generally accelerated by higher temperatures, and slowed by water deficits, but the relative strengths of these controls are highly variable. Western forests are inherently limited by evaporation that exceeds precipitation during much of the growing season. Xeric (drier) eastern forests grow on shallow, coarse textured soils and experience water deficits during long periods without rain. Mesic (wetter) eastern forests experience severe water deficits only for relatively brief periods in abnormally dry years so the carbon exchanges are more controlled by temperature fluctuations. (Figure source: adapted from Vose et al. 2012[1]).

Forest Carbon Sequestration and Carbon Management

From the onset of European settlement to the start of the last century, changes in U.S. forest cover due to expansion of agriculture, tree harvests, and settlements resulted in net emissions of carbon.[37,38] More recently, with forests reoccupying land previously used for agriculture, technological advances in harvesting, and changes in forest management, U.S. forests and associated wood products now serve as a substantial carbon sink, capturing and storing more than 227.6 million tons of carbon per year.[3] The amount of carbon taken up by U.S. land is dominated by forests (Figure 7.5), which have annually absorbed 7% to 24% of fossil fuel carbon dioxide (CO_2) emissions in the U.S. over the past two decades. The best estimate is that forests and wood products stored about 16% (833 teragrams, or 918.2 million short tons, of CO_2 equivalent in 2011) of all the CO_2 emitted annually by fossil fuel burning in the United States (see also "Estimating the U.S. Carbon Sink" in Ch. 15: Biogeochemical Cycles).[3]

Forest Growth Provides an Important Carbon Sink

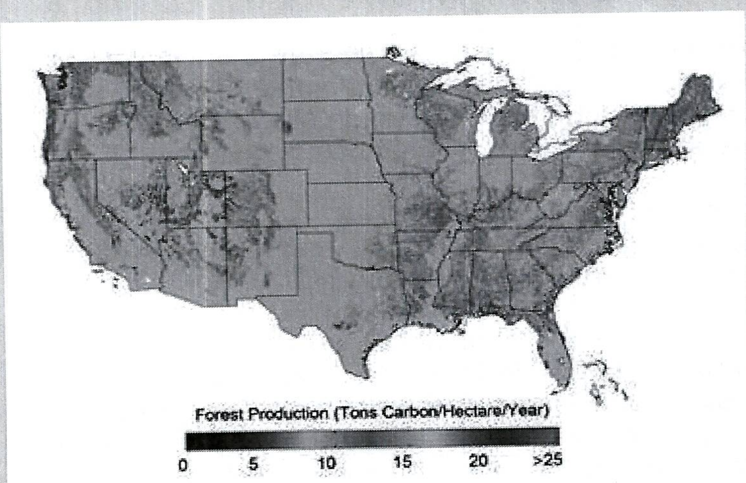


Figure 7.5. Forests are the largest component of the U.S. carbon sink, but growth rates of forests vary widely across the country. Well-watered forests of the Pacific Coast and Southeast absorb considerably more than the arid southwestern forests or the colder northeastern forests. Climate change and disturbance rates, combined with current societal trends regarding land use and forest management, are projected to reduce forest CO_2 uptake in the coming decades.[1] Figure shows average forest growth as measured by net primary production from 2000 to 2006. (Figure source: adapted from Running et al. 2004[46]).

The future role of U.S. forests in the carbon cycle will be affected by climate change through changes in disturbances (see Figures 7.3 and 7.4), as well as shifts in tree species, ranges, and productivity (Figure 7.6).[19,38] Economic factors will affect any future carbon cycle of forests, as the age class and condition of forests are affected by the acceleration of harvesting,[39,40] land-use changes such as urbanization,[41] changes in forest types,[42] and bioenergy development.[41,43,44,45]

Efforts in forestry to reduce atmospheric CO_2 levels have focused on forest management and forest product use. Forest management strategies include land-use change to increase forest area (afforestation) and/or to avoid deforestation and optimizing carbon management in existing forests. Forest product-use strategies include the use of wood wherever possible as a structural substitute for steel and concrete, which require more carbon emissions to produce.[38] The carbon emissions offset from using wood rather than alternate materials for a range of applications can be two or more times the carbon content of the product.[47]

In the U.S., afforestation (active establishment or planting of forests) has the potential to capture and store a maximum of 225 million tons of additional carbon per year from 2010 to 2110[39,48] (an amount almost equivalent to the current annual carbon storage in forests). Tree and shrub encroachment into grasslands, rangelands, and savannas provides a large potential carbon sink that could exceed half of what existing U.S. forests capture and store annually.[48]

Expansion of urban and suburban areas is responsible for much of the current and expected loss of U.S. forestland, although these human-dominated areas often have extensive tree cover and potential carbon storage (see also Ch. 13: Land Use & Land Cover Change).[41] In addition, the increasing prevalence of extreme conditions that encourage wildfires can convert some forests to shrublands and meadows[25] or permanently reduce the amount of carbon stored in existing forests if fires occur more frequently.[49]

Carbon management on existing forests can include practices that increase forest growth, such as fertilization, irrigation, switching to fast-growing planting stock, shorter rotations, and weed, disease, and insect control.[50] In addition, forest management can increase average forest carbon stocks by increasing the interval between harvests, by decreasing harvest intensity, or by focused density/species management.[4,51] Since 1990, CO_2 emissions from wildland forest fires in the lower 48 United States have averaged about 67 million tons of carbon per year.[52,53] While forest management practices can reduce on-site carbon stocks, they may also help reduce future climate change by providing feedstock material for bioenergy production and by possibly avoiding future, potentially larger, wildfire emissions through fuel treatments (Figure 7.2).[1]

Forests and Carbon

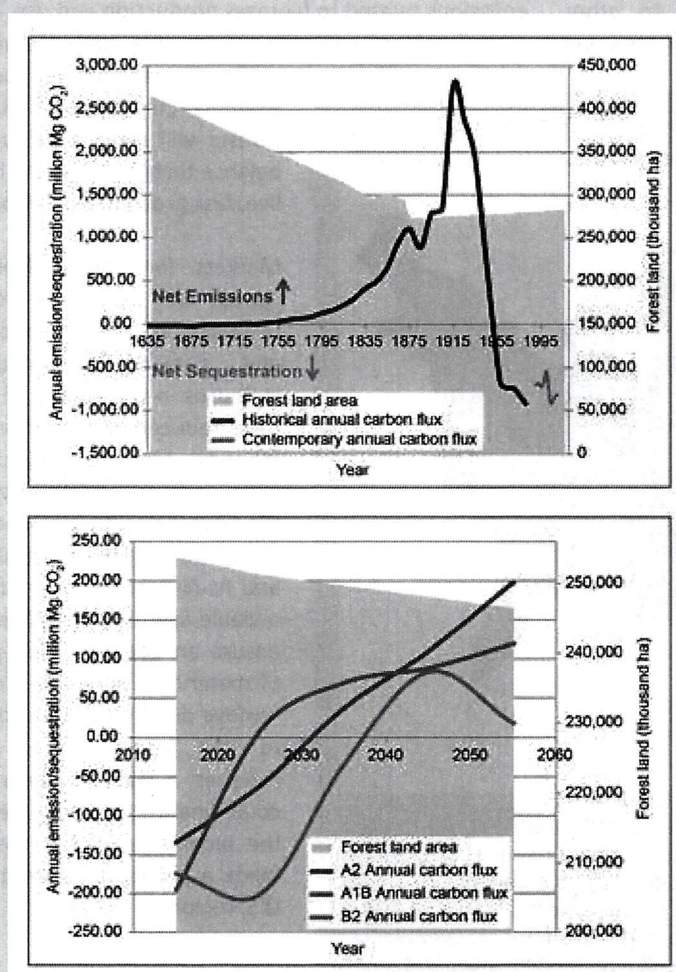


Figure 7.6. Historical, current, and projected annual rates of forest ecosystem and harvested wood product CO_2 net emissions/sequestration in the U.S. from 1635 to 2055. In the top panel, the change in the historical annual carbon emissions (black line) in the early 1900s corresponds to the peak in the transformation of large parts of the U.S. from forested land to agricultural land uses. Green shading shows this decline in forest land area. In the bottom panel, future projections shown under higher (A2) and lower (B2 and A1B) emissions scenarios show forests as carbon sources (due to loss of forest area and accelerating disturbance rates) rather than sinks in the latter half of this century. The A1B scenario assumes similar emissions to the A2 scenario used in this report through 2050, and a slow decline thereafter. (Data from Birdsey 2006;[37] USFS 2012;[41] EPA 2013.[53])

Key Message 3: Bioenergy Potential

Bioenergy could emerge as a new market for wood and could aid in the restoration of forests killed by drought, insects, and fire.

Bioenergy refers to the use of plant-based material to produce energy, and comprises about 28% of the U.S. renewable energy supply (Ch. 10: Energy, Water, and Land). Forest resources potentially could produce bioenergy from 504 million acres of timberland and 91 million acres of other forested land (Figure 7.7). Bioenergy from all sources, including agricultural and forests, could theoretically supply the equivalent of up to 30% of current U.S. petroleum consumption, but only if all relevant policies were optimized.[45] The *maximum* projected potential for forest bioenergy ranges from 3% to 5% of total current U.S. energy consumption.[54]

Forest biomass energy could be one component of an overall bioenergy strategy to reduce emissions of carbon from fossil fuels,[55] while also improving water quality[56,57] and maintaining lands for timber production as an alternative to other socioeconomic options. Active biomass energy markets using wood and forest residues have emerged in the southern and northeastern United States, particularly in states that have adopted renewable fuel standards. The economic viability of using forests for bioenergy depends on regional context and circumstances, such as species type and prior management, land conditions, transport and storage logistics, conversion processes used to produce energy, distribution, and use.[58] The environmental and socioeconomic consequences of bioenergy production vary greatly with region and intensity of human management.

The potential for biomass energy to increase timber harvests has led to debates about whether forest biomass energy leads to higher carbon emissions.[44,59] The debate on biogenic emissions regulations revolves around how to account for emissions related to biomass production and use.[60] The forest carbon balance naturally changes over time and also depends on forest management scenarios. For example, utilizing natural beetle-killed forests will yield a different carbon balance than growing and harvesting a live, fast-growing plantation.

Markets for energy from biomass appear to be ready to grow in response to energy pricing, policy, and demand,[44] although recent increases in the supply of natural gas have reduced the perceived urgency for new biomass projects. Further, because energy facilities typically buy the lowest quality wood at prices that rarely pay much more than cutting and hauling costs, they often require a viable saw timber market nearby to ensure an adequate, low-cost supply of material.[61] Where it is desirable to remove dead wood after disturbances to thin forests or to dispose of residues, a viable bioenergy industry could finance such activities. However, the bioenergy market has yet to be made a profitable enterprise in most U.S. regions.

Location of Potential Forestry Biomass Resources

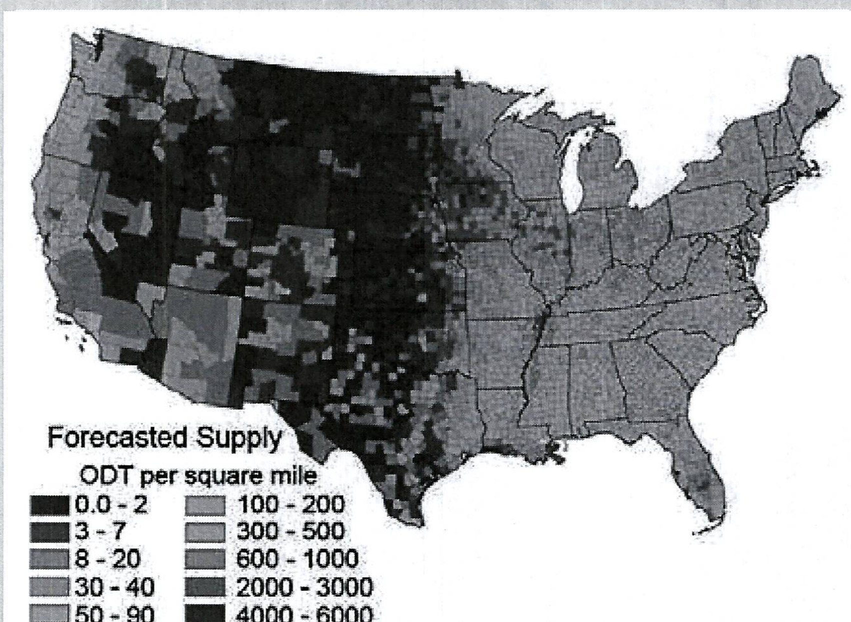


Figure 7.7. Potential forestry bioenergy resources by 2030 at $80 per dry ton of biomass based on current forest area, production rates based on aggressive management for fast-growth, and short rotation bioenergy plantations. Units are oven dry tons (ODT) per square mile at the county level, where an ODT is 2,000 pounds of biomass from which the moisture has been removed. Includes extensive material from existing forestland, such as residues, simulated thinnings, and some pulpwood for bioenergy, among other sources. (Figure source: adapted from U.S. Department of Energy 2011[45]).

Key Message 4: Influences on Management Choices

Forest management responses to climate change will be influenced by the changing nature of private forestland ownership, globalization of forestry markets, emerging markets for bioenergy, and U.S. climate change policy.

Climate change will affect trees and forests in urban areas, the wildland-urban interface, and in rural areas. It will also challenge forest landowners managing forests for commercial products, energy development, environmental services such as watershed protection, or the conversion of forestland to developed and urban uses or agriculture. With increases in urbanization, the value of forests in and around urban areas in providing environmental services required by urban residents will increase.[41] Potentially the greatest shifts in goods and environmental services produced from forests could occur in rural areas where social and economic factors will interact with the effects of climate change at landscape scales.

Owner objectives, markets for forest products, crops and energy, the monetary value of private land, and policies governing private and public forestland all influence the actions taken to manage U.S. forestlands (56% privately owned, 44% public) (Figure 7.8). Ownership changes can bring changes in forest objectives. Among corporate owners (18% of all forestland), ownership has shifted from forest industry to investment management organizations that may or may not have active forest management as a primary objective. Non-corporate private owners, an aging demographic, manage 38% of forestland. Their primary objectives are maintaining aesthetics and the privacy that the land provides as well as preserving the land as part of their family legacy.[62]

A significant economic factor facing private forest owners is the value of their forestlands for conversion to urban or developed uses. Economic opportunities from forests include wood products, non-timber forest products, recreation activities, and in some cases, environmental services.[1,41] Less than 1% of the volume of commercial trees from U.S. forestlands is harvested annually, and 92% of this harvest comes from private forestlands.[2] Markets for wood products in the United States have been affected by increasingly competitive global markets,[63] and timber prices are not projected to increase without substantial increases in wood energy consumption or other new timber demands.[41] Urban conversions of forestland over the next 50 years could result in the loss of 16 to 31 million acres.[41] The willingness of private forest owners to actively manage forests in the face of climate change will be affected primarily by market and policy incentives, not climate change itself.

The ability of public, private, and tribal forest managers to adapt to future climate change will be enhanced by their capacity to alter management regimes relatively rapidly in the face of changing conditions. The response to climate change may be greater on private forestlands where, in the past, owners have been highly responsive to market and policy signals.[64] These landowners may be able to use existing or current forest management practices to reduce disturbance effects, increase the capture and storage of carbon, and modify plant species distributions under climate change. In addition, policy incentives, such as carbon pricing or cap and trade markets, could influence landowner choices. For human communities dependent upon forest resources, maintaining or enhancing their current resilience to change will influence their ability to respond to future stresses from climate change.[65]

On public, private, and tribal lands, management practices that can be used to reduce disturbance effects include altering tree planting and harvest strategies through species selection and timing; factoring in genetic variation; managing for reduced stand densities, which could reduce wildfire risk; reducing other stressors such as poor air quality; using forest management practices to minimize drought stress; and developing regional networks to mitigate impacts on ecosystem goods and services.[1,30,66] Legally binding regulatory requirements may constrain adaptive management where plants, animals, ecosystems, and people are responding to climate change.[67]

Lack of fine-scale information about the possible effects of climate changes on locally managed forests limits the ability of managers to weigh these risks to their forests against the economic risks of implementing forest management practices such as adaptation and/or mitigation treatments. This knowledge gap will impede the implementation of effective management on public or private forestland in the face of climate change.

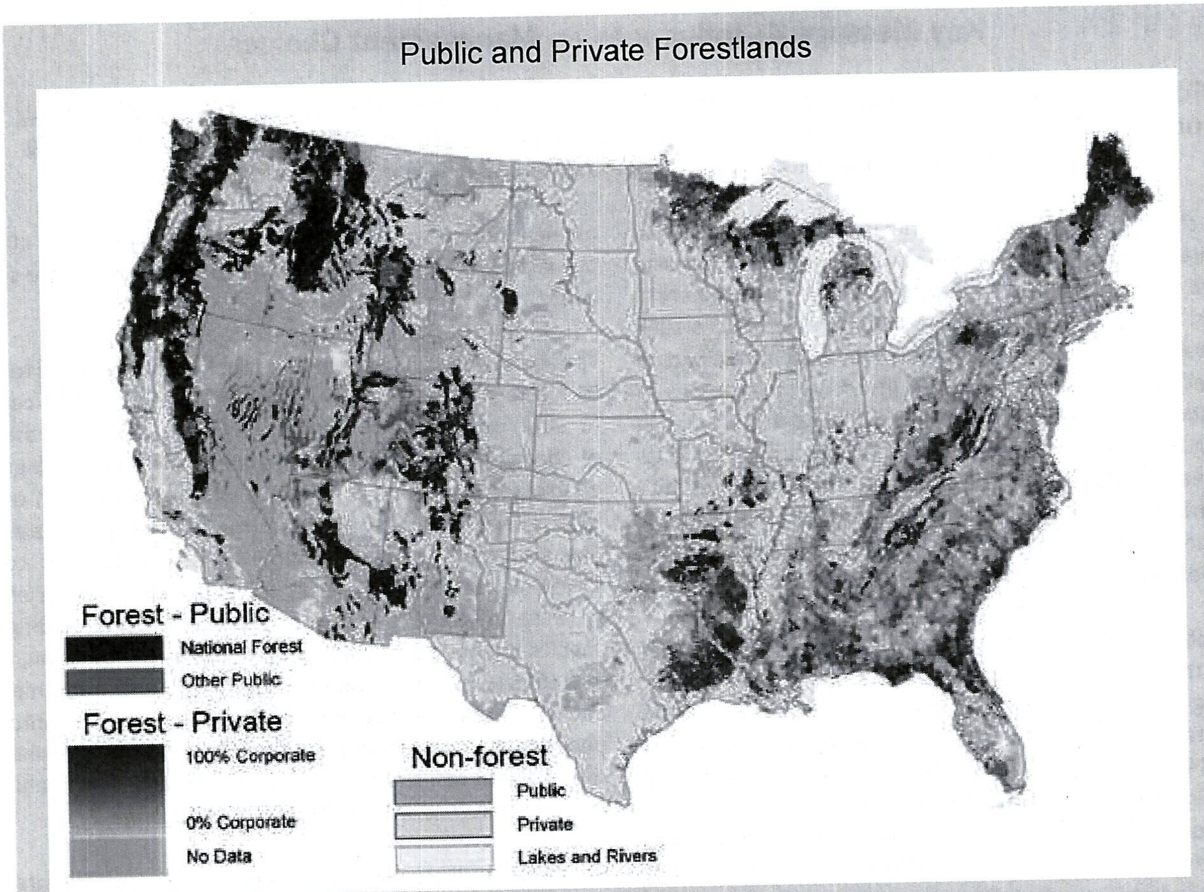


Figure 7.8. The figure shows forestland by ownership category in the contiguous U.S. in 2007.[41] Western forests are most often located on public lands, while eastern forests, especially in Maine and in the Southeast, are more often privately held. (Figure source: U.S. Forest Service 2012[41]).

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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages:
A central component of the process was a workshop held in July 2011 by the U.S. Department of Agriculture Forest Service to guide the development of the technical input report (TIR). This session, along with numerous teleconferences, led to the foundational TIR, "Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector."[1]

The chapter authors engaged in multiple technical discussions via teleconference between January and June 2012, which included careful review of the foundational TIR and of 58 additional technical inputs provided by the public, as well as other published literature and professional judgment. Discussions were followed by expert deliberation of draft key messages by the authors and targeted consultation with additional experts by the lead author of each message.

Key message #1 Traceable Account

Climate change is increasing the vulnerability of many forests to ecosystem changes and tree mortality through fire, insect infestations, drought, and disease outbreaks.

Description of evidence base
The key message and supporting text summarizes extensive evidence documented in the TIR, "Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector."[1] Technical input reports (58) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Dale et al.[8] addressed a number of climate change factors that will affect U.S. forests and how they are managed. This is supported by additional publications focused on effects of drought and by more large-scale tree die-off events,[11,22] wildfire,[16,23,25] insects and pathogens.[11,22] Other studies support the negative impact of climate change by examining the tree mortality rate due to rising temperatures,[9,11,14,15,16,17,19,22] which is projected to increase in some regions.[22]

Although it is difficult to detect a trend in disturbances because they are inherently infrequent and it is impossible to attribute an individual disturbance event to changing climate, there is nonetheless much that past events, including recent ones, reveal about expected forest changes due to future climate. Observational[17] and experimental[22] studies show strong associations between forest disturbance and extreme climatic events and/or modifications in atmospheric evaporative demand related to warmer temperature. Regarding eastern forests, there are fewer observational or experimental studies, with Dietz and Moorcroft[18] being the most comprehensive.

Pollution and stand age are the most important factors in mortality. Tree survival increases with increased temperature in some groups. However, for other tree groups survival decreases with increased temperature.[18] In addition, this study[18] needs to be considered in the context that there have been fewer severe droughts in this region. However, physiological relationships suggest that trees will generally be more susceptible to mortality under an extreme drought, especially if it is accompanied by warmer temperatures.[13,68] Consequently, it is misleading to assume that, because eastern forests have not yet experienced the types of large-scale die-off seen in the western forests, they are not vulnerable to such events if an extreme enough drought occurs. Although the effect of temperature on the rate of mortality during drought has only been shown for one species,[22] the basic physiological relationships for trees suggest that warmer temperatures will exacerbate mortality for other species as well.[13,68]

Figure 7.1: This figure uses a figure from Goetz et al. 2012[7] which uses the MODIS Global Disturbance Index (MGDI) results from 2005 to 2009 to illustrate the geographic distribution of major ecosystem disturbance types across North America (based on Mildrexler et al. 2007, 2009[6,69]). The MGDI uses remotely sensed information to assess the intensity of the disturbance. Following the occurrence of a major disturbance, there will be a reduction in Enhanced Vegetation Index (EVI) because of vegetation damage; in contrast, Land Surface Temperature (LST) will increase because more absorbed solar radiation will be converted into sensible heat as a result of the reduction in evapotranspiration from less vegetation density. MGDI takes advantage of the contrast changes in EVI and LST following a disturbance to enhance the signal to ef-

fectively detect the location and intensity of disturbances (http://www.ntsg.umt.edu/project/mgdi). Moderate severity disturbance is mapped in orange and represents a 65%-100% divergence of the current-year MODIS Global Disturbance Index value from the range of natural variability, High severity disturbance (in red) signals a divergence of over 100%.[7]

New information and remaining uncertainties

Forest disturbances have large ecosystem effects, but high interannual variability in regional fire and insect activity makes detection of trends more difficult than for changes in mean conditions.[20,21,70] Therefore, there is generally less confidence in assessment of future projections of disturbance events than for mean conditions (for example, growth under slightly warmer conditions).[21]

There are insufficient data on trends in windthrow, ice storms, hurricanes, and landslide-inducing storms to infer that these types of disturbance events are changing.

Factors affecting tree death, such as drought, warmer temperatures, and/or pests and pathogens are often interrelated, which means that isolating a single cause of mortality is rare.[11,12,13,17,22,68]

Assessment of confidence based on evidence

Very High. There is very high confidence that under projected climate changes there is high risk (high risk = high probability and high consequence) that western forests in the United States will be affected increasingly by large and intense fires that occur more frequently.[16,23,25] This is based on the strong relationships between climate and forest response, shown observationally[17] and experimentally.[22] Expected responses will increase substantially to warming and also in conjunction with other changes such as an increase in the frequency and/or severity of drought and amplification of pest and pathogen impacts. Eastern forests are less likely to experience immediate increases in wildfire unless/until a point is reached at which warmer temperatures, concurrent with seasonal dry periods or more protracted drought, trigger wildfires.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

KEY MESSAGE #2 TRACEABLE ACCOUNT

U.S. forests and associated wood products currently absorb and store the equivalent of about 16% of all carbon dioxide (CO_2) emitted by fossil fuel burning in the U.S. each year. Climate change, combined with current societal trends in land use and forest management, is projected to reduce this rate of forest CO_2 uptake.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the TIR, "Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector."[1] Technical input reports (58) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

A recent study[3] has shown that forests are a big sink of CO_2 nationally. However, the permanence of this carbon sink is contingent on forest disturbance rates, which are changing, and on economic conditions that may accelerate harvest of forest biomass.[56] Market response can cause changes in the carbon source/sink dynamics through shifts in forest age,[39,40] land-use changes and urbanization that reduce forested areas,[41] forest type changes,[42] and bioenergy development changing forest management.[41,43,44,45] Additionally, publications have reported that fires can convert a forest into a shrubland or meadow,[25] with frequent fires permanently reducing the carbon stock.[49]

New information and remaining uncertainties

That economic factors and societal choices will affect future carbon cycle of forests is known with certainty; the major uncertainties come from the future economic picture, accelerating disturbance rates, and societal responses to those dynamics.

Assessment of confidence based on evidence

Based on the evidence and uncertainties, confidence is **high** that climate change, combined with current societal trends regarding land use and forest management, is projected to reduce forest CO_2 uptake in the U.S. The U.S. has already seen large-scale shifts in forest cover due to interactions between forestland use and agriculture (for example, between the onset of European settlement to the present). There are competing demands for how forestland is used today. The future role of U.S. forests in the carbon cycle will be affected by climate change through changes in disturbances (Key Message 1), growth rates, and harvest demands.

Key message #3 Traceable Account

Bioenergy could emerge as a new market for wood and could aid in the restoration of forests killed by drought, insects, and fire.

Description of evidence base

The key message and supporting text summarize extensive evidence documented in the TIR, "Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector."[1] Technical input reports (58) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Studies have shown that harvesting forest bioenergy can prevent carbon emissions[55] and replace a portion of U.S. energy consumption to help reduce future climate change. Some newer literature has explored how use of forest bioenergy can replace a portion of current U.S. energy production from oil.[20,45] Some more recent publications have reported some environmental benefits, such as improved water quality[56,57] and better management of timber lands,[45] that can result from forest bioenergy implementation.

New information and remaining uncertainties

The implications of forest product use for bioenergy depends on regional context and circumstances, such as feedstock type and prior management, land conditions, transport and storage logistics, conversion processes used to produce energy, distribution and use.[58]

The potential for biomass energy to increase forest harvests has led to debates about whether biomass energy is net carbon neutral.[59] The debate on biogenic emissions regulations revolves around how to account for emissions related to biomass production and use.[60] Deforestation contributes to atmospheric CO_2 concentration, and that contribution has been declining over time. The bioenergy contribution question is largely one of incentives for appropriate management. When forests have no value, they are burned or used inappropriately. Bioenergy can be produced in a way that provides more benefits than costs or vice versa. The market for energy from biomass appears to be ready to grow in response to energy pricing, policy, and demand; however, this industry is yet to be made a large-scale profitable enterprise in most regions of the United States.

Assessment of confidence based on evidence

High. Forest growth substantially exceeds annual harvest for normal wood and paper products, and much forest harvest residue is now unutilized. Forest bioenergy will become viable if policy and economic energy valuations make it competitive with fossil fuels.

Key message #4 Traceable Account

Forest management responses to climate change will be influenced by the changing nature of private forestland ownership, globalization of forestry markets, emerging markets for bioenergy, and U.S. climate change policy.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the TIR, "Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector."[1] Technical input reports (58) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input.

The forest management response to climate change in urban areas, the wildland-urban interface, and in rural areas has been studied from varying angles. The literature on urban forests identifies the value of those forests to clean air, aesthetics, and recreation and suggests that under a changing climate, urban communities will continue to enhance their environment with trees and urban forests.[1,41] In the wildland-urban area and the rural areas, the changing composition of private forest landowners will affect the forest management response to climate change. Shifts in corporate owners to include investment organizations that may or may not have forest management as a primary objective has been described nationally.[1,2] Family forest owners are an aging demographic; one in five acres of forestland is owned by someone who is at least 75 years of age.[62] Multiple reasons for ownership are given by family forest owners, including the most commonly cited reasons of beauty/scenery, to pass land on to heirs, privacy, nature protection, and part of home/cabin. Many family forest owners feel it is necessary to keep the woods healthy but many are not familiar with forest management practices.[62] Long-term studies of the forest sector in the southern United States document the adaptive response of forest landowners to market prices as they manage to supply wood and associated products from their forests;[64] however prices are less of an incentive in other parts of the United States.[1,41] Econometric approaches have been used to explore the economic activities in the forest sector, including interactions with other sectors such as agriculture, impact of climate change, and the potential for new markets with bioenergy.[43,44] An earlier study explored the effects of globalization on forest management[63] and a newer study looked at the effect of U.S. climate change policy.[67] One of the biggest challenges is the lack of climate change information that results in inaction from many forest owners.[62]

New information and remaining uncertainties

Human concerns regarding the effects of climate change on forests and the role of adaptation and mitigation will be viewed from the perspective of the values that forests provide to human populations, including timber products, water, recreation, and aesthetic and spiritual benefits.[1] Many people, organizations, institutions, and governments influence the management of U.S. forests. Economic opportunities influence the amount and nature of private forestland (and much is known quantitatively about this dynamic) and societal values have a strong influence on how public forestland is managed. However, it remains challenging to project exactly how humans will respond to climate change in terms of forest management.

Climate change will alter known environmental and economic risks and add new risks to be addressed in the management of forests in urban areas, the wildland-urban interface, and rural areas. The capacity to manage risk varies greatly across landowners. While adaptation strategies provide a means to manage risks associated with climate change, a better understanding of risk perception by forest landowners would enhance the development and implementation of these management strategies. Identification of appropriate monitoring information and associated tools to evaluate monitoring data could facilitate risk assessment. Information and tools to assess environmental and economic risks associated with the impacts of climate change in light of specific management decisions would be informative to forestland managers and owners.

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainty, there is **medium** confidence in this key message. Climate change and global and national economic events will have an integral impact on forest management, but it is uncertain to what magnitude. While forest landowners have shown the capacity to adapt to new economic conditions, potential changes in the international markets coincident with large-scale natural disturbances enhanced by climate change (fire, insects) could challenge this adaptive capacity. An important uncertainty is how people will respond to climate change in terms of forest management.

Climate Change Impacts in the United States

CHAPTER 8
ECOSYSTEMS,
BIODIVERSITY, AND ECOSYSTEM SERVICES

Convening Lead Authors

Peter M. Groffman, Cary Institute of Ecosystem Studies

Peter Kareiva, The Nature Conservancy

Lead Authors

Shawn Carter, U.S. Geological Survey

Nancy B. Grimm, Arizona State University

Josh Lawler, University of Washington

Michelle Mack, University of Florida

Virginia Matzek, Santa Clara University

Heather Tallis, Stanford University

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8 ECOSYSTEMS, BIODIVERSITY, AND ECOSYSTEM SERVICES

Key Messages

1. **Climate change impacts on ecosystems reduce their ability to improve water quality and regulate water flows.**
2. **Climate change, combined with other stressors, is overwhelming the capacity of ecosystems to buffer the impacts from extreme events like fires, floods, and storms.**
3. **Landscapes and seascapes are changing rapidly, and species, including many iconic species, may disappear from regions where they have been prevalent or become extinct, altering some regions so much that their mix of plant and animal life will become almost unrecognizable.**
4. **Timing of critical biological events, such as spring bud burst, emergence from overwintering, and the start of migrations, has shifted, leading to important impacts on species and habitats.**
5. **Whole system management is often more effective than focusing on one species at a time, and can help reduce the harm to wildlife, natural assets, and human well-being that climate disruption might cause.**

Climate change affects the living world, including people, through changes in ecosystems, biodiversity, and ecosystem services. Ecosystems entail all the living things in a particular area as well as the non-living things with which they interact, such as air, soil, water, and sunlight.[1] Biodiversity refers to the variety of life, including the number of species, life forms, genetic types, and habitats and biomes (which are characteristic groupings of plant and animal species found in a particular climate). Biodiversity and ecosystems produce a rich array of benefits that people depend on, including fisheries, drinking water, fertile soils for growing crops, climate regulation, inspiration, and aesthetic and cultural values.[2] These benefits are called "ecosystem services" – some of which, like food, are more easily quantified than others, such as climate regulation or cultural values. Changes in many such services are often not obvious to those who depend on them.

Ecosystem services contribute to jobs, economic growth, health, and human well-being. Although we interact with ecosystems and ecosystem services every day, their linkage to climate change can be elusive because they are influenced by so many additional entangled factors.[3] Ecosystem perturbations driven by climate change have direct human impacts, including reduced water supply and quality, the loss of iconic species and landscapes, distorted rhythms of nature, and the potential for extreme events to overwhelm the regulating services of ecosystems. Even with these well-documented ecosystem impacts, it is often difficult to quantify human vulnerability that results from shifts in ecosystem processes and services. For example, although it is more straightforward to predict how precipitation will change water flow, it is much harder to pinpoint which farms, cities, and habitats will be at risk of running out of water, and even more difficult to say how people will be affected by the loss of a favorite fishing spot or a wildflower that no longer blooms in the region. A better understanding of how a range of ecosystem responses affects people – from altered water flows to the loss of wildflowers – will help to inform the management of ecosystems in a way that promotes resilience to climate change.

Forests absorb carbon dioxide and provide many other ecosystem services, such as purifying water and providing recreational opportunities.

Key Message 1: Water

Climate change impacts on ecosystems reduce their ability to improve water quality and regulate water flows.

Climate-driven factors that control water availability and quality are moderated by ecosystems. Land-based ecosystems regulate the water cycle and are the source of sediment and other materials that make their way to aquatic ecosystems (streams, rivers, lakes, estuaries, oceans, groundwater). Aquatic ecosystems provide the critically important services of storing water, regulating water quality, supporting fisheries, providing recreation, and carrying water and materials downstream (Ch. 25: Coasts). Humans utilize, on average, the equivalent of more than 40% of renewable supplies of freshwater in more than 25% of all U.S. watersheds.[4] Freshwater withdrawals are even higher in the arid Southwest, where the equivalent of 76% of all renewable freshwater is appropriated by people.[5] In that region, climate change has likely decreased and altered the timing of streamflow due to reduced snowpack and lower precipitation in spring, although the precipitation trends are weak due to large year-to-year variability, as well as geographic variation in the patterns (Ch. 3: Water; Ch. 20: Southwest).[6] Depriving ecosystems of water reduces their ability to provide water to people as well as for aquatic plant and animal habitat (see Figure 8.1).

Habitat loss and local extinctions of fish and other aquatic species are projected from the combined effects of increased water withdrawal and climate change.[7] In the U.S., 47% of trout habitat in the interior West would be lost by 2080 under a scenario (A1B) that assumes similar emissions to the A2 scenario used in this report (Ch. 1: Overview, Ch. 2: Our Changing Climate) through 2050, and a slow decline thereafter.[8]

Across the entire U.S., precipitation amounts and intensity and associated river discharge are major drivers of water pollution in the form of excess nutrients, sediment, and dissolved organic carbon (DOC) (Ch. 3: Water).[9] At high concentrations, nutrients that are required for life (such as nitrogen and phosphorus) can become pollutants and can promote excessive phytoplankton growth – a process known as eutrophication. Currently, many U.S. lakes and rivers are polluted (have concentrations above government standards) by excessive nitrogen, phosphorus, or sediment. There are well-established links among fertilizer use, nutrient pollution, and river discharge, and many studies show that recent increases in rainfall in several regions of the United States have led to higher nitrogen amounts carried by rivers (Northeast,[10,11] California,[12] and Mississippi Basin[13,14]). Over the past 50 years, due to both climate and land-use change, the Mississippi Basin is yielding an additional 32 million acre-feet of water each year – equivalent to four Hudson Rivers – laden with materials washed from its farmlands.[15] This flows into the Gulf of Mexico, which is the site of the nation's largest hypoxic (low oxygen) "dead" zone.[4] The majority of U.S. estuaries are moderately to highly eutrophic.[16]

Links between discharge and sediment transport are well established,[17] and cost estimates for in-stream and off-stream damages from soil erosion range from $2.1 to $10 billion per year.[18,19] These estimates include costs associated with damages to, or losses of, recreation, water storage, navigation, commercial fishing, and property, but do not include costs of biological impacts.[18] Sediment transport, with accompanying nutrients, can play a positive role in the shoreline dynamics of coastlines and the life cycles of coastal and marine plants and animals. However, many commercially and recreationally important fish species such as salmon and trout that lay their eggs in the gravel at the edges of streams are especially sensitive to elevated sediment fluxes in rivers.[20] Sediment loading in lakes has been shown to have substantial detrimental effects on fish population sizes, community composition, and biodiversity.[21]


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Dissolved organic carbon (DOC) fluxes to rivers and lakes are strongly driven by precipitation;[22] thus in many regions where precipitation is expected to increase, DOC loading will also increase. Dissolved organic carbon is the substance that gives many rivers and lakes a brown, tea-colored look. Precipitation-driven increases in DOC concentration not only increase the cost of water treatment for municipal use,[23] but also alter the ability of sunlight to act as nature's water treatment plant. For example, *Cryptosporidium*, a pathogen potentially lethal to the elderly, babies, and people with compromised immune systems, is present in 17% of drinking water supplies sampled in the United States.[24] This pathogen is inactivated by doses of ultraviolet (UV) light equivalent to less than a day of sun exposure.[25] Similarly, UV exposures reduce fungal parasites that infect *Daphnia*, a keystone aquatic grazer and food source for fish.[26] Increasing DOC concentrations may thus reduce the ability of sunlight to regulate these UV-sensitive parasites.

Few studies have projected the impacts of climate change on nitrogen, phosphorus, sediment, or DOC transport from the land to rivers. However, given the tight link between river discharge and all of these potential pollutants, areas of the United States that are projected to see increases in precipitation, and increases in intense rainfalls, like the Northeast, Midwest, and mountainous West,[27] will also see increases in excess nutrients, DOC, and sediments transported to rivers. One of the few future projections available suggests that downstream and coastal impacts of increased nitrogen inputs could be profound for the Mississippi Basin. Under a scenario in which atmospheric CO_2 reaches double pre-industrial levels, a 20% increase in river discharge is expected to lead to higher nitrogen loads and a 50% increase in algae growth in the Gulf of Mexico, a 30% to 60% decrease in deep-water dissolved oxygen concentration, and an expansion of the dead zone.[28] A recent comprehensive assessment[10] shows that, while climate is an important driver, nitrogen carried by rivers to the oceans is most strongly driven by fertilizer inputs to the land. Therefore, in the highly productive agricultural systems of the Mississippi Basin, the ultimate impact of more precipitation on the expansion of the dead zone will depend on agricultural management practices in the Basin.[14,29]

Rising air temperatures can also lead to declines in water quality through a different set of processes. Some large lakes, including the Great Lakes, are warming rapidly.[30] Warmer surface waters can stimulate blooms of harmful algae in both lakes and coastal oceans,[9] which may include toxic cyanobacteria that are favored at higher temperatures.[31] Harmful algal blooms, which are caused by many factors, including climate change, exact a cost in freshwater degradation of approximately $2.2 billion annually in the United States alone.[32]

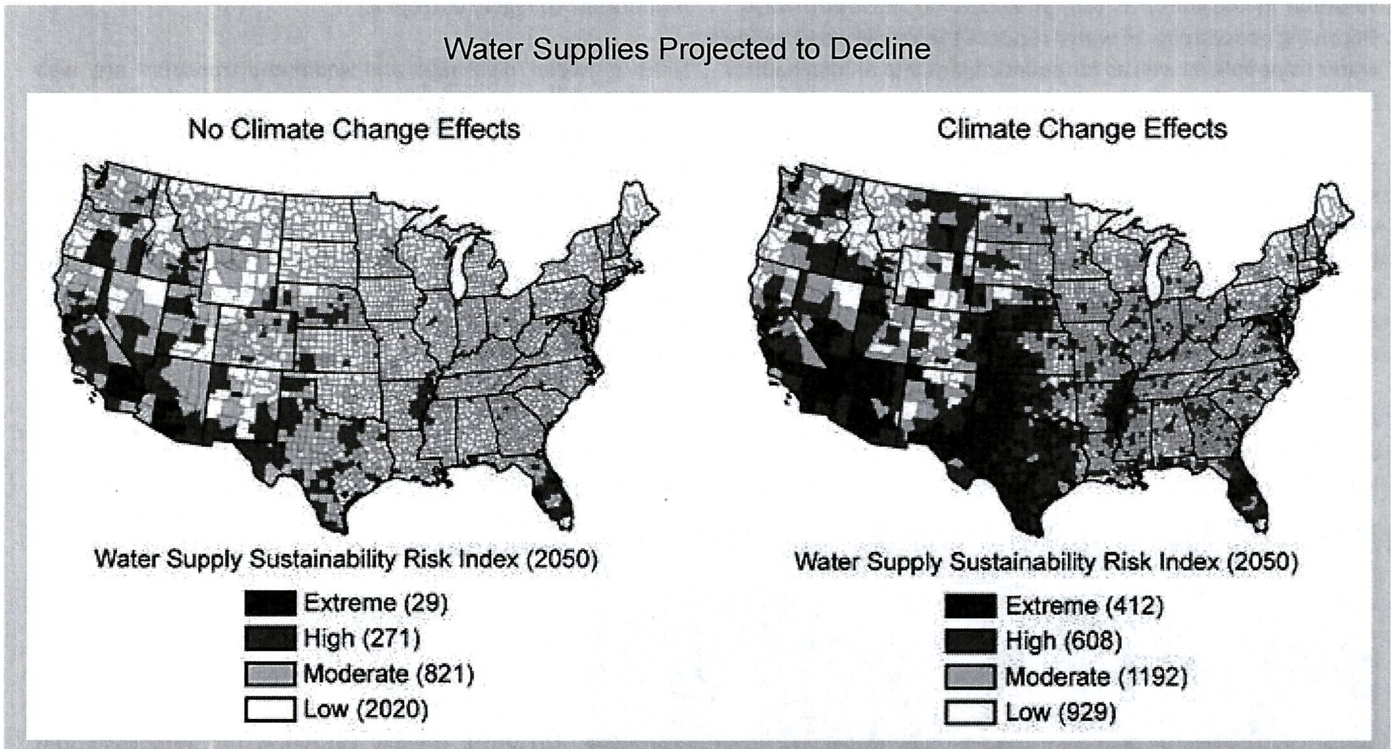


Figure 8.1. Climate change is projected to reduce the ability of ecosystems to supply water in some parts of the country. This is true in areas where precipitation is projected to decline, and even in some areas where precipitation is expected to increase. Compared to 10% of counties today, by 2050, 32% of counties will be at high or extreme risk of water shortages. Projections assume continued increases in greenhouse gas emissions through 2050 and a slow decline thereafter (A1B scenario). Numbers in parentheses indicate number of counties in each category. (Reprinted with permission from Roy et al., 2012.[27] Copyright 2012 American Chemical Society).

The Aftermath of Hurricanes

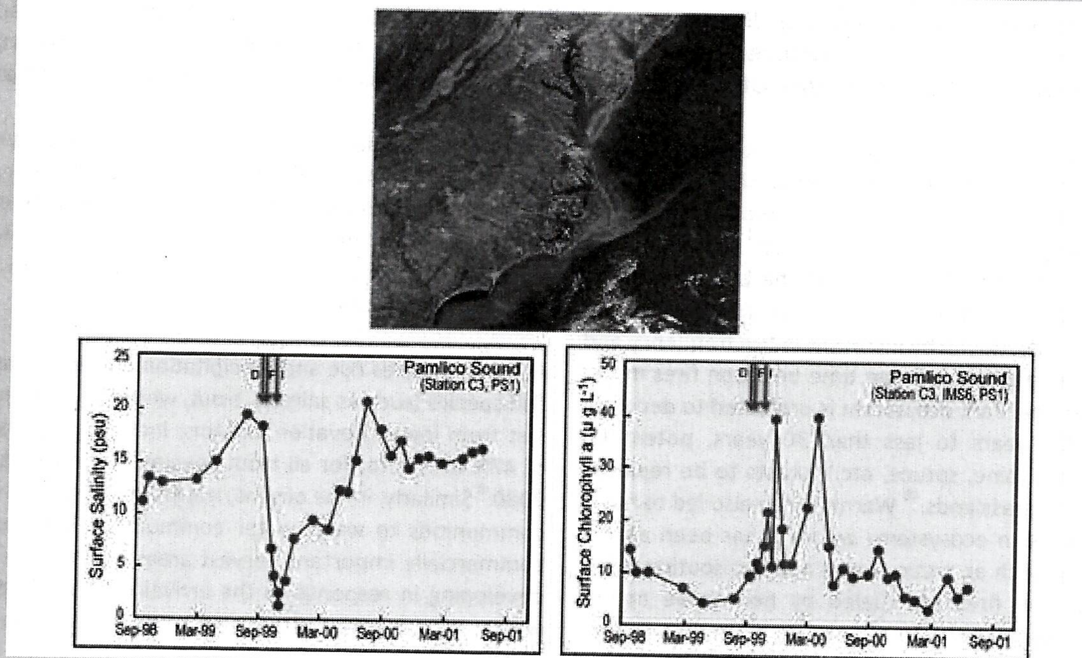


Figure 8.2. Hurricanes illustrate the links among precipitation, discharge and nutrient loading to coastal waters. Hurricanes bring intense rainfall to coastal regions, and ensuing runoff leads to blooms of algae. These blooms contribute to dead zone formation after they die and decompose. Photo above shows Pamlico Sound, North Carolina, after Hurricane Floyd. Note light green area off the coast, which is new algae growth. The graph on the left shows a steep drop in salinity of ocean water due to the large influx of freshwater from rain after a series of hurricanes. Red arrows indicate Hurricanes Dennis, Floyd, and Irene, which hit sequentially during the 1999 hurricane season. The graph on the right shows a steep rise in the amount of surface chlorophyll after these hurricanes, largely due to increased algae growth. (Figure source: (top) NASA SeaWiFS; (bottom) Paerl et al. 2003[33]).

Key Message 2: Extreme Events

Climate change, combined with other stressors, is overwhelming the capacity of ecosystems to buffer the impacts from extreme events like fires, floods, and storms.

Ecosystems play an important role in "buffering" the effects of extreme climate conditions (floods, wildfires, tornadoes, hurricanes) on the movement of materials and the flow of energy through the environment.[34] Climate change and human modifications often increase the vulnerability of ecosystems and landscapes to damage from extreme events while at the same time reducing their natural capacity to modulate the impacts of such events. Salt marshes, reefs, mangrove forests, and barrier islands provide an ecosystem service of defending coastal ecosystems and infrastructure against storm surges.[35] Losses of these natural features – from coastal development, erosion, and sea level rise – render coastal ecosystems and infrastructure more vulnerable to catastrophic damage during or after extreme events (Ch. 25: Coasts).[36] Floodplain wetlands, although greatly reduced from their historical extent, provide an ecosystem service of absorbing floodwaters and reducing the impact of high flows on river-margin lands. In the Northeast, even a small sea level rise (1.6 feet) would dramatically increase the numbers of people (47% increase) and property loss (73% increase) affected by storm surge in Long Island compared to present day storm surge impacts.[37] Extreme weather events that produce sudden increases in water flow and the materials it carries can decrease the natural capacity of ecosystems to process pollutants, both by reducing the amount of time water is in contact with reactive sites and by removing or harming the plants and microbes that remove the pollutants.[36]

Warming and, in some areas, decreased precipitation (along with past forest fire suppression practices) have increased the risk of fires exceeding historical size, resulting in unprecedented social and economic challenges. Large fires put people living in the wildland-urban interface at risk for health problems and property loss. In 2011 alone, more than 8 million acres burned in wildfires, causing 15 deaths and property losses greater than $1.9 billion.[38]

Key Message 3: Plants and Animals

Landscapes and seascapes are changing rapidly, and species, including many iconic species, may disappear from regions where they have been prevalent or become extinct, altering some regions so much that their mix of plant and animal life will become almost unrecognizable.

Vegetation model projections suggest that much of the United States will experience changes in the composition of species characteristic of specific areas. Studies applying different models for a range of future climates project biome changes for about 5% to 20% of the land area of the U.S. by 2100.[4,39] Many major changes, particularly in the western states and Alaska, will in part be driven by increases in fire frequency and severity. For example, the average time between fires in the Yellowstone National Park ecosystem is projected to decrease from 100 to 300 years to less than 30 years, potentially causing coniferous (pine, spruce, etc.) forests to be replaced by woodlands and grasslands.[40] Warming has also led to novel wildfire occurrence in ecosystems where it has been absent in recent history, such as arctic Alaska and the southwestern deserts where new fires are fueled by non-native annual grasses (Ch. 20: Southwest; Ch. 22: Alaska). Extreme weather conditions linked to sea ice decline in 2007 led to the ignition of the Anaktuvuk River Fire, which burned more than 380 square miles of arctic tundra that had not been disturbed by fire for more than 3,000 years.[41] This one fire (which burned deeply into organic peat soils) released enough carbon to the atmosphere to offset all of the carbon taken up by the entire arctic tundra biome over the past quarter-century.[42]

In addition to shifts in species assemblages, there will also be changes in species distributions. In recent decades, in both land and aquatic environments, plants and animals have moved to higher elevations at a median rate of 36 feet (0.011 kilometers) per decade, and to higher latitudes at a median rate of 10.5 miles (16.9 kilometers) per decade.[43] As the climate continues to change, models and long-term studies project even greater shifts in species ranges.[44] However, many species may not be able to keep pace with climate change for several reasons, for example because their seeds do not disperse widely or because they have limited mobility, thus leading, in some places, to local extinctions of both plants and animals. Both range shifts and local extinctions will, in many places, lead to large changes in the mix of plants and animals present in the local ecosystem, resulting in new communities that bear little resemblance to those of today.[4,8,45,46]

Some of the most obvious changes in the landscape are occurring at the boundaries between biomes. These include shifts in the latitude and elevation of the boreal (northern) forest/tundra boundary in Alaska;[47] elevation shifts of the boreal and subalpine forest/tundra boundary in the Sierra Nevada, California;[48] an elevation shift of the temperate broadleaf/conifer boundary in the Green Mountains, Vermont,[49] the shift of temperate the shrubland/conifer forest boundary in Bandelier National Monument, New Mexico,[50] and upslope shifts of the temperate mixed forest/conifer boundary in Southern California.[51] All of these are consistent with recent climatic trends and represent visible changes, like tundra switching to forest, or conifer forest switching to broadleaf forest or even to shrubland.

As temperatures rise and precipitation patterns change, many fish species (such as salmon, trout, whitefish, and char) will be lost from lower-elevation streams, including a projected loss of 47% of habitat for all trout species in the western U.S. by 2080.[8] Similarly, in the oceans, transitions from cold-water fish communities to warm-water communities have occurred in commercially important harvest areas,[52] with new industries developing in response to the arrival of new species.[53] Also, warm surface waters are driving some fish species to deeper waters.[54,55]

Warming is likely to increase the ranges of several invasive plant species in the United States,[56] increase the probability of establishment of invasive plant species in boreal forests in south-central Alaska, including the Kenai Peninsula,[57] and expand the range of the hemlock wooly adelgid, an insect that has killed many eastern hemlocks in recent years.[58] Invasive species costs to the U.S. economy are estimated at $120 billion per year,[59] including substantial impacts on ecosystem services. For instance, the yellow star-thistle, a wildland pest which is predicted to thrive with increased atmospheric CO_2,[60] currently costs California ranchers and farmers $17 million in forage and control efforts[61] and $75 million in water losses.[62] Iconic desert species such as saguaro cactus are damaged or killed by fires fueled by non-native grasses, leading to a large-scale transformation of desert shrubland into grassland in many of the familiar landscapes of the American West.[63] Bark beetles have infested extensive areas of the western United States and Canada, killing stands of temperate and boreal conifer forest across areas greater than any other outbreak in the last 125 years.[64] Climate change has been a major causal factor, with higher temperatures allowing more beetles to survive winter, complete two life cycles in a season rather than one, and to move to higher elevations and latitudes.[64,65] Bark beetle outbreaks in the Greater Yellowstone Ecosystem are occurring in habitats where outbreaks either did not previously occur or were limited in scale.[66]

It is important to realize that climate change is linked to far more dramatic changes than simply altering species' life cycles or shifting their ranges. Several species have exhibited population declines linked to climate change, with some declines so severe that species are threatened with extinction.[67] Perhaps the most striking impact of climate change is its effect on iconic species such as the polar bear, the ringed seal, and coral species (Ch. 22: Alaska; Ch. 24: Oceans). In 2008, the polar bear (*Ursus maritimus*) was listed as a threatened species, with the primary cause of its decline attributed to climate change.[68] In 2012, NOAA determined that four subspecies of the ringed seal (*Phoca hispida*) were threatened or endangered, with the primary threat being climate change.[69]

Key Message 4: Seasonal Patterns

Timing of critical biological events, such as spring bud burst, emergence from overwintering, and the start of migrations, has shifted, leading to important impacts on species and habitats.

The effect of climate change on phenology – the pattern of seasonal life cycle events in plants and animals, such as timing of leaf-out, blooming, hibernation, and migration – has been called a "globally coherent fingerprint of climate change impacts" on plants and animals.[70] Observed long-term trends towards shorter, milder winters and earlier spring thaws are altering the timing of critical spring events such as bud burst and emergence from overwintering. This can cause plants and animals to be so out of phase with their natural phenology that outbreaks of pests occur, or species cannot find food at the time they emerge.

Recent studies have documented an advance in the timing of springtime phenological events across species in response to increased temperatures.[71] Long-term observations of lilac flowering indicate that the onset of spring has advanced one day earlier per decade across the northern hemisphere in response to increased winter and spring temperatures[72] and by 1.5 days per decade earlier in the western United States.[73] Other multi-decadal studies for plant species have documented similar trends for early flowering.[74,75] In addition, plant-pollinator relationships may be disrupted by changes in nectar and pollen availability, as the timing of bloom shifts in response to temperature and precipitation.[76,77]

As spring is advancing and fall is being delayed in response to regional changes in climate,[78] the growing season is lengthening. A longer growing season will benefit some crops and natural species, but there may be a timing mismatch between the microbial activity that makes nutrients available in the soil and the readiness of plants to take up those nutrients for growth.[78,79] Where plant phenology is driven by day length, an advance in spring may exacerbate this mismatch, causing available nutrients to be leached out of the soil rather than absorbed and recycled by plants.[80] Longer growing seasons also exacerbate human allergies. For example, a longer fall allows for bigger ragweed plants that produce more pollen later into the fall (see also Ch. 9: Health).[81]

Changes in the timing of springtime bird migrations are well-recognized biological responses to warming, and have been documented in the western,[82] midwestern,[83] and eastern United States.[84,85] Some migratory birds now arrive too late for the peak of food resources at breeding grounds because temperatures at wintering grounds are changing more slowly than at spring breeding grounds.[86]

In a 34-year study of an Alaskan creek, young pink salmon (*Oncorhynchus gorbuscha*) migrated to the sea increasingly earlier over time.[87] In Alaska, warmer springs have caused earlier onset of plant emergence, and decreased spatial variation in growth and availability of forage to breeding caribou (*Rangifer tarandus*).

Key Message 5: Adaptation

Whole system management is often more effective than focusing on one species at a time, and can help reduce the harm to wildlife, natural assets, and human well-being that climate disruption might cause.

Adaptation in the context of biodiversity and natural resource management is fundamentally about managing change, which is an inherent property of natural ecosystems.[4,88,89] One strategy – adaptive management, which is a structured process of flexible decision-making under uncertainty that incorporates learning from management outcomes – has received renewed attention as a tool for helping resource managers make decisions relevant to whole systems in response to climate change.[89,90] Other strategies tinclude assessments of vulnerability and impacts,[91] and scenario planning,[92] that can be assembled into a general planning process that is flexible and iterative.

Guidance on adaptation planning for conservation has proliferated at the federal[92,93,94] and state levels,[95] and often emphasizes cooperation between scientists and managers.[94,96,97] Ecosystem-based adaptation[98,99] uses "biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change."[99] An example is the explicit use of storm-buffering coastal wetlands or mangroves rather than built infrastructure like seawalls or levies to protect coastal regions (Ch. 25: Coasts).[100] An additional example is the use of wildlife corridors to connect fragmented wildlife habitat.[101]

Adaptation strategies to protect biodiversity include: 1) habitat manipulation, 2) conserving populations with higher genetic diversity or more flexible behaviors or morphologies, 3) re-planting with species or ecotypes that are better suited for future climates, 4) managed relocation (sometimes referred to as assisted migration) to help move species and populations from current locations to those areas expected to become more suitable in the future, and 5) offsite conservation such as seed banking, biobanking, and captive breeding.[92,94,96,97,102,103] Additional approaches focus on identifying and protecting features that are important for biodiversity and are less likely to be altered by climate change. The idea is to conserve the "stage" (the biophysical conditions that contribute to high levels of biodiversity) for whatever "actors" (species and populations) find those areas suitable in the future.[104]

One of the greatest challenges for adaptation in the face of climate change is the revision of management goals in fundamental ways. In particular, not only will climate change make it difficult to achieve existing conservation goals, it will demand that goals be critically examined and potentially altered in dramatic ways.[102,105] Climate changes can also severely diminish the effectiveness of current strategies and require fresh approaches. For example, whereas establishing networks of nature reserves has been a standard approach to protecting species, fixed networks of reserve do not lend themselves to adjustments for climate change.[105] Finally, migratory species and species with complex life histories cannot be simply addressed by defining preferred habitat and making vulnerability assessments. Often it could be specific life history stages that are the weak point in the species, and it is key to identify those weak links.[106]

While there is considerable uncertainty about how climate change will play out in particular locations, proactive measures can be taken to both plan for connectivity[96,107] and to identify places or habitats that may in the future become valuable habitat as a result of climate change and vegetation shifts.[108] It is important to note that when the Endangered Species Act (ESA) was passed in 1973, climate change was not a known threat or factor and was not considered in setting recovery goals or critical habitat designations.[109] However, agencies are actively working to include climate change considerations in their ESA implementation activities.

Adaptation Planning and Implementation Framework

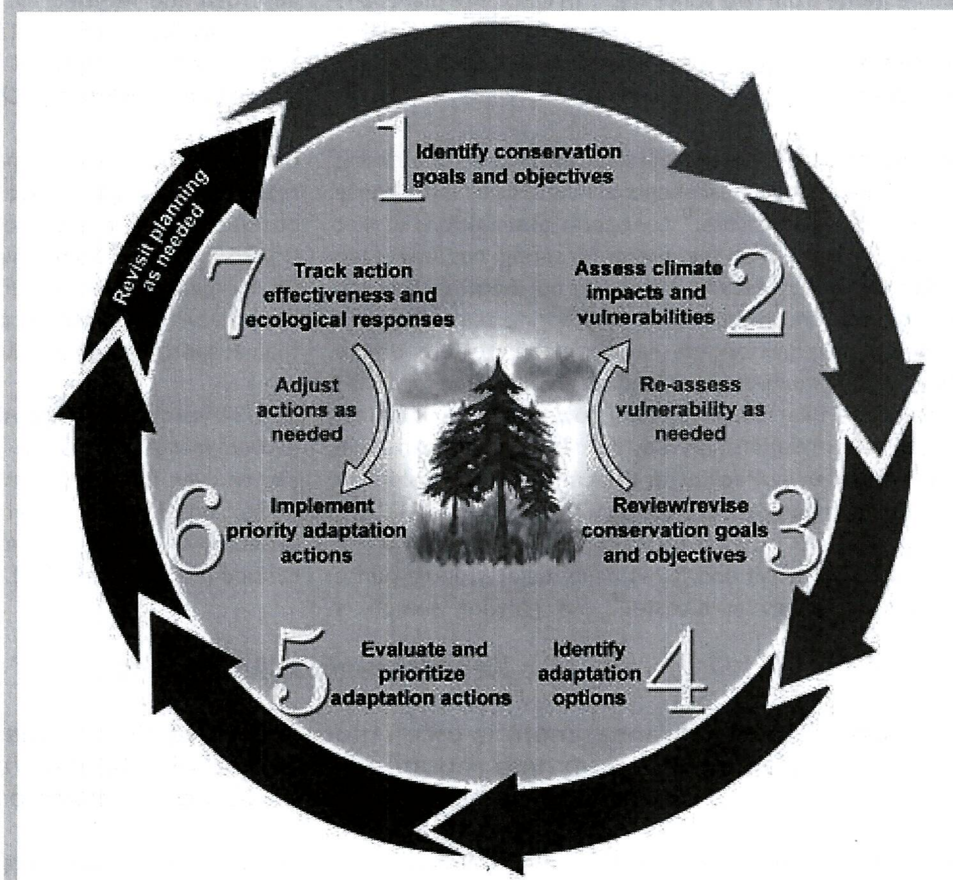


Figure 8.3. Iterative approaches to conservation planning require input and communication among many players to ensure flexibility in response to climate change. (Figure source: adapted from the National Wildlife Federation, 2013[142]).

Case Study of the 2011 Las Conchas, New Mexico Fire

In the midst of severe drought in the summer of 2011, Arizona and New Mexico suffered the largest wildfires in their recorded history, affecting more than 694,000 acres. Some rare threatened and endangered species, like the Jemez salamander, were damaged by this unusually severe fire.[110] Fires are often part of the natural disturbance regime, but if drought, poor management, and high temperatures combine, a fire can be so severe and widespread that species are damaged that otherwise might even be considered to be fire tolerant (such as spotted owls). Following the fires, heavy rainstorms led to major flooding and erosion, including at least ten debris flows. Popular recreation areas were evacuated and floods damaged the newly renovated, multi-million dollar U.S. Park Service Visitor Center at Bandelier National Monument. Sediment and ash eroded by the floods were washed downstream into the Rio Grande, which supplies 50% of the drinking water for Albuquerque, the largest city in New Mexico. Water withdrawals by the city from the Rio Grande were stopped entirely for a week and reduced for several months due to the increased cost of treatment.

These fires provide an example of how forest ecosystems, biodiversity, and ecosystem services are affected by the impacts of climate change, other environmental stresses, and past management practices. Higher temperatures, reduced snowpack, and earlier onset of springtime are leading to increases in wildfire in the western United States,[111] while extreme droughts are becoming more frequent.[112] In addition, climate change is affecting naturally occurring bark beetles: warmer winter conditions allow these pests to breed more frequently and successfully.[113,114] The dead trees left behind by bark beetles may make crown fires more likely, at least until needles fall from killed trees.[114,115] Forest management practices also have made the forests more vulnerable to catastrophic fires. In New Mexico, even-aged, second-growth forests were hit hardest because they are much denser than naturally occurring forest and consequently consume more water from the soil and increase the availability of dry above-ground fuel.

Biological Responses to Climate Change

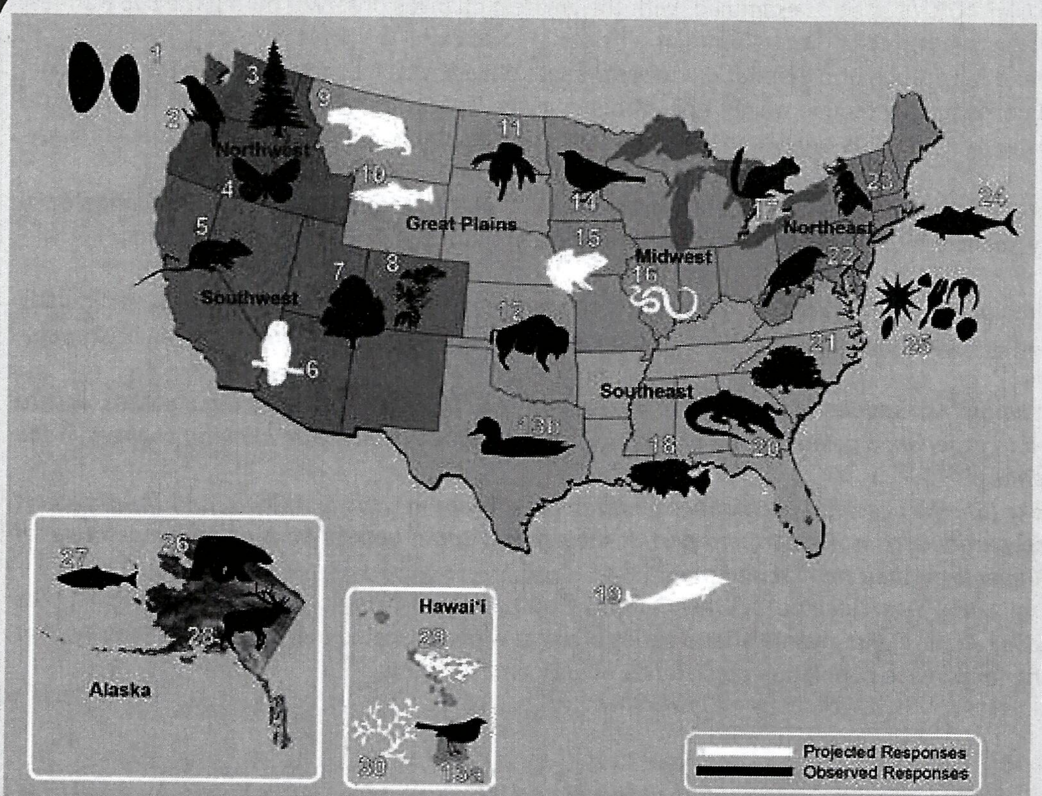


Figure 8.4. Map of selected observed and projected biological responses to climate change across the United States. Case studies listed below correspond to observed responses (black icons on map) and projected responses (white icons on map, bold italicized statements). In general, because future climatic changes are projected to exceed those experienced in the recent past, projected biological impacts tend to be of greater magnitude than recent observed changes. Because the observations and projections presented here are not paired (that is, they are not for the same species or systems), that general difference is not illustrated. (Figure source: Staudinger et al., 2012[4]).

Continued

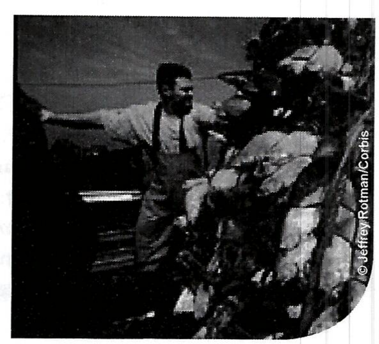
Biological responses to climate change (continued)

1. Mussel and barnacle beds have declined or disappeared along parts of the Northwest coast due to higher temperatures and drier conditions that have compressed habitable intertidal space.[116]
2. Northern flickers arrived at breeding sites earlier in the Northwest in response to temperature changes along migration routes, and egg laying advanced by 1.15 days for every degree increase in temperature, demonstrating that this species has the capacity to adjust their phenology in response to climate change.[117]
3. Conifers in many western forests have experienced mortality rates of up to 87% from warming-induced changes in the prevalence of pests and pathogens and stress from drought.[118]
4. Butterflies that have adapted to specific oak species have not been able to colonize new tree species when climate change-induced tree migration changes local forest types, potentially hindering adaptation.[119]
5. In response to climate-related habitat change, many small mammal species have altered their elevation ranges, with lower-elevation species expanding their ranges and higher-elevation species contracting their ranges.[120]
6. ***Northern spotted owl populations in Arizona and New Mexico are projected to decline during the next century and are at high risk for extinction due to hotter, drier conditions, while the southern California population is not projected to be sensitive to future climatic changes.***[121]
7. Quaking aspen-dominated systems are experiencing declines in the western U.S. after stress due to climate-induced drought conditions during the last decade.[122]
8. Warmer and drier conditions during the early growing season in high-elevation habitats in Colorado are disrupting the timing of various flowering patterns, with potential impacts on many important plant-pollinator relationships.[77]
9. ***Population fragmentation of wolverines in the northern Cascades and Rocky Mountains is expected to increase as spring snow cover retreats over the coming century.***[123]
10. ***Cutthroat trout populations in the western U.S. are projected to decline by up to 58%, and total trout habitat in the same region is projected to decline by 47%, due to increasing temperatures, seasonal shifts in precipitation, and negative interactions with non-native species.***[8]
11. Comparisons of historical and recent first flowering dates for 178 plant species from North Dakota showed significant shifts occurred in over 40% of species examined, with the greatest changes observed during the two warmest years of the study.[75]
12. Variation in the timing and magnitude of precipitation due to climate change was found to decrease the nutritional quality of grasses, and consequently reduce weight gain of bison in the Konza Prairie in Kansas and the Tallgrass Prairie Preserve in Oklahoma.[124] Results provide insight into how climate change will affect grazer population dynamics in the future.
13. (a and b) Climatic fluctuations were found to influence mate selection and increase the probability of infidelity in birds that are normally socially monogamous, increasing the gene exchange and the likelihood of offspring survival.[125]
14. Migratory birds monitored in Minnesota over a 40-year period showed significantly earlier arrival dates, particularly in short-distance migrants, indicating that some species are capable of responding to increasing winter temperatures better than others.[126]
15. ***Up to 50% turnover in amphibian species is projected in the eastern U.S. by 2100, including the northern leopard frog, which is projected to experience poleward and elevational range shifts in response to climatic changes in the latter quarter of the century.***[127]
16. ***Studies of black ratsnake (Elaphe obsoleta) populations at different latitudes in Canada, Illinois, and Texas suggest that snake populations, particularly in the northern part of their range, could benefit from rising temperatures if there are no negative impacts on their habitat and prey.***[128]
17. Warming-induced hybridization was detected between southern and northern flying squirrels in the Great Lakes region of Ontario, Canada, and in Pennsylvania after a series of warm winters created more overlap in their habitat range, potentially acting to increase population persistence under climate change.[129]

Continued

Biological Responses to Climate Change (continued)

18. Some warm-water fishes have moved northwards, and some tropical and subtropical fishes in the northern Gulf of Mexico have increased in temperate ocean habitat.[130] Similar shifts and invasions have been documented in Long Island Sound and Narragansett Bay in the Atlantic.[131]
19. ***Global marine mammal diversity is projected to decline at lower latitudes and increase at higher latitudes due to changes in temperatures and sea ice, with complete loss of optimal habitat for as many as 11 species by mid-century; seal populations living in tropical and temperate waters are particularly at risk to future declines.***[132]
20. Higher nighttime temperatures and cumulative seasonal rainfalls were correlated with changes in the arrival times of amphibians to wetland breeding sites in South Carolina over a 30-year time period (1978-2008).[133]
21. Seedling survival of nearly 20 resident and migrant tree species decreased during years of lower rainfall in the Southern Appalachians and the Piedmont areas, indicating that reductions in native species and limited replacement by invading species were likely under climate change.[134]
22. Widespread declines in body size of resident and migrant birds at a bird-banding station in western Pennsylvania were documented over a 40-year period; body sizes of breeding adults were negatively correlated with mean regional temperatures from the preceding year.[85]
23. Over the last 130 years (1880-2010), native bees have advanced their spring arrival in the northeastern U.S. by an average of 10 days, primarily due to increased warming. Plants have also showed a trend of earlier blooming, thus helping preserve the synchrony in timing between plants and pollinators.[135]
24. In the Northwest Atlantic, 24 out of 36 commercially exploited fish stocks showed significant range (latitudinal and depth) shifts between 1968 and 2007 in response to increased sea surface and bottom temperatures.[55]
25. Increases in maximum, and decreases in the annual variability of, sea surface temperatures in the North Atlantic Ocean have promoted growth of small phytoplankton and led to a reorganization in the species composition of primary (phytoplankton) and secondary (zooplankton) producers.[136]
26. Changes in female polar bear reproductive success (decreased litter mass and numbers of yearlings) along the north Alaska coast have been linked to changes in body size and/or body condition following years with lower availability of optimal sea ice habitat.[137]
27. Water temperature data and observations of migration behaviors over a 34-year time period showed that adult pink salmon migrated earlier into Alaskan creeks, and fry advanced the timing of migration out to sea. Shifts in migration timing may increase the potential for a mismatch in optimal environmental conditions for early life stages, and continued warming trends will likely increase pre-spawning mortality and egg mortality rates.[87]
28. Warmer springs in Alaska have caused earlier onset of plant emergence, and decreased spatial variation in growth and availability of forage to breeding caribou. This ultimately reduced calving success in caribou populations.[138]
29. ***Many Hawaiian mountain vegetation types were found to vary in their sensitivity to changes in moisture availability; consequently, climate change will likely influence elevation-related vegetation patterns in this region.***[139]
30. ***Sea level is predicted to rise by 1.6 to 3.3 feet in Hawaiian waters by 2100, consistent with global projections of 1 to 4 feet of sea level rise (see Ch. 2: Our Changing Climate, Key Message 10). This is projected to increase wave heights, the duration of turbidity, and the amount of re-suspended sediment in the water; consequently, this will create potentially stressful conditions for coral reef communities.***[140]



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SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages

The key messages and supporting chapter text summarize extensive evidence documented in the Ecosystems Technical Input Report, *Impacts of Climate Change on Biodiversity, Ecosystems, and Ecosystem Services: Technical Input to the 2013 National Climate Assessment.*[4] This foundational report evolved from a technical workshop held at the Gordon and Betty Moore Foundation in Palo Alto, CA, in January 2012 and attended by approximately 65 scientists. Technical inputs (127) on a wide range of topics related to ecosystems were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Key message #1 Traceable Account

Climate change impacts on ecosystems reduce their ability to improve water quality and regulate water flows.

Description of evidence base

The author team digested the contents of more than 125 technical input reports on a wide array of topics to arrive at this key message. The foundational Technical Input Report[4] was the primary source used.

Studies have shown that increasing precipitation is already resulting in declining water quality in many regions of the country, particularly by increasing nitrogen loading.[10,11,12,13,14] This is because the increases in flow can pick up and carry greater loads of nutrients like nitrogen to rivers.[11,12,13,14]

One model for the Mississippi River Basin, based on a doubling of CO_2, projects that increasing discharge and nitrogen loading will lead to larger algal blooms in the Gulf of Mexico and a larger dead zone.[28] The Gulf of Mexico is the recipient system for the Mississippi Basin, receiving all of the nitrogen that is carried downriver but not removed by river processes, wetlands, or other ecosystems.

Several models project that declining streamflow, due to the combined effects of climate change and water withdrawals, will cause local extinctions of fish and other aquatic organisms,[7] particularly trout in the interior western U.S. (composite of 10 models, A1B scenario).[8] The trout study[8] is one of the few studies of impacts on fish that uses an emissions scenario and a combination of climate models. The researchers studied four different trout species. Although there were variations among species, their overall conclusion was robust across species for the composite model.

Water quality can also be negatively affected by increasing temperatures. There is widespread evidence that warmer lakes can promote the growth of harmful algal blooms, which produce toxins.[31]

New information and remaining uncertainties

Recent research has improved understanding of the relative importance of the effects of climate and human actions (for example, fertilization) on nitrogen losses from watersheds,[10,12] and how the interactions between climate and human actions (for example, water withdrawals) will affect fish populations in the west.[7,8] However, few studies have projected the impacts of future climate change on water quality. Given the tight link between river discharge and pollutants, only areas of the U.S. that are projected to see increases in precipitation will see increases in pollutant transport to rivers. It is also important to note that pollutant loading – for example, nitrogen fertilizer use – is often more important as a driver of water pollution than climate.[10,12]

Assessment of confidence based on evidence

Given the evidence base and uncertainties, there is **high** confidence that climate change impacts on ecosystems reduce their ability to improve water quality and regulate water flows.

It is well established that precipitation and associated river discharge are major drivers of water pollution in the form of excess nutrients, sediment, and dissolved organic carbon (DOC) transport into rivers. Increases in precipitation in many regions of the country are therefore contributing to declines in water quality in those areas. However, those areas of the country that will see reduced precipitation may experience water-quality improvement; thus, any lack of agreement on future water-quality impacts of climate change may be due to locational differences.

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

Key message #2 Traceable Account

Climate change, combined with other stressors, is overwhelming the capacity of ecosystems to buffer the impacts from extreme events like fires, floods, and storms.

Description of evidence base

The author team digested the contents of more than 125 technical input reports on a wide array of topics to arrive at this key message. The foundational Technical Input Report[4] was the primary source used.

Fires: Climate change has increased the potential for extremely large fires with novel social, economic, and environmental impacts. In 2011, more than 8 million acres burned, with significant human mortality and property damage ($1.9 billion).[38] Warming and decreased precipitation have made fire-prone ecosystems more vulnerable to "mega-fires" – large fires that are unprecedented in their social, economic, and environmental impacts. Large fires put people living in the urban-wildland interface at risk for health problems and property loss.

Floods: Natural ecosystems such as salt marshes, reefs, mangrove forests, and barrier islands defend coastal ecosystems and infrastructure against flooding due to storm surges. The loss of these natural features due to coastal development, erosion, and sea level rise render coastal ecosystems and infrastructure more vulnerable to catastrophic damage during or after extreme events (see Ch. 25: Coasts).[36] Floodplain wetlands, which are also vulnerable to loss by inundation, absorb floodwaters and reduce the impact of high flows on river-margin lands. In the Northeast, a sea level rise of 1.6 feet (within the range of 1 to 4 feet projected for 2100; Ch. 2: Our Changing Climate, Key Message 9) will dramatically increase impacts of storm surge on people (47% increase) and property loss (73% increase) in Long Island.[37]

Storms: Natural ecosystems have a capacity to buffer extreme weather events that produce sudden increases in water flow and materials. These events reduce the amount of time water is in contact with sites that support the plants and microbes that remove pollutants (Chapter 25: Coasts).[36]

New information and remaining uncertainties

A new analytical framework was recently developed to generate insights into the interactions among the initial state of ecosystems, the type and magnitude of disturbance, and effects of disturbance.[34] Progress in understanding these relationships is critical for predicting how human activities and climate change, including extreme events like droughts, floods, and storms, will interact to affect ecosystems.

Uncertainties: The ability of ecosystems to buffer extreme events is extremely difficult to assess and quantify, as it requires understanding of complex ecosystem responses to very rare events. However, it is clear that the loss of this buffering ecosystem service is having important effects on coastal and fire-prone ecosystems across the United States.

Assessment of confidence based on evidence

Given the evidence base and uncertainties, there is **high** confidence that climate change, combined with other stressors, is overwhelming the capacity of ecosystems to buffer the impacts from extreme events like droughts, floods, and storms.

Ecosystem responses to climate change will vary regionally. For example, whether salt marshes and mangroves will be able to accrue sediment at rates sufficient to keep ahead of sea level rise and maintain their protective function will vary by region.

Climate has been the dominant factor controlling burned area during the 20th century, even during periods of fire suppression by forest management,[40,111] and the area burned annually has increased steadily over the last 20 years concurrent with warming and/or drying climate. Warming and decreased precipitation have also made fire-prone ecosystems more vulnerable to "mega-fires" – large fires that are unprecedented in their social, economic, and environmental impacts. Large fires put people living in the urban-wildland interface at risk for health problems and property loss. In 2011 alone, 8.3 million acres burned in wildfires, causing 15 deaths and property losses greater than $1.9 billion.[38]

Key message #3 Traceable Account

Landscapes and seascapes are changing rapidly, and species, including many iconic species, may disappear from regions where they have been prevalent or become extinct, altering some regions so much that their mix of plant and animal life will become almost unrecognizable.

Description of evidence base

The analysis for the Technical Input Report applied a range of future climate scenarios and projected biome changes across 5% to about 20% of the land area in the U.S. by 2100.[4] Other analyses support these projections.[39] Studies predict that wildfire will be a major driver of change in some areas, including Yellowstone National Park[40] and the Arctic.[41] These biome shifts will be associated with changes in species distributions.[43]

Evidence indicates that the most obvious changes will occur at the boundaries between ecosystems.[47,48,49,51] Plants and animals are already moving to higher elevations and latitudes in response to climate change,[43] with models projecting greater range shifts[8,46] and local extinctions in the future, leading to new plant and animal communities that may be unrecognizable in some regions.[4,45,46] One study on fish[8] used global climate models (GCMs) simulating conditions in the 2040s and 2080s under the A1B emissions scenario, with the choice of models reflecting predictions of high and low climate warming as well as an ensemble of ten models. Their models additionally accounted for biotic interactions. In a second study, a 30-year baseline (1971-2000) and output from two GCMs under the A2 scenario (continued increases in global emissions) were used to develop climate variables that effectively predict present and future species ranges.[46] Empirical data from the Sonoran Desert (n=39 plots) were used to evaluate species responses to past climate variability.

Iconic species: Wildfire is expected to damage and kill iconic desert species, including saguaro cactus.[63] Bark beetle outbreaks, which have been exacerbated by climate change, are damaging extensive areas of temperate and boreal conifer forests that are characteristic of the western United States.[64]

New information and remaining uncertainties

In addition to the Technical Input Report, more than 20 new studies of observed and predicted effects of climate change on biomes and species distribution were incorporated in the assessment.

While changes in ecosystem structure and biodiversity, including the distribution of iconic species, are occurring and are highly likely to continue, the impact of these changes on ecosystem services is unclear, that is, there is uncertainty about the impact that loss of familiar landscapes will have on people.

Assessment of confidence based on evidence

Based on the evidence base and uncertainties, confidence is **high** that familiar landscapes are changing so rapidly that iconic species may disappear from regions where they have been prevalent, altering some regions so much that their mix of plant and animal life will become almost unrecognizable. Many changes in species distribution have already occurred and will inevitably continue, resulting in the loss of familiar landscapes and the production of novel species assemblages.

Key message #4 Traceable Account

Timing of critical biological events, such as spring bud burst, emergence from overwintering, and the start of migrations, has shifted, leading to important impacts on species and habitats.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in the Ecosystems Technical Input, *Phenology as a bio-indicator of climate change impacts on people and ecosystems: Towards an integrated national assessment approach.*[71] An additional 127 input reports, on a wide range of topics related to ecosystems, were also received and reviewed as part of the Federal Register Notice solicitation for public input.

Many studies have documented an advance in springtime phenological events of species in response to climate warming. For example, long-term observations of lilac flowering indicate that the onset of spring has advanced one day earlier per decade across the northern hemisphere in response to increased winter and spring temperatures, and by 1.5 days per decade earlier in the western United States.[72,73] Other multi-decadal studies for plant species have documented similar trends for early flowering.[74,75] Evidence suggests that insect emergence from overwintering may become out of sync with pollen sources,[77] and that the beginning of bird and fish migrations are shifting.[82,83,84,85,86,87]

New information and remaining uncertainties

In addition to the Ecosystems Technical Input[71] many new studies have been conducted since the previous National Climate Assessment,[141] contributing to our understanding of the impacts of climate change on phenological events. Many studies, in many areas, have shown significant changes in phenology, including spring bud burst, emergence from overwintering, and migration shifts.

A key uncertainty is "phase effects" where organisms are so out of phase with their natural phenology that outbreaks of pests occur, species emerge and cannot find food, or pollination is disrupted. This will vary with specific species and is therefore very difficult to predict.[70]

Assessment of confidence based on evidence

Given the evidence base and uncertainties, there is very high confidence that the timing of critical events, such as spring bud burst, emergence from overwintering, and the start of migrations, has shifted, leading to important impacts on species and habitats.

Key message #5 Traceable Account

Whole system management is often more effective than focusing on one species at a time, and can help reduce the harm to wildlife, natural assets, and human well-being that climate disruption might cause.

Description of evidence base

Adaptation planning for conservation at federal[92,93,94] and state levels,[95] is focused on cooperation between scientists and managers.[34,94,96,97] Development of ecosystem-based whole system management[98] utilizes concepts about "biodiversity and ecosystem services to help people adapt to climate change."[99] An example is the use of coastal wetlands or mangroves rather than built infrastructure like seawalls or levees to protect coastal regions from storms (Chapter 25: Coasts).[100]

New information and remaining uncertainties

Adaptation strategies to protect biodiversity include: 1) habitat manipulations, 2) conserving populations with higher genetic diversity or more plastic behaviors or morphologies, 3) changing seed sources for re-planting to introduce species or ecotypes that are better suited for future climates, 4) managed relocation (sometimes referred to as assisted migration) to help move species and populations from current locations to those areas expected to become more suitable in the future, and 5) ex-situ conservation such as seed banking and captive breeding.[92,94,96,97,102] Alternative approaches focus on identifying and protecting features that are important for biodiversity and are projected to be less altered by climate change. The idea is to conserve the physical conditions that contribute to high levels of biodiversity so that species and populations can find suitable areas in the future.[104]

Assessment of confidence based on evidence

Given the evidence and remaining uncertainties, there is **very high** confidence that ecosystem-based management approaches are increasingly prevalent, and provide options for reducing the harm to biodiversity, ecosystems, and the services they provide to society. The effectiveness of these actions is much less certain, however.

Climate Change Impacts in the United States

CHAPTER 9
HUMAN HEALTH

Convening Lead Authors

George Luber, Centers for Disease Control and Prevention

Kim Knowlton, Natural Resources Defense Council and Mailman School of Public Health, Columbia University

Lead Authors

John Balbus, National Institutes of Health

Howard Frumkin, University of Washington

Mary Hayden, National Center for Atmospheric Research

Jeremy Hess, Emory University

Michael McGeehin, RTI International

Nicky Sheats, Thomas Edison State College

Contributing Authors

Lorraine Backer, Centers for Disease Control and Prevention

C. Ben Beard, Centers for Disease Control and Prevention

Kristie L. Ebi, ClimAdapt, LLC

Edward Maibach, George Mason University

Richard S. Ostfeld, Cary Institute of Ecosystem Studies

Christine Wiedinmyer, National Center for Atmospheric Research

Emily Zielinski-Gutiérrez, Centers for Disease Control and Prevention

Lewis Ziska, United States Department of Agriculture

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INFORMATION DRAWN FROM THIS CHAPTER IS INCLUDED IN THE HIGHLIGHTS REPORT AND IS IDENTIFIED BY THIS ICON

9 HUMAN HEALTH

Key Messages

1. **Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, threats to mental health, and illnesses transmitted by food, water, and disease-carriers such as mosquitoes and ticks. Some of these health impacts are already underway in the United States.**
2. **Climate change will, absent other changes, amplify some of the existing health threats the nation now faces. Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color.**
3. **Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited.**
4. **Responding to climate change provides opportunities to improve human health and well-being across many sectors, including energy, agriculture, and transportation. Many of these strategies offer a variety of benefits, protecting people while combating climate change and providing other societal benefits.**

Climate change, together with other natural and human-made health stressors, influences human health and disease in numerous ways. Some existing health threats will intensify and new health threats will emerge. Not everyone is equally at risk. Important considerations include age, economic resources, and location. Preventive and adaptive actions, such as setting up extreme weather early warning systems and improving water infrastructure, can reduce the severity of these impacts, but there are limits to the effectiveness of such actions in the face of some projected climate change threats.

Climate change presents a global public health problem, with serious health impacts predicted to manifest in varying ways in different parts of the world. Public health in the U.S. can be affected by disruptions of physical, biological, and ecological systems, including disturbances originating in the U.S. and elsewhere. Health effects of these disruptions include increased respiratory and cardiovascular disease, injuries and premature deaths related to extreme weather events, changes in the prevalence and geographical distribution of food- and waterborne illnesses and other infectious diseases, and threats to mental health.

Key weather and climate drivers of health impacts include increasingly frequent, intense, and longer-lasting extreme heat, which worsens drought, wildfire, and air pollution risks; increasingly frequent extreme precipitation, intense storms, and changes in precipitation patterns that lead to drought and ecosystem changes (Ch. 2: Our Changing Climate); and rising sea levels that intensify coastal flooding and storm surge (Ch. 25: Coasts). Key drivers of vulnerability include the attributes of certain groups (age, socioeconomic status, race, current level of health – see Ch. 12: Indigenous Peoples for examples of health impacts on vulnerable populations) and of place (floodplains, coastal zones, and urban areas), as well as the resilience of critical public health infrastructure. Multi-stressor situations, such as impacts on vulnerable populations following natural disasters that also damage the social and physical infrastructure necessary for resilience and emergency response, are particularly important to consider when preparing for the impacts of climate change on human health.


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Key Message 1: Wide-ranging Health Impacts

Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, threats to mental health, and illnesses transmitted by food, water, and disease-carriers such as mosquitoes and ticks. Some of these health impacts are already underway in the United States.

Air Pollution

Climate change is projected to harm human health by increasing ground-level ozone and/or particulate matter air pollution in some locations. Ground-level ozone (a key component of smog) is associated with many health problems, such as diminished lung function, increased hospital admissions and emergency room visits for asthma, and increases in premature deaths.[1,2,3] Factors that affect ozone formation include heat, concentrations of precursor chemicals, and methane emissions, while particulate matter concentrations are affected by wildfire emissions and air stagnation episodes, among other factors.[4,5] By increasing these different factors, climate change is projected to lead to increased concentration of ozone and particulate matter in some regions.[6,7,8,9] Increases in global temperatures could cause associated increases in premature deaths related to worsened ozone and particle pollution. Estimates made assuming no change in regulatory controls or population characteristics have ranged from 1,000 to 4,300 additional premature deaths nationally per year by 2050 from combined ozone and particle health effects.[10,11] There is less certainty in the responses of airborne particles to climate change than there is about the response of ozone. Health-related costs of the current effects of ozone air pollution exceeding national standards have been estimated at $6.5 billion (in 2008 U.S. dollars) nationwide, based on a U.S. assessment of health impacts from ozone levels during 2000 to 2002.[12,13]

Climate Change Projected to Worsen Asthma

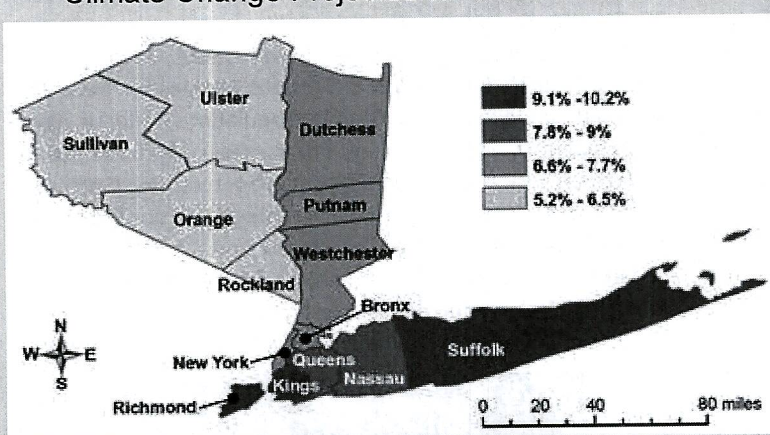


Figure 9.1. Projected increases in temperature, changes in wind patterns, and ecosystem changes will all affect future ground-level ozone concentrations. Climate projections using an increasing emissions scenario (A2) suggest that ozone concentrations in the New York metropolitan region will increase because of future climate change. This figure shows the estimated increase in ozone-related emergency room visits for children in New York in the 2020s (compared to the mid-1990s) resulting from climate change related increases in ozone concentrations. The results from this modeling exercise are shown as a percent change in visits specifically attributed to ozone exposure. For example, the 10.2% increase in Suffolk County represents five additional emergency room visits that could be attributed to increased ozone exposure over the baseline of 46 ozone-related visits from the mid-1990s. In 2010, an estimated 25.7 million Americans had asthma, which has become a problem in every state. (Figure source: Sheffield et al. 2011[14]).

Allergens

Climate change, resulting in more frost-free days and warmer seasonal air temperatures, can contribute to shifts in flowering time and pollen initiation from allergenic plant species, and increased CO_2 by itself can elevate production of plant-based allergens.[14,15,16,17,18,19] Higher pollen concentrations and longer pollen seasons can increase allergic sensitizations and asthma episodes,[20,21,22] and diminish productive work and school days.[19,22,23] Simultaneous exposure to toxic air pollutants can worsen allergic responses.[24,25,26] Extreme rainfall and rising temperatures can also foster indoor air quality problems, including the growth of indoor fungi and molds, with increases in respiratory and asthma-related conditions.[27] Asthma prevalence (the percentage of people who have ever been diagnosed with asthma and still have asthma) increased nationwide from 7.3% in 2001 to 8.4% in 2010. Asthma visits in primary care settings, emergency room visits, and hospitalizations were all stable from 2001 to 2009, and asthma death rates per 1,000 persons with asthma declined from 2001 to 2009.[28] To the extent that increased pollen exposures occur, patients and their physicians will face increased challenges in maintaining adequate asthma control.

Ragweed Pollen Season Lengthens

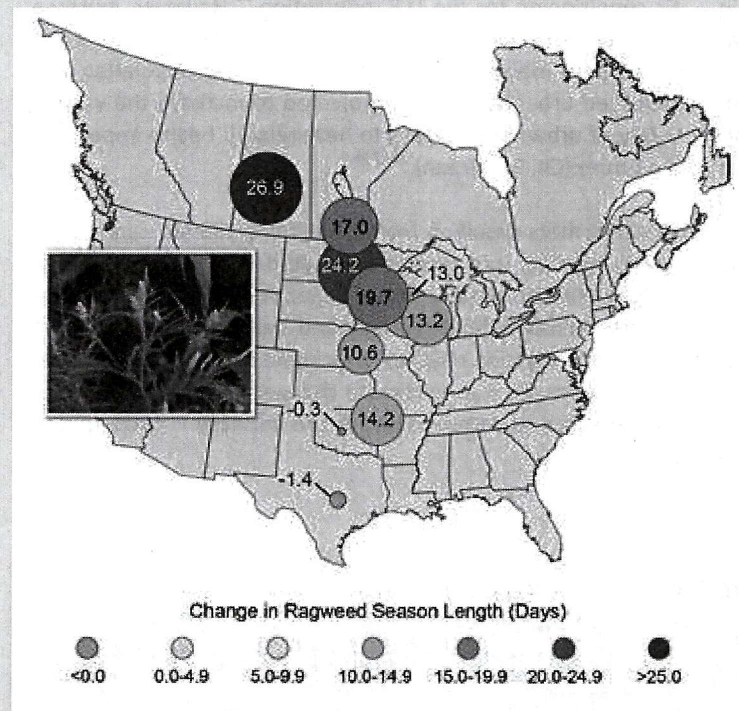


Figure 9.2. Ragweed pollen season length has increased in central North America between 1995 and 2011 by as much as 11 to 27 days in parts of the U.S. and Canada in response to rising temperatures. Increases in the length of this allergenic pollen season are correlated with increases in the number of days before the first frost. As shown in the figure, the largest increases have been observed in northern cities. (Data updated from Ziska et al. 2011[19]; Photo credit: Lewis Ziska, USDA).

Wildfires

Climate change is currently increasing the vulnerability of many forests to wildfire. Climate change is projected to increase the frequency of wildfire in certain regions of the United States (Ch. 7: Forests).[17,29] Long periods of record high temperatures are associated with droughts that contribute to dry conditions and drive wildfires in some areas.[30] Wildfire smoke contains particulate matter, carbon monoxide, nitrogen oxides, and various volatile organic compounds (which are ozone precursors)[31] and can significantly reduce air quality, both locally and in areas downwind of fires.[32,33] Smoke exposure increases respiratory and cardiovascular hospitalizations, emergency department visits, and medication dispensations for asthma, bronchitis, chest pain, chronic obstructive pulmonary disease (commonly known by its acronym, COPD), respiratory infections, and medical visits for lung illnesses.[32,34,35] It has been associated with hundreds of thousands of deaths annually, in an assessment of the global health risks from landscape fire smoke.[32,34,36,37] Future climate change is projected to increase wildfire risks and associated emissions, with harmful impacts on health.[17,38,39,40]

Wildfire Smoke has Widespread Health Effects

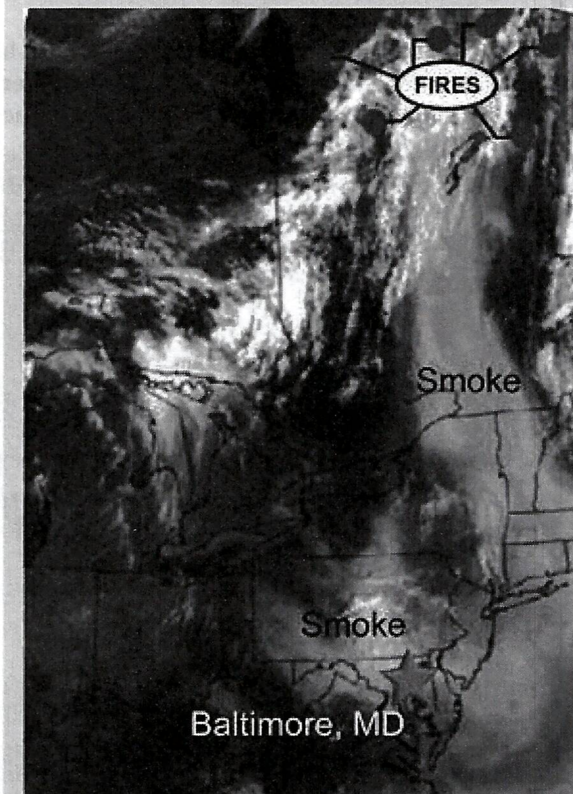


Figure 9.3. Wildfires, which are projected to increase in some regions due to climate change, have health impacts that can extend hundreds of miles. Shown here, forest fires in Quebec, Canada, during July 2002 (red circles) resulted in up to a 30-fold increase in airborne fine particle concentrations in Baltimore, Maryland, a city nearly a thousand miles downwind. These fine particles, which are extremely harmful to human health, not only affect outdoor air quality, but also penetrate indoors, increasing the long-distance effects of fires on health.[41] An average of 6.4 million acres burned in U.S. wildfires each year between 2000 and 2010, with 9.5 and 9.1 million acres burned in 2006 and 2012, respectively.[42] Total global deaths from the effects of landscape fire smoke have been estimated at 260,000 to 600,000 annually between the years 1997 and 2006.[37] (Figure source: Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on the Terra satellite, Land Rapid Response Team, NASA/GSFC).

Temperature Extremes

Extreme heat events have long threatened public health in the United States.[43,44,45] Many cities, including St. Louis, Philadelphia, Chicago, and Cincinnati, have suffered dramatic increases in death rates during heat waves. Deaths result from heat stroke and related conditions,[44,45,46] but also from cardiovascular disease, respiratory disease, and cerebrovascular disease.[47,48] Heat waves are also associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders.[48,49,50] Extreme summer heat is increasing in the United States (Ch. 2: Our Changing Climate, Key Message 7),[51] and climate projections indicate that extreme heat events will be more frequent and intense in coming decades (Ch. 2: Our Changing Climate, Key Message 7).[2,52,53,54]

Some of the risks of heat-related sickness and death have diminished in recent decades, possibly due to better forecasting, heat-health early warning systems, and/or increased access to air conditioning for the U.S. population.[55] However, extreme heat events remain a cause of preventable death nationwide. Urban heat islands, combined with an aging population and increased urbanization, are projected to increase the vulnerability of urban populations to heat-related health impacts in the future (Ch. 11: Urban).[56,57,58]

Milder winters resulting from a warming climate can reduce illness, injuries, and deaths associated with cold and snow. Vulnerability to winter weather depends on many non-climate factors, including housing, age, and baseline health.[59] While deaths and injuries related to extreme cold events are projected to decline due to climate change, these reductions are not expected to compensate for the increase in heat-related deaths.[60,61]

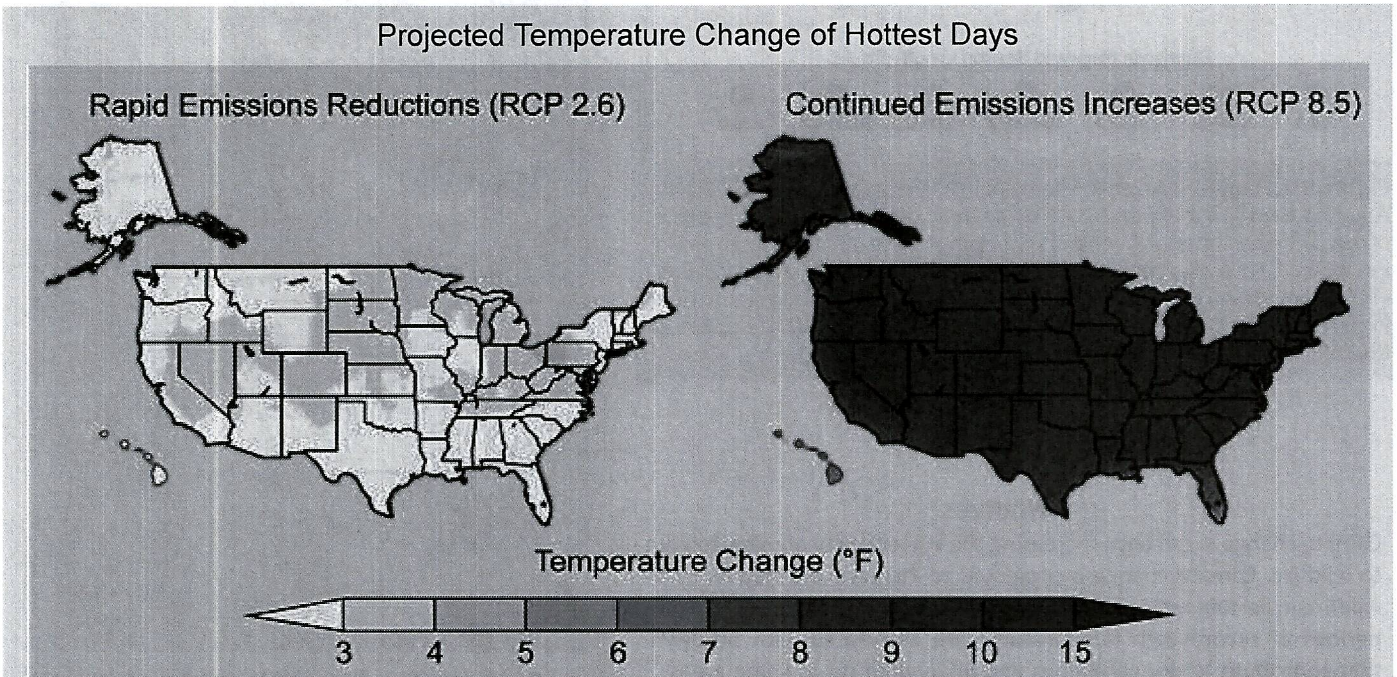


Figure 9.4. The maps show projected increases in the average temperature on the hottest days by late this century (2081-2100) relative to 1986-2005 under a scenario that assumes a rapid reduction in heat-trapping gases (RCP 2.6) and a scenario that assumes continued increases in these gases (RCP 8.5). The hottest days are those so hot they occur only once in 20 years. Across most of the continental United States, those days will be about 10°F to 15°F hotter in the future under the higher emissions scenario. (Figure source: NOAA NCDC / CICS-NC).

Precipitation Extremes: Heavy Rainfall, Flooding, and Droughts

The frequency of heavy precipitation events has already increased for the nation as a whole, and is projected to increase in all U.S. regions (Ch. 2: Our Changing Climate).[54,62] Increases in both extreme precipitation and total precipitation have contributed to increases in severe flooding events in certain regions (see Ch. 2: Our Changing Climate, Figure 2.21). Floods are the second deadliest of all weather-related hazards in the United States, accounting for approximately 98 deaths per year,[63] most due to drowning.[64] Flash floods (see Ch. 3: Water, "Flood Factors and Flood Types") and flooding associated with tropical storms result in the highest number of deaths.[63]

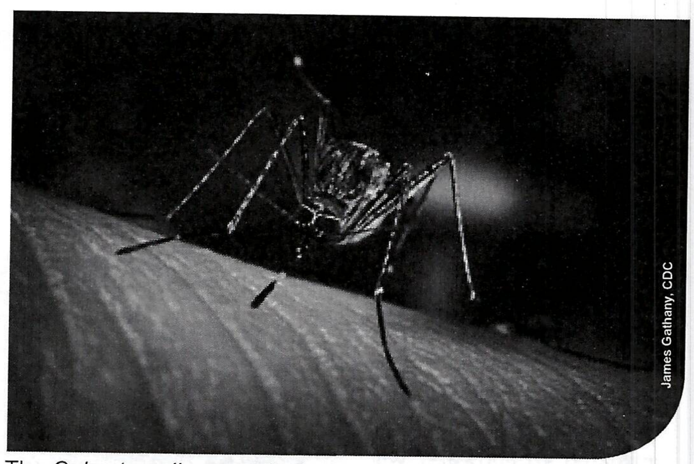
In addition to the immediate health hazards associated with extreme precipitation events when flooding occurs, other hazards can often appear once a storm event has passed. Elevated waterborne disease outbreaks have been reported in the weeks following heavy rainfall,[65] although other variables may affect these associations.[66] Water intrusion into buildings can result in mold contamination that manifests later, leading to indoor air quality problems. Buildings damaged during hurricanes are especially susceptible to water intrusion. Populations living in damp indoor environments experience increased prevalence of asthma and other upper respiratory tract symptoms, such as coughing and wheezing[67] as well as lower respiratory tract infections such as pneumonia, Respiratory Syncytial Virus (RSV), and RSV pneumonia (see Figure 9.7).[68]

At the opposite end of precipitation extremes, drought also poses risks to public health and safety.[69] Drought conditions may increase the environmental exposure to a broad set of health hazards including wildfires, dust storms, extreme heat events, flash flooding, degraded water quality, and reduced water quantity. Dust storms associated with drought conditions contribute to degraded air quality due to particulates and have been associated with increased incidence of Coccidioidomycosis (Valley fever), a fungal pathogen, in Arizona and California.[70]

Disease Carried by Vectors

Climate is one of the factors that influence the distribution of diseases borne by vectors (such as fleas, ticks, and mosquitoes, which spread pathogens that cause illness).[71,72,73,74,75,76,77,78] The geographic and seasonal distribution of vector populations, and the diseases they can carry, depend not only on climate but also on land use, socioeconomic and cultural factors, pest control, access to health care, and human responses to disease risk, among other factors.[72,73,79,80,81] Daily, seasonal, or year-to-year climate variability can sometimes result in vector/pathogen adaptation and shifts or expansions in their geographic ranges.[73,74,81] Such shifts can alter disease incidence depending on vector-host interaction, host immunity, and pathogen evolution.[71] North Americans are currently at risk from numerous vector-borne diseases, including Lyme,[75,82,83,84] dengue fever,[85] West Nile virus,[86] Rocky Mountain spotted fever,[87] plague, and tularemia.[88] Vector-borne pathogens not currently found in the United States, such as chikungunya, Chagas disease, and Rift Valley fever viruses, are also threats. Climate change effects on the geographical distribution and incidence of vector-borne diseases in other countries where these diseases are already found can also affect North Americans, especially as a result of increasing trade with, and travel to, tropical and subtropical areas.[74,81] Whether climate change in the U.S. will increase the chances of domestically acquiring diseases such as dengue fever is uncertain, due to vector-control efforts and lifestyle factors, such as time spent indoors, that reduce human-insect contact.

Infectious disease transmission is sensitive to local, small-scale differences in weather, human modification of the landscape, the diversity of animal hosts,[83] and human behavior that affects vector-human contact, among other factors. There is a need for finer-scale, long-term studies to help quantify the relationships among weather variables, vector range, and vector-borne pathogen occurrence, the consequences of shifting distributions of vectors and pathogens, and the impacts on human behavior. Enhanced vector surveillance and human disease tracking are needed to address these concerns.



The *Culex tarsalis* mosquito is a vector that transmits West Nile Virus.

Transmission Cycle of Lyme Disease

The development and survival of blacklegged ticks, their animal hosts, and the Lyme disease bacterium, *Borrelia burgdorferi*, are strongly influenced by climatic factors, especially temperature, precipitation, and humidity. Potential impacts of climate change on the transmission of Lyme disease include: 1) changes in the geographic distribution of the disease due to the increase in favorable habitat for ticks to survive off their hosts;[89] 2) a lengthened transmission season due to earlier onset of higher temperatures in the spring and later onset of cold and frost; 3) higher tick densities leading to greater risk in areas where the disease is currently observed, due to milder winters and potentially larger rodent host populations; and 4) changes in human behaviors, including increased time outdoors, which may increase the risk of exposure to infected ticks.

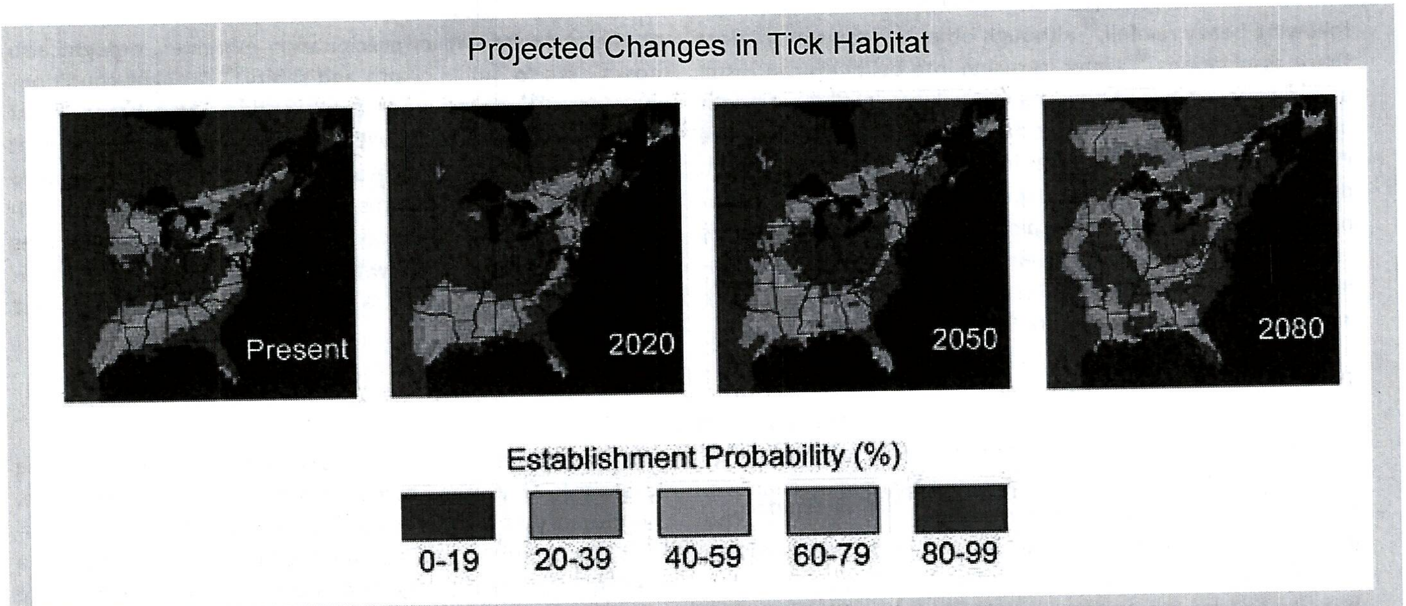


Figure 9.5. The maps show the current and projected probability of establishment of tick populations (*Ixodes scapularis*) that transmit Lyme disease. Projections are shown for 2020, 2050, and 2080. The projected expansion of tick habitat includes much of the eastern half of the country by 2080. For some areas around the Gulf Coast, the probability of tick population establishment is projected to decrease by 2080. (Figure source: adapted from Brownstein et al. 2005[90]).

Food- and Waterborne Diarrheal Disease

Diarrheal disease is a major public health issue in developing countries and, while not generally increasing in the United States, remains a persistent concern nonetheless. Exposure to a variety of pathogens in water and food causes diarrheal disease. Air and water temperatures, precipitation patterns, extreme rainfall events, and seasonal variations are all known to affect disease transmission.[65,91,92] In the United States, children and the elderly are most vulnerable to serious outcomes, and those exposed to inadequately or untreated groundwater will be among those most affected.

In general, diarrheal diseases including Salmonellosis and Campylobacteriosis are more common when temperatures are higher,[93,94] though patterns differ by place and pathogen. Diarrheal diseases have also been found to occur more frequently in conjunction with both unusually high and low precipitation.[95] Sporadic increases in streamflow rates, often preceded by rapid snowmelt[96] and changes in water treatment,[97] have also been shown to precede outbreaks. Risks of waterborne illness and beach closures resulting from changes in the magnitude of recent precipitation (within the past 24 hours) and in lake temperature are expected to increase in the Great Lakes region due to projected climate change.[98,99]

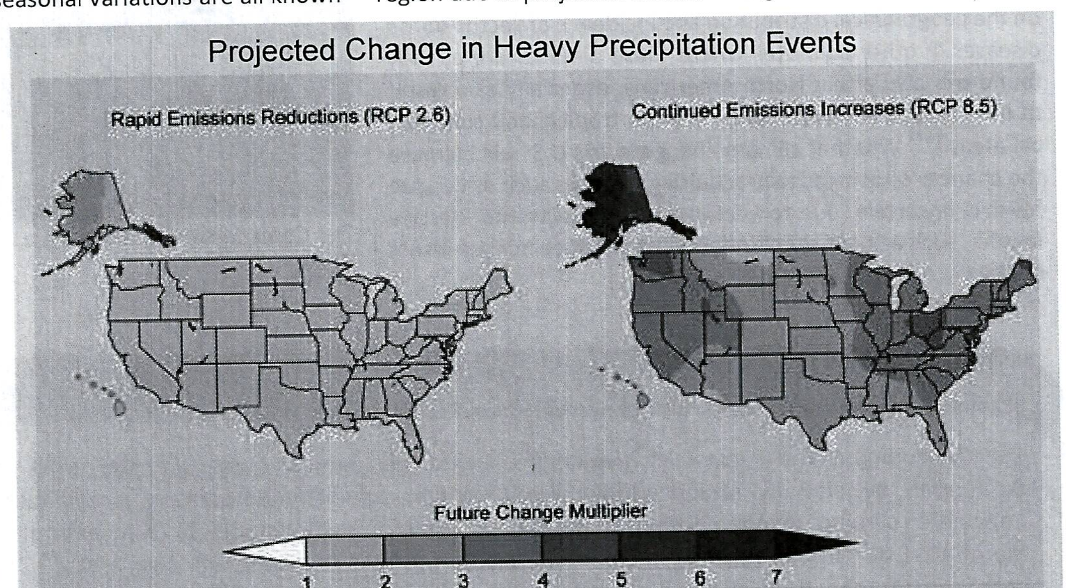


Figure 9.6. Maps show the increase in frequency of extreme daily precipitation events (a daily amount that now occurs just once in 20 years) by the later part of this century (2081-2100) compared to the latter part of the last century (1981-2000). Such extreme events are projected to occur more frequently everywhere in the United States. Under a rapid emissions reduction scenario (RCP 2.6), these events would occur nearly twice as often. For a scenario assuming continued increases in emissions (RCP 8.5), these events would occur up to five times as often. (Figure source: NOAA NCDC / CICS-NC).

Heavy Downpours are Increasing Exposure to Disease

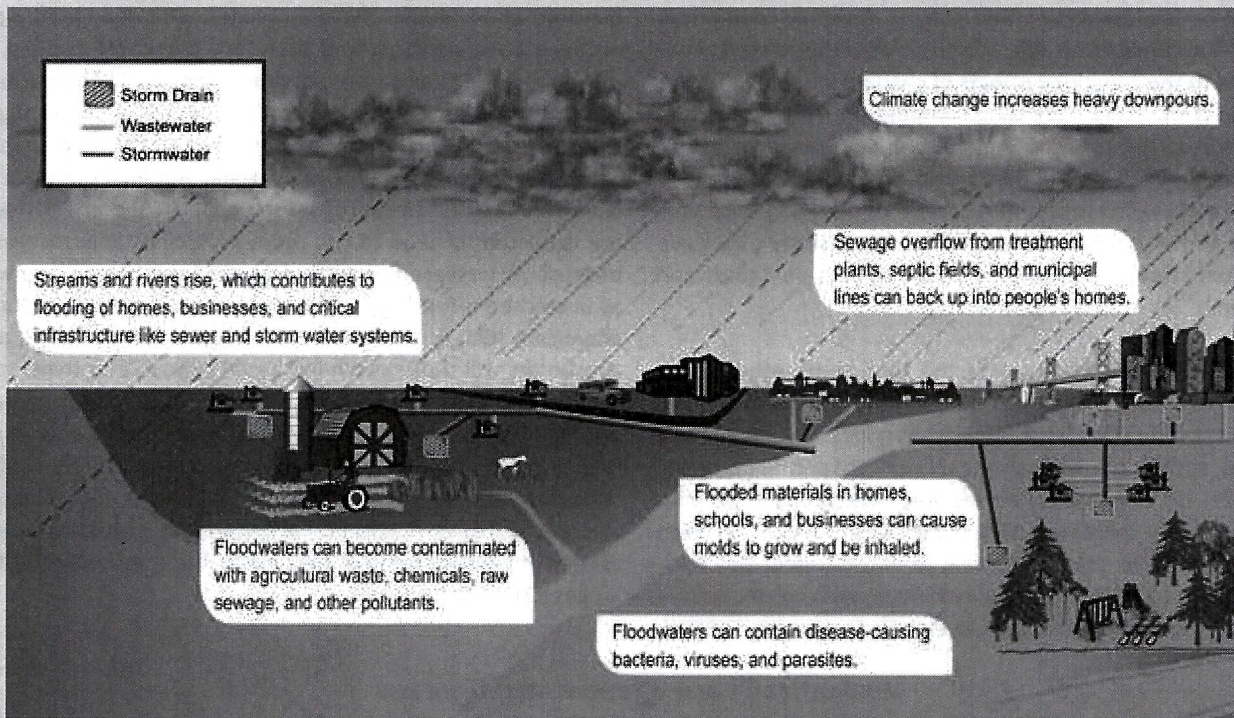


Figure 9.7. Heavy downpours, which are increasing in the United States, have contributed to increases in heavy flood events (Ch. 2: Our Changing Climate, Key Message 6). The figure above illustrates how people can become exposed to waterborne diseases. Human exposures to waterborne diseases can occur via drinking water, as well as recreational waters.[100,101,102,103] (Figure source: NOAA NCDC / CICS-NC).

Harmful Bloom of Algae

Figure 9.8. Remote sensing color image of harmful algal bloom in Lake Erie on October 9, 2011. The bright green areas have high concentrations of algae, which can be harmful to human health. The frequency and range of harmful blooms of algae are increasing.[102,103] Because algal blooms are closely related to climate factors, projected changes in climate could affect algal blooms and lead to increases in water- and food-borne exposures and subsequent cases of illness.[103] Other factors related to increases in harmful algal blooms include shifts in ocean conditions such as excess nutrient inputs.[101,102,103] (Figure source: NASA Earth Observatory[104]).

Food Security

Globally, climate change is expected to threaten food production and certain aspects of food quality, as well as food prices and distribution systems. Many crop yields are predicted to decline due to the combined effects of changes in rainfall, severe weather events, and increasing competition from weeds and pests on crop plants (Ch. 6: Agriculture, Key Message 6).[105,106] Livestock and fish production is also projected to decline.[107] Prices are expected to rise in response to declining food production and associated trends such as increasingly expensive petroleum (used for agricultural inputs such as pesticides and fertilizers).[108]

While the U.S. will be less affected than some other countries,[109,110] the nation will not be immune. Health can be affected in several ways. First, Americans with particular dietary patterns, such as Alaska Natives, will confront shortages of key foods (Ch. 12: Indigenous Peoples, Key Message 1).[111] Second, food insecurity increases with rising food prices.[112] In such situations, people cope by turning to nutrient-poor but calorie-rich foods, and/or they endure hunger, with consequences ranging from micronutrient malnutrition to obesity.[113] Third, the nutritional value of some foods is projected to decline. Elevated atmospheric CO_2 is associated with decreased plant nitrogen concentration, and therefore decreased protein, in many crops, such as barley, sorghum, and soy.[114] The nutrient content of crops is also projected to decline if soil nitrogen levels are suboptimal, with reduced levels of nutrients such as calcium, iron, zinc, vitamins, and sugars, although this effect is alleviated if sufficient nitrogen is supplied.[115] Fourth, farmers are expected to need to use more herbicides and pesticides because of increased growth of pests[116] and weeds[117] as well as decreased effectiveness[118] and duration[119] of some of these chemicals (Ch. 6: Agriculture). Farmers, farmworkers, and consumers will thus sustain increased exposure to these substances and their residues, which can be toxic. These climate change impacts on the nutritional value of food exist within a larger context in which other factors, such as agricultural practices, food distribution systems, and consumer food choices, also play key roles. Adaptation activities can reduce the health-related impacts of some of the anticipated food security challenges (Ch. 6: Agriculture).

Mental Health and Stress-related Disorders

Mental illness is one of the major causes of suffering in the United States, and extreme weather events can affect mental health in several ways.[120,121,122,123] First, following disasters, mental health problems increase, both among people with no history of mental illness, and those at risk – a phenomenon known as "common reactions to abnormal events." These reactions may be short-lived or, in some cases, long-lasting.[124] For example, research demonstrated high levels of anxiety and post-traumatic stress disorder among people affected by Hurricane Katrina,[125] and similar observations have followed floods[126] and heat waves.[127] Some evidence suggests wildfires have similar effects.[128] All of these events are increasingly fueled by climate change (see Ch. 2: Our Changing Climate). Other health consequences of intensely stressful exposures are also a concern, such as adverse birth outcomes including pre-term birth, low birth weight, and maternal complications.[129] Second, some patients with mental illness are especially susceptible to heat.[130] Suicide rates vary with weather,[131] rising with high temperatures,[132] suggesting potential climate change impacts on depression and other mental illnesses. Dementia is a risk factor for hospitalization and death during heat waves.[127,133] Patients with severe mental illness such as schizophrenia are at risk during hot weather because their medications may interfere with temperature regulation or even directly cause hyperthermia.[134] Additional potential mental health impacts, less well understood, include the possible distress associated with environmental degradation[135] and displacement,[136] and the anxiety and despair that knowledge of climate change might elicit in some people (Ch. 12: Indigenous Peoples, Key Message 5).[122]

Key Message 2: Most Vulnerable at Most Risk

Climate change will, absent other changes, amplify some of the existing health threats the nation now faces. Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color.

Climate change will increase the risk of climate-related illness and death for a number of vulnerable groups in the United States, as when Hurricane Katrina devastated New Orleans in 2005. Children, primarily because of physiological and developmental factors, will disproportionately suffer from the effects of heat waves,[47] air pollution, infectious illness, and trauma resulting from extreme weather events.[14,16,18,22,138,139,140,141] The country's older population also could be harmed more as the climate changes. Older people are at much higher risk of dying during extreme heat events.[45,47,139,142] Pre-existing health conditions also make older adults susceptible to cardiac and respiratory impacts of air pollution[26] and to more severe consequences from infectious diseases;[143] limited mobility among older adults can also increase flood-related health risks.[144] Limited resources and an already high burden of chronic health conditions, including heart disease, obesity, and diabetes, will place the poor at higher risk of health impacts from climate change than higher income groups.[26,47] Potential increases in food cost and limited availability of some foods will exacerbate current dietary inequalities and have significant health ramifications for the poorer segments of our population (Ch. 12: Indigenous Peoples, Key Message 1).[110,145]

Climate change will disproportionately affect low-income communities and some communities of color (Ch. 12: Indigenous Peoples, Key Message 2),[139,149,151,152,153,154,155,156,157] raising environmental justice concerns. Existing health disparities[153,158,159] and other inequities[160,161] increase vulnerability. Climate change related issues that have an equity component include heat waves, air quality, and extreme weather and climate events. For example, Hurricane Katrina demonstrated how vulnerable certain groups of people were to extreme weather events, because many low-income and of-color New Orleans residents were killed, injured, or had difficulty evacuating and recovering from the storm.[154,155,156,161,162,163,164]

Elements of Vulnerability to Climate Change

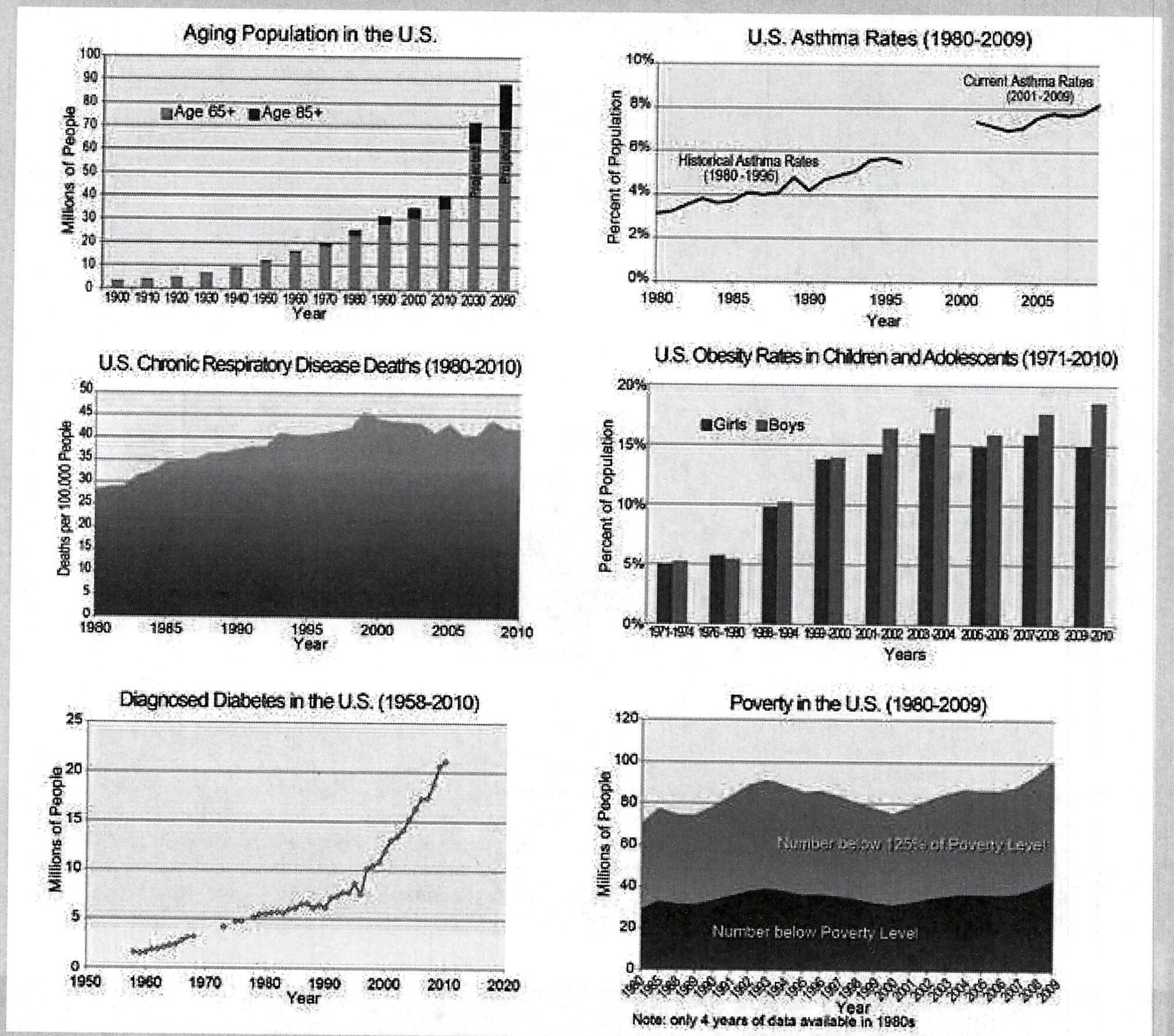


Figure 9.9. A variety of factors can increase the vulnerability of a specific demographic group to health effects due to climate change. For example, older adults are more vulnerable to heat stress because their bodies are less able to regulate their temperature. Overall population growth is projected to continue to at least 2050, with older adults comprising an increasing proportion of the population. Similarly, there are an increasing number of people who are obese and have diabetes, heart disease, or asthma, which makes them more vulnerable to a range of climate-related health impacts. Their numbers are also rising. The poor are less able to afford the kinds of measures that can protect them from and treat them for various health impacts. (Data from CDC; Health E-Stat; U.S. Census Bureau 2010, 2012; and Akinbami et al. 2011[137]).

Societal System Failures During Extreme Events

We have already seen multiple system failures during an extreme weather event in the United States, as when Hurricane Katrina struck New Orleans.[146] Infrastructure and evacuation failures and collapse of critical response services during a storm is one example of multiple system failures. Another example is a loss of electrical power during a heat wave or wildfires, which can reduce food and water safety.[147] Air conditioning has helped reduce illness and death due to extreme heat,[148] but if power is lost, everyone is vulnerable. By their nature, such events can exceed our capacity to respond.[79] In succession, these events severely deplete our resources needed to respond, from the individual to the national scale, but disproportionately affect the most vulnerable populations.[149]

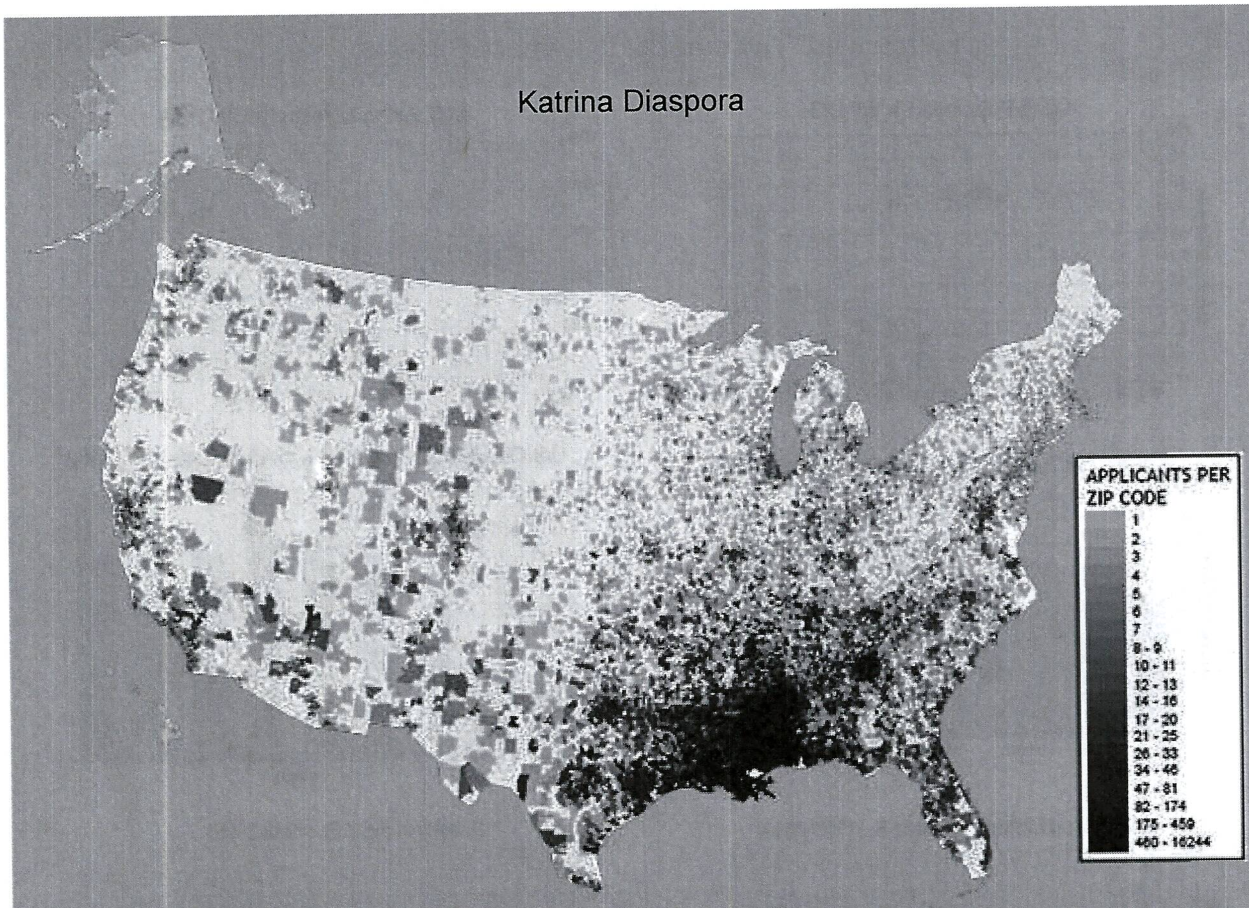


Figure 9.10. This map illustrates the national scope of the dispersion of displaced people from Hurricane Katrina. It shows the location by zip code of the 800,000 displaced Louisiana residents who requested federal emergency assistance. The evacuees ended up dispersed across the entire nation, illustrating the wide-ranging impacts that can flow from extreme weather events, such as those that are projected to increase in frequency and/or intensity as climate continues to change (Ch. 2: Our Changing Climate, Key Message 8). (Figure source: Kent 2006[150]).

Multiple Climate Stressors and Health

Climate change impacts add to the *cumulative* stresses currently faced by vulnerable populations including children, the elderly, the poor, some communities of color, and people with chronic illnesses. These populations, and others living in certain places such as cities, floodplains, and coastlines, are more vulnerable not only to extreme events but also to ongoing, persistent climate-related threats. These threats include poor air quality, heat, drought, flooding, and mental health stress. Over time, the accumulation of these stresses will be increasingly harmful to these populations.

the strongest climate-health preparedness programs possible.[153] One survey highlighted opportunities to address climate change preparedness activities and climate-health research[181] before needs become more widespread. *America's Climate Choices: Adapting to the Impacts of Climate Choices* (Table 3.5) provides examples of health adaptation options.[187]

Key Message 4: Responses Have Multiple Benefits

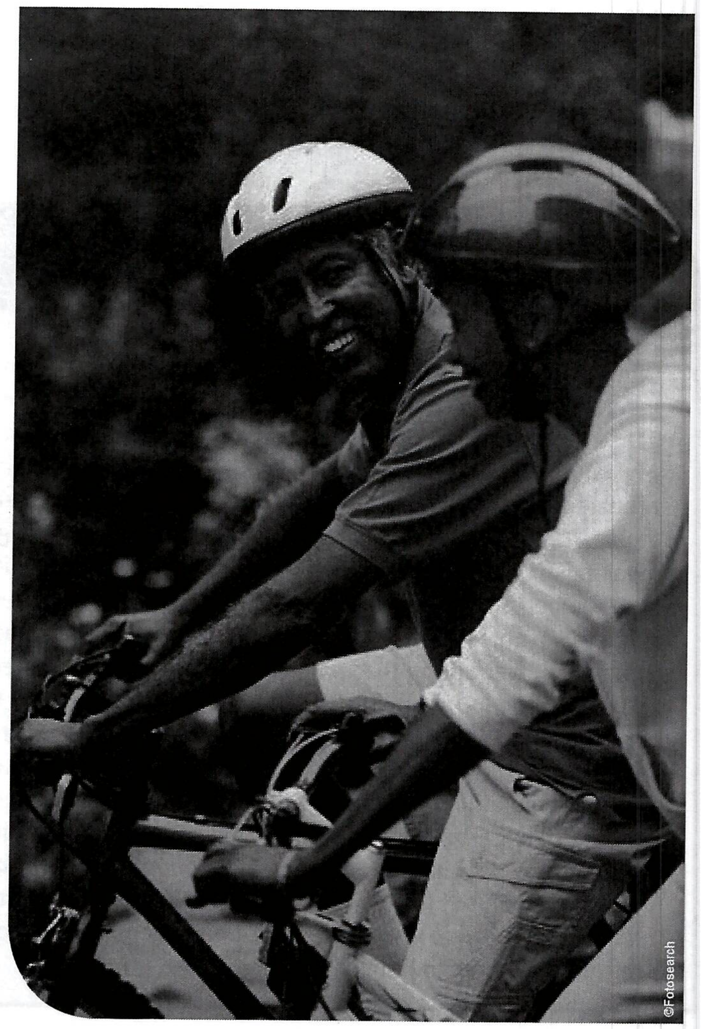
Responding to climate change provides opportunities to improve human health and well-being across many sectors, including energy, agriculture, and transportation. Many of these strategies offer a variety of benefits, protecting people while combating climate change and providing other societal benefits.

Policies and other strategies intended to reduce carbon pollution and mitigate climate change can often have independent influences on human health. For example, reducing CO_2 emissions through renewable electrical power generation can reduce air pollutants like particles and sulfur dioxide. Efforts to improve the resiliency of communities and human infrastructure to climate change impacts can also improve human health. There is a growing recognition that the magnitude of health "co-benefits," like reducing both pollution and cardiovascular disease, could be significant, both from a public health and an economic standpoint.[176,188,189] Some climate change resilience efforts will benefit health, but potential co-harms should be considered when implementing these strategies. For example, although there are numerous benefits to urban greening, such as reducing the urban heat island effect while simultaneously promoting an active healthy lifestyle,[159,190,191] the urban planting of certain allergenic pollen producing species[22] could increase human pollen exposure and allergic illness. Increased pollen exposure has been linked to increased emergency department visits related to asthma and wheezing[192] in addition to respiratory allergic illnesses such as allergic rhinitis or hay fever.[193] The selective use of low to moderate pollen-producing species can decrease pollen exposure.[194]

Much of the focus of health co-benefits has been on reducing health-harming air pollution.[6,174,175,195,196] One study projects that replacing 50% of short motor vehicle trips with bicycle use and the other 50% with other forms of transportation like walking or public transit would avoid nearly 1,300 deaths in 11 midwestern metropolitan areas and create up to $8 billion in health benefits annually for the upper Midwest region.[188] Such multiple-benefit actions can reduce heat-trapping gas emissions that lead to climate change, improve air quality by reducing vehicle pollutant emissions, and improve fitness and health through increased physical activity.[99,197,198,199,200]

Innovative urban design could create increased access to active transport.[99] The compact geographical area found in cities presents opportunities to reduce energy use and emissions of heat-trapping gases and other air pollutants through active transit, improved building construction, provision of services, and infrastructure creation, such as bike paths and sidewalks.[197,201] Urban planning strategies designed to reduce the urban heat island effect, such as green/cool roofs, increased green space, parkland and urban canopy, could reduce indoor temperatures, improve indoor air quality, and could produce additional societal co-benefits by promoting social interaction and prioritizing vulnerable urban populations.[191,197]

Patterns of change related to improving health can also have co-benefits in terms of reducing carbon pollution and mitigating climate change. Current U.S. dietary guidelines and many health professionals have recommended diets higher in fruits and vegetables and lower in red meat as a means of helping



Key Message 3: Prevention Provides Protection

Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited.

Prevention is a central tenet of public health. Many conditions that are difficult and costly to treat when a patient gets to the doctor could be prevented before they occur at a fraction of the cost. Similarly, many of the larger health impacts associated with climate change can be prevented through early action at significantly lower cost than dealing with them after they occur.[153,165] Early preventive interventions, such as early warnings for extreme weather, can be particularly cost-effective.[166,167,168] As with many illnesses,[169] once impacts are apparent, even the best adaptive efforts can be overwhelmed, and damage control becomes the priority.[62]

Activities that reduce carbon pollution often also provide co-benefits in the form of preventive health measures. For example, reliance on cleaner energy sources for electricity production[174] and more efficient and active transport, like biking or walking,[175] can have immediate public health benefits, through improved air quality and lowered rates of obesity, diabetes, and heart disease.[176] Reducing carbon pollution also reduces long-term adverse climate-health impacts, thus producing cost savings in the near and longer term.[176] Preventing exposures to other climate-sensitive impacts already apparent can similarly result in cost savings. For instance, heat wave early warning systems protect vulnerable groups very effectively and are much less expensive than treating and coping with heat illnesses. Systems that monitor for early outbreaks of disease are also typically much less expensive than treating communities once outbreaks take hold.[12,49,177]

Effective communication is a fundamental part of prevention. The public must understand risk in order to endorse proactive risk management. The public is familiar with the health risks of smoking, but not so for climate change. When asked about climate change impacts, Americans do not mention health impacts,[178] and when asked about health impacts specifically, most believe it will affect people in a different time or place.[179] But diverse groups of Americans find information on health impacts to be helpful once received, particularly information about the health benefits of mitigation (reducing carbon emissions) and adaptation.[180]

Determining which types of prevention to invest in (such as monitoring, early warning systems, and land-use changes that reduce the impact of heat and floods) depends on several factors, including health problems common to that particular area, vulnerable populations, the preventive health systems already in place, and the expected impacts of climate change.[181] Local capacity to adapt is very important; unfortunately the most vulnerable populations also frequently have limited resources for managing climate-health risks.

Overall, the capacity of the American public health and health care delivery systems faces many challenges.[182] The cost of dealing with current health problems is diverting resources from preventing them in the first place. This makes the U.S. population more vulnerable.[183,184] Without careful consideration of how to prevent future impacts, similar patterns could emerge regarding the health impacts from climate change. However, efforts to quantify and map vulnerability factors at the community level are underway.[151,164,185]

There are public health programs in some locations that address climate-sensitive health issues, and integrating such programs into the mainstream public health toolkit as adaptation needs increase would improve public health resilience to climate change.[79,186,187] Given that these programs have demonstrated efficacy against current threats that are expected to worsen with climate change, it is prudent to invest in creating

Large-Scale Environmental Change Favors Disease Emergence

Climate change is causing large-scale changes in the environment, increasing the likelihood of the emergence or reemergence of unfamiliar disease threats.[170] Factors include shifting ranges of disease-carrying pests, lack of immunity and preparedness, inadequate disease monitoring, and increasing global travel. Diseases including Lyme disease and dengue fever pose increasing health threats to the U.S. population; the number of U.S. patients hospitalized with dengue fever more than tripled from 2000 to 2007.[171] Although most cases of dengue fever during that time period were acquired outside the contiguous United States, the introduction of infected people into areas where the dengue virus vector is established increases the risk of locally acquired cases. The public health system is not fully prepared to monitor or respond to these growing disease risks. The introduction of new diseases into non-immune populations has been and continues to be a major challenge in public health. There are concerns that climate change may provide opportunities for pathogens to expand or shift their geographic ranges.[172,173]

to reduce the risk of cardiovascular disease and some cancers.[199,202,203] These changes in food consumption, and related changes to food production, could have co-benefits in terms of reducing greenhouse gas emissions. While the greenhouse gas footprint of the production of other foods, compared to sources such as livestock, is highly dependent on a number of factors, production of livestock currently accounts for about 30% of the U.S. total emissions of methane.[199,203,204] This amount of methane can be reduced somewhat by recovery methods such as the use of biogas digesters, but future changes in dietary practices, including those motivated by considerations other than climate change mitigation, could also have an effect on the amount of methane emitted to the atmosphere.[205]

In addition to producing health co-benefits,[206] climate change prevention and preparedness measures could also yield positive equity impacts. For example, several studies have found that communities of color and poor communities experience disproportionately high exposures to air pollution.[207,208] Climate change mitigation policies that improve local air quality thus have the potential to strongly benefit health in these communities.

An area where adaptation policy could produce more equitable health outcomes is with respect to extreme weather events. As discussed earlier, Hurricane Katrina demonstrated that communities of color, poor communities, and certain other vulnerable populations (like new immigrant communities) are at a higher risk to the adverse effects of extreme weather events.[152,155] These vulnerable populations could benefit from urban planning policies that ensure that new buildings, including homes, are constructed to resist extreme weather events.[197]

9: HUMAN HEALTH

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PHOTO CREDITS

Introduction to chapter; tourists walking close to misters keeping cool during heat wave in Las Vegas, Nevada, as shown in top banner: ©Julie Jacobson/AP/Corbis

SUPPLEMENTAL MATERIAL
TRACEABLE ACCOUNTS

Process for Developing Key Messages

The key messages were developed during technical discussions and expert deliberation at a two-day meeting of the eight chapter Lead Authors, plus Susan Hassol and Daniel Glick, held in Boulder, Colorado May 8-9, 2012; through multiple technical discussions via six teleconferences from January through June 2012, and an author team call to finalize the Traceable Account draft language on Oct 12, 2012; and through other various communications on points of detail and issues of expert judgment in the interim. The author team also engaged in targeted consultations during multiple exchanges with Contributing Authors, who provided additional expertise on subsets of the key message. These discussions were held after a review of the technical inputs and associated literature pertaining to human health, including a literature review,[209] workshop reports for the Northwest and Southeast United States, and additional technical inputs on a variety of topics.

Key message #1 Traceable Account

Climate change threatens human health and well-being in many ways, including impacts from increased extreme weather events, wildfire, decreased air quality, threats to mental health, and illnesses transmitted by food, water, and diseases-carriers such as mosquitoes and ticks. Some of these health impacts are already underway in the United States.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and workshop reports for the Northwest and Southeast United States. Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

Air Pollution:

The effects of decreased ozone air quality on human health have been well documented concerning projected increases in ozone,[6,7,9,11,39] even with uncertainties in projections owing to the complex formation chemistry of ozone and climate change, precursor chemical inventories, wildfire emission, stagnation episodes, methane emissions, regulatory controls, and population characteristics.[4] Ozone exposure leads to a number of health impacts.[1,2]

Allergens:

The effects of increased temperatures and atmospheric CO_2 concentration have been documented concerning shifts in flowering time and pollen initiation from allergenic plants, elevated production of plant-based allergens, and health effects of increased pollen concentrations and longer pollen seasons.[15,16,17,18,20,22,23,24,26,106] Additional studies have shown extreme rainfall and higher temperatures can lead to increased indoor air quality issues such as fungi and mold health concerns.[27]

Wildfire:

The effects of wildfire on human health have been well documented with increase in wildfire frequency[17,29,39,40] leading to decreased air quality[31,32,33] and negative health impacts.[32,34,36]

Temperature Extremes:

The effects of temperature extremes on human health have been well documented for increased heat waves,[51,53,54] which cause more deaths,[47,48] hospital admissions[50] and population vulnerability.[56,57]

Precipitation Extremes - Heavy Rainfall, Flooding, and Droughts:

The effects of weather extremes on human health have been well documented, particularly for increased heavy precipitation, which has contributed to increases in severe flooding events in certain regions. Floods are the second deadliest of all weather-related hazards in the United States.[63,64] Elevated waterborne disease outbreaks have been reported in the weeks following heavy rainfall,[65] although other variables may affect these associations.[66] Populations living in damp indoor environments experience increased prevalence of asthma and other upper respiratory tract symptoms.[67]

Disease Carried by Vectors:

Climate is one of the factors that influence the range of disease vectors;[73,74,76] a shift in the current range may increase interactions with people and affect human health.[71] North Americans are currently at risk from a number of vector-borne diseases.[75,82,83,85,86,87] There are some ambiguities on the relative role and contribution of climate change among the range of factors that affect disease transmission dynamics.[71,72,73,74,75,76] However, observational studies are already underway and confidence is high based on scientific literature that climate change has contributed to the expanded range of certain disease vectors, including *Ixodes* ticks which are vectors for Lyme disease in the United States.[78,84,89]

Food- and Waterborne Diarrheal Disease:
There has been extensive research concerning the effects of climate change on water- and food-borne disease transmission.[92,93,95,96,97] The current evidence base strongly supports waterborne diarrheal disease being both seasonal and sensitive to climate variability. There are also multiple studies associating extreme precipitation events with waterborne disease outbreaks.[65] This evidence of responsiveness of waterborne disease to weather and climate, combined with evidence strongly suggesting that temperatures will increase and extreme precipitation events will increase in frequency and severity (Ch. 2: Our Changing Climate), provides a strong argument for climate change impacts on waterborne disease by analogy. There are multiple studies associating extreme precipitation events with waterborne disease outbreaks and strong climatological evidence for increasing frequency and intensity of extreme precipitation events in the future. The scientific literature modeling the projected impacts of climate change on waterborne disease is somewhat limited, however. Combined, we therefore have overall medium confidence in the impact of climate change on waterborne and food-borne disease.

Harmful Algal Blooms:
Because algal blooms are closely related to climate factors, projected changes in climate could affect algal blooms and lead to increases in food- and waterborne exposures and subsequent cases of illness.[96,97,98,99,103] Harmful algal blooms have multiple exposure routes.[100]

Food Security:
Climate change is expected to have global impacts on both food production and certain aspects of food quality. The impact of temperature extremes, changes in precipitation and elevated atmospheric CO_2, and increasing competition from weeds and pests on crop plants are areas of active research (Ch. 6: Agriculture, Key Message 6).[105,106] The U.S. as a whole will be less affected than some other countries. However, the most vulnerable, including those dependent on subsistence lifestyles, especially Alaska Natives and low-income populations, will confront shortages of key foods.

Mental Health and Stress-Related Disorders:
The effects of extreme weather on mental health have been extensively studied.[120,122,123] Studies have shown the impacts of mental health problems after disasters,[124] with extreme events like Hurricane Katrina,[125] floods,[126] heat waves,[127] and wildfires[128] having led to mental health problems. Further work has shown that some people with mental illnesses are especially vulnerable to heat. Suicide rates vary with weather,[131,132] dementia is a risk factor for hospitalization and death during heat waves,[127,133] and medications for schizophrenia may interfere with temperature regulation or even directly cause hyperthermia.[134] Additional potential mental health impacts include distress associated with environmental degradation, displacement, and the knowledge of climate change.[122,123,136]

New information and remaining uncertainties
Important new evidence on heat-health effects[44,45] confirmed many of the findings from a prior literature review. Uncertainties in the magnitude of projections of future climate-related morbidity and mortality can result from differences in climate model projections of the frequency and intensity of extreme weather events such as heat waves and other climate parameters such as precipitation.

Efforts to improve the information base should address the coordinated monitoring of climate and improved surveillance of health effects.

Assessment of confidence based on evidence
Overall: **Very High** confidence. There is considerable consensus and a high quality of evidence in the published peer-reviewed literature that a wide range of health effects will be exacerbated by climate change in the United States. There is less agreement on the magnitude of these effects because of the exposures in question and the multi-factorial nature of climate-health vulnerability, with regional and local differences in underlying health susceptibilities and adaptive capacity. Other uncertainties include how much effort and resources will be put into improving the adap-

Confidence Level
Very High
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus
High
Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus
Medium
Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought
Low
Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

tive capacity of public health systems to prepare in advance for the health effects of climate change, prevent harm to individual and community health, and limit associated health burdens and societal costs.

Increased Ozone Exposure: **Very High** confidence.
Allergens: **High** confidence.
Wildfires: **Very High** confidence.
Thermal Extremes: **Very High** confidence.
Extreme Weather Events: **Very High** confidence.
Vector-borne Infectious Diseases: **High** or **Very High** confidence for shift in range of disease-carrying vectors. **Medium** confidence for whether human disease transmission will follow.
Food- and Waterborne disease: **Medium** confidence.
Harmful Algal Blooms: **Medium** confidence.
Food Security: **Medium** confidence for food quality; **High** confidence for food security.

Threats to Mental Health: **Very High** confidence for post-disaster impacts; **Medium** confidence for climate-induced stress.

Key message #2 Traceable Account

Climate change will, absent other changes, amplify some of the existing health threats the nation now faces. Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color.

Description of evidence base

The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and workshop reports for the Northwest and Southeast regions.[210] Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

Current epidemiological evidence on climate-sensitive health outcomes in the U.S. indicates that health impacts will differ substantially by location, pathway of exposure, underlying susceptibility, and adaptive capacity. These disparities in health impacts will largely result from differences in the distribution of individual attributes in a population that confers vulnerability (age, socioeconomic status, and race), attributes of place that reduce or amplify exposure (floodplain, coastal zone, and urban heat island), and the resilience of critical public health infrastructure.

Amplification of existing health threats: The effects of extreme heat and heat waves, projected worsening air pollution and asthma, extreme rainfall and flooding, and displacement and injuries associated with extreme weather events, fueled by climate change, are already substantial public health issues. Trends projected under a changing climate are projected to exacerbate these health effects in the future.[62]

Children: The effects of climate change increase vulnerability of children to extreme heat, and increased health damage (morbidity, mortality) resulting from heat waves has been well documented.[16,22,51,53,140] Extreme heat also causes more pediatric deaths,[47,48] and more emergency room visits and hospital admissions.[49,50] Adverse effects from increased heavy precipitation can lead to more pediatric deaths, waterborne diseases,[66] and illness.[141]

The elderly: Heat stress is especially damaging to the health of older people,[45,49,60,133,142,209] as are climate-sensitive increases in air pollution.

The sick: People and communities lacking the resources to adapt or to enhance mobility and escape health-sensitive situations are at relatively high risk.[164]

The poor: People and communities lacking the resources to adapt or to move and escape health-sensitive situations are at relatively high risk.[164]

Some communities of color: There are racial disparities in climate-sensitive exposures to extreme heat in urban areas, and in access to means of adaptation – for example air conditioning use.[149,151,157,211] There are also racial disparities in withstanding, and recovering from, extreme weather events.[155,162]

Climate change will disproportionately impact low-income communities and some communities of color, raising environmental justice concerns.[139,149,151,154,155,157,161,164] Existing health disparities[153,158,159] and other inequities[161] increase vulnerability. For example, Hurricane Katrina demonstrated how vulnerable these populations were to extreme weather events because many low-income and of-color New Orleans residents were killed, injured, or had difficulty evacuating and recovering from the storm.[155,162] Other climate change related issues that have an equity component include heat waves and air quality.[139,149,154,164]

New information and remaining uncertainties

Important new evidence[45] confirmed findings from a prior literature review.[139]

The potential for specific climate-vulnerable communities to experience highly harmful health effects is not entirely clear in specific regions and on specific time frames due to uncertainties in rates of adaptation and uncertainties about the outcome of public health interventions currently being implemented that aim to address underlying health disparities and determinants of health.[206] The public health community has not routinely conducted evaluations of the overall success of adaptation interventions or of particular elements of those interventions.

Assessment of confidence based on evidence
Given the evidence base and remaining uncertainties, confidence that climate change will amplify existing health threats: **Very High**.
Among those especially vulnerable are:
Children: **Very High**.
The elderly: **Very High**.
The sick: **Very High**.
The poor: **Very High**.
Some communities of color: **High**.

KEY MESSAGE #3 TRACEABLE ACCOUNT

Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Early action provides the largest health benefits. As threats increase, our ability to adapt to future changes may be limited.

Description of evidence base
The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and workshop reports for the Northwest and Southeast United States. Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

A number of studies have demonstrated that prevention activities that reduce carbon pollution, like using alternative energy sources[174] and using active transportation like biking or walking,[188] can lead to significant public health benefits, which can save costs in the near and long term.[176] Health impacts associated with climate change can be prevented through early action at significantly lower cost than dealing with them after they occur. For example, heat wave early warning systems are much less expensive than treating heat-related illnesses.[165] Existing adaptation programs have improved public health resilience.[9,153] One survey highlighted opportunities to address climate change preparedness activities and climate-health research[181] before needs become more widespread.

Considering U.S. public health in general, the cost-effectiveness of many prevention activities is well established.[183] Some preventive actions are cost-saving, while others are deemed cost-effective based on a pre-determined threshold. Early preventive interventions, such as early warnings for extreme weather, can be particularly cost-effective.[166] However, there is less information on the cost-effectiveness of specific prevention interventions relevant to climate sensitive health threats (for example, heat early warning systems). Overall, we have high confidence that public health actions can do much to protect people from some of the impacts of climate change, and that early action provides the largest health benefits.

The inverse relationship between the magnitude of an impact and a community's ability to adapt is well established and understood. Two extreme events, Hurricane Katrina and the European heat wave of 2003, illustrate this relationship well.[167] Extreme events interact with social vulnerability to produce extreme impacts, and the increasing frequency of extreme events associated with climate change is prompting concern for impacts that may overwhelm adaptive capacity.[62,173] This is equally true of the public health sector, specifically, leading to very high confidence that as threats increase, our ability to adapt to future changes may be limited.

New information and remaining uncertainties
A key issue (uncertainty) is the extent to which the nation, states, communities and individuals will be able to adapt to climate change because this depends on the levels of local exposure to climate-health threats, underlying susceptibilities, and the capacities to adapt that are available at each scale. Overall, the capacity of the American public health and health care delivery systems faces many challenges.[182] The cost of dealing with current health problems is diverting resources from preventing them in the first place. This makes the U.S. population more vulnerable.[56,183]

Steps for improving the information base on adaptation include undertaking a more comprehensive evaluation of existing climate-health preparedness programs and their effectiveness in various jurisdictions (cities, counties, states, nationally).

Assessment of confidence based on evidence
Overall, given the evidence base and remaining uncertainties: **High**.
High: Public health actions, especially preparedness and prevention, can do much to protect people from some of the impacts of climate change. Prevention provides the most protection; but we do not as yet have a lot of post-implementation information with which to evaluate preparedness plans.
High: Early action provides the largest health benefits. There is evidence that heat-health early warning systems have saved lives and money in U.S. cities like Philadelphia, PA.[165]
Very High: Our ability to adapt to future changes may be limited.

KEY MESSAGE #4 TRACEABLE ACCOUNT

Responding to climate change provides opportunities to improve human health and well-being across many sectors, including energy, agriculture, and transportation. Many of these strategies offer a variety of benefits, protecting people while combating climate change and providing other societal benefits.

Description of evidence base
The key message and supporting text summarizes extensive evidence documented in several foundational technical inputs prepared for this chapter, including a literature review[209] and work-

shop reports for the Northwest and Southeast U.S. regions.[210] Nearly 60 additional technical inputs related to human health were received and reviewed as part of the Federal Register Notice solicitation for public input.

A number of studies have explored the opportunities available to improve health and well-being as a result of adapting to climate change,[176] with many recent publications illustrating the benefit of reduced air pollution.[6,174,175,195] Additionally, some studies have looked at the co-benefits to climate change and health of applying innovative urban design practices which reduce energy consumption and pollution while increasing public health,[99,188,197,198] decrease vulnerability of communities to extreme events[152,197] and reduce the disparity between different societal groups.[206,207,212]

New information and remaining uncertainties

More studies are needed to fully evaluate both the intended and unintended health consequences of efforts to improve the resiliency of communities and human infrastructure to climate change impacts. There is a growing recognition that the magnitude of these health co-benefits or co-harms could be significant, both from a public health and an economic standpoint.[176,188,189]

Assessment of confidence based on evidence

Given the evidence base and remaining uncertainties, confidence is **Very High**.