Appendix A

Model Performance Evaluation of the CD-C CAMx 2005 and 2006 Base Case Simulations

APPENDIX A – MODEL PERFORMANCE EVALUATION OF THE CD-C CAMX 2005 AND 2006 BASE CASE SIMULATIONS

A1. INTRODUCTION

The air quality impact assessment for the Continental Divide-Creston (CD-C) EIS is being performed using the photochemical grid model CAMx (Comprehensive Air quality Model with Extensions; ENVIRON, 2009; www.camx.com). The basic modeling strategy used in any EIS that employs a photochemical grid model, such as CAMx, is to first simulate a current year base case using a comprehensive regional emission inventory of actual emissions from all sources (including motor vehicles, power plants, oil and gas exploration and production sources, biogenic sources, etc.). It is preferable to run the model for more than one year so that as many different meteorological regimes as possible are simulated. Pollutants emitted from Project sources may only influence a particular sensitive receptor under certain conditions (wind direction, atmospheric stability) and a conservative estimate of AQ and AQRV impacts requires that those conditions be simulated. While it is not possible to ensure that all possible meteorological conditions that might lead to transport of pollutants from Project sources to sensitive receptors are simulated, modeling two full years increases the likelihood that the relevant conditions will occur.

The base case simulation is evaluated with respect to ambient air quality measurements. If the base case simulation reproduces concentrations of observed species with reasonable fidelity, then the model can be used in the future year impact assessment. The future year modeling involves development of a future year Project emission inventory as well as a future year regional emission inventory. In the future year regional emission inventory, the emissions from human activities are projected from the base year to the future year and changes such as population growth and planned emissions controls (such as controls on motor vehicle emissions) are accounted for. Emissions that are not controllable, such as biogenics and wildfire emissions, are held fixed. The Project emissions are included in the future year emission inventory. The model is run using the future year regional emission inventory with the rest of the model (meteorological fields, boundary conditions, model settings, etc.) in the same configuration as in the base case. If multiple years were simulated in the base case, then the meteorological conditions for those same years are used together with the future year emissions scenario in the future year modeling. Project AQ and AQRV impacts are determined from the future year simulations.

For the CD-C EIS, a base case simulation has been developed and evaluated. CAMx has been applied for the calendar years 2005 and 2006 using a nested-grid modeling domain with horizontal spatial resolution 36/12/4 km (Figure A1-1). The primary function of the 36 km grid is to provide lateral boundary conditions to the 12 km grid. The 4 km grid encompasses the CD-C Project Area and nearby Class I and sensitive Class II areas. The 2005 and 2006 base case model runs use actual emissions of NO_x, SO_2, PM_{10}, $PM_{2.5}$, VOC and CO from all sources for those years. The CAMx gas phase and particle phase model estimates have been compared against observed values for those two years and a model performance evaluation has been conducted.

This Appendix summarizes the CD-C CAMx 2005 and 2006 base case simulations and model performance evaluation. The focus of the model performance evaluation is on the evaluation for ozone and $PM_{2.5}$ and its component species in Southwest Wyoming and surrounding areas in the 4 and 12 km domains. We also present the regional modeling performance evaluation of the CAMx model across the continental U.S. 36 km grid domain as

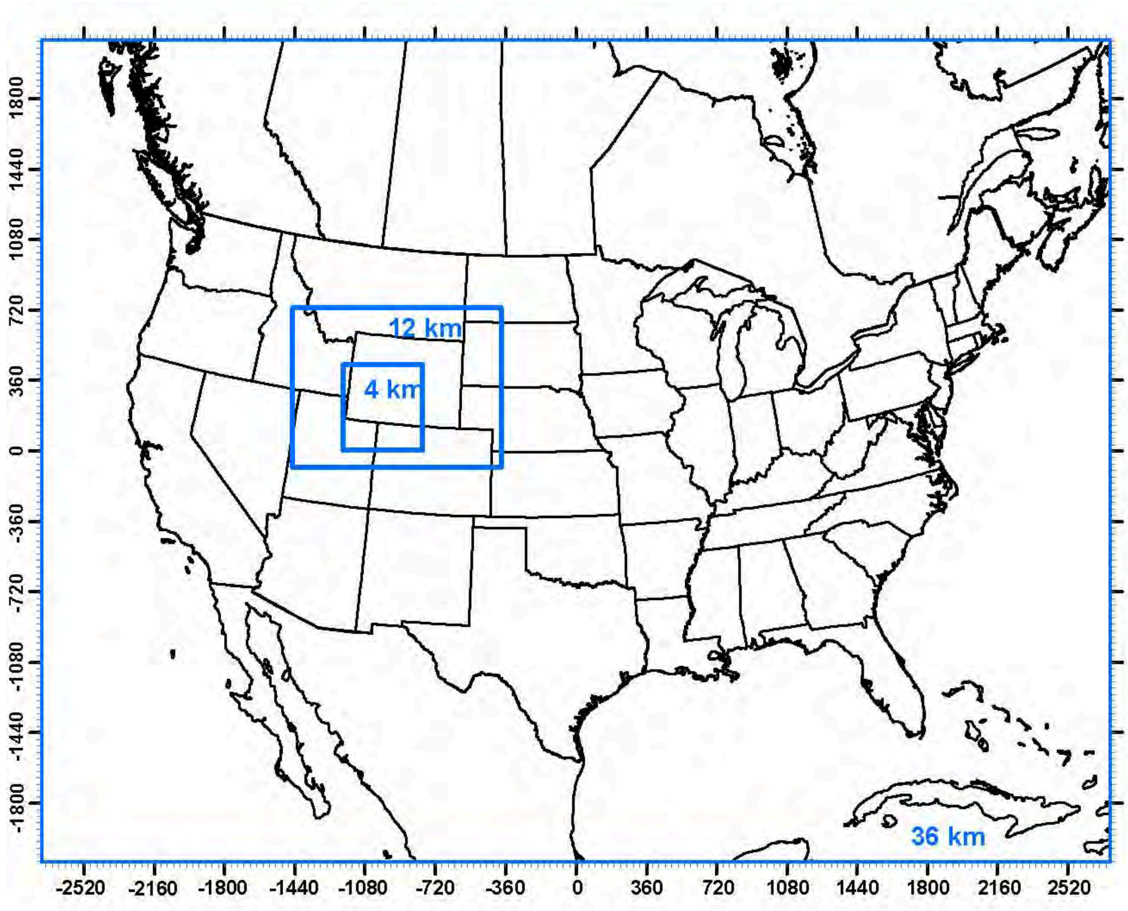


Figure A1-1. 36 km, 12 km, and 4 km modeling domains.

that performance helps assess the reliability of the transport of ozone, $PM_{2.5}$ and their precursors into the 12/4 km domains. This is important for characterizing the background reactivity of the atmosphere that affects the chemical transformation and consequently the ozone and $PM_{2.5}$ impacts of oil and gas (O&G) emissions from the CD-C Project, which are the focus of this study. Less emphasis is placed on the model performance in the urban areas in the region (e.g., Salt Lake City and Denver), as to adequately simulate ozone and $PM_{2.5}$ in these areas requires a model configuration that focuses on the urban areas, rather than on Southwest Wyoming (see, for example, Morris et al., 2008a,b; 2009).

A preliminary CAMx base case simulation and model performance evaluation was conducted using the same two years (2005 and 2006) and 36/12/4 km horizontal domain structure used in the CD-C study under the Hiawatha Regional Energy Development Project EIS (Kemball-Cook et al., 2009). At the August 2009 Hiawatha stakeholders meeting, concerns were raised regarding the performance of the Hiawatha CAMx base case simulation. In particular, concerns were raised regarding the underestimation of nitrate and, particularly, the underestimation of ozone at the southwest Wyoming industrial monitoring sites in Sublette County. In the fall of 2009, the CD-C EIS study performed diagnostic sensitivity tests to determine a more optimal model configuration for simulating ozone and nitrate formation in southwestern Wyoming. Appendix E describes the diagnostic sensitivity tests and the resulting updates to the CAMx model configuration that were approved by the CD-C stakeholders early 2010 for use in the CD-C CAMx base case simulations. 2005-6 base case CAMx modeling was carried out in January-February 2010 with the understanding that the runs would be used for the CD-C base case. Because of the link between the CD-C revised and earlier Hiawatha preliminary CAMx base case simulations, the CAMx model performance for both base case simulations are presented in this document. Where the figures and captions in this Appendix cite the Hiawatha run, they refer to the Hiawatha base case run that was performed in 2009.

In this Appendix, the evaluation methodology and ambient data sets used in the evaluation are described. Next, the PM and ozone performance on the 36 km grid are summarized. We present the 12/4 km grid ozone model performance evaluation and finally, describe the 12/4 km PM performance. A summary of the entire evaluation is provided at the end of the Appendix as well as recommendations regarding the use of the CD-C 2005-2006 base case simulations in the CD-C EIS future year AQ and AQRV impact assessment.

A2. EVALUATION METHODOLOGY

In the 2005 and 2006 CD-C base case model performance evaluation, the CAMx results were compared with observations from the **I**nteragency **M**onitoring of **PRO**tected **V**isual **E**nvironments (IMPROVE), **S**peciated **T**rends **N**etwork (STN)[1], **C**lean **A**ir **S**tatus **T**rends **Net**work (CASTNet), **F**ederal **R**eference **M**ethod (FRM) $PM_{2.5}$ mass, **N**ational **A**cid **D**eposition **P**rogram (NADP) and EPA **A**ir **Q**uality **S**tation (AQS) study monitoring networks. The CD-C CAMx evaluation focuses primarily on the operational model evaluation of the air quality model's performance with respect to ozone, the individual components of fine particulate matter ($PM_{2.5}$), and total $PM_{2.5}$ mass. Some elements of a diagnostic evaluation were also performed, including analysis of the ability of the model to reproduce gaseous PM precursor (e.g., SO_2) and product (e.g., HNO_3) species.

A2.1 EVALUATION APPROACH

EPA's integrated ozone, $PM_{2.5}$ and regional haze modeling guidance calls for a comprehensive, multi-layered approach to model performance testing, consisting of the four major components: operational, diagnostic, mechanistic (or scientific) and probabilistic (EPA, 2007). The CAMx model performance evaluation effort for $PM_{2.5}$ discussed in this Appendix focused on the first two components of the EPA's recommended evaluation approach, namely:

- **<u>Operational Evaluation</u>**: Tests the ability of the model to estimate ozone, $PM_{2.5}$ mass concentrations and the components of $PM_{2.5}$, that is sulfate, nitrate, ammonium, organic carbon matter, elemental carbon, and other inorganic $PM_{2.5}$. This evaluation examines whether the measurements are properly represented by the model predictions but does not necessarily ensure that the model is getting "the right answer for the right reason"; and
- **<u>Diagnostic Evaluation:</u>**Tests the ability of the model to predict visibility and extinction, PM chemical composition including ozone and PM precursors (e.g., SOx, NOx, VOC and NH_3) and associated oxidants (e.g., nitric acid); PM size distribution; temporal variation; spatial variation; mass fluxes; and components of light extinction (i.e., scattering and absorption).

The diagnostic evaluation also typically includes the performance of diagnostic tests to better understand model performance and identify potential flaws in the modeling system that can be corrected. As part of the CD-C EIS study, a series of diagnostic sensitivity tests were conducted as discussed in Appendix E.

In this model performance evaluation of the CD-C 2005 and 2006 CAMx 36/12/4 km base case simulations, the operational evaluation has been given the greatest attention since this is the primary thrust of EPA's modeling guidance. However, we have also examined certain diagnostic features dealing with the model's ability to simulate sub-regional and monthly/diurnal gas phase and aerosol concentration distributions. We also compare the CD-C CAMx base case model performance with the preliminary CAMx 2005 and 2006 base case model performance performed under the Hiawatha EIS study.

[1]The Speciated Trends Network (STN) is now referred to as the Chemical Speciation Network (CSN). The terms STN and CSN refer to the same $PM_{2.5}$ speciation network.

A2.2 PARTICULATE MATTER AND COMPONENT SPECIES

$PM_{2.5}$ attainment is based on $PM_{2.5}$ mass measurements using Federal Reference Method (FRM) monitoring devices that consists of the following $PM_{2.5}$ components:

- Sulfate (SO_4)
- Nitrate (NO_3)
- Ammonium (NH_4)
- Organic Carbon Matter (OCM)
- Elemental Carbon (EC) [also called Black Carbon (BC) and Light Absorbing Carbon (LAC)]
- Other Inorganic $PM_{2.5}$ that is also referred to as Soil (also known as crustal material, fine soil, major metal oxides, or other $PM_{2.5}$)
- Particle Bound Water (PBW)
- Sea Salt (that is mostly NaCl)
- Passive Mass (Blank Correction)

With the exception of the Passive Mass (that is assumed to be a constant 0.5µg/m^3), PBW (that is associated with SO4 and NO3) and Sea Salt (which is an insignificant component of $PM_{2.5}$ mass in Southwest Wyoming, Northern Colorado and Northern Utah) each of these components is evaluated.

Visibility is assessed using the IMPROVE equation that expresses light extinction as a series of PM species components multiplied by their extinction efficiency. In the original IMPROVE equation, the total light extinction (b_{ext}) is assumed to be the sum of the light extinction due to the six PM species listed above plus Rayleigh (blue sky) background (b_{Ray}) that is assumed to be 10 Mm^{-1}.

$$b_{ext} = b_{Ray} + b_{Sulfate} + b_{Nitrate} + b_{EC} + b_{OCM} + b_{Soil} + b_{CM}$$

The total light extinction (b_{ext}) in Mm^{-1} is related to visual range (VR) in km using the following relationship:

$$VR = 3912 / b_{ext},$$

for b_{ext} in Mm^{-1}.

The incremental visibility impairment is typically expressed in terms of deciviews where the haze index (HI) in units of deciviews (dv) is calculated as follows:

$$HI = 10 \ln(b_{ext}/10$$

The original IMPROVE equation that converts PM species concentrations to light extinction is given as follows (Malm et al., 2000):

$$b_{Sulfate} = 3 \times f(RH) \times [Sulfate]$$

$$b_{Nitrate} = 3 \times f(RH) \times [Nitrate]$$

$$b_{EC} = 10 \times [EC]$$

$$b_{OCM} = 4 \times [OCM]$$

$$b_{Soil} = 1 \times [Soil]$$

$$b_{CM} = 0.6 \times [CM]$$

Here, f(RH) are relative humidity adjustment factors where both day-specific and monthly average values are used in the visibility assessment. Sulfate and nitrate are assumed to be completely neutralized by ammonium in the IMPROVE equation [$SO_4(NH_4)_2$ and NO_3NH_4]. The model simulates total OCM concentration, whereas the IMPROVE and STN monitoring network only measure the Organic Carbon (OC) component of OCM. OCM/OC ratios tend to range from 1.2 to 2.4 with lower ratios associated with fresh (e.g., urban) OCM emissions and higher ratios associated with OCM that has undergone photochemical processing and aging. There are significant uncertainties in the OCM evaluation as the selection of the incorrect assumed OCM/OC ratio can introduce errors approaching 50%. To convert the OC to OCM in the 12-4 km model performance evaluation, we assumed an OCM/OC ratio of 1.8 for the IMPROVE monitors, which is more representative of rural areas. For the STN monitors, which are located within and near urban areas, a value of 1.2 was used for the OCM/OC ratio. In the evaluation of the 36 km grid performance, a ratio of 1.4 was used for consistency with the Western Regional Air Partnership (WRAP) 2002 36 km continental U.S. modeling, against which the 36 km CD-C and Hiawatha base case simulations for 2005-2006 were compared.

A2.3 AMBIENT AIR QUALITY DATA

A ground-level model evaluation database for 2005 and 2006 was compiled using several monitoring networks that carry out routine measurements. The focus of the CD-C evaluation of the CAMx model was on the ozone and the PM components that make up total $PM_{2.5}$ mass and can cause visibility impairment. The primary monitoring networks available to evaluate this component of the CAMx are: (a) Interagency Monitoring of Protected Visual Environments (IMPROVE); (b) Clean Air Status and Trends Network (CASTNET); (c) EPA Federal Reference Method (FRM) $PM_{2.5}$ and PM_{10} Mass Networks (EPA-FRM); (d) EPA Speciation Trends Network (STN) of $PM_{2.5}$ species; (e) National Acid Deposition Network (NADP); and (f) the EPA Air Information Retrieval System (AIRS) Air Quality Station (AQS) network. These ozone and PM monitoring networks may also provide other gas phase precursors, product species, and visibility measurements at some sites. Table A2-1 summarizes the species collected and averaging times of the monitoring sites for the IMPROVE, STN, CASTNet, NADP and FRM monitoring networks use in the CD-C model evaluation. The locations of the monitoring sites used in the model evaluation within the CD-C 36 km grid are shown in Figure A2-1 and sites within the 12/4 km domain are shown in Figure A2-2.

The IMPROVE and STN monitors collect 24-hour average PM samples on a 1:3 day sampling schedule and speciate the $PM_{2.5}$ into its component species. STN collects ammonium but IMPROVE does not. IMPROVE also obtains coarse mass that is not collected at STN monitoring sites. The CASTNet PM monitoring network collects weekly samples of sulfate, nitrate, ammonium, nitric acid and SO2. Thus, the CASTNet monitoring network can also be used to evaluate the model for Total Nitrate (HNO_3+NO_3). This is a valuable diagnostic tool for helping to deduce whether any particulate NO_3 performance problems may be related to the oxidation of the NOx to form Total Nitrate or to the aerosol thermodynamic partitioning of Total Nitrate between particulate NO3 and gaseous HNO_3. The NADP monitoring sites collect weekly samples of wet deposited sulfate, nitrate and ammonium.

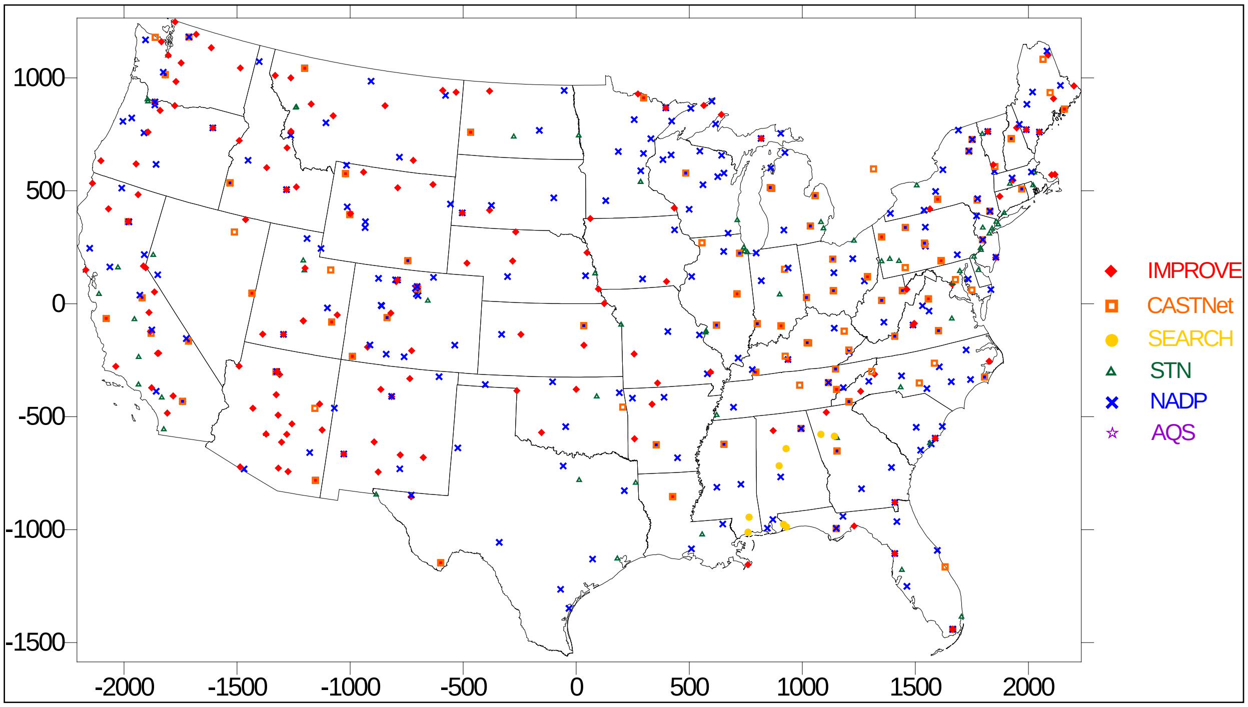


Figure A2-1. Locations of sites in each of the PM ambient monitoring networks and the 36 km modeling domain.

Table A2-1.Ambient monitoring data available in the 12/4 km domains during 2005 and 2006.

Monitoring Network	Chemical Species Measured	Sampling Frequency; Duration
IMPROVE	Speciated $PM_{2.5}$ and PM_{10}	1 in 3 days; 24 hr
CASTNET	Speciated $PM_{2.5}$, Ozone, HNO_3	Hourly, Weekly; 1 hr, Week
NADP	WSO_4, WNO_3, WNH_4	Weekly
EPA-FRM	Total fine PM mass ($PM_{2.5}$)	1 in 3 days; 24 hr
EPA-STN	Speciated $PM_{2.5}$	1 in 3 days; 24 hr
AIRS/AQS	CO, NO, NO_2, NO_x, O_3	Hourly; Hourly

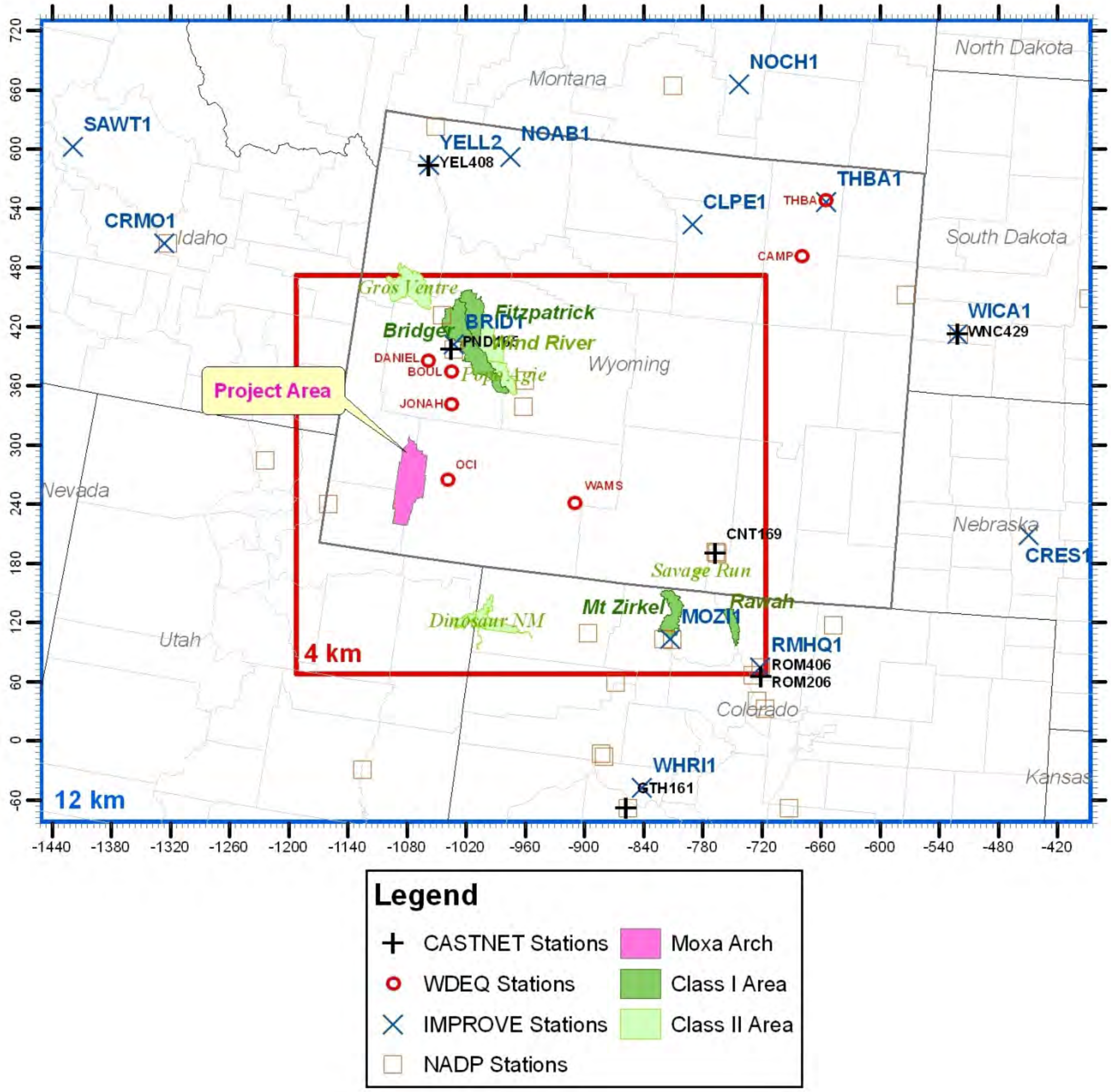


Figure A2-2. Locations of monitoring sites within the 12/4 km grid domain.

A2.4 MODEL PERFORMANCE STATISTICSAND GOALS

To quantify model performance, several statistical measures were calculated and evaluated for all the IMPROVE, STN, CASTNet, FRM, NADP and AQS monitors within the 12/4 km domains. The statistical measures selected were based on the recommendations outlined in section 18.4 of the USEPA's Guidance On The Use Of Models And Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze (EPA, 2007). Table 2-2 lists the definitions of several statistical performance measures that are used in model performance evaluation discussed below.

Table A2-2.Statistical metric calculations.

Statistical Measure	Shorthand Notation	Mathematical Expression	Units
Accuracy of Paired Peak	A_p	$\frac{P - O_{peak}}{O_{peak}}$	Percent
Mean Bias	MB	$\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)$	Concentration
Mean Absolute Gross Error	MAGE	$\frac{1}{N}\sum_{i=1}^{N}\lvert P_i - O_i\rvert$	Concentration
Normalized Mean Bias	NMB	$\frac{\sum_{i=1}^{N}(P_i - O_i)}{\sum_{i=1}^{N}O_i}$	Percent
Normalized Mean Error	NME	$\frac{\sum_{i=1}^{N}\lvert P_i - O_i\rvert}{\sum_{i=1}^{N}O_i}$	Percent
Mean Normalized Bias	MNB	$\frac{1}{N}\sum_{i=1}^{N}\frac{(P_i - O_i)}{O_i}$	Percent
Mean Normalized Gross Error	MNGE	$\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert P_i - O_i\rvert}{O_i}$	Percent
Mean Fractionalized Bias (Fractional Bias)	MFB	$\frac{2}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{P_i + O_i}\right)$	Percent
Mean Fractional Error	MFE	$\frac{2}{N}\sum_{i=1}^{N}\left\lvert\frac{P_i - O_i}{P_i + O_i}\right\rvert$	Percent

The issue of model performance goals and criteria in the model performance evaluation has undergone refinement over the last several decades. The main objective of the model performance evaluation is to ascertain whether the model is getting the right answer for the right reason and is an accurate and reliable tool for estimating future year air quality levels. Model performance goals and criteria are useful for helping interpret model performance and comparing model performance across studies, models and temporal and spatial periods. In 1991, EPA established model performance goals for ozone State Implementation Plan (SIP) modeling that bias should be within ±15% and error should be within 35% (EPA, 1991). The EPA 1991 ozone bias and error performance goals were based on the Mean Normalized Bias (MNB) and Mean Normalized Gross Error (MNGE) using predicted and observed hourly ozone pairs for which the observed value was greater than a 60 ppb ozone concentration threshold.

APPENDIX A – MODEL PERFORMANCE EVALUATION OF THE CD-C CAMX 2005 AND 2006 BASE CASE SIMULATIONS

In some of the early ozone SIP modeling, the model evaluation focused on achieving the model performance goals rather than whether the model was getting the right answer for the right reason and is a reliable future year air quality forecasting tool. Thus, in EPA's latest air quality modeling guidance they have emphasized use of model performance measures and displays to ascertain whether the model is realistically simulating the observed air quality and de-emphasized the use of model performance goals. EPA's latest guidance provides a list of studies and the ranges of model performance they have achieved (EPA, 2007), rather than specifying performance goals that must be achieved. However, model performance goals and criteria are still useful tools for assisting in judging model performance and recent modeling studies have developed goals for particulate matter to complement EPA's ozone performance goals.

Several Regional Planning Organizations (RPOs)[2] have established model performance goals and criteria for components of fine particle mass based on previous model performance for ozone and fine particles (Boylan, 2004; e.g., Morris et al., 2004a,b,c; 2007; 2008a,b). EPA modeling guidance for fine particulate matter notes that PM models might not be able to achieve the same level of performance as ozone models. The RPOs reviewed numerous model performance evaluation metrics to evaluate their descriptive capabilities for summarizing the salient features of the model performance evaluation. Although numerous model performance statistics measures are routinely calculated, the RPOs have found that the mean fractional bias (MFB) and mean fractional error (MFE) provide the best descriptive power over a wide range of concentrations that occur for PM component species. The fractional bias and error are expressed as a percentage and are normalized by the average of the predicted and observed values (see Table A2-2). Consequently, they are bounded statistics, with the fractional bias bounded by -200% to +200% and the fraction error bounded by 0% to 200%. Table A2-3 lists the model performance goals and criteria developed by the RPOs to assist in evaluating regional model performance for PM species. These goals have been applied to fractional bias and error, but can also be applied for the mean normalized and normalized mean bias and error metrics as well (Table A2-3). The most stringent model performance goals are the same as the EPA 1991 ozone performance goal with bias/error goals of within ±15%/35%. For PM species the bias/error performance goal has been relaxed to be within ±30%/50% to reflect the fact that there are many more processes and sources involved in PM and that PM measurements are much less accurate than for ozone (uncertainties in the measurements for some PM species, such as OCM, are as high or higher than the ozone model performance goal). Finally, the RPOs have a PM bias/error model performance criteria of within ±60%/75% above which concerns regarding the reliability of the model are raised.

[2] Five RPOs were established in the U.S. consisting of States, Local and Federal Agencies and Stakeholders to perform the technical analysis needed to develop the regional haze SIPs.

Table A2-3. RPO model performance goals and criteria for components of fine particle mass.

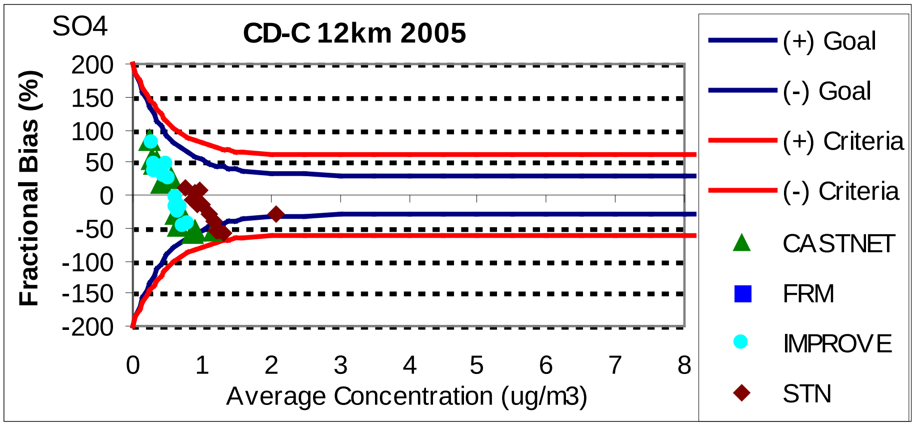
Fractional Bias	Fractional Error	Comment
<u><</u>±15%	<u><</u>35%	Goal for PM model performance based on ozone model performance, considered excellent performance
<u><</u>±30%	<u><</u>50%	Goal for PM model performance, considered good performance
<u><</u>±60%	<u><</u>75%	Criteria for PM model performance, considered average performance. Exceeding this level of performance indicates fundamental concerns with the modeling system and triggers diagnostic evaluation.

For calculating ozone model performance statistics, a threshold is typically used to screen out predicted and observed hourly ozone pairs whose observed value is below the threshold. For 1-hour ozone SIP modeling of urban nonattainment areas, an hourly observed ozone threshold of 60 ppb has typically been used in the past, but a lower thresholds of 40 and 50 ppb were also adopted in the CD-C modeling, which is focused on rural areas with lower regional background ozone levels. This issue is discussed further in Section 4 of this Appendix.

As noted in EPA's PM modeling guidance, less abundant PM species should have less stringent model performance goals than those PM species that make up a substantial portion of the $PM_{2.5}$ mass or visibility degradation due to PM (EPA, 2001; 2007). To address this issue, the RPOs have used PM performance goals that are a continuous function of average concentration that have the following features (Boylan, 2004):

- Asymptotically approaching the proposed performance goal or criteria (e.g., the ±30% and ±60% MFB performance goal and criteria given in Table A2-3) when the mean observed concentration is greater than 2.5 $\mu g/m^3$.
- Approaching 200% error and ±200% bias when the mean observed concentrations approach zero.

The MFB and MFE are plotted as a function of average observed concentration (Figure A2-3). As the mean observed concentration approaches zero. The MFB performance goal and criteria flare out to ±200% creating a horn shape. Hence, these model performance plots have been named "Bugle Plots". The RPOs have identified three levels of performance in the Bugle Plots (Boylan, 2004): (1) Zone 1 meets the ±30%/60% MFB/MFE PM performance goal and is considered "good" model performance for a PM model; (2) Zone 2 has MFB/MFE that lies between the ±30%/60% PM performance goal and ±60%/75% performance criteria and is an area where concern for model performance is raised, but is not uncommon model performance for PM models; and (3) Zone 3 is when the MFB/MFE lies outside of the ±60%/75% PM performance criteria and is an area of questionable model performance.



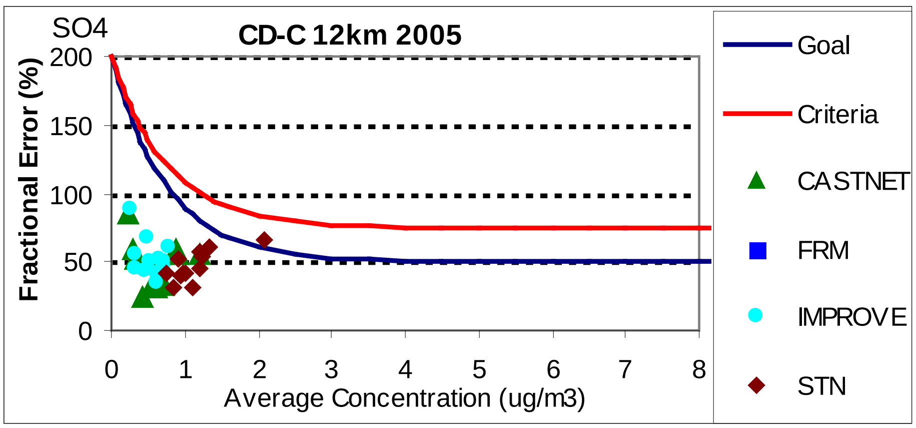


Figure A2-3.Example Bugle Plots used for evaluation of model PM performance. Shown are monthly fractional bias (top) and error (bottom) for sulfate (SO4) performance for the CAMx 2005 base case across CASTNet, IMPROVE and STN monitoring sites in 12 km modeling domain that are compared against the PM model performance goals (blue) and criteria (red).

A3.REGIONAL CAMx 36 KM MODEL PERFORMANCE EVALUATION

The CD-C CAMx 2005 and 2006 base case simulation of the continental U.S. 36 km domain was evaluated across two separate regions of the U.S. using monitoring sites that lie within the WRAP (western states) and VISTAS (southeastern states) Regional Planning Organization (RPO) regions (Figure A3-1). A broad-brush evaluation of the 2005 and 2006 36 km CAMx base case simulations was made using monthly fractional bias and fractional error statistical performance metrics that were compared against the PM model performance goals and criteria as well as with the RPO model performance for 2002 using the CMAQ modeling system (Byun and Ching, 1999) on the same 36 km U.S. modeling domain used in the CD-C CAMx modeling. The WRAP and VISTAS 2002 CMAQ modeling was used to develop regional haze State Implementation Plans (SIPs) and the comparison of the CD-C CAMx 2006-2006 36 km model performance with the CMAQ 2002 performance from WRAP and VISTAS is used as a point of reference and comparison. The focus of the evaluation of the 36 km base case simulations is on particulate matter (PM) species since EPA recommends that finer grid resolution (e.g., at least 12 km with 4 km in high emission areas) be used for ozone modeling (EPA, 2007). The evaluation of the CD-C 2005-2006 12/4 km base case modeling for ozone is presented in Section 4 of this Appendix.

Surface layer particulate matter (PM) fields from the CD-C CAMx base case simulation for 2005-2006 were evaluated relative to speciated PM observations from the IMPROVE, CASTNet, and STN[3] ambient air quality monitoring networks. The location of monitoring sites within the 36 km domain is shown in Figure A2-1. Although observations from other networks were available (i.e. NADP), the present evaluation of the CD-C 36 km base case simulation focuses on these three networks for the purposes of comparison with annual 36 km CMAQ modeling of 2002 done by the WRAP and VISTAS RPOs. Note that the CD-C 36 km domain definition is identical to what WRAP and VISTAS used, although the CD-C modeling used 34 vertical layers versus 19 in WRAP and VISTAS. A more refined model performance evaluation of CD-C CAMx run PM performance on the 12/4 km domain was carried out using additional observational networksand isdiscussed in Section 5 of this Appendix.

The comparison of the CD-C 2005 and 2006 36 km CAMx base case simulation with the WRAP 2002 36 km CMAQ run was carried out over the WRAP RPO region, which encompasses most of the western U.S., including Wyoming and the CD-C Project Area (Figure A4-1). The comparison of the CD-C 2005 and 2006 36 km CAMx run with the VISTAS 2002 36 km CMAQ run was carried out over the VISTAS RPO region, which covers the southeastern U.S (Figure A3-1).

For the CD-C 2005 and 2006 CAMx, the VISTAS 2002 CMAQ and the WRAP 2002 CMAQ base case simulations, monthly fractional bias and fractional error statistics were calculated using paired predictions and observations from all available sites in the CASTNET, IMPROVE, and STN networks for all monitors across the WRAP and VISTAS regions. The resulting statistics are displayed in Bugle Plots of monthly fractional bias in order to compare model performance for the three runs and compare the performance with the PM performance goals and criteria. Note that the Bugle Plot performance goal and criteria lines as they approach the zero observed concentration are incorrectly placed on the WRAP 2002 CMAQ run Bugle Plots, but the monthly

[3] The STN is now referred to as the Chemical Speciation Network (CSN)

performance statistics may be compared directly with those of the CD-C 2005 and 2006 CAMx base case simulation.

Figure A3-1. Map of the five Regional Planning Organization (RPO) regions.

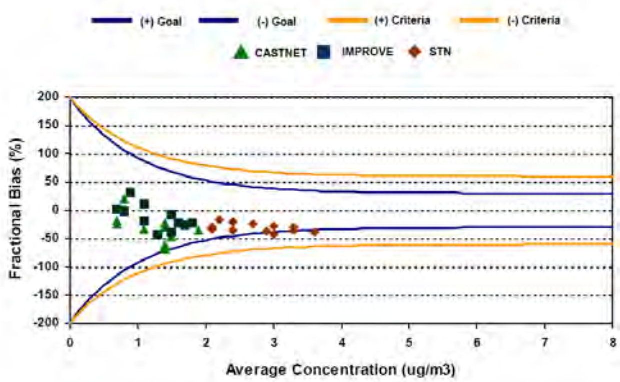
A3.1 SULFATE (SO4) MODEL PERFORMANCE

The bugle plots for the CD-C 2005 and 2006 CAMx 36 km base case simulations evaluated for SO_4 across the WRAP and VISTAS regions and the comparisons with the WRAP and VISTAS 2002 CMAQ model performance are shown in Figures A3-2 and A3-3, respectively. With the exception of one month in 2005 and 2006 across STN monitoring sites, the CD-C SO_4 bias in the WRAP region always achieves the PM performance criteria (Figure A3-2). Of the 72 months across the two years of modeling and three networks, the CD-C 36 km CAMx simulation's SO_4 bias achieves the PM performances goal 85% of the time (61 out of 72). It appears that the WRAP 2002 CMAQ simulation achieves the performance goals and criteria more frequently than the CD-C simulation, but that is because WRAP used a much more lenient definition of the flare in the Bugle Plot, whereas in the CD-C study we adhered to the peer-reviewed formulation from the Bugle Plot's developer (Boylan, 2004).

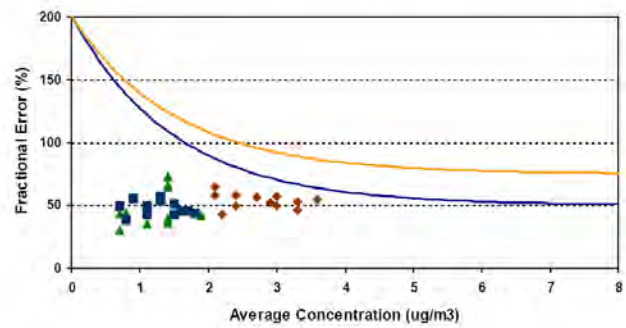
Both the CD-C 2005-2006 CAMx 36 km and VISTAS 2002 CMAQ 36 km have much higher predicted SO_4 concentrations across the southeastern U.S. VISTAS region (Figure A3-3). The SO_4 bias and error across the VISTAS region always achieves the PM performance criteria and usually achieves the PM performance criteria for both the CD-C and VISTAS base case simulations. The models are characterized by a summer underestimation and winter overestimation bias. The VISTAS 2002 CMAQ simulation exhibits better SO_4 model performance in the southeastern U.S. than the CD-C 2005-2006 CAMx simulations. This is probably due to the fact that VISTAS optimized their 2002 CMAQ modeling database for simulating PM in the southeastern U.S., whereas the CD-C focus was on Wyoming and adjacent regions.

In general, SO_4 model performance for both the CD-C CAMx and WRAP and VISTAS CMAQ simulations was good, meeting the performance goals most of the time and always meeting the performance criteria.

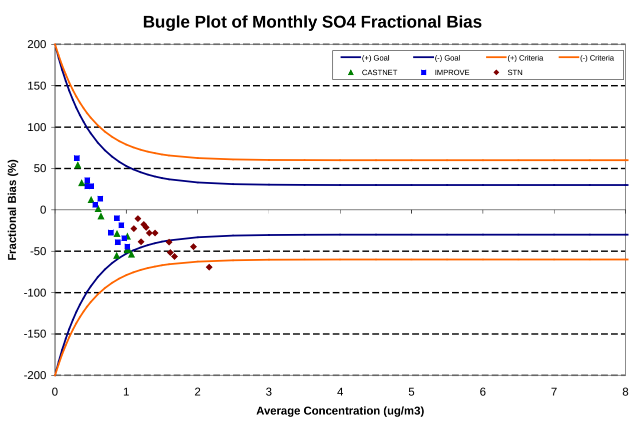
WRAP 2002 CMAQ SO4 Bias



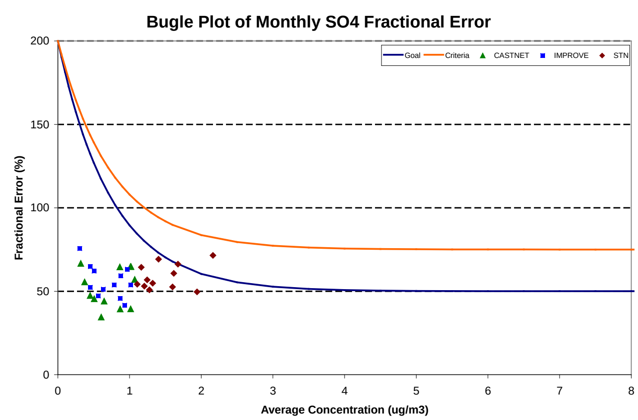
WRAP 2002 CMAQ SO4 Error



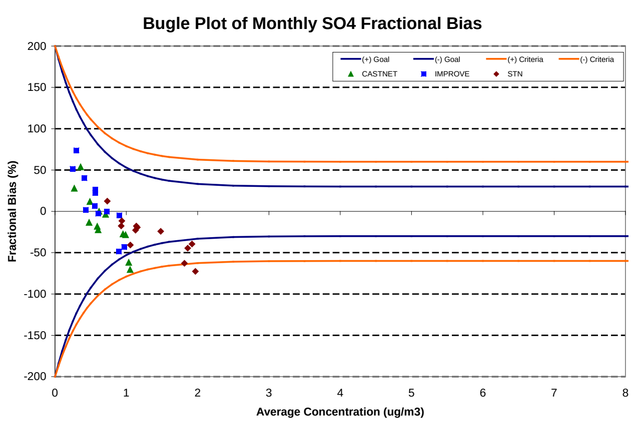
CD-C2005 SO4 Bias



CD-C2005 SO4 Error



CD-C2006 SO4 Bias



CD-C2006 SO4 Error

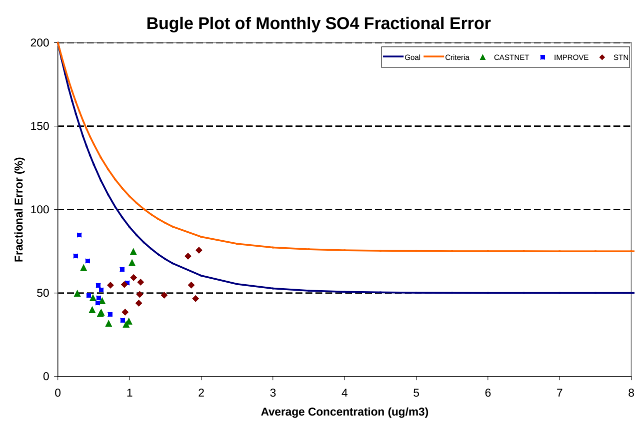


Figure A3-2. Bugle Plots of SO_4 fractional bias (left) and fractional error (right) for the WRAP 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

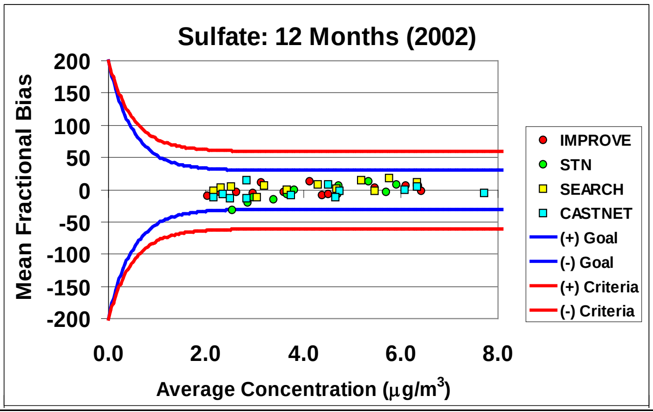
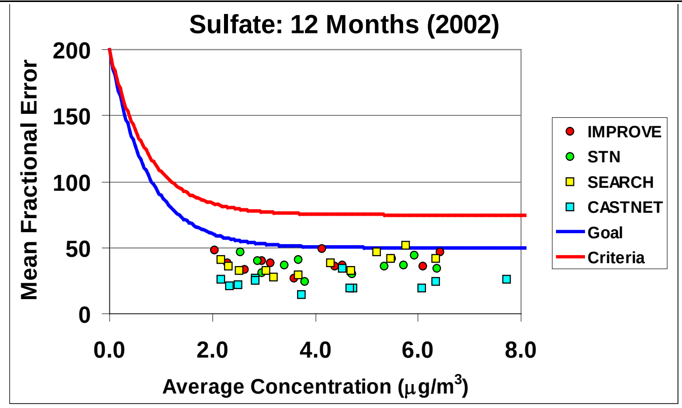
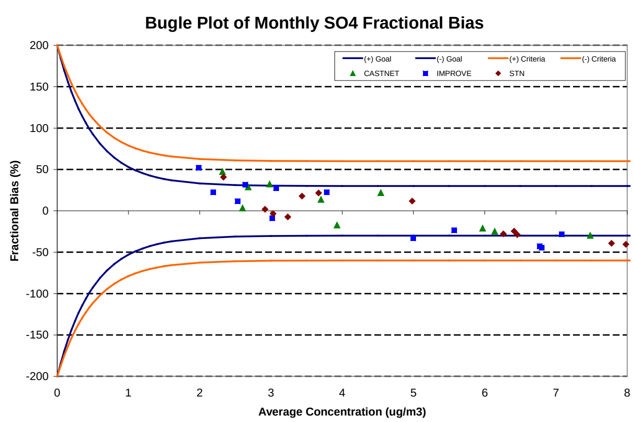
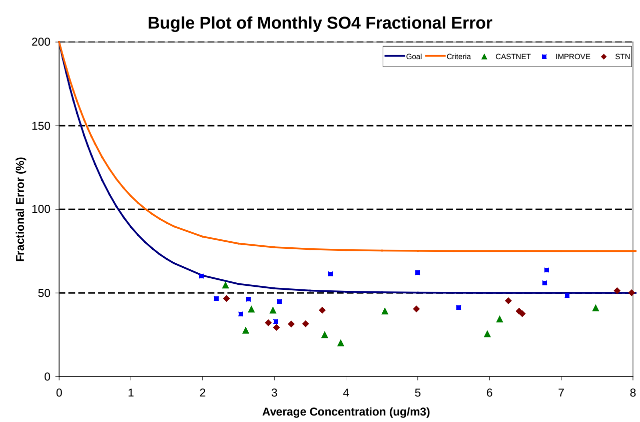
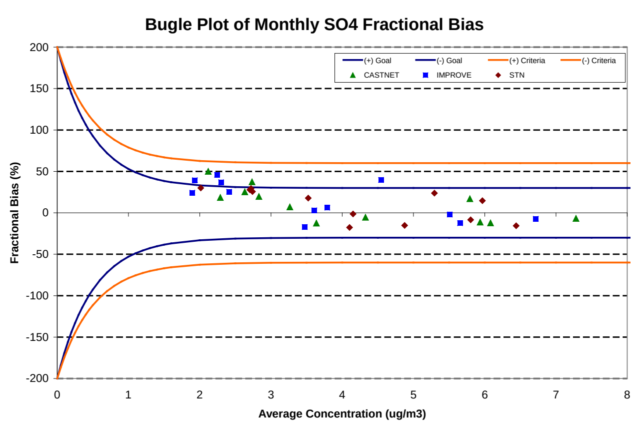
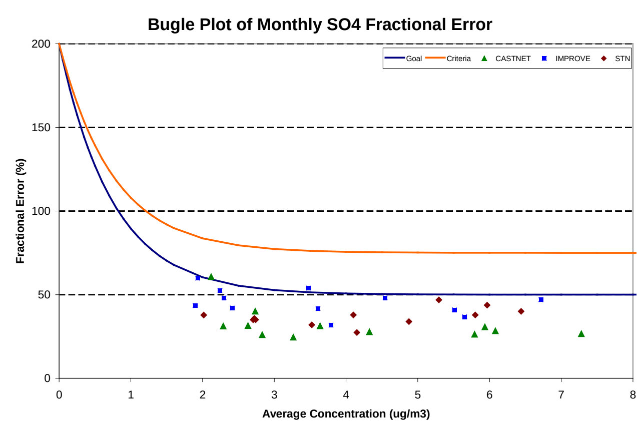
VISTAS 2002 CMAQ SO4 Bias	VISTASA 2002 CMAQ SO4 Error
	
CD-C2005 SO4 Bias	**CD-C2005 SO4 Error**
	
CD-C2006 SO4 Bias	**CD-C2006 SO4 Error**
	

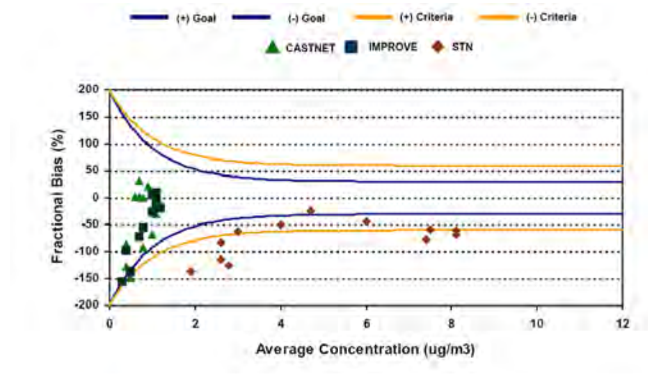
Figure A3-3. Bugle Plots of SO_4 fractional bias (left) and fractional error (right) for the VISTAS 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

A3.2 NITRATE (NO_3) MODEL PERFORMANCE

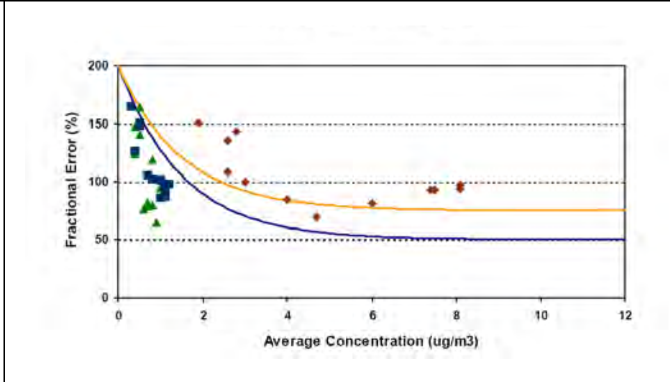
Over the WRAP region, the 2005 and 2006 CD-C CAMx runs show both overestimations and underestimations of NO_3, whereas the WRAP 2002 CMAQ run show mainly underestimations (Figure A3-4). Because the observed NO3 concentrations at the IMPROVE and CASTNet monitoring sites in the western U.S. are so low, the monthly bias and error performance statistics are in the flared portions of the Bugle Plots. Thus, even though bias can approach ±100%, the CD-C and WRAP base case simulations NO_3 performance achieves the PM performance goal across the IMPROVE and CASTNet networks in the western U.S. Across the STN network in the western U.S., however, the observed NO_3 concentrations are higher and fall outside the flare in the Bugle Plot resulting in many months not meeting even the PM performance criteria in both the CD-C CAMx and WRAP CMAQ plots due to excessive underestimation bias.

Over the VISTAS region, the CD-C CAMx base case showed performance that was comparable to or better than the VISTAS 2002 CMAQ run (Figure A3-5), with better performance in the CD-C run coming at average concentrations higher than 1 $\mu g/m^3$. Whereas both CAMx and CMAQ exhibit a summer underestimation bias for NO_3 across the VISTAS region, it occurs under low observed NO_3 conditions so many of the fractional bias points fall on the PM performance goal and criteria flare. During the winter, the VISTAS 2002 CMAQ concentrations exhibits an overestimation bias that occurs under much higher observed NO3 conditions and can be quite large not achieving the PM performance criteria. The CD-C CAMx runs do not exhibit this widespread overestimation bias and achieves the performance goals and criteria more often than the VISTAS CMAQ run.

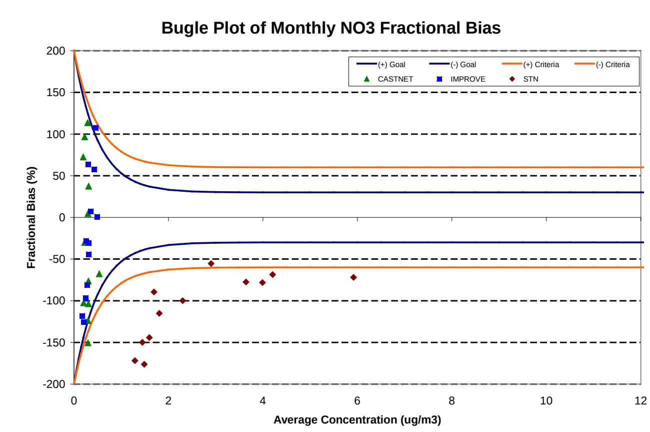
WRAP 2002 CMAQ NO3 Bias



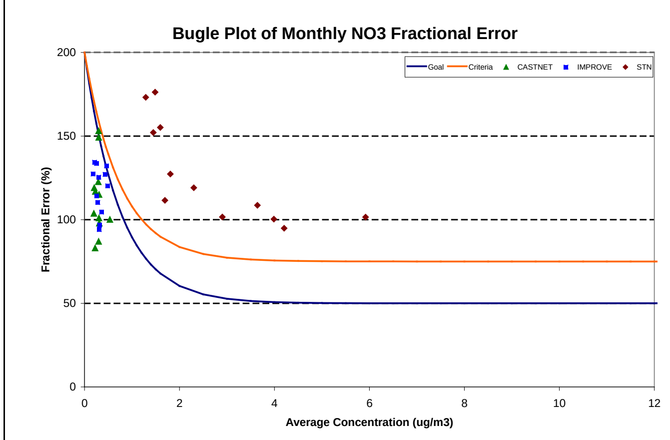
WRAP 2002 CMAQ NO3 Error



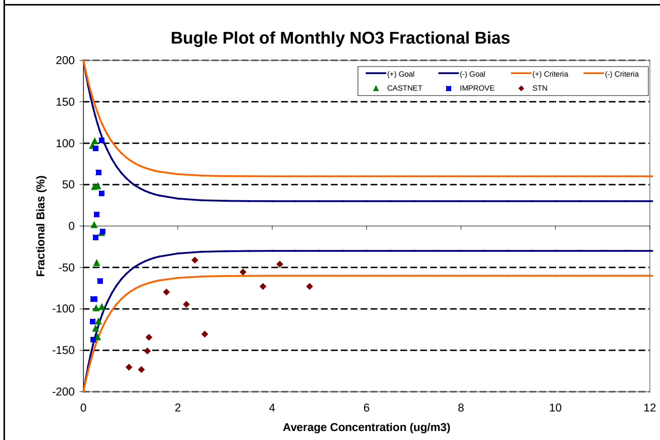
CD-C 2005 NO3 Bias



CD-C 2005 NO3 Error



CD-C 2006 NO3 Bias



CD-C 2006 NO3 Error

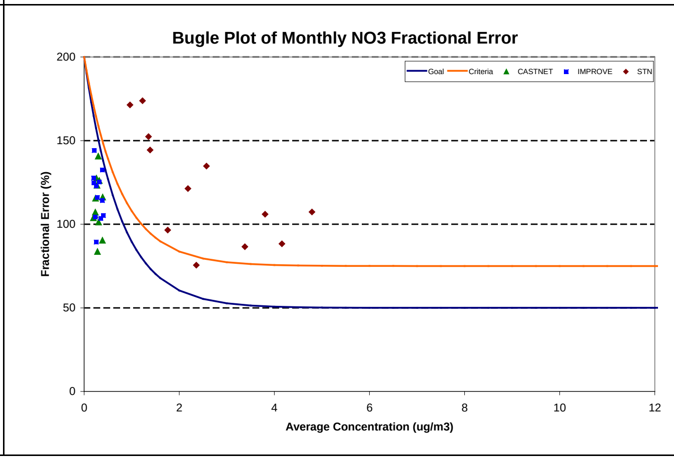


Figure A3-4. Bugle Plots of NO_3 fractional bias (left) and fractional error (right) for the WRAP 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

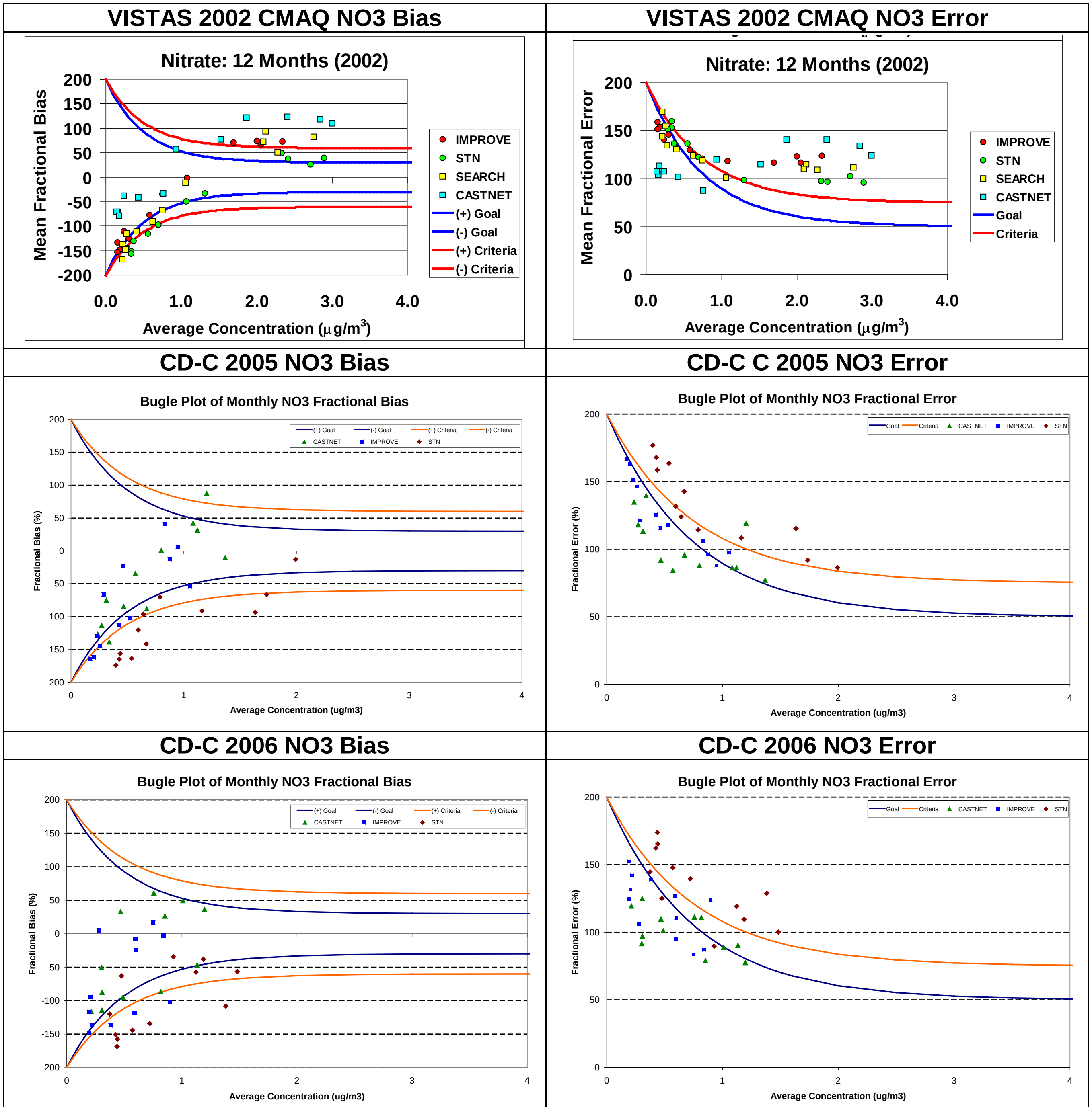


Figure A3-5. Bugle Plots of NO_3 fractional bias (left) and fractional error (right) for the VISTAS 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

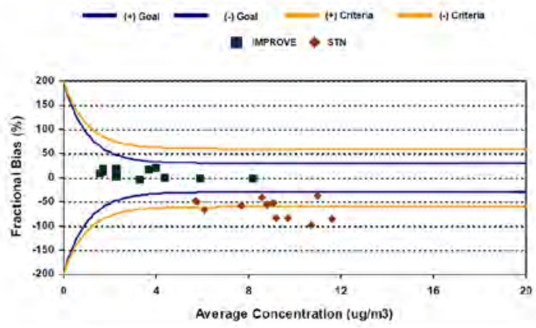
A3.3 ORGANIC CARBON MASS (OCM) PERFORMANCE

OCM is not directly measured in the atmosphere. Instead, OC is measured and must be converted to OCM for comparison with the modeled OCM and for constructing $PM_{2.5}$ mass. Thus, the assumed OCM/OC ratio introduces a source of uncertainty and potential bias in the measured OCM. Even measuring OC is difficult, with different measurement technologies producing different OC values. For example, co-located STN and IMPROVE OC measurement technologies can produce measured OC that differs by 50%. Issues in simulating OC in air quality models are discussed further in Section 5 of this Appendix. During the course of the WRAP study, OCM/OC ratios of 1.4 and 1.0 have been used. It was unclear which OCM/OC ratio was used in generating the Bugle Plots downloaded from the WRAP modeling website. More recent information suggests that an average OCM/OC ratio of 1.8 is appropriate for the more rural IMPROVE monitor network, so that was adopted for the CD-C CAMx OCM evaluation. Thus, the OCM observations in the CD-C evaluation will be 30% to 80% higher than what was used in the WRAP OCM evaluation just due to the assumed observed OCM/OC ratios.

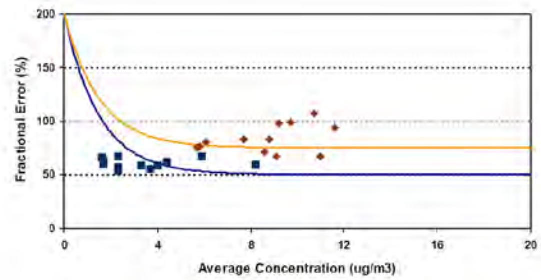
Figure A3-6 compares the CD-C CAMx and WRAP CMAQ OCM Bugle Plots across sites in the western U.S., Not surprisingly, the CD-C fractional bias values are 30-80% lower than seen for WRAP, which is due to different observed OCM/OC ratios. When accounting for that, the OCM performance is comparable.

Similar observed OCM/OC ratio issues exist in the comparisons with the VISTAS CMAQ OCM performance, only in this case we know VISTAS used a 1.4 factor to convert the observed OC to OCM so the CD-C OCM observations are 30% higher than assumed in VISTAS. Both models underestimate OCM across the southeastern U.S. with the VISTAS CMAQ OCM underestimation bias ranging from approximately 0% to -100% and the CD-C CAMx OCM underestimation bias ranging from approximately -30% to -130% (Figure A3-7). These differences in OCM model performance can be completely explained by the assumed observed OCM/OC ratios in the two studies.

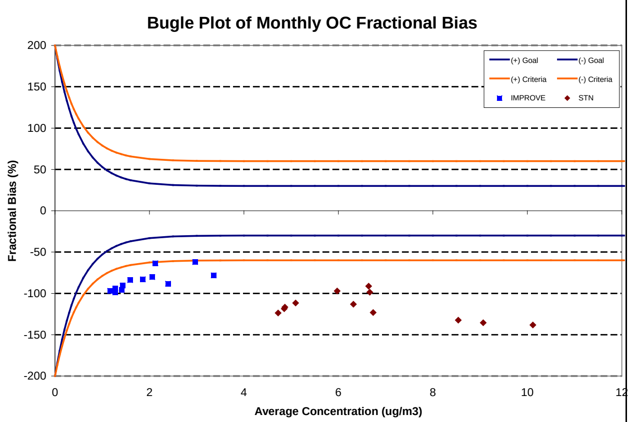
WRAP 2002 CMAQ OCM Bias



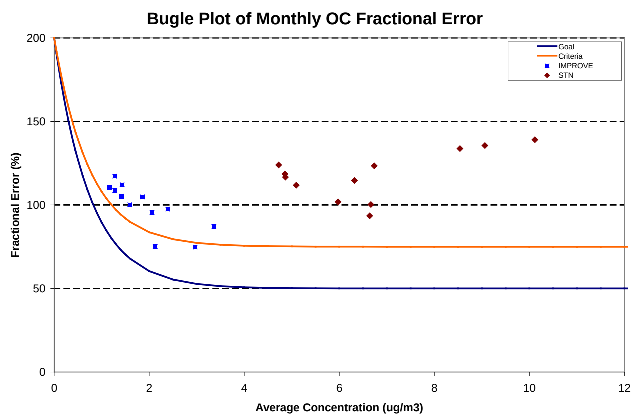
WRAP 2002 CMAQ OCM Error



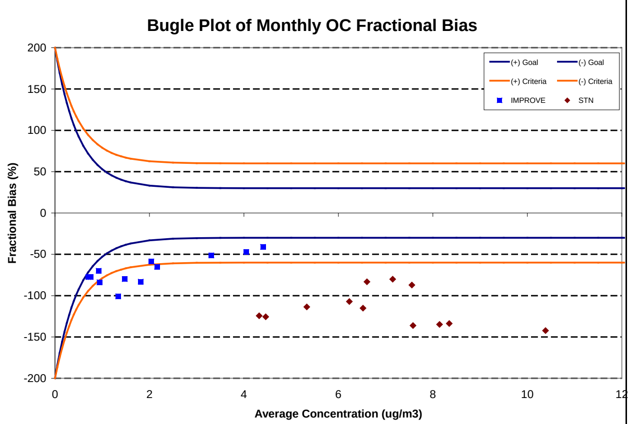
CD-C 2005 OCM Bias



CD-C 2005 OCM Error



CD-C 2006 OCM Bias



CD-C 2006 OCM Error

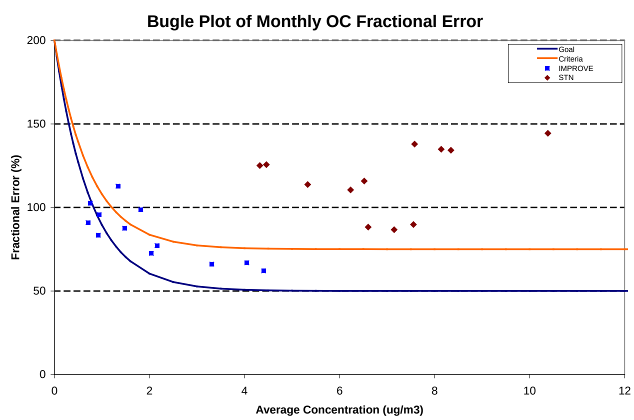
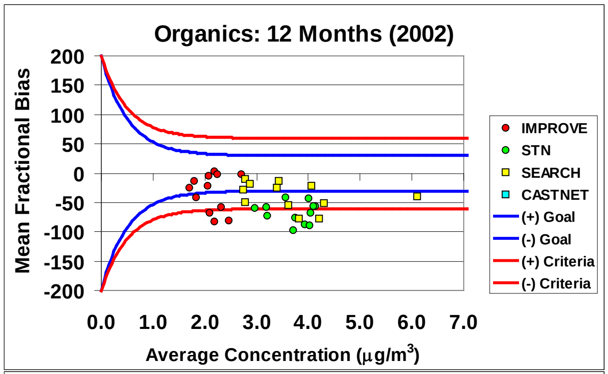
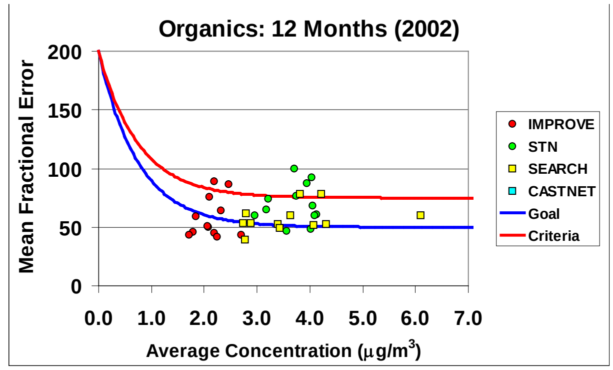


Figure A3-6. Bugle Plots of OCM fractional bias (left) and fractional error (right) for the WRAP 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

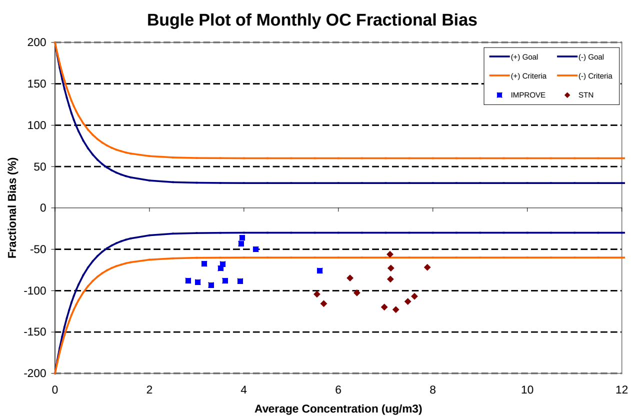
VISTAS 2002 CMAQ OCM Bias



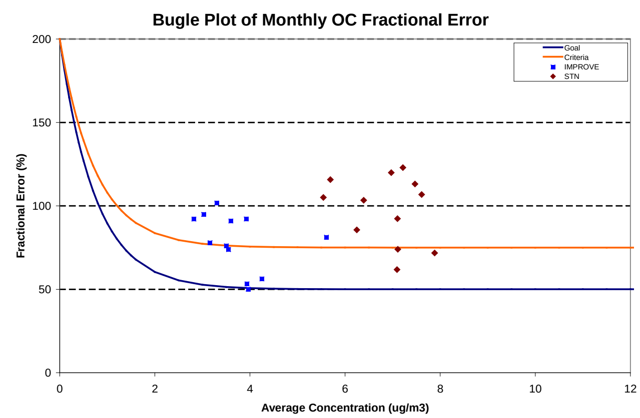
VISTAS 2002 CMAQ OCM Error



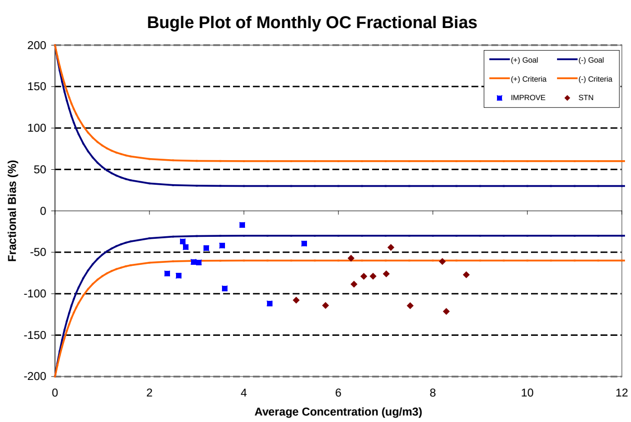
CD-C 2005 OCM Bias



CD-C 2005 OCM Error



CD-C 2006 OCM Bias



CD-C 2006 OCM Error

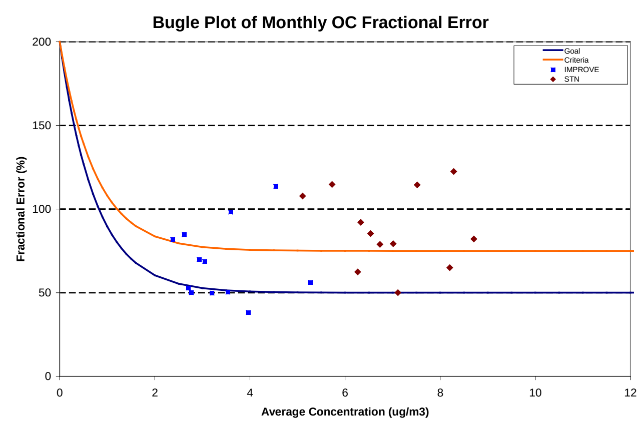
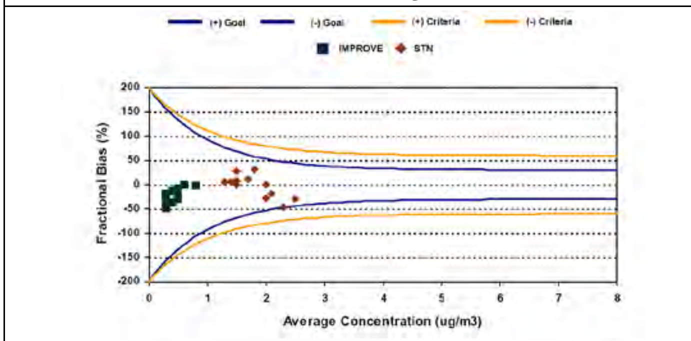


Figure A3-7. Bugle Plots of OCM fractional bias (left) and fractional error (right) for the VISTAS 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the VISTA region.

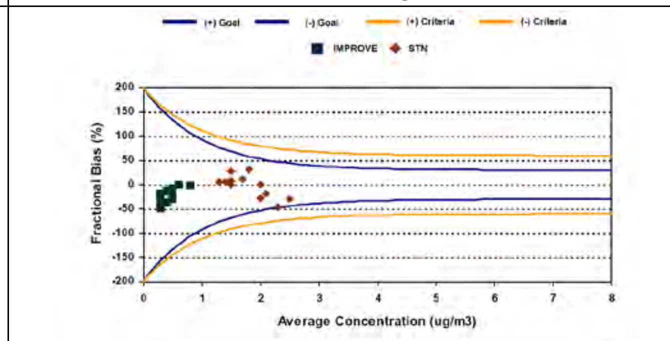
A3.4 ELEMENTAL CARBON (EC) PERFORMANCE

The CD-C 2005 and 2006 CAMx and WRAP 2002 CMAQ runs generally show good performance for EC that almost always achieves the PM performance goals and criteria (Figure A3-8). For one month from 2005 and two months from 2006 the EC bias did not achieve the PM performance criteria, whereas the WRAP CMAQ run always achieves it. Good EC performance is also seen in the CD-C CAMx and VISTAS CMAQ runs across the southeastern U.S. with both models always achieving the PM performance goal (Figure A3-9).

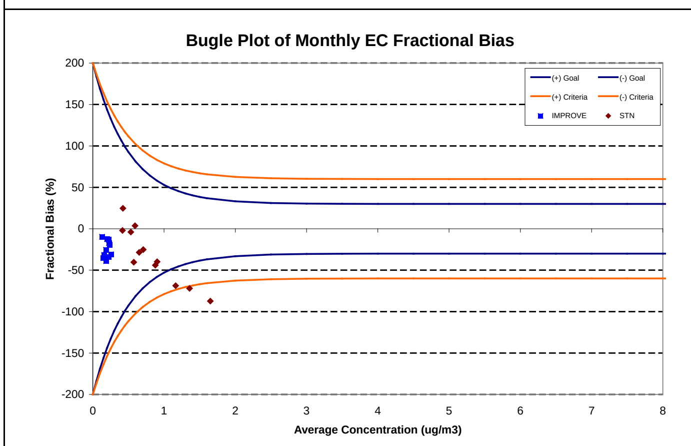
WRAP 2002 CMAQ EC Bias



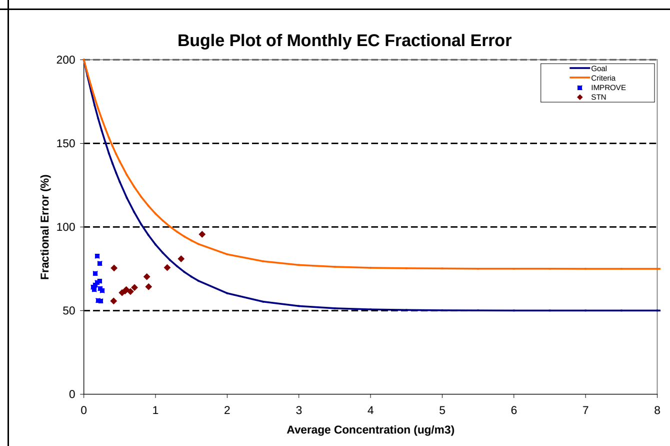
WRAP 2002 CMAQ EC Error



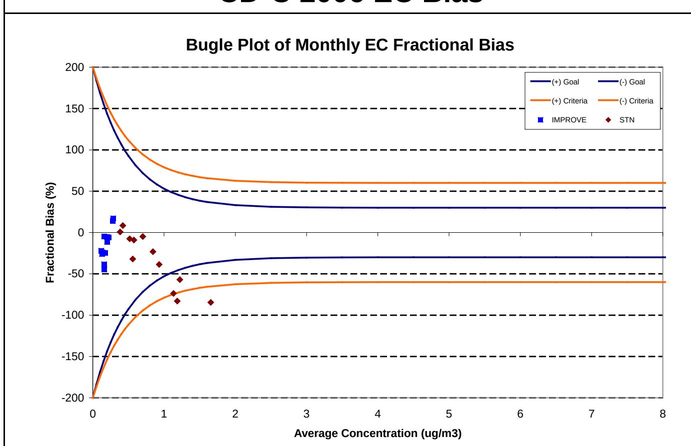
CD-C 2005 EC Bias



CD-C 2005 EC Error



CD-C 2006 EC Bias



CD-C 2006 EC Error

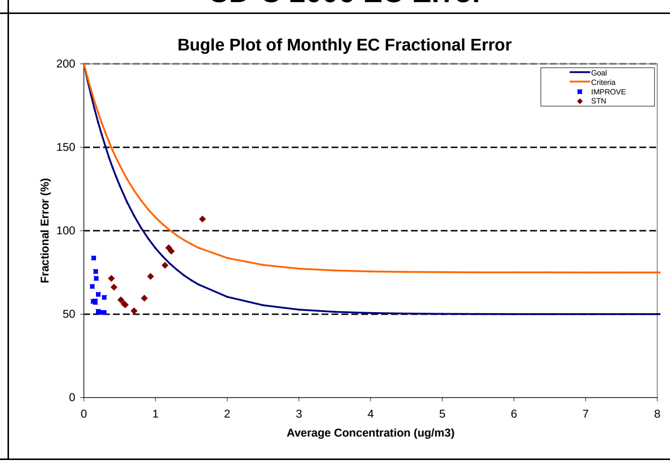


Figure A3-8. Bugle Plots of EC fractional bias (left) and fractional error (right) for the WRAP 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

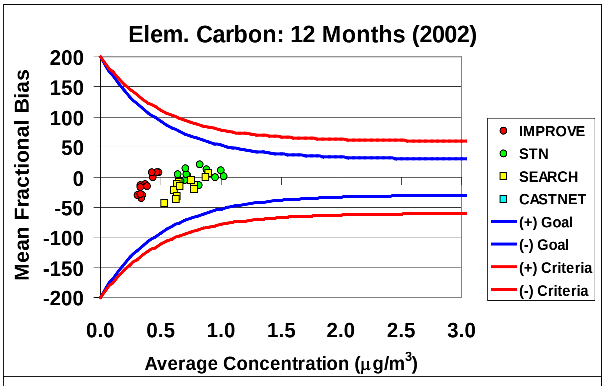
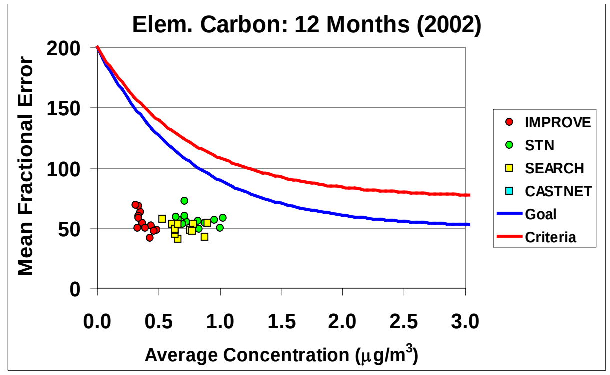
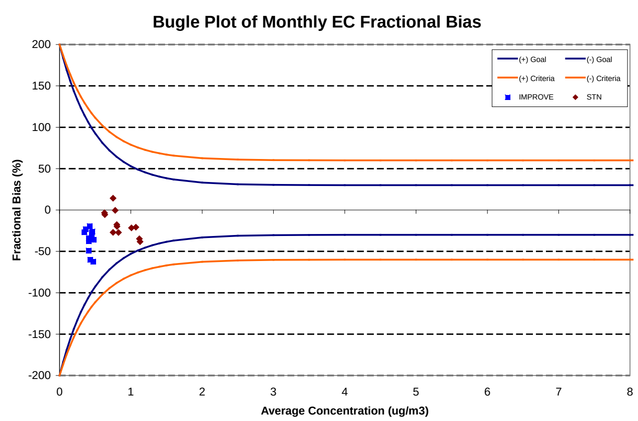
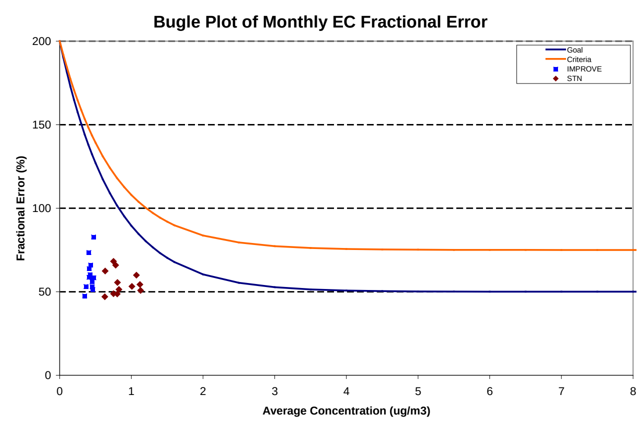
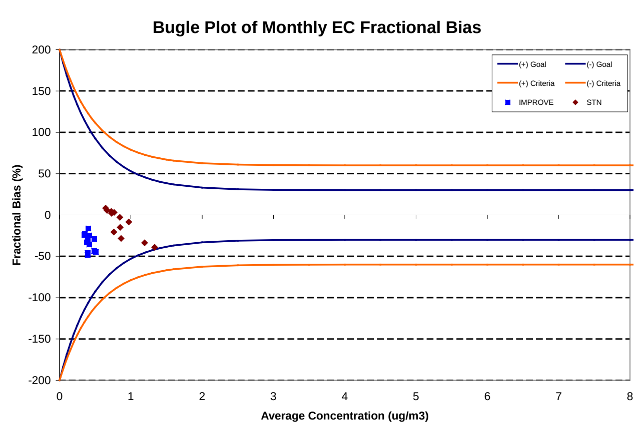
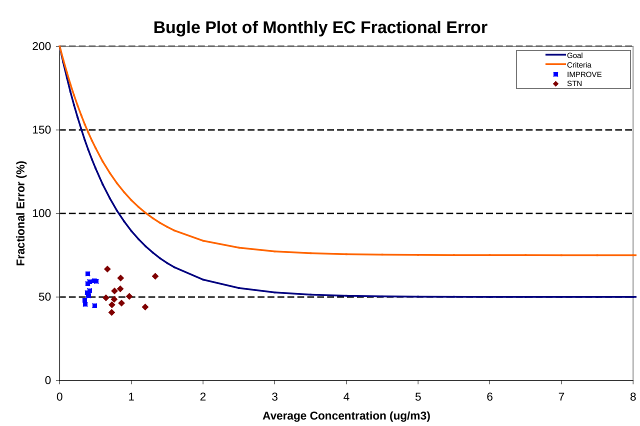
VISTAS 2002 CMAQ EC Bias	VISTAS 2002 CMAQ EC Error
	
CD-C 2005 EC Bias	**CD-C 2005 EC Error**
	
CD-C 2006 EC Bias	**CD-C 2006 EC Error**
	

Figure A3-9. Bugle Plots of EC fractional bias (left) and fractional error (right) for the VISTAS 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the VISTAS region.

A3.5 COARSE MASS (CM OR $PM_{2.5\text{-}10}$) PERFORMANCE

Coarse Mass (CM) is the coarse fraction of PM_{10} and is defined to be the difference PM_{10}-$PM_{2.5}$ obtained by subtracting the fine PM contribution from the total $PM_{10.}$ The average observed coarse mass concentrations across the western states during 2005 and 2006 range from approximately 2 $\mu g/m^3$ in the winter to almost 7 $\mu g/m^3$ in the summer. Over the WRAP region, the CD-C CAMx and the WRAP CMAQ base case simulations both failed to meet the performance goals and the performance criteria for CM for most months (Figure A3-10). CAMx and CMAQ both underestimate the observed CM for all months with a fractional bias greater than 100% for the summer months. In terms of CM performance, the 2005 and 2006 CD-C CAMx runs are comparable to the WRAP 2002 CMAQ run.

The poor model performance in simulating CM by both CAMx and CMAQ is not surprising as the transport distance of CM is much shorter than for fine PM species so that much of the CM impacts measured at IMPROVE monitors is of local origin and is therefore not resolved by the model.

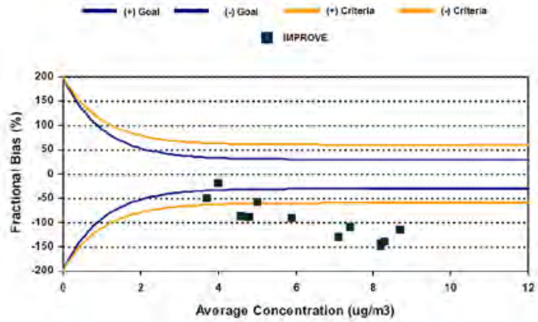
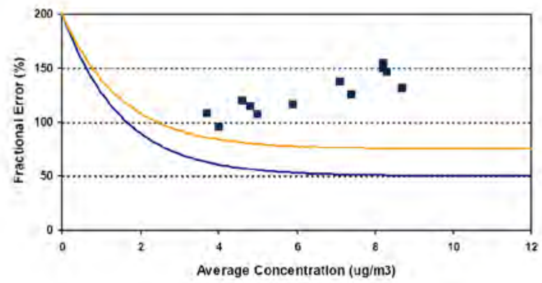
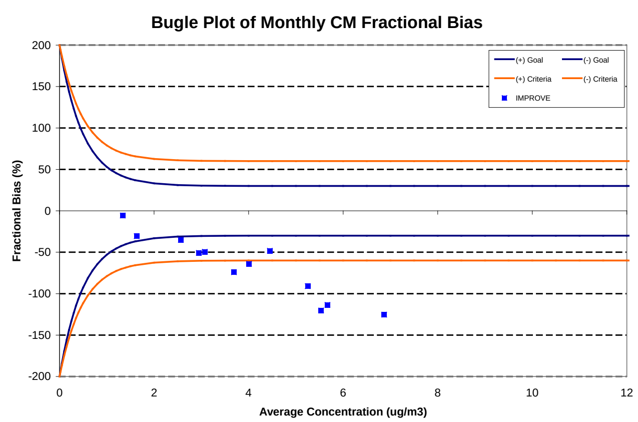
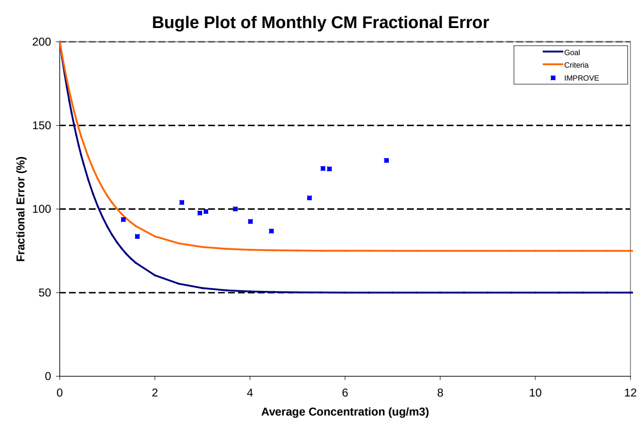
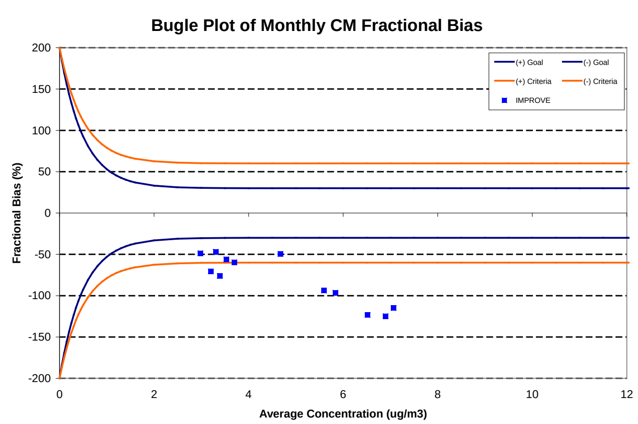
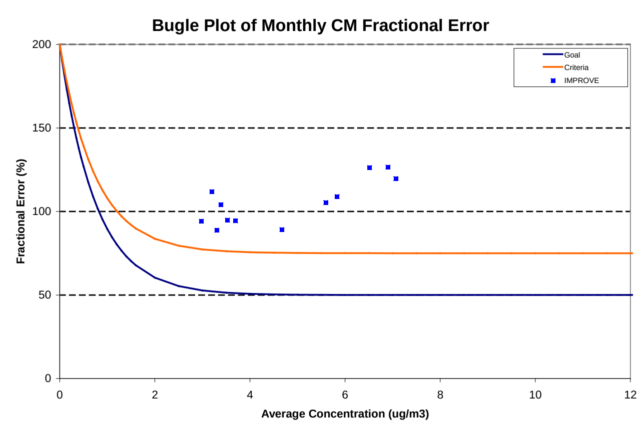
WRAP 2002 CMAQ CM Bias	WRAP 2002 CMAQ CM Error
	
CD-C 2005 CM Bias	**CD-C 2005 CM Error**
	
CD-C 2006 CM Bias	**CD-C 2006 CM Error**
	

Figure A3-10. Bugle Plots of CM fractional bias (left) and fractional error (right) for the WRAP 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

A3.5 OZONE

The resolution of the CD-C CAMx 36 km base case simulations are too coarse to accurately simulate ozone concentrations, so a detailed ozone evaluation against observations was not performed using the 36 km modeling results. Because the primary purpose of the 36 km CAMx simulations are to provide boundary conditions to the 12/4 km CAMx simulations, we did evaluate the models ability to simulate ozone concentrations at the mainly rural CASTNet monitors near the location of the 12 km boundaries and they were determined to be reasonable. Details on the CAMx 2005 and 2006 base case simulation ozone model performance in the 12/4 km modeling domains is provided in Chapter 5.

A3.6 CONCLUSIONS FROM EVALUATION OF 36 KM CAMX RUN

The performance of the 2005 and 2006 36 km CD-C CAMx runs was generally within accepted performance benchmarks for PM and is comparable to similar annual runs made by the WRAP and VISTAS RPOs for the year 2002. The WRAP and VISTAS 2002 CMAQ model performance was deemed sufficiently good that the modeling was accepted for use in regional haze SIP modeling, which is a more stringent task then simply providing boundary conditions to a 12/4 km nested grid simulations. The broad brush evaluation indicates no serious performance issues that would prevent the CD-C CAMx 36 km runs from being used to supply boundary conditions to the 2005 and 2006 CD-C 12/4 km CAMx runs.

A4. OZONE MODEL PERFORMANCE EVALUATION

The CAMx model performance for ozone was evaluated within the 12/4 km modeling domain for the revised 2005 and 2006 base case simulations (Figure A1-2). The CAMx modeling results were compared with observational data from the EPA's**A**ir **Q**uality **S**tation (AQS) and the **C**lean **A**ir **S**tatus **T**rends **Net**work (CASTNet) monitoring networks and at the Wyoming Department of Environmental Quality (WDEQ) industrial ozone monitors within the state of Wyoming. The evaluation focuses on the operational model evaluation of the air quality model's performance with respect to ozone.

Ozone monitoring sites within the 4 km modeling domain that were in operation during the 2005 and 2006 modeling period were two CASTNet sites at Pinedale and Centennial and Wyoming state industrial site monitors at Jonah, Boulder, Daniel, OCI and Wamsutter (OCI and Wamsutter started operation in 2006). There were no AQS monitoring sites located within the 4 km domain, as the AQS network is oriented toward urban areas and the region encompassed by the 4 km domain is generally rural. Within the 12 km domain were 18 AQS sites and a total of 6 CASTNet sites, including Centennial and Pinedale.

A majority of the AQS ozone monitoring sites in the 12 km grid are located in the Salt Lake City, Utah and Denver, Colorado urban areas. The CAMx 2005 and 2006 modeling was configured for simulating ozone and PM concentrations from O&G sources in southwestern Wyoming (SWWY) and was not designed for simulating ozone in the Salt Lake City and Denver ozone nonattainment areas. For example, the Colorado Department of Health and Environment (CDPHE) has spent considerable effort performing meteorological and photochemical modeling to identify the optimal model configuration for simulating ozone formation in the Denver area for their ozone State Implementation Plan (SIP)[4]. Thus, our ozone model performance evaluation focuses on the performance at the more rural CASTNet ozone monitoring sites within the 12/4 km domains and at the Southwest Wyoming industrial sites within the 4 km domain.

A4.1 COMPARISON OF HOURLY OZONE MODEL PERFORMANCE WITH PERFORMANCE GOALS IN THE 4 KM MODELING DOMAIN

The CAMx hourly average ozone performance across CASTNet and Wyoming industrial monitoring sites in the 4 km domain are compared against EPA's ≤±15% and ≤35% performance goals for bias and error, respectively (EPA, 1991). Although these ozone performance goals were originally developed for the Mean Normalized Bias (MNB) and Mean Normalized Gross Error (MNGE) statistical performance metrics, we have also compared them to the Fractional Bias (FB), Normalized Mean Bias (NMB), Fractional Error (FE) and Normalized Mean Gross Error (NMGE) statistical performance metrics as well (See Table A2-2 for definitions). EPA procedures for calculating these performance goals are to use all predicted and observed hourly ozone pairs with the observed ozone concentration above a concentration threshold value. EPA's original guidance suggested using an observed hourly ozone concentrations threshold of 60 ppb (EPA, 1991). However, this guidance was developed almost two decades ago for urban ozone

[4]http://www.colorado.gov/airquality/documents/deno308/

modeling to address the 120 ppb ozone NAAQS under ozone conditions much higher than currently occur in more rural southwest Wyoming. Use of a 60 ppb cutoff threshold may result in too few predicted and observed hourly ozone pairs to calculate robust model performance statistics. Thus, the hourly ozone bias and error performance statistics were calculated using three different observed hourly ozone cutoff thresholds: 60, 50 and 40 ppb. This ensures that the model performance evaluation is focused on times when ozone is high, rather than on relatively clean days or on nighttime conditions, and assures, at least for the lower cutoff concentration thresholds, that there are sufficient predicted and observed hourly ozone pairs so that the statistics are meaningful.

Table A4-1 summarizes the hourly ozone performance statistics metrics for bias and error across the CASTNet and Wyoming industrial sites in the 4 km domain for 2005 and 2006 by Quarter. Performance statistics were calculated across all CASTNet and Wyoming industrial sites and separately at each site. The Wyoming industrial sites are located within or near the Jonah-Pinedale Anticline region of intensive oil and gas exploration and production in SubletteCounty. Although the Pinedale CASTNet site lies adjacent to the Pinedale Anticline natural gas field, it is located at a higher elevation than the field, and ozone data gathered at Pinedale is more similar in character to Centennial CASTNet site located ~350 km to the southeast on the border of Carbon and Albany Counties than nearby monitors at lower elevations such as Jonah and Boulder. When the bias or error ozone statistical performance measure exceeds EPA's ozone performance goal, the value is highlighted in yellow in Table A4-1. Table A4-1 contains the bias and error ozone performance statistics for the original (June 2009) CAMx base case simulation performed under the Hiawatha EIS (Kemball-Cook et al., 2009) as well as the latest revised CAMx base case simulation performed as part of the CD-C EIS study.

Across all monitoring sites in the 4 km modeling domain and for the entire 2005 year ("All Sites" entry in Table A4-1a), both the Hiawatha and CD-C CAMx base case simulations achieve EPA's bias and error performance goals for the bias and error performance metrics using a 40 ppb ozone cutoff (Table A4-1a). However, looking at the individual monitoring sites in 2005, EPA's performance goals are met or nearly met at the two CASTNet sites and Daniel, but there is an underestimation of -18% to -29% at the Jonah and Boulder sites; the CD-C revised CAMx base case simulation ozone performance is slightly better (bias being a couple percentage points closer to zero) than the preliminary Hiawatha base case simulation for the annual performance statistics in 2005.

It is not surprising that EPA's bias performance goals during Q1 are not achieved since the model was not configured to reproduce the observed winter ozone events in SWWY. The WDEQ AQD has indicated that Q1 will not be included in the CD-C ozone impact analysis as simulation of winter ozone using photochemical grid models is an active area of scientific research and is therefore not appropriate for a NEPA analysis; this is discussed further in Section 4.2. During Q2 and Q3 in 2005, when the highest ozone occurs outside of the winter ozone events, both CAMx base case simulations achieve EPA's performance goals across all monitoring sites in the 4 km domain using a 40 ppb cutoff (Table A4-1a). For 2005 Q2, both models achieve EPA's performance goals individually across the monitoring sites with the exception of Jonah and the preliminary Hiawatha base case simulation that exhibits bias of -16% to -20%. The diagnostic model tests that were performed to arrive at the CD-C model configuration was able to reduce the -16% to -20% bias at Jonah during 2005 Q2 to be able to achieve EPA's bias performance goal (-13% to -15%) in the CD-C base case simulation. In 2005 Q3, EPA's performance goals are achieved across all sites but Jonah and Boulder for the Hiawatha base case. Again the model improvements implemented in the revised CD-C CAMx base case simulations are able to bring these two sites into achievement of EPA's bias performance goals.

The use of the higher ozone cutoff thresholds results in larger ozone underestimation bias during 2005 (Tables A4-2b and 5-2c). Even so, the revised CD-C bias metrics exhibit much lower bias compared to the Hiawatha base case in most cases, resulting in improved ozone model performance.

In 2006, the two base case simulations exhibit better model performance than is seen in 2005 (Table A4-1d). The revised CD-C CAMx base case is performing worse than the Hiawatha base case during the two colder quarters in 2006 (Q1 and Q4), but better during warmest quarter (Q3) and performance is slightly degraded during Q2. Across all sites, both the CD-C and Hiawatha CAMx base case simulations achieve EPA's performance goals for the annual and by-quarter time periods for 2006.

Table A4-1a.Ozone model performance bias and error statistical measures with 40 ppb threshold for the CASTNet network and industrial sites for 2005by annual and quarter for all sites and for each site in the CD-C 4 km domain.

Period	EPA	FB(%) ± 15%		FGE(%) ± 35%		MNB(%) ± 15%		MNGE(%) ± 35%		NMB(%) ± 15%		NME(%) ± 35%		Number of Points
	Site\Run	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	
ANN	All Sites	-9.9	-14.6	17.4	18.5	-7.1	-11.9	15.3	16.1	-7.7	-12.2	15.5	16.3	24373
	Jonah	-28.6	-24.6	29.9	27.1	-21.8	-19.0	23.2	21.7	-22.1	-19.3	23.4	21.8	3688
	Boulder	-24.8	-22.0	26.9	25.0	-19.6	-17.7	21.8	20.9	-19.7	-18.0	21.7	20.9	4739
	Daniel	-14.2	-15.9	16.0	19.8	-12.5	-13.5	14.5	17.7	-13.0	-13.5	14.8	17.5	1960
	Centennial	4.2	-7.4	11.4	12.5	5.3	-6.3	11.9	11.8	4.7	-6.4	11.8	11.8	7279
	Pinedale	-3.0	-11.3	10.7	15.4	-2.0	-9.6	10.3	14.0	-2.6	-9.9	10.5	14.2	6707
Q1	All Sites	-11.0	-19.2	18.8	20.5	-7.2	-15.7	15.6	17.1	-8.4	-16.6	16.3	18.0	6025
	Jonah	-39.5	-43.6	41.0	44.1	-27.1	-31.3	28.7	31.9	-28.5	-32.6	29.8	33.1	965
	Boulder	-30.0	-24.4	31.6	25.0	-23.2	-20.7	24.8	21.3	-24.5	-22.2	25.9	22.7	1138
	Centennial	7.0	-6.8	10.3	10.1	7.9	-6.0	10.9	9.5	7.6	-6.2	10.8	9.6	1903
	Pinedale	-3.5	-16.2	8.9	16.5	-2.8	-14.4	8.5	14.8	-3.3	-14.8	8.7	15.1	2019
Q2	All Sites	-4.1	-10.0	16.0	15.4	-1.9	-8.1	15.2	14.0	-2.5	-8.6	15.0	14.1	6785
	Jonah	-20.0	-15.0	22.1	18.8	-16.2	-12.3	18.4	16.5	-16.3	-12.6	18.3	16.5	1319
	Boulder	-13.9	-13.4	18.0	18.3	-11.4	-11.0	15.9	16.4	-11.7	-11.6	15.7	16.4	1527
	Centennial	9.7	-4.1	14.1	11.4	11.5	-3.1	15.5	11.0	10.8	-3.5	15.1	10.9	1989
	Pinedale	0.2	-9.8	12.2	14.9	1.5	-8.1	12.2	13.6	0.6	-8.7	12.1	13.8	1950
Q3	All Sites	-11.5	-9.3	17.3	15.9	-9.0	-7.4	15.3	14.6	-9.7	-7.9	15.4	14.6	7313
	Jonah	-30.0	-17.6	30.7	20.9	-24.0	-14.5	24.7	18.0	-23.8	-14.5	24.4	17.8	1074
	Boulder	-26.4	-16.1	27.5	20.5	-21.3	-13.2	22.5	18.1	-21.1	-13.7	22.2	17.8	1247
	Daniel	-13.6	-8.9	16.0	15.6	-11.9	-7.2	14.6	14.6	-12.6	-7.7	14.9	14.4	1083
	Centennial	1.5	-5.3	10.3	12.8	2.3	-4.1	10.5	12.3	1.3	-4.3	10.4	12.3	2040
	Pinedale	-4.0	-4.8	11.3	13.6	-3.0	-3.3	10.9	13.0	-4.0	-4.0	11.2	13.1	1869
Q4	All Sites	-14.7	-24.6	17.7	25.1	-11.9	-20.4	15.1	20.8	-12.1	-20.6	15.2	21.0	4250
	Jonah	-26.4	-30.1	26.6	30.3	-21.5	-24.1	21.7	24.3	-21.4	-24.1	21.6	24.3	330
	Boulder	-35.6	-43.5	35.9	43.8	-27.1	-32.7	27.3	32.9	-26.9	-32.5	27.1	32.8	827
	Daniel	-14.9	-24.7	15.9	25.0	-13.3	-21.3	14.3	21.6	-13.6	-21.6	14.6	21.9	877
	Centennial	-3.9	-16.6	10.5	17.2	-3.1	-14.8	10.1	15.5	-3.6	-15.1	10.2	15.8	1347
	Pinedale	-6.8	-17.1	9.9	17.5	-6.0	-15.1	9.3	15.5	-6.2	-15.2	9.3	15.6	869

Table A4-1b.Ozone model performance bias and error statistical measures with 50 ppb threshold for the CASTNet network and industrial sites for 2005by annual and quarter for all sites and for each site in the CD-C 4 km domain.

Period	EPA	FB(%) ± 15%		FGE(%) ± 35%		MNB(%) ± 15%		MNGE(%) ± 35%		NMB(%) ± 15%		NME(%) ± 35%		Number of Points
	Site\Run	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	
ANN	All Sites	-12.2	-15.1	16.9	18.1	-9.8	-12.6	14.9	15.7	-10.5	-13.0	15.3	16.1	11263
	Jonah	-26.3	-22.7	27.1	24.6	-21.0	-17.8	21.8	19.9	-21.8	-18.6	22.5	20.6	2000
	Boulder	-22.6	-21.5	23.6	22.8	-18.7	-18.1	19.7	19.5	-19.3	-18.5	20.2	19.8	2364
	Daniel	-17.2	-14.3	17.9	17.1	-15.4	-12.4	16.0	15.4	-15.6	-12.4	16.2	15.3	763
	Centennial	0.5	-7.7	10.4	12.5	1.4	-6.5	10.5	11.7	1.0	-6.7	10.6	11.8	3149
	Pinedale	-6.7	-12.9	11.5	16.0	-5.7	-11.0	10.7	14.3	-6.2	-11.4	11.0	14.6	2987
Q1	All Sites	-18.7	-25.6	22.4	26.1	-13.8	-20.7	17.8	21.2	-15.6	-22.2	19.3	22.6	2192
	Jonah	-44.6	-48.8	45.2	49.1	-31.0	-34.6	31.6	34.9	-33.0	-36.7	33.5	36.9	394
	Boulder	-33.4	-30.3	33.8	30.5	-25.8	-25.2	26.2	25.4	-27.4	-26.7	27.8	26.8	577
	Centennial	3.6	-9.1	8.9	10.9	4.2	-8.1	9.1	10.0	3.9	-8.4	9.1	10.2	455
	Pinedale	-7.6	-20.0	10.2	20.1	-6.6	-17.6	9.4	17.7	-7.1	-18.0	9.8	18.1	766
Q2	All Sites	-5.7	-11.9	14.0	15.1	-4.0	-10.2	13.2	13.5	-4.6	-10.5	13.3	13.7	4130
	Jonah	-17.8	-15.2	19.1	17.8	-15.2	-12.8	16.6	15.6	-15.5	-13.1	16.8	15.8	806
	Boulder	-14.5	-16.2	16.4	18.4	-12.5	-13.9	14.5	16.2	-12.7	-13.9	14.5	16.2	891
	Centennial	6.3	-6.3	11.6	10.8	7.5	-5.4	12.4	10.2	7.2	-5.6	12.3	10.3	1225
	Pinedale	-3.2	-12.3	11.4	15.2	-2.1	-10.5	10.9	13.6	-2.7	-10.9	11.1	13.9	1208
Q3	All Sites	-14.1	-10.8	16.4	15.3	-12.2	-9.1	14.6	13.9	-12.7	-9.4	14.9	14.0	4333
	Jonah	-26.2	-16.6	26.6	18.9	-22.1	-14.0	22.5	16.5	-22.3	-14.1	22.7	16.5	732
	Boulder	-22.7	-17.7	23.1	19.1	-19.6	-15.4	20.0	16.8	-19.7	-15.4	20.2	16.7	754
	Daniel	-16.2	-11.0	17.0	14.4	-14.5	-9.6	15.3	13.2	-14.8	-9.8	15.6	13.2	635
	Centennial	-3.9	-5.7	9.1	12.7	-3.2	-4.6	8.8	12.1	-3.7	-4.9	9.0	12.2	1260
	Pinedale	-10.1	-7.4	12.4	13.4	-8.9	-5.9	11.3	12.3	-9.5	-6.5	11.8	12.6	952
Q4	All Sites	-20.3	-29.1	20.6	29.1	-17.7	-24.4	18.0	24.4	-17.9	-24.5	18.1	24.5	608
	Jonah	-22.9	-25.4	22.9	25.4	-19.9	-21.7	19.9	21.7	-20.4	-22.2	20.4	22.2	68
	Boulder	-29.2	-39.3	29.2	39.3	-24.2	-30.4	24.2	30.4	-24.2	-30.3	24.2	30.3	142
	Daniel	-22.3	-30.6	22.3	30.6	-19.8	-26.3	19.8	26.3	-19.8	-26.2	19.8	26.2	128
	Centennial	-14.1	-24.6	14.8	24.6	-12.8	-21.7	13.5	21.7	-13.0	-21.8	13.7	21.8	209
	Pinedale	-14.1	-21.7	14.3	21.7	-12.5	-18.9	12.7	18.9	-12.7	-19.0	12.9	19.0	61

Table A4-1c.Ozone model performance bias and error statistical measures with 60 ppb threshold for the CASTNet network and industrial sites for 2005by annual and quarter for all sites and for each site in the CD-C 4 km domain.

Period	EPA	FB(%) ± 15%		FGE(%) ± 35%		MNB(%) ± 15%		MNGE(%) ± 35%		NMB(%) ± 15%		NME(%) ± 35%		Number of Points
	Site\Run	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	
ANN	All Sites	-27	-25	28	26	-22	-21	23	22	-23	-22	24	22	1853
	Jonah	-36	-32	36	33	-28	-25	29	26	-30	-27	30	28	421
	Boulder	-30	-25	31	26	-25	-21	25	22	-26	-22	26	23	655
	Daniel	-24	-16	24	16	-21	-14	21	15	-21	-14	21	15	145
	Centennial	-12	-17	15	18	-11	-15	14	16	-11	-15	14	16	289
	Pinedale	-24	-27	24	28	-20	-22	20	24	-20	-23	21	24	343
Q1	All Sites	-50	-51	50	51	-37	-39	37	39	-39	-40	39	40	362
	Jonah	-57	-66	57	66	-42	-47	42	47	-44	-49	44	49	113
	Boulder	-51	-44	51	44	-39	-35	39	35	-40	-36	40	36	186
	Centennial	-34	-47	34	47	-29	-38	29	38	-29	-38	29	38	8
	Pinedale	-30	-44	30	44	-25	-35	25	35	-25	-36	25	36	55
Q2	All Sites	-18	-20	19	22	-15	-17	17	19	-15	-17	17	19	593
	Jonah	-26	-22	26	23	-22	-18	22	20	-22	-19	22	20	139
	Boulder	-18	-18	19	20	-16	-16	16	17	-16	-16	17	17	207
	Centennial	-4	-16	11	17	-2	-13	10	15	-3	-14	11	16	109
	Pinedale	-20	-26	21	28	-17	-21	17	23	-17	-21	18	23	138
Q3	All Sites	-24	-18	24	18	-21	-15	21	16	-21	-16	21	16	891
	Jonah	-29	-18	29	19	-25	-15	25	16	-25	-16	25	16	167
	Boulder	-25	-17	25	17	-22	-15	22	16	-22	-15	22	16	260
	Daniel	-24	-15	24	16	-21	-14	21	14	-21	-14	21	14	143
	Centennial	-17	-16	17	17	-15	-15	15	16	-15	-15	16	16	171
	Pinedale	-25	-22	25	23	-21	-18	21	20	-22	-19	22	20	150
Q4	All Sites	-39	-47	39	47	-31	-36	31	36	-33	-38	33	38	7
	Jonah	-71	-76	71	76	-52	-55	52	55	-53	-56	53	56	2
	Boulder	-14	-19	14	19	-13	-17	13	17	-13	-17	13	17	2
	Daniel	-41	-52	41	52	-34	-41	34	41	-34	-41	34	41	2
	Centennial	-25	-31	25	31	-22	-27	22	27	-22	-27	22	27	1
	Pinedale	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0

Table A4-1d.Ozone model performance bias and error statistical measures with 40 ppb threshold for the CASTNet network and industrial sites for 2006by annual and quarter for all sites and for each site in the CD-C 4 km domain.

Period	EPA	FB(%) ± 15%		FGE(%) ± 35%		MNB(%) ± 15%		MNGE(%) ± 35%		NMB(%) ± 15%		NME(%) ± 35%		Number of Points
	Site\Run	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	
ANN	All Sites	-4.6	-9.9	13.2	15.8	-3.1	-7.9	12.5	14.5	-3.7	-8.2	12.4	14.4	29823
	Jonah	-19.1	-17.6	21.4	21.4	-15.1	-14.2	17.7	18.3	-15.2	-14.2	17.5	18.2	3119
	Boulder	-14.2	-19.1	18.0	23.2	-11.8	-15.3	15.9	19.9	-12.2	-15.5	15.9	19.7	4889
	Daniel	-6.2	-11.5	12.0	16.5	-5.1	-9.6	11.4	15.2	-5.8	-9.9	11.6	15.1	4658
	Wamsutter	0.1	-0.2	12.2	14.2	1.3	1.5	12.3	14.4	0.4	0.8	12.1	14.0	2060
	Centennial	4.2	-7.1	10.2	12.0	5.1	-6.0	10.7	11.4	4.4	-6.4	10.4	11.4	6777
	OCI	-6.8	-3.1	12.3	13.1	-5.6	-1.7	11.6	12.8	-6.1	-2.4	11.6	12.4	2185
	Pinedale	0.9	-6.0	10.0	12.3	1.8	-4.9	10.2	11.7	1.2	-4.8	10.1	11.6	6135
Q1	All Sites	-6.0	-19.5	13.4	20.2	-4.3	-16.6	12.3	17.3	-4.6	-16.7	12.3	17.3	8643
	Jonah	-22.8	-28.8	24.9	29.4	-17.6	-23.5	19.9	24.1	-17.6	-23.7	19.7	24.2	879
	Boulder	-18.2	-34.1	21.5	34.6	-14.7	-27.1	18.3	27.6	-14.9	-26.8	18.2	27.2	1610
	Daniel	-5.9	-18.1	11.1	18.7	-4.9	-15.9	10.5	16.6	-5.4	-16.1	10.7	16.7	1908
	Wamsutter	0.5	-10.7	9.2	12.6	1.2	-9.4	9.1	11.4	1.1	-9.6	8.9	11.4	286
	Centennial	2.7	-13.1	8.6	13.6	3.3	-11.9	8.8	12.4	3.3	-11.9	8.7	12.4	2010
	OCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Pinedale	1.4	-12.7	9.5	13.7	2.1	-11.4	9.6	12.4	2.1	-11.4	9.5	12.3	1950
Q2	All Sites	-3.8	-8.6	13.7	14.7	-2.3	-6.9	13.2	13.6	-3.1	-7.5	13.0	13.6	9801
	Jonah	-15.6	-16.6	19.0	20.4	-12.5	-13.3	16.2	17.5	-12.8	-13.6	16.1	17.4	1186
	Boulder	-9.3	-12.5	15.7	18.1	-7.5	-10.3	14.5	16.4	-8.5	-11.4	14.6	16.7	1597
	Daniel	-4.3	-8.7	13.5	15.8	-2.9	-6.8	13.1	14.8	-4.1	-8.0	13.2	14.8	1399
	Wamsutter	-4.9	-5.7	12.5	12.6	-3.7	-4.4	12.1	11.9	-4.3	-4.7	11.9	11.7	1194
	Centennial	3.4	-7.9	11.3	11.9	4.5	-6.8	11.9	11.1	3.6	-7.3	11.5	11.3	2092
	OCI	-5.8	-3.6	13.4	12.8	-4.4	-2.3	12.7	12.4	-4.9	-3.2	12.5	12.2	888
	Pinedale	4.0	-3.9	11.8	12.4	5.2	-2.6	12.4	11.9	4.0	-3.2	11.9	11.9	1445
Q3	All Sites	-4.6	-1.1	13.4	13.0	-3.0	0.4	12.7	13.0	-3.9	-0.3	12.6	12.8	8448
	Jonah	-20.6	-9.7	22.0	16.2	-16.3	-7.4	17.8	14.6	-16.4	-7.4	17.7	14.3	969
	Boulder	-15.9	-7.0	17.7	15.4	-13.5	-5.1	15.4	14.8	-13.8	-6.0	15.4	14.7	1163
	Daniel	-9.4	-0.2	12.4	12.7	-8.4	1.2	11.5	13.0	-9.0	0.5	11.8	12.7	889
	Wamsutter	10.1	16.5	13.1	18.3	11.6	19.2	14.4	20.9	11.1	19.1	14.1	20.9	577
	Centennial	6.2	-0.6	11.2	11.2	7.3	0.5	12.0	11.2	6.3	-0.1	11.6	11.2	1885
	OCI	-7.3	-1.5	11.7	13.0	-6.3	-0.1	11.0	12.9	-7.0	-0.9	11.1	12.4	1104
	Pinedale	-0.8	1.0	10.1	10.3	0.0	1.9	10.2	10.4	-1.0	1.4	10.1	10.3	1861
Q4	All Sites	-3.4	-11.0	10.2	14.6	-2.6	-9.3	9.9	13.2	-2.9	-9.5	10.0	13.3	2931
	Jonah	-12.4	-7.0	13.6	13.2	-11.1	-5.6	12.4	12.2	-11.3	-5.6	12.5	12.1	85
	Boulder	-13.4	-20.2	14.9	21.3	-12.0	-17.1	13.5	18.2	-12.3	-17.2	13.8	18.3	519
	Daniel	-7.4	-14.3	10.6	16.5	-6.6	-12.3	9.9	14.7	-6.9	-12.4	10.1	14.7	462
	Wamsutter	9.9	1.8	20.8	18.0	12.3	3.5	22.4	18.0	12.4	3.6	22.4	17.9	3
	Centennial	5.3	-5.3	8.6	10.3	5.9	-4.5	9.0	9.9	5.6	-4.7	8.9	10.0	790
	OCI	-8.6	-10.1	11.0	15.3	-7.6	-8.1	10.2	13.6	-7.7	-7.9	10.2	13.5	193
	Pinedale	-1.2	-9.6	8.2	13.6	-0.6	-8.2	8.1	12.6	-0.9	-8.3	8.1	12.6	879

Table A4-1e.Ozone model performance bias and error statistical measures with 50 ppb threshold for the CASTNet network and industrial sites for 2006by annual and quarter for all sites and for each site in the CD-C 4 km domain.

Period	EPA	FB(%) ± 15%		FGE(%) ± 35%		MNB(%) ± 15%		MNGE(%) ± 35%		NMB(%) ± 15%		NME(%) ± 35%		Number of Points
	Site\Run	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	
ANN	All Sites	-6.9	-10.8	12.4	14.8	-5.7	-9.1	11.6	13.5	-6.2	-9.3	11.7	13.6	15654
	Jonah	-17.2	-16.9	18.2	19.6	-14.7	-14.1	15.7	16.9	-15.0	-14.2	15.9	17.0	1861
	Boulder	-15.0	-18.3	17.1	20.5	-12.9	-15.4	15.1	17.8	-13.2	-15.5	15.3	17.9	2545
	Daniel	-9.9	-12.9	13.2	16.0	-8.6	-11.1	12.2	14.5	-9.1	-11.4	12.5	14.7	2172
	Wamsutter	-4.5	-3.9	10.8	12.5	-3.7	-2.6	10.4	12.2	-4.0	-2.8	10.4	12.1	1082
	Centennial	1.4	-8.8	9.2	12.3	2.1	-7.7	9.3	11.4	1.7	-7.9	9.3	11.5	3919
	OCI	-8.9	-6.5	12.1	11.7	-7.9	-5.4	11.3	11.0	-8.1	-5.6	11.4	10.9	1234
	Pinedale	-2.2	-5.4	9.1	11.3	-1.6	-4.4	9.0	10.8	-2.0	-4.5	9.0	10.9	2841
Q1	All Sites	-6.4	-18.7	12.8	19.0	-4.9	-16.2	11.6	16.5	-5.4	-16.5	11.8	16.8	3492
	Jonah	-20.1	-28.5	20.8	28.5	-16.4	-23.7	17.1	23.7	-16.8	-24.0	17.4	24.0	433
	Boulder	-18.1	-28.7	20.0	28.8	-14.8	-23.6	16.8	23.6	-15.2	-23.7	17.0	23.7	631
	Daniel	-9.4	-19.5	12.3	19.7	-8.2	-17.2	11.2	17.4	-8.8	-17.6	11.6	17.8	653
	Wamsutter	-0.3	-13.1	8.1	13.8	0.3	-11.5	7.9	12.1	0.2	-11.6	8.0	12.2	117
	Centennial	3.0	-12.5	8.4	12.8	3.6	-11.4	8.5	11.7	3.5	-11.5	8.5	11.8	1082
	OCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Pinedale	0.9	-12.5	8.6	13.3	1.5	-11.3	8.6	12.1	1.4	-11.4	8.6	12.3	576
Q2	All Sites	-6.0	-10.9	12.4	14.4	-4.8	-9.3	11.7	13.0	-5.3	-9.7	11.8	13.2	6963
	Jonah	-15.5	-17.0	17.1	19.1	-13.3	-14.1	15.0	16.4	-13.5	-14.3	15.1	16.5	777
	Boulder	-12.4	-17.2	15.7	19.3	-10.6	-14.8	14.2	17.0	-11.2	-15.2	14.4	17.2	1081
	Daniel	-8.5	-13.2	13.4	15.9	-7.2	-11.3	12.6	14.3	-7.7	-11.7	12.8	14.5	946
	Wamsutter	-7.1	-6.4	11.6	11.1	-6.1	-5.4	10.9	10.4	-6.4	-5.5	10.9	10.4	803
	Centennial	1.3	-9.3	10.1	12.1	2.1	-8.2	10.3	11.2	1.5	-8.5	10.1	11.4	1783
	OCI	-7.6	-7.6	12.4	11.9	-6.4	-6.5	11.6	11.0	-6.6	-6.7	11.6	11.0	566
	Pinedale	-0.4	-5.8	9.3	12.1	0.3	-4.7	9.2	11.4	-0.3	-5.0	9.3	11.5	1007
Q3	All Sites	-8.2	-4.7	12.0	12.3	-7.1	-3.5	11.1	11.8	-7.6	-3.6	11.4	11.7	5046
	Jonah	-17.4	-9.2	17.7	14.3	-15.2	-7.5	15.6	13.0	-15.6	-7.6	15.9	13.0	646
	Boulder	-15.5	-10.9	16.2	15.3	-13.7	-9.2	14.4	14.1	-14.0	-9.3	14.7	14.1	778
	Daniel	-12.1	-4.3	13.2	11.6	-11.0	-3.2	12.2	11.2	-11.3	-3.2	12.4	11.2	551
	Wamsutter	4.9	15.5	9.2	18.6	5.6	18.0	9.7	20.9	5.5	18.1	9.6	21.0	162
	Centennial	0.4	-3.6	8.5	11.6	0.9	-2.6	8.5	11.2	0.5	-2.8	8.5	11.2	1007
	OCI	-10.1	-5.6	11.9	11.6	-9.1	-4.5	11.0	10.9	-9.4	-4.6	11.2	10.7	668
	Pinedale	-4.8	-1.5	9.0	9.6	-4.2	-0.8	8.7	9.6	-4.7	-0.8	8.9	9.6	1234
Q4	All Sites	-19.6	-20.5	19.7	21.9	-17.1	-17.6	17.3	19.1	-17.6	-18.1	17.8	19.5	153
	Jonah	-26.2	-12.5	26.2	12.5	-23.1	-11.7	23.1	11.7	-23.2	-11.7	23.2	11.7	5
	Boulder	-26.3	-24.9	26.3	25.1	-22.7	-21.1	22.7	21.3	-23.1	-21.5	23.1	21.6	55
	Daniel	-26.3	-21.9	26.3	22.6	-22.6	-18.5	22.6	19.3	-23.2	-19.2	23.2	19.9	22
	Wamsutter	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Centennial	-7.3	-17.5	7.9	20.1	-6.7	-15.3	7.3	18.1	-7.1	-15.8	7.7	18.4	47
	OCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Pinedale	-20.6	-16.6	20.6	19.5	-18.1	-14.2	18.1	17.2	-18.6	-14.8	18.6	17.7	24

Table A4-1f. Ozone model performance bias and error statistical measures with 60 ppb threshold for the CASTNet network and industrial sites for 2006 by annual and quarter for all sites and for each site in the CD-C 4 km domain.

Period	EPA	FB(%) ± 15%		FGE(%) ± 35%		MNB(%) ± 15%		MNGE(%) ± 35%		NMB(%) ± 15%		NME(%) ± 35%		Number of Points
	Site\Run	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	Hiawatha	CD-C	
ANN	All Sites	-14.4	-13.9	15.8	16.5	-12.7	-11.9	14.1	14.7	-12.9	-12.1	14.3	14.9	3791
	Jonah	-20.8	-18.6	21.0	20.5	-18.1	-15.5	18.3	17.5	-18.3	-15.7	18.6	17.7	493
	Boulder	-19.1	-19.9	20.1	21.3	-16.6	-17.0	17.6	18.6	-16.8	-17.1	17.8	18.7	887
	Daniel	-16.3	-15.7	17.6	18.2	-14.3	-13.5	15.8	16.1	-14.6	-13.8	16.0	16.3	589
	Wamsutter	-10.0	-6.7	12.3	10.9	-8.9	-5.9	11.3	10.3	-9.0	-6.0	11.4	10.4	263
	Centennial	-7.1	-12.7	9.7	14.4	-6.4	-11.2	9.1	13.0	-6.7	-11.4	9.3	13.2	658
	OCI	-11.3	-8.0	13.1	10.7	-10.2	-7.0	12.0	10.0	-10.4	-7.1	12.1	9.9	435
	Pinedale	-11.9	-6.6	12.6	12.7	-10.8	-5.3	11.6	11.9	-10.9	-5.6	11.7	12.0	466
Q1	All Sites	-18.4	-27.3	19.0	27.4	-15.7	-23.3	16.4	23.3	-16.3	-23.6	16.9	23.7	483
	Jonah	-21.0	-30.7	21.1	30.7	-18.1	-25.9	18.2	25.9	-19.1	-26.4	19.2	26.4	103
	Boulder	-22.4	-29.1	22.8	29.1	-18.7	-24.4	19.2	24.4	-19.0	-24.6	19.5	24.6	159
	Daniel	-18.3	-25.9	19.0	26.0	-15.9	-22.3	16.6	22.4	-16.4	-22.7	17.0	22.8	149
	Wamsutter	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Centennial	-3.8	-21.1	6.4	21.1	-3.3	-18.8	6.1	18.8	-3.3	-18.8	6.0	18.8	41
	OCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Pinedale	-9.0	-22.3	9.1	22.3	-8.3	-19.6	8.4	19.6	-8.4	-19.7	8.4	19.7	31
Q2	All Sites	-12.2	-14.7	14.3	16.3	-10.7	-12.8	12.9	14.5	-10.9	-13.0	13.1	14.6	2133
	Jonah	-18.2	-20.3	18.6	21.2	-15.9	-16.9	16.3	17.8	-16.0	-16.9	16.4	17.8	226
	Boulder	-17.0	-21.0	18.5	21.8	-14.7	-18.1	16.3	18.9	-15.1	-18.2	16.6	19.0	454
	Daniel	-14.7	-16.5	16.8	17.4	-12.9	-14.4	15.1	15.4	-13.1	-14.6	15.3	15.5	323
	Wamsutter	-10.2	-7.3	12.5	10.8	-9.2	-6.5	11.5	10.2	-9.3	-6.6	11.6	10.2	254
	Centennial	-6.5	-13.0	9.7	14.4	-5.9	-11.5	9.2	13.0	-6.1	-11.7	9.3	13.2	480
	OCI	-9.2	-9.4	12.2	11.7	-8.1	-8.4	11.3	10.8	-8.2	-8.6	11.3	10.9	201
	Pinedale	-9.1	-10.4	11.0	13.3	-8.1	-9.0	10.1	12.0	-8.5	-9.3	10.3	12.2	195
Q3	All Sites	-16.7	-6.7	17.0	12.2	-15.0	-5.5	15.3	11.5	-15.1	-5.5	15.4	11.5	1169
	Jonah	-24.1	-8.6	24.1	13.1	-21.1	-7.1	21.1	12.0	-21.2	-7.0	21.2	11.9	164
	Boulder	-20.5	-12.2	20.7	15.7	-18.1	-10.6	18.4	14.4	-18.3	-10.5	18.5	14.4	269
	Daniel	-18.1	-0.7	18.2	10.4	-16.5	0.2	16.5	10.3	-16.5	0.3	16.5	10.2	117
	Wamsutter	-2.2	9.7	7.0	13.4	-1.9	10.9	6.8	14.4	-2.0	10.6	6.8	14.3	9
	Centennial	-9.9	-8.8	10.4	12.1	-9.1	-7.7	9.6	11.1	-9.3	-7.9	9.8	11.2	136
	OCI	-13.2	-6.7	13.8	9.9	-12.0	-5.8	12.7	9.3	-12.2	-5.8	12.8	9.1	234
	Pinedale	-14.4	-1.5	14.4	10.9	-13.3	-0.6	13.3	10.9	-13.3	-0.7	13.3	10.9	240
Q4	All Sites	-42.2	-42.4	42.2	42.4	-34.8	-34.6	34.8	34.6	-34.9	-35.0	34.9	35.0	6
	Jonah	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Boulder	-41.2	-39.2	41.2	39.2	-34.1	-32.6	34.1	32.6	-34.1	-32.6	34.1	32.6	5
	Daniel	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Wamsutter	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Centennial	-47.6	-58.1	47.6	58.1	-38.4	-45.0	38.4	45.0	-38.4	-45.0	38.4	45.0	1
	OCI	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0
	Pinedale	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0

A4.2 HOURLY OZONE TIME SERIES FOR MONITORS IN 4 KM GRID

Time series plots of predicted and observed hourly ozone concentrations by Quarter at the Jonah, Boulder, Daniel, Pinedale and Centennial monitoring sites are presented in Figures A4-1 and A4-2 for the 2005 and 2006 simulation years, respectively. Fractional bias and fractional gross error statistics using a 40 ppb cutoff concentration for each quarter are presented on the time series plot for each monitor. Early on in the CAMx base case modeling, the WDEQ-AQD instructed the CD-C modeling team to not address the wintertime ozone exceedances as they are a research topic so should not be part of NEPA and instead focus on the summer ozone time periods. During the warmer quarters (Q2 and Q3) in 2005, the CAMx model is exhibits an ozone underestimation bias at the Wyoming industrial sites with the CD-C run generally displaying better performance (lower bias) than the Hiawatha base case run. Better performance is seen at the two CASTNET sites (Figures A4-1d and A4-1e) with both base case simulations achieving (or nearly achieving) EPA's performance goals for all four Quarters in 2005.

In 2006, the CAMx performance is again characterized by an underestimation bias at the monitoring sites within the 4 km domain, although EPA's performance goals are achieved more often than in 2005 (Figure A4-2). Performance is better at the two CASTNet sites than the Sublette County sites. In 2006 new ozone monitoring sites came online at Wamsutter and OCI. The ozone bias and error metrics at the Wamsutter monitor achieve EPA's performance goals in Q3 (Figure A4-2f). EPA's performance goals are also achieved at the OCI monitor for Q2 and Q3 (Figure A4-2g).

Jonah

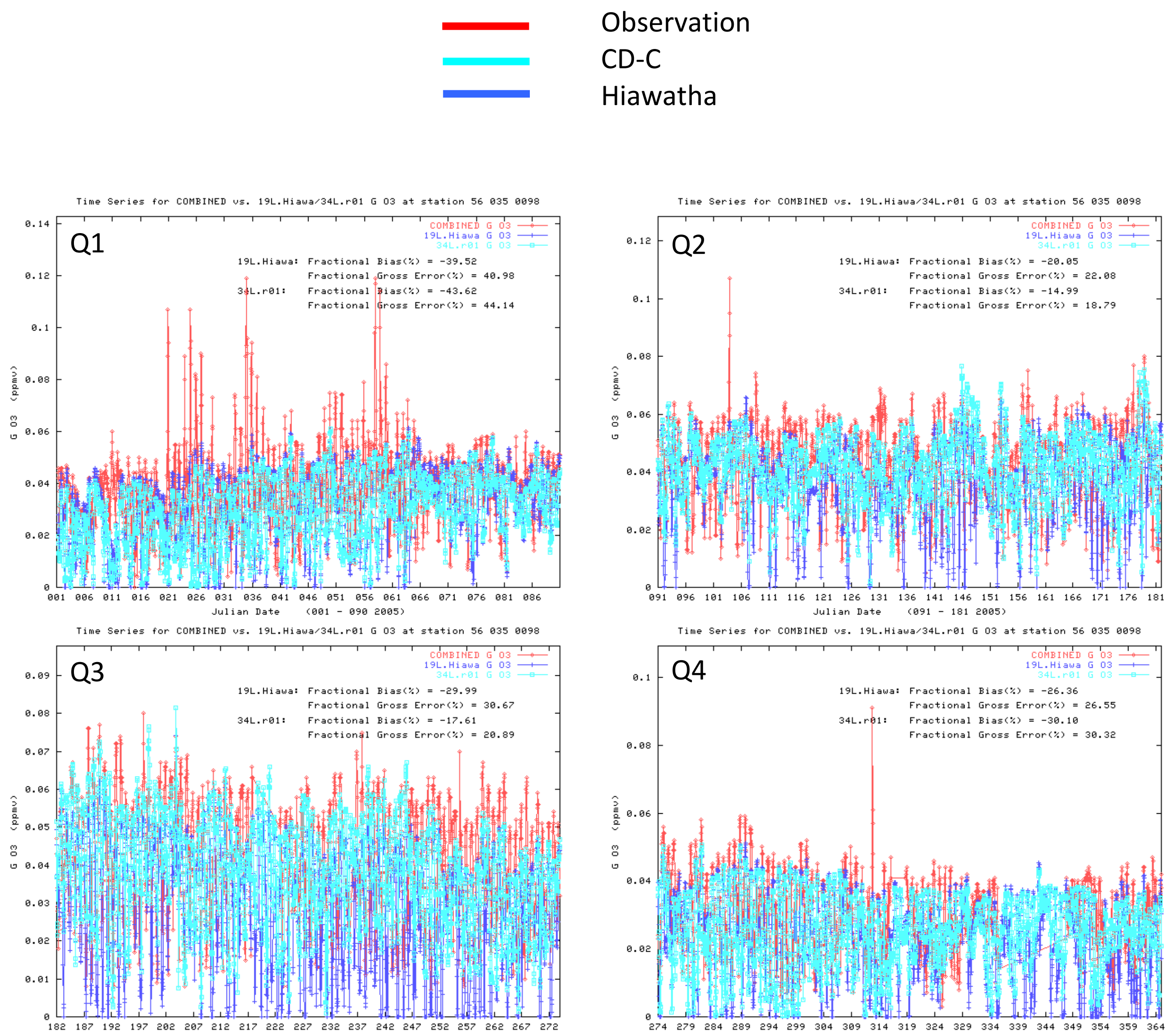


Figure A4-1a. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Jonah monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Boulder

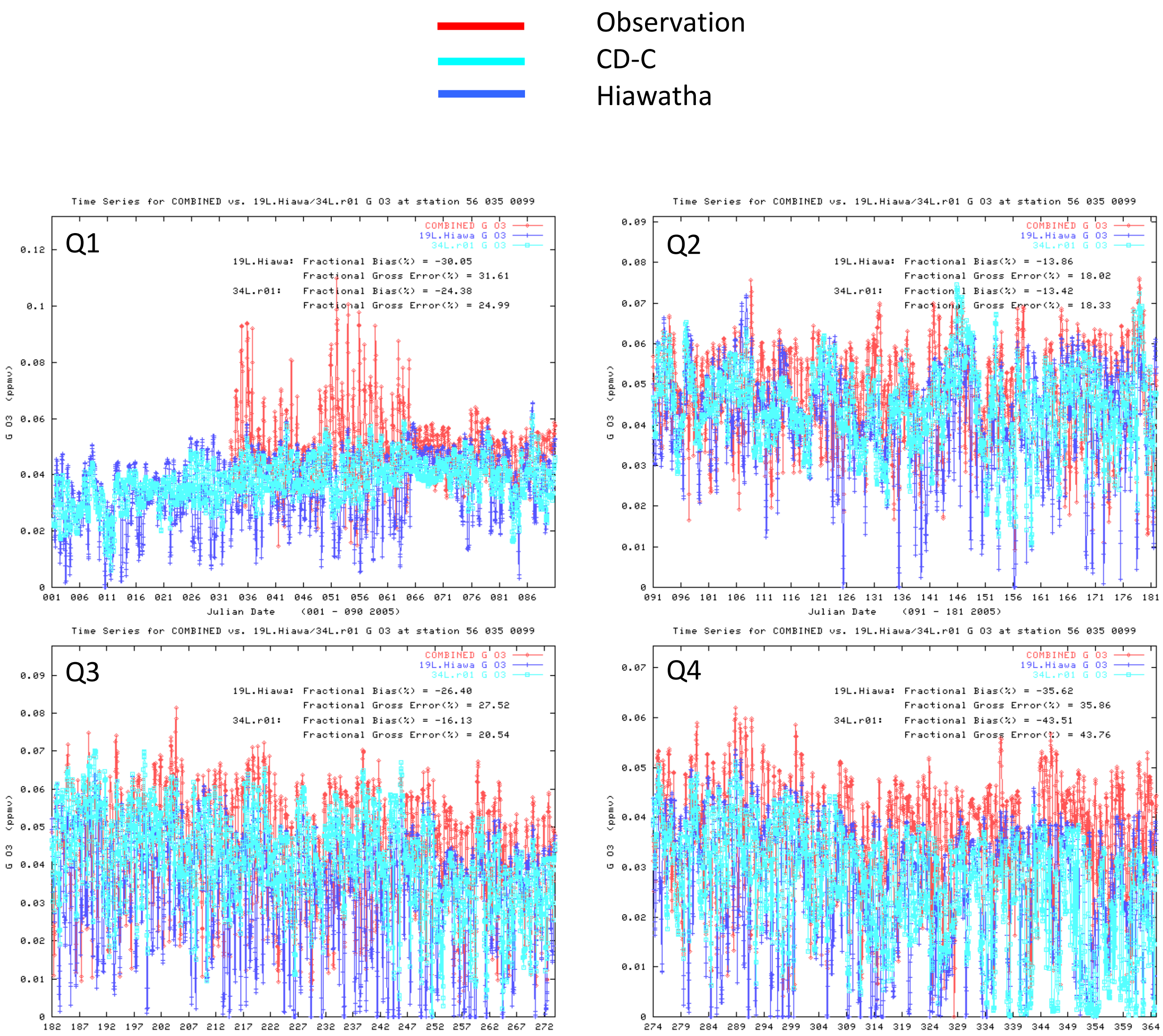


Figure A4-1b. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Boulder monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Daniel

Observation
CD-C
Hiawatha

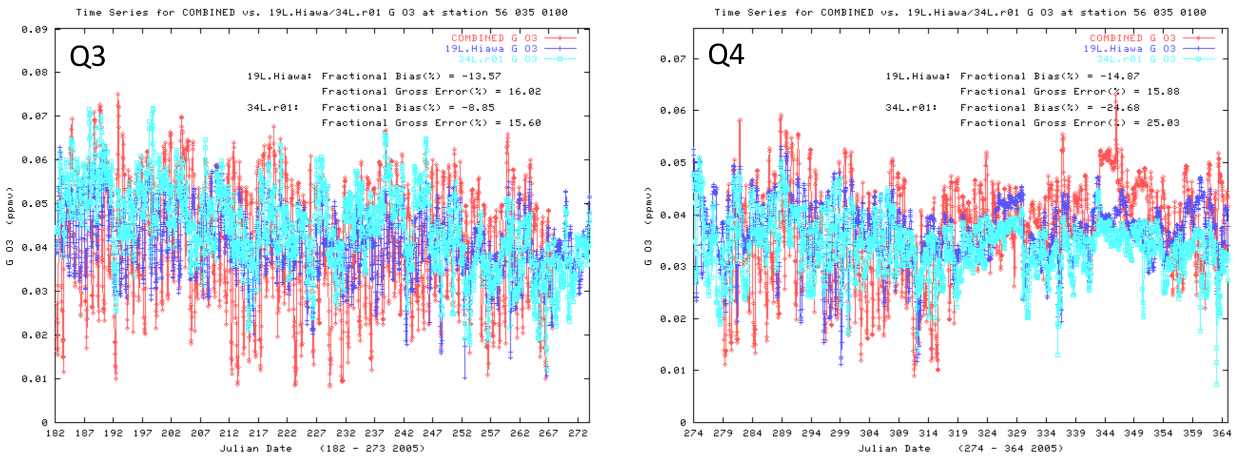


Figure A4-1c. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 3 (left column), and Quarter 4 (right column) at the Daniel monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Pinedale

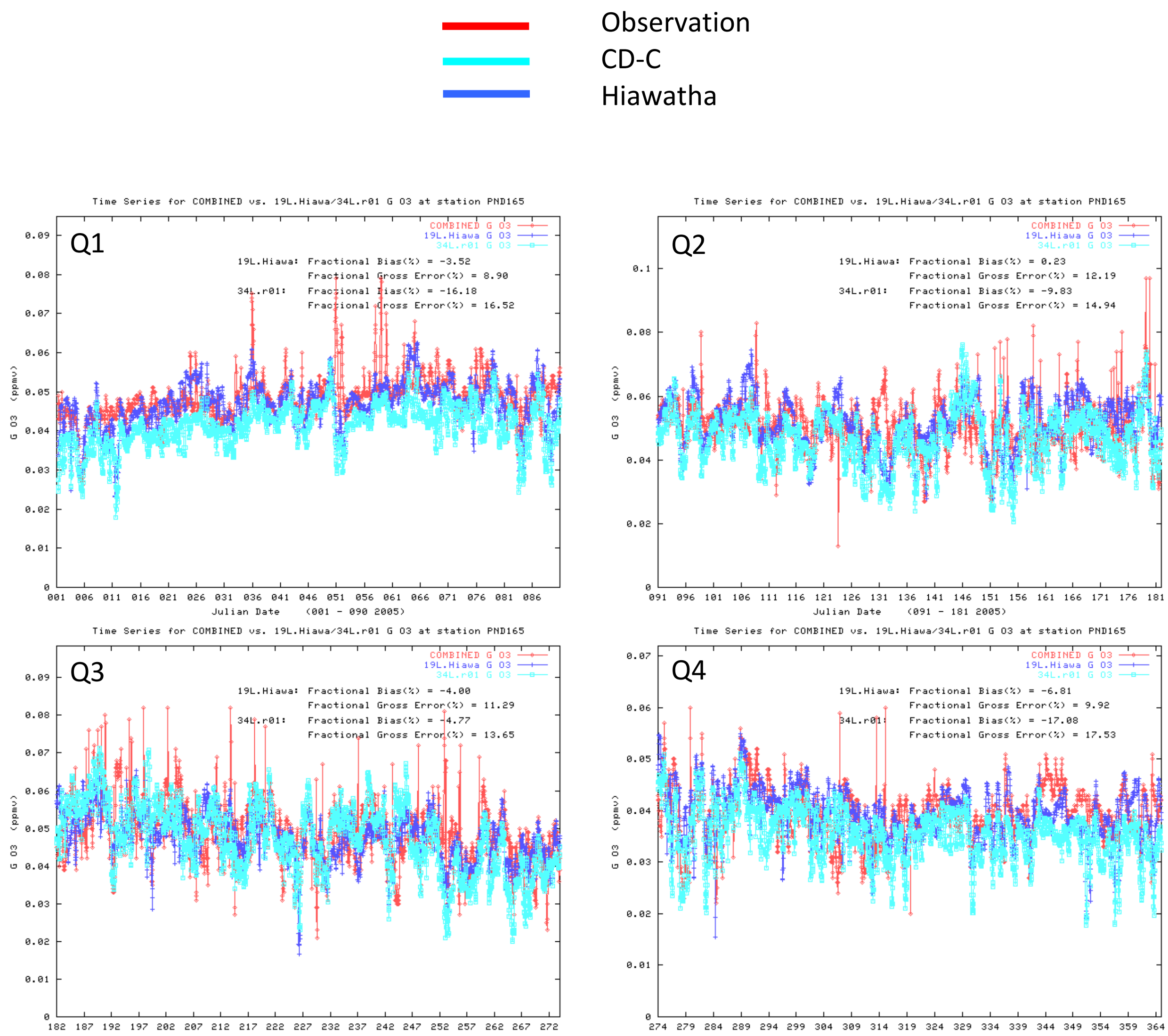
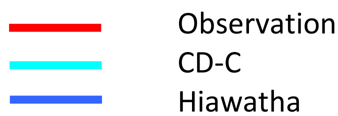


Figure A4-1d. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Pinedale monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Centennial



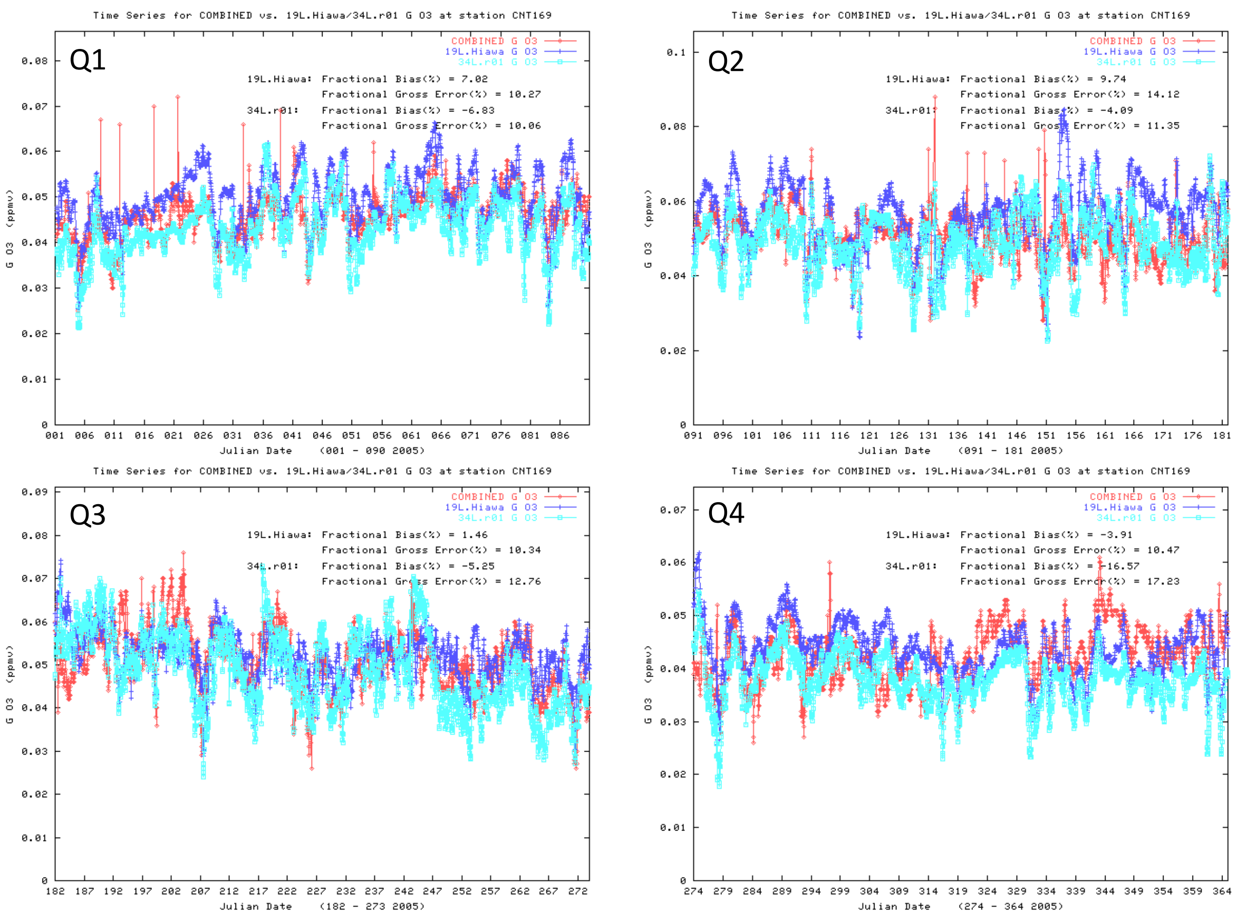


Figure A4-1e. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Centennial monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Jonah

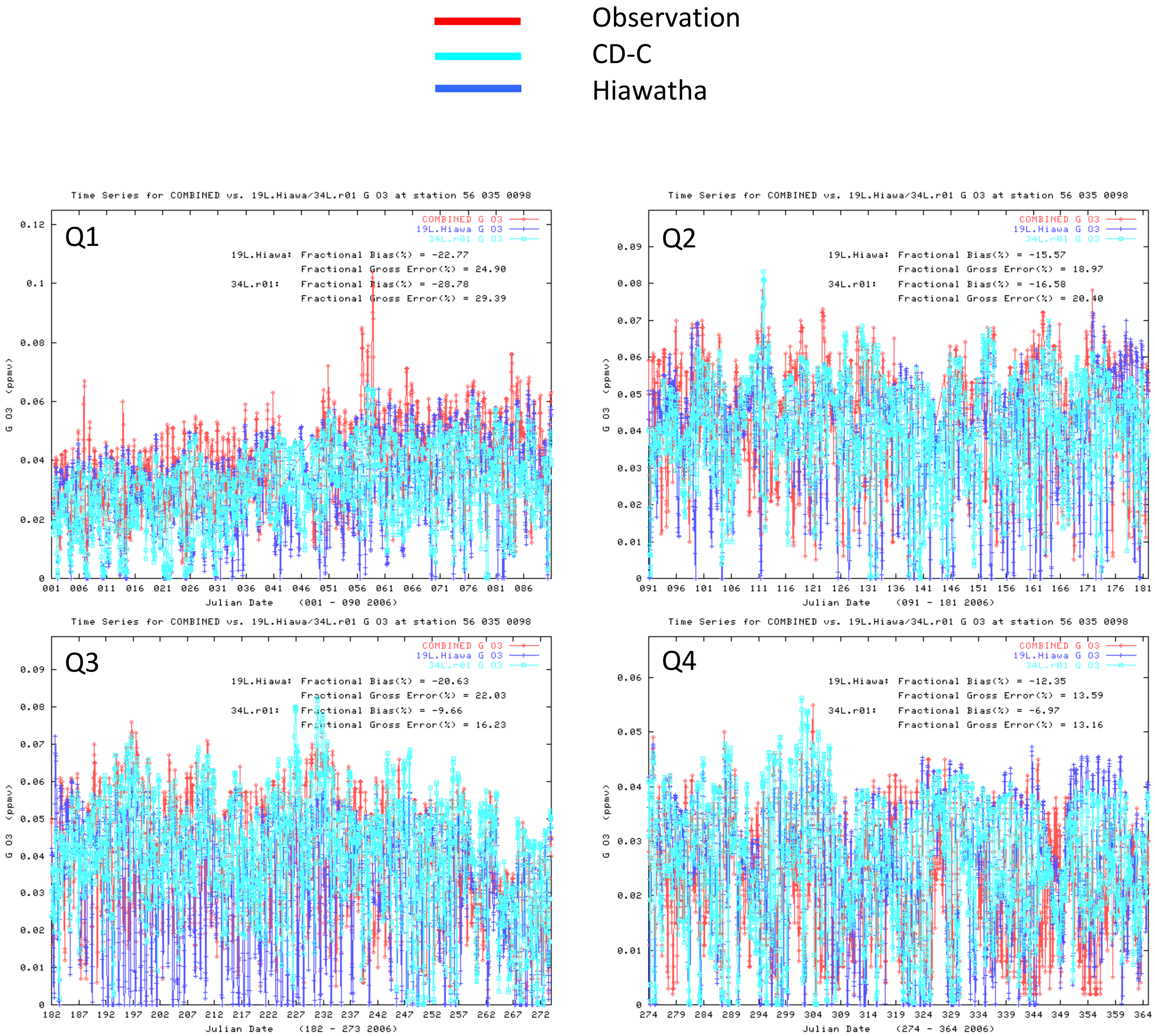


Figure A4-2a. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Jonah monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Boulder

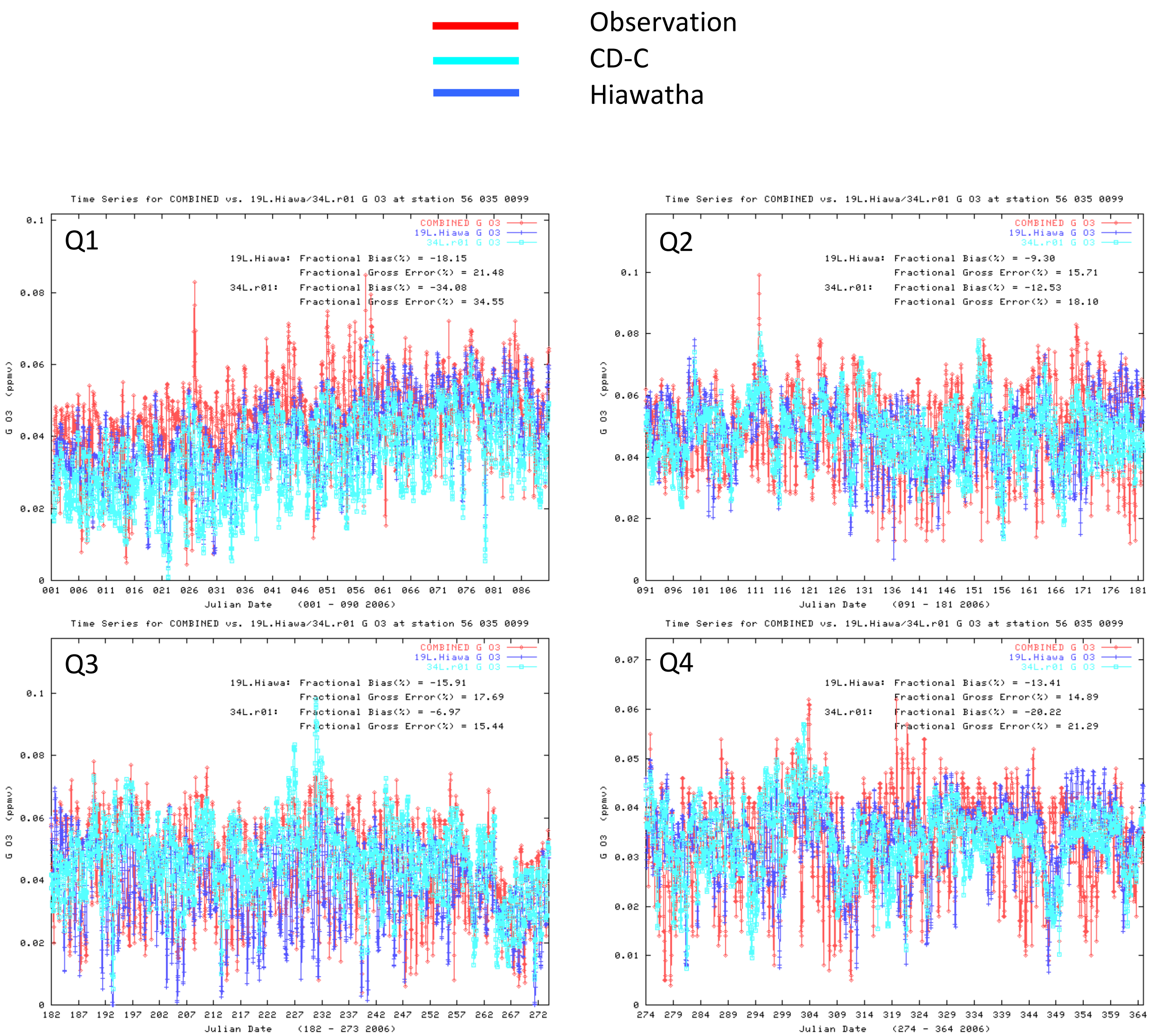


Figure A4-2b. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Boulder monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Daniel

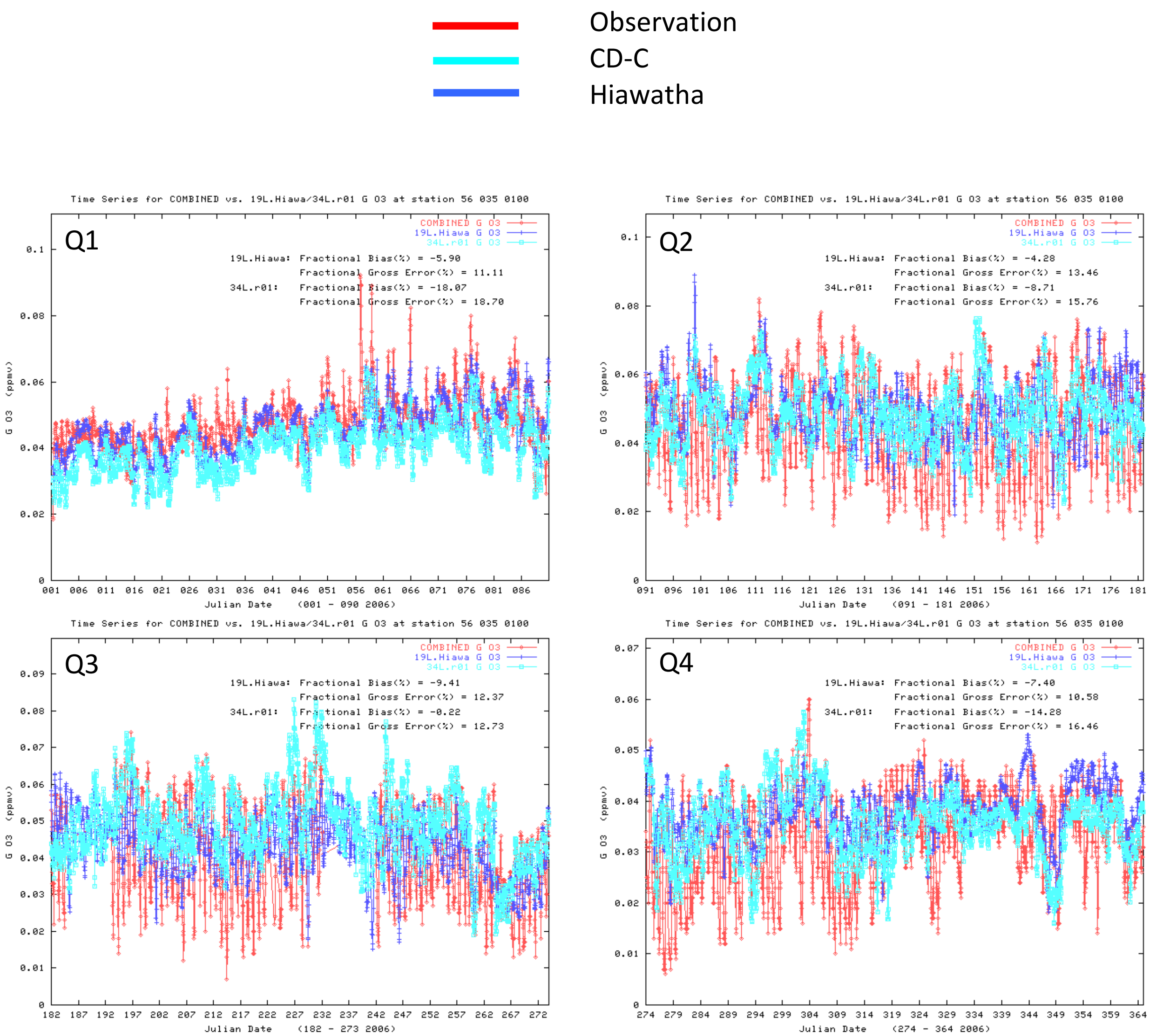
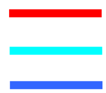


Figure A4-2c. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Daniel monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Pinedale



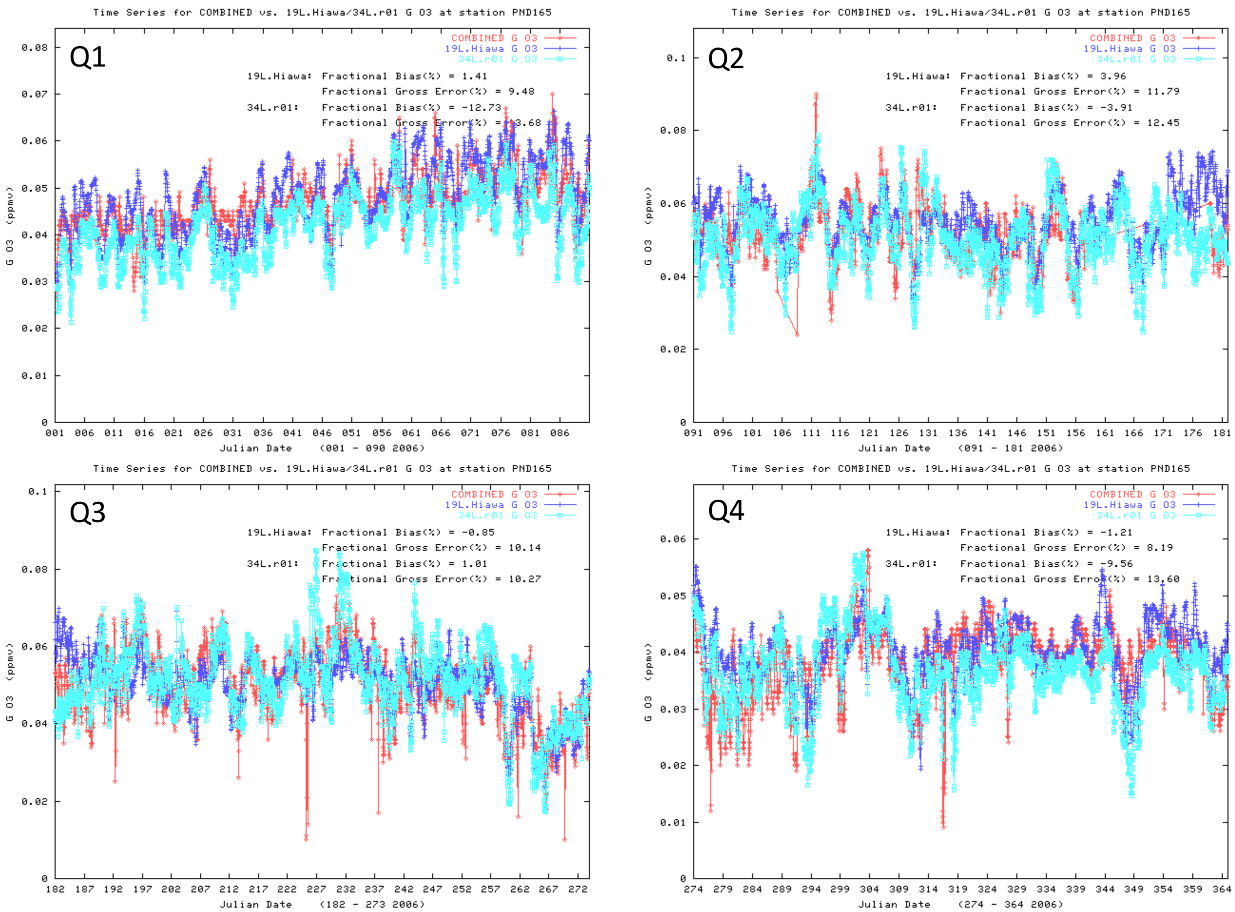
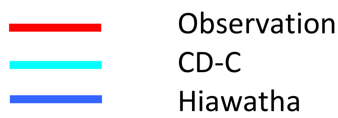


Figure A4-2d. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Pinedale monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Centennial



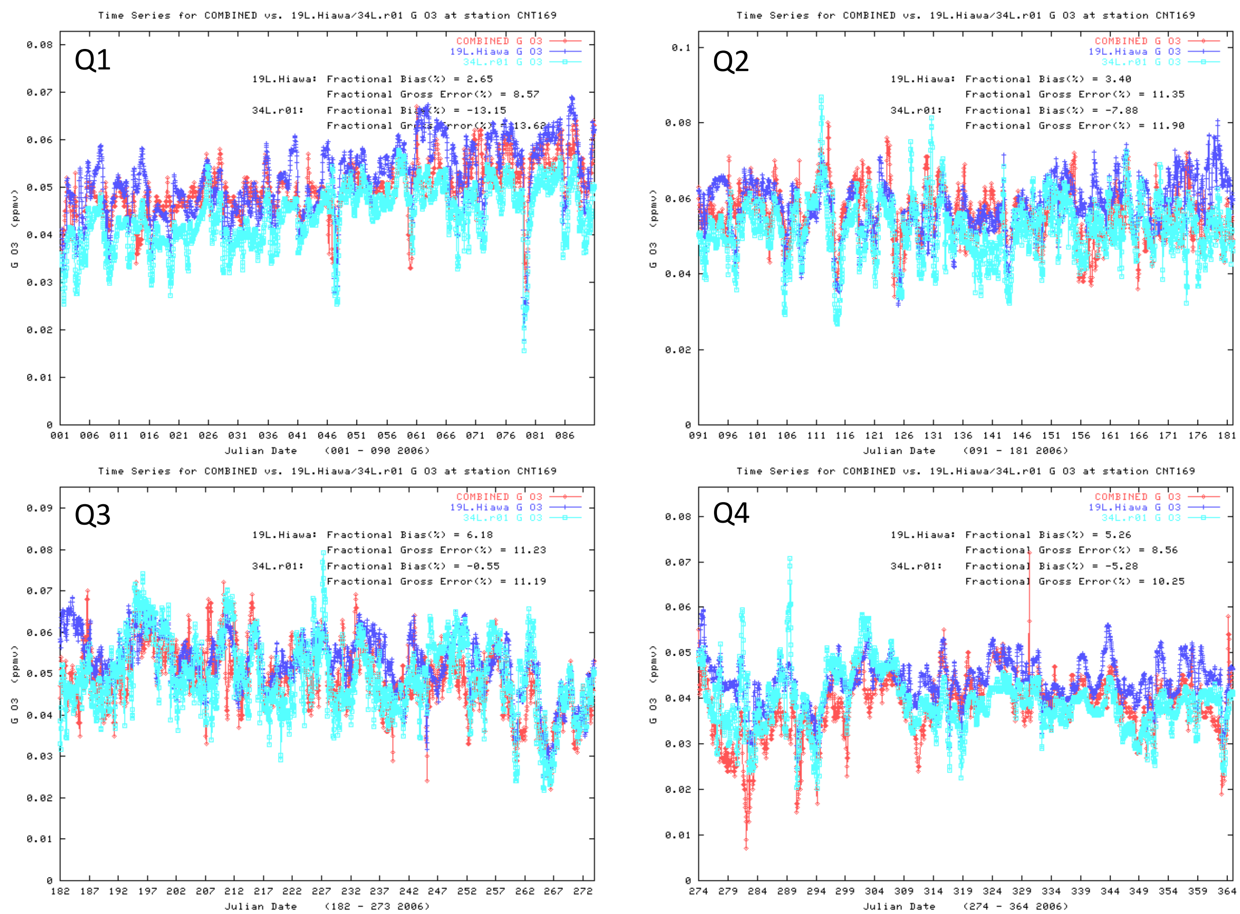


Figure A4-2e. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Centennial monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Wamsutter

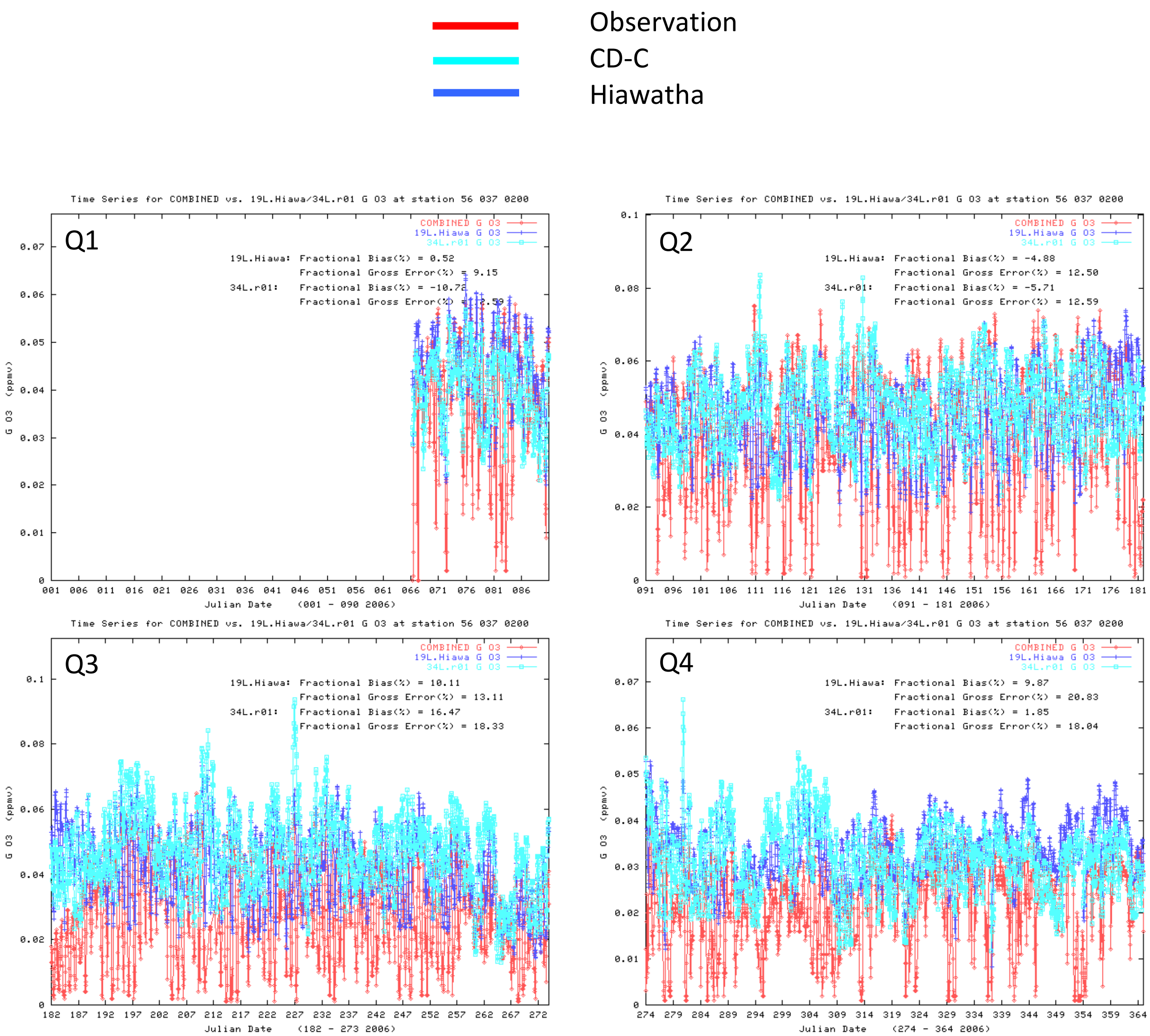


Figure A4-2f. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Wamsutter monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

OCI

Observation
CD-C
Hiawatha

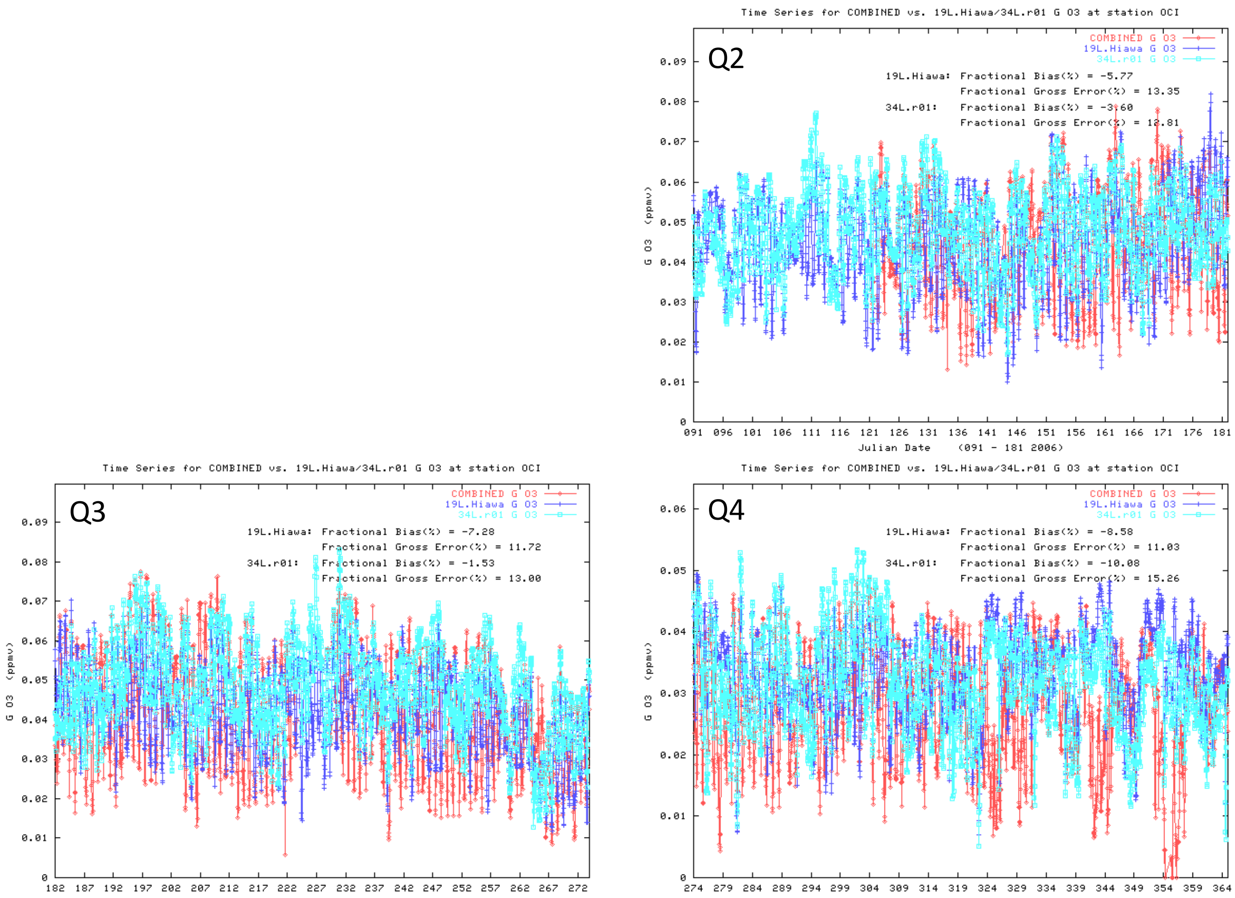


Figure A4-2g. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the OCI monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

A4.3 DAILY MAX 8-HOUR RUNNING AVERAGE OZONE STANDARD FOR MONITORS IN 4 KM GRID

In January 2010, EPA proposed revising the primary 8-hour ozone NAAQS with a threshold between 0.060 and 0.070 ppm (60-70 ppb). In order to evaluate the model performance at these ozone levels we compared the predicted and observed daily maximum 8-hour ozone concentration at each monitor in the 4 km domain during 2005 and 2006 in which either the observed or predicted value was above either a 65 ppb (Table A4-2) or 70 ppb (Table A4-3) concentration threshold. Values equal to or exceeding the threshold are shown in yellow in each table. At Boulder during 2005 (Table A4-2a), there are 28 observed days with daily maximum 8-hour ozone concentrations that exceed the 65 ppb threshold and only 1 and 5 predicted days for the Hiawatha and CD-C base case simulations, respectively. However, many of the observed ozone days > 65 ppb in 2005 at Boulder occur during the winter (Feb-Mar) for conditions that the model was not configured to simulate. During the summer the CD-C base case simulation reproduces the high observed ozone days at Boulder with greater accuracy than the preliminary Hiawatha base case simulation. For example, the maximum observed 8-hour ozone at Boulder during the summer of 2005 is 72.7 ppb on June 27th where the Hiawatha base case simulates 58.8 ppb (-19%) and CD-C base case simulation estimates a 66.8 ppb (-8%) 8-hour ozone peak that is much closer to the observed value.

The 65 ppb threshold 2005 8-hour ozone model performance at the Centennial CASTNet site exhibits quite different performance from Boulder (Table A4-2b). Whereas there are only 6 observed days with 8-hour ozone at Centennial in 2005 exceeding 65 ppb that occur mainly in late June and July, the Hiawatha base case simulation had 24 days that exceed the 65 ppb threshold with most of the days occurring in the spring. The CD-C base case simulation, on the other hand, had only 10 days with 8-hour ozone concentrations exceeding 65 ppb with most of the days occurring in the summer as was observed.

The Daniel monitor came online in July 2005 and recorded 4 days above 65 ppb as compared to no days for the Hiawatha base case and 3 days for the CD-C base case after the Daniel monitor started its measurements. The highest observed 8-hour ozone concentration at the Daniel monitor in 2005 occurred on July 8th (70.8 ppb) that was reproduced to within -19% (57.7 ppb) by the Hiawatha and within -4% (67.7 ppb) by the CD-C base cases.

The Jonah monitor had 22 days with observed 8-hour ozone concentrations exceeding 65 ppb with 13 of those days occurring early (January-April) in the year (Table A4-2d). Not surprisingly, neither the Hiawatha nor CD-C base case simulations estimate 8-hour ozone concentrations in excess of 65 ppb during January-April 2005. During the warmer May-August 2005 period, there were 9 observed days with 8-hour ozone exceeding 65 ppb as compared to none for the Hiawatha base case simulation and 8 days for the CD-C base case simulation. The maximum observed 8-hour ozone concentrations at the Jonah monitor was 73.9 ppb and occurred on June 27th which the Hiawatha base case underestimated by -19% (60.2 ppb) and the CD-C base case only underestimated by -4% (70.9 ppb). Clearly, the CD-C base case is better able to reproduce the observed high summer 8-hour ozone concentrations than the preliminary base case performed under Hiawatha.

The Pinedale CASTNet monitoring site had 12 days in 2005 with 8-hour ozone greater than 65 ppb, 5 in February-April and 7 during June and July (Table A4-2e). The Hiawatha base case had 5 days over 65 ppb with 4 of them in April, but not overlapping with the observed 65 ppb exceedance days, and one day in June 27' 2005 when the highest observed 8-hour ozone concentration in 2005 at Pinedale occurred (76.4 ppb). The Hiawatha base case reproduced this highest observed ozone day to within -12% (66.9 ppb), which was not as good as the CD-C base case that reproduced it to within -8% (70.5 ppb). The CD-C base case had 7 days in 2005 that exceeded 65 ppb at Pinedale, with all of them occurring during May-July and with 4 of the days overlapping with observed 65 ppb exceedance days.

The Wamsutter site was not operating in 2005 and there were 2 and 11 days that the estimated 8-hour ozone concentrations exceeded the 65 ppb threshold in the Hiawatha and CD-C base case simulations, respectively (Table A4-2f).

In 2006, the Boulder monitoring site had the most days (43) with 8-hour ozone concentrations exceeding the 65 ppb threshold (Table A4-3a). Most of these days (26) occurred during June-September. The Hiawatha and CD-C base case simulations had 10 and 13 days, respectively, that exceeded the 65 ppb threshold at Boulder during 2006 with most days overlapping with observed 65 ppb exceedance days. The highest observed 8-hour ozone day at Boulder during 2006 was April 21st (81.0 ppb) which the Hiawatha base case reproduced to within -14% (69.9 ppb) and the CD-C base case reproduced to within -8% (74.2 ppb). It is interesting to note that the Hiawatha base case generally estimated higher ozone than the CD-C base case in June but the reverse is true in July. This effect was also seen using the Denver ozone SIP June-July 2006 modeling database when it was updated from CAMx V4.51 to CAMx VV and is due to CAMx V4.51 bringing more ozone of stratospheric origin down to ground level from the top most layers of the model. The stratospheric ozone was introduced into the model through the lateral boundary conditions that were generated using output from the GEOS-Chem global chemistry model.

As we saw in 2005, the Hiawatha base case had the most days with 8-hour ozone greater than 65 ppb at the Centennial monitoring site (31) compared to 19 observed days and 15 days estimated in the CD-C base case (Table A4-3b).

The Daniel monitoring site had 26 days in 2006 with 8-hour ozone exceeding 65 ppb compared to 9 and 17 days for the Hiawatha and CD-C base case simulations, respectively (Table A4-3c). As expected, the very highest observed 8-hour ozone concentration on February 25, 2006 (82.7 ppb) is greatly underestimated by both base case simulations (almost a factor of 2). The next highest observed ozone day (75.6 ppb on May 2) is underestimated by the Hiawatha and CD-C base case simulations by, respectively, -24% (57.7 ppb) and -18% (62.2 ppb). The 9 days estimated in the Hiawatha base case to exceed 65 ppb are approximately evenly split between the March-April (4 days) and June (5 days) time periods. Whereas the CD-C runs estimates that a vast majority (15 of 17 days) of the 65 ppb exceedance days occur during May-August 2006.

There were 22 observed 8-hour ozone 65 ppb exceedance days at Jonah in 2006 compared to 3 and 8 days predicted in the Hiawatha and CD-C base case simulations, respectively (Table A4-3d). During the June-August summer months, both base case simulations underestimate the highest observed 8-hour ozone on June 11th (69.8 ppb) by -15%. However, the next highest summer observed 8-hour ozone concentration on July 15th (69.4 ppb) is reproduced better in the CD-C base case (within -1% at 68.4 ppb) than the Hiawatha base case (within -14% at 60.0 ppb).

The OCI monitor came on line in May 2006 and had 24 observed 65 ppb 8-hour ozone exceedance days during May-December 2006 which was exactly matched by the CD-C base case simulation, with the Hiawatha base case simulation only having 10 days that exceeded 65 ppb (Table A4-3e).

The Pinedale monitor had 11 65 ppb exceedance days in 2006 compared to 17 and 21 days in the Hiawatha and CD-C base case simulations, respectively (Table A4-3f). The peak observed 8-hour ozone concentration at Pinedale in 2006 was 80.1 ppb on April 21st that the Hiawatha base case reproduced to within -15% (68.0 ppb) and the CD-C base case reproduced to within -9% (72.9 ppb).

There are 11 observed 65 ppb exceedance days at the Wamsutter monitor in 2006 compared to 9 and 18 days for the Hiawatha and CD-C base case simulations, respectively (Table A4-3g). However, the two base case simulations only have 2 65 ppb exceedance days that overlap with the observed 65 ppb exceedance days. The two models estimate many 65 ppb exceedance days during July-August when no observed values over 65 occurred.

Table A4-4 compares the observed and predicted days during 2005 and 2006 that the 8-hour ozone concentrations exceeded a 70 ppb threshold. As these days are also 65 ppb exceedance days, then much of the discussion above on Tables A4-2 and A4-3 also holds for Table A4-4.

Table A4-2a. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Boulder monitoring site during 2005.

Site	2005		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
Boulder	Total exceeding		28	1	5
Boulder	Feb	02	66.0	44.2	42.3
Boulder	Feb	03	82.0	41.4	43.3
Boulder	Feb	04	80.2	54.3	50.2
Boulder	Feb	19	79.9	46.1	49.8
Boulder	Feb	20	89.3	38.5	35.2
Boulder	Feb	22	75.9	51.5	48.3
Boulder	Feb	24	80.9	45.7	49.2
Boulder	Feb	25	72.2	44.4	45.9
Boulder	Feb	26	70.2	53.2	54.7
Boulder	Feb	27	74.5	49.1	49.2
Boulder	Mar	03	71.9	45.3	49.3
Boulder	Mar	04	66.2	54.1	56.0
Boulder	Apr	16	56.4	65.6	55.6
Boulder	Apr	18	68.6	56.9	53.1
Boulder	May	11	67.5	44.4	48.7
Boulder	May	21	66.2	54.5	54.1
Boulder	May	25	65.0	60.5	72.8
Boulder	May	26	63.9	58.9	68.4

Site	2005 Month	Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Boulder	Jun	13	65.4	58.7	52.2
Boulder	Jun	26	65.1	55.7	58.1
Boulder	Jun	27	72.7	58.8	66.8
Boulder	Jul	03	66.3	50.8	63.0
Boulder	Jul	08	45.2	61.2	69.0
Boulder	Jul	12	68.1	55.3	56.0
Boulder	Jul	17	59.2	51.0	66.3
Boulder	Jul	20	66.2	52.0	52.6
Boulder	Jul	22	69.7	54.0	57.7
Boulder	Jul	23	70.7	57.1	58.1
Boulder	Aug	05	65.6	53.8	57.0
Boulder	Aug	06	66.6	52.7	57.3
Boulder	Aug	08	67.9	52.8	60.1
Boulder	Aug	26	66.6	49.0	62.6

Table A4-2b. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Centennial monitoring site during 2005.

Site	2005 Month	Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Centennial	Total exceeding		6	24	10
Centennial	Mar	05	57.9	65.3	53.6
Centennial	Apr	06	57.3	67.6	59.7
Centennial	Apr	07	56.6	71.8	59.9
Centennial	Apr	08	57.8	66.4	51.4
Centennial	Apr	13	61.4	69.4	60.9
Centennial	Apr	15	60.9	67.3	57.6
Centennial	Apr	16	61.3	70.7	56.1
Centennial	Apr	17	61.9	65.3	51.9
Centennial	Apr	18	62.3	65.4	53.5
Centennial	Apr	19	57.4	65.9	54.4
Centennial	Apr	20	66.8	61.3	60.9
Centennial	Apr	23	57.5	65.2	54.7
Centennial	May	11	68.3	50.4	58.6
Centennial	May	26	58.4	59.6	65.5
Centennial	Jun	01	57.1	77.9	61.5
Centennial	Jun	02	59.1	82.8	64.6
Centennial	Jun	03	51.6	79.9	63.3
Centennial	Jun	06	52.8	67.1	56.5
Centennial	Jun	07	62.7	67.1	66.8
Centennial	Jun	08	56.1	71.3	56.3
Centennial	Jun	13	60.9	70.4	59.9
Centennial	Jun	14	57.0	70.6	60.7
Centennial	Jun	15	51.5	68.2	53.7
Centennial	Jun	16	51.5	65.6	51.3
Centennial	Jun	21	57.0	65.8	52.0
Centennial	Jun	27	65.8	69.2	68.8
Centennial	Jul	01	52.1	70.2	65.4
Centennial	Jul	07	60.9	63.1	65.5
Centennial	Jul	08	58.3	62.8	66.3

Site	2005		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
Centennial	Jul	09	54.5	62.2	65.7
Centennial	Jul	19	67.1	55.3	60.6
Centennial	Jul	20	69.1	57.7	55.9
Centennial	Jul	22	70.0	58.5	59.0
Centennial	Aug	05	58.3	59.1	70.6
Centennial	Aug	31	64.4	55.3	69.1
Centennial	Sep	01	56.6	56.8	66.7

Table A4-2c. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Daniel monitoring site during 2005..

Site	2005 Month	2005 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Daniel	Total exceeding		4	2	6
Daniel	Apr	16	N/A	66.0	56.8
Daniel	Apr	17	N/A	66.5	54.8
Daniel	May	25	N/A	62.1	72.2
Daniel	May	26	N/A	59.0	68.9
Daniel	Jun	27	N/A	60.9	69.3
Daniel	Jul	06	56.7	55.8	66.1
Daniel	Jul	07	67.3	54.4	61.0
Daniel	Jul	08	70.8	57.7	67.7
Daniel	Jul	11	66.6	44.5	50.4
Daniel	Jul	17	56.0	50.4	66.8
Daniel	Jul	22	66.9	53.2	56.9

Table A4-2d. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Jonah monitoring site during 2005.

Site	2005 Month	2005 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Jonah	Total exceeding		22	0	8
Jonah	Jan	20	66.5	32.4	23.1
Jonah	Jan	24	78.3	46.4	35.9
Jonah	Jan	25	67.3	50.6	42.2
Jonah	Jan	26	66.9	50.6	42.2
Jonah	Feb	03	98.4	40.8	37.2
Jonah	Feb	04	76.4	52.9	46.7
Jonah	Feb	19	67.4	44.6	42.3
Jonah	Feb	20	65.4	37.8	33.4
Jonah	Feb	26	89.4	51.8	50.4
Jonah	Feb	27	75.4	48.0	48.1
Jonah	Feb	28	69.5	51.7	51.0
Jonah	Apr	13	75.3	55.0	50.4
Jonah	Apr	18	68.3	48.1	46.3
Jonah	May	25	60.5	60.7	71.3
Jonah	May	26	59.6	54.5	68.0
Jonah	Jun	01	60.8	60.9	66.5
Jonah	Jun	06	65.3	52.5	51.2
Jonah	Jun	26	65.9	53.9	66.0
Jonah	Jun	27	73.9	60.2	70.9
Jonah	Jul	06	65.4	53.5	62.6
Jonah	Jul	07	60.7	54.9	65.5
Jonah	Jul	08	72.0	57.1	67.7
Jonah	Jul	11	68.9	43.8	50.3
Jonah	Jul	12	66.8	50.3	54.3
Jonah	Jul	16	65.9	51.9	57.3
Jonah	Jul	17	58.3	49.7	69.8
Jonah	Jul	22	67.3	56.9	62.3

Table A4-2e. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Pinedale monitoring site during 2005.

Site	2005		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
Pinedale	Total exceeding		12	5	7
Pinedale	Feb	04	68.3	58.2	48.5
Pinedale	Feb	19	71.0	50.9	48.8
Pinedale	Feb	27	70.1	51.0	48.4
Pinedale	Apr	06	58.6	65.6	57.3
Pinedale	Apr	08	66.0	56.8	52.2
Pinedale	Apr	15	58.1	65.1	53.9
Pinedale	Apr	16	54.9	68.9	56.4
Pinedale	Apr	17	59.3	70.4	58.4
Pinedale	Apr	18	70.9	61.0	53.5
Pinedale	May	25	63.1	62.8	72.9
Pinedale	May	26	61.0	61.8	67.8
Pinedale	Jun	27	76.4	66.9	70.5
Pinedale	Jun	28	66.3	63.4	65.8
Pinedale	Jul	07	65.5	61.0	66.0
Pinedale	Jul	08	67.3	62.3	68.6
Pinedale	Jul	11	66.4	47.0	48.3
Pinedale	Jul	12	66.8	54.1	52.6
Pinedale	Jul	17	53.4	54.0	67.5
Pinedale	Jul	22	65.6	56.4	55.8

Table A4-2f. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Wamsutter monitoring site during 2005.

Site	2005		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
Wamsutter	Total exceeding		NA	2	11
Wamsutter	May	26	N/A	55.2	65.5
Wamsutter	May	28	N/A	60.9	67.2
Wamsutter	Jun	27	N/A	69.3	76.5
Wamsutter	Jun	29	N/A	56.6	65.8
Wamsutter	Jul	01	N/A	67.9	65.5
Wamsutter	Jul	03	N/A	54.1	65.5
Wamsutter	Jul	06	N/A	61.7	74.1
Wamsutter	Jul	08	N/A	57.7	65.5
Wamsutter	Jul	17	N/A	51.9	72.4
Wamsutter	Aug	05	N/A	59.9	67.9
Wamsutter	Sep	01	N/A	51.1	65.8

Table A4-3a. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Boulder monitoring site during 2006.

Site	2006		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
Boulder	Total exceeding		43	10	13
Boulder	Jan	26	67.2	47.0	44.5
Boulder	Feb	12	67.2	41.7	40.3
Boulder	Feb	19	69.9	52.3	50.9
Boulder	Feb	26	67.8	59.5	57.0
Boulder	Feb	27	71.0	56.9	61.2
Boulder	Mar	17	67.4	63.1	59.4
Boulder	Apr	08	63.1	66.1	52.3
Boulder	Apr	09	64.5	70.6	63.7
Boulder	Apr	13	65.1	54.4	53.8
Boulder	Apr	20	67.0	60.8	60.3
Boulder	Apr	21	81.0	69.9	74.2
Boulder	Apr	22	61.2	66.8	63.1
Boulder	Apr	28	71.0	60.1	60.6
Boulder	May	02	76.5	63.7	64.4
Boulder	May	03	67.1	63.4	61.9
Boulder	May	06	67.3	65.2	64.8
Boulder	May	08	71.3	43.8	38.7
Boulder	May	09	69.0	55.6	69.2
Boulder	May	10	63.3	52.4	68.1
Boulder	May	11	66.5	56.1	58.2
Boulder	May	25	66.5	52.0	53.8
Boulder	May	31	69.1	62.8	74.5
Boulder	Jun	01	72.8	63.6	68.2
Boulder	Jun	02	71.8	62.8	60.8
Boulder	Jun	10	67.6	53.4	50.4
Boulder	Jun	11	72.1	62.6	60.4
Boulder	Jun	12	70.5	68.5	64.7
Boulder	Jun	13	68.8	57.0	60.6
Boulder	Jun	14	68.5	50.2	50.0
Boulder	Jun	17	69.8	47.7	57.3
Boulder	Jun	18	79.5	49.5	60.9
Boulder	Jun	20	67.9	69.8	59.6
Boulder	Jun	22	70.6	65.6	60.3
Boulder	Jun	23	68.8	56.1	54.2
Boulder	Jun	26	65.3	68.3	51.8
Boulder	Jun	27	67.5	67.5	55.0
Boulder	Jul	08	70.8	60.5	61.4
Boulder	Jul	14	29.0	55.4	68.9
Boulder	Jul	15	61.5	63.8	70.3
Boulder	Jul	27	67.5	55.4	60.4
Boulder	Jul	28	65.4	55.3	59.6
Boulder	Jul	29	66.8	55.2	62.5
Boulder	Aug	13	58.9	52.8	69.3
Boulder	Aug	14	64.5	55.8	78.3
Boulder	Aug	17	68.0	51.4	57.8
Boulder	Aug	18	72.4	59.9	91.5
Boulder	Aug	19	68.4	60.4	77.6
Boulder	Aug	20	70.1	54.6	66.2
Boulder	Aug	21	67.0	59.5	61.4
Boulder	Aug	31	67.4	52.6	67.7
Boulder	Sep	02	65.1	48.1	56.0

Table A4-3b. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Centennial monitoring site during 2006.

Site	2006 Month	2006 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Centennial	Total exceeding		19	31	15
Centennial	Mar	01	59.0	65.2	51.9
Centennial	Mar	02	54.1	66.0	52.8
Centennial	Mar	03	54.1	66.3	53.5
Centennial	Mar	27	59.3	68.4	53.4
Centennial	Mar	28	62.9	66.1	55.1
Centennial	Apr	04	55.4	65.4	54.6
Centennial	Apr	08	63.0	65.8	58.7
Centennial	Apr	09	64.1	65.5	59.6
Centennial	Apr	13	68.4	63.1	59.7
Centennial	Apr	20	66.3	58.0	64.4
Centennial	Apr	21	73.0	69.6	79.8
Centennial	Apr	22	73.6	66.1	66.8
Centennial	Apr	27	65.5	62.0	60.3
Centennial	Apr	28	66.0	52.9	51.2
Centennial	Apr	29	67.6	56.4	61.9
Centennial	May	01	61.6	69.9	61.7
Centennial	May	02	73.3	63.0	59.3
Centennial	May	03	70.4	60.7	56.5
Centennial	May	06	59.0	57.6	67.5
Centennial	May	09	70.0	62.3	63.4
Centennial	May	10	61.6	56.8	75.0
Centennial	May	11	66.3	64.5	66.5
Centennial	May	12	64.0	65.2	68.8
Centennial	May	31	61.3	68.0	61.7
Centennial	Jun	01	62.3	67.7	63.0
Centennial	Jun	02	65.5	67.6	60.7
Centennial	Jun	03	69.5	63.5	55.3
Centennial	Jun	06	53.0	68.5	54.0
Centennial	Jun	07	50.5	68.8	55.0
Centennial	Jun	10	62.9	67.8	54.9
Centennial	Jun	11	59.0	68.3	54.8
Centennial	Jun	12	64.0	72.1	69.9
Centennial	Jun	19	57.5	66.1	56.3
Centennial	Jun	20	56.6	69.0	55.3
Centennial	Jun	21	59.3	69.5	58.0
Centennial	Jun	22	69.1	69.2	58.6
Centennial	Jun	23	65.4	69.6	58.7
Centennial	Jun	24	58.4	67.2	54.6
Centennial	Jun	26	56.3	71.3	54.0
Centennial	Jun	27	55.1	74.2	57.6
Centennial	Jun	28	53.9	74.9	58.1
Centennial	Jun	29	59.1	66.4	55.6
Centennial	Jul	02	49.8	66.6	45.9
Centennial	Jul	13	69.3	63.1	69.2
Centennial	Jul	14	62.8	63.4	70.7
Centennial	Jul	15	61.6	63.4	66.4
Centennial	Jul	28	66.9	61.4	65.1
Centennial	Jul	29	54.9	62.9	67.7
Centennial	Jul	30	64.8	59.5	65.9
Centennial	Aug	02	67.0	58.8	60.8
Centennial	Aug	14	59.6	60.0	73.2
Centennial	Aug	15	59.3	60.7	70.6
Centennial	Aug	20	65.4	61.9	59.6

Table A4-3c. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Daniel monitoring site during 2006.

Site	2006 Month	2006 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Daniel	Total exceeding		26	9	17
Daniel	Feb	25	82.7	47.7	44.8
Daniel	Feb	27	74.8	61.3	60.6
Daniel	Mar	06	70.1	62.8	54.9
Daniel	Mar	14	66.7	56.2	52.8
Daniel	Mar	17	71.6	65.1	60.2
Daniel	Mar	18	65.3	62.9	58.1
Daniel	Apr	09	62.8	76.8	67.1
Daniel	Apr	20	67.6	58.2	64.4
Daniel	Apr	21	74.9	72.8	71.0
Daniel	Apr	22	68.1	70.4	64.0
Daniel	Apr	28	68.4	54.5	57.5
Daniel	May	02	75.6	57.7	62.2
Daniel	May	03	66.5	61.1	60.7
Daniel	May	06	67.3	60.7	63.2
Daniel	May	08	71.3	42.1	45.7
Daniel	May	09	67.0	52.7	65.8
Daniel	May	10	62.3	51.3	65.4
Daniel	May	11	65.3	56.4	63.2
Daniel	May	30	53.6	50.8	70.0
Daniel	May	31	61.1	59.1	72.4
Daniel	Jun	01	69.9	65.2	66.7
Daniel	Jun	02	66.6	62.1	61.0
Daniel	Jun	11	65.9	63.7	59.8
Daniel	Jun	12	67.4	69.2	68.1
Daniel	Jun	18	73.1	52.8	62.1
Daniel	Jun	20	60.0	72.2	59.4
Daniel	Jun	22	67.3	68.0	61.7
Daniel	Jun	23	67.0	59.1	54.2
Daniel	Jun	27	63.0	68.2	56.1
Daniel	Jul	14	66.8	55.3	70.6
Daniel	Jul	15	68.8	62.4	71.0
Daniel	Aug	13	55.3	50.5	69.7
Daniel	Aug	14	60.5	54.2	76.1
Daniel	Aug	15	57.0	53.5	66.7
Daniel	Aug	18	68.3	54.0	78.1
Daniel	Aug	19	64.9	58.2	77.6
Daniel	Aug	20	N/A	53.5	67.6
Daniel	Aug	31	62.9	53.6	71.9

Table A4-3d. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Jonah monitoring site during 2006.

Site	2006 Month	2006 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Jonah	Total exceeding		22	3	8
Jonah	Feb	25	81.0	50.5	49.1
Jonah	Feb	26	69.1	59.9	59.3
Jonah	Feb	27	93.0	57.2	60.2
Jonah	Mar	24	68.1	50.4	39.3
Jonah	Apr	08	65.8	58.8	49.8
Jonah	Apr	09	67.5	68.0	57.2
Jonah	Apr	10	65.8	54.8	55.2
Jonah	Apr	21	66.6	63.1	77.4
Jonah	Apr	28	68.0	56.5	59.5
Jonah	May	02	71.5	56.5	56.6
Jonah	May	09	63.1	52.0	65.8
Jonah	Jun	02	65.4	60.0	62.3
Jonah	Jun	11	69.8	58.6	59.5
Jonah	Jun	12	66.1	66.4	62.6
Jonah	Jun	20	68.7	68.8	60.1
Jonah	Jul	14	66.5	52.1	67.5
Jonah	Jul	15	69.4	60.0	68.4
Jonah	Jul	16	67.0	53.5	63.0
Jonah	Jul	29	65.3	54.0	64.2
Jonah	Aug	14	61.8	53.5	75.4
Jonah	Aug	17	66.8	51.0	60.5
Jonah	Aug	18	68.0	54.9	77.0
Jonah	Aug	19	67.4	56.1	75.5
Jonah	Aug	20	66.3	51.5	65.8

Table A4-3e. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the OCI monitoring site during 2006.

Site	2006 Month	2006 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
OCI	Total exceeding		24	10	26
OCI	Apr	20	N/A	56.5	69.8
OCI	Apr	21	N/A	60.8	74.3
OCI	May	02	66.8	57.1	56.9
OCI	May	09	64.8	54.1	67.0
OCI	May	10	61.4	56.0	65.6
OCI	May	11	64.0	58.0	67.5
OCI	May	31	66.6	66.9	65.9
OCI	Jun	01	63.2	68.2	67.8
OCI	Jun	02	69.8	64.7	66.0
OCI	Jun	10	66.1	63.0	63.8
OCI	Jun	11	72.8	62.9	62.5
OCI	Jun	12	65.9	69.0	67.1
OCI	Jun	18	71.4	51.0	56.7
OCI	Jun	19	66.1	59.4	55.5
OCI	Jun	20	65.9	63.0	59.8
OCI	Jun	21	57.4	65.8	58.9
OCI	Jun	22	67.9	65.6	62.6
OCI	Jun	26	64.5	66.0	52.1
OCI	Jun	27	64.5	73.8	58.6
OCI	Jun	28	56.2	67.9	58.2
OCI	Jun	29	60.6	66.4	58.6
OCI	Jul	13	71.1	57.5	68.1
OCI	Jul	14	71.9	59.1	73.2
OCI	Jul	15	69.6	66.8	71.9
OCI	Jul	16	72.3	64.6	70.6
OCI	Jul	17	68.3	57.2	60.4
OCI	Jul	18	67.2	64.2	70.5
OCI	Jul	22	65.5	57.5	61.1
OCI	Jul	25	68.0	53.5	52.3
OCI	Jul	27	67.4	61.0	66.3
OCI	Jul	28	69.2	62.2	65.9
OCI	Jul	29	64.3	59.8	68.3
OCI	Jul	30	61.2	52.5	65.2
OCI	Aug	03	59.4	59.9	65.2
OCI	Aug	10	61.7	60.1	65.1
OCI	Aug	14	N/A	59.4	77.5
OCI	Aug	18	71.7	62.4	78.5
OCI	Aug	19	67.7	59.3	68.8
OCI	Aug	20	67.5	57.8	68.2
OCI	Aug	21	66.1	60.1	61.5
OCI	Sep	03	53.5	58.3	65.6
OCI	Sep	04	56.5	60.4	67.2

Table A4-3f. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Boulder monitoring site during 2006.

Site	2006		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
Pinedale	Total exceeding		11	17	21
Pinedale	Apr	08	61.1	67.5	63.1
Pinedale	Apr	09	60.9	66.8	64.7
Pinedale	Apr	20	68.4	62.1	70.5
Pinedale	Apr	21	80.1	68.0	72.9
Pinedale	Apr	22	64.1	67.0	64.7
Pinedale	Apr	28	66.0	56.6	59.1
Pinedale	May	02	73.4	66.0	66.2
Pinedale	May	03	66.6	63.5	63.2
Pinedale	May	05	52.5	64.4	71.5
Pinedale	May	06	64.5	64.2	70.9
Pinedale	May	08	69.1	43.3	45.2
Pinedale	May	09	64.6	56.8	71.2
Pinedale	May	10	59.3	56.2	69.6
Pinedale	May	11	61.9	60.0	65.2
Pinedale	May	30	53.1	54.8	67.7
Pinedale	May	31	60.1	63.7	70.0
Pinedale	Jun	01	66.6	67.5	67.4
Pinedale	Jun	11	N/A	65.2	60.7
Pinedale	Jun	12	N/A	67.1	63.9
Pinedale	Jun	20	N/A	71.4	58.5
Pinedale	Jun	21	N/A	68.3	57.2
Pinedale	Jun	22	N/A	70.9	60.1
Pinedale	Jun	25	N/A	69.7	50.2
Pinedale	Jun	26	N/A	70.6	50.1
Pinedale	Jun	27	58.2	71.4	57.3
Pinedale	Jun	28	49.5	68.3	52.6
Pinedale	Jul	01	53.9	65.1	44.7
Pinedale	Jul	02	53.5	65.4	45.8
Pinedale	Jul	14	63.5	57.7	68.5
Pinedale	Jul	15	67.7	63.2	69.7
Pinedale	Jul	29	64.1	58.5	65.3
Pinedale	Aug	13	57.6	54.6	73.3
Pinedale	Aug	14	61.6	58.6	79.8
Pinedale	Aug	15	57.7	56.2	65.2
Pinedale	Aug	17	67.8	53.9	62.3
Pinedale	Aug	18	67.8	58.6	80.4
Pinedale	Aug	19	65.0	60.1	77.0
Pinedale	Aug	20	66.0	56.7	72.8
Pinedale	Aug	31	62.3	54.0	71.8

Table A4-3g. Summary of days having daily maximum 8-hour ozone concentrations exceeding 65 ppb at the Wamsutter monitoring site during 2006.

Site	2006 Month	2006 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Wamsutter	Total exceeding		11	9	18
Wamsutter	Apr	20	71.4	53.7	64.6
Wamsutter	Apr	21	63.1	61.4	75.8
Wamsutter	Apr	28	65.3	55.6	57.5
Wamsutter	May	02	67.1	60.4	59.3
Wamsutter	May	06	59.6	55.9	69.6
Wamsutter	May	10	59.3	52.5	69.6
Wamsutter	May	11	66.1	59.0	65.7
Wamsutter	May	12	61.9	60.3	67.5
Wamsutter	Jun	01	63.8	67.5	67.8
Wamsutter	Jun	02	65.6	62.8	62.4
Wamsutter	Jun	03	69.3	61.4	58.8
Wamsutter	Jun	10	67.1	61.4	58.2
Wamsutter	Jun	11	65.8	62.8	57.8
Wamsutter	Jun	12	66.8	68.2	69.0
Wamsutter	Jun	18	66.5	55.6	60.9
Wamsutter	Jun	20	64.4	66.9	63.3
Wamsutter	Jun	21	63.0	65.8	62.2
Wamsutter	Jun	22	66.3	66.3	62.0
Wamsutter	Jun	27	62.8	71.6	58.3
Wamsutter	Jun	29	19.8	65.5	57.2
Wamsutter	Jul	13	58.1	62.3	72.0
Wamsutter	Jul	14	56.8	55.7	70.9
Wamsutter	Jul	15	54.5	62.1	69.9
Wamsutter	Jul	16	54.6	64.6	71.2
Wamsutter	Jul	18	49.1	58.3	67.0
Wamsutter	Jul	28	54.1	69.8	75.2
Wamsutter	Jul	29	22.5	68.6	78.1
Wamsutter	Jul	30	25.7	58.2	70.4
Wamsutter	Aug	14	55.3	61.4	86.7
Wamsutter	Aug	18	55.9	55.9	66.3
Wamsutter	Aug	20	58.3	60.9	72.6

Table A4-4a. Summary of days having daily maximum 8-hour ozone concentrations exceeding 70 ppb during 2005.

Site	2005 Month	2005 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Boulder	Total exceeding		12	0	1
Boulder	Feb	03	82.0	41.4	43.3
Boulder	Feb	04	80.2	54.3	50.2
Boulder	Feb	19	79.9	46.1	49.8
Boulder	Feb	20	89.3	38.5	35.2
Boulder	Feb	22	75.9	51.5	48.3
Boulder	Feb	24	80.9	45.7	49.2
Boulder	Feb	25	72.2	44.4	45.9
Boulder	Feb	26	70.2	53.2	54.7
Boulder	Feb	27	74.5	49.1	49.2
Boulder	Mar	03	71.9	45.3	49.3
Boulder	May	25	65.0	60.5	72.8
Boulder	Jun	27	72.7	58.8	66.8
Boulder	Jul	23	70.7	57.1	58.1
Centennial	Total exceeding		0	9	1
Centennial	Apr	07	56.6	71.8	59.9
Centennial	Apr	16	61.3	70.7	56.1
Centennial	Jun	01	57.1	77.9	61.5
Centennial	Jun	02	59.1	82.8	64.6
Centennial	Jun	03	51.6	79.9	63.3
Centennial	Jun	08	56.1	71.3	56.3
Centennial	Jun	13	60.9	70.4	59.9
Centennial	Jun	14	57.0	70.6	60.7
Centennial	Jul	01	52.1	70.2	65.4
Centennial	Aug	05	58.3	59.1	70.6
Daniel	Total exceeding		1	0	1
Daniel	May	25	N/A	62.1	72.2
Daniel	Jul	08	70.8	57.7	67.7
Jonah	Total exceeding		8	0	2
Jonah	Jan	24	78.3	46.4	35.9
Jonah	Feb	03	98.4	40.8	37.2
Jonah	Feb	04	76.4	52.9	46.7
Jonah	Feb	26	89.4	51.8	50.4
Jonah	Feb	27	75.4	48.0	48.1
Jonah	Apr	13	75.3	55.0	50.4
Jonah	May	25	60.5	60.7	71.3
Jonah	Jun	27	73.9	60.2	70.9
Jonah	Jul	08	72.0	57.1	67.7
Pinedale	Total exceeding		4	1	2
Pinedale	Feb	19	71.0	50.9	48.8
Pinedale	Feb	27	70.1	51.0	48.4
Pinedale	Apr	17	59.3	70.4	58.4
Pinedale	Apr	18	70.9	61.0	53.5
Pinedale	May	25	63.1	62.8	72.9
Pinedale	Jun	27	76.4	66.9	70.5
Wamsutter	Total exceeding		NA	0	3
Wamsutter	Jun	27	N/A	69.3	76.5
Wamsutter	Jul	06	N/A	61.7	74.1
Wamsutter	Jul	17	N/A	51.9	72.4

Table A4-4b. Summary of days having daily maximum 8-hour ozone concentrations exceeding 70 ppb during 2006.

Site	2006 Month	2006 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Boulder	Total exceeding		14	1	6
Boulder	Feb	27	71.0	56.9	61.2
Boulder	Apr	09	64.5	70.6	63.7
Boulder	Apr	21	81.0	69.9	74.2
Boulder	Apr	28	71.0	60.1	60.6
Boulder	May	02	76.5	63.7	64.4
Boulder	May	08	71.3	43.8	38.7
Boulder	May	31	69.1	62.8	74.5
Boulder	Jun	01	72.8	63.6	68.2
Boulder	Jun	02	71.8	62.8	60.8
Boulder	Jun	11	72.1	62.6	60.4
Boulder	Jun	12	70.5	68.5	64.7
Boulder	Jun	18	79.5	49.5	60.9
Boulder	Jun	22	70.6	65.6	60.3
Boulder	Jul	08	70.8	60.5	61.4
Boulder	Jul	15	61.5	63.8	70.3
Boulder	Aug	14	64.5	55.8	78.3
Boulder	Aug	18	72.4	59.9	91.5
Boulder	Aug	19	68.4	60.4	77.6
Boulder	Aug	20	70.1	54.6	66.2
Centennial	Total exceeding		4	4	5
Centennial	Apr	21	73.0	69.6	79.8
Centennial	Apr	22	73.6	66.1	66.8
Centennial	May	02	73.3	63.0	59.3
Centennial	May	03	70.4	60.7	56.5
Centennial	May	10	61.6	56.8	75.0
Centennial	Jun	12	64.0	72.1	69.9
Centennial	Jun	26	56.3	71.3	54.0
Centennial	Jun	27	55.1	74.2	57.6
Centennial	Jun	28	53.9	74.9	58.1
Centennial	Jul	14	62.8	63.4	70.7
Centennial	Aug	14	59.6	60.0	73.2
Centennial	Aug	15	59.3	60.7	70.6
Daniel	Total exceeding		8	4	8
Daniel	Feb	25	82.7	47.7	44.8
Daniel	Feb	27	74.8	61.3	60.6
Daniel	Mar	06	70.1	62.8	54.9
Daniel	Mar	17	71.6	65.1	60.2
Daniel	Apr	09	62.8	76.8	67.1
Daniel	Apr	21	74.9	72.8	71.0
Daniel	Apr	22	68.1	70.4	64.0
Daniel	May	02	75.6	57.7	62.2
Daniel	May	08	71.3	42.1	45.7
Daniel	May	31	61.1	59.1	72.4
Daniel	Jun	18	73.1	52.8	62.1
Daniel	Jun	20	60.0	72.2	59.4
Daniel	Jul	14	66.8	55.3	70.6
Daniel	Jul	15	68.8	62.4	71.0
Daniel	Aug	14	60.5	54.2	76.1
Daniel	Aug	18	68.3	54.0	78.1
Daniel	Aug	19	64.9	58.2	77.6
Daniel	Aug	31	62.9	53.6	71.9

Table A4-4c. Summary of days having daily maximum 8-hour ozone concentrations exceeding 70 ppb during 2006.

Site	2006 Month	Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
Jonah	Total exceeding		3	0	4
Jonah	Feb	25	81.0	50.5	49.1
Jonah	Feb	27	93.0	57.2	60.2
Jonah	Apr	21	66.6	63.1	77.4
Jonah	May	02	71.5	56.5	56.6
Jonah	Aug	14	61.8	53.5	75.4
Jonah	Aug	18	68.0	54.9	77.0
Jonah	Aug	19	67.4	56.1	75.5
OCI	Total exceeding		6	1	7
OCI	Apr	21	N/A	60.8	74.3
OCI	Jun	11	72.8	62.9	62.5
OCI	Jun	18	71.4	51.0	56.7
OCI	Jun	27	64.5	73.8	58.6
OCI	Jul	13	71.1	57.5	68.1
OCI	Jul	14	71.9	59.1	73.2
OCI	Jul	15	69.6	66.8	71.9
OCI	Jul	16	72.3	64.6	70.6
OCI	Jul	18	67.2	64.2	70.5
OCI	Aug	14	N/A	59.4	77.5
OCI	Aug	18	71.7	62.4	78.5
Pinedale	Total exceeding		2	4	11
Pinedale	Apr	20	68.4	62.1	70.5
Pinedale	Apr	21	80.1	68.0	72.9
Pinedale	May	02	73.4	66.0	66.2
Pinedale	May	05	52.5	64.4	71.5
Pinedale	May	06	64.5	64.2	70.9
Pinedale	May	09	64.6	56.8	71.2
Pinedale	Jun	20	N/A	71.4	58.5
Pinedale	Jun	22	N/A	70.9	60.1
Pinedale	Jun	26	N/A	70.6	50.1
Pinedale	Jun	27	58.2	71.4	57.3
Pinedale	Aug	13	57.6	54.6	73.3
Pinedale	Aug	14	61.6	58.6	79.8
Pinedale	Aug	18	67.8	58.6	80.4
Pinedale	Aug	19	65.0	60.1	77.0
Pinedale	Aug	20	66.0	56.7	72.8
Pinedale	Aug	31	62.3	54.0	71.8
Wamsutter	Total exceeding		1	1	9
Wamsutter	Apr	20	71.4	53.7	64.6
Wamsutter	Apr	21	63.1	61.4	75.8
Wamsutter	Jun	27	62.8	71.6	58.3
Wamsutter	Jul	13	58.1	62.3	72.0
Wamsutter	Jul	14	56.8	55.7	70.9
Wamsutter	Jul	16	54.6	64.6	71.2
Wamsutter	Jul	28	54.1	69.8	75.2
Wamsutter	Jul	29	22.5	68.6	78.1
Wamsutter	Jul	30	25.7	58.2	70.4
Wamsutter	Aug	14	55.3	61.4	86.7
Wamsutter	Aug	20	58.3	60.9	72.6

A4.4. OZONE TIME SERIES OF DAILY MAXIMUM 8-HOUR OZONE CONCENTRATIONS FOR MONITORS IN 4 KM DOMAIN

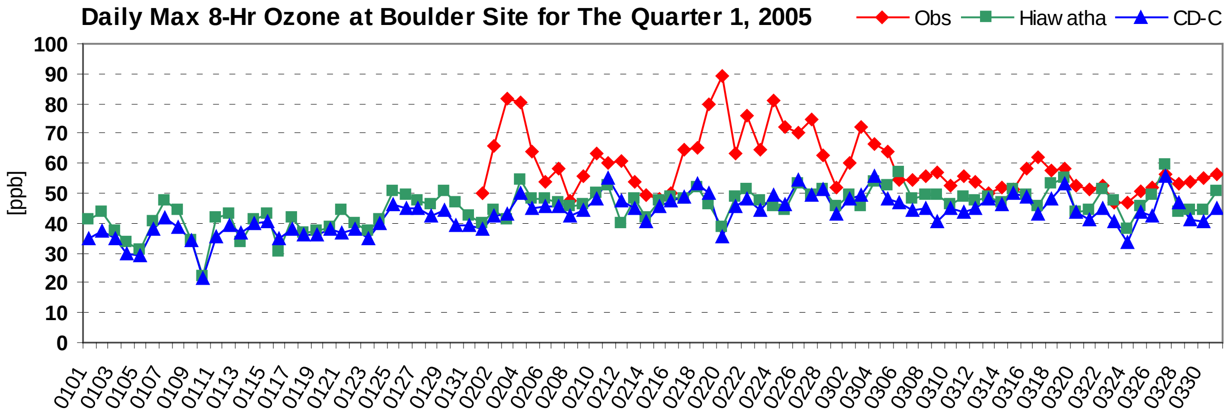
Figures A4-3 and A4-4 compare the predicted and observed 8-hour ozone time series for monitors in the 4 km domain and the years 2005 and 2006, respectively. At the Boulder monitor for Quarter 1 (Q1) in 2005 (Figure A4-3a, top) neither base case simulation reproduces the observed high winter ozone concentrations. There is also a tendency for both models to underestimate the observed 8-hour ozone concentrations during Q4 in 2005 at Boulder, however both modeled and observed ozone values are below 60 ppb. During Q3 and Q4 of 2005, the two base case simulations match the observed 8-hour ozone values better, albeit with a general underestimation bias with Hiawatha base case matching the observed values in June better and CD-C matching them better in July and August.

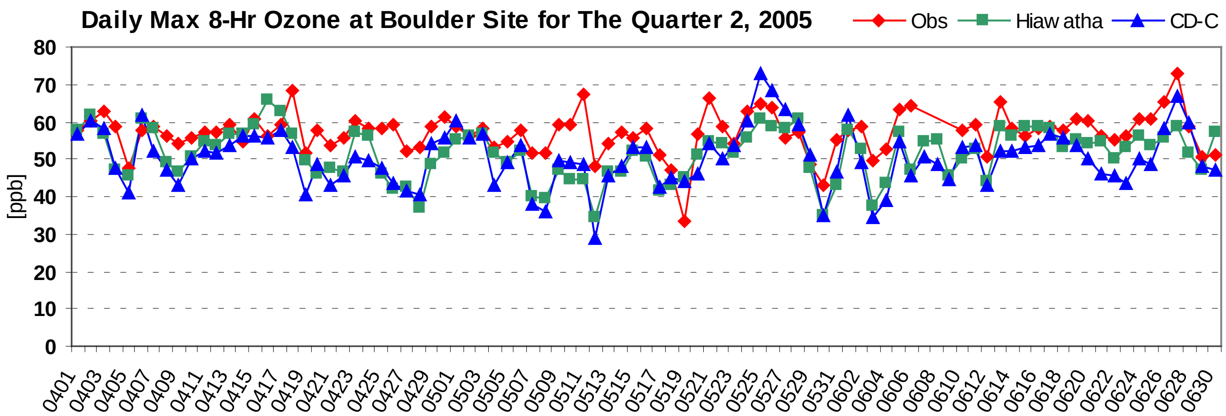
With the exception of a few observed high winter ozone events in January and February 2005, the two models do a much better job of reproducing the winter (Q1 and Q4) observed 8-hour ozone concentrations at the Jonah monitor (Figure A4-3b) than is seen at the Boulder monitor (Figure A4-3a). In Q3 during 2005, both models miss a few days with high observed ozone concentrations at Jonah in April with the CD-C base case generally predicting ozone closer to observed than the Hiawatha base case, including much better reproduction of the observed high ozone at the end of June 2005. During 2005 Q4, both models tend to underestimate the high observed ozone days at Jonah, with the CD-C base case generally higher and closer to the observed values than the Hiawatha base case.

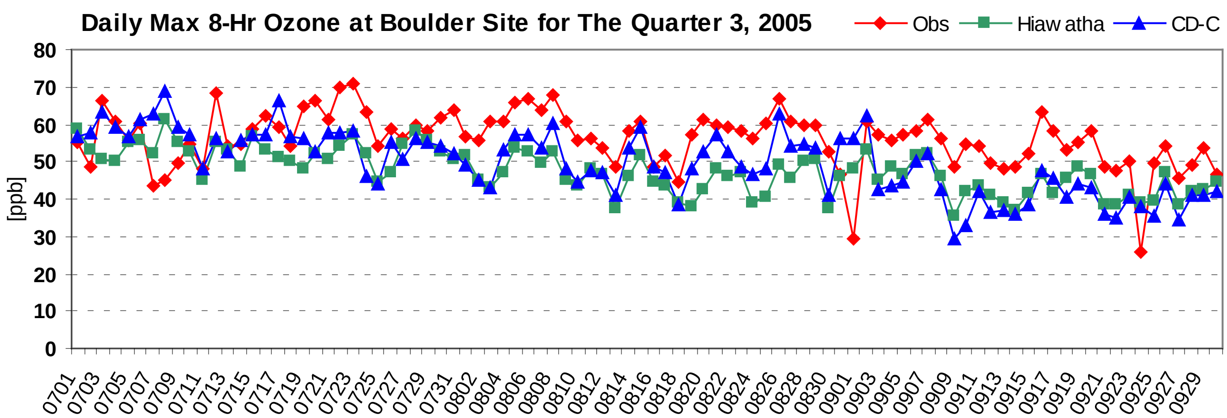
Observed daily maximum ozone concentrations for Daniel during 2005 are only available for Q3 and Q4 (Figure A4-3c). In general, the CD-C base case is exhibiting better performance in Q3, whereas the Hiawatha performance is superior in Q4.

2005 daily maximum 8-hour ozone comparisons for the Pinedale and Centennial CASTnet sites are shown in Figures A4-4d and 5-4e, respectively. The Hiawatha base case is performing better for Q1 and Q4 with the CD-C base case exhibiting an underestimation bias at these two sites. However, for Q2 and Q3 the CD-C base case is generally performing better than the Hiawatha base case that exhibits an overestimation bias at Centennial in Q2 that can be quite large on some days.

The daily maximum 8-hour ozone results for 2006 and Boulder are somewhat similar to 2005 with the Hiawatha base case generally performing better in Q1 and the CD-C base case generally performing better in Q3, but there are some interesting differences (Figure A4-4a). In Q2 there are high observed ozone events in mid April and the end of May and beginning of June that is captured better by the CD-C base case. The CD-C base case estimates the highest ozone concentrations in mid-August when high observed ozone also occurs, just not as high as estimated by the CD-C base case. The Wamsutter (Figure A4-4f) and OCI (Figure A4-4g) monitoring sites came online in 2006. At Wamsutter both models perform reasonable well in Q3 but have an overestimation bias in Q4. With the exception of a few days, the two base case simulations reproduce the observed ozone at OCI reasonably well.







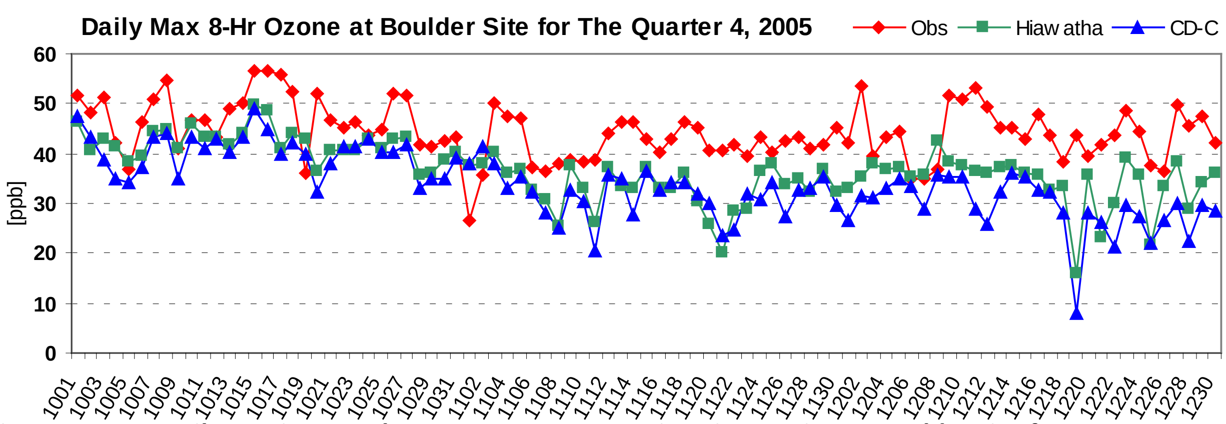


Figure A4-3a. Daily maximum 8-hour ozone concentration time series at Boulder site for 2005.

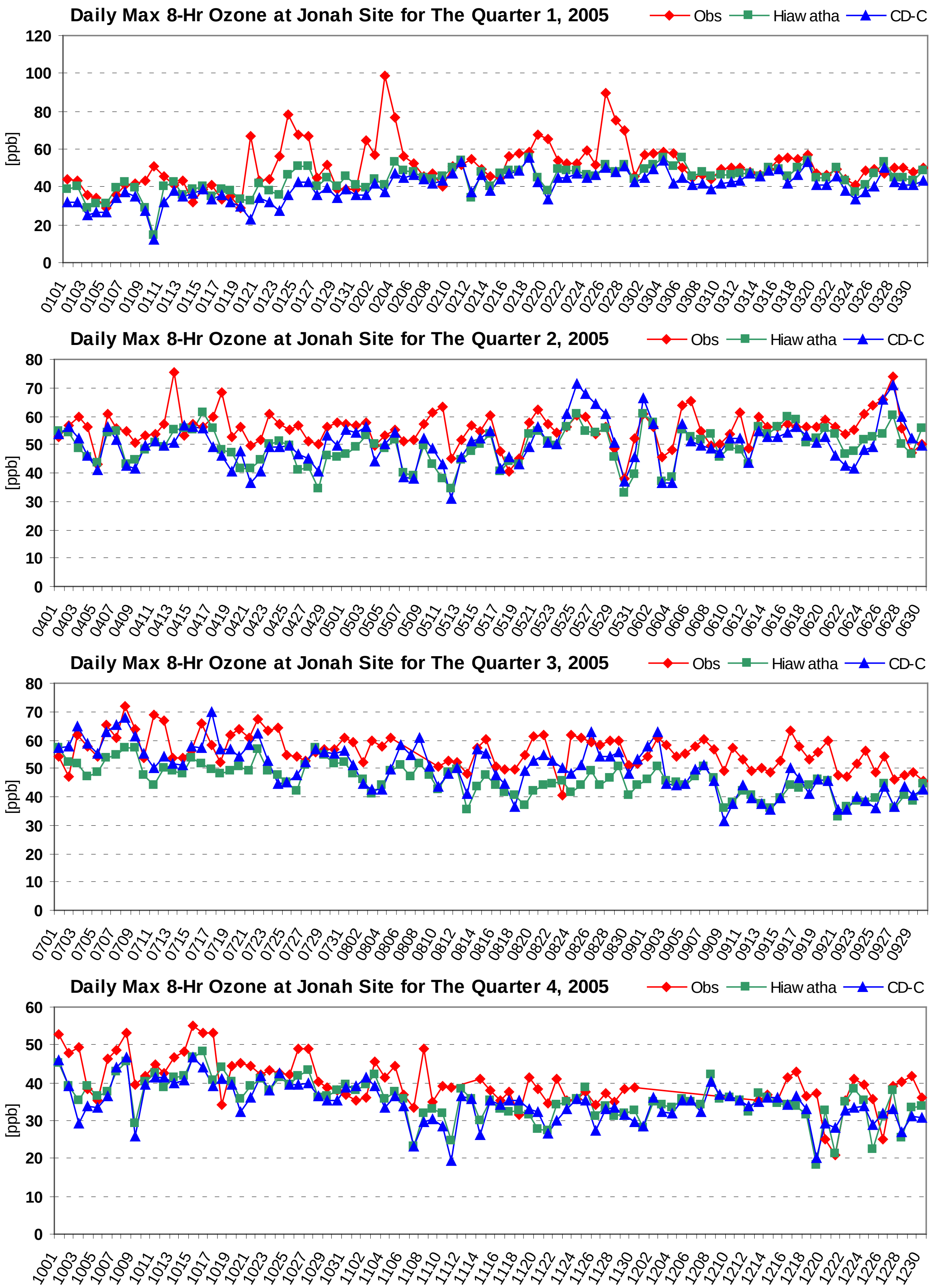


Figure A4-3b. Daily maximum 8-hour ozone concentration time series at Jonah site for 2005.

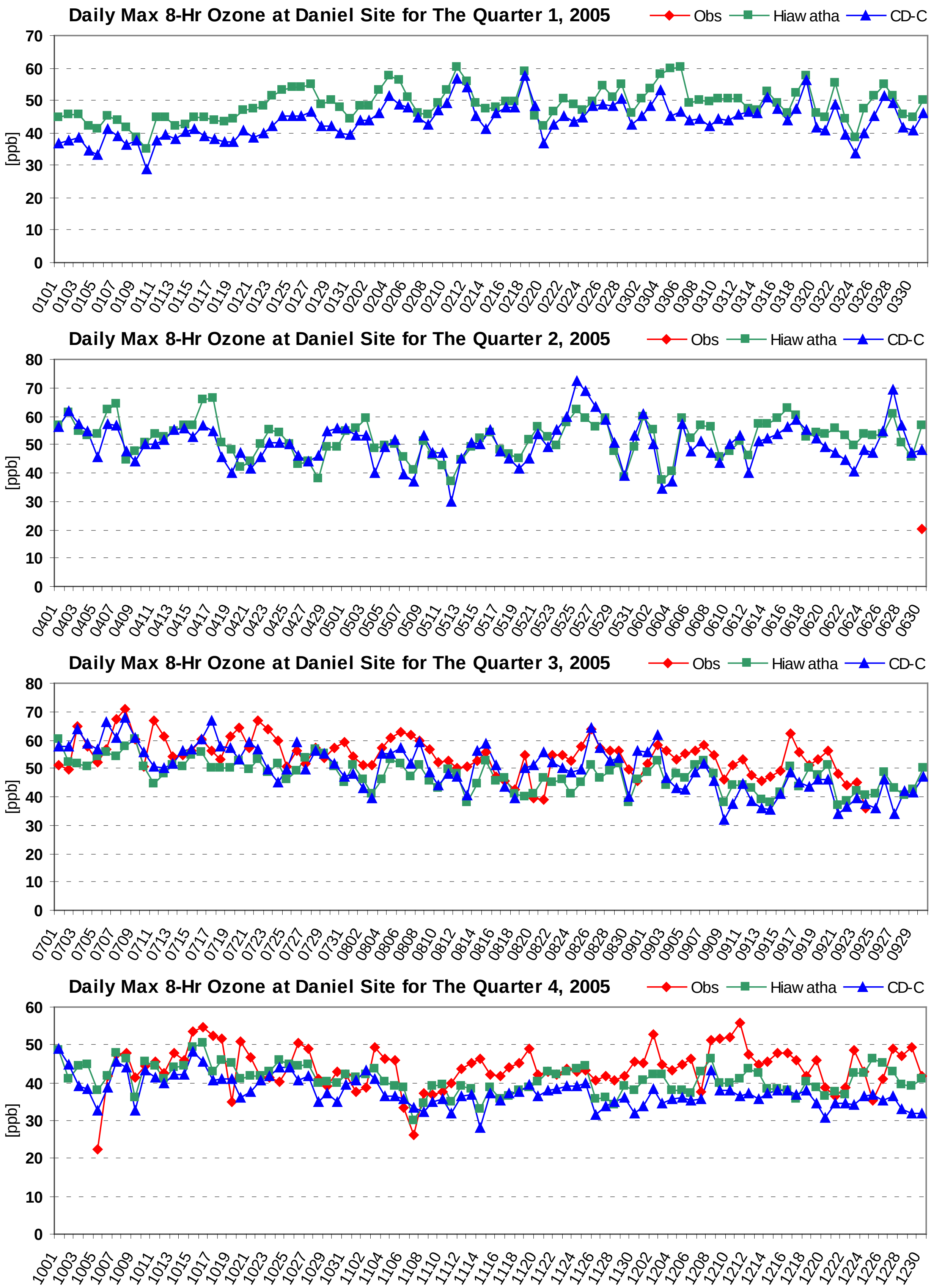


Figure A4-3c. Daily maximum 8-hour ozone concentration time series at Daniel site for 2005.

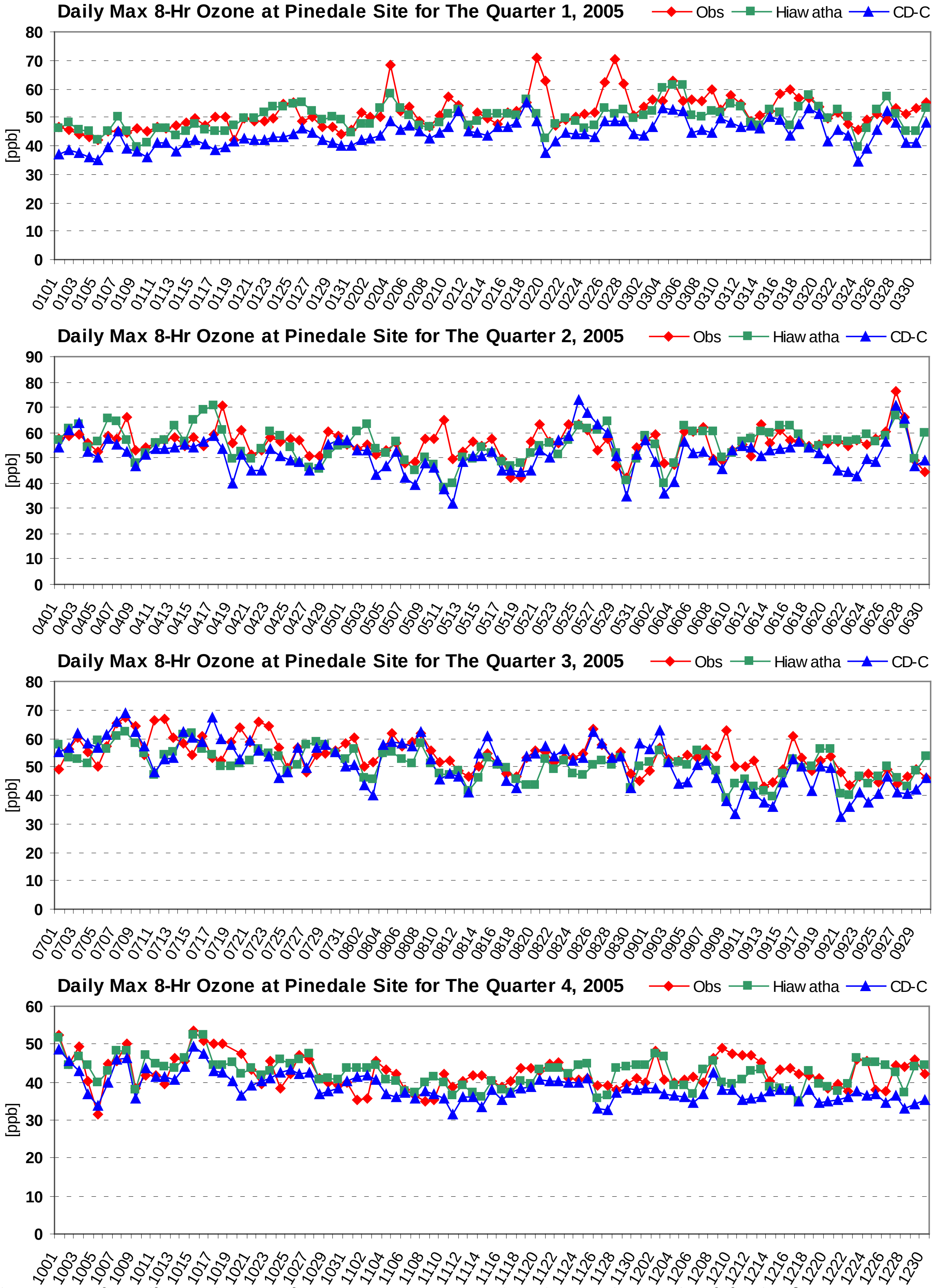


Figure A4-3d. Daily maximum 8-hour ozone concentration time series at Pinedale site for 2005.

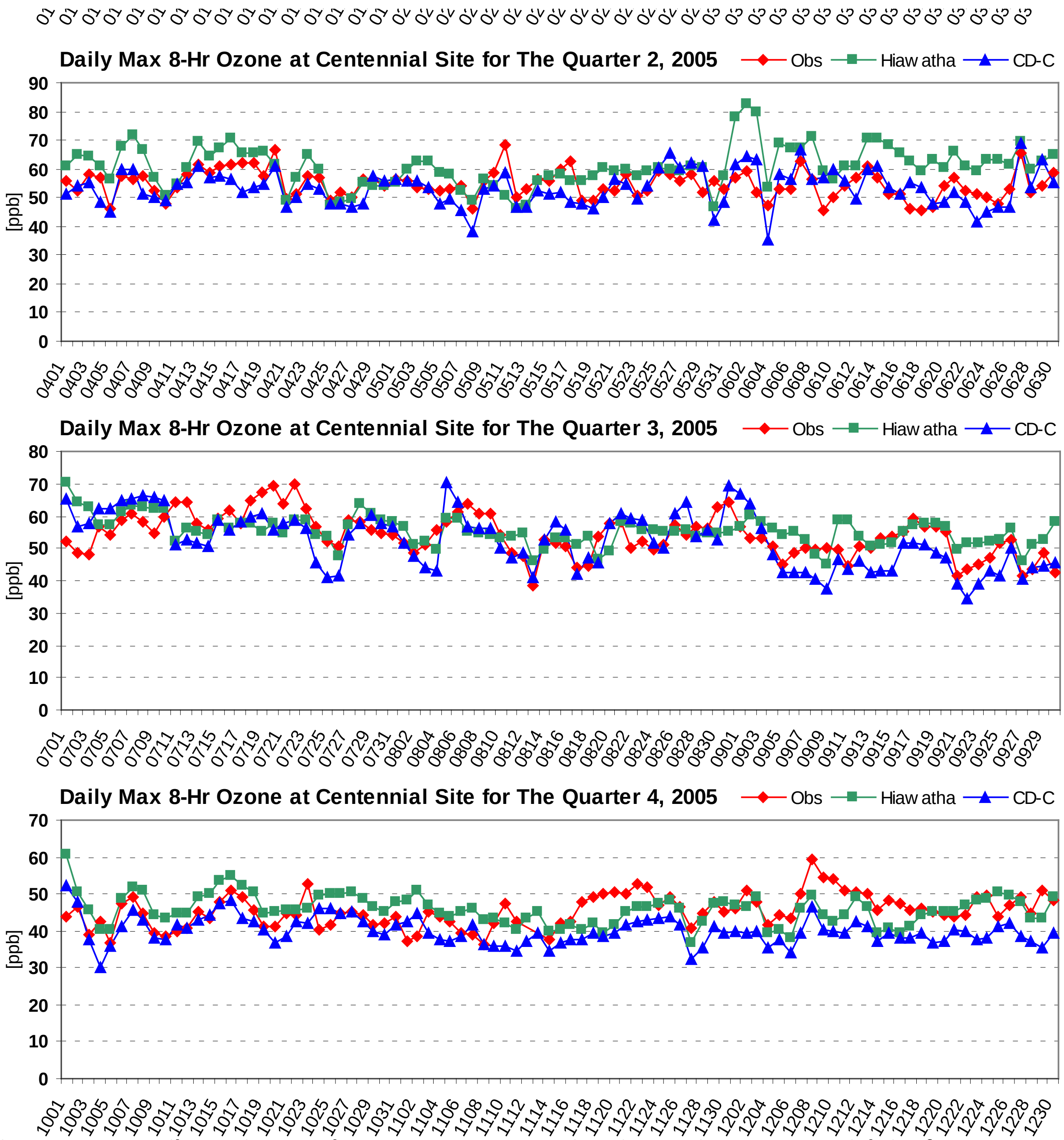


Figure A4-3e. Daily maximum 8-hour ozone concentration time series at Centennial site for 2005.

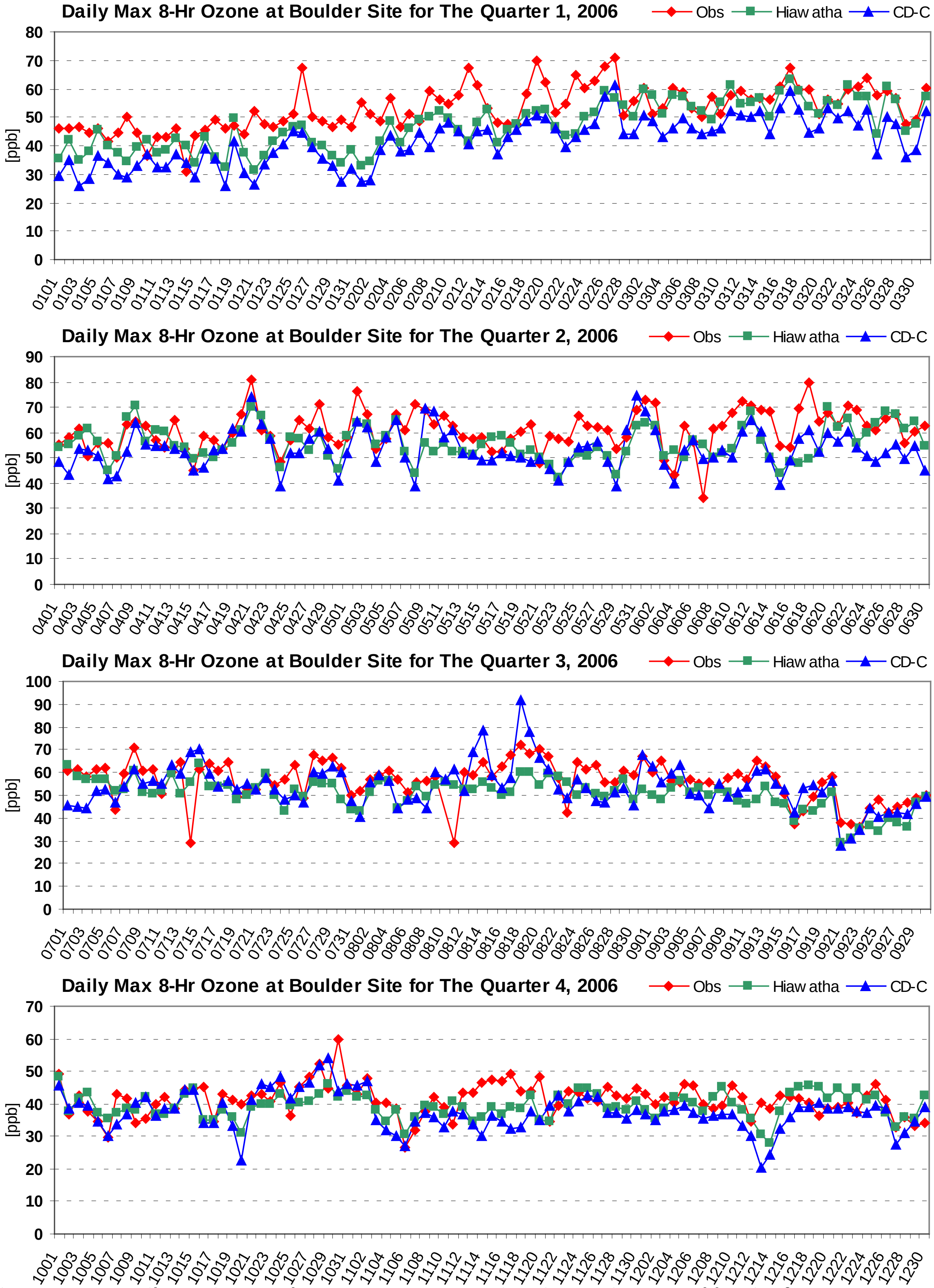


Figure A4-4a. Daily maximum 8-hour ozone concentration time series at Boulder site for 2006.

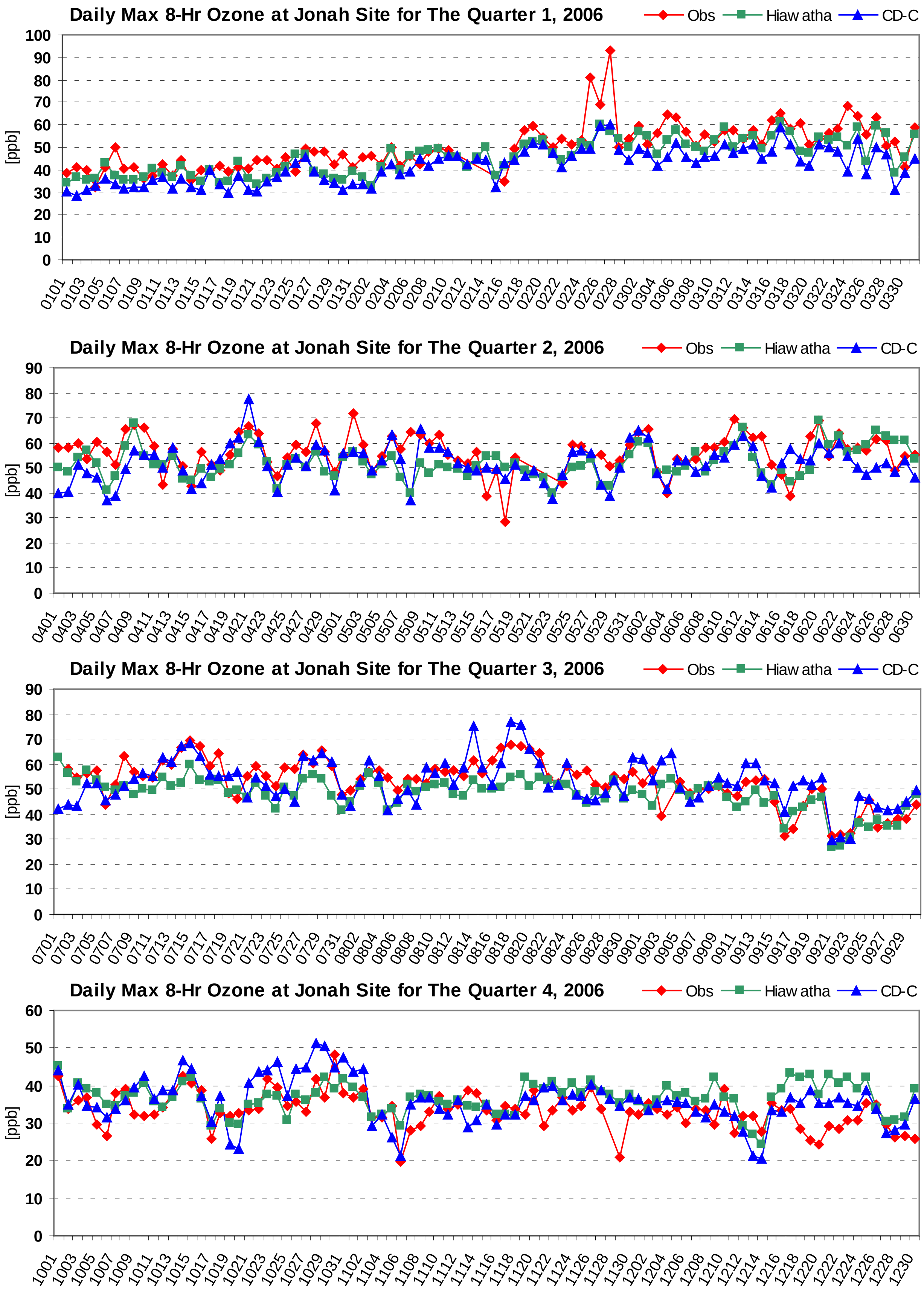


Figure A4-4b. Daily maximum 8-hour ozone concentration time series at Jonah site for 2006.

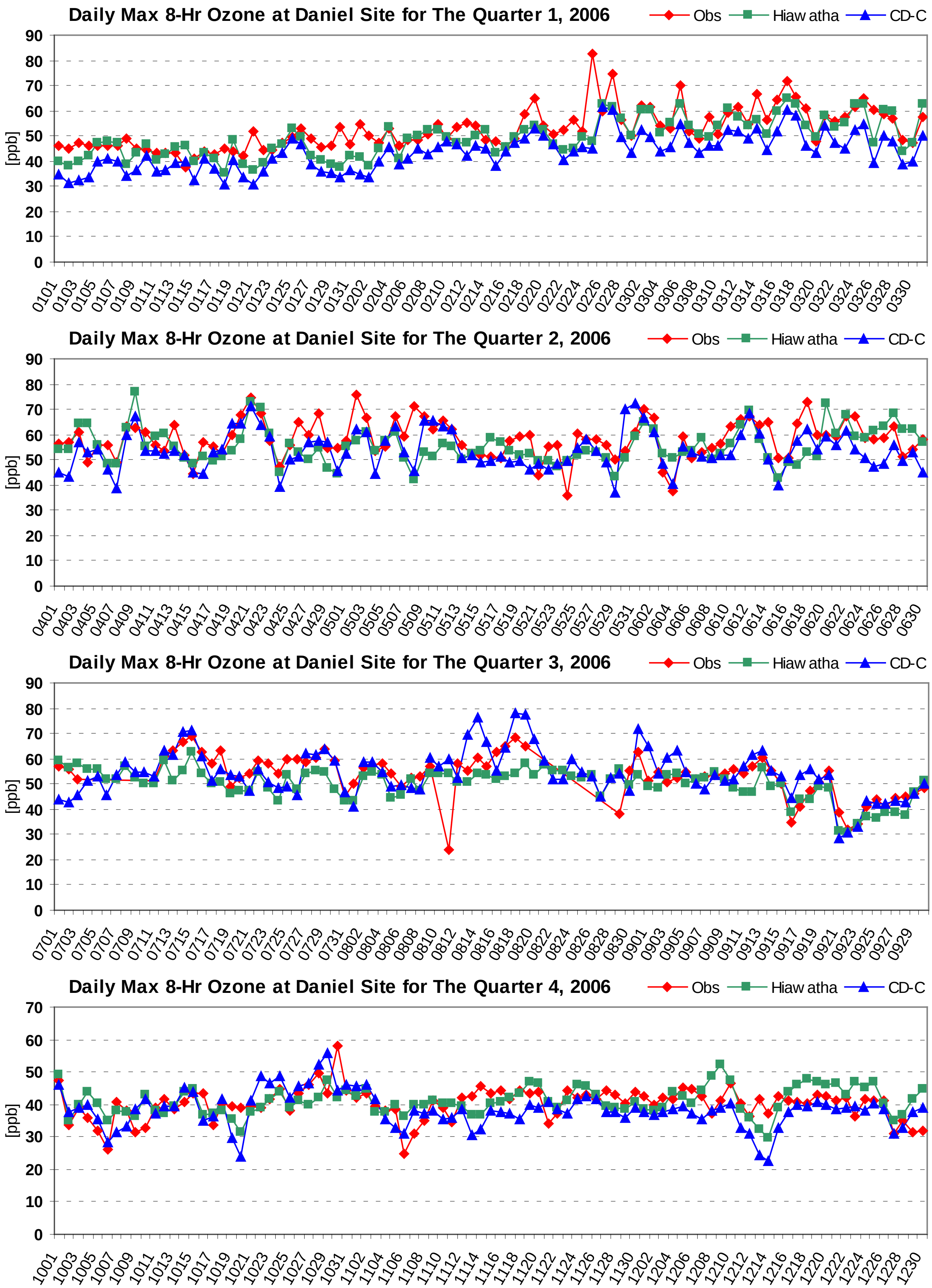


Figure A4-4c. Daily maximum 8-hour ozone concentration time series at Daniel site for 2006.

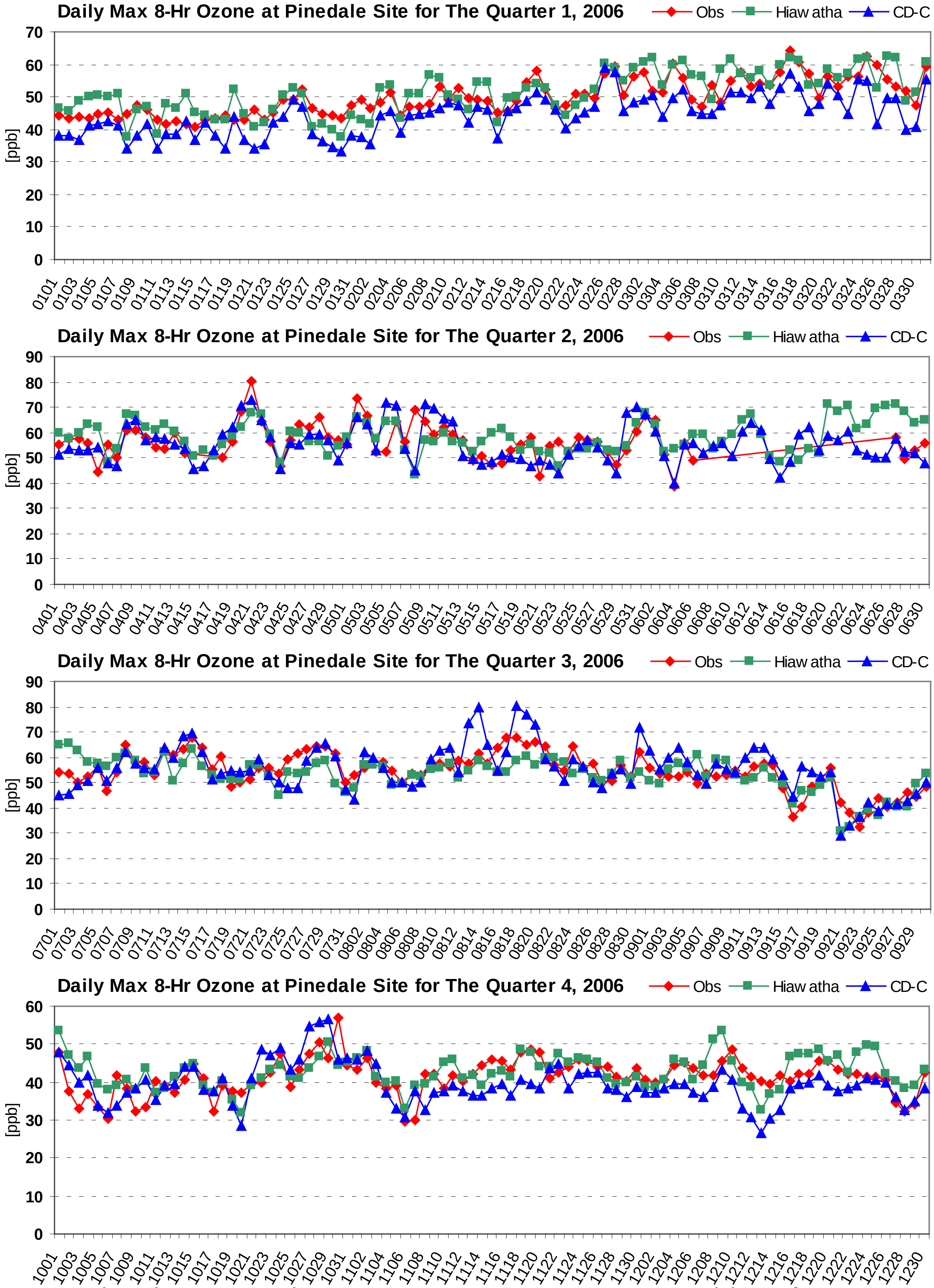


Figure A4-4d. Daily maximum 8-hour ozone concentration time series at Pinedale site for 2006.

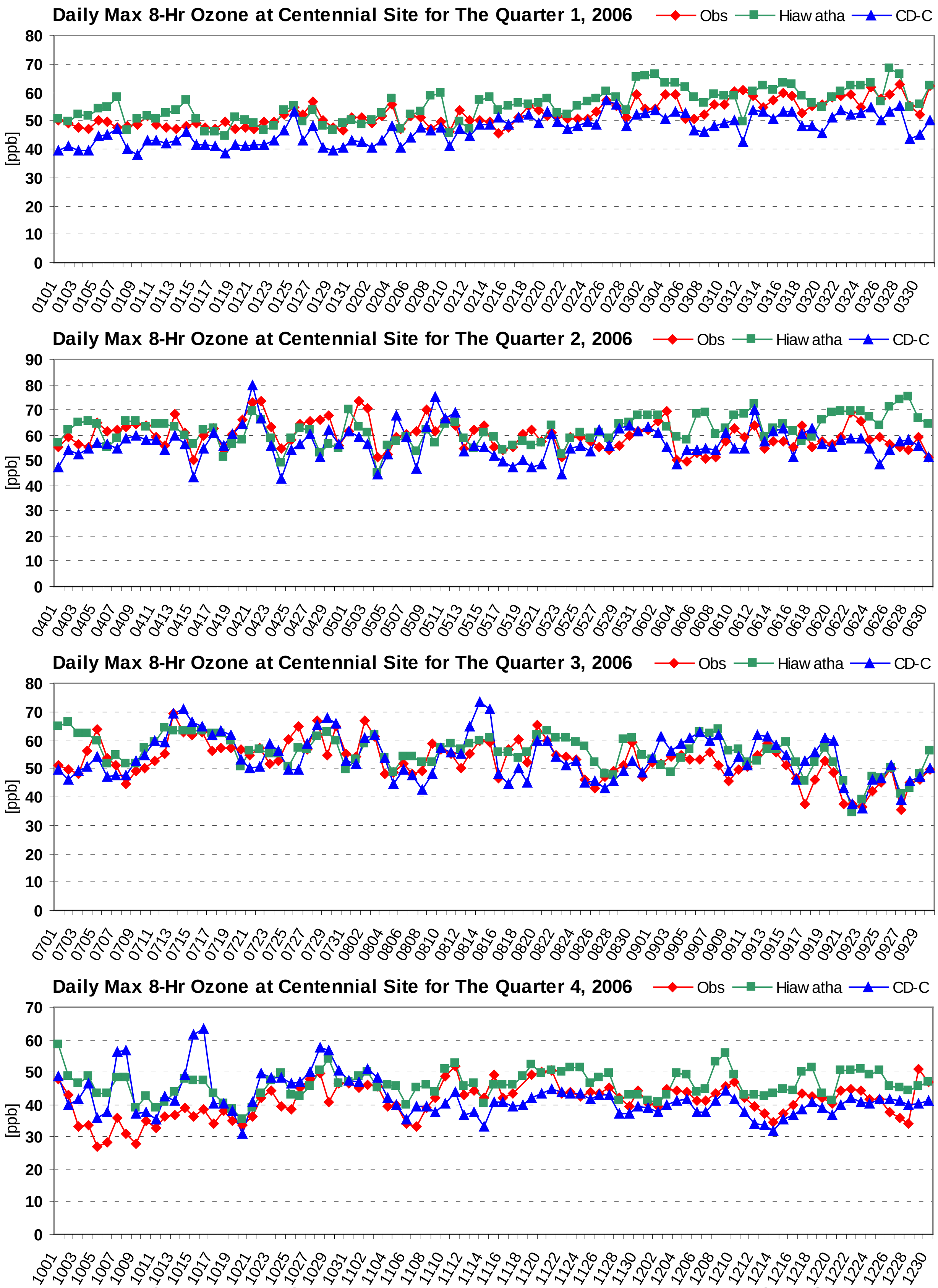


Figure A4-4e. Daily maximum 8-hour ozone concentration time series at Centennial site for 2006.

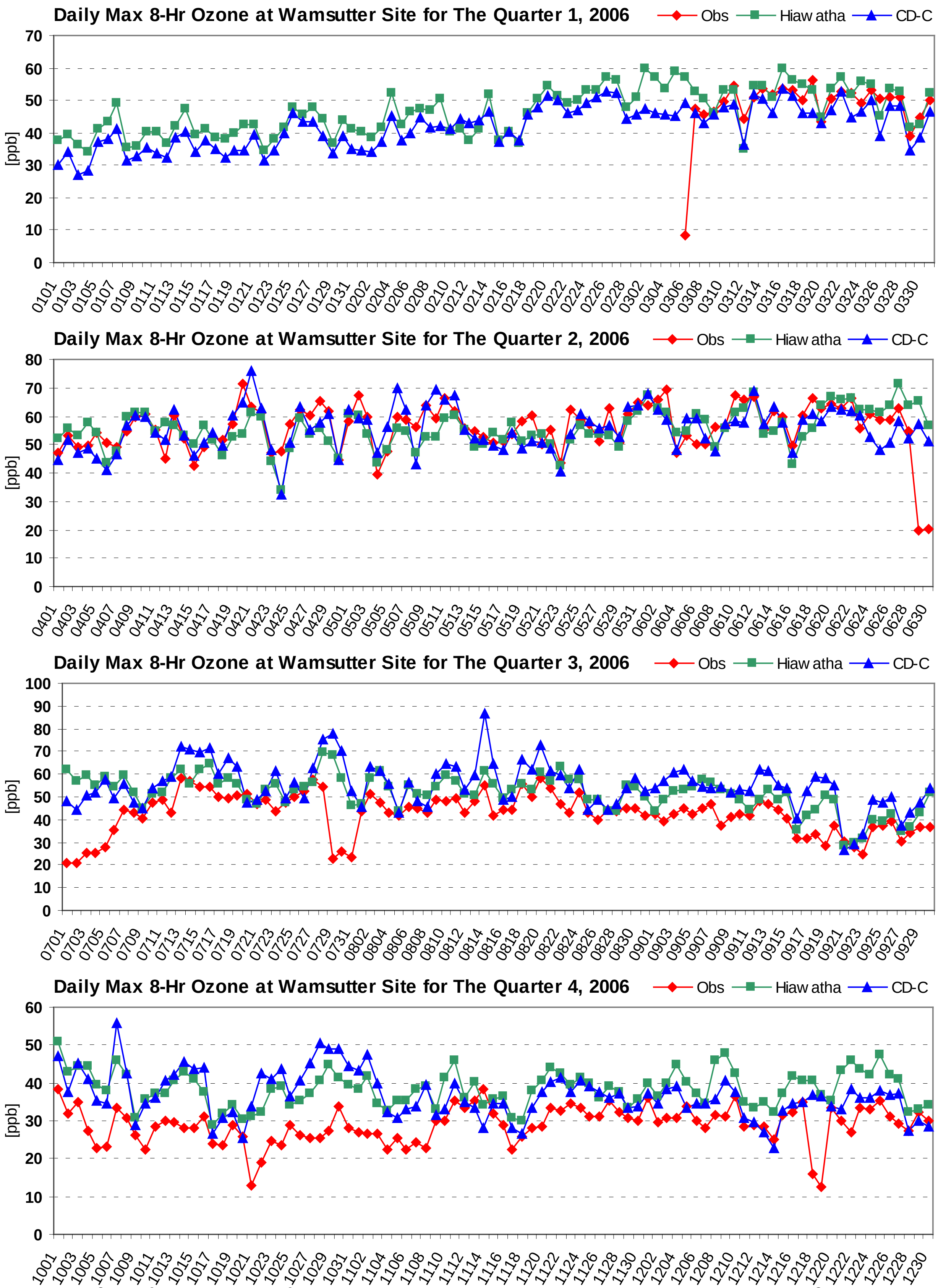


Figure A4-4f. Daily maximum 8-hour ozone concentration time series at Wamsutter site for 2006.

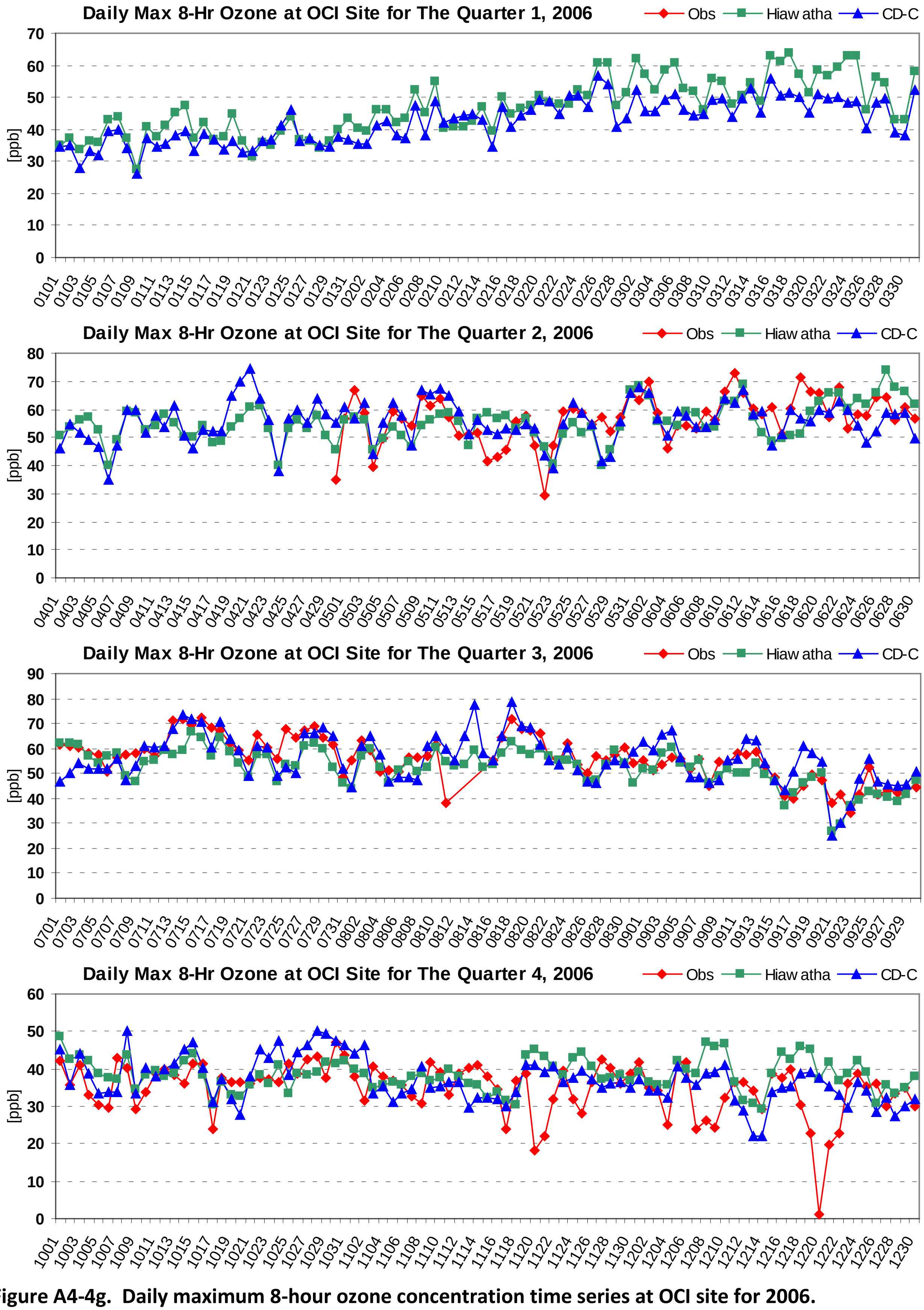


Figure A4-4g. Daily maximum 8-hour ozone concentration time series at OCI site for 2006.

A4.5 DIURNAL HOURLY OZONE PERFORMANCE DURING APRIL-OCTOBER 2005 AND 2006 HIGH OZONE EVENTS

WDEQ-AQD has identified high ozone days that occurred in southwestern Wyoming during April-October of 2005 and 2006. Design values at the Wyoming monitors used in projecting future year ozone are determined by the ozone values on base year high ozone days, so good model performance on these days is critical for confidence in future year projections. In this section, we evaluate the CAMx model performance on high ozone days during 2005-2006. Figures A4-5 through 5-12 display hourly ozone time series for all available monitors in the 4 km grid during each high ozone event identified by the WDEQ-AQD. The time series begin one day before the first day with an 8-hour daily maximum ozone value greater than 70 ppb and end one day after the last episode day with 8-hour daily max ozone greater than 70 ppb. The hourly time series plots include the observed values (red) and predicted values for the CD-C (blue) and Hiawatha (green) base cases as well as a grey area that represents the maximum and minimum predicted value in a 7 x 7 array of grid cells centered on the monitor for the CD-C base case simulation.

June 26-28, 2005

The ozone time series for the June 26-28 episode are shown in Figure A4-5. As noted in the quarterly time series, the diurnal cycle has greater amplitude at Jonah and Boulder than at Pinedale and Centennial, likely due to the presence of local emissions sources. The two base case simulations perform well at Pinedale, although it does not replicate the hourly ozone spikes on June 28, which are likely measurement artifacts since they are not supported by observed hourly ozone concentrations on either side of the spike. At Centennial, the Hiawatha base case simulation generally overestimates ozone during the June 26-28 period, with the CD-C base case showing good agreement with the hourly ozone observations on June 28, but underestimates on June 27 (Figure A4-5b, top). At the Jonah and Boulder monitoring sites, the CD-C base case is reproducing the observed hourly ozone concentrations much better than Hiawatha base case with hourly ozone concentrations in the afternoon that are 10-20 ppb higher and close to the observed values.

July 7-9, 2005

On July 7-9, 2005, The CD-C base case is simulating higher afternoon ozone concentrations that match the observed values at the Jonah monitoring site much better than the Hiawatha base case simulation (Figure A4-6a, top). Note that the Boulder monitor observations are missing during the periods of peak ozone in the afternoon for this episode (Figure A4-6a, bottom). The two model simulations underestimate the observed ozone variability at Daniel, with the Hiawatha base case undershooting the observed ozone peaks and the CD-C base case matching the observed ozone maximum much better (Figure A4-6c). Both base cases overestimate the observed ozone at Centennial during July 7-9, 2005 with CD-C matching the observed values slightly better at Pinedale, except during a few observed 1-hour long ozone spikes which may be measurement artifacts.

April 20-22, 2006

Both models fail to capture the observed ~100 ppb hourly ozone peak at Boulder on April 21, 2006 that occurs early in the day, although the CD-C matches the observed high ozone at Jonah (~80 ppb) later in the day (Figure A4-7a). Looking at the Pinedale hourly ozone traces (Figure 5-8b) we see that although the maximum CD-C base case predicted ozone at the monitoring on April 21 (~75 ppb) is below the observed value (~90 ppb), there are CD-C base case predictions within the 7x7 array of 4 km grid cells that match the observed value quite well suggesting that the CD-C base case is predicting the right magnitude of ozone, but there is a spatial displacement. This is important since in EPA's 8-hour ozone Design Value projection procedures the maximum predicted ozone concentration in a 7x7 array of 4 km grid cells is used in developing the Relative Response Factors (RRFs).

May 1-9, 2006

The two base case simulations tend to underestimate the observed ozone peaks on May 2 and 8, but simulate the observed ozone reasonably well in between (Figure A4-8). At Wamsutter, both base case simulations underestimate the observed ozone peak on May 2 by ~10 ppb then match the observed ozone very well until the CD-C base case overestimates the observed afternoon ozone on May 7, during which time the Hiawatha base case simulates the observed values well (Figure A4-8c, bottom). Both models underestimate the observed ozone at Wamsutter on May 8, but by May 9, the CD-C base case matches the observed ozone well, whereas Hiawatha base case underestimates it. Both models simulate the observed hourly ozone concentrations well at OCI (Figure A4-8d).

May 30-June 3, 2006

During the May 30-June 3 episode, the two base case simulations produce an excellent simulation of the observed ozone time series at OCI (Figure A4-9d). The two base case simulations have a high bias at the Pinedale CASTNet site, with the overestimation bias also seen at the Centennial CASTNet site for the Hiawatha base case, whereas the CD-C base case matches the observed ozone at Centennial well (Figure A4-9b). At the Jonah, Boulder, Daniel, and Wamsutter monitors (Figure A4-9a and 5-9c, top), the CD-C base case simulates the observed afternoon ozone concentrations better than the Hiawatha base case that has an underestimation bias, but night time minima are not accurately reproduced by either base case simulation.

June 10-19, 2006

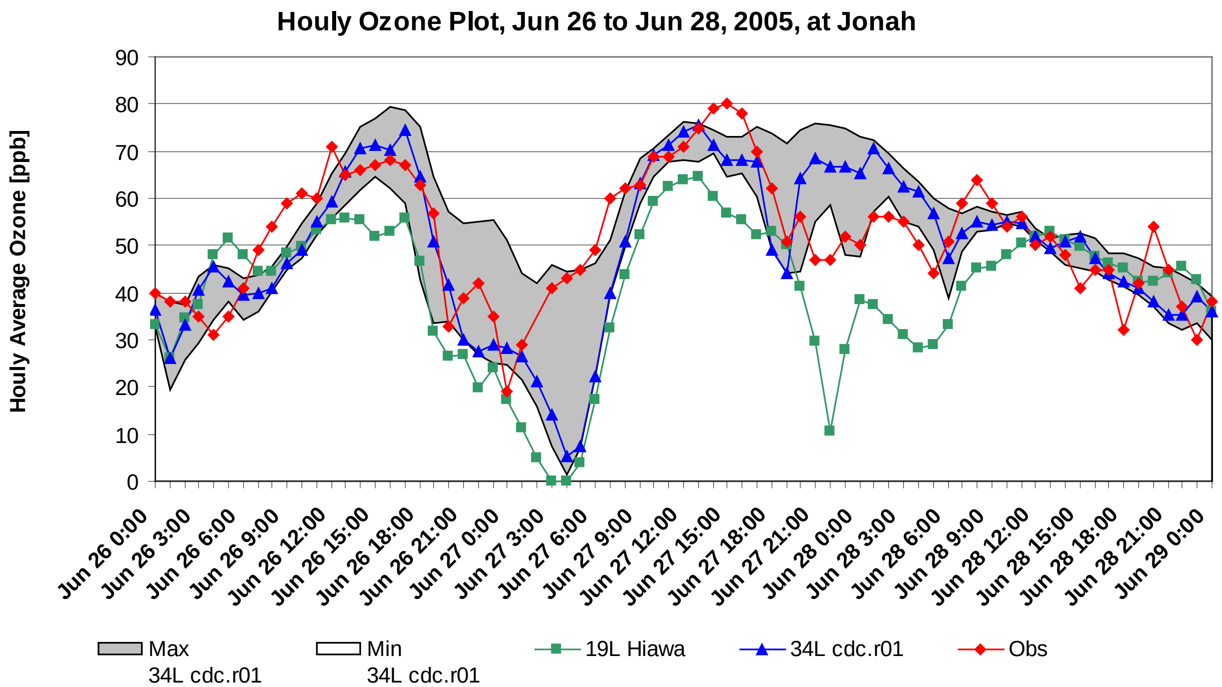
The two base case simulations have a tendency to underestimate the observed ozone peaks for all monitors except Centennial during June 10-19, 2006 (Figure A4-10). This suggests that the regional background ozone is well simulated but that the underprediction of peak ozone may be due insufficient ozone formation from local sources of emissions. The CD-C base case generally simulates slightly higher afternoon ozone concentrations, and therefore matches the observed values better than the Hiawatha base case simulation.

July 7-17, 2006

At Wamsutter, the two model simulations overestimate observed peak ozone values throughout most of the July 7-17 period, and predict nighttime minima that are ~30 ppb too high (Figure 5-11c, bottom). This is especially true for the CD-C base case simulation on July 13-15, 2006 that predicts afternoon ozone maximum that are 10-20 ppb higher than observed. At Jonah, on the other hand, the CD-C base case matches the observed afternoon high and nighttime low ozone concentrations well, whereas the Hiawatha base case afternoon ozone concentrations are much too low and the nighttime values drop to zero (Figure A4-11a, top). Similar results are seen at Boulder (Figure A4-11a, bottom) and Daniel (Figure A4-11c, top) with the CD-C base case matching the observed high ozone much better than the Hiawatha base case simulation.

August 17-19, 2006

For this episode, the Hiawatha base case underestimates the observed ozone peaks at the three Sublette County industrial ozone monitors (Figure A4-12). The CD-C base case, on the other hand, reproduces the observed hourly ozone well on August 17 and 19 at these three sites, and overestimates on August 19. The Hiawatha base case underestimation bias is smallest at Wamsutter, where the CD-C base model exhibits an overestimation bias (Figure A4-12c, bottom). The performance of the two base case simulations at the Pinedale and Centennial CASTNet monitoring sites is quite different (Figure A4-12b). At the Pinedale site, the CD-C base case matches the observed ozone well during August 17-18 and overestimates on August 19, whereas the Hiawatha base case underestimates the entire episode. But at Centennial the Hiawatha base case overestimates On August 17 and 19 when the CD-C base case matches the observed ozone well and both models underestimate the observed ozone on August 18.



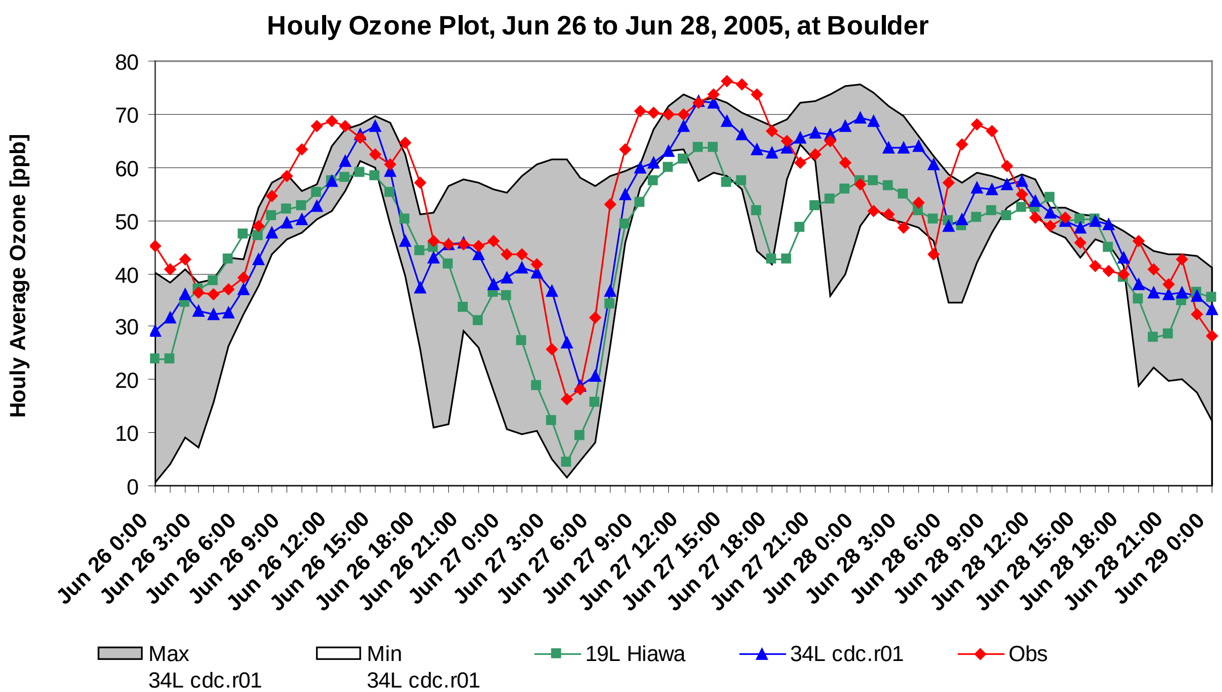
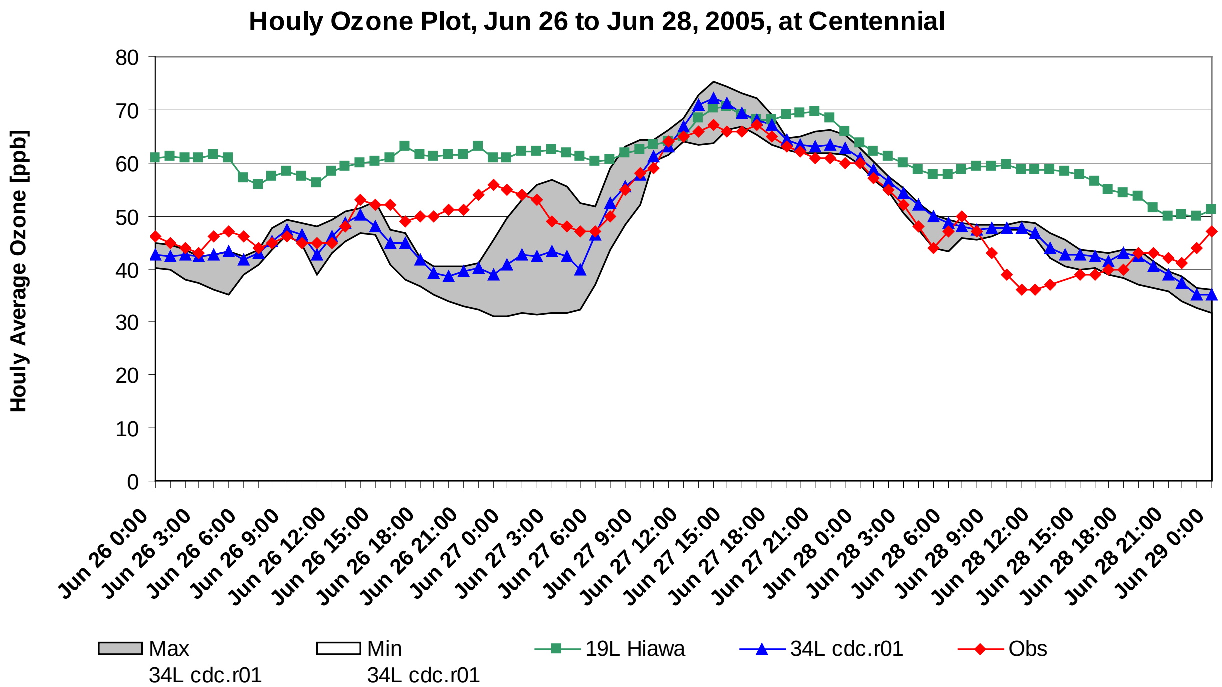


Figure A4-5a. 1-hour ozone time series for June 26-28, 2005.



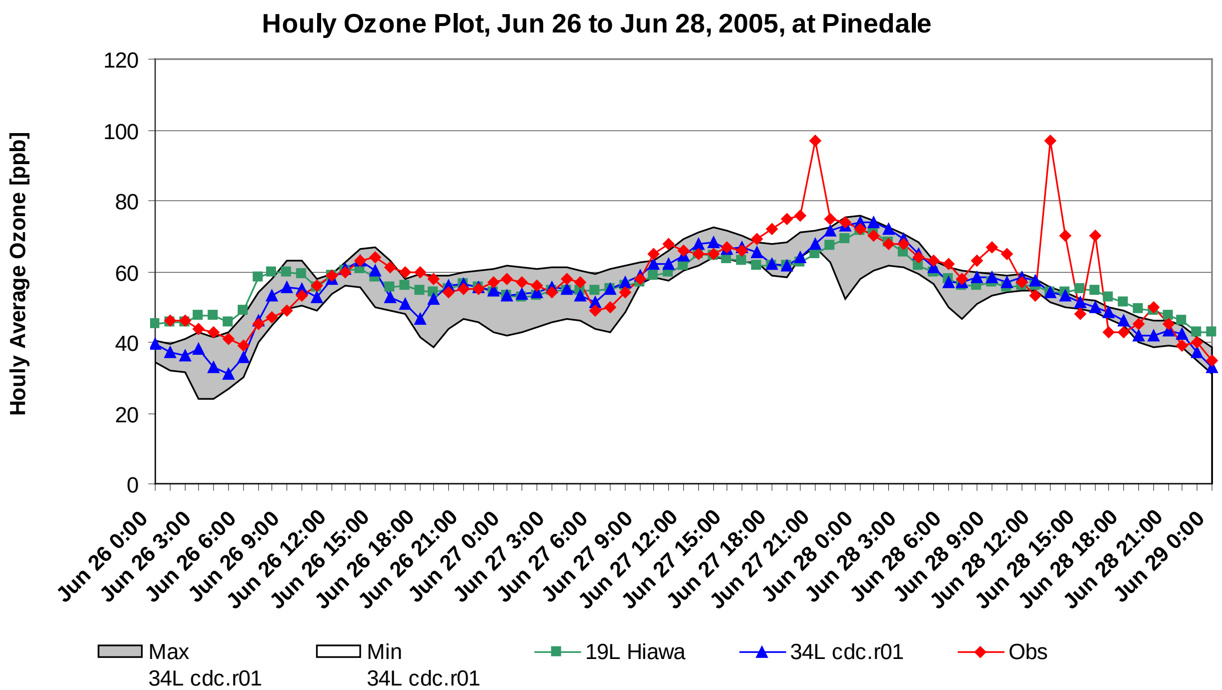
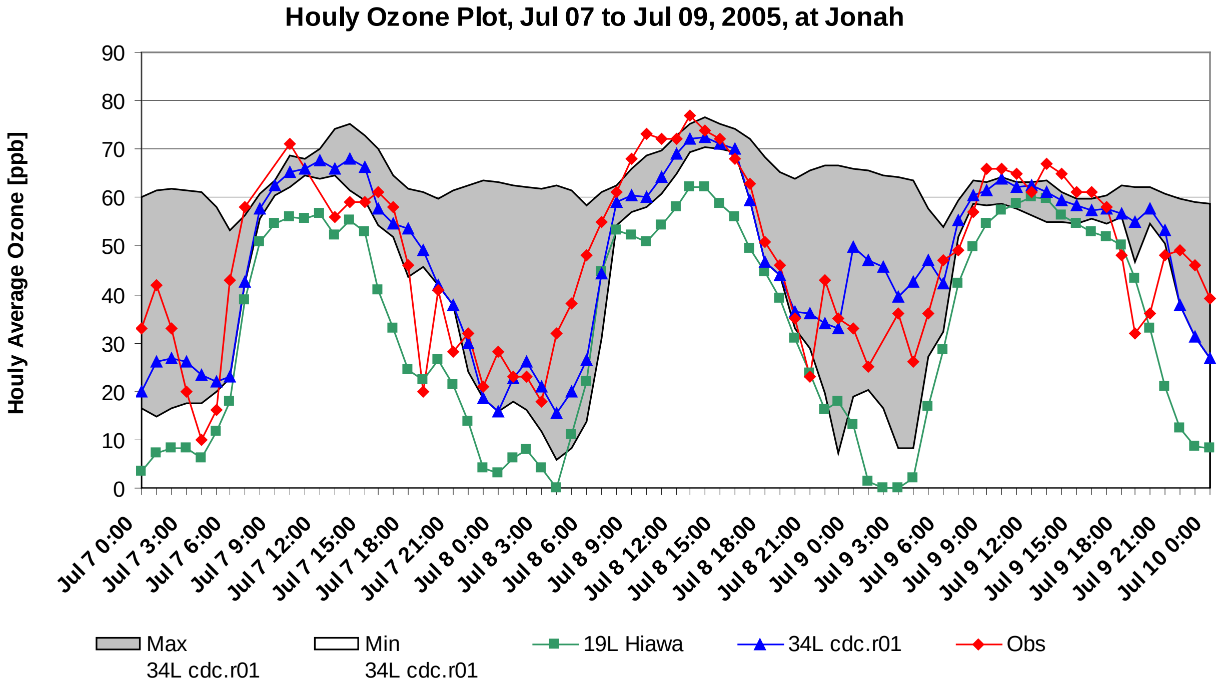


Figure A4-5b. 1-hour ozone time series for June 26-28, 2005.

APPENDIX A – MODEL PERFORMANCE EVALUATION OF THE CD-C CAMX 2005 AND 2006 BASE CASE SIMULATIONS



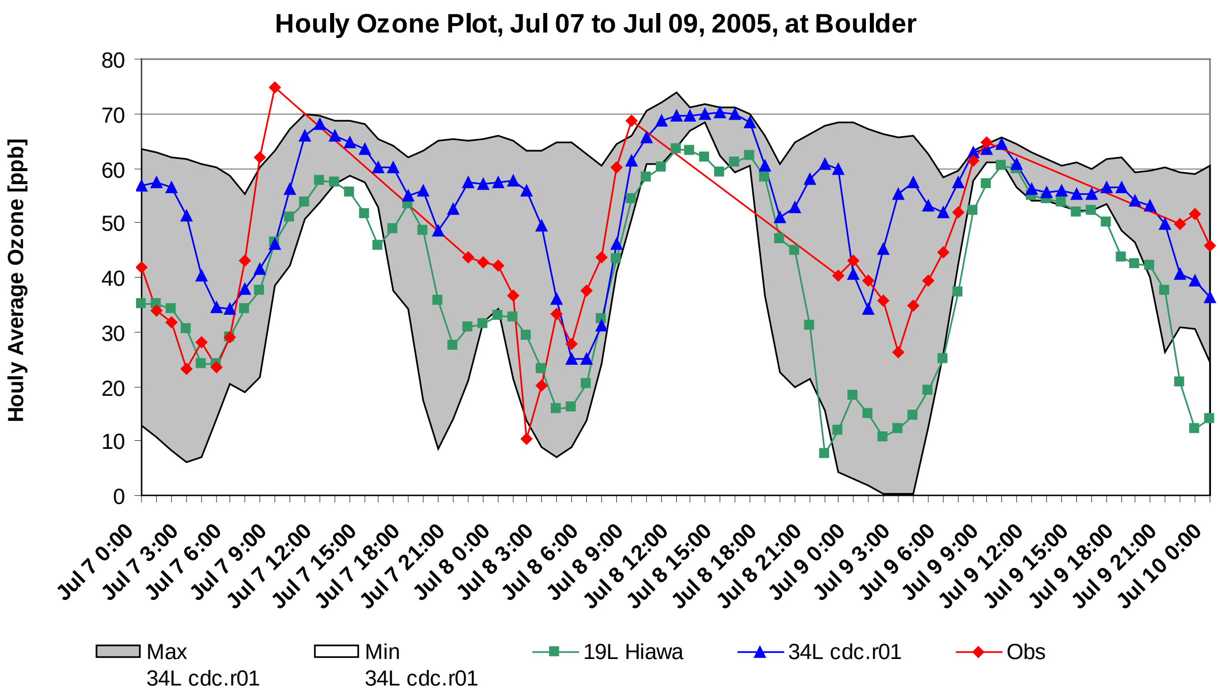
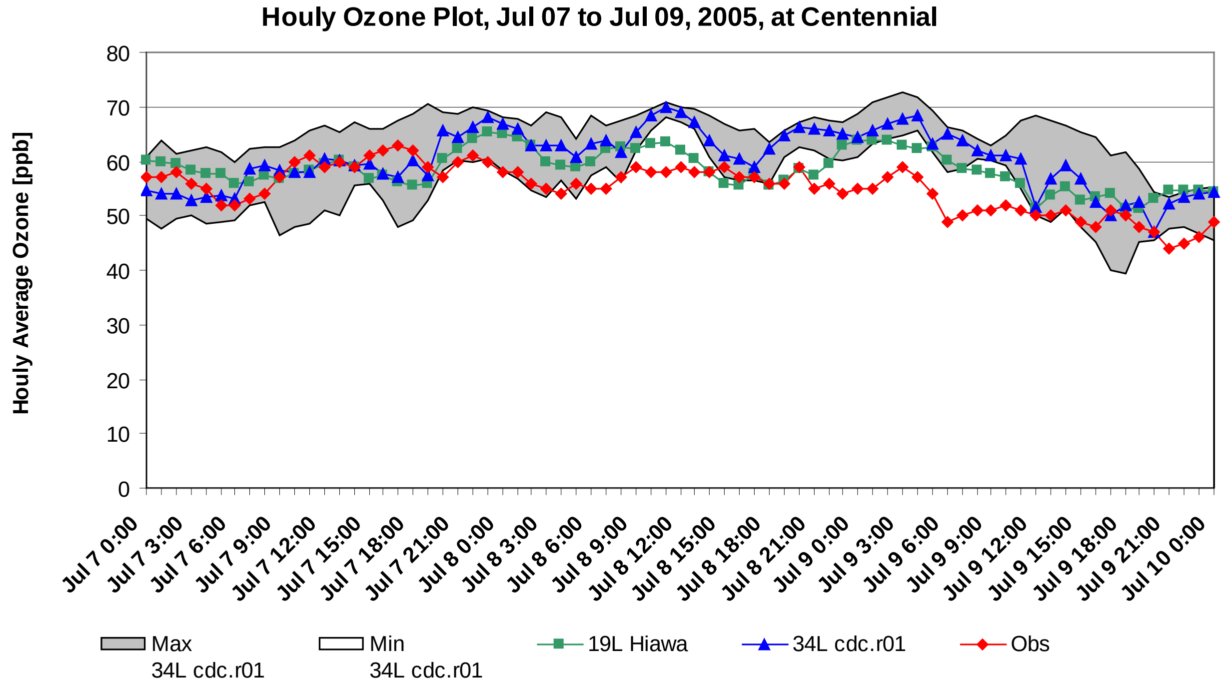


Figure A4-6a. 1-hour ozone time series for Jul7-9, 2005.



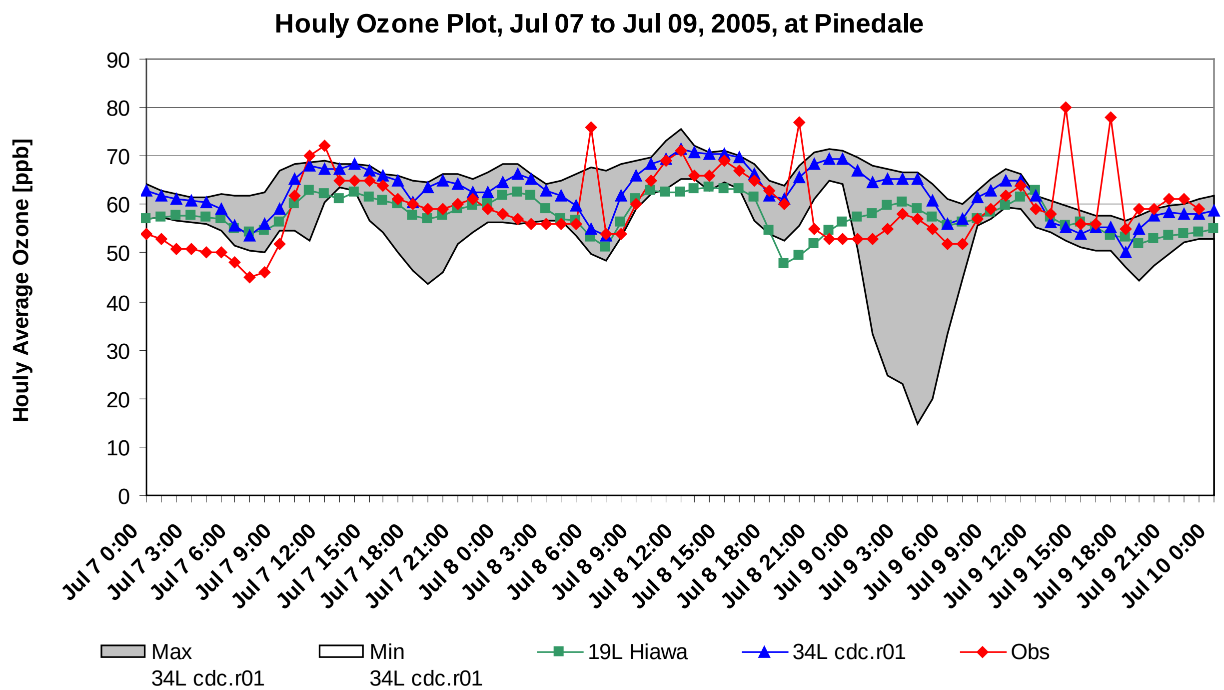


Figure A4-6b. 1-hour ozone time series for July7-9, 2005.

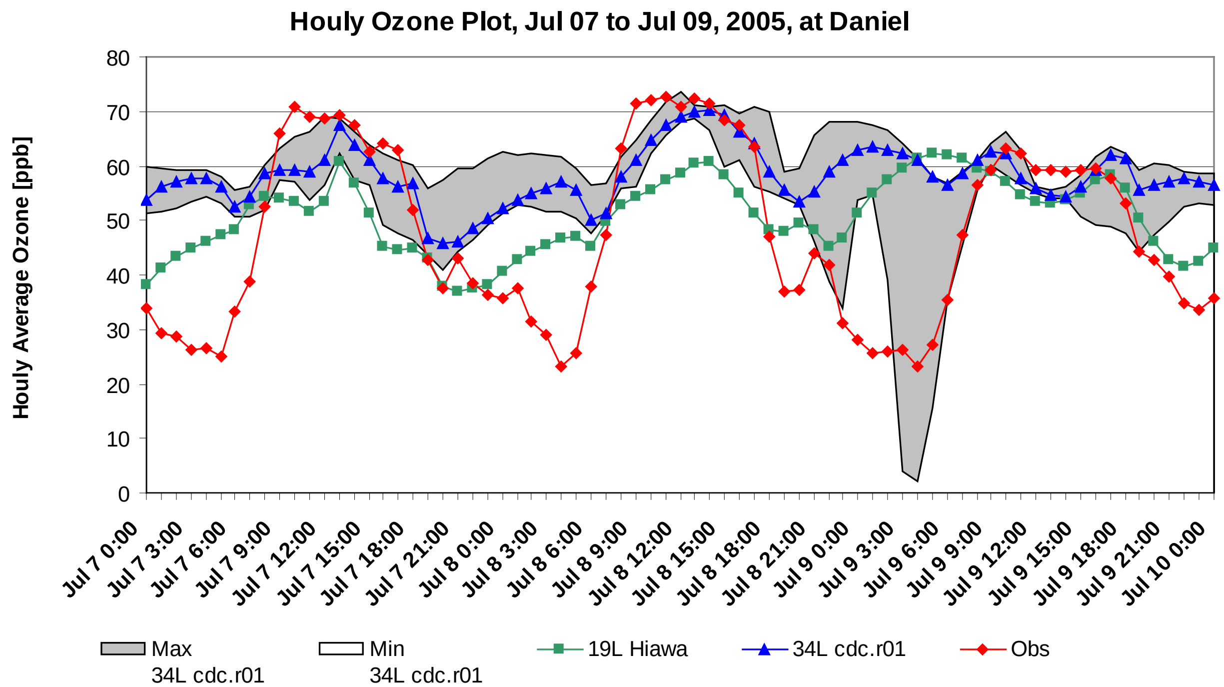
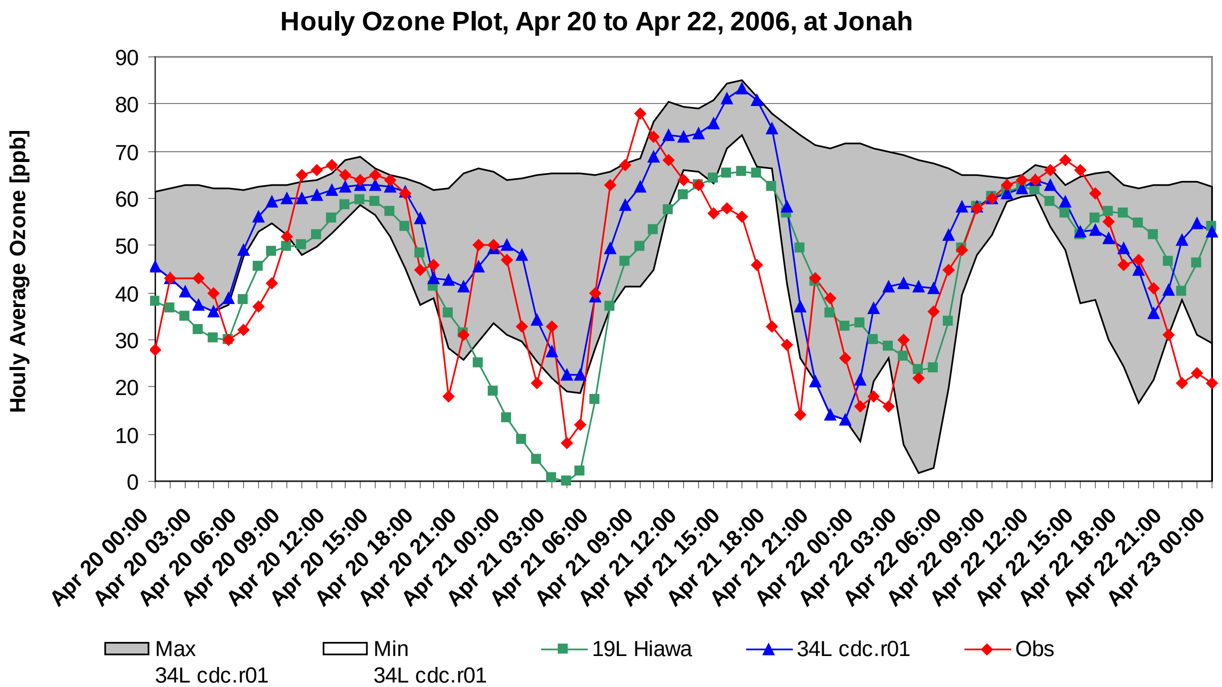


Figure A4-6c.1-hour ozone time series for July7-9, 2005.



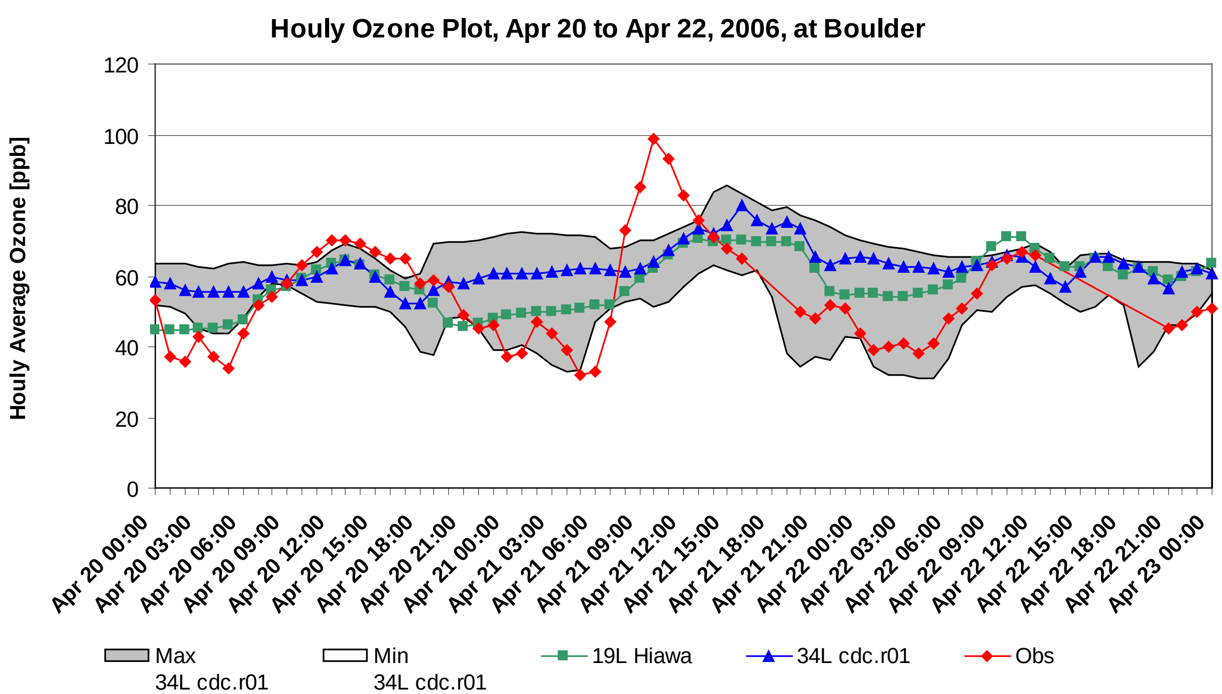
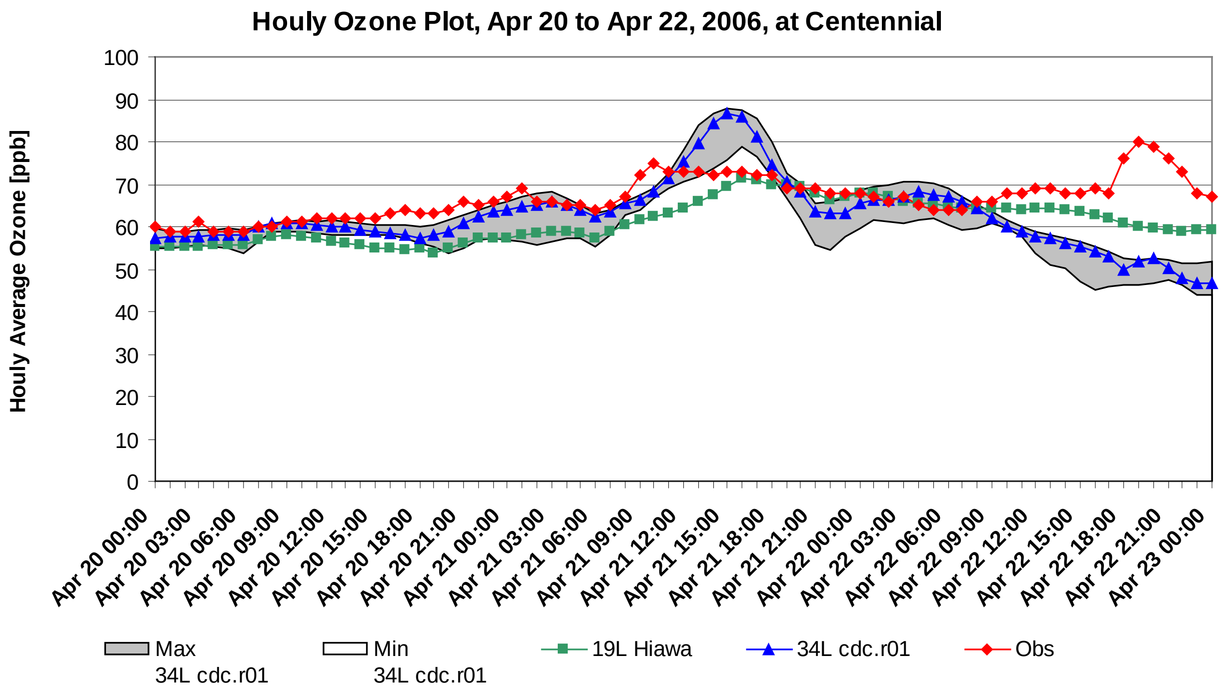


Figure A4-7a. 1-hour ozone time series for April20-22, 2006.



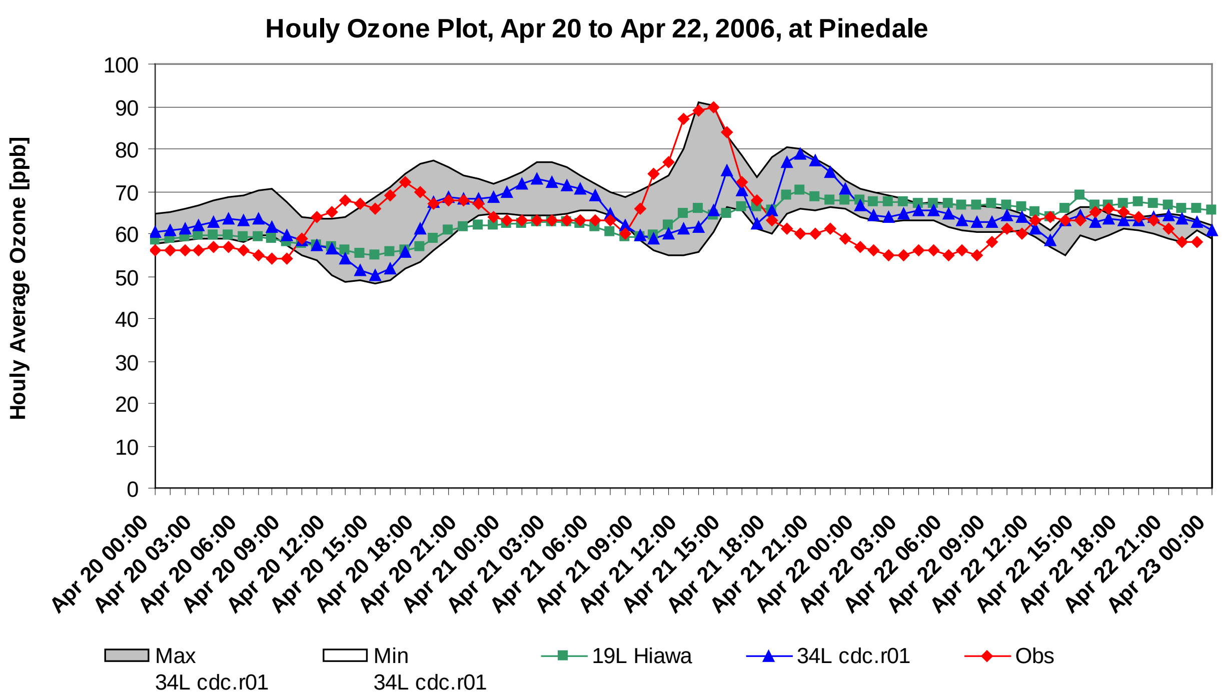
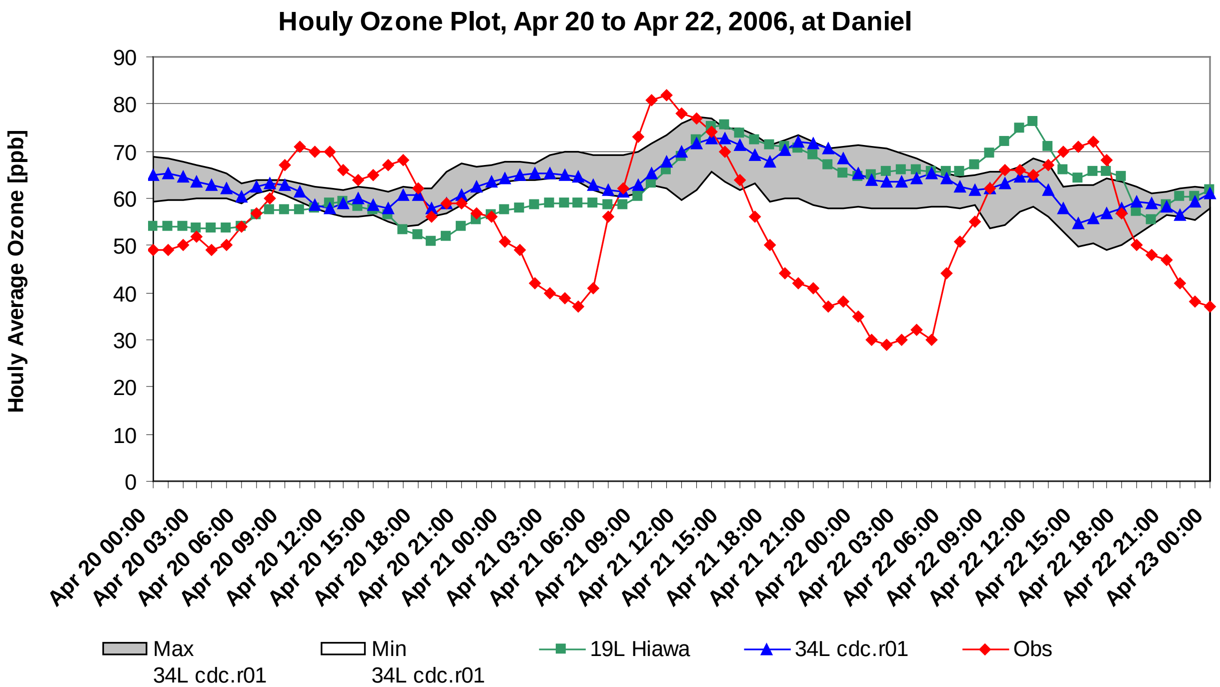


Figure A4-7b. 1-hour ozone time series for April20-22, 2006.



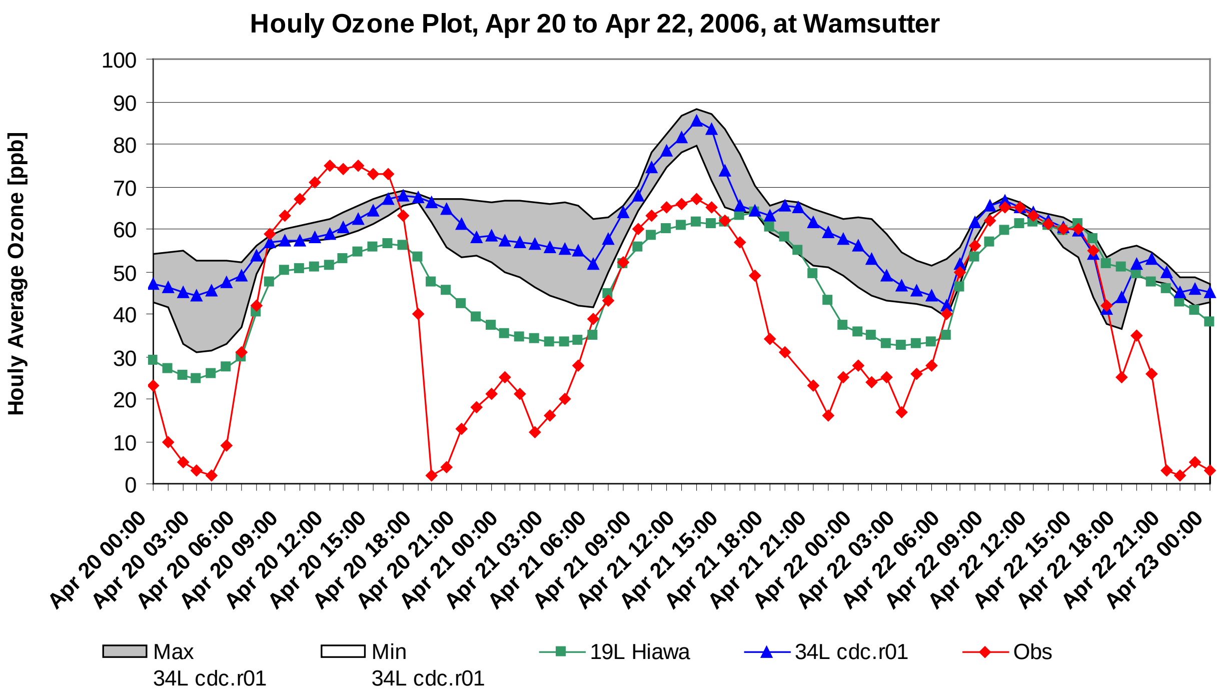
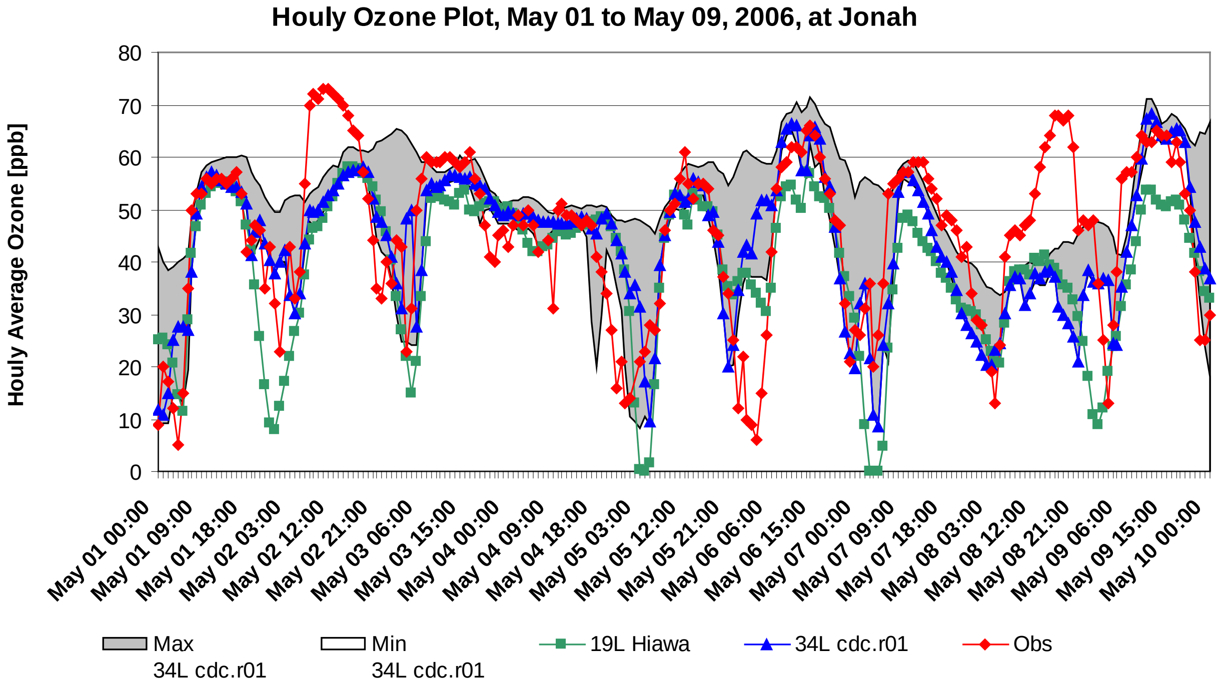


Figure A4-7c.1-hour ozone time series for April20-22, 2006.



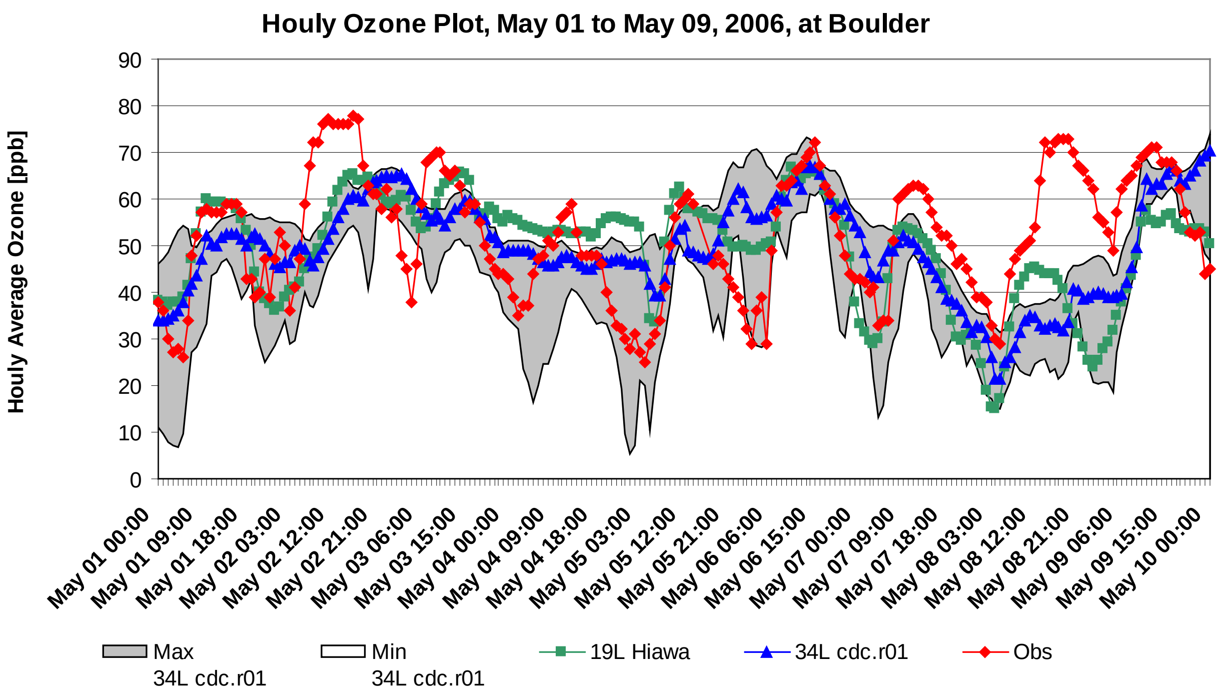
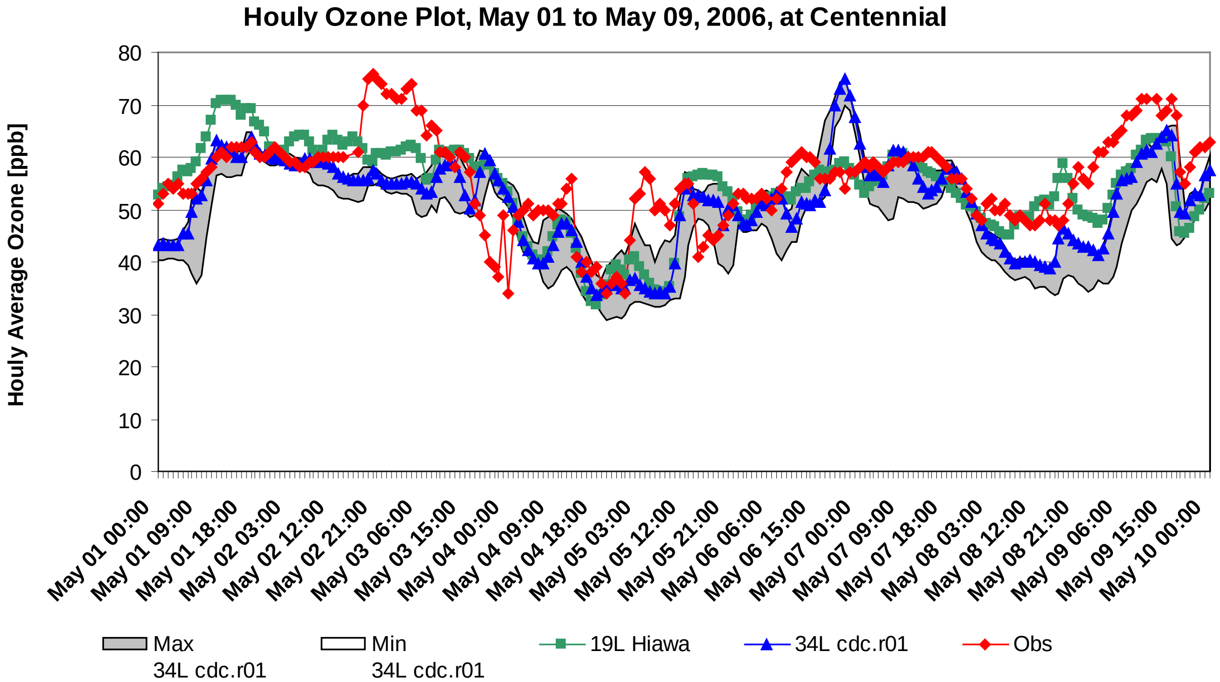


Figure A4-8a. 1-hour ozone time series for May 1-9, 2006.



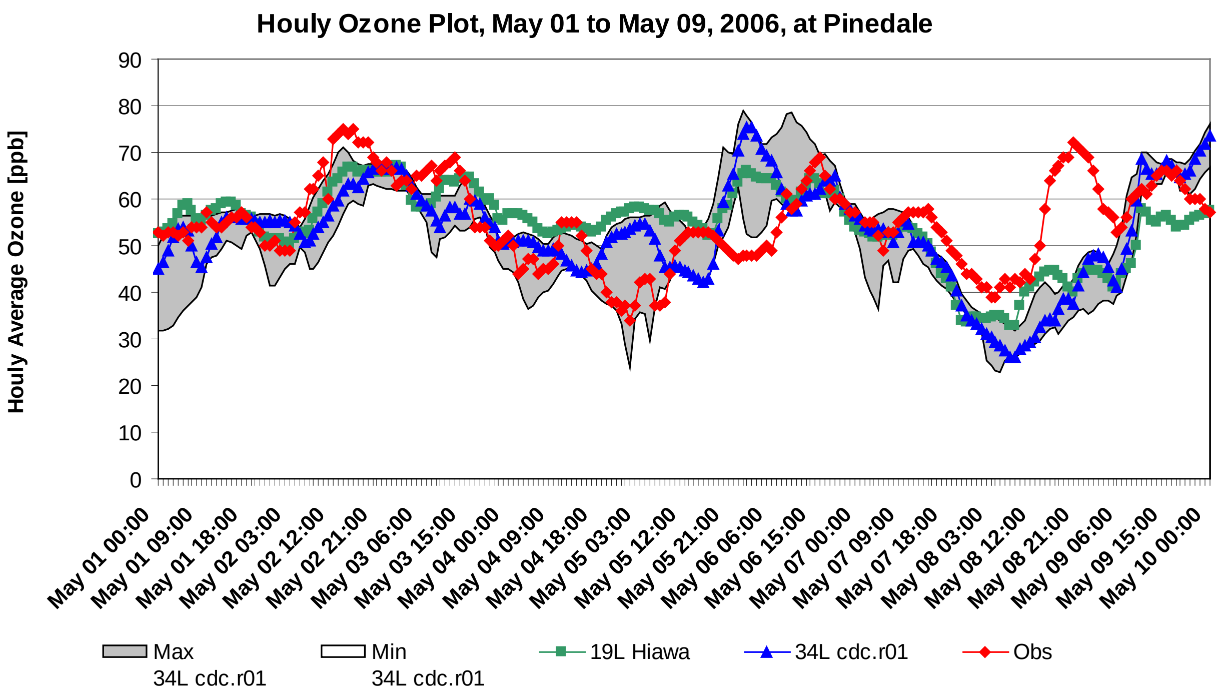
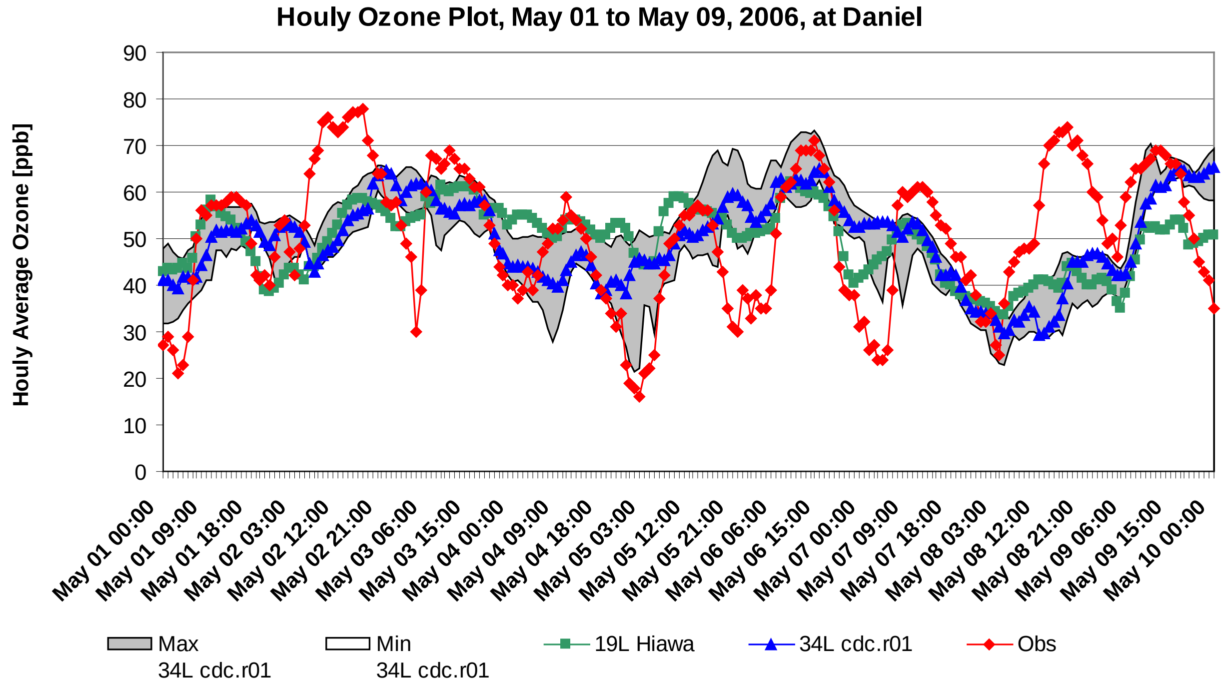


Figure A4-8b. 1-hour ozone time series for May 1-9, 2006.



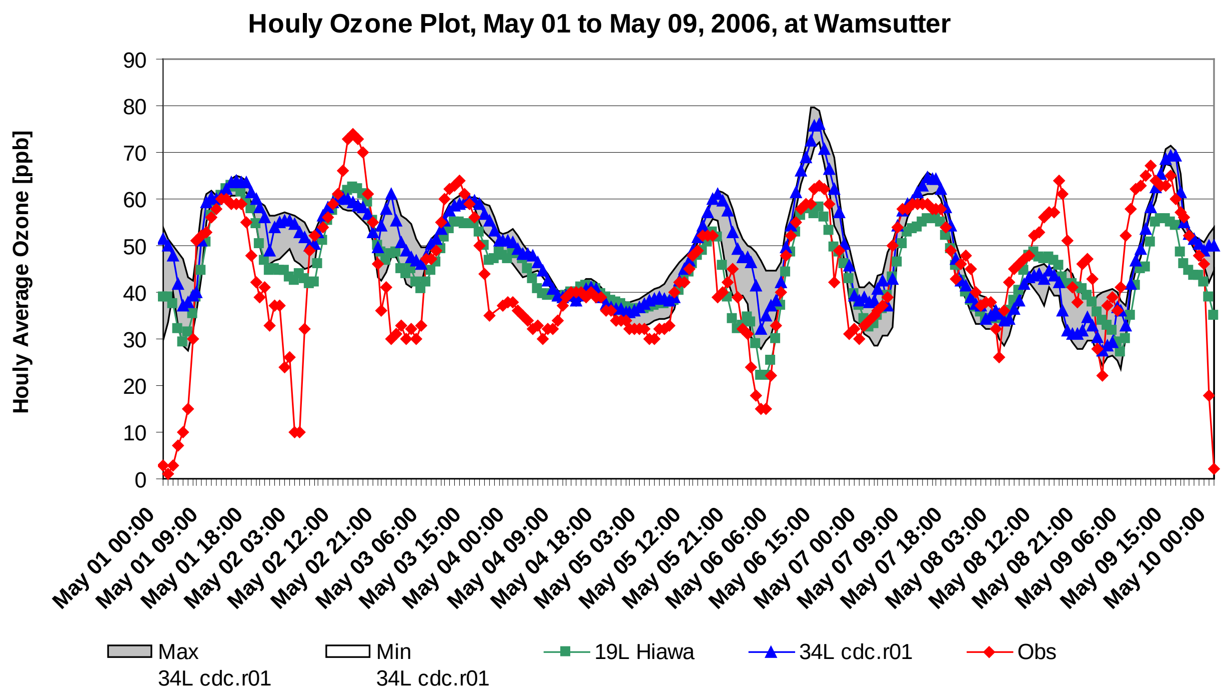


Figure A4-8c.1-hour ozone time series for May 1-9, 2006.

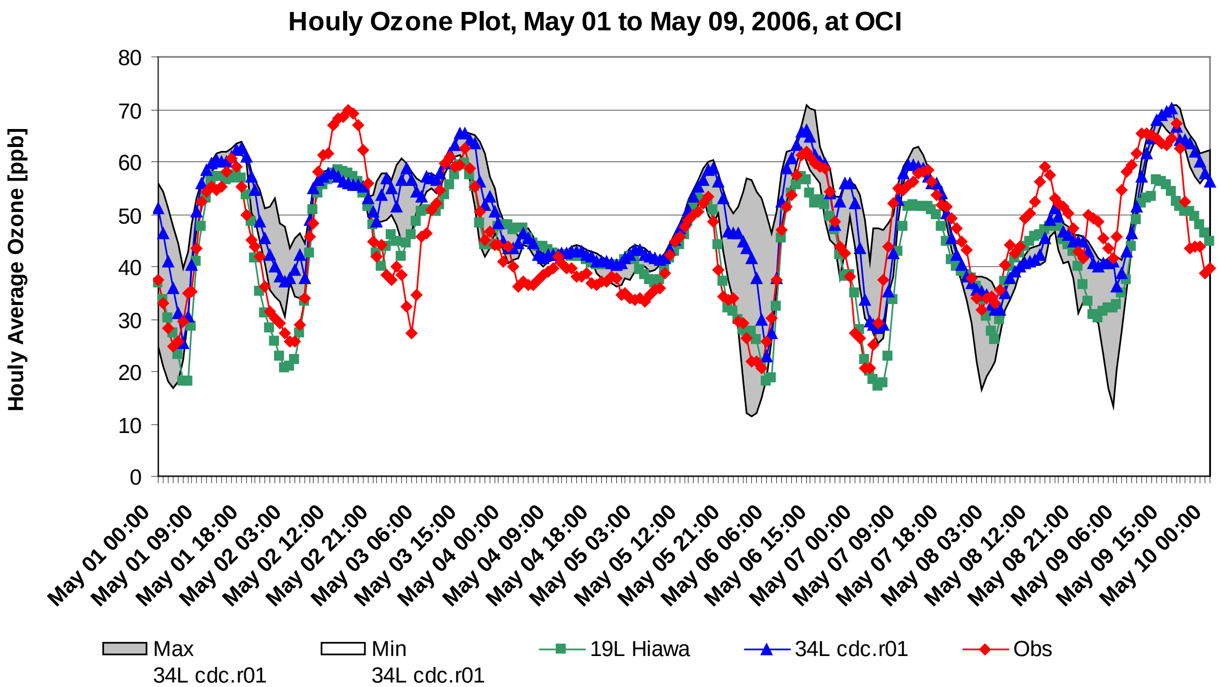
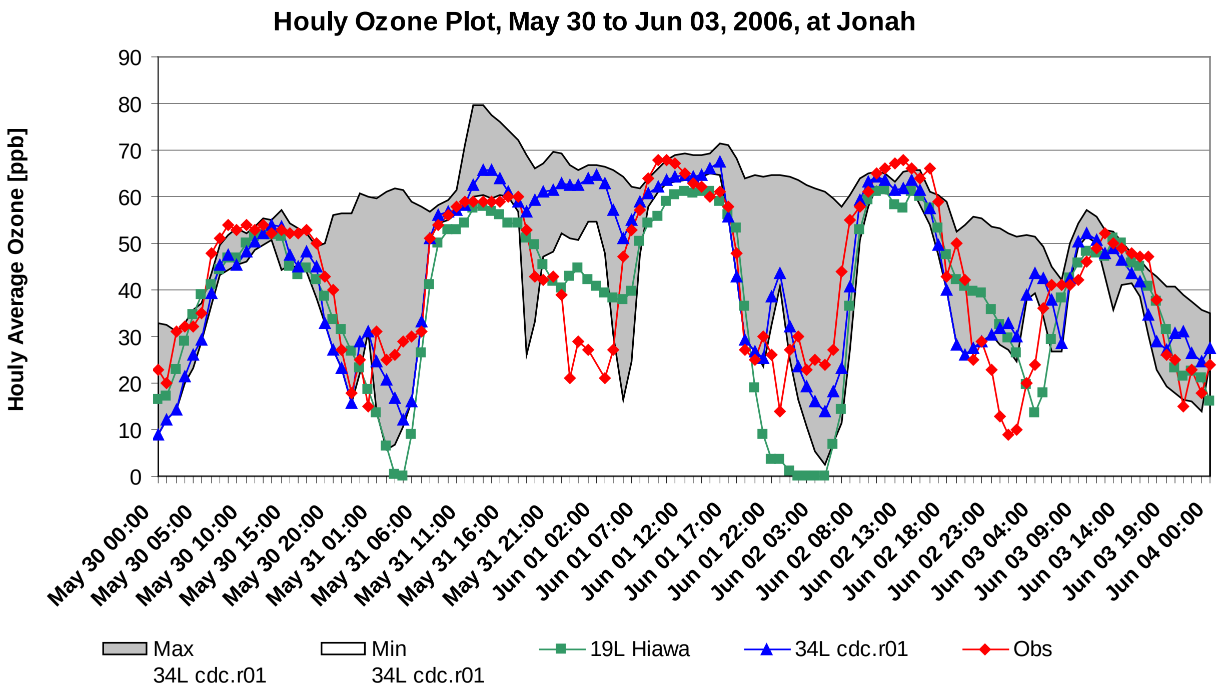


Figure A4-8d. 1-hour ozone time series for May 1-9, 2006.



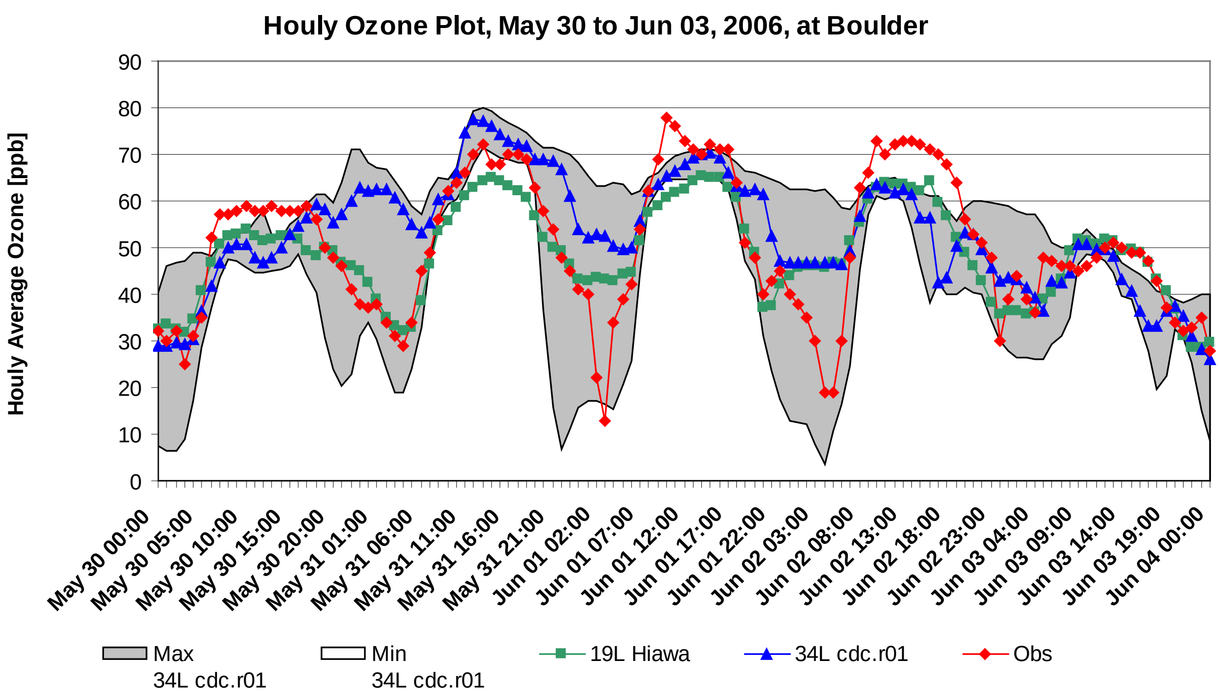
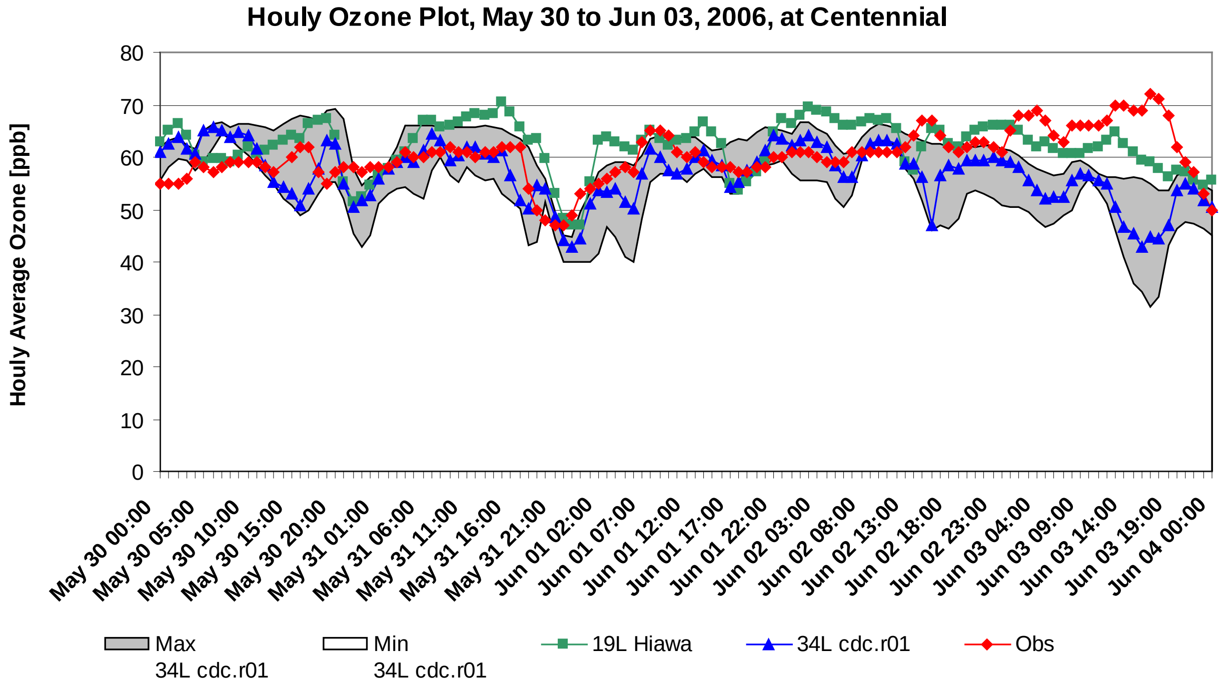


Figure A4-9a. 1-hour ozone time series for May 30-June 3, 2006.



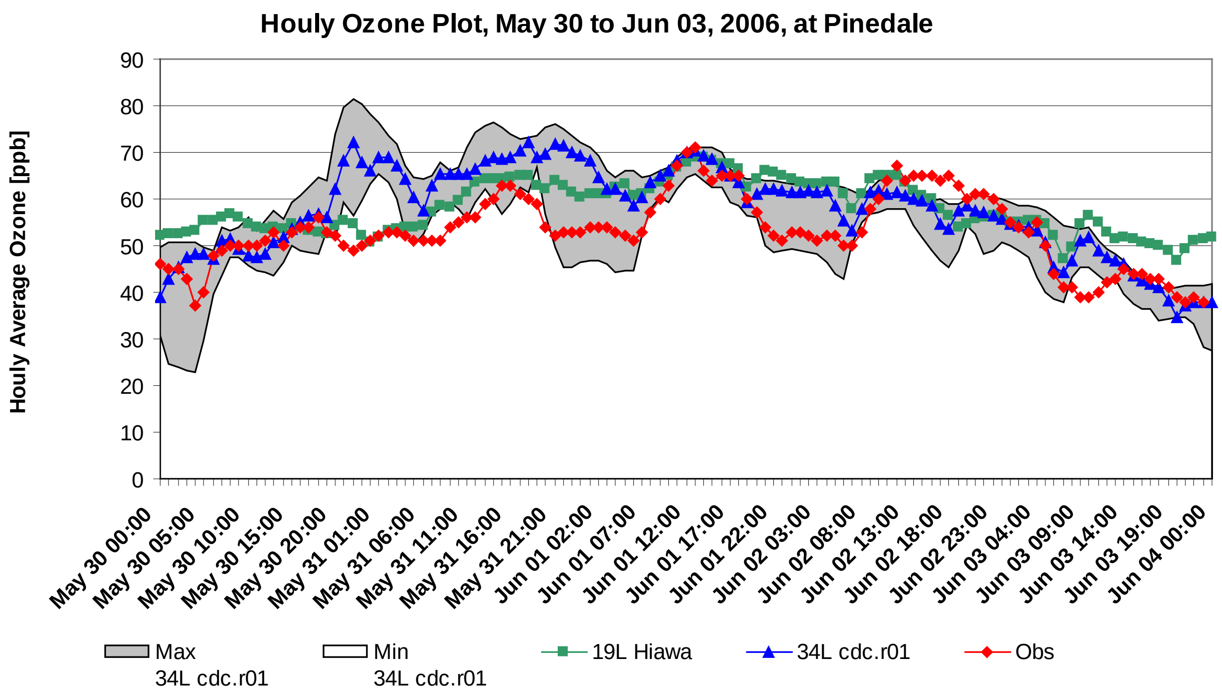
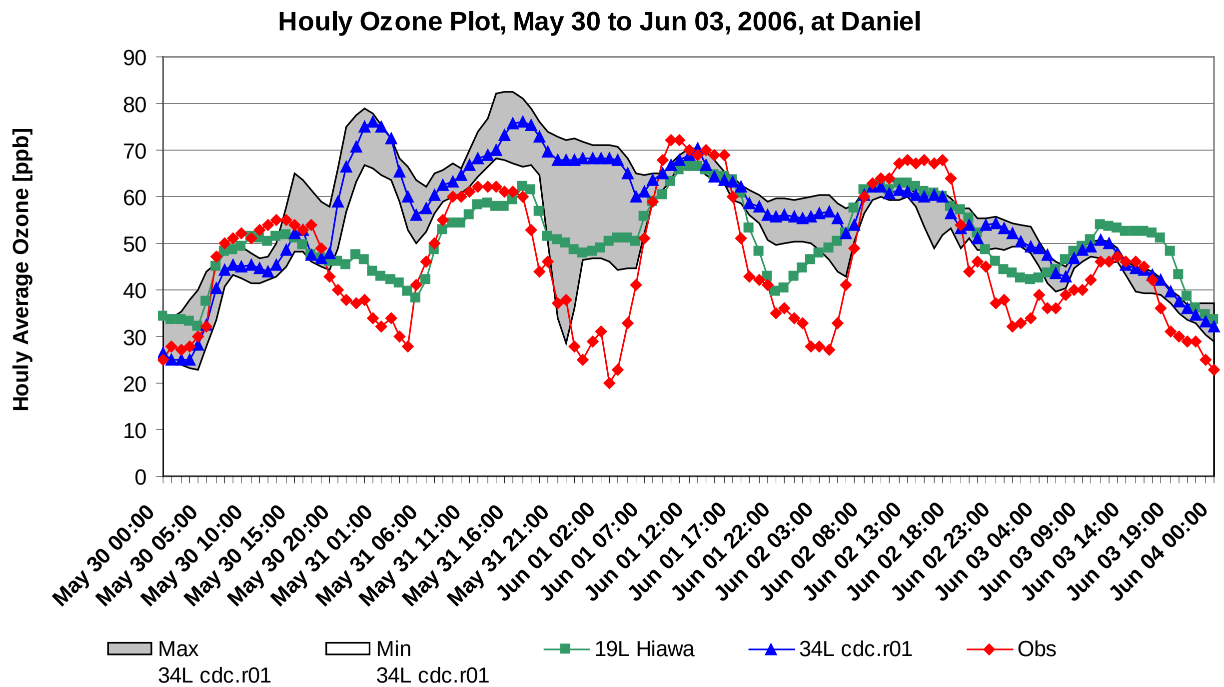


Figure A4-9b. 1-hour ozone time series for May 30-June 3, 2006.



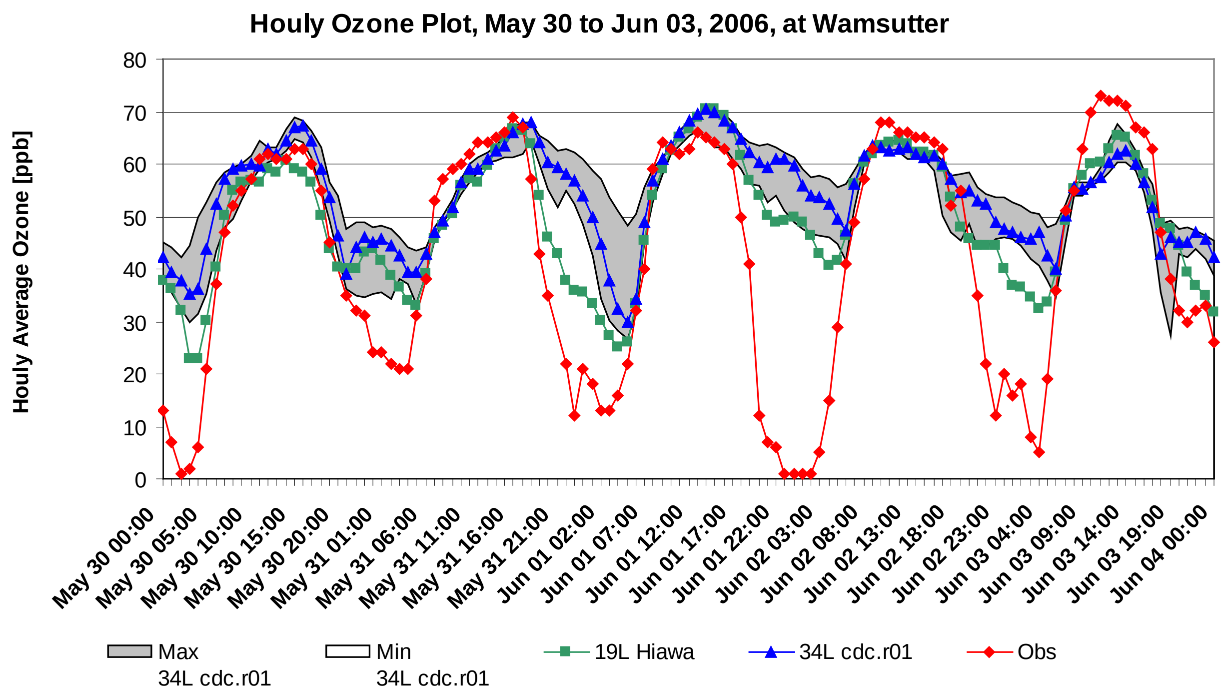


Figure A4-9c.1-hour ozone time series for May 30-June 3, 2006.

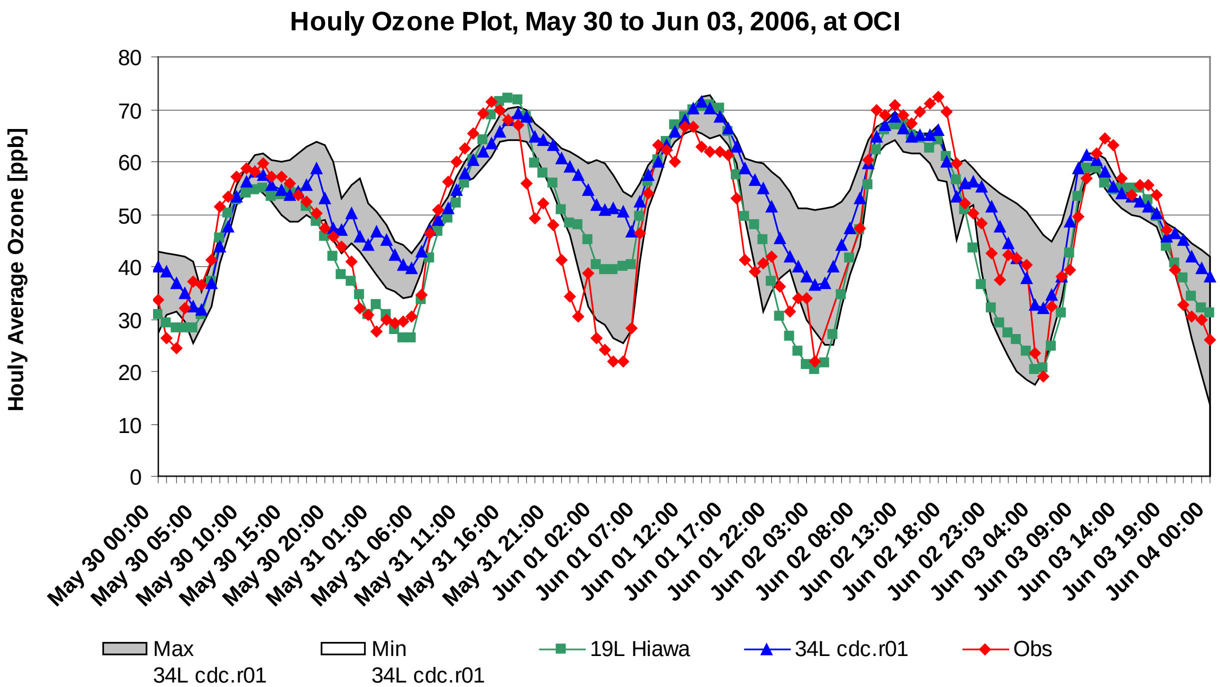
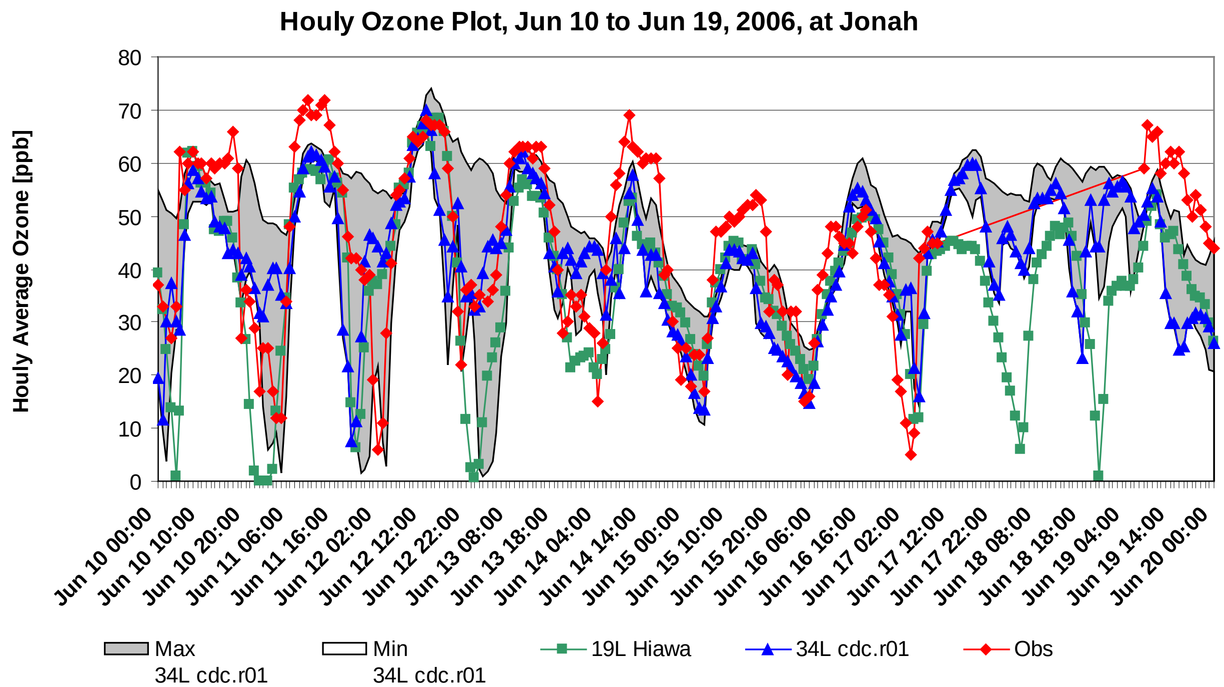


Figure A4-9d. 1-hour ozone time series for May 30-June 3, 2006.



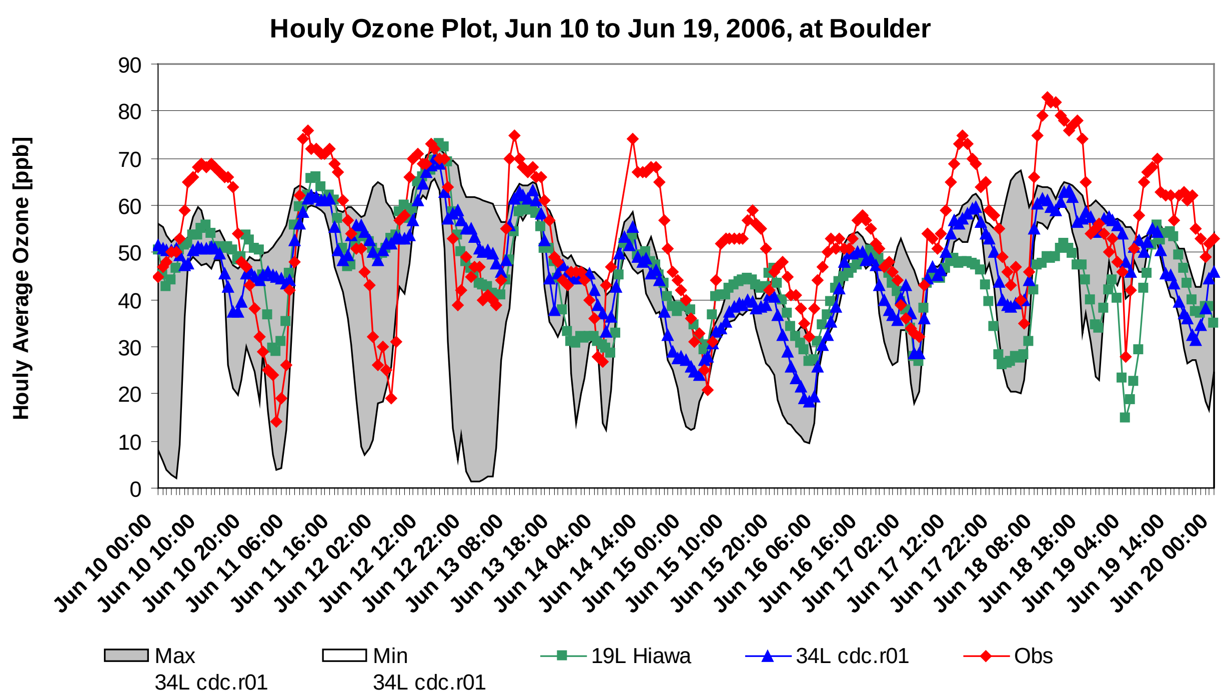
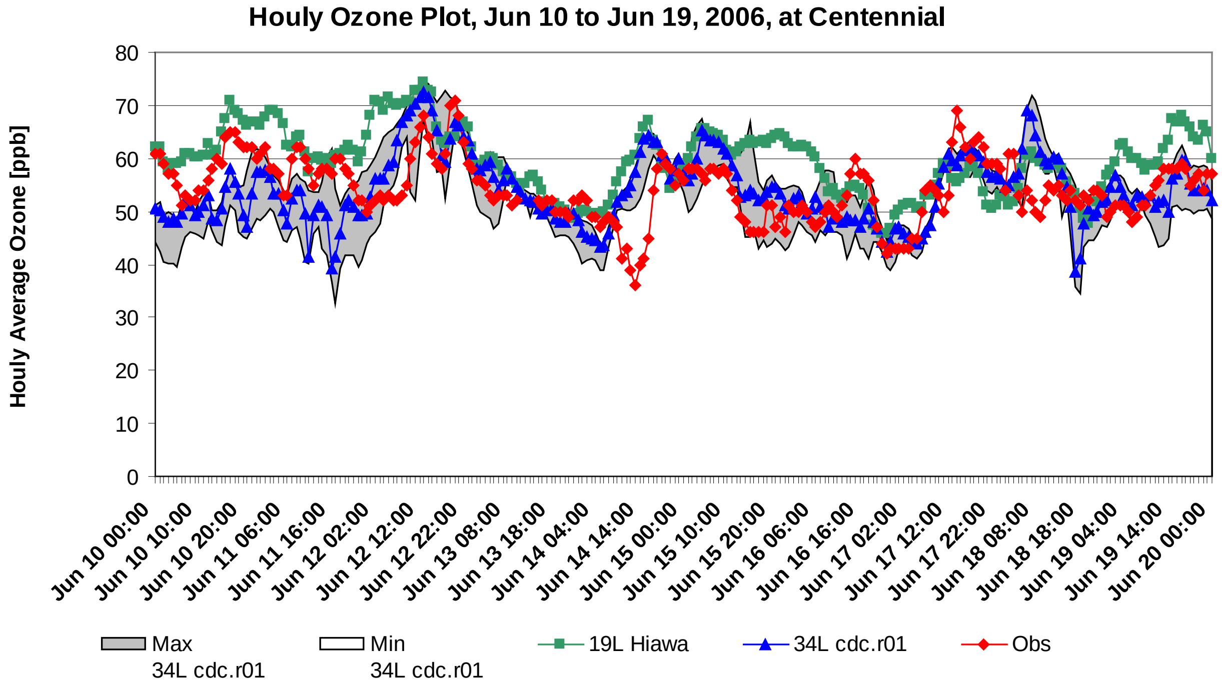


Figure A4-10a. 1-hour ozone time series for June 10-19, 2006.



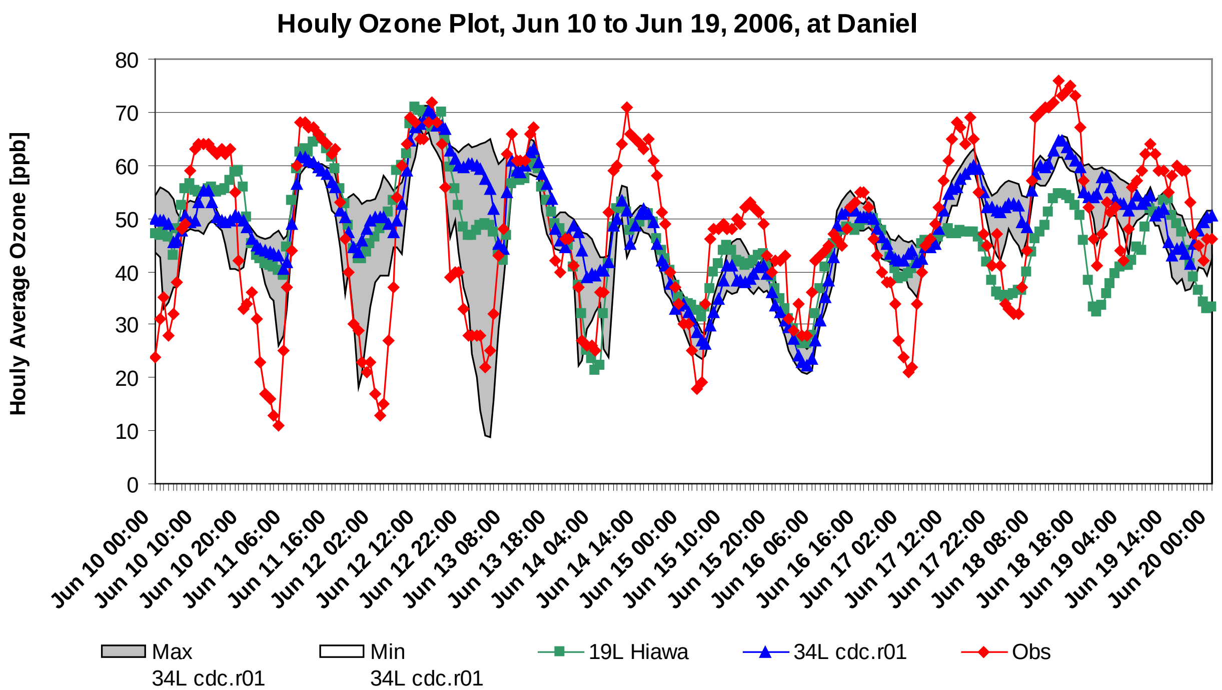
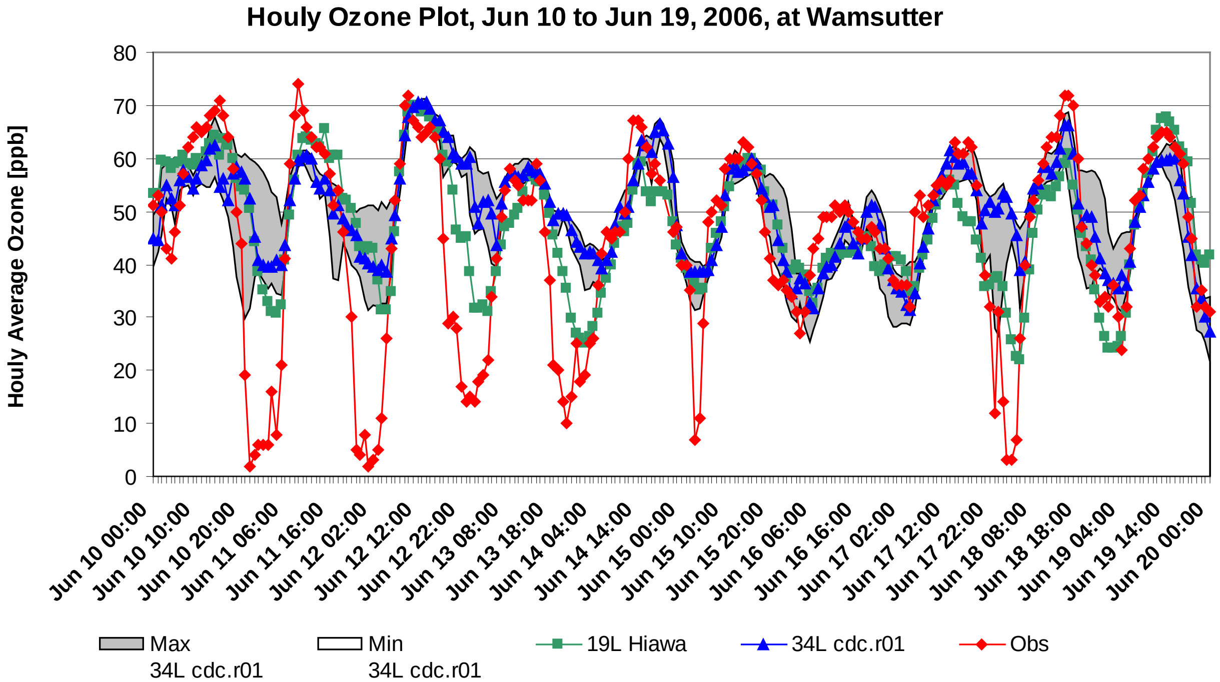


Figure A4-10b. 1-hour ozone time series for June 10-19, 2006.



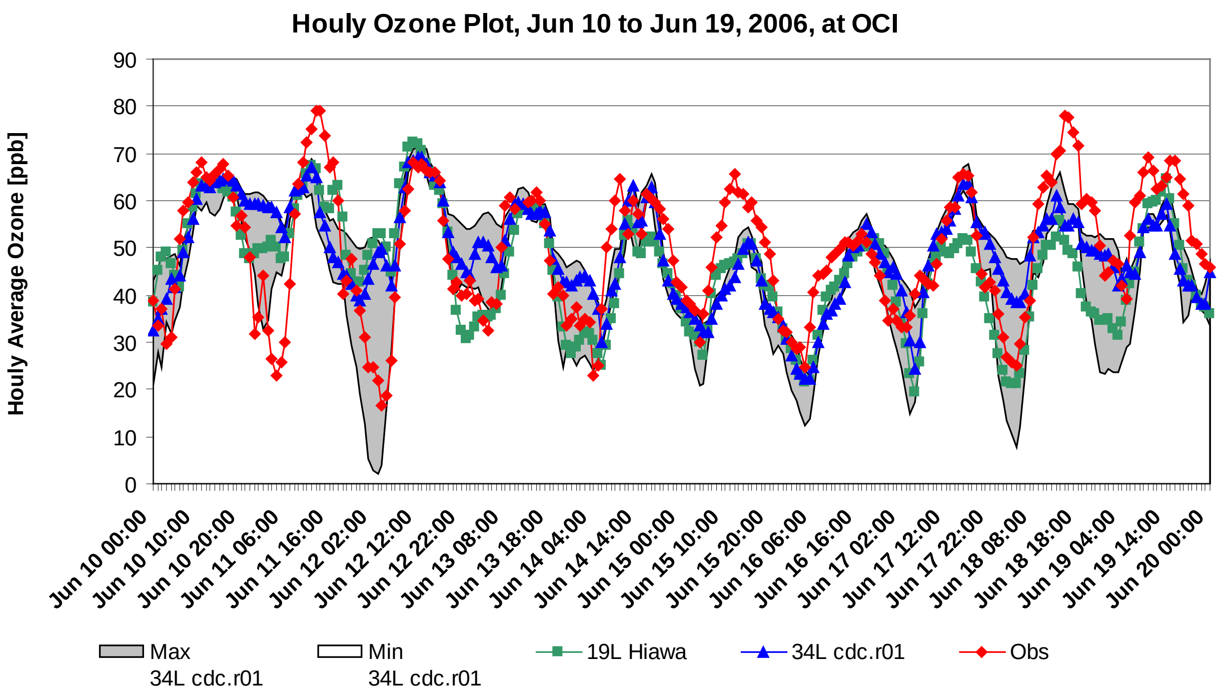
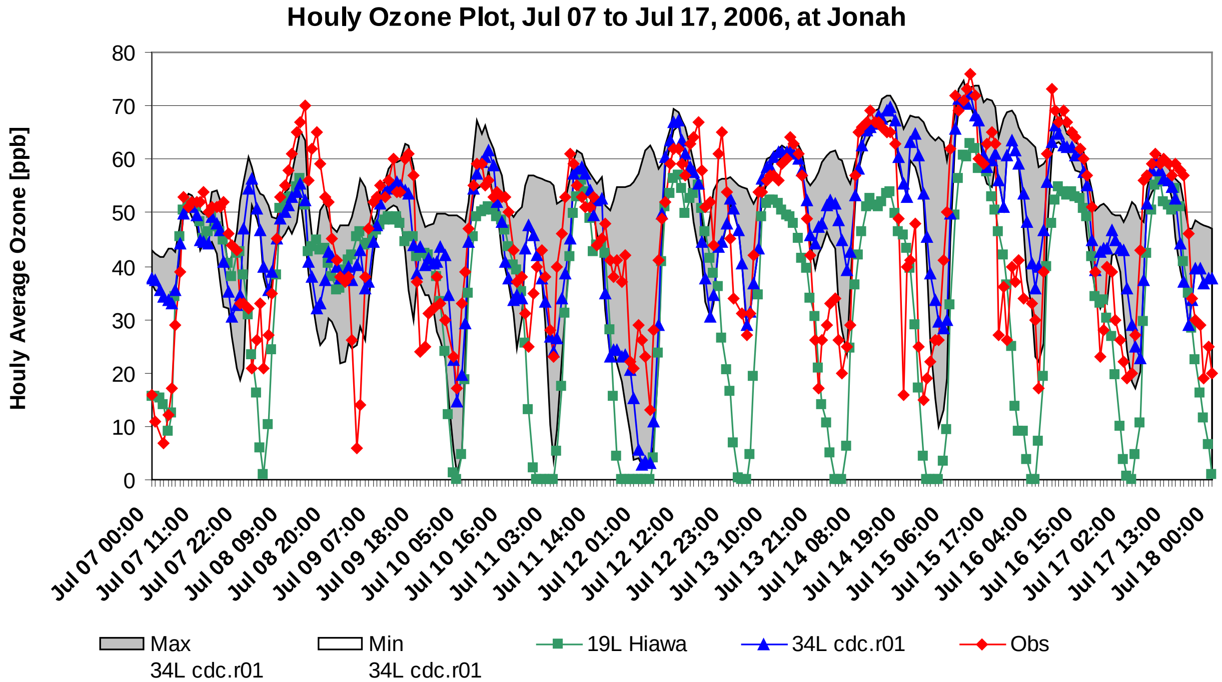


Figure A4-10c.1-hour ozone time series for June 10-19, 2006.



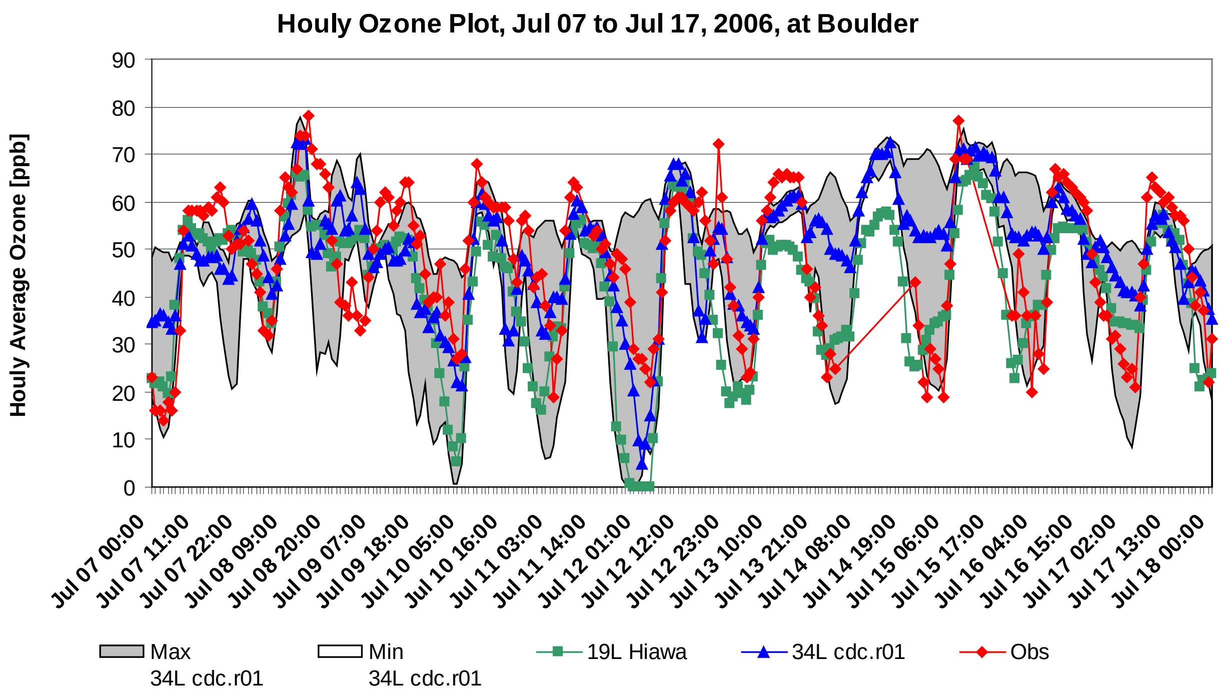
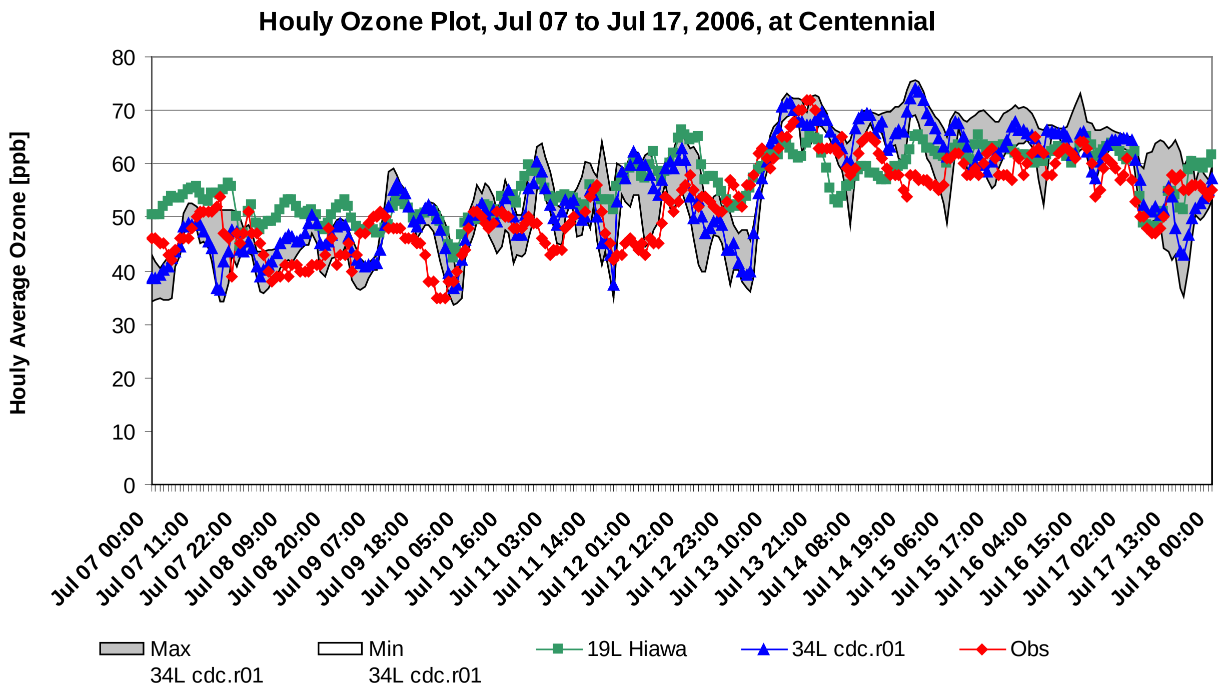


Figure A4-11a. 1-hour ozone time series for July 7-17, 2006.



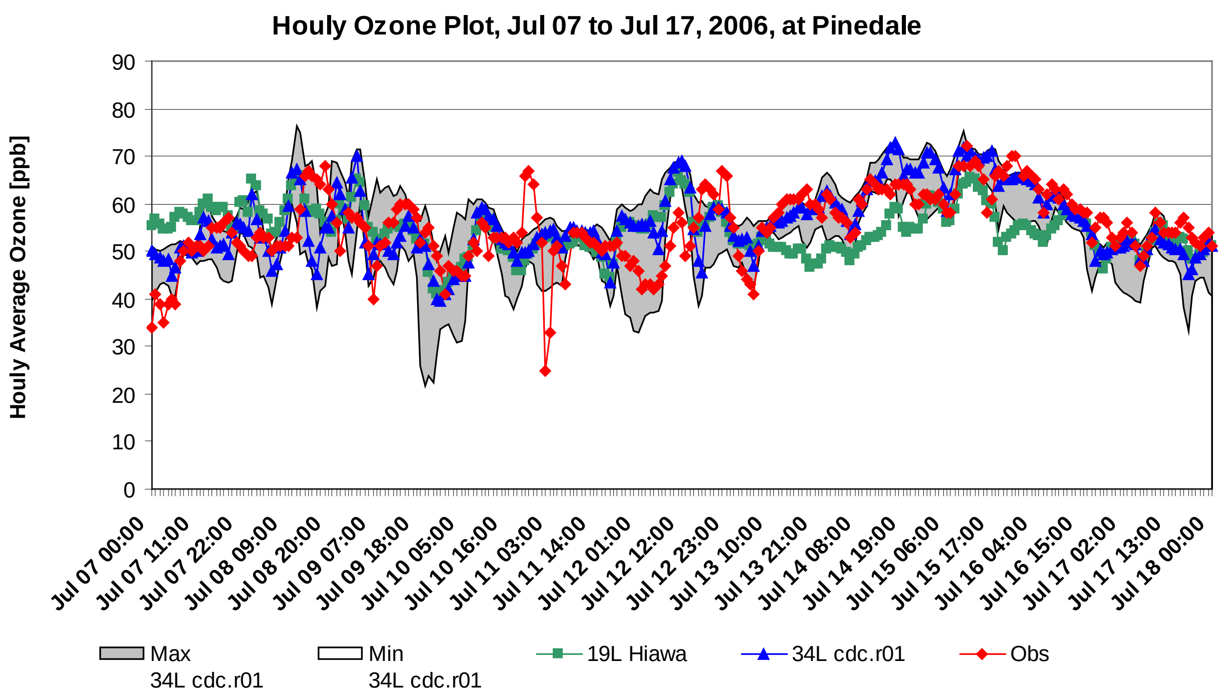
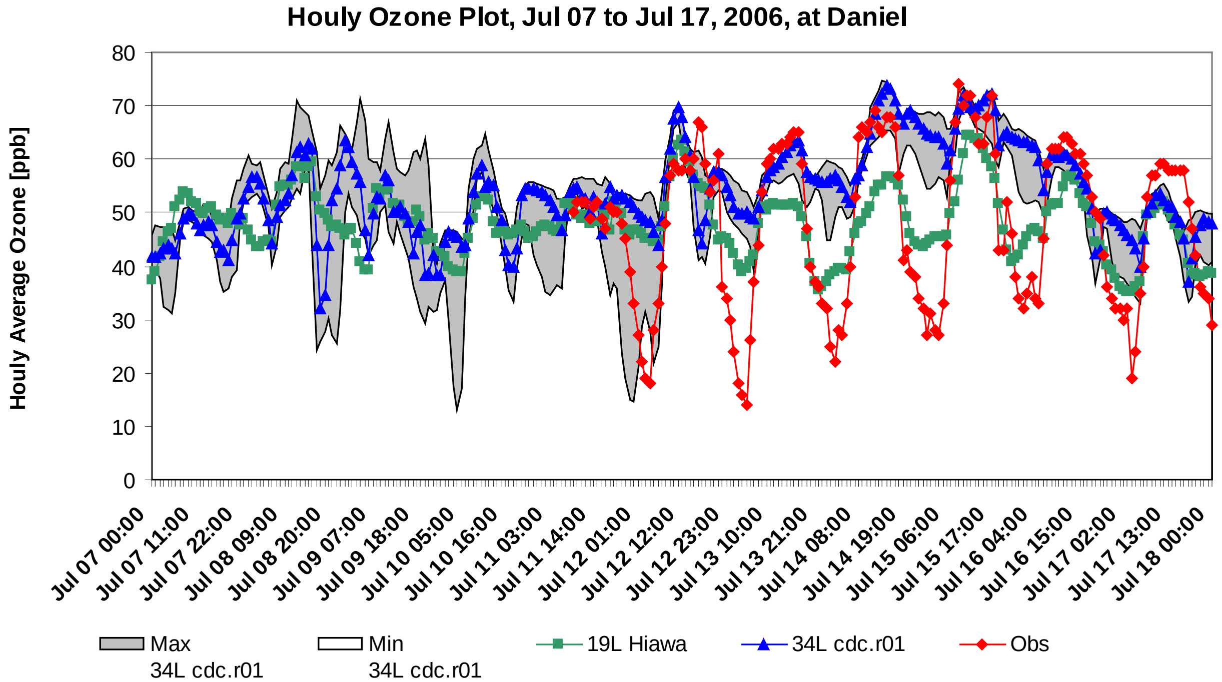


Figure A4-11b. 1-hour ozone time series for July 7-17, 2006.



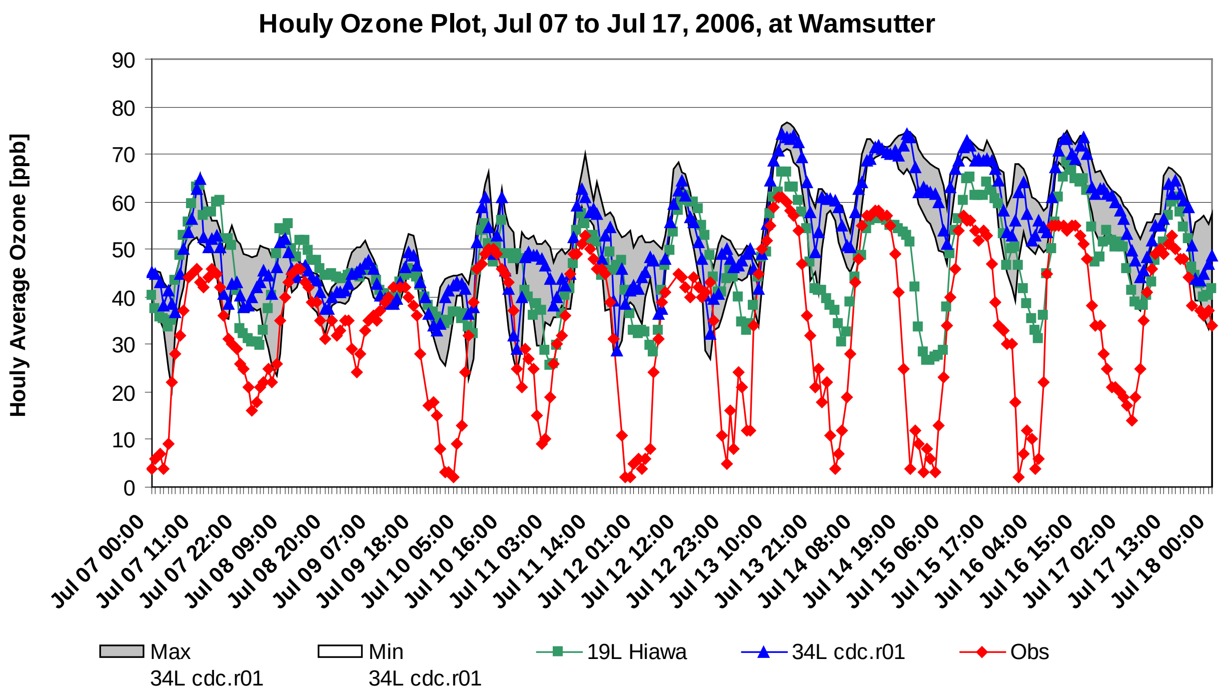


Figure A4-11c.1-hour ozone time series for July 7-17, 2006.

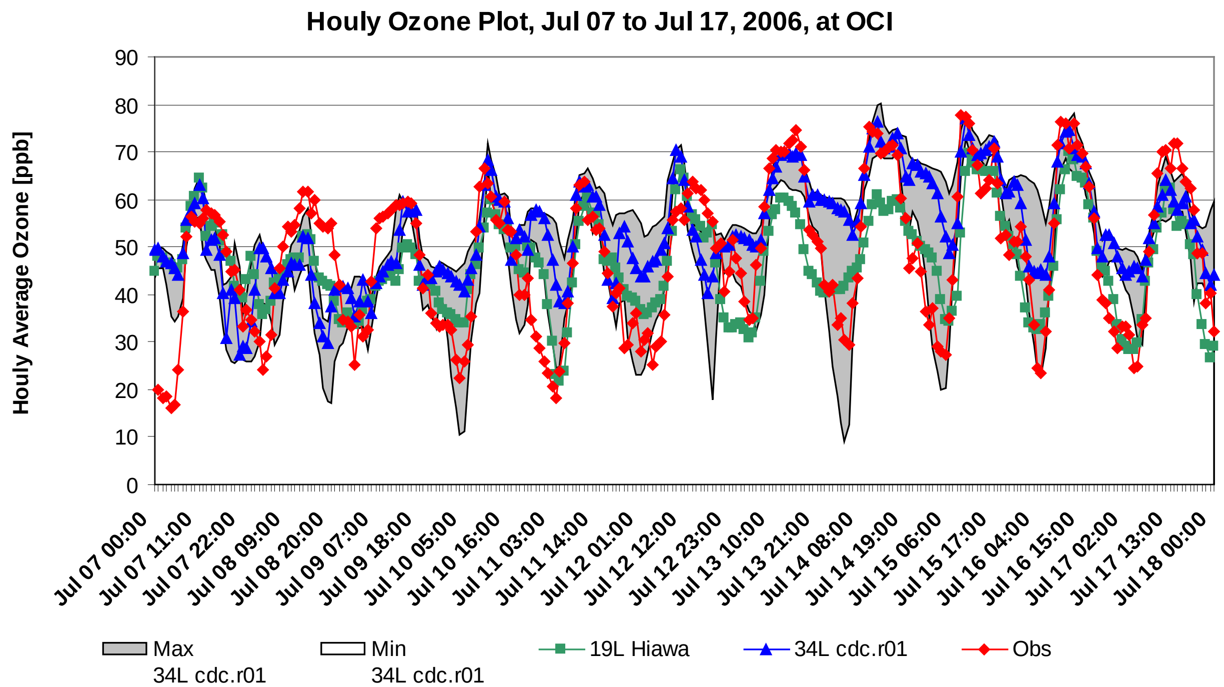
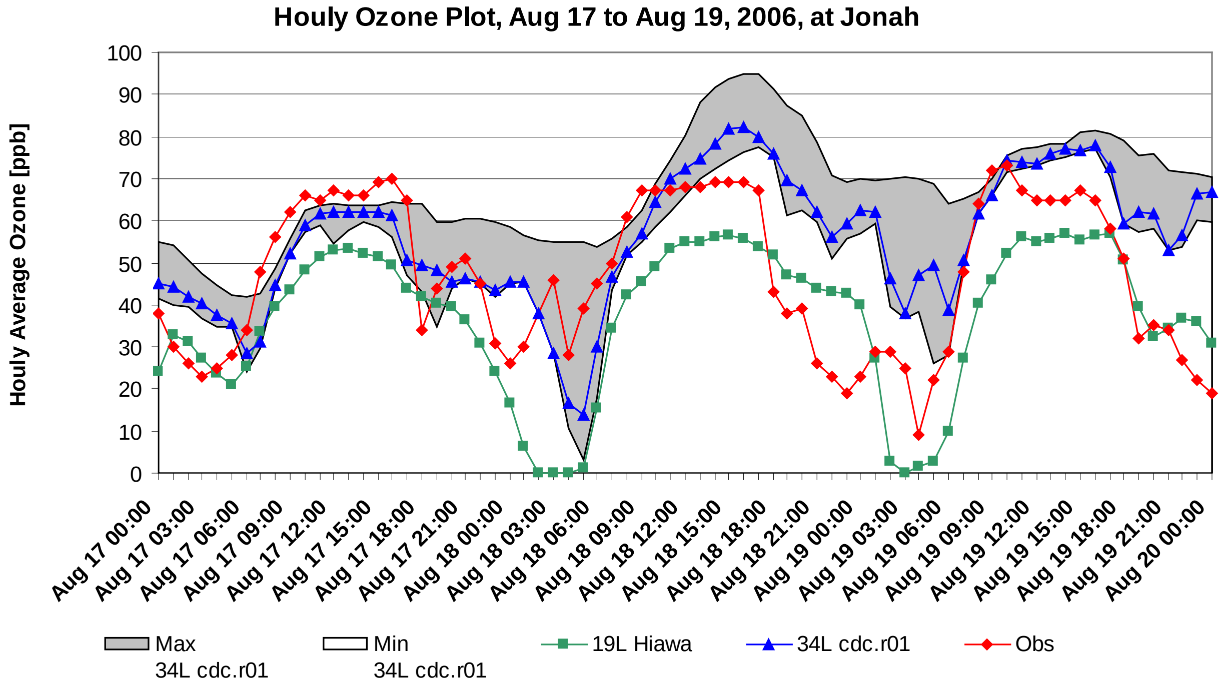


Figure A4-11d. 1-hour ozone time series for July 7-17, 2006.



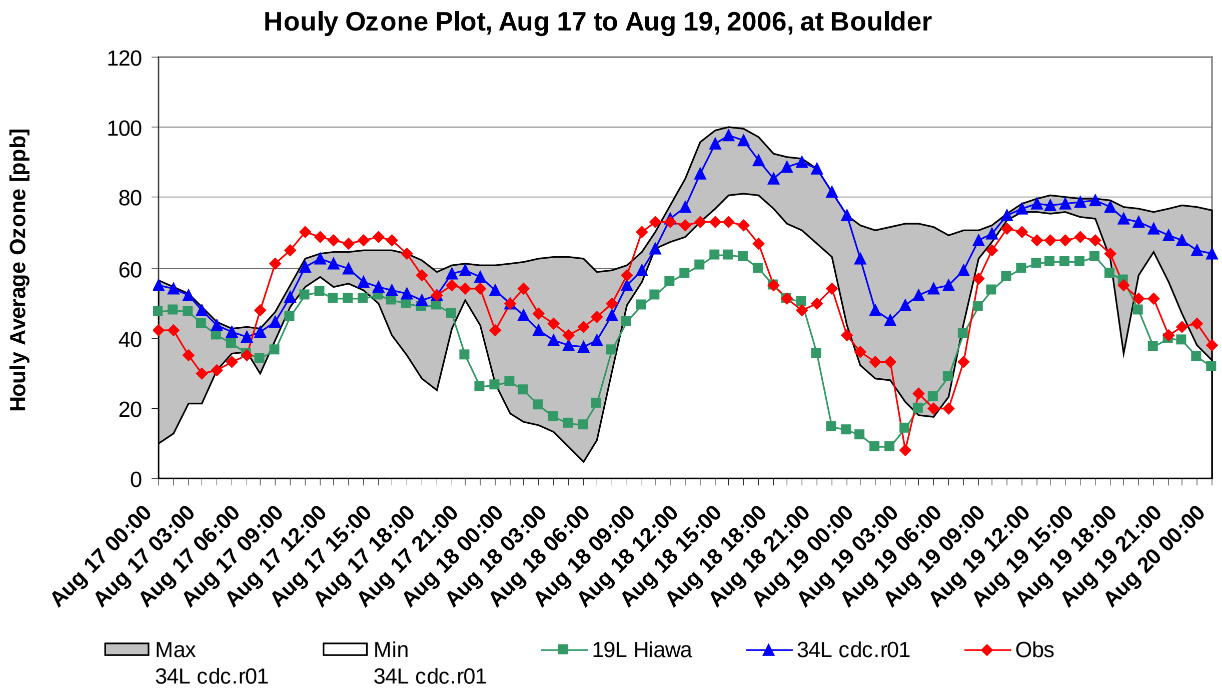
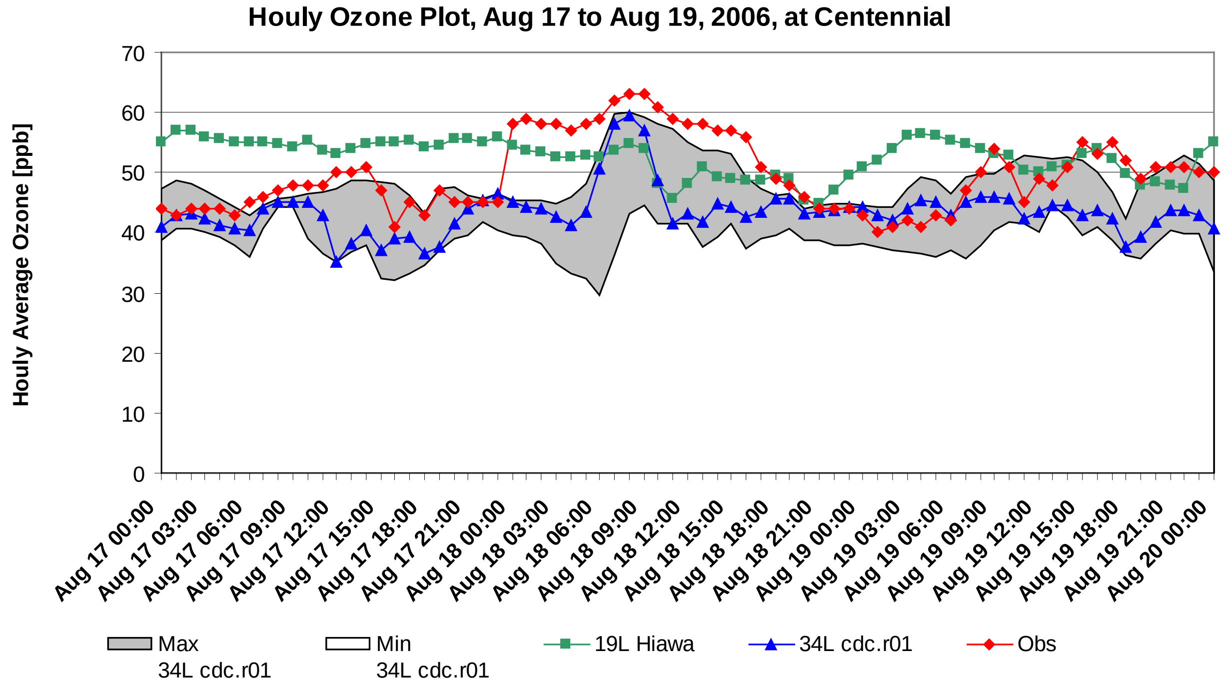


Figure A4-12a. 1-hour ozone time series for August 17-19, 2006.



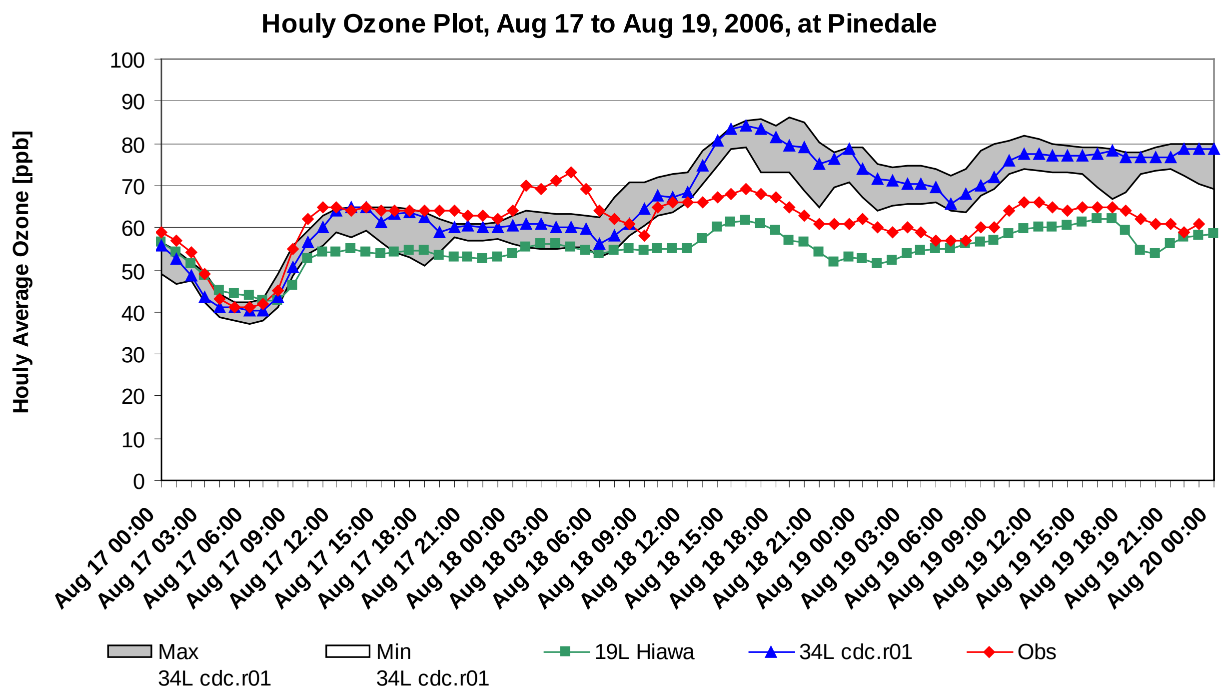
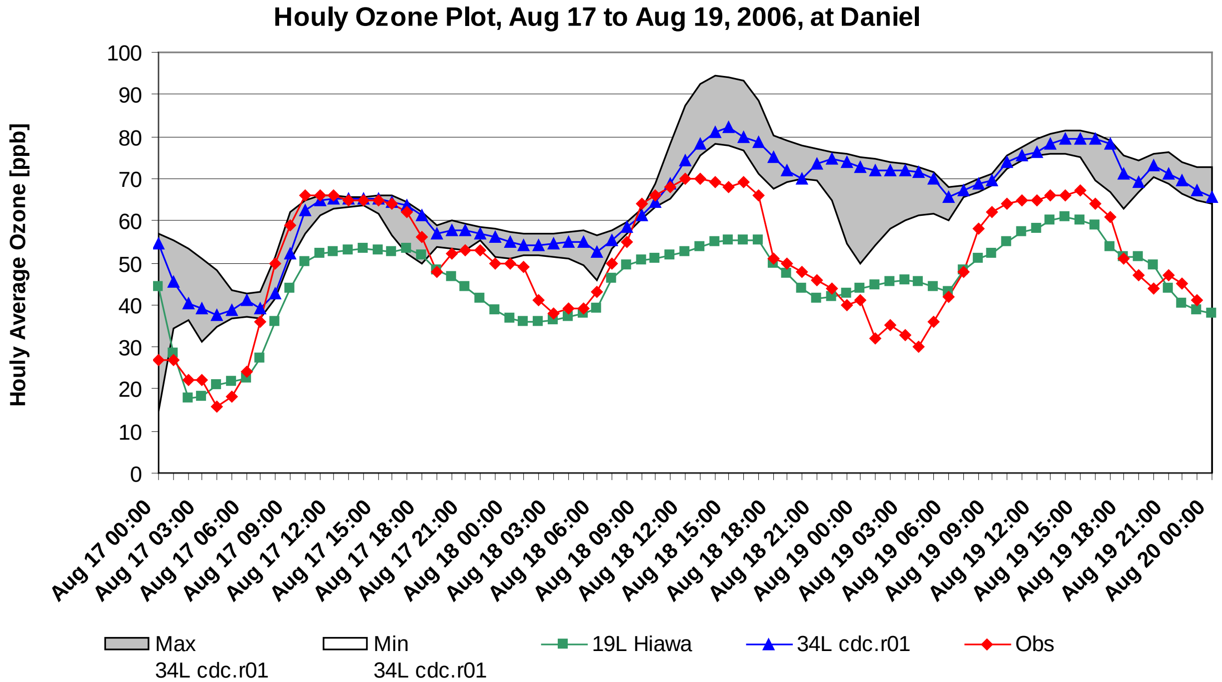


Figure A4-12b. 1-hour ozone time series for August 17-19, 2006.



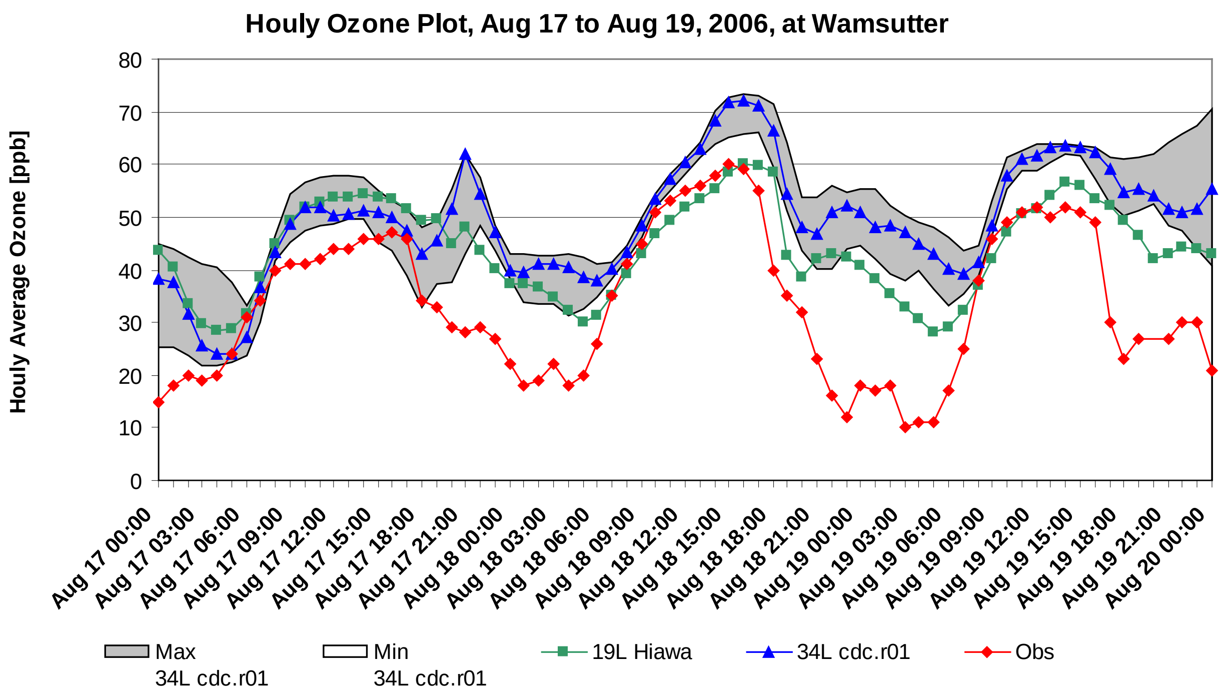


Figure A4-12c.1-hour ozone time series for August 17-19, 2006.

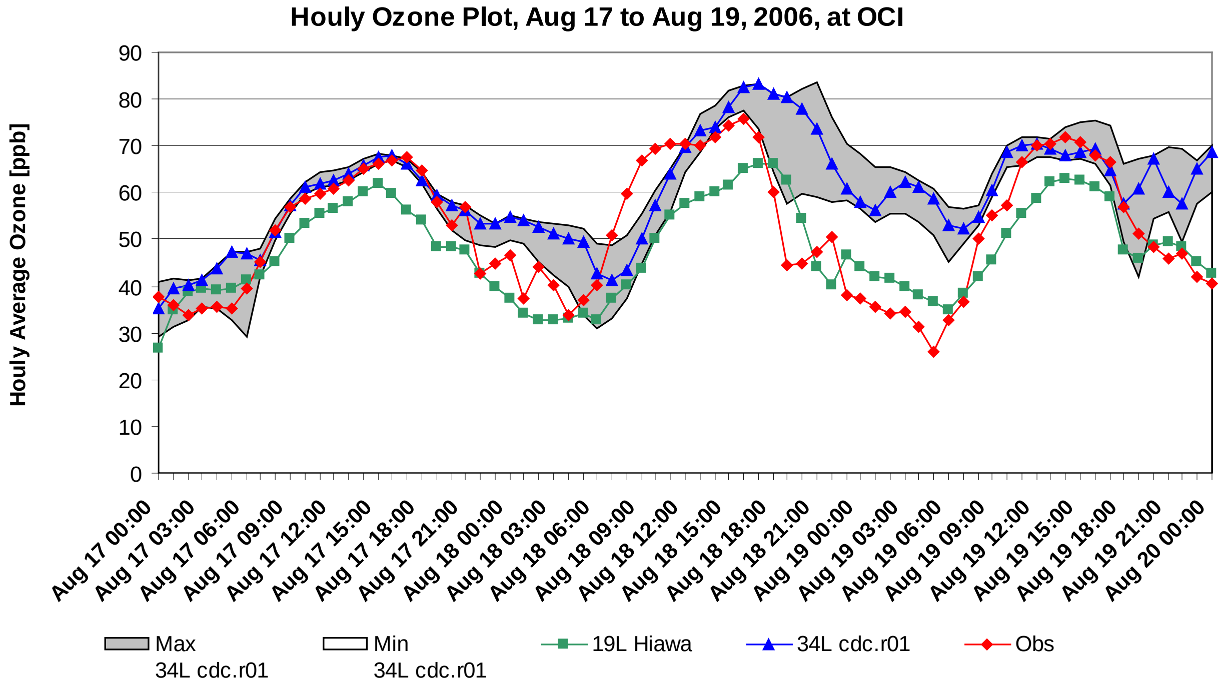


Figure A4-12d. 1-hour ozone time series for August 17-19, 2006.

A4.6 SPATIAL DISTRIBUTION OF DAILY MAXIMUM HOURLY AND 8-HOUR OZONE MODEL PERFORMANCE

Figure A4-13 displays the spatial distribution of the predicted daily maximum 1-hour (top) and 8-hour (bottom) for the Hiawatha (left) and CD-C (right) base case simulations within the 4 km southwestern Wyoming modeling domain for each of the high ozone days identified for analysis by the WDEQ-AQD. The observed daily maximum 1-hour and 8-hour ozone concentrations are also provided in Figure A4-13 at the locations of the ozone monitoring sites in the 4 km domain.

June 27, 2005

On June 27, 2005 the observed daily maximum 8-hour ozone concentrations range from 73-76 ppb at the Sublette County sites and is 66 ppb at the Centennial CASTNet site (Figure A4-13a). At the locations of the Sublette County monitoring sites the Hiawatha base case daily maximum 8-hour ozone concentrations are in the 55-65 ppb range, which is much lower than observed. The CD-C base case simulation, on the other hand, estimates daily maximum 8-hour ozone concentrations at the Sublette County monitoring site locations of 60-72.5 ppb, which is much closer to what was observed. At the Centennial site both models estimates values in the 67.5-70 ppb range, which is close to what was observed (66 ppb). Between the Sublette County and Centennial monitoring sites, the CD-C base case estimates daily maximum 8-hour ozone concentrations in the 75-80 ppb range that cannot be evaluated due to a lack of observed data.

July 8, 2005

With the exception of a 45 ppb ozone value at Boulder that is due to missing afternoon observed ozone concentrations, the observed daily maximum 8-hour ozone concentrations at the Sublette County monitoring site range from 67-72 ppb (Figure A4-13b). The Hiawatha base case estimates values in the 55-65 ppb range, whereas the CD-C base case estimates values in the 67.5-72.5 ppb range that is much closer to the observed values. At Centennial, where a 58 ppb daily maximum 8-hour ozone concentration is observed, the Hiawatha and CD-C base case simulations simulate values in the 60-65 ppb and 65-67.5 ppb range, respectively. Again, the CD-C base case simulates higher daily maximum 8-hour ozone concentrations in the 72.5-77.5 ppb range diagonally across Sweetwater County between the locations of the monitoring sites.

April 21, 2006

Very high observed daily maximum 8-hour ozone concentrations of 81 ppb (Boulder) and 80 ppb (Pinedale) occur in Sublette County on April 21, 2006 (Figure A4-13c). The CD-C base case estimates daily maximum 8-hour ozone concentrations in excess of 80 ppb on either side of the four Sublette County monitoring sites, but at the location of the 4 sites, it estimates values in the 70-77.5 ppb range. This is in contrast to the Hiawatha base case that estimates values in the 60-75 ppb range at the locations of the four Sublette County monitoring sites. At Wamsutter, the CD-C base case (72.5 ppb) overestimates the observed (63 ppb) daily maximum 8-hour ozone concentration, whereas the Hiawatha base case (65-67.5 ppb) does a better job in reproducing the observed ozone value. The observed value at Centennial (73 ppb) is overestimated by the CD-C (77.5-80 ppb) and underestimated by the Hiawatha (67.5-70 ppb) base case simulations.

May 2, 2006

Both base case simulations (60-67.5 ppb) underestimate the observed daily maximum 8-hour ozone concentrations in Sublette County (72-77 ppb) on May 2, 2006 (Figure A4-13d). The observed 8-hour ozone at Centennial (73 ppb) is also underestimated by the CD-C (55-60 ppb) and Hiawatha (60-65 ppb) base case simulations. Across Sweetwater County, both base case simulations estimate daily maximum 8-hour ozone concentrations in the 55-60 ppb when the observed values at Wamsutter and OCI are 67 ppb.

May 8, 2006

The observed daily maximum 8-hour ozone concentrations in Sublette County on May 8, 2006 range from 65-71 ppb with the modeled values much lower ranging from 40-45 ppb for Hiawatha and 40-47.5 ppb for the CD-C base case (Figure A4-13e). The modeled 8-hour ozone across Sweetwater County (40-45 ppb) is also lower than observed (54-56 ppb). And at the Centennial monitoring site the Hiawatha base case (52.5-55 ppb) is closer to the observed value (61 ppb) than the CD-C base case (45-47.5 ppb).

June 1, 2006

The spatial distribution of the modeled daily maximum 8-hour ozone concentrations on June 1, 2006 is fairly flat for both base case simulations (Figure A4-13f). At the Sublette County monitoring sites, where the observed 8-hour ozone concentrations are in the 65-73 ppb range, the modeled values range from 60-67.5 ppb for the Hiawatha and 60-70 ppb for the CD-C base case simulations. There is reasonable agreement in 8-hour ozone concentrations for both base cases (65-70 ppb) at the Wamsutter (64 ppb), OCI (63 ppb) and Centennial (62 ppb) monitoring sites.

June 2, 2006

The two base case simulations tend to underestimate the highest observed ozone concentrations on June 2, 2006 (Figure A4-13g). Both base cases predict 8-hour ozone in the 60-65 ppb range at the locations on the Sublette County monitors where 65-72 ppb is observed. Again, the spatial distribution of the modeled ozone concentrations is fairly flat, typically in the 60-67.5 ppb, which is similar to the observed ozone concentrations at Wamsutter and Centennial (66 ppb) but lower than OCI (70 ppb).

June 11, 2006

On June 11, 2006 the observed ozone concentrations are in the high 60s to 70s across Sublette and Sweetwater Counties where the modeled ozone is lower, 60-65 for Hiawatha and 55-65 ppb for CD-C base case simulations (Figure A4-13h).

June 18, 2006

Observed daily maximum ozone concentrations of 73 and 80 ppb are recorded in Sublette County on June 18, 2006, along with values of 71 ppb at OCI and 67 ppb at Wamsutter (Figure A4-13i). The two base case simulations greatly underestimate the observed values on this day with the Hiawatha base case predicted values below 55 ppb and CD-C base case predicting values in the 55-65 ppb range.

July 8, 2006

Both the modeled and observed daily maximum 8-hour ozone concentrations on July 8, 2006 exhibit a concentration gradient going from the southeast to northwest with lower values in the southeast (< 50 ppb) to values as high as 71 ppb in Sublette County (Figure A4-13j). In Sublette County, where observed values range from 63-71 ppb, the predicted values range from 50-65 ppb.

July 13, 2006

The CD-C base case exhibits better ozone model performance than the Hiawatha base case on July 13, 2006 (Figure A4-13k). In Sublette County, where the observed ozone ranges from 60-65 ppb, the Hiawatha base case estimates values of 50-55 ppb with the CD-C base case being closer to the observed values (55-65 ppb). At the OCI monitor, where the highest observed 8-hour ozone concentration occurs (71 ppb), the Hiawatha base case underestimates (55-60 ppb) and the CD-C base case reproduced the observation well (67.5-70 ppb). The Wamsutter observed ozone on this day (58 ppb) is better replicated by the Hiawatha base case than the CD-C base case which overestimates. However, the observed ozone at Centennial (69 ppb) is underestimated by the Hiawatha base case (60-65 ppb) but reproduced quite well in the CD-C base case simulation.

July 14, 2006

The differences in the modeled daily maximum 8-hour ozone concentrations on July 14, 2006 in the two base case simulations are quite dramatic (Figure A4-13l). Whereas the Hiawatha base case simulation estimates 8-hour ozone concentrations that are mostly in the 55-65 ppb range, the CD-C base case estimates values that are mostly in the 67.5 to 77.5 ppb range. Observed 8-hour ozone concentrations in Sublette County range from 64-67 ppb which the Hiawatha base case underestimates (50-60 ppb) but the CD-C matches more closely (67.5-72.5 ppb. At the OCI monitor, where the highest observed 8-hour ozone concentration on this day occurs (72 ppb), the Hiawatha base case underestimates (55-60 ppb) and the CD-C base case reproduces the observed value quite well (72.5-75 ppb).

July 16, 2006

The CD-C base case estimates higher ozone than the Hiawatha base case on July 16, 2006 that better matches the observed values (Figure A4-13m). Although the CD-C base case slightly underestimates (55-65 ppb) the observed 8-hour ozone (64-67 ppb) in Sublette County, the Hiawatha underestimation bias is much more substantial (50-55 ppb). The highest observed 8-hour ozone concentration on this day is 72 ppb at OCI that is reproduced very well by the CD-C base case (70-72.5 ppb), but underestimated by the Hiawatha base case (60-65 ppb).

August 18, 2006

The CD-C base case estimates 8-hour ozone concentrations in excess of 80 ppb in an area across Sublette and Lincoln Counties and further west including the locations of the Sublette County ozone monitors where 68-72 ppb is observed so it overestimates. The Hiawatha base case estimates lower ozone (60-67/5 ppb) in Sublette County that is lower than observed. At the OCI monitor where 72 ppb ozone is observed, the CD-C base case overestimates (75-77.5 ppb) and the Hiawatha base case underestimates (65-67.5 ppb).

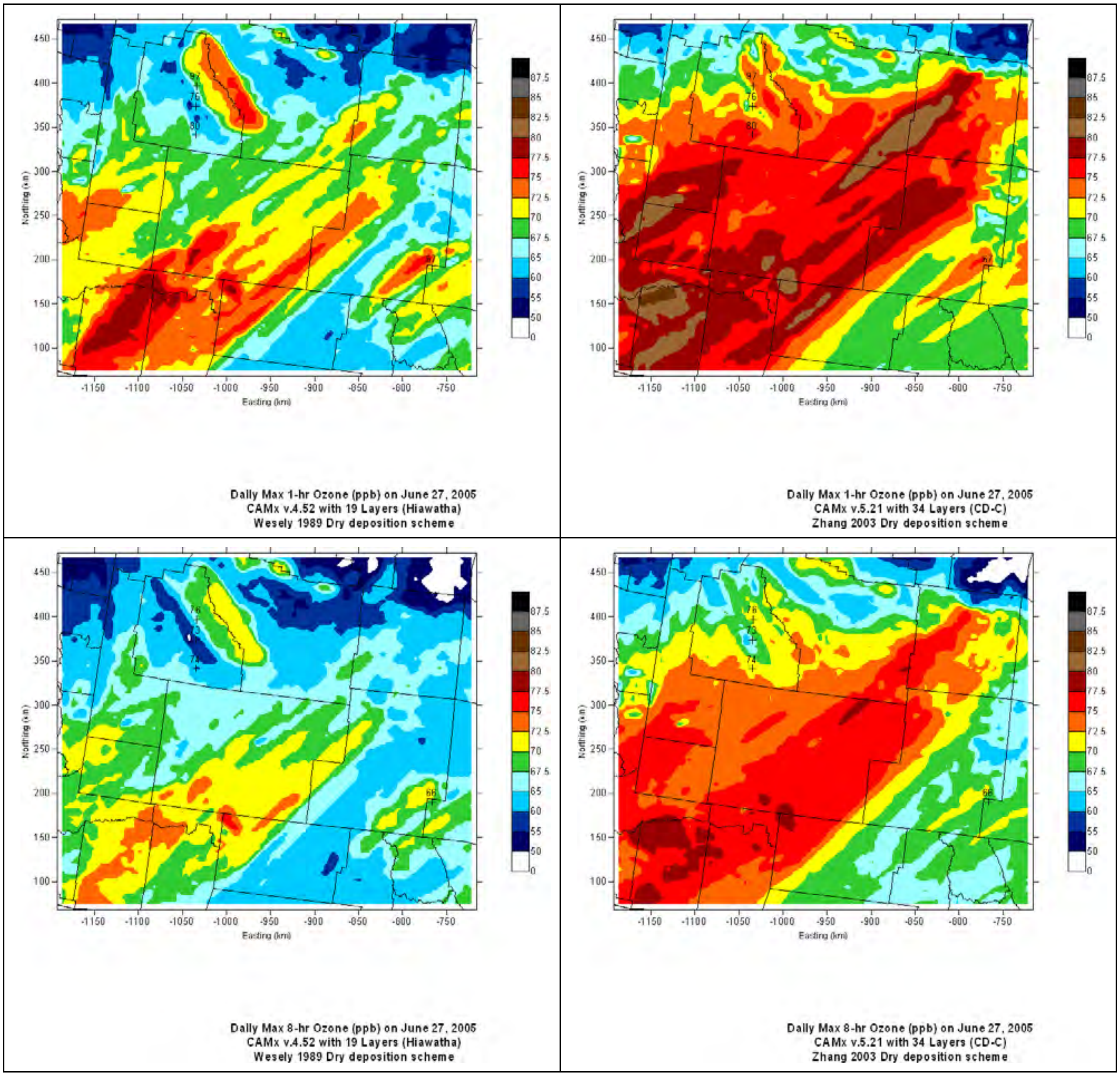


Figure A4-13a. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on June 27, 2005.

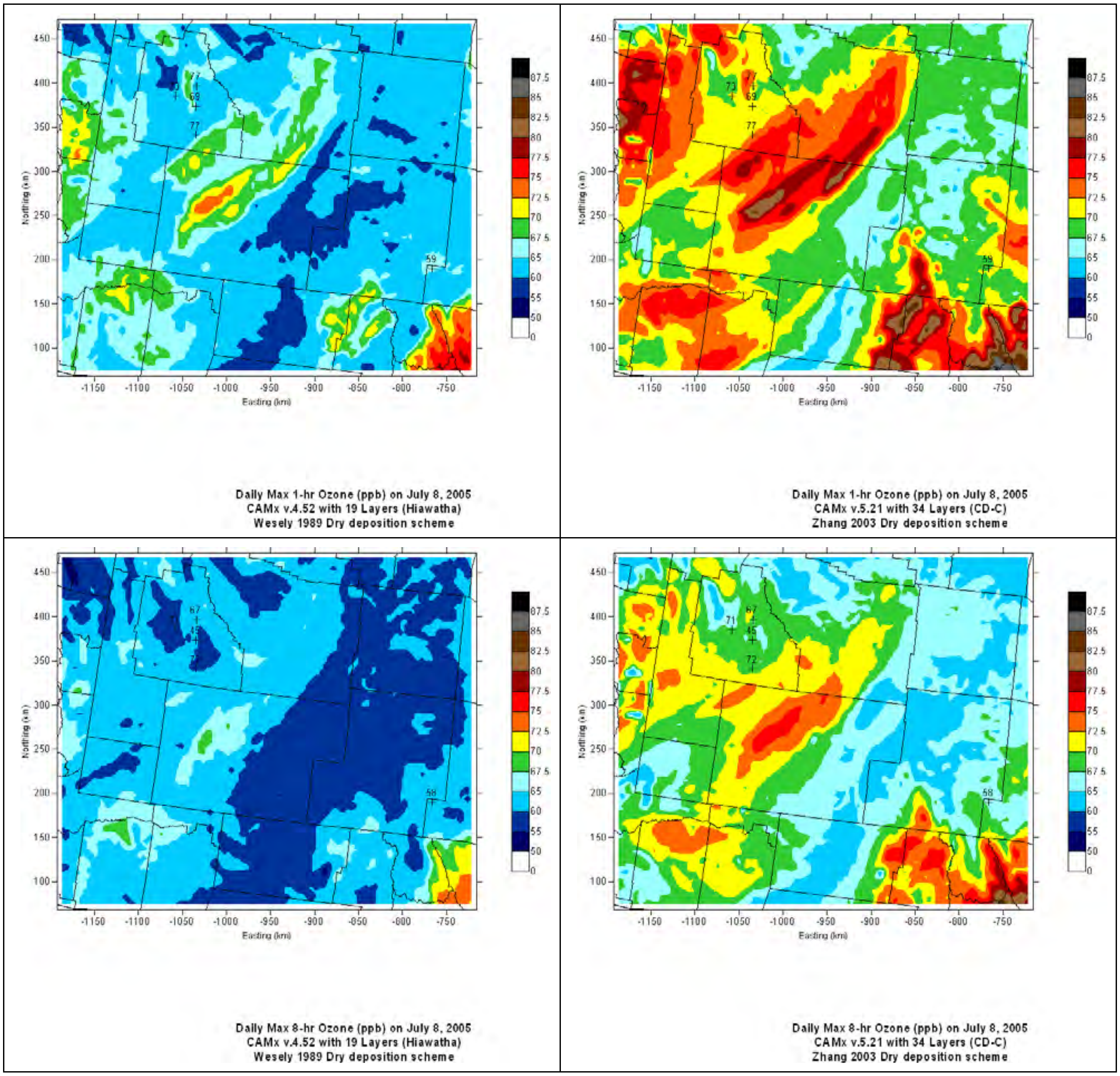


Figure A4-13b. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on July 8, 2005.

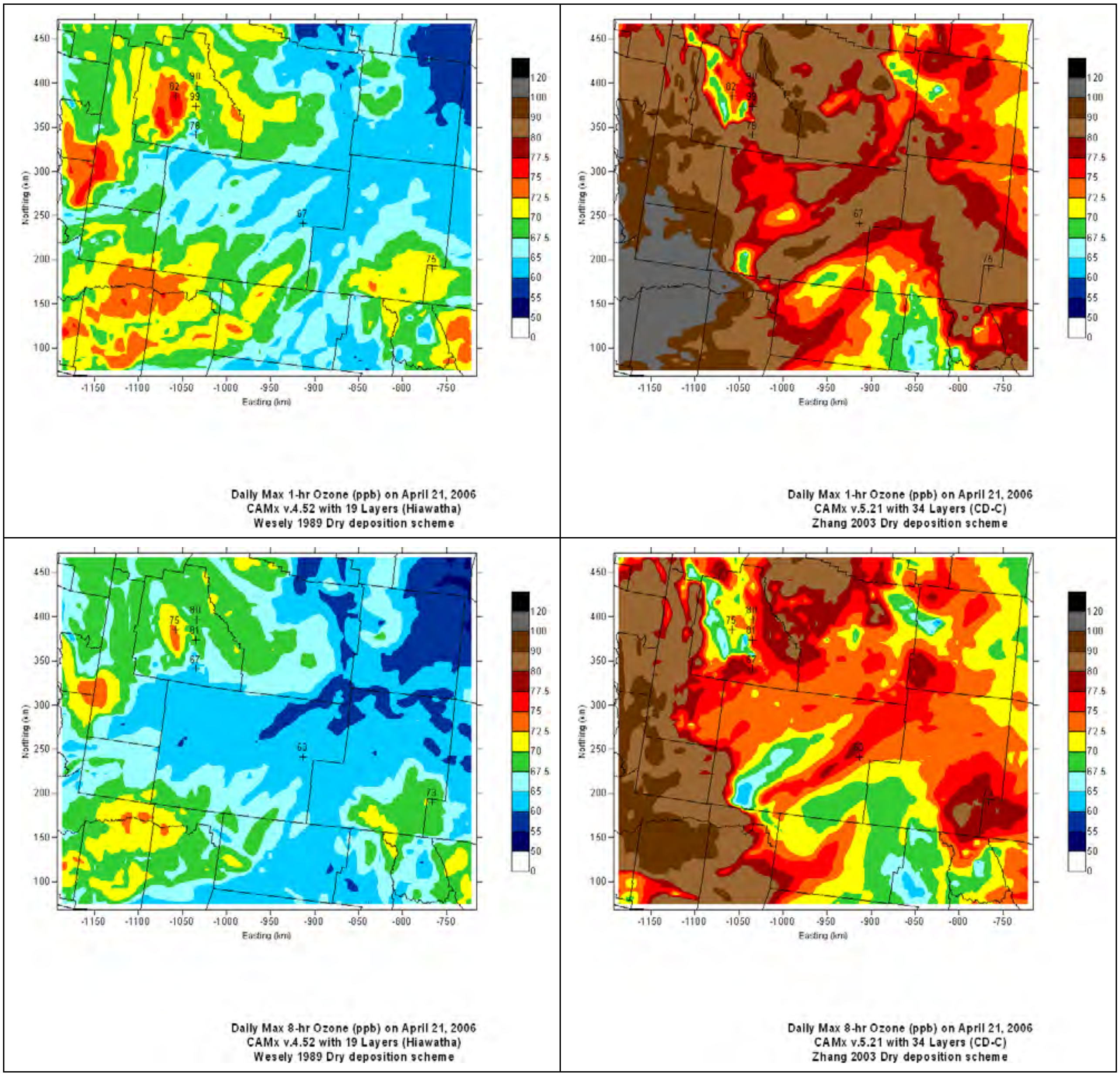


Figure A4-13c. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on April 21, 2006.

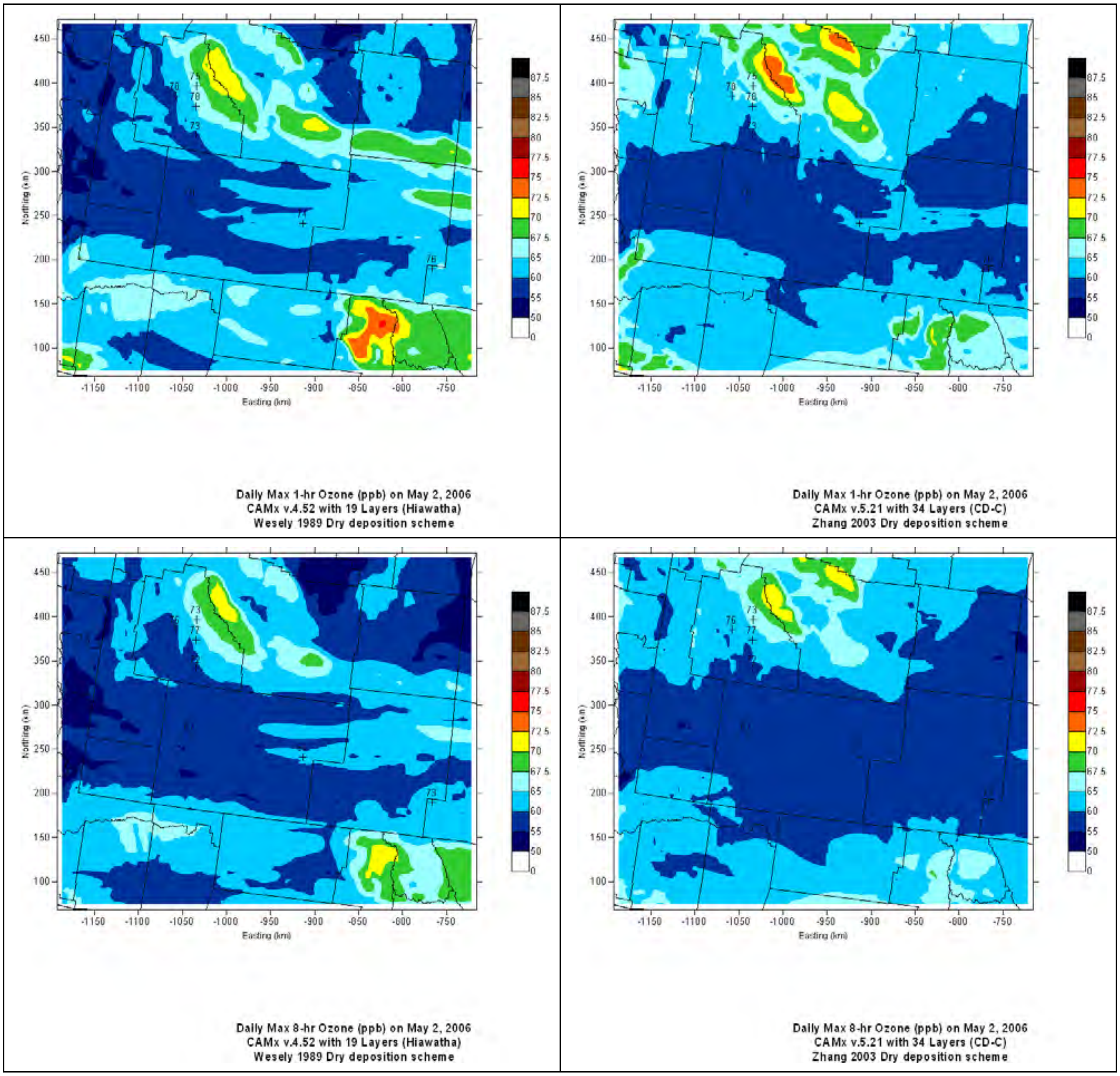


Figure A4-13d. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on May 2, 2006.

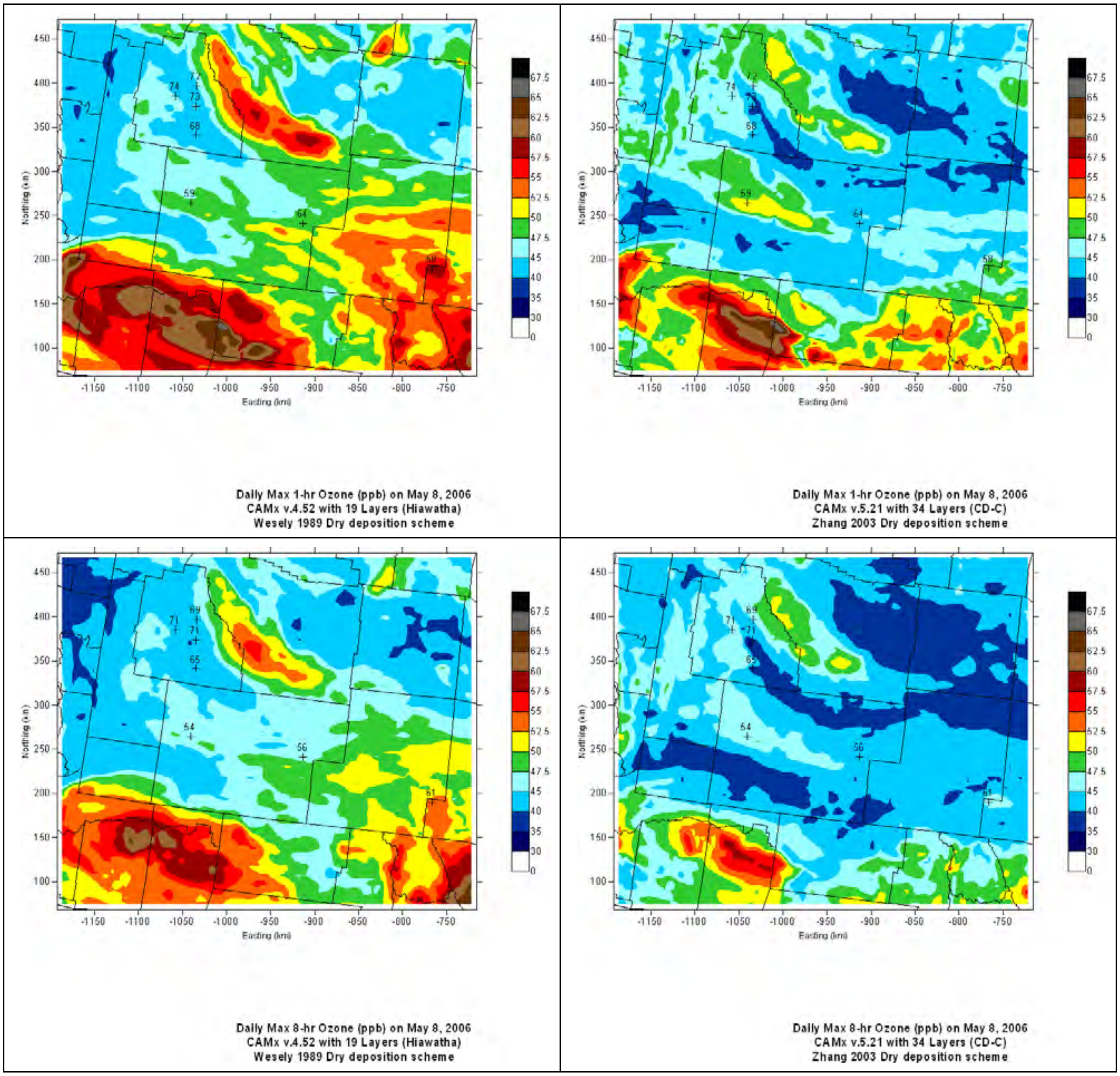


Figure A4-13e. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on May 8, 2006.

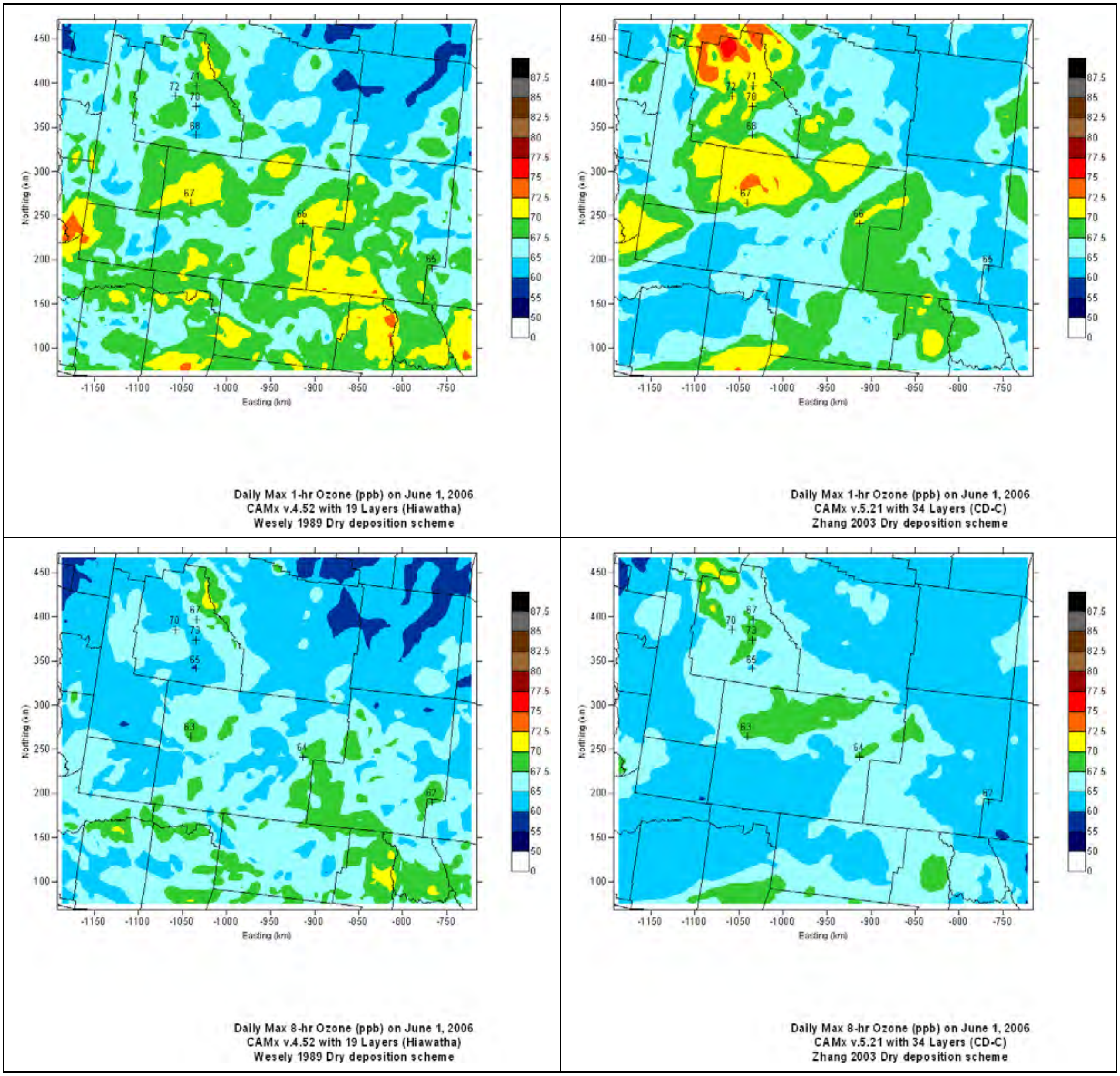


Figure A4-13f. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on June 1, 2006.

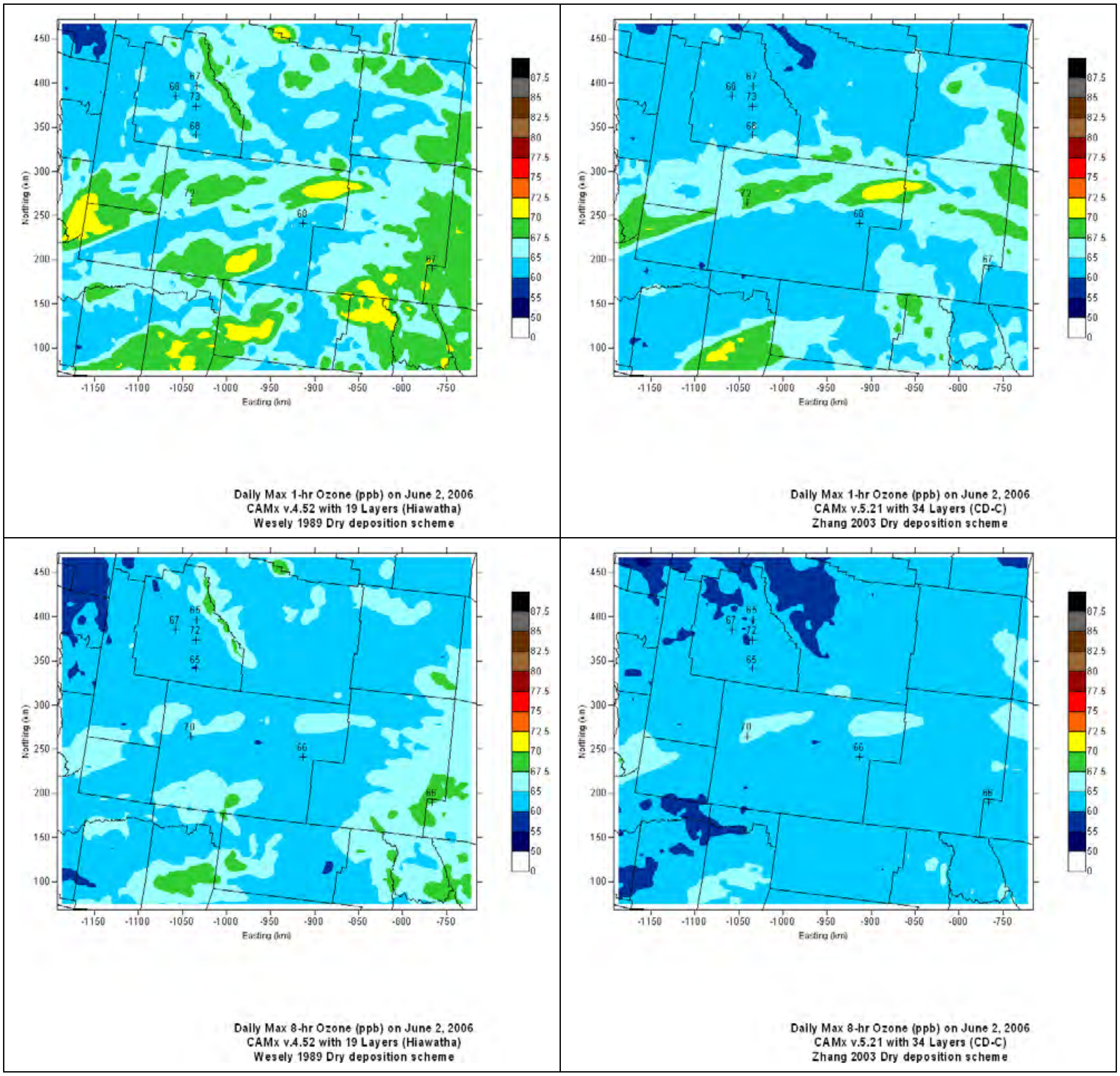


Figure A4-13g. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on June 2, 2006.

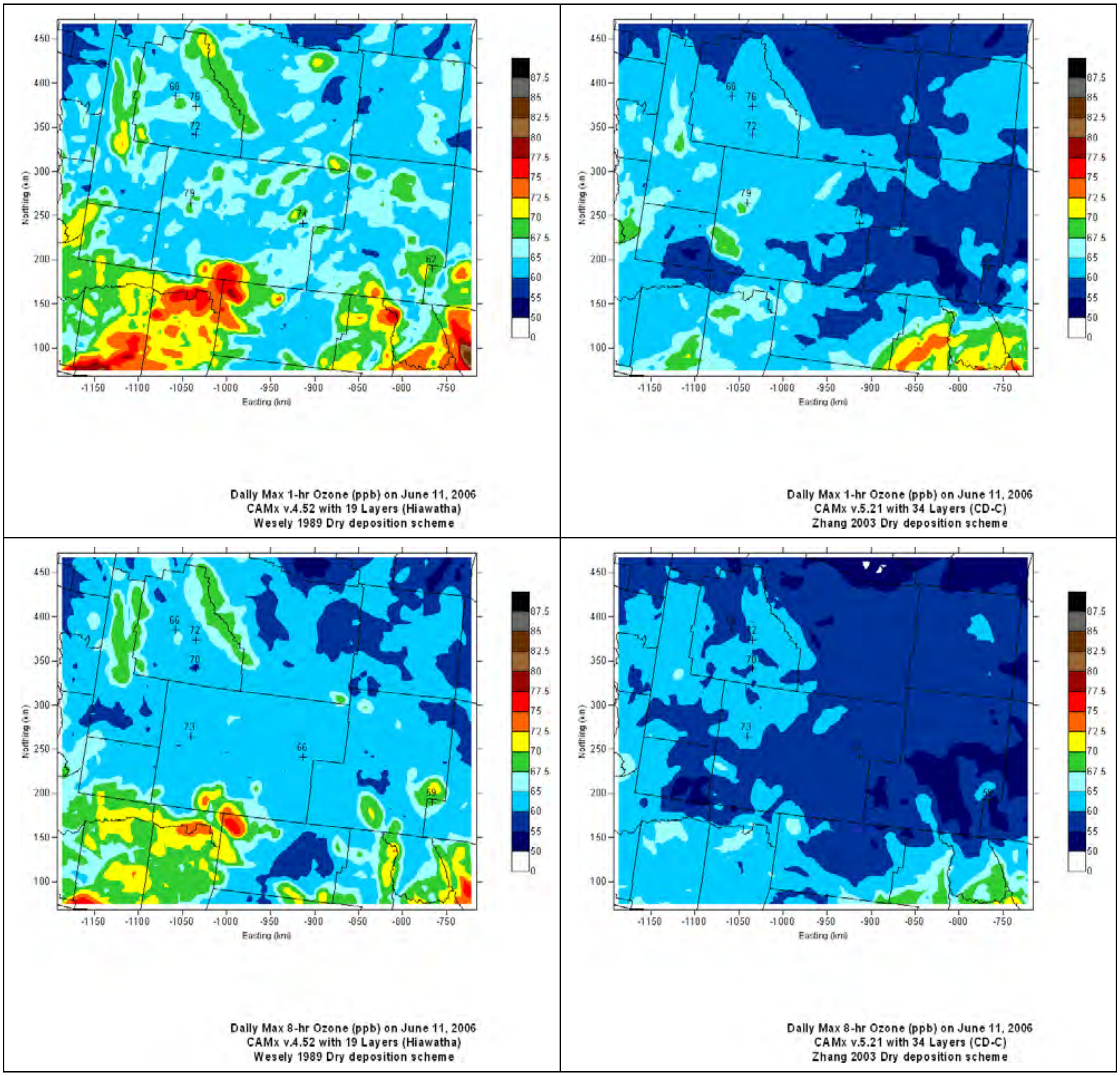


Figure A4-13h. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on June 11, 2006.

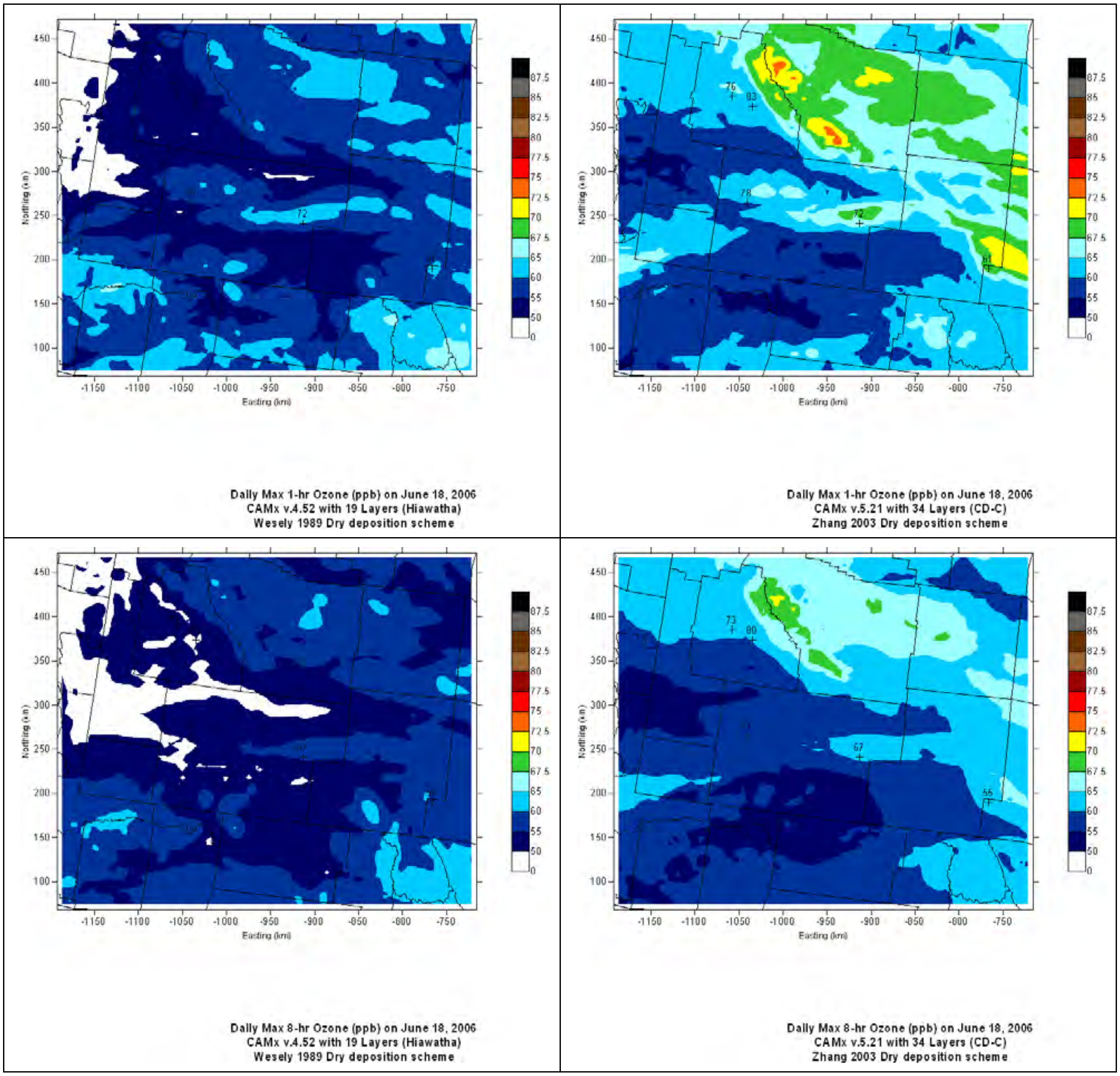


Figure A4-13i. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on June 18, 2006.

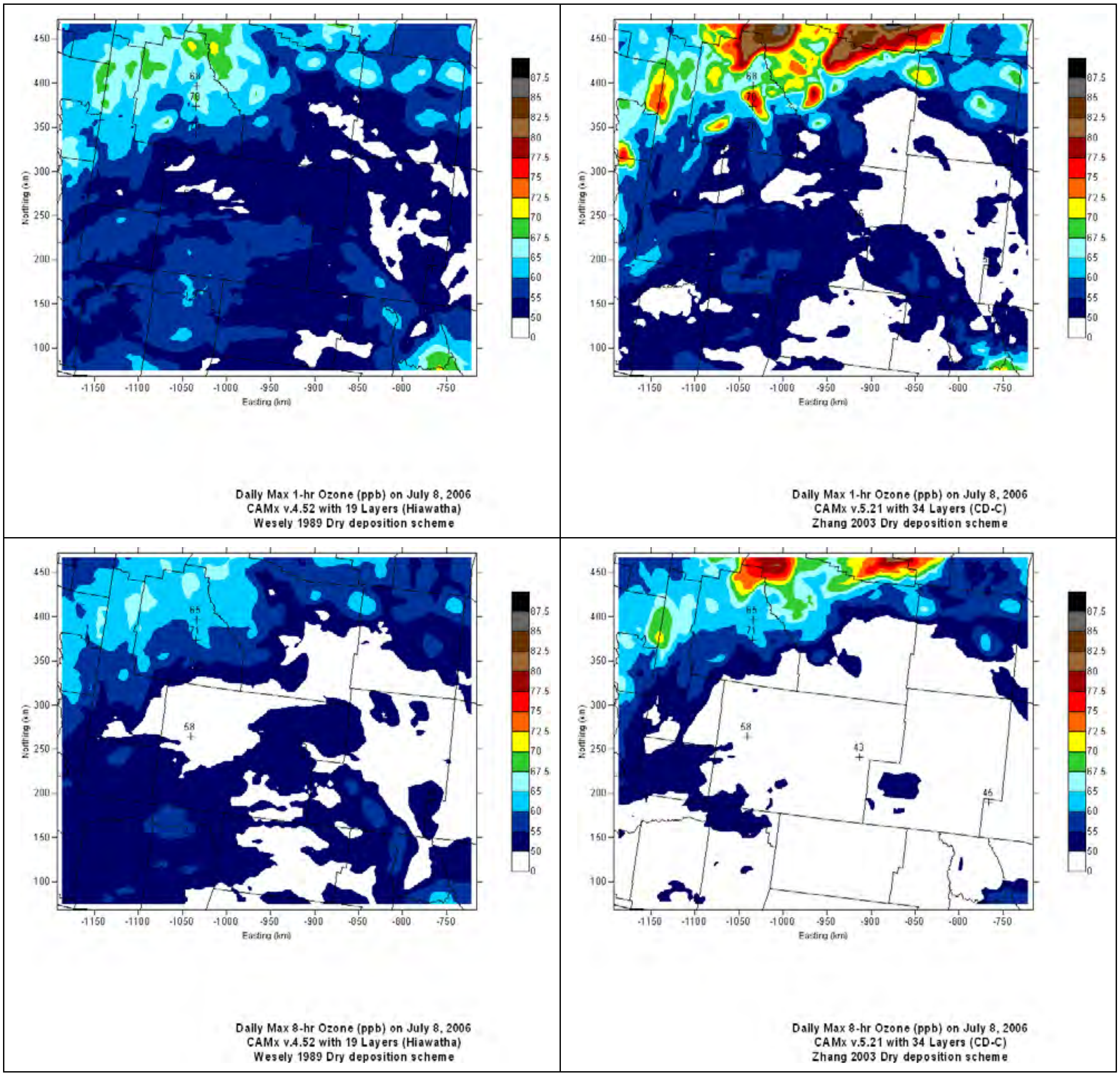


Figure A4-13j. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on July 8, 2006.

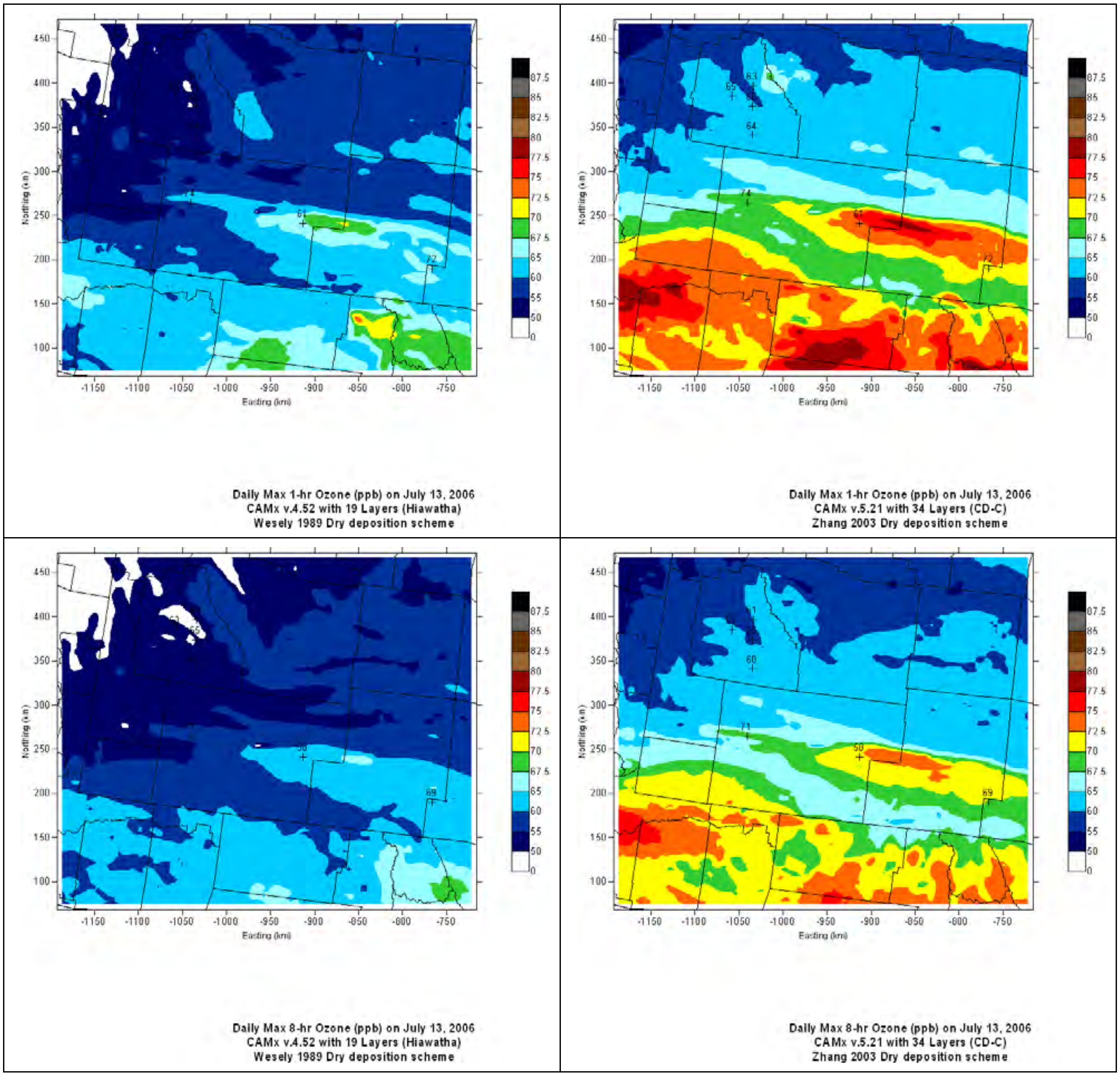


Figure A4-13k. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on July 13, 2006.

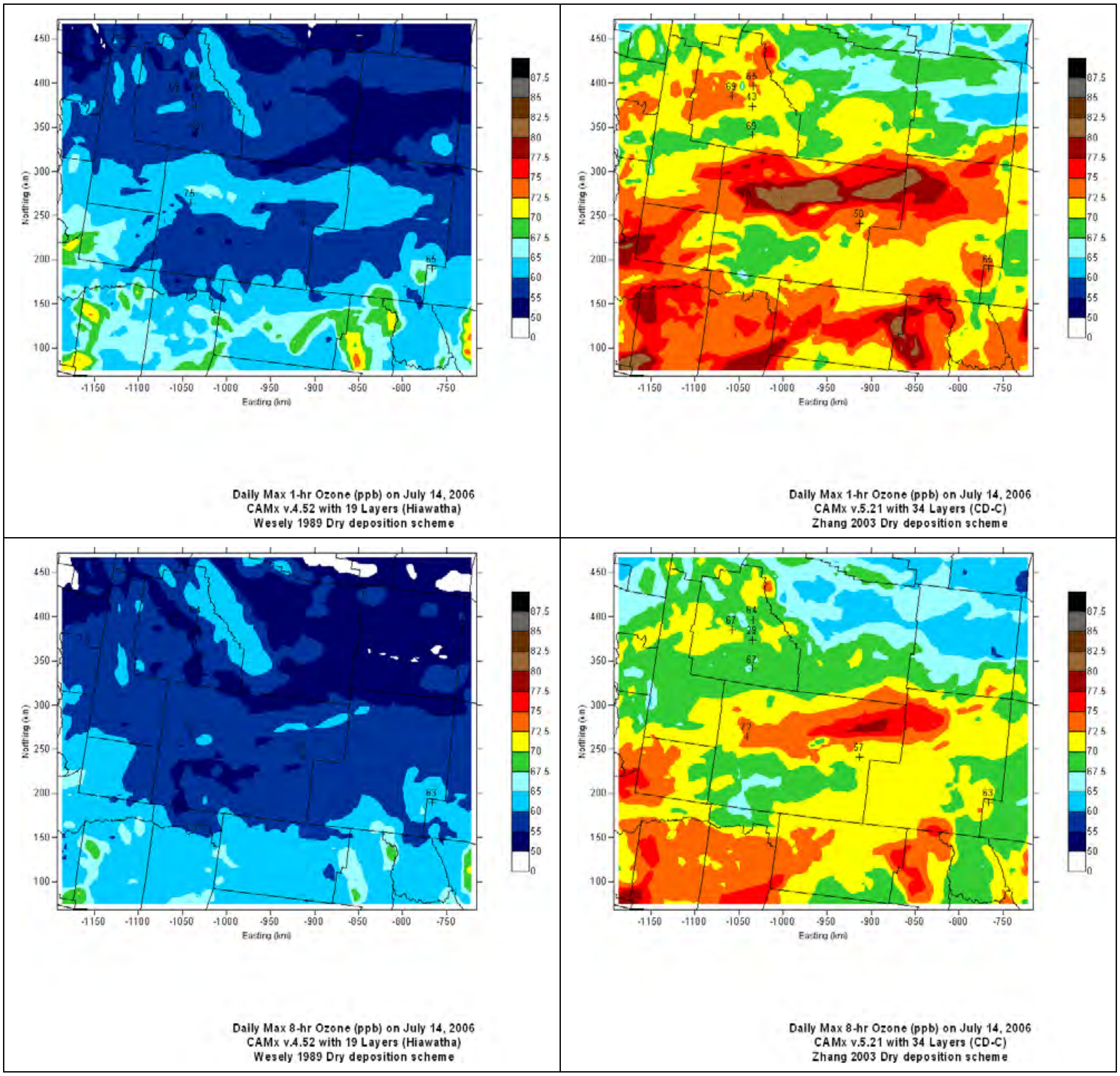


Figure A4-13l. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observations site within the 4 km domain on July 14, 2006.

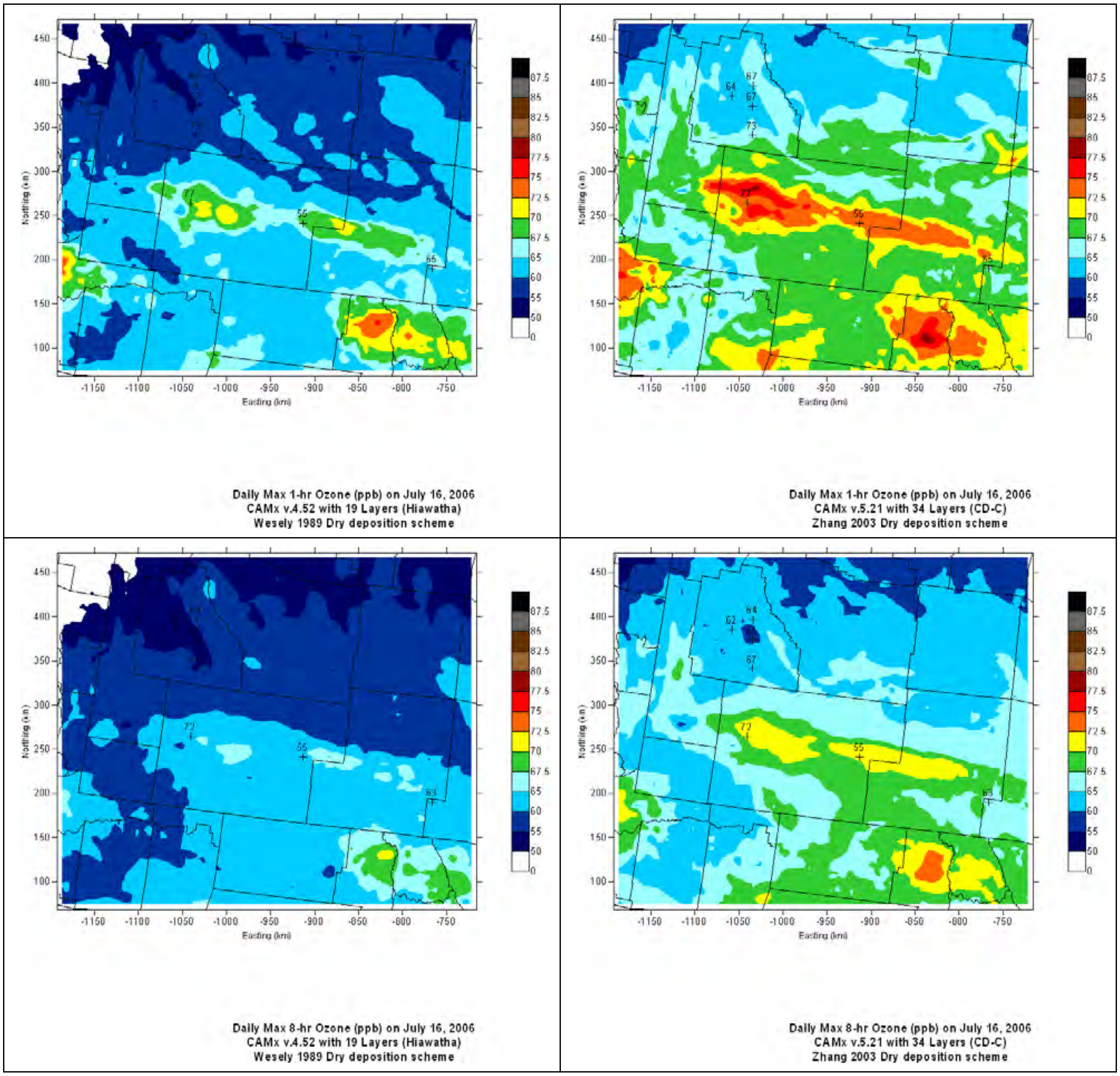


Figure A4-13m. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on July 16, 2006.

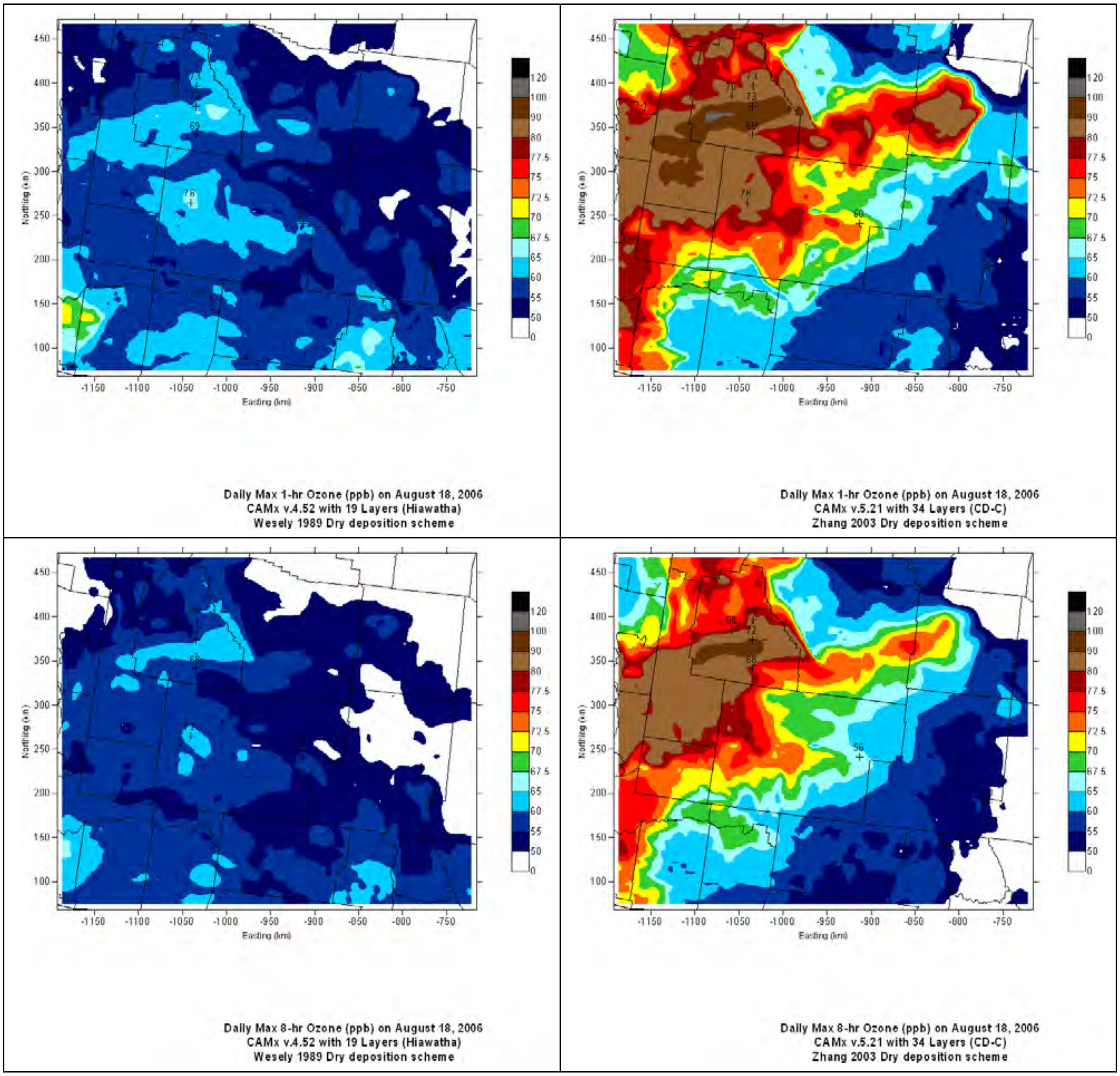


Figure A4-13n. Comparison of predicted daily maximum 1-hour (top) and 8-hour (bottom) ozone concentrations from Hiawatha (left) and CD-C (right) base case simulations with superimposed observation sites within the 4 km domain on August 18, 2006.

A4.7 COMPARISON OF 8-HOUR OZONE PERFORMANCE WITH MODEL PERFORMANCE GOALS

EPA's 1999 draft 8-hour ozone modeling guidance presented a useful performance goal that compares the observed daily maximum 8-hour ozone concentrations with modeled values "nearthe monitor", with the goal being that most of the observed and modeled values near the monitor be within ±20% of each other. This performance goal is particularly relevant because these are the very same modeled daily maximum 8-hour ozone concentrations near the monitor that are used in making 8-hour ozone projections. The Denver ozone SIP model evaluation (Morris et al., 2003; 2008) used three approaches for defining "near the monitor". For two of the approaches we define "near" as the same NX by NY array of cells centered on the monitor as used in EPA's procedures for making 8-hour ozone projections (e.g., 7 x 7 for 4 km and 3 x 3 km 12 km grid) and the two tests differ in only which estimated value is selected from this array of cells. For the third test, we select the estimated value at the monitor (i.e., spatially paired). The three methods for defining "near the monitor" are as follows:

> <u>Maximum</u>: Select the maximum estimated daily maximum 8-hour ozone concentration near the ozone monitor for each day. This is the same approach for selecting model daily maximum 8-hour ozone to construct relative response factors (RRFs) that are used in EPA's 8-hour ozone attainment test.
>
> <u>Closest</u>: Select the estimated daily maximum 8-hour ozone concentrations near the monitor that most closely matches the observed value.
>
> <u>Spatially Paired</u>: Select the estimated 8-hour ozone concentrations at the location of the monitoring site.

Table A4-5 summarizes the performance goal for daily maximum 8-hour ozone concentrations using these three approaches for "near the monitor".

Table A4-5.8-hour ozone model performance goal comparing observed daily maximum 8-hour ozone concentrations with predicted values "near the monitor" (EPA, 1999).

"Near The Monitor"	Threshold	Goal
Maximum modeled daily maximum 8-hour ozone concentrations within a 7 x 7 array of 4 km grid cells around monitor	<±20%	Most pairs within ±20%
Modeled daily maximum 8-hour ozone concentrations within a 7 x 7 array of 4 km grid cells around monitor that is closest to the observed value at the monitor.	<±20%	Most pairs within ±20%
Spatially Paired modeled daily maximum 8-hour ozone concentration at the location of the monitoring site	<±20%	Most pairs within ±20%

Figure A4-14 shows an example of how the three definitions of "near the monitor" are used in comparing observed and modeled values of 8-hour ozone. Consider a hypothetical ozone monitor located at center of a 3x3 array of 12km grid cells (within the central blue shaded cell). Assume that the monitor records a daily maximum 8-hour ozone value of 84 ppb within the center grid cell. The model output values of the daily maximum 8-hour ozone are shown in each grid cell, and red type indicates the modeled value selected by each method.

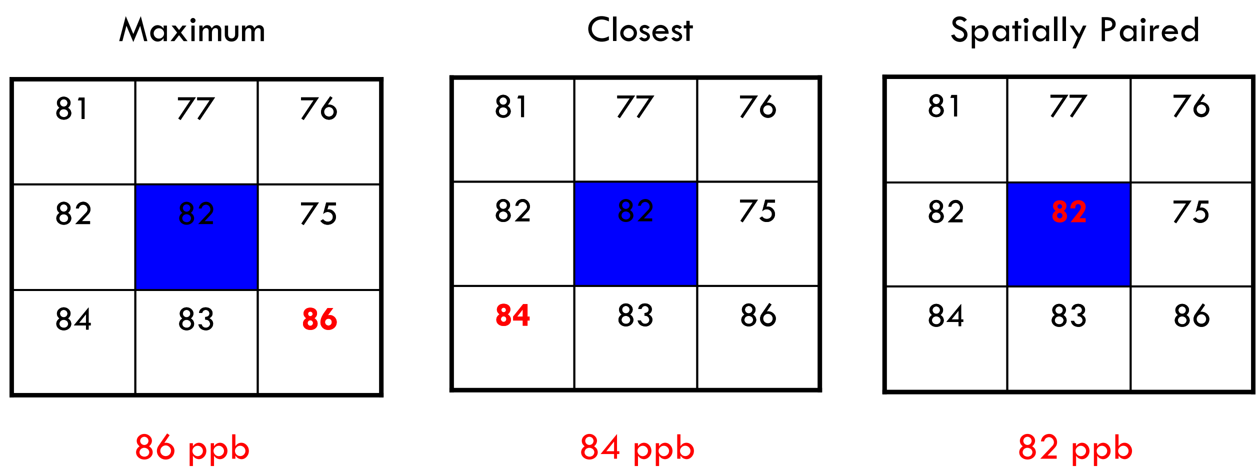


Figure A4-14. Example of comparison of observed and modeled 8-hour daily maximum ozone using the three methods described in Table A4-5. Each of the three grids represents a 3x3 array of 12 km model grid cells, and the blue shaded cell contains the monitor. Values shown in red type are the modeled value selected using each of the three methods for comparison with the observed value measured at the monitor.

The maximum method selects the highest value recorded anywhere within the 3 x 3 array, 86 ppb, while the closest method selects the closest modeled value to the observed value of 84 ppb, or 84 ppb. The spatially paired method selects the value in the blue shaded grid cell where the monitor is located. The spatially paired test is the most stringent, and the model performance statistics for this method with generally reflect higher values of bias and error than the closest method.

Tables A4-6 and 5-7 summarize the number of monitor-days and percent of the monitor-days in which the predicted and observed daily maximum 8-hour ozone concentrations are within ±20% of each other using all three definitions of near the monitor during the May-August periods during 2005 and 2006. During 2005 and using the maximum predicted ozone near the monitor, the Hiawatha base case estimated that the predicted daily maximum 8-hour ozone concentration is within ±20% of the observed value 82%-93% of the time for the four months examined. Similar results for 2005 and the CD-C base case are within ±20% 90%-96% of the time. Using the closest predicted value near the monitor results in modeled 8-hour ozone concentrations within ±20% of the observed values of 89%-97% for the Hiawatha and 93%-98% for the CD-C base case simulations. Finally, using the most stringent spatially paired definition of near the monitor, the Hiawatha and CD-C base case simulations estimate that the predicted 8-hour ozone concentrations is within ±20% of the observed value 74%-88% and 84%-91% of the time, respectively. Thus, in 2005 both the CD-C and Hiawatha base case simulations satisfy the EPA 8-hour ozone performance goal that the predicted daily maximum 8-hour ozone near the monitor is within of the observed value most of the time, with the CD-C base case simulation satisfying this performance goal more often than the Hiawatha base case simulation. Results for 2006 are similar, with both bases cases typically predicting they would match the observed daily maximum 8-hour ozone concentrations 80-90% of the time.

Figures A4-15 and 5-16 display scatter plots of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet and WDEQ sites within the 4 km domain for May through August in 2005 and 2006 using the Closest (Nearest) and Spatially Paired definition of “near the monitor”. The 1:1 line of perfect agreement is a dashed line and the envelope of within ±20% agreement is shown with a dotted line in Figures A4-15 and 5-16. The scatter plots show that most of the observed-modeled pairs fall within the ±20% agreement line and that there are no serious systematic flaws in model performance.

Table A4-6a.Summary of number of monitor-days predicted and observed daily maximum 8-hour ozone concentrations are within ±20% of each other using the three definitions of "near the monitor" for the 2005 CD-C and Hiawatha, 4 km domain, May-August 2005 and using the CASTNet network and WDEQ additional industrial sites.

2005	Maximum Near Monitor Within						Closest Near Monitor Within						Co-located with Monitor Within					
	Hiawatha			CD-C			Hiawatha			CD-C			Hiawatha			CD-C		
Month	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%
May	5	110	4	4	106	9	0	115	4	0	110	9	0	104	14	0	105	13
Jun	21	96	0	6	107	4	13	104	0	0	113	4	17	97	3	2	98	17
Jul	7	137	5	8	135	6	3	141	5	3	140	6	4	125	20	4	133	12
Aug	2	127	12	5	135	1	0	129	12	2	138	1	1	104	36	4	128	9

Table A4-6b. Summary of percent of the monitor-days predicted and observed daily maximum 8-hour ozone concentrations are within ±20% of each other using the three definitions of "near the monitor" for the 2005 CD-C and Hiawatha, 4 km domain, May-August 2005 and using the CASTNet network and WDEQ additional industrial sites.

2005	Maximum Near Monitor Within						Closest Near Monitor Within						Co-located with Monitor Within					
	Hiawatha			CD-C			Hiawatha			CD-C			Hiawatha			CD-C		
Month	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%
May	4%	93%	3%	3%	90%	8%	0%	97%	3%	0%	93%	8%	0%	88%	12%	0%	89%	11%
Jun	18%	82%	0%	5%	91%	3%	11%	89%	0%	0%	97%	3%	15%	83%	3%	2%	84%	15%
Jul	5%	92%	3%	5%	91%	4%	2%	95%	3%	2%	94%	4%	3%	84%	13%	3%	89%	8%
Aug	1%	90%	9%	4%	96%	1%	0%	91%	9%	1%	98%	1%	1%	74%	26%	3%	91%	6%

Table A4-7a. Summary of number of monitor-days predicted and observed daily maximum 8-hour ozone concentrations are within ±20% of each other using the three definitions of "near the monitor" for the 2006CD-C and Hiawatha, 4 km domain, May-August 2006 and using the CASTNet network and WDEQ additional industrial sites.

2006	Maximum Near Monitor Within						Closest Near Monitor Within						Co-located with Monitor Within					
	Hiawatha			CD-C			Hiawatha			CD-C			Hiawatha			CD-C		
Month	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%
May	6	190	5	13	177	11	2	194	5	0	190	11	4	185	12	4	177	20
Jun	27	146	6	3	172	4	10	163	6	1	174	4	19	150	10	1	164	14
Jul	21	174	1	20	171	5	11	184	1	15	176	5	18	172	6	18	163	15
Aug	16	179	0	41	154	0	6	189	0	15	180	0	11	172	12	26	162	7

Table A4-7b. Summary of percent of the monitor-days predicted and observed daily maximum 8-hour ozone concentrations are within ±20% of each other using the three definitions of "near the monitor" for the 2006CD-C and Hiawatha, 4 km domain, May-August 2006 and using the CASTNet network and WDEQ additional industrial sites.

2006	Maximum Near Monitor Within						Closest Near Monitor Within						Co-located with Monitor Within					
	Hiawatha			CD-C			Hiawatha			CD-C			Hiawatha			CD-C		
Month	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%	>+20%	20%	<-20%
May	3%	95%	2%	6%	88%	5%	1%	97%	2%	0%	95%	5%	2%	92%	6%	2%	88%	10%
Jun	15%	82%	3%	2%	96%	2%	6%	91%	3%	1%	97%	2%	11%	84%	6%	1%	92%	8%
Jul	11%	89%	1%	10%	87%	3%	6%	94%	1%	8%	90%	3%	9%	88%	3%	9%	83%	8%
Aug	8%	92%	0%	21%	79%	0%	3%	97%	0%	8%	92%	0%	6%	88%	6%	13%	83%	4%

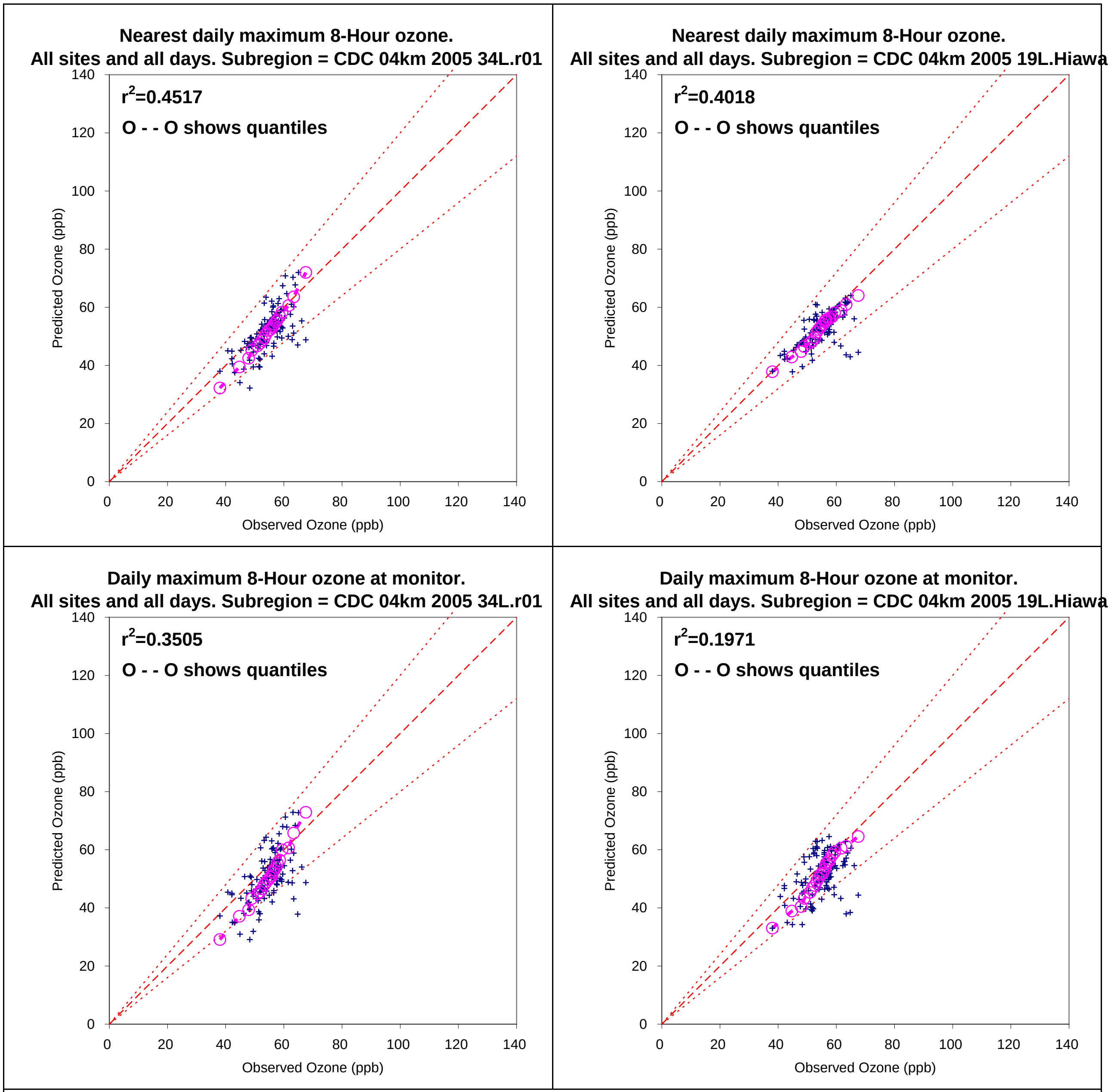


Figure A4-15a. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for May 2005.

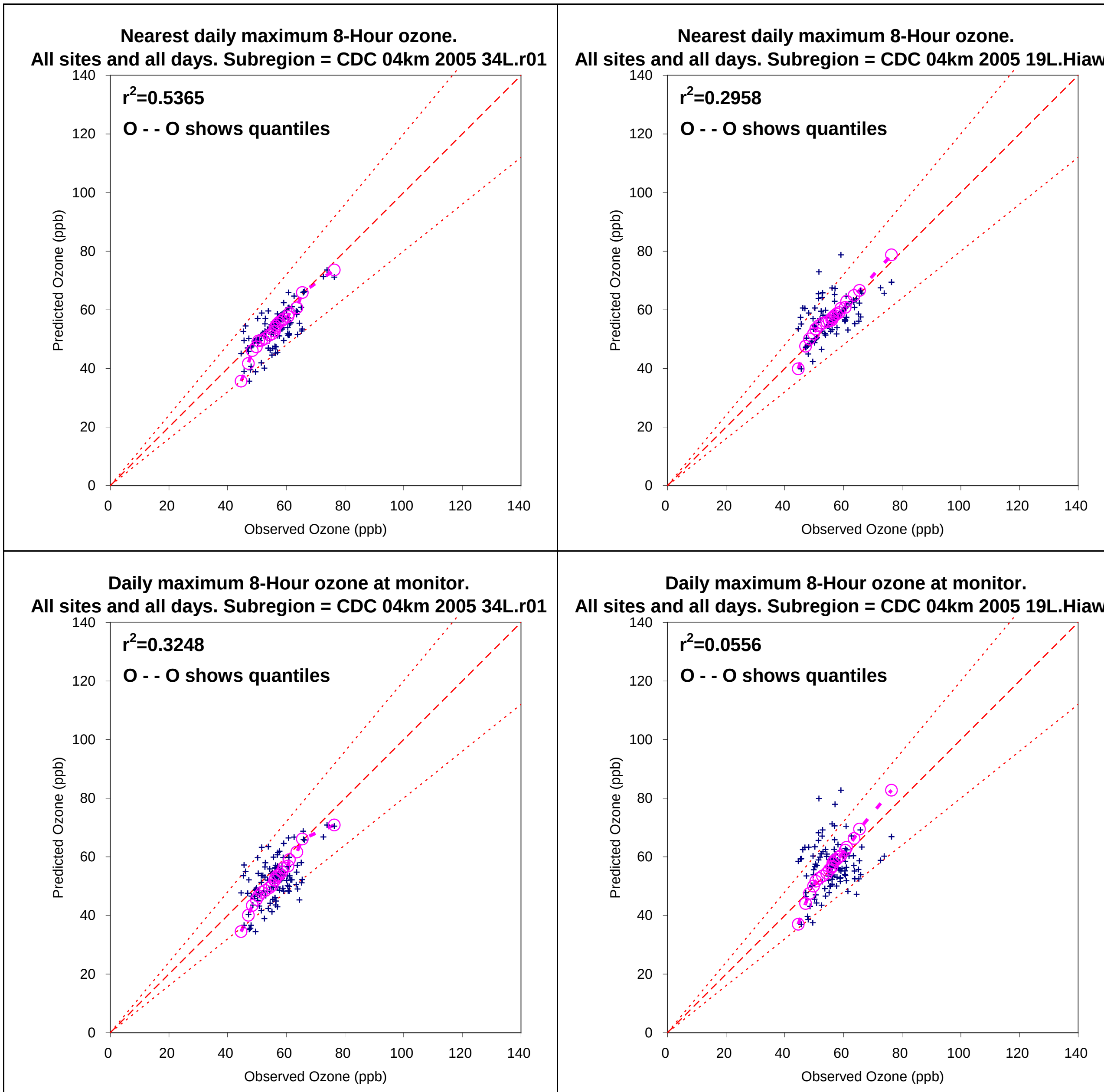


Figure A4-15b. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for June 2005.

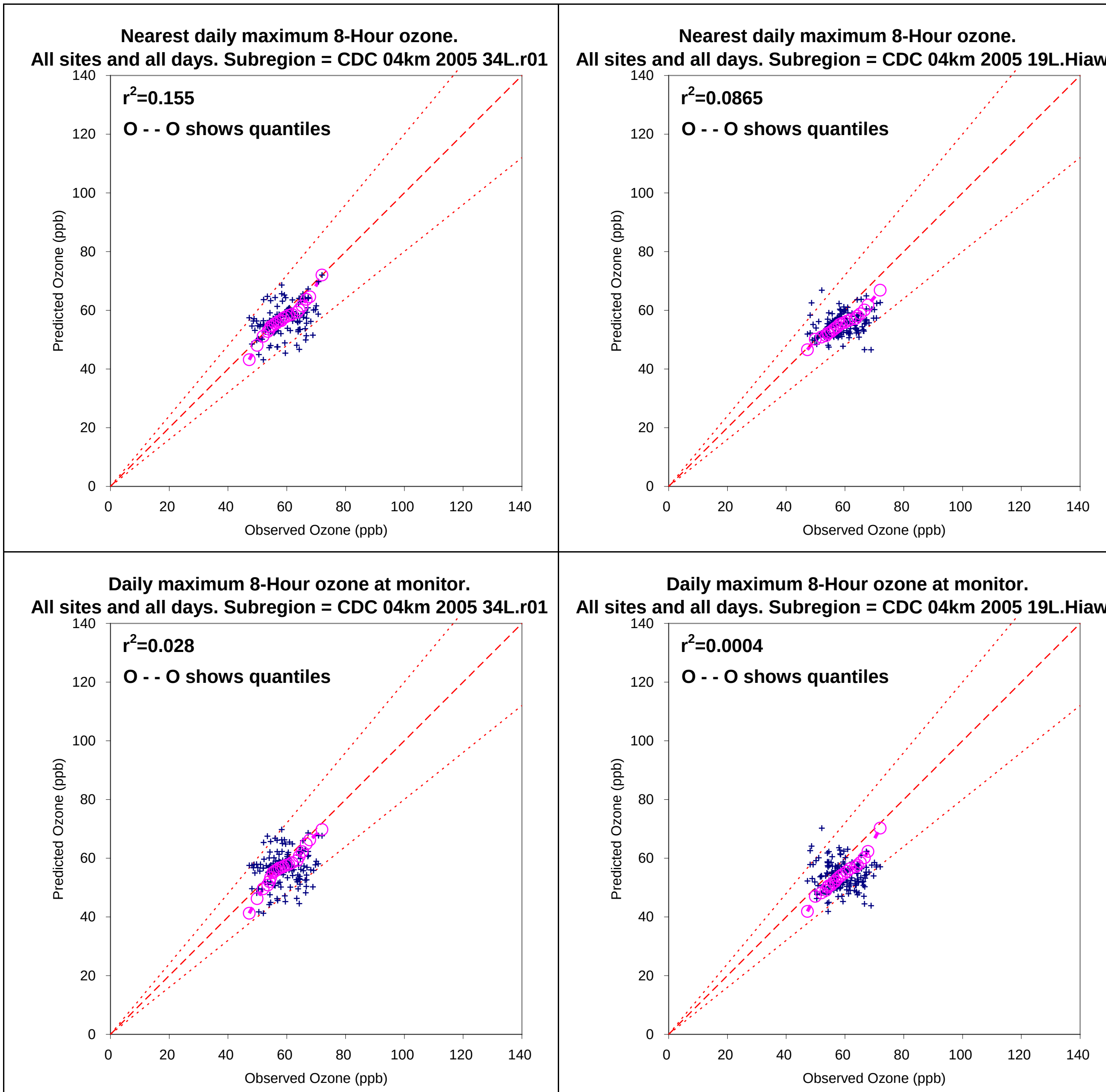


Figure A4-15c. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for July 2005.

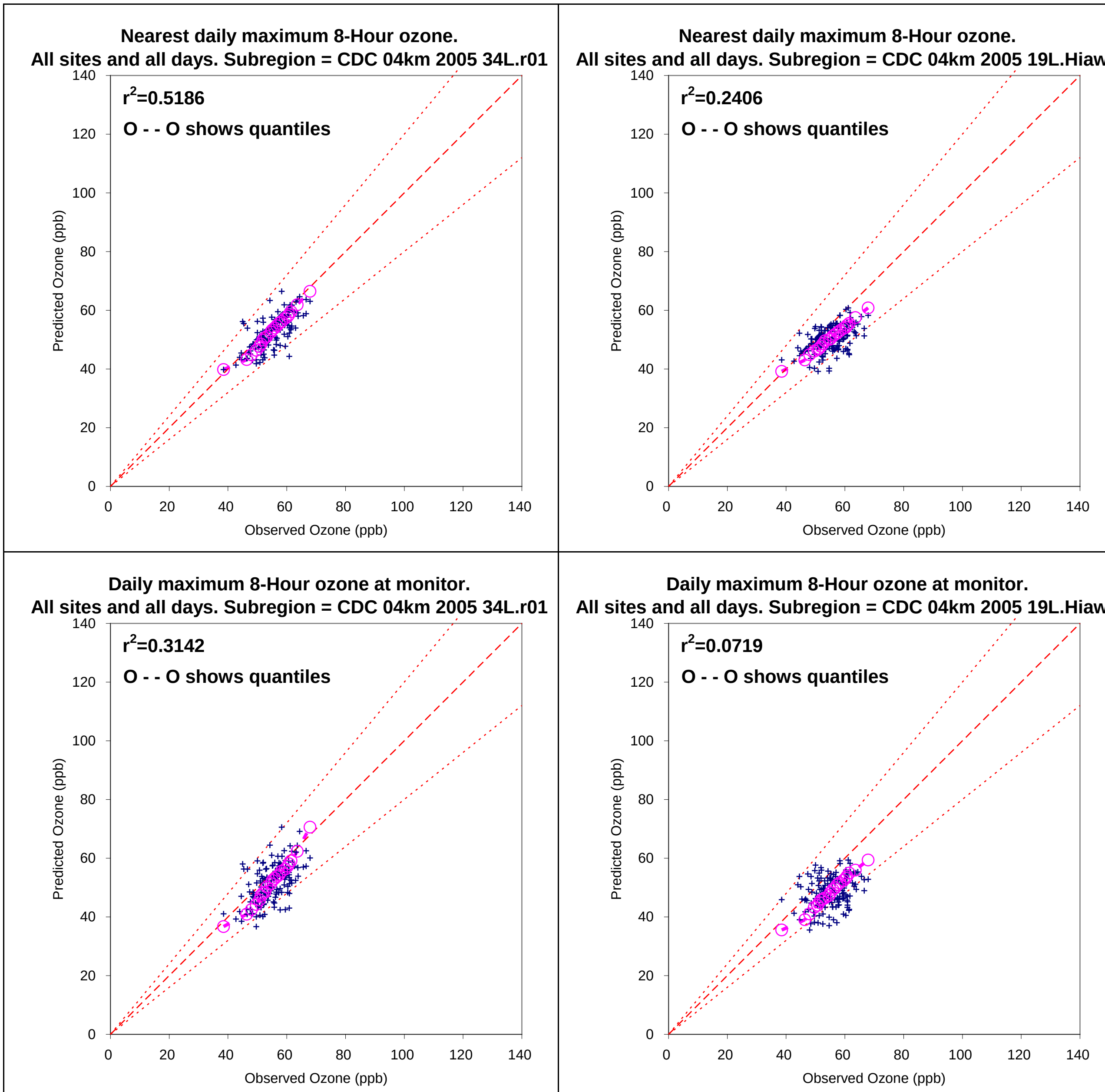


Figure A4-15d. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for August 2005.

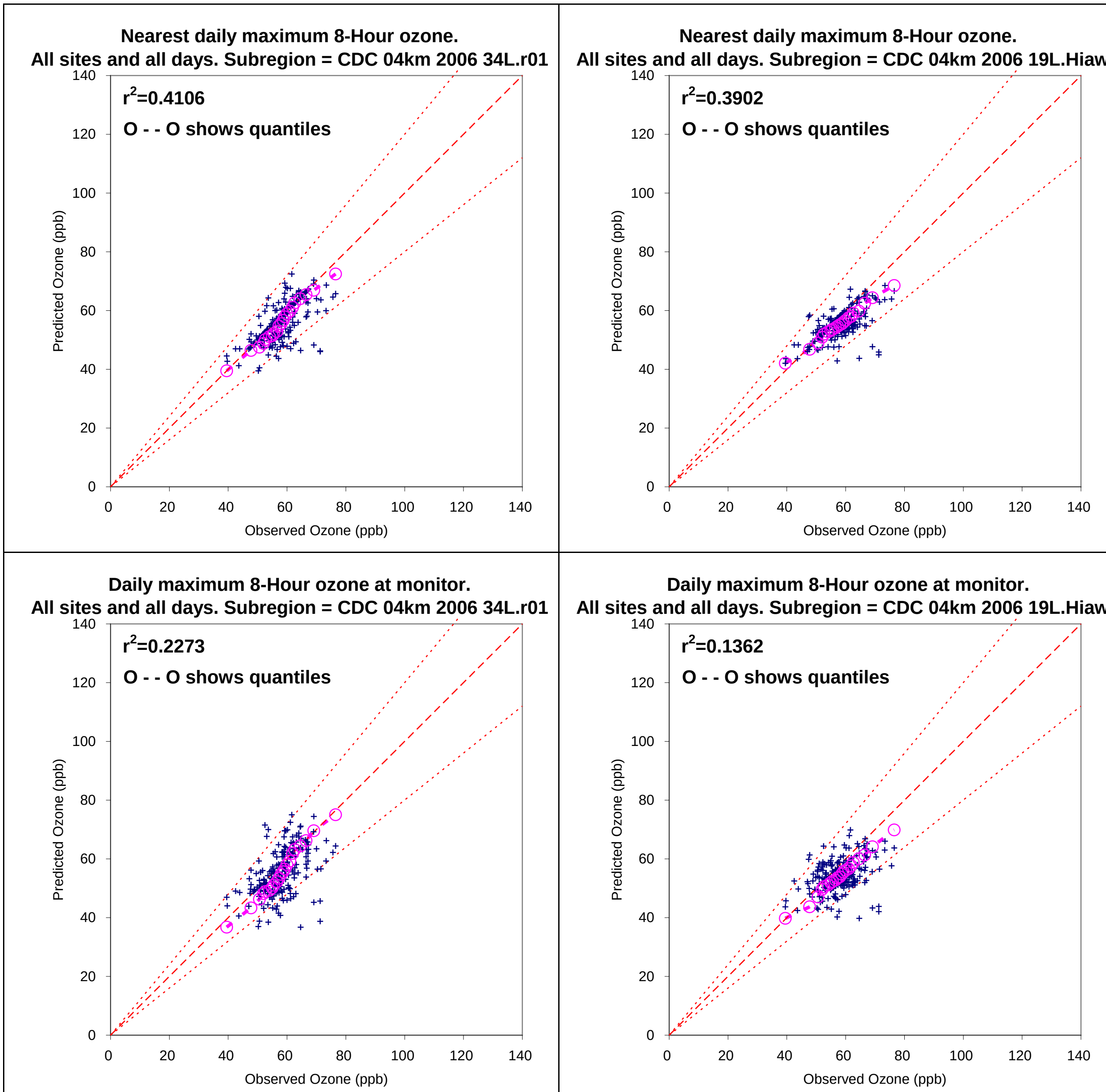


Figure A4-16a. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for May 2006.

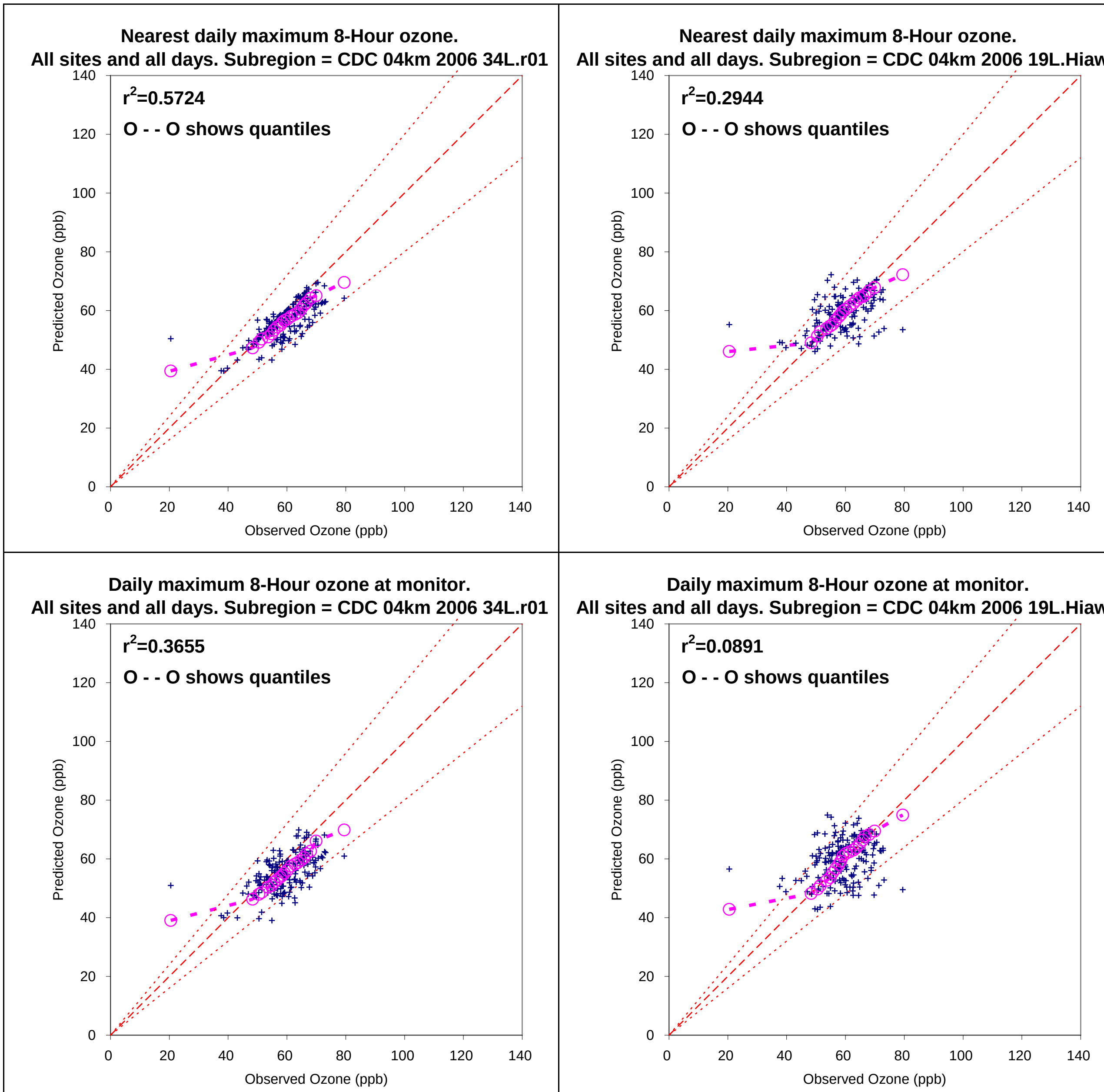


Figure A4-16b. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for June 2006.

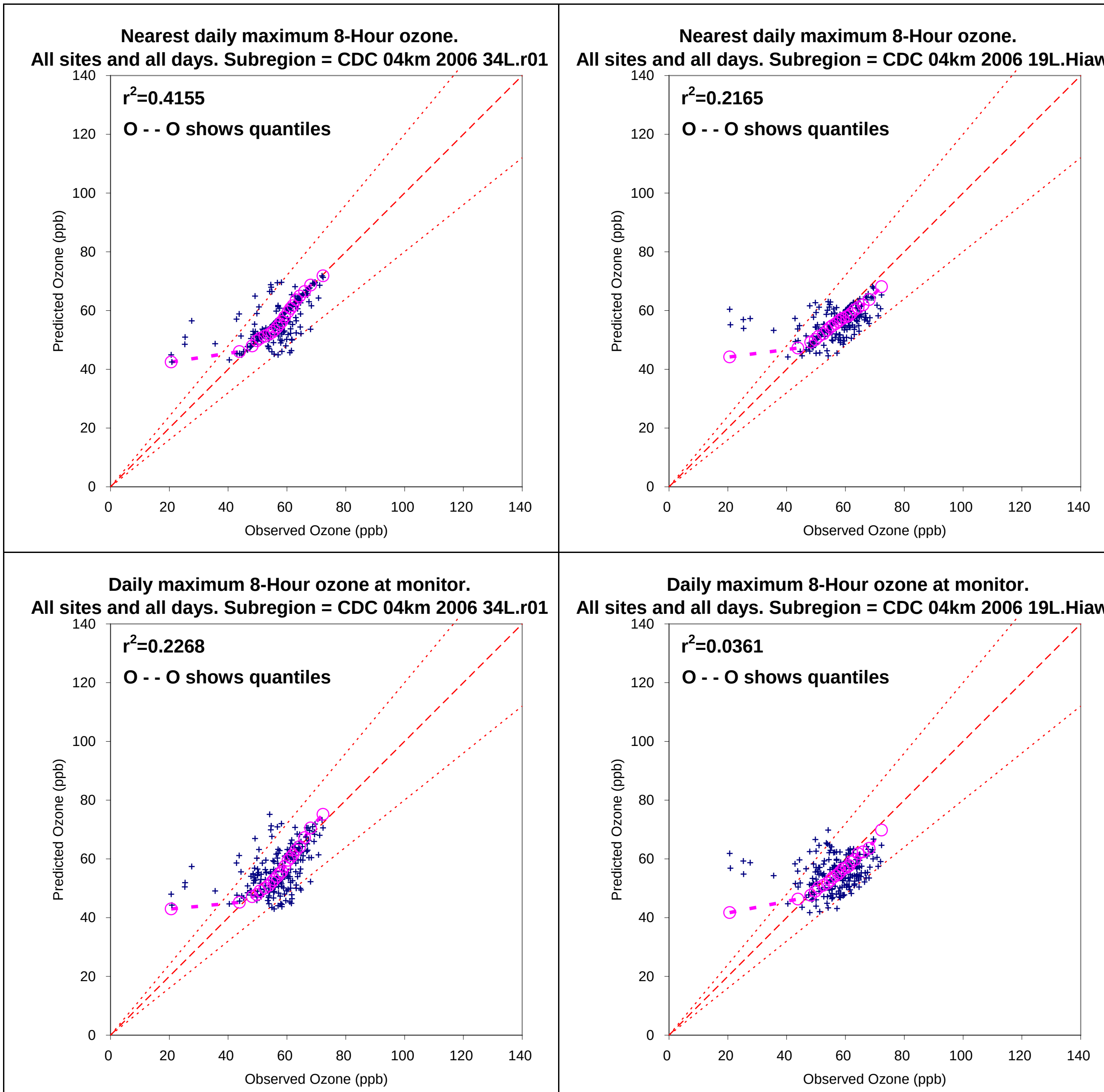


Figure A4-16c. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for July 2006.

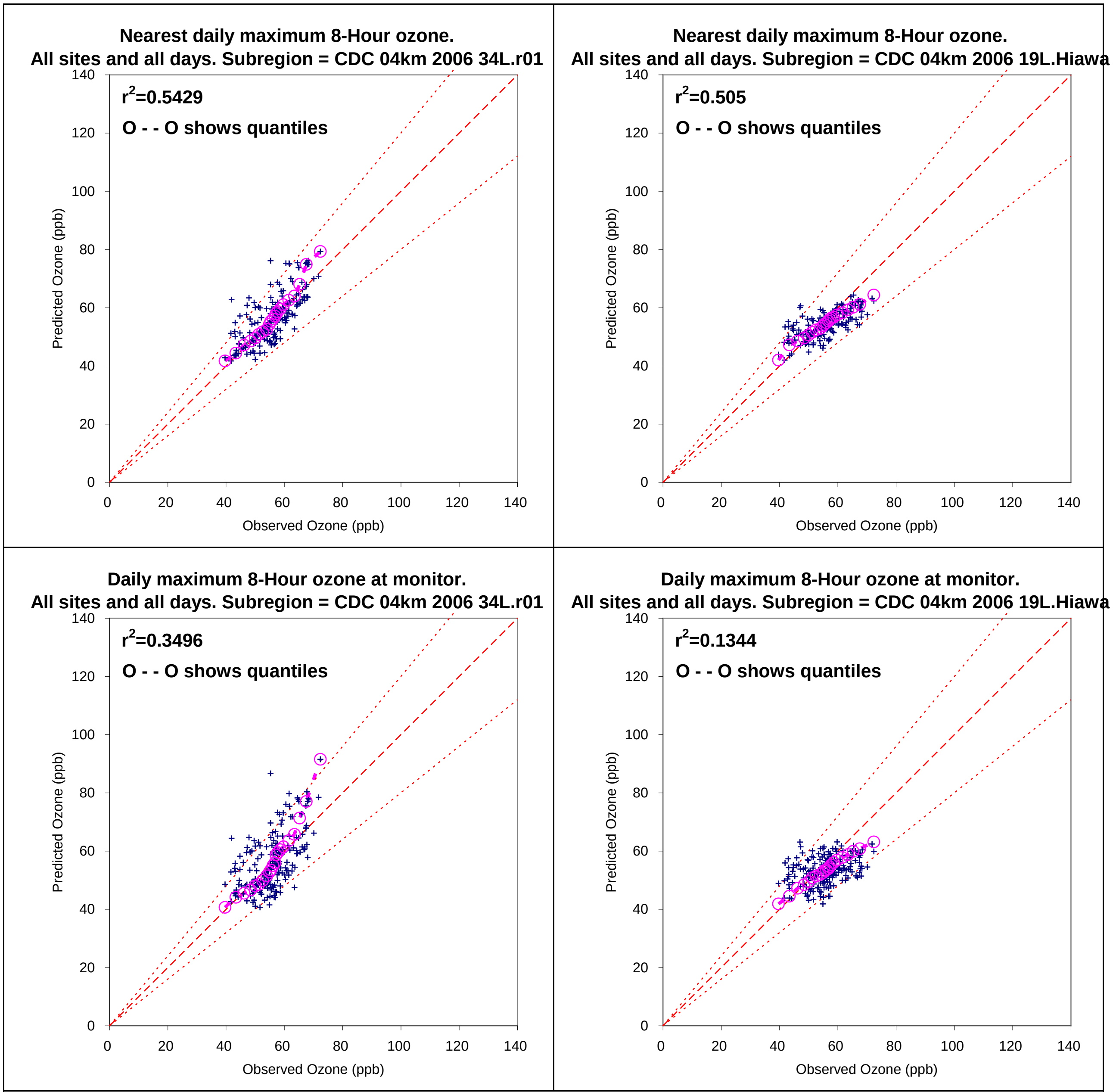


Figure A4-16d. Comparison of predicted and observed daily maximum 8-hour ozone concentrations at CASTNet (top) and WDEQ (bottom) monitoring sites within 4 km domain for August 2006.

A4.8 FOURTH HIGHEST DAILY MAXIMUM 8-HOUR OZONE CONCENTRATION COMPARISONS

The 8-hour ozone National Ambient Air Quality Standard (NAAQS) is based on the three year average of the 4th highest daily maximum 8-hour ozone concentrations. The 1997 ozone NAAQS specified a threshold of 0.08 ppm (85 ppb) that was revised to 0.075 ppm (76 ppb) in March 2008. In January 2010 EPA proposed to revise the ozone NAAQS further to a threshold in the 0.060-0.070 ppm range, but keeping the same form of the NAAQS. Thus, an important ozone performance issue when projecting the future year CAMx absolute modeling results is the simulation of the fourth highest daily maximum 8-hour ozone concentration. Figure A4-17 shows the modeled 4th highest daily maximum 8-hour ozone concentration at each grid cell in the 4 km domain (Figure A4-17a) and the 12 km grid (Figure A4-17b) for the 2005 and 2006 years, the Hiawatha and CD-C CAMx base case simulations and Quarters 2, 3 and 4. Quarter 1 was excluded in this analysis due to the presence of wintertime high ozone concentrations that the WDEQ/AQD has advised us to not account for at this time. Figure A4-17 shows that modeled ozone in the 4 km domain was generally higher in 2006 than in 2005 and higher in the CD-C than Hiawatha base case simulations. The Q2-Q4 observed fourth highest daily maximum 8-hour ozone concentrations in Sublette County are in the 67-69 ppb range in 2005, compared to modeled values in the 60-65 ppb and 65-70 ppb ranges for the, respectively, Hiawatha and CD-C base case simulations (Figure A4-17a, top). Similar results in Sublette County for the 2006 model year were observed values in the 68-73 ppb range and predicted values in the 65-72.5 range for the Hiawatha and 70-77.5 ppb range for the CD-C base case simulations. Thus, in Sublette County the Hiawatha base case is underestimating the observed 4th highest ozone in 2005 with values closer to the observations in 2006 and the CD-C base case matches the observe 4th highest values in 2005 and overestimates in 2006.

At the Centennial monitoring site in 2005 (Figure A4-17a, top), the observed 4th highest 8-hour ozone concentration is 67 ppb and the Hiawatha base case predicts values in the 70-72.5 ppb range with the CD-C base case predicting closer values of ~67.5 ppb. In 2006 both base cases predict 4th highest 8-hour ozone in the 70-72.5 ppb range that is close to what was observed (70 ppb). The observed ozone concentrations at the OCI (72 ppb) site in 2006 is underestimated by the Hiawatha (67.5-70 ppb) and reproduced better by the CD-C (72.5-75 ppb) base case simulations. Whereas for the Wamsutter site the reverse is true with the Hiawatha base case (67.5-70 ppb) matching the observed value (67 ppb) better and the CD-C base case that overestimates (72.5-75 ppb).

Figure A4-17b compares isopleths of the CAMx-estimated fourth highest daily maximum 8-hour ozone concentration with the observed values (numbers) from the CASTNet network for 2005 and 2006 within the 12 km grid. At Yellowstone NP in Wyoming, the observed fourth highest 8-hour ozone concentrations were 60 in 2005 and 70 in 2006. The Hiawatha base case predicts values to be in the 60-67.5 ppb range for both years, whereas the CD-C base case predicts values in the 60-65 ppb in 2005 and ~77.5 ppb in 2006.

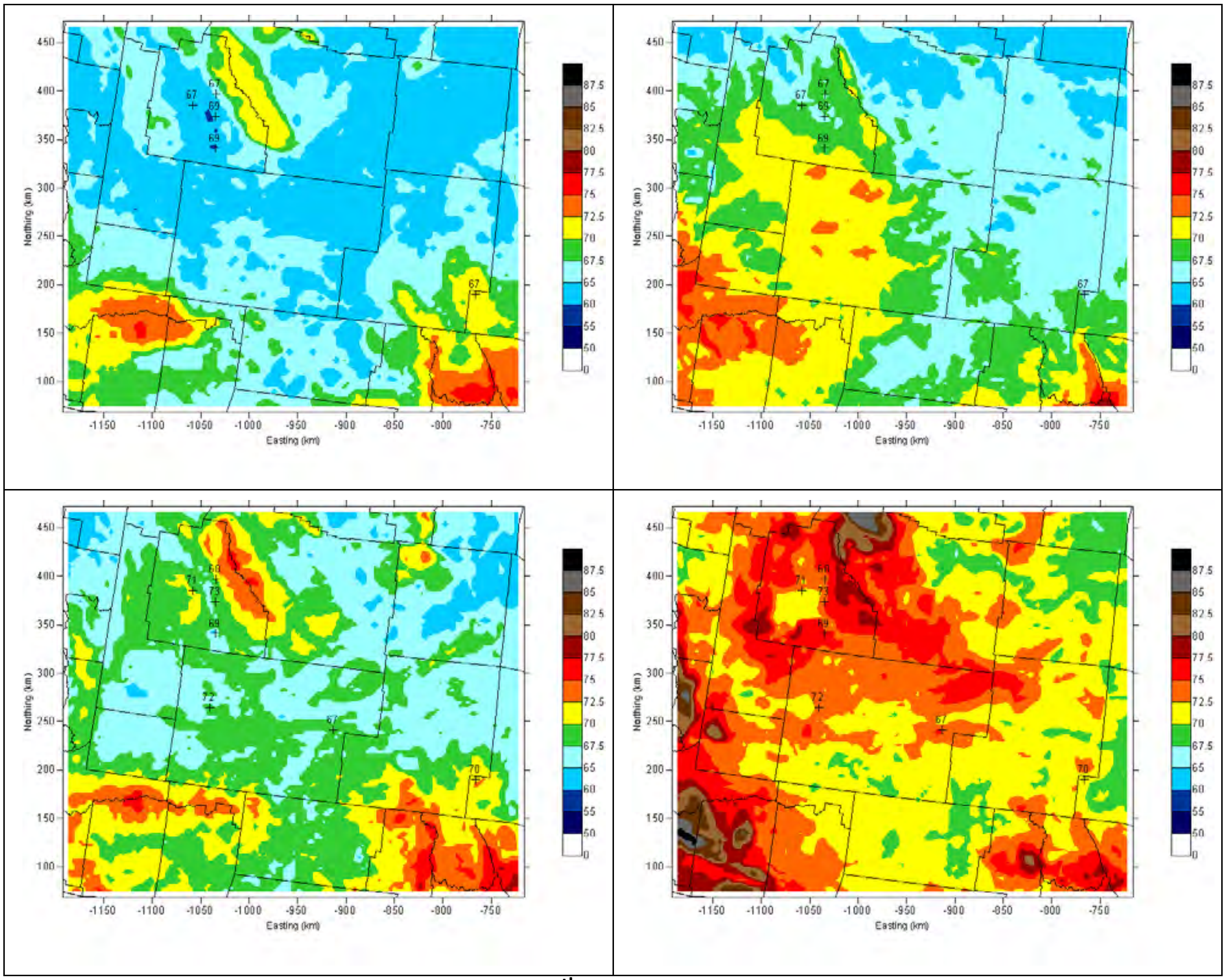


Figure A4-17a. Comparison of predicted 4th highest daily maximum 8-hour ozone concentrations from Hiawatha (left) and CD-C (right) simulations during Q2-Q4 with superimposed observed values at CASTNet and WDEQ industrial sites within 4 km domain for 2005 (top) and 2006 (bottom) years.

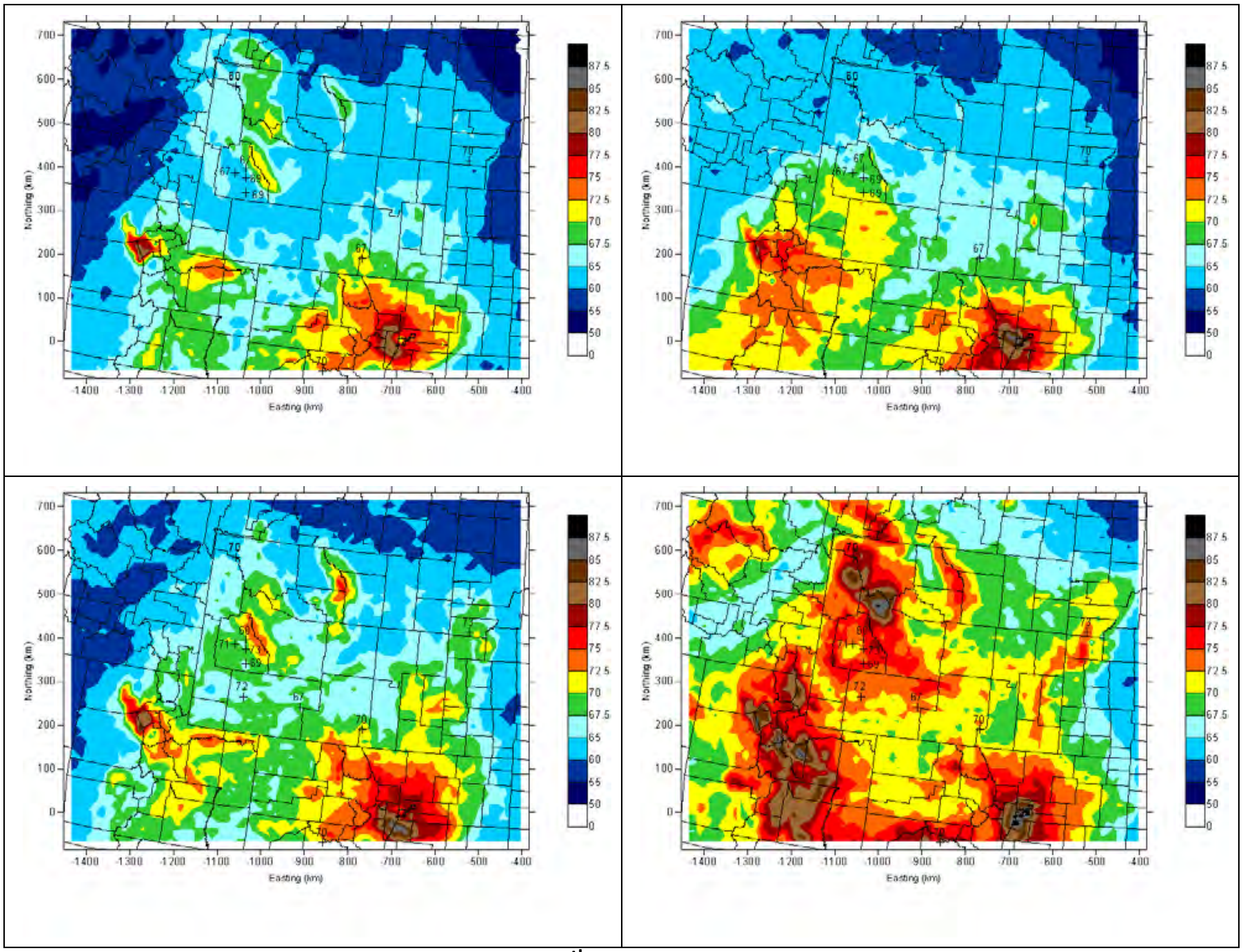


Figure A4-17b. Comparison of predicted 4th highest daily maximum 8-hour ozone concentrations from Hiawatha (left) and CD-C (right) simulations during Q2-Q4 with superimposed observed values at CASTNet and WDEQ industrial sites within 12 km domain for 2005 (top) and 2006 (bottom) years.

A4.9 SUMMARY OF OZONE PERFORMANCE ON 12/4 KM GRIDS

The original CAMx 2005 and 2006 base case simulation performed under the Hiawatha EIS mostly achieved EPA's model performance goals but with an underpredictions bias. This underprediction bias was most pronounced at the southwest Wyoming industrial sites in SubletteCounty. Based on the results of a series of diagnostic sensitivity tests (Appendix E), the configuration of the CAMx modeling system was revised and an updated base case simulation conducted under the CD-C EIS. The revised CD-C base case simulation generally exhibited better ozone model performance at the Sublette County monitoring sites and achieved EPA's performance goals more frequently than the preliminary Hiawatha base case simulation.

A5.12/4 KM GRID PM MODEL PERFORMANCE EVALUATION

This Section summarizes the CAMx 2005 and 2006 Base Case model performance evaluation for particulate matter (PM_{10} and $PM_{2.5}$) and their component species in the 12 km and 4 km modeling domains. The CAMx base case model performance performed under the CD-C study is compared with the preliminary CAMx base case performed under the Hiawatha study (Kemball-Cook et al., 2009). The CAMx modeling results were compared with observational data from the **I**nteragency **M**onitoring of **PRO**tected **V**isual **E**nvironments (IMPROVE), **S**peciated **T**rends **N**etwork (STN)5, **C**lean **A**ir **S**tatus **T**rends **Net**work (CASTNet), **F**ederal **R**eference **M**ethod (FRM) $PM_{2.5}$ mass, and **N**ational **A**cid **D**eposition **P**rogram (NADP) monitoring networks. The evaluation focuses on the operational model evaluation of the air quality model's performance with respect to the individual components of PM_{10} and fine ($PM_{2.5}$), particulate matter as well as total PM_{10} and $PM_{2.5}$ mass.These component species are NO3, SO4, OCM, EC, Soil, CM,and NH4. Some elements from a diagnostic evaluation analysis of the ability of the model to reproduce gaseous PM precursor (e.g., SO2 and NH3) and product (e.g., HNO3) species were also carried out.

Model performance was evaluated by quarter, using scatter plots showing observed versus modeled values for all monitors and all days along with quarterly bias and error statistics. Examining performance by quarter affords an overview of model performance, and shows seasonal trends in model performance. Model performance was also evaluated by month using monthly time series bar charts and bugle plots comparing model performance with PM performance goals that are a continuous function of average concentration. Monthly evaluation shows detailed changes in model performance with time of year. For species that are expected to play a critical role in the CD-C impact assessment (e.g. NO3 and SO4), the CAMx performance in the CD-C 2005-2006 modeling was compared with preliminary CAMx base case performed under the Hiawatha study.

Within the 4 km grid there are two IMPROVE monitoring sites [Bridger (BRID) and Mount Zirkel (MOZI)] and two CASTNet monitoring sites (Pinedale and Centennial, WY). No STN sites were available within the 4 km grid. The 12 km grid contained 12 IMPROVE sites: Bridger (BRID), Mount Zirkel (MOZI), Cloud Peak (CLPE), North Absaroka (NOAB), White River (WHRI), Wind Cave (WICA), Craters of the Moon (CRMO), Crescent Lake (CRES), Northern Cheyenne (NOCH), Sawtooth (SAWT), Yellowstone (YELL), Thunder Basin (THBA), Rocky Mountain NP headquarters (RMHQ). Also within the 12 km grid were 5 CASTNet Sites: Pinedale (PND), Centennial (CNT), Gothic (GTH), Rocky Mountain (ROM), and Yellowstone (YEL). There were 3 STN sites in the 12 km domain that were located in the greater Salt Lake City and Denver Metro Areas.

A5.1 SULFATE MODEL PERFORMANCE

Figures A5-1 and A5-2 display scatter plots of predicted and observed sulfate (SO4) and related compounds (e.g., gaseous SO2 and wet SO4 deposition) by quarter for sites within the 12 km domain for the 2005 and 2006 modeling years, respectively. The Figures also include the mean fractional bias (MFB) and mean fractional error (MFE) statistical performance metrics that can be compared with the performance goals (Table A2-3). In these figures, the results for the 34

[5] The STN network is now referred to as the Chemical Speciation Network (CSN)

layer CD-C CAMx base case simulation are shown in red (34L.r01), whereas the results for the preliminary Hiawatha 19 layer CAMx base case simulation are shown in blue (19L.Hiawa). For both the IMPROVE (Figure A5-1a) and CASTNet (Figure A5-1b) monitoring networks, CAMx SO4 performance from both base case simulations achieve PM bias/error performance criteria (≤±60%/≤75%) for all quarters. In 2005, both CAMx base case simulations SO4 bias achieves the PM performance goal (≤±30%) at the IMPROVE sites for Q2 and Q3 and the error achieves the PM performance goal (≤50%) in Q3 (Figure A5-1a). At the CASTNET sites (Figure A5-1b), both base case simulations achieve or nearly achieve the PM error performance goal for all four Quarters and SO4, but neither base case simulations achieves the bias PM performance goal for any Quarter in 2005. Although the SO4 performance in 2005 across the CASTNet monitoring sites does achieve the PM performance criteria for both bias and error and the CD-C and Hiawatha base case simulations. At the STN sites in 2005 (Figure A5-1c), SO4 model performance was better at the CASTNet and IMPROVE monitoring sites for both base case simulations with the CD-C and Hiawatha CAMx base case simulations achieving the PM performance goal for bias/error (≤±30%/≤50%) during Q1 and Q4. CD-C base case SO4 performance at the STN sites in 2005 was better than the Hiawatha base case as the CD-C SO4 bias achieved the bias performance goal in Q3 and error performance goal in Q2, but the Hiawatha base case simulation did not. However, both base case simulations' 2005 SO4 bias and error performance achieves the PM performance criteria for all four quarters.

For 2005 and SO2 model performance (Figure A5-1d), CD-C base case mostly exhibits better performance than the Hiawatha base case, but both models are performing fairly well. Both models are within the PM performance goal for bias/error during Q2, Q3, and Q4 and are within the goal for bias during Q1. The error from both models during Q1 is well within performance criteria (≤75%) with SO2 error of 53% and 57% for the CD-C and Hiawatha base case simulations, respectively. The SO2 performance at the CASTNet sites showed smaller absolute values of bias than SO4 and values of error for SO2 that were comparable to those of SO4 at the CASTNet sites.

The 2005 SO4 wet deposition model performance (Figure A5-1e) measured at the NADP sites shows both base case simulations achieving the bias performance goal during Q1 and Q3 and achieving the bias performance criteria during Q2 and Q4, but fail to achieve the criteria for error for any of the four quarters of 2005, except for CD-C base case during Q2. Simulation of wet deposition is a particularly challenging task for the model as it depends not only on predicting SO4 concentrations correctly, but also on accurate reproduction of the precipitation fields predicted by the meteorological model. For example, a monitoring site may be affected by rainfall from a thunderstorm that is a few kilometers wide, causing sulfate deposition at the site while nearby areas are unaffected. If the meteorological model places the storm a few grid cells away from the monitor and/or times the rainfall incorrectly, the sulfate deposition performance will suffer. The large values of error seen in the wet deposition model performance statistics are therefore due partly to the simulation of rainfall. The negative values of bias for all quarters of 2005 indicate that CAMx consistently underestimated the wet deposition of sulfate. The underestimate of wet deposition during summer is consistent with the model's tendency to underpredict summer SO4 concentrations.The reasons for the underestimate of SO4 wet deposition during winter, when the model has positive biases for SO4 concentrations at both the CASTNet and IMPROVE sites, are less clear.

In 2006, the two base case simulations' SO4 performance achieves the PM bias/error performance goal for Q2 and Q3 across the IMPROVE network and achieves the PM performance criteria for Q1, Q2, and Q3 (Figure A5-2a). For Q4, the CD-C base case 2006 SO4 error was within the PM performance criteria, whereas the Hiawatha base case did not with both models exhibiting a large SO4 overestimation bias (65% for CD-C and 70% for Hiawatha) that falls outside of the PM performance criteria (≤±60%). Similar good SO4 performance is seen across the CASTNet monitoring sites in the 12 km domain for both base case simulations with the PM performance goal for bias/error (≤±30%/≤50%) being achieved for Q1 and Q3 and the PM performance criteria achieved throughout the year (Figure A5-2b). At the STN sites (Figure A5-2c), the 2006 SO4 model performance for both base case simulations achieves the bias/error performance goal for Q1 and Q3, and achieves only the error performance goal during Q2 and Q4 except the CD-C performance is within bias goal for Q4; the PM performance criteria is achieved throughout the year by both base case simulations. Performance for SO2 at the CASTNet sites is fairly good with the two base case simulations achieving the PM performance goal for Q1, Q2, and Q4, and the PM criteria for all four quarters (Figure A5-2d). Similar to 2005, 2006 SO2 performance is marked by a low bias and large error, indicating that the model does not have a systematic tendency to under- or overestimate SO2, but that there is considerable scatter of the observed/modeled pairs about the 1:1 line. As in 2005, wet SO4 deposition is underpredicted across the NADP sites in the 12 km domain for 2006 (Figure A5-2e). The model achieves the goal for bias for Q1 and Q3, and achieves the criteria during Q2 and Q4, but does not achieve the PM performance criteria for error in any quarter.

Figure A5-3displays Bar Charts of SO4 monthly mean fractional bias across the IMPROVE, CASTNet and STN monitoring networks in the 4 km (Figure A5-3a) and 12 km (Figure A5-3b) modeling domains for 2005 and 2006 and the CD-C and Hiawatha CAMx base case simulations. Note that there are no STN monitors within the 4 km grid and the FRM monitoring network does not measure SO4. The Bar Charts make clear the model's tendency to overestimate sulfate in winter and underestimate sulfate during summer. This pattern occurs for both years and is apparent on both the 4 km and 12 km grids. Figure A5-4 displays Bugle Plots of monthly SO4 model performance during 2005 and 2006 for the two base case simulations and compares them with the PM performance goals and criteria and the performance of the WRAP 2002 CMAQ simulation model performance. The Bugle Plots plot the fractional bias and error performance metrics as a function of average observed concentration and relaxes the PM performance goals and criteria as the average observed SO4 concentration approaches zero to account for the fact that SO4 performance is not as important as SO4 concentrations become an insignificant component of $PM_{2.5}$ mass or visibility impairment. Figure A5-3 and 6-4 showthat the model always achieves the PM performance criteria, but does not achieve the performance goal for some months and networks. The SO4 performance of both CD-C and Hiawatha CAMx 2005/2006 base case simulations are very similar and similar to the performance of the WRAP 2002 CMAQ performance.

In summary, the SO4 performance for the CD-C base case modeling is very similar to Hiawatha base case simulation. As seen in the Bugle Plots, the SO4 performance of the two models achieve the bias/error PM performance goal most of the time with only a few months falling outside of the PM performance goal range and always achieves the PM performance criteria.

IMPROVE – SO4

CD-C

Hiawatha

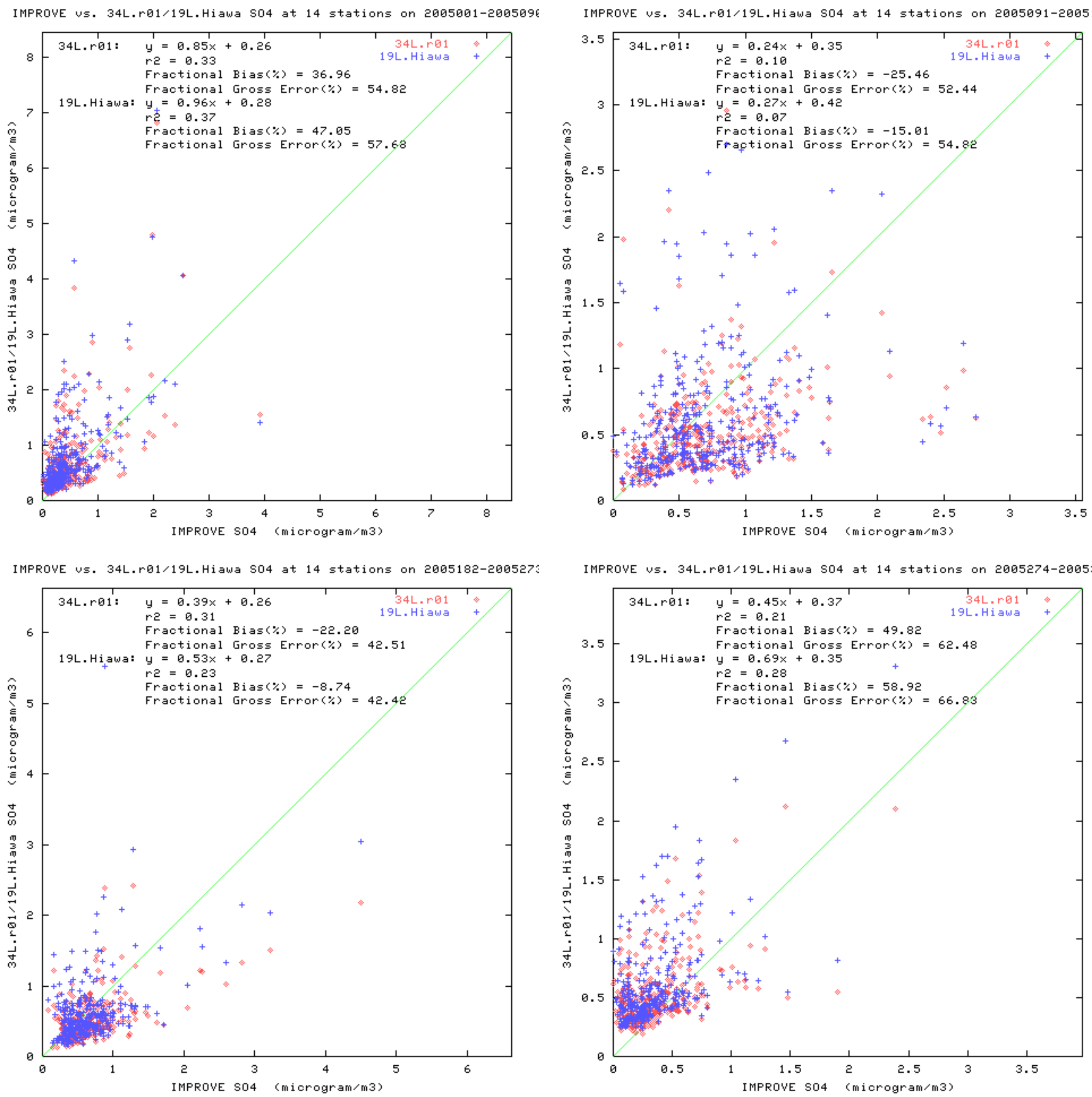


Figure A5-1a. Comparison of predicted and observed 24-hour average SO4 concentration for IMPROVE sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – SO4

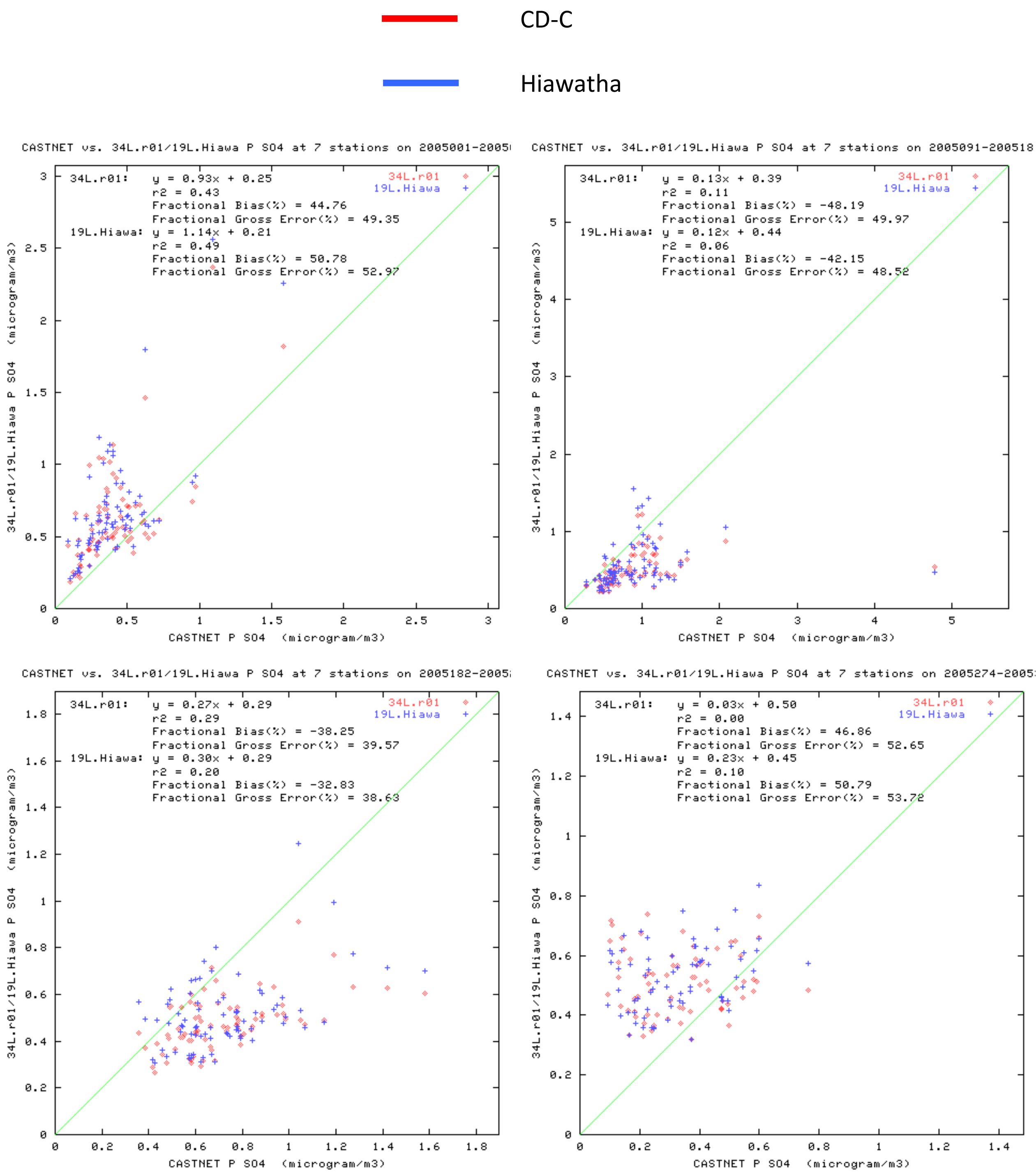


Figure A5-1b. Comparison of predicted and observed 24-hour average SO4 concentration for CASTNet sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – SO4

Observation

Hiawatha

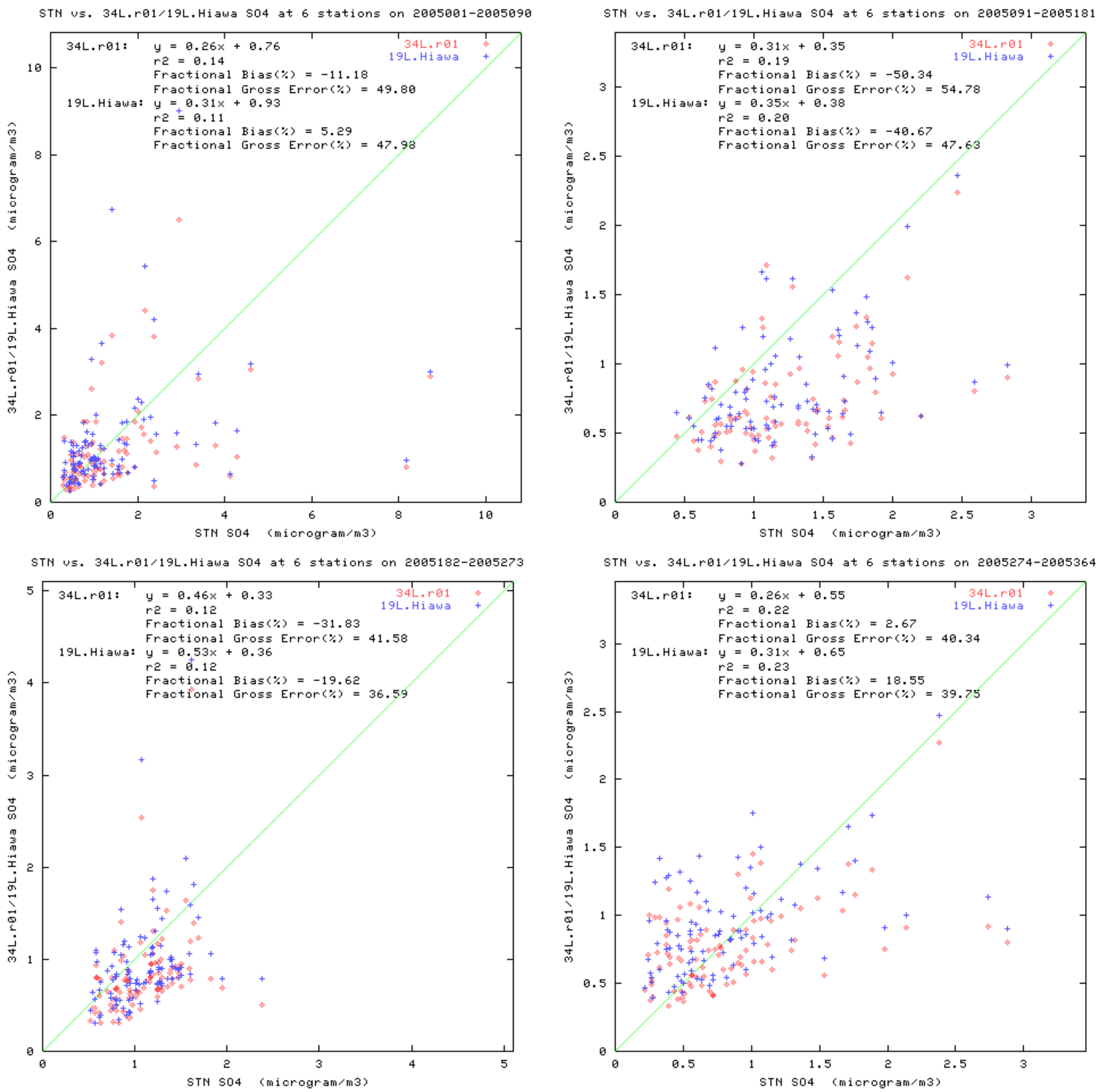


Figure A5-1c. Comparison of predicted and observed 24-hour average SO4 concentration for STN sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – SO2

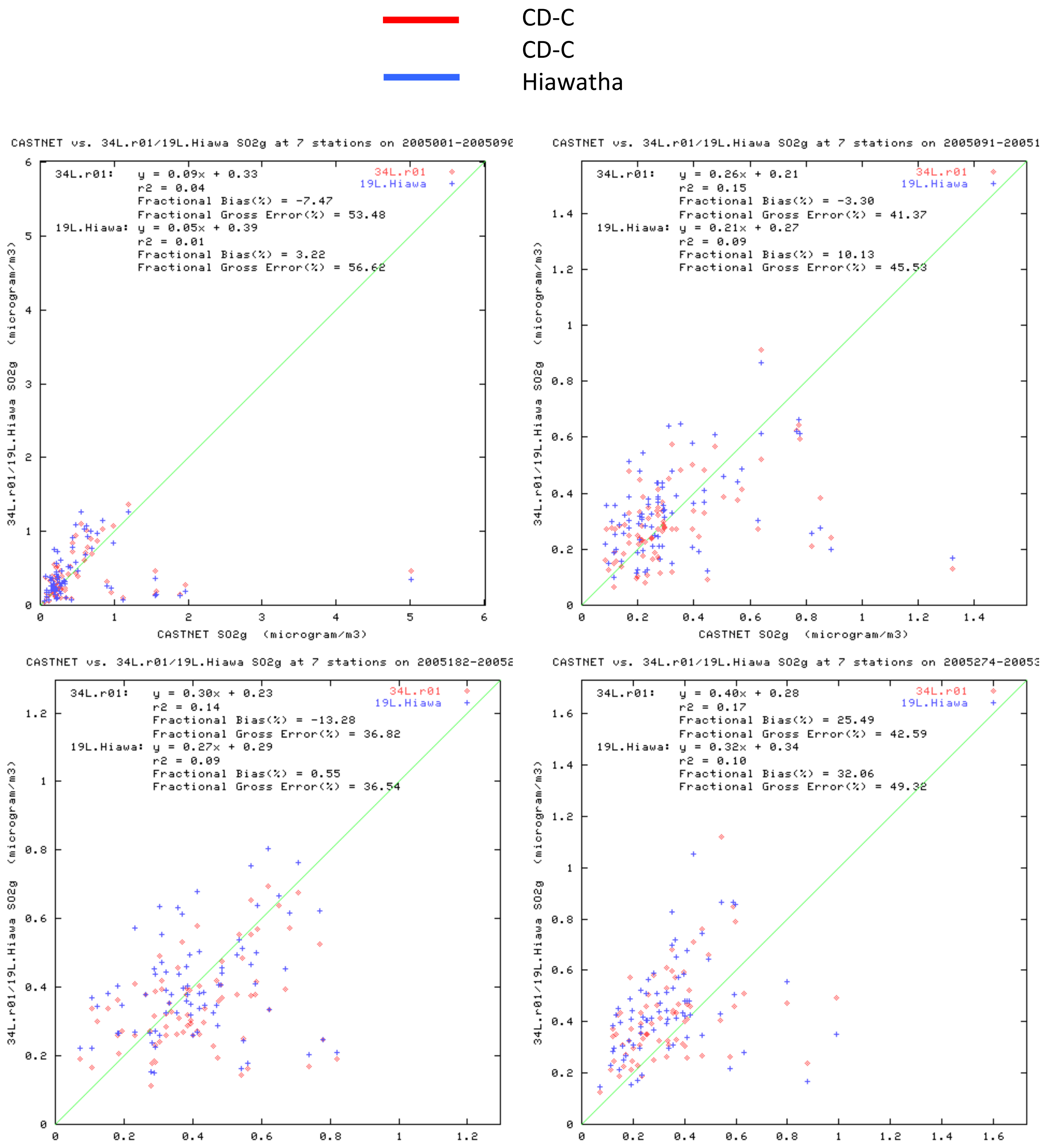


Figure A5-1d. Comparison of predicted and observed 24-hour average SO2 concentration for CASTNet sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

NADP – SO4 wet deposition

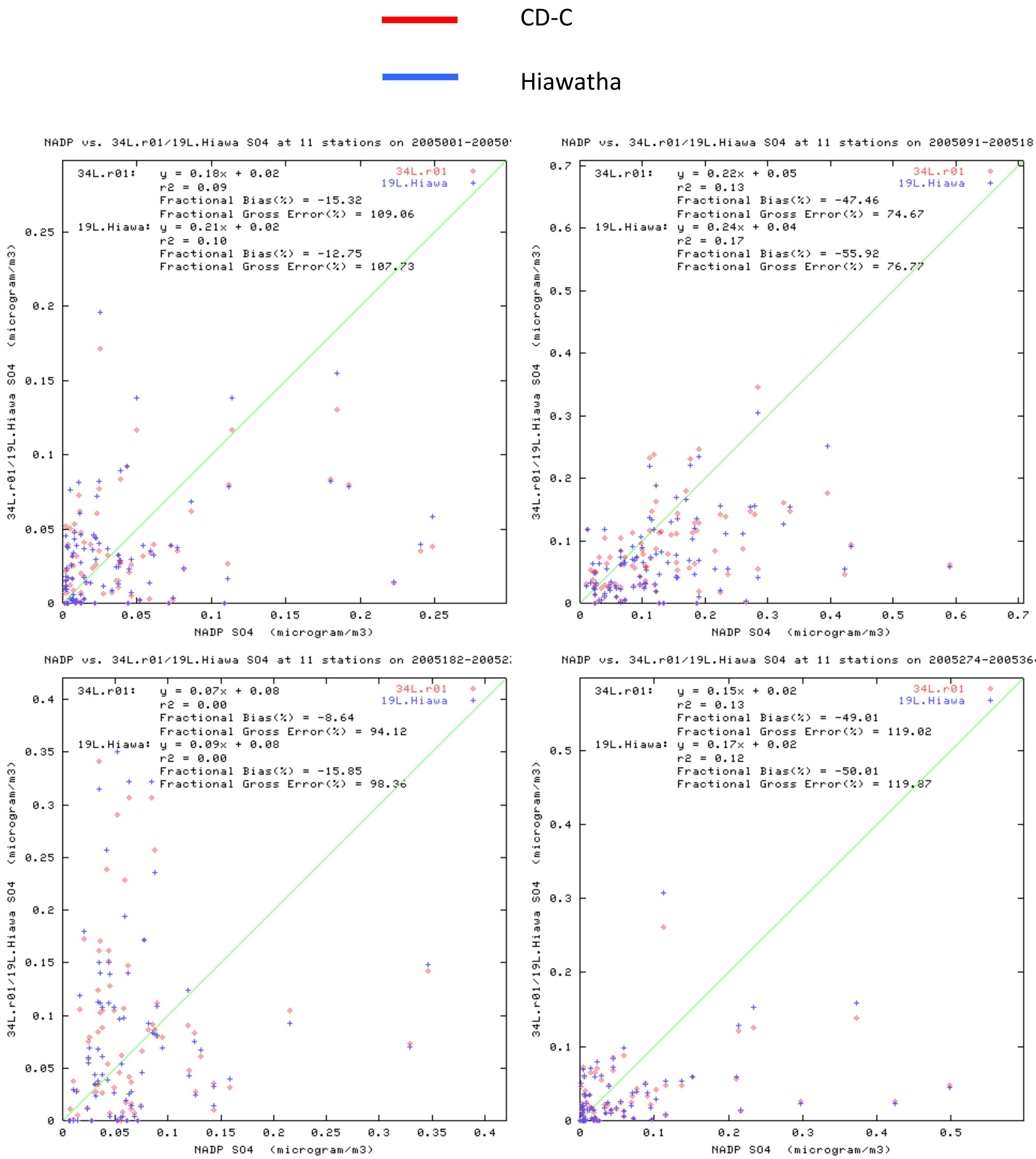


Figure A5-1e. Comparison of predicted and observed weekly average SO4 wet deposition for NADP sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – SO4

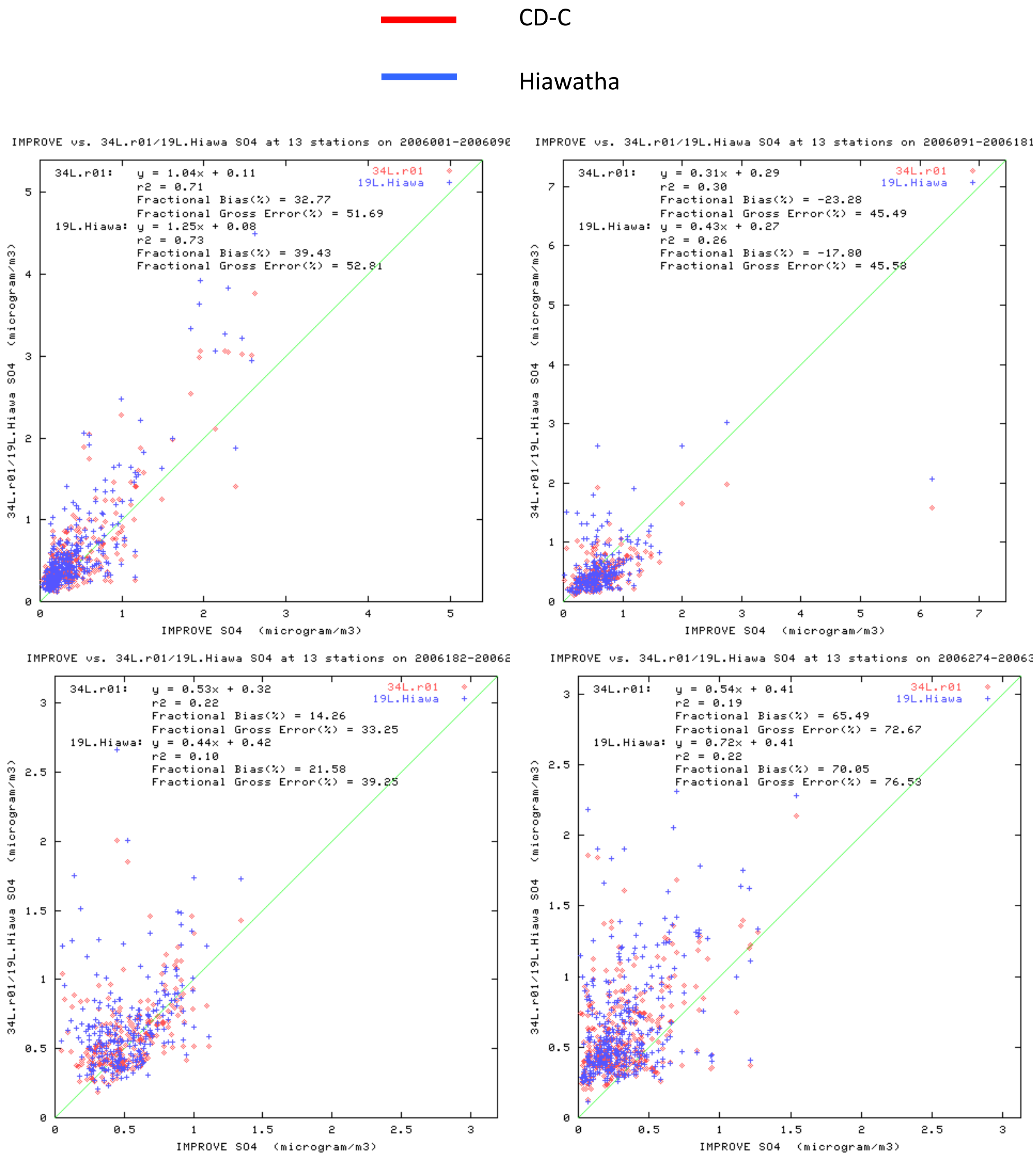


Figure A5-2a. Comparison of predicted and observed 24-hour average SO4 concentration for IMPROVE sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – SO4

CD-C

Hiawatha

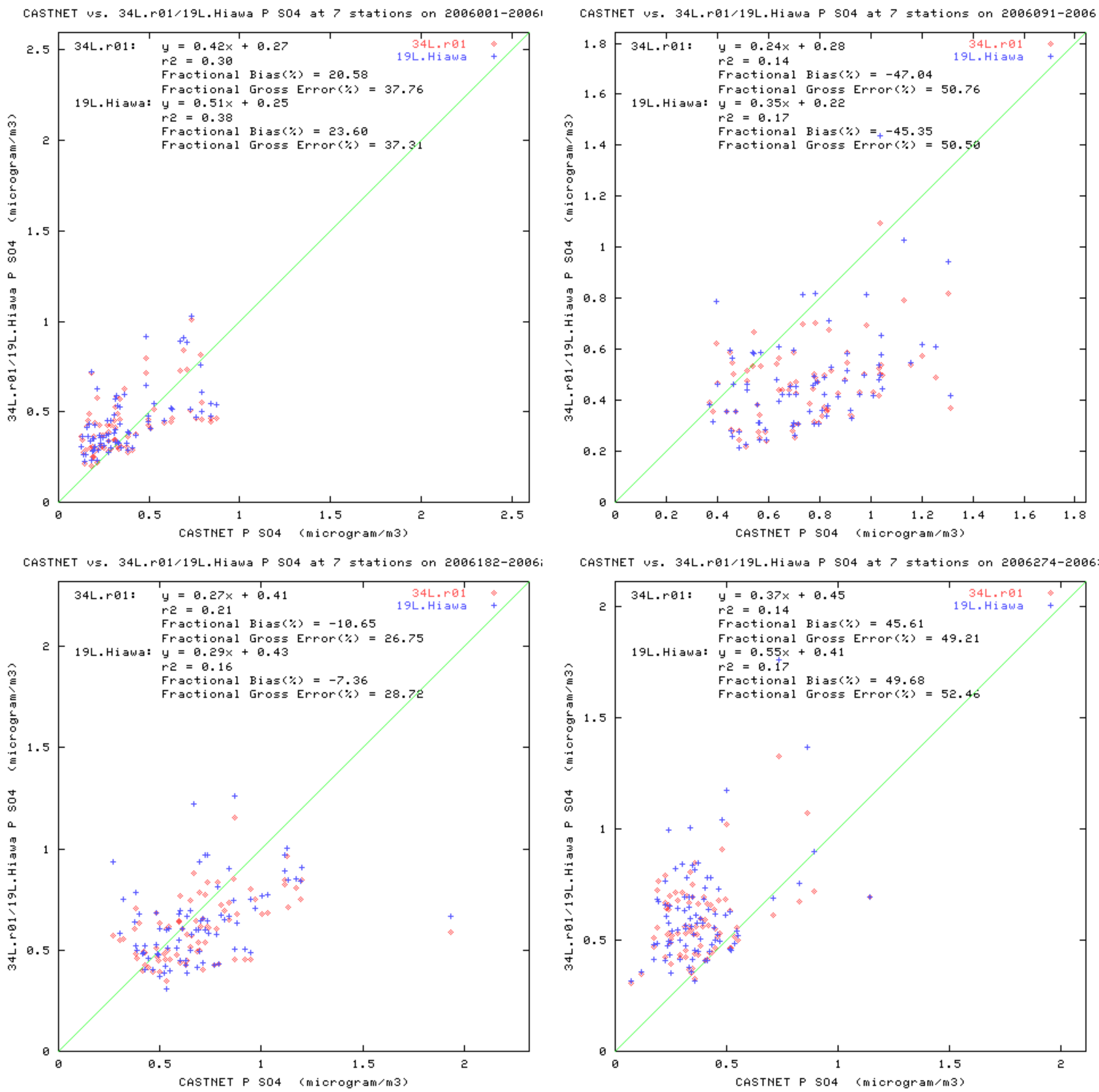


Figure A5-2b. Comparison of predicted and observed 24-hour average SO4 concentration for CASTNet sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – SO4

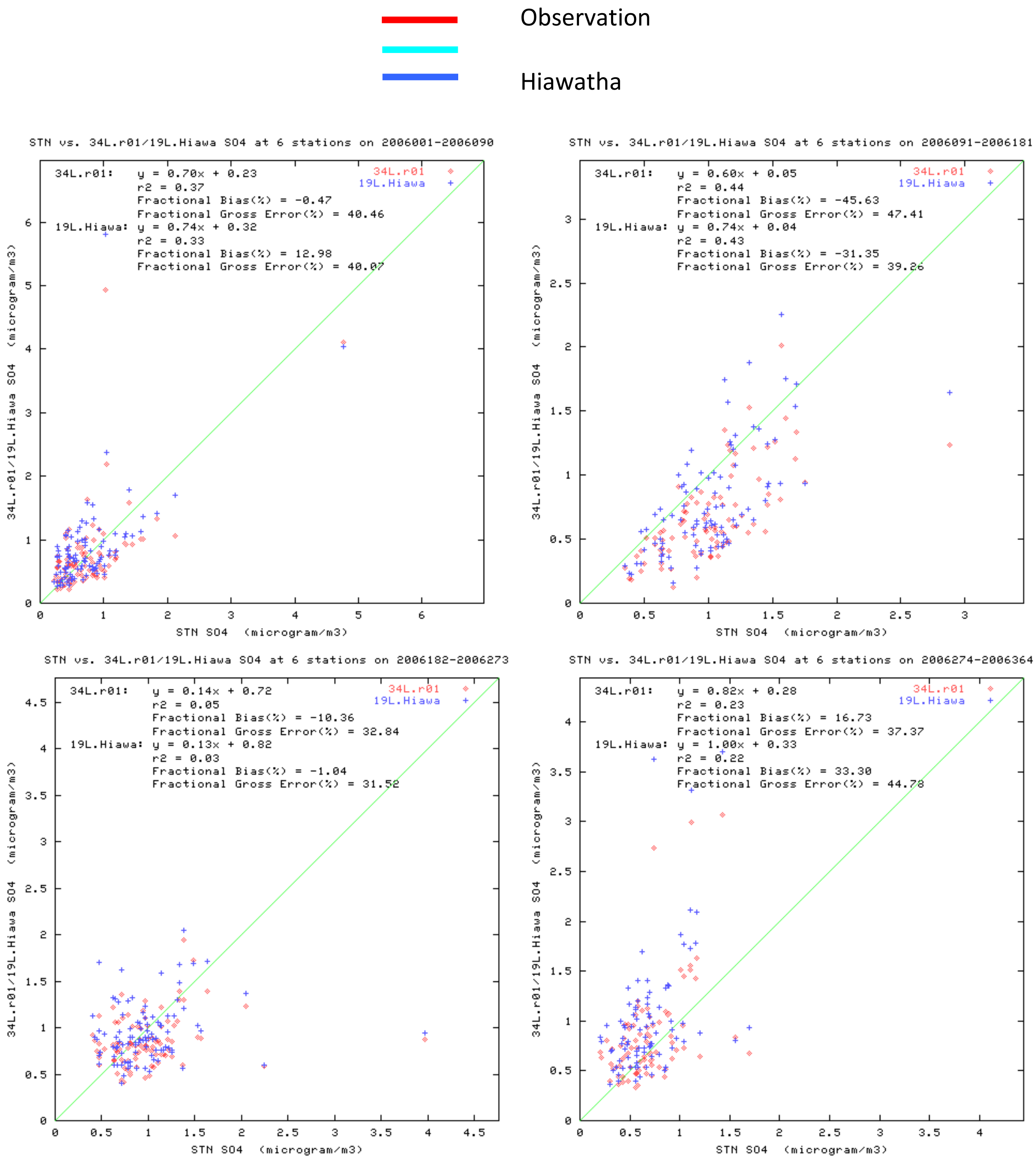


Figure A5-2c. Comparison of predicted and observed 24-hour average SO4 concentration for STN sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – SO2

CD-C

Hiawatha

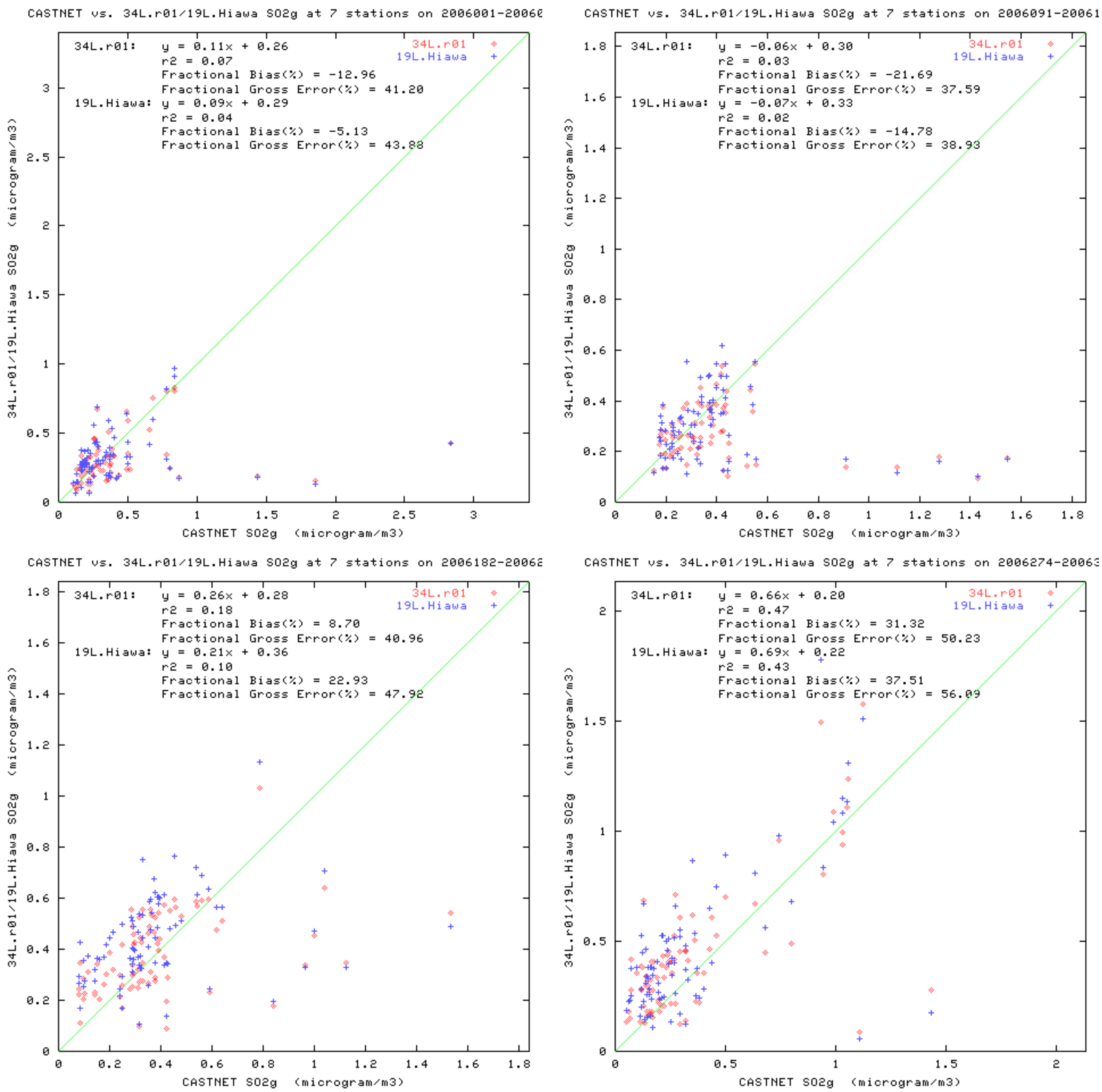


Figure A5-2d. Comparison of predicted and observed 24-hour average SO2 concentration for CASTNet sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

NADP – SO4 wet deposition

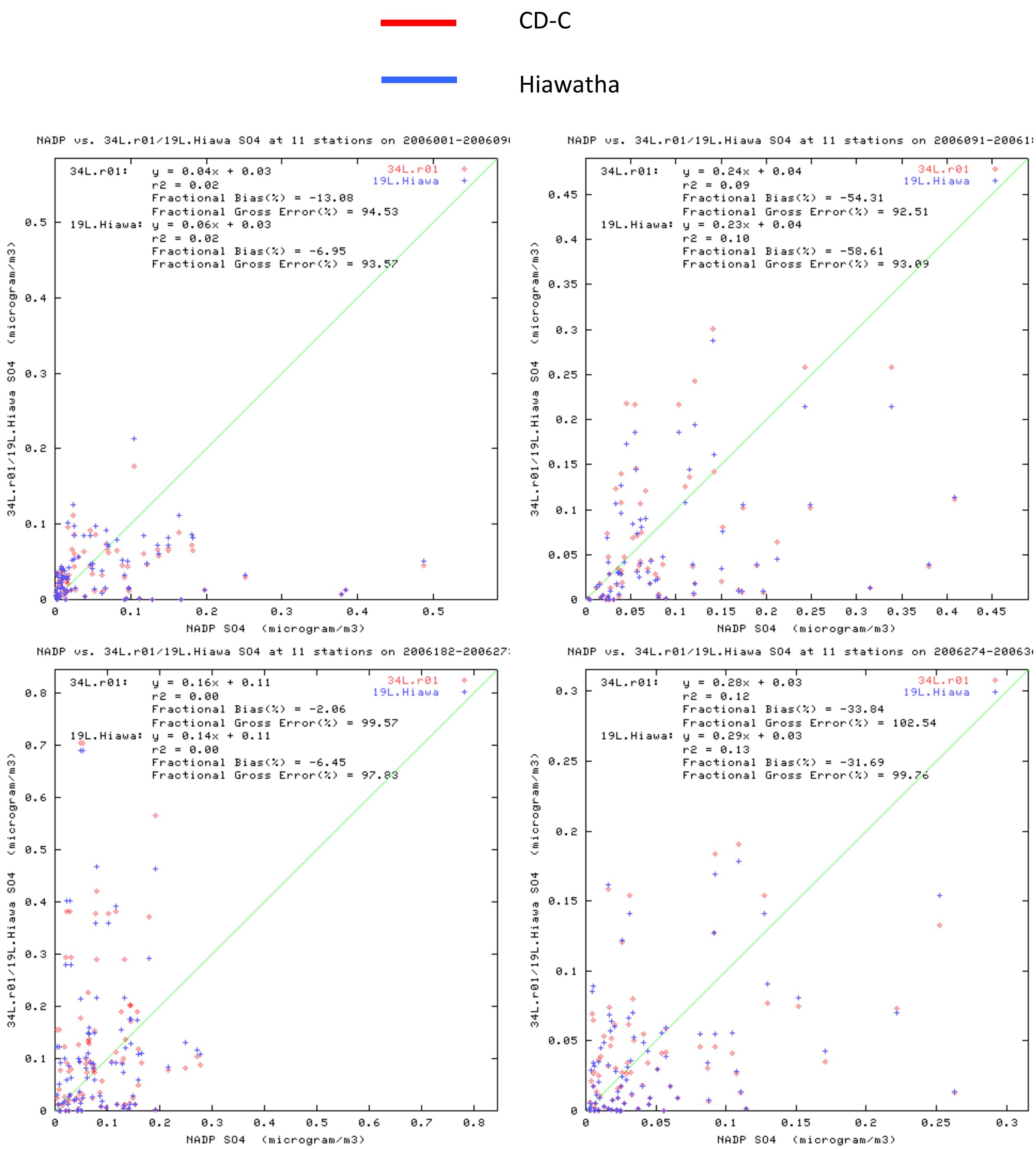
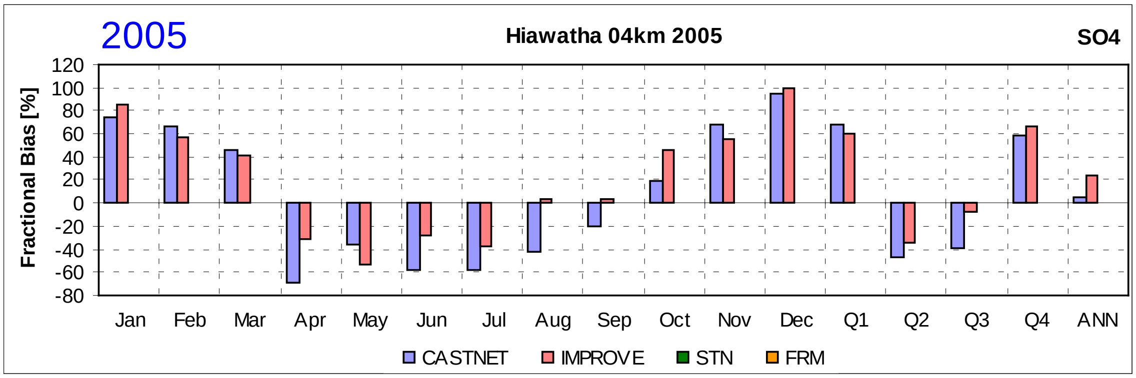
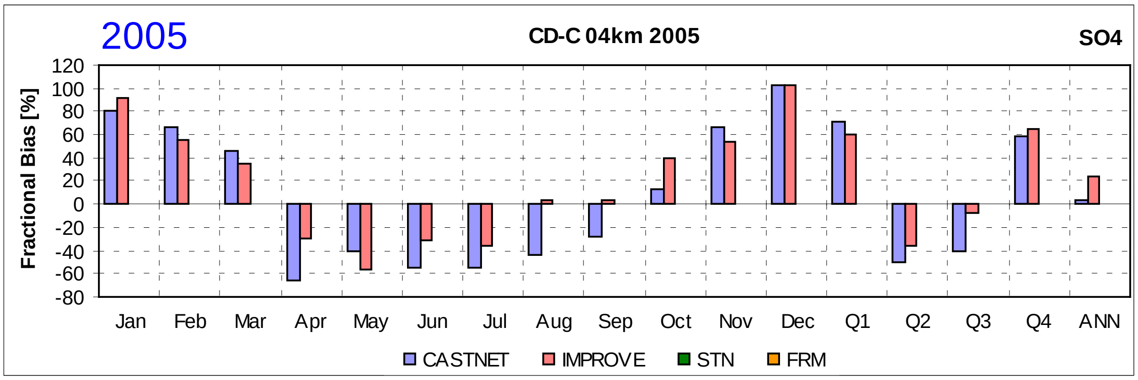


Figure A5-2e. Comparison of predicted and observed weekly average SO4 wet deposition for NADP sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

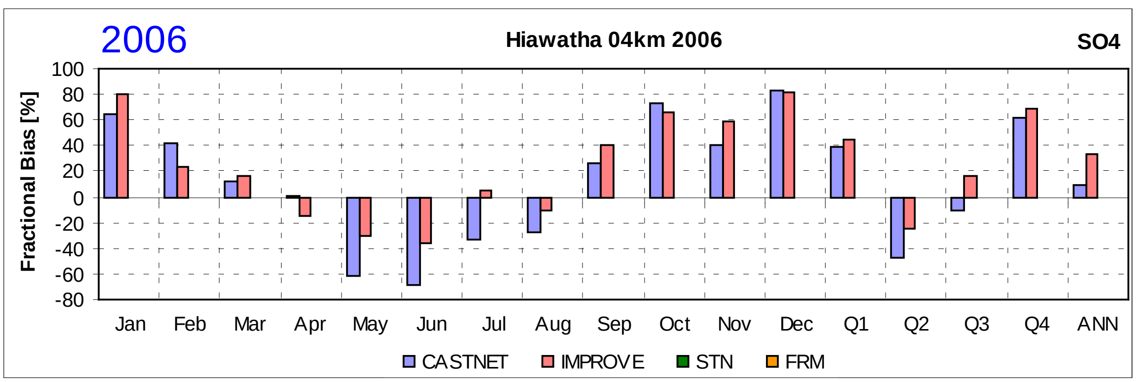
(1)



(2)



(3)



(4)

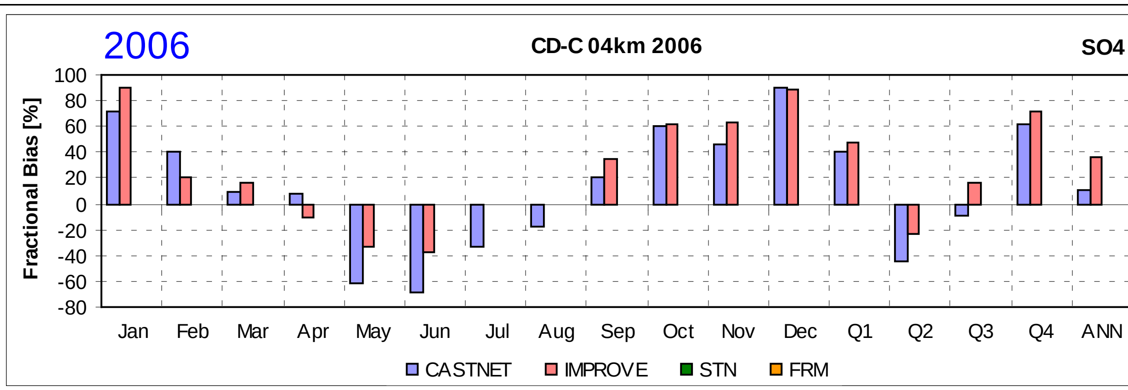
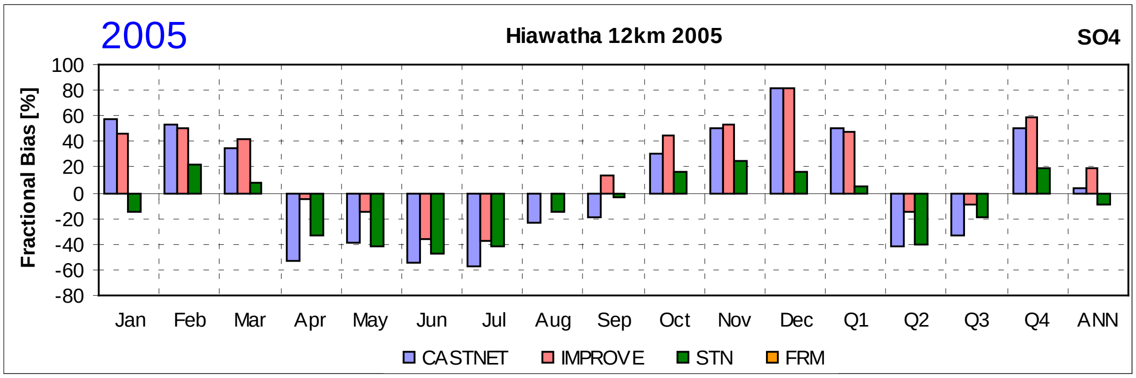
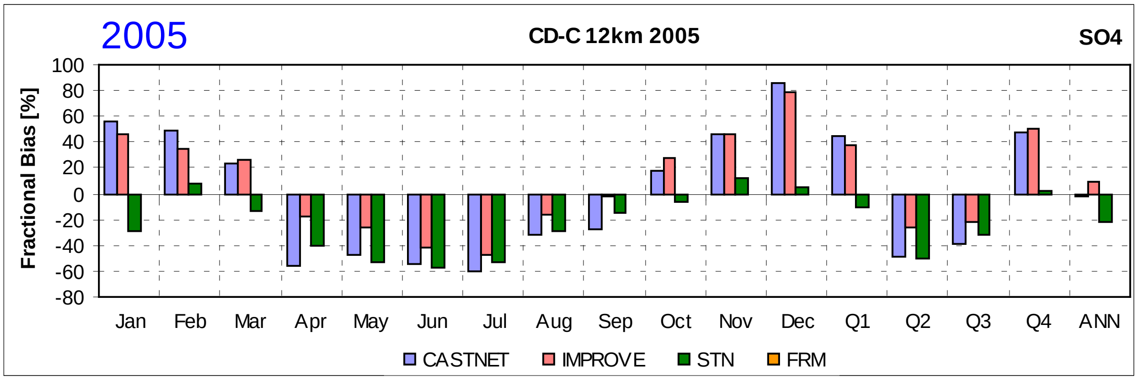


Figure A5-3a. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for SO4 in 4 km grid.

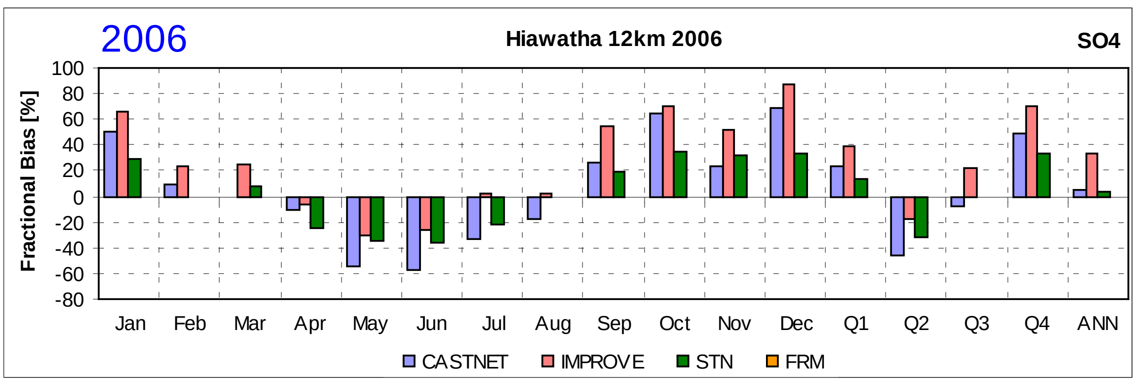
(1)



(2)



(3)



(4)

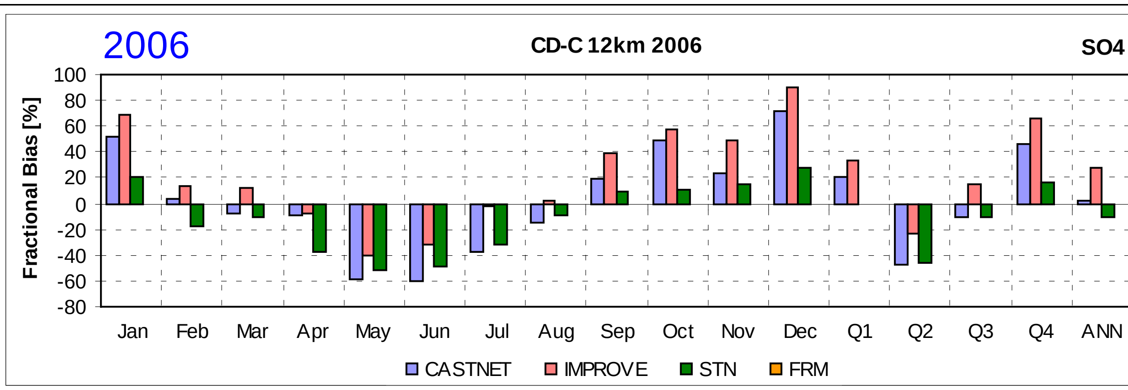


Figure A5-3b. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for SO4 in 12 km grid.

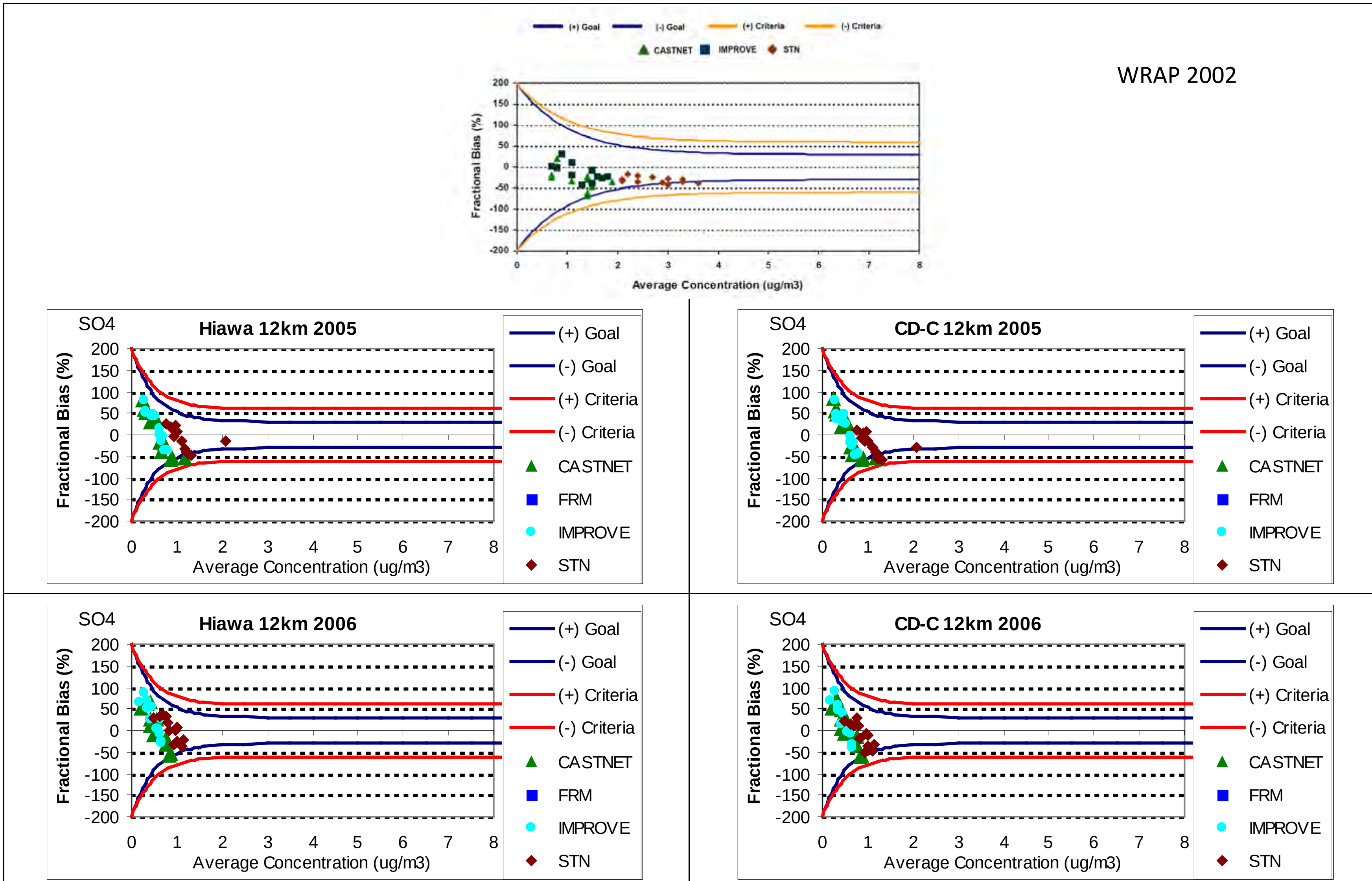


Figure A5-4a. Bugle Plots of SO4 model performance comparing mean fractional bias for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

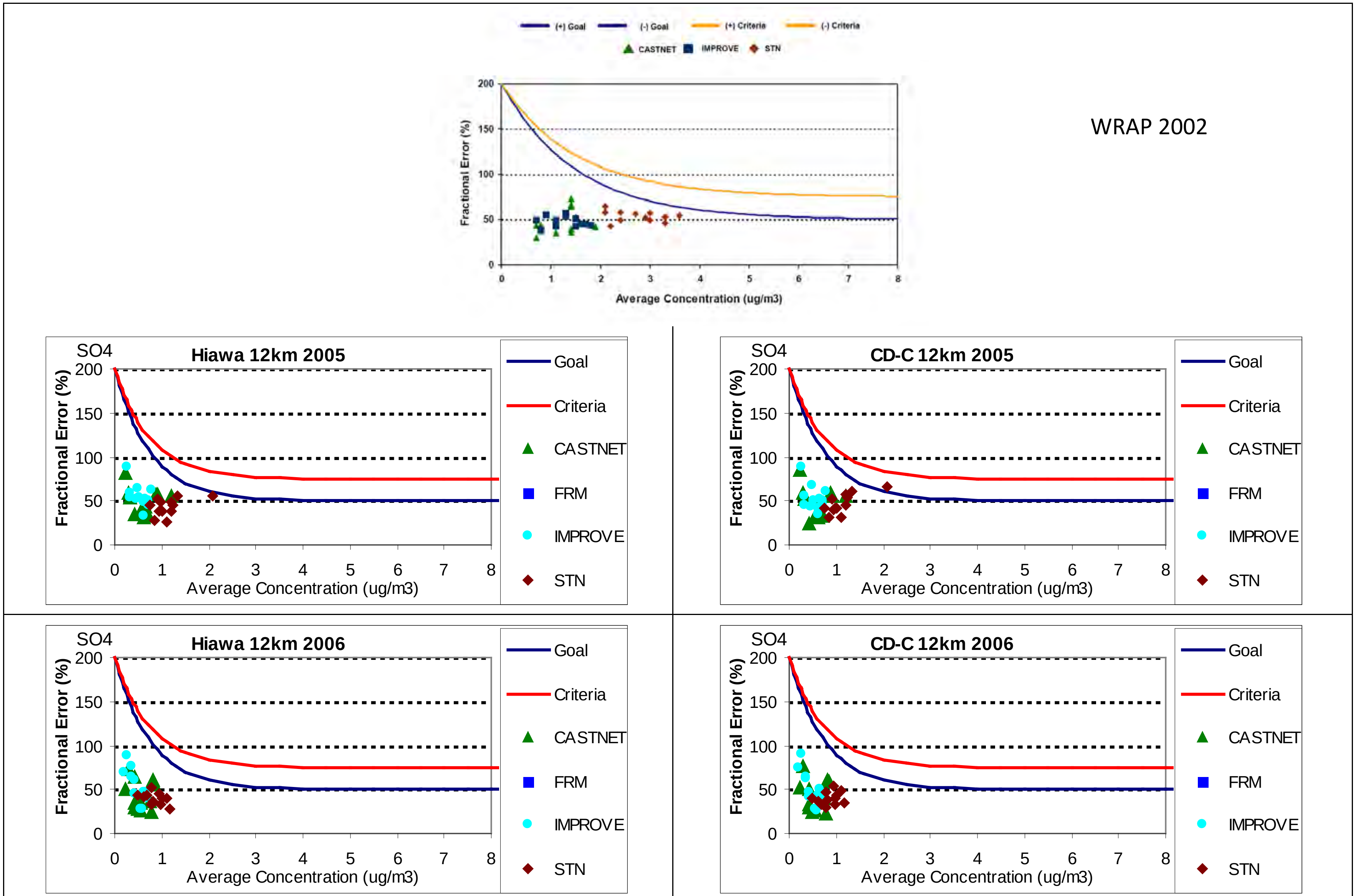


Figure A5-4b. Bugle Plots of SO4 model performance comparing mean fractional error for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

A5.2 NITRATE MODEL PERFORMANCE

Figures A5-5 and A5-6 display scatter plots and performance statistics for nitrate (NO3) and nitrate-related species for CD-C and Hiawatha base case simulations by Quarter for2005 and 2006, respectively. The species examined in these figures are: (a) IMPROVE NO3 (b) CASTNet NO3; (c) STN NO3; (d) CASTNet nitric acid (HNO3); (e) CASTNet total nitrate (NO3+HNO3); (f) CASTNet ammonium (NH4); (g) STN NH4; (h) wet NO3 deposition; and (i) wet NH4 deposition. With the exception of the STN sites, where NO3 is underpredicted year-round, the NO3 model performance is characterized by a winter (e.g., Q1 and Q4) overprediction and a summer (Q2 and Q3) underprediction bias. However, during the summer and adjacent period (Q2 and Q3) the NO3 observations are very small, rarely exceeding 0.5 $\mu g/m^3$. For the IMPROVE and CASTNet sites in 2005, as well as the IMPROVE network in 2006, the Q3 bias is within the PM performance criteria; however for all other quarters for both networks and both years the NO3 bias and error do not achieve the PM performance criteria. At the STN sites both base cases underestimate the observed values throughout the year and both years with the CD-C base case underestimation bias being greater than the Hiawatha base case.

The performance for nitric acid (HNO3) across the CASTNet network is much better with CD-C base case bias and error values achieving the PM performance goal for all Quarters and both years except for Q1 error in 2005 and Q4 error in 2006 (Figures A5-6d and A5-7d). The Hiawatha nitric acid performance error does not achieve the PM performance goal in Q4 in both 2005 and 2006. The two base case simulations performance for total nitrate (NO3+HNO3; Figures A5-6e and A5-7e) achieve the PM performance goal during Q2 and Q3 of both 2005 and 2006, but do not even achieve the PM performance criteria during Q1 and Q4 when theyare affected by the large overestimation of NO3. The Q2 and Q3 nitric acid and total nitrate performance are better than the NO3 performance, which suggests that the summer NO3 performance issues may be partly related to the aerosol equilibrium between HNO3 and NO3 rather than the oxidation rate of NOx. Ammonia emissions are highly uncertain and have a large effect on the NO3 equilibrium. There may also be additional crustal basic compound available to form particulate NO3 that are not fully accounted for in the modeling (e.g., sodium). In Q1 and Q4 both NO3 and total NO3 are greatly overestimated, which may be related to oxidation rates and loss mechanisms in additional to aerosol thermodynamics. Ammonium (NH4) performance results are presented in Figures A5-6f-g andA5-7f-g. Note that ammonium is not measured directly at IMPROVE sites, but can be derived assuming that NO3 and SO4 are completely neutralized. The ammonium concentrations are underestimated for Q2-Q4 for both 2005 and 2006 (Figures A5-6f and A5-7f). The Q2 and Q3 (summer) ammonium underprediction is very large with the Hiawatha base case exhibiting a larger underestimation bias than the CD-C base case. Both wet deposited NO3 and NH4 are underestimated, with the underestimation highest in the summer (e.g., Q2 and Q3), when the NO3 and NH4 concentration underprediction is greatest.

Figure A5-7 displays the monthly bias bar charts that clearly show the large seasonal dependenceof the NO3 model performance, with a summer underestimation and winter overestimation bias. At the IMPROVE and CASTNet sites, the NO3 winter overprediction bias occurs roughly from November through February and the summer underprediction bias occurs roughly from April through August. March and September-October are transition periods when the NO3 bias is typically closest to zero. At the STN sites, there is a year round underestimate of NO3, with the largest underestimation bias coming during summer. Although the magnitude of the summer NO3 underestimation fractional bias is large, it is of less concern than the winter overestimate because both the observations and model estimates have near zero NO3 in the summer. This is illustrated in the Bugle Plots in Figure A5-9. NO3 can get fairly high at the STN sites in the winter (e.g. >12 $\mu g/m^3$; Figure A5-6c), but across the IMPROVE and CASTNet sites,the average observed NO3 is quite low, averaging less than 0.2 $\mu g/m^3$. Thus, the CD-C and Hiawatha NO3 bias and error metrics are in the flared portion of the PM performance goal and criteria in the Bugle Plots for the IMPROVE and CASTNet sites. The Hiawatha base case NO3 performance at the STN sites is better than the CD-C STN NO3 performance; the reasons for this are unclear. Overall, the CD-C and Hiawatha base case NO3 performance is comparable to that of the 2002 WRAP RPO simulation, with the Hiawatha NO3 performance better than WRAP at the STN sites.

Like NO3, NH4 (Figure A5-8) performance shows a strong seasonality, with both model runs exhibiting a smaller bias in winter than in summer. There is a low bias in summer in both the Hiawatha and the CD-C runs, with CD-C showing s smaller bias overall than Hiawatha. The NH4 bugle plots for 2005 and 2006 (Figure A5-10) show that performance is fairly comparable for the Hiawatha and CD-C runs, but CD-C performing better overall at the IMPROVE monitors and slightly worse at the STN monitors. Both simulations are generally within the performance criteria.

IMPROVE – NO3

CD-C

Hiawatha

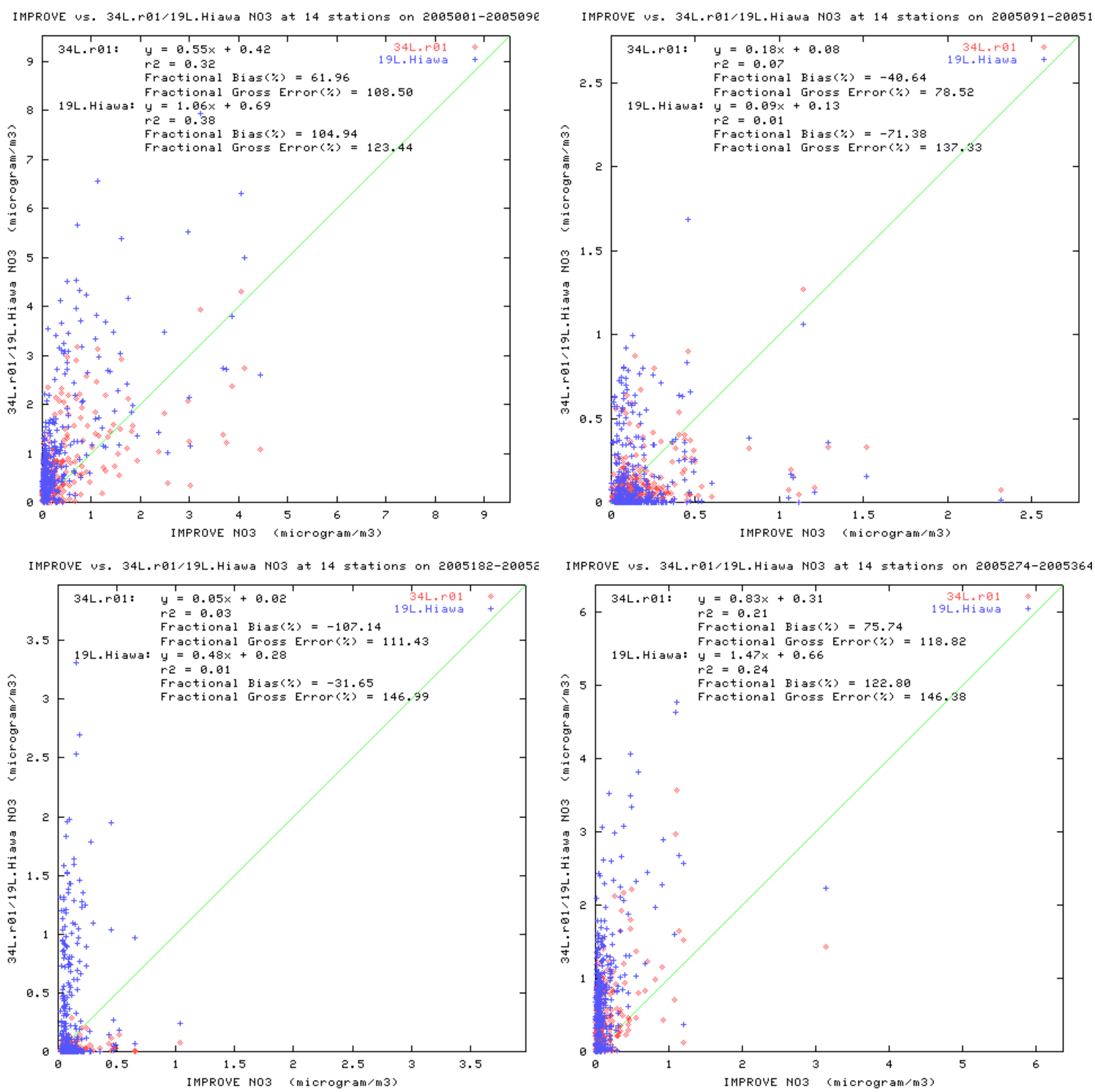


Figure A5-5a. Comparison of predicted and observed 24-hour average NO3 concentration for IMPROVE sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – NO3

CD-C

Hiawatha

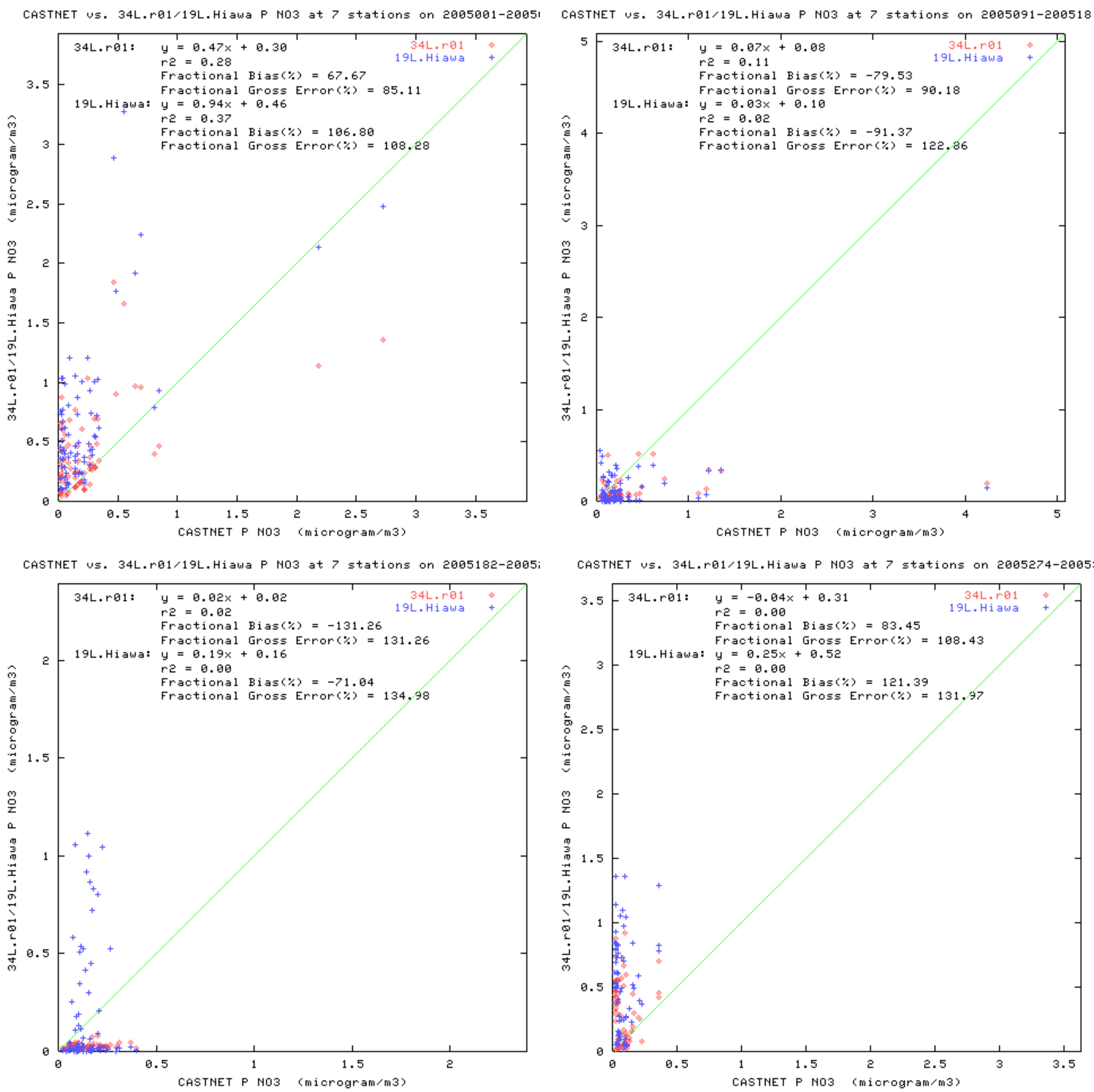


Figure A5-5b. Comparison of predicted and observed 24-hour average NO3 concentration for CASTNet sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – NO3

CD-C

Hiawatha

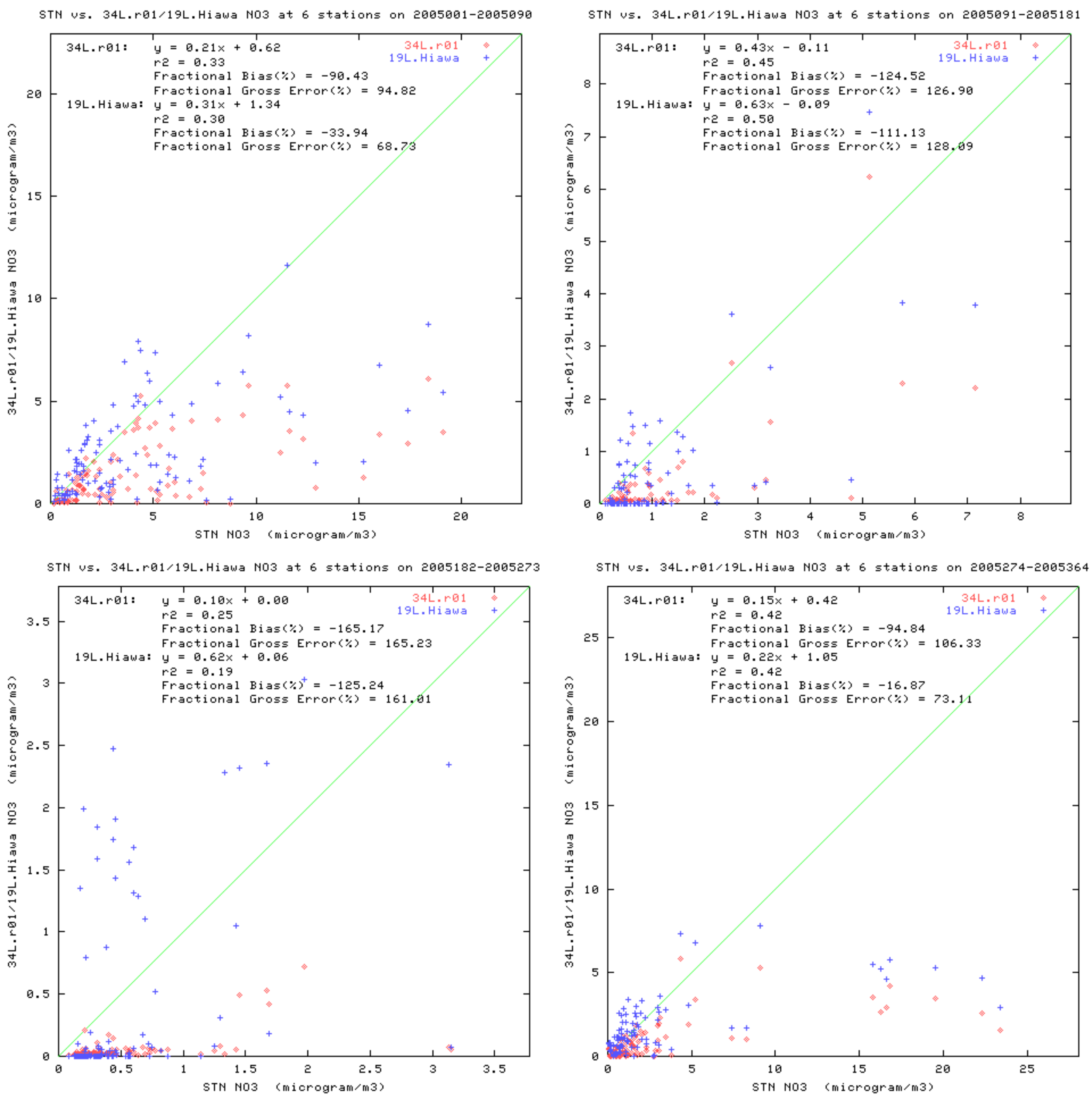


Figure A5-5c. Comparison of predicted and observed 24-hour average NO3 concentration for STN sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – HNO3

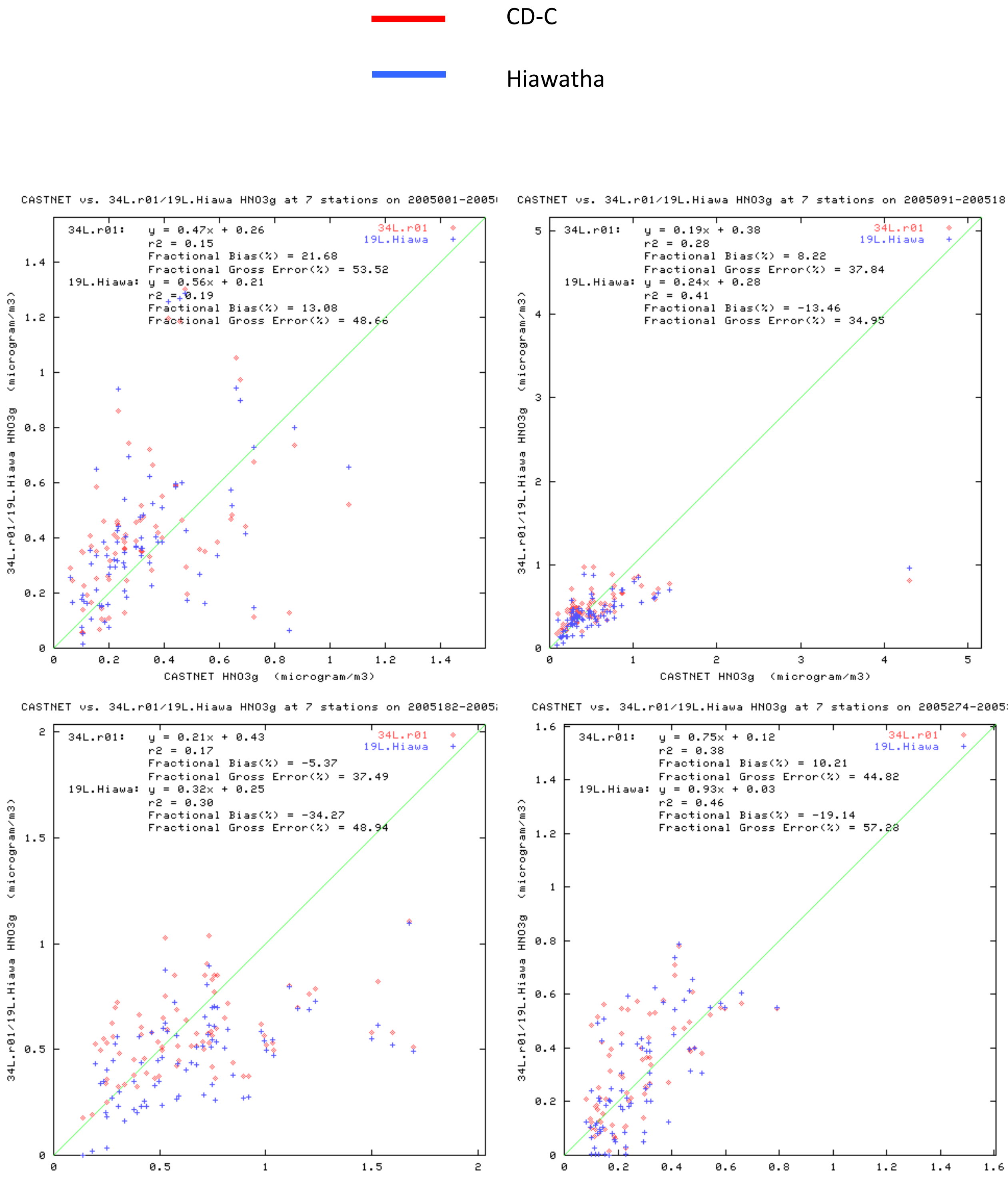


Figure A5-5d. Comparison of predicted and observed 24-hour average HNO3 concentration for CASTNet sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – Total Nitrate

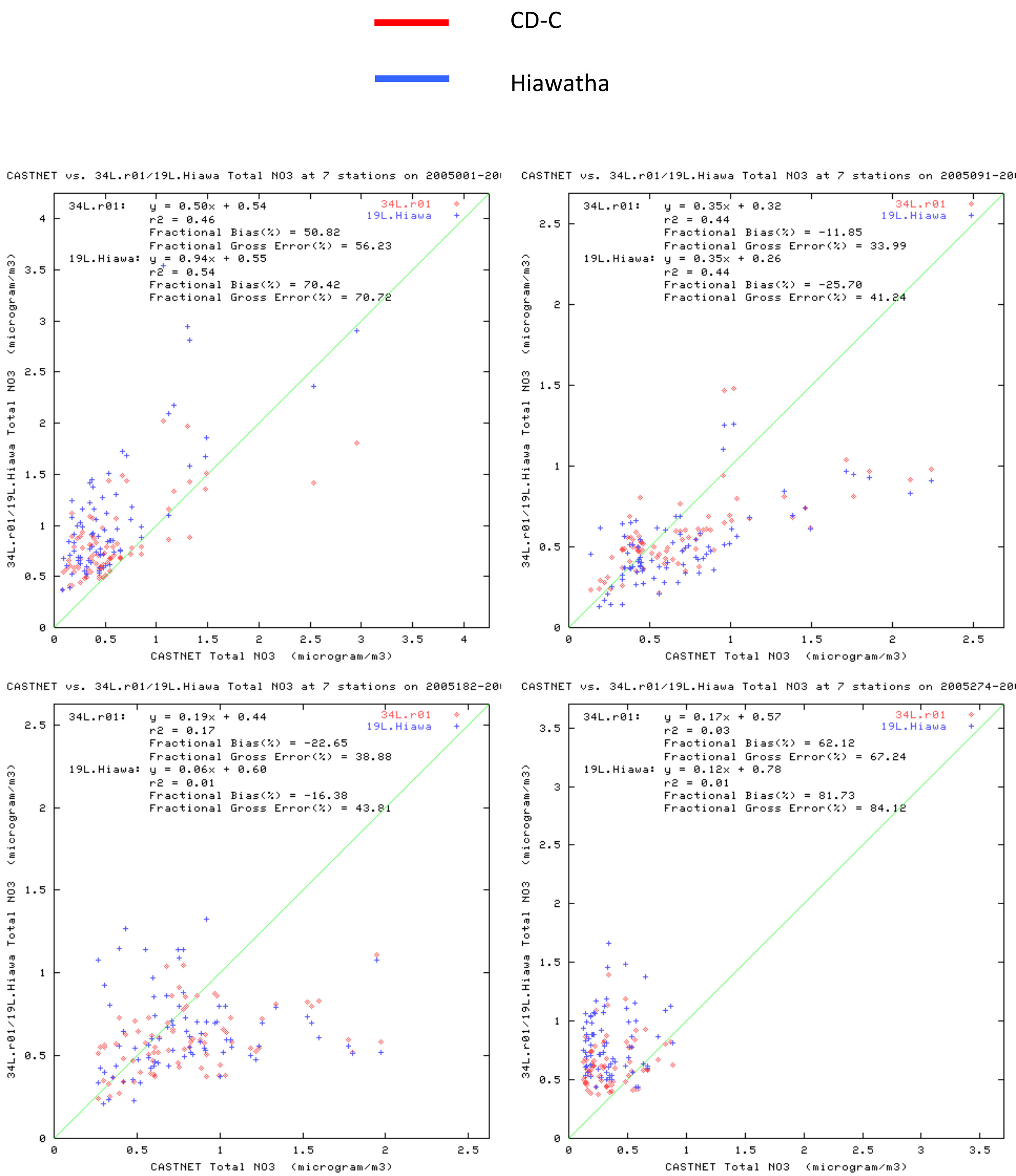


Figure A5-5e. Comparison of predicted and observed 24-hour average Total Nitrate (NO3+HNO3) concentration for CASTNet sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – NH4

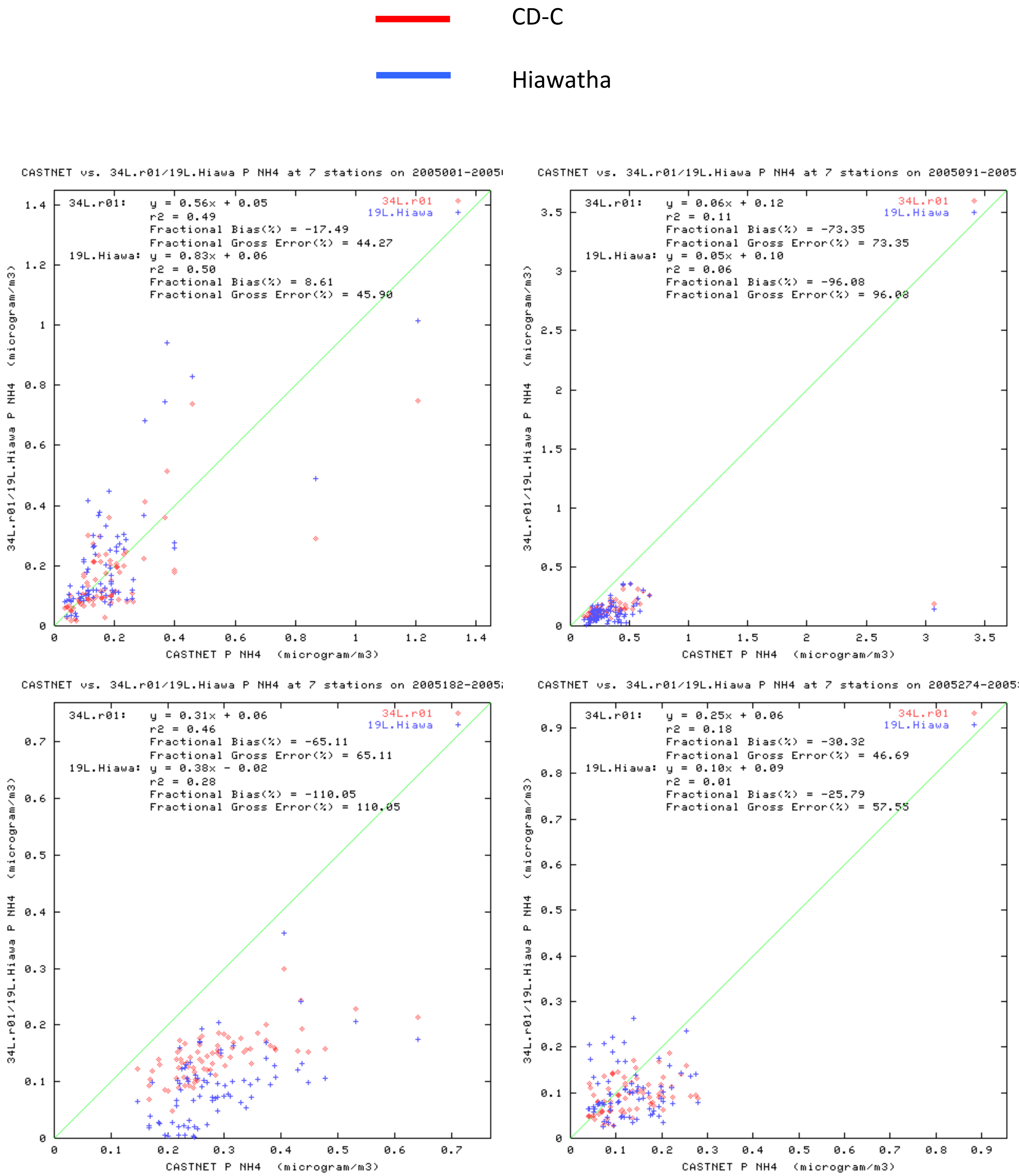


Figure A5-5f. Comparison of predicted and observed 24-hour average NH4 concentration for CASTNet sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – NH4

CD-C

Hiawatha

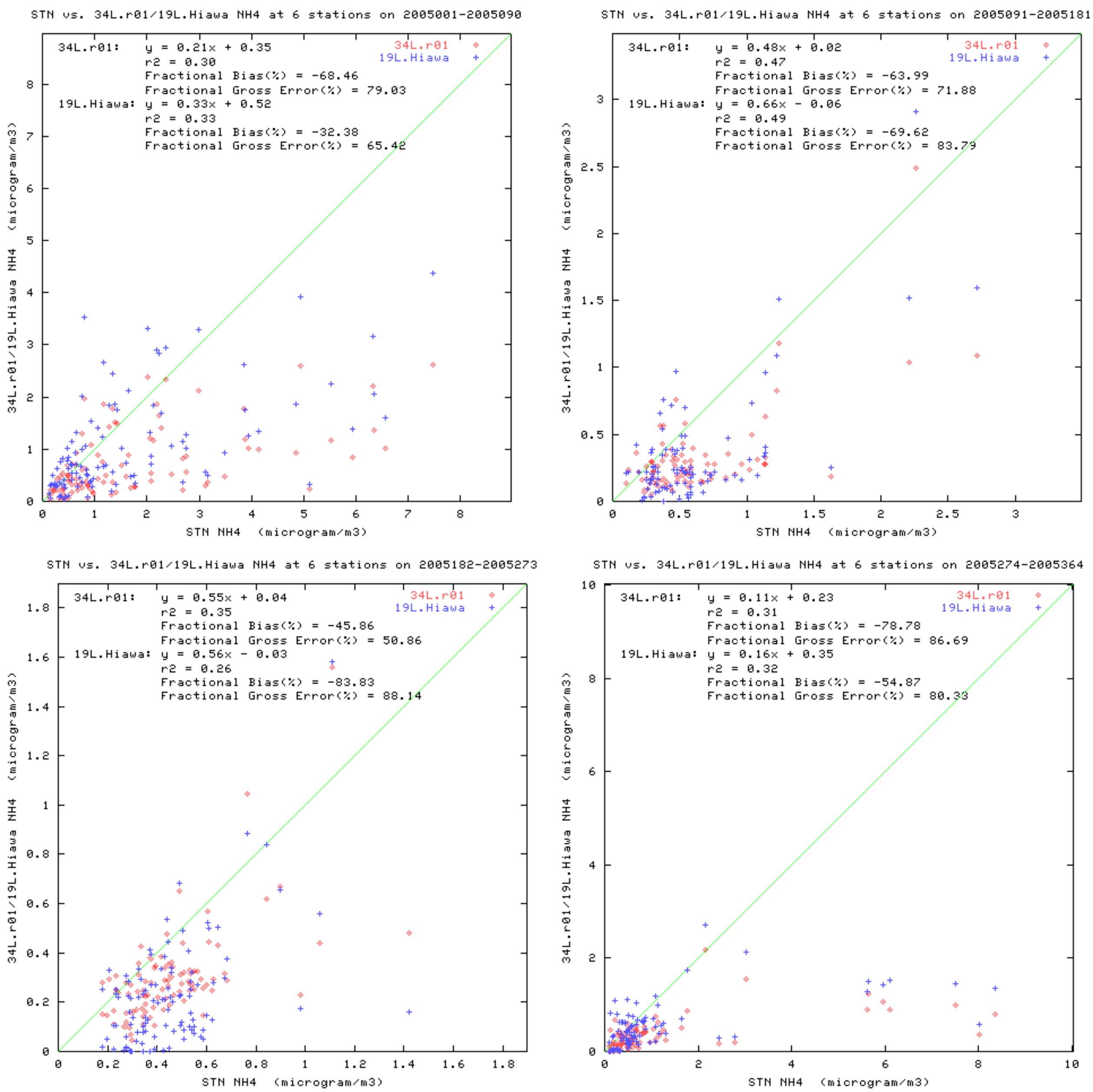


Figure A5-5g. Comparison of predicted and observed 24-hour average NH4 concentration for STN sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

NADP – NO3 wet deposition

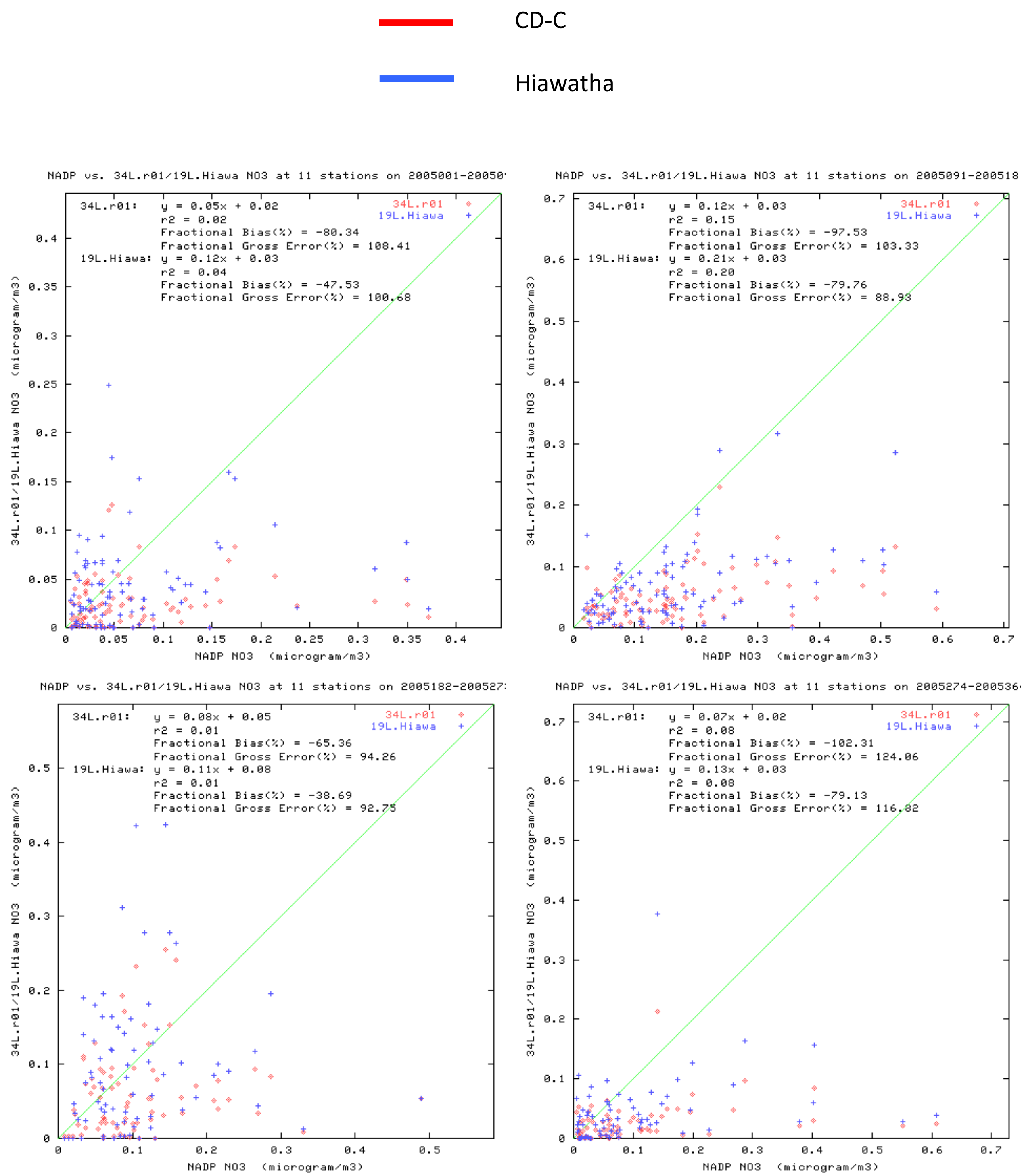


Figure A5-5h. Comparison of predicted and observed weekly average NO3 wet deposition for NADP sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

NADP – NH4 wet deposition

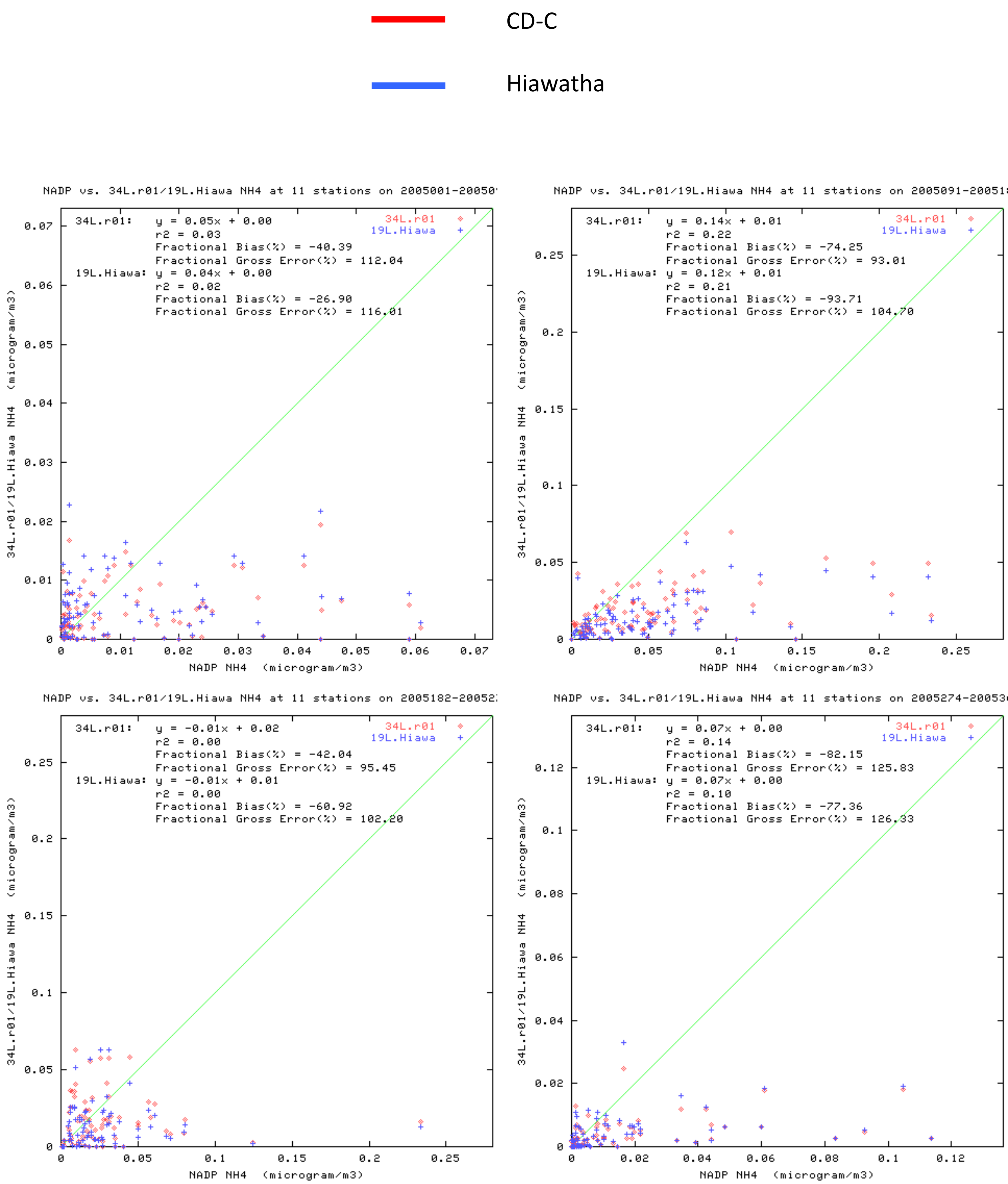


Figure A5-5i. Comparison of predicted and observed weekly average NH4 wet deposition for NADP sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – NO3

CD-C

Hiawatha

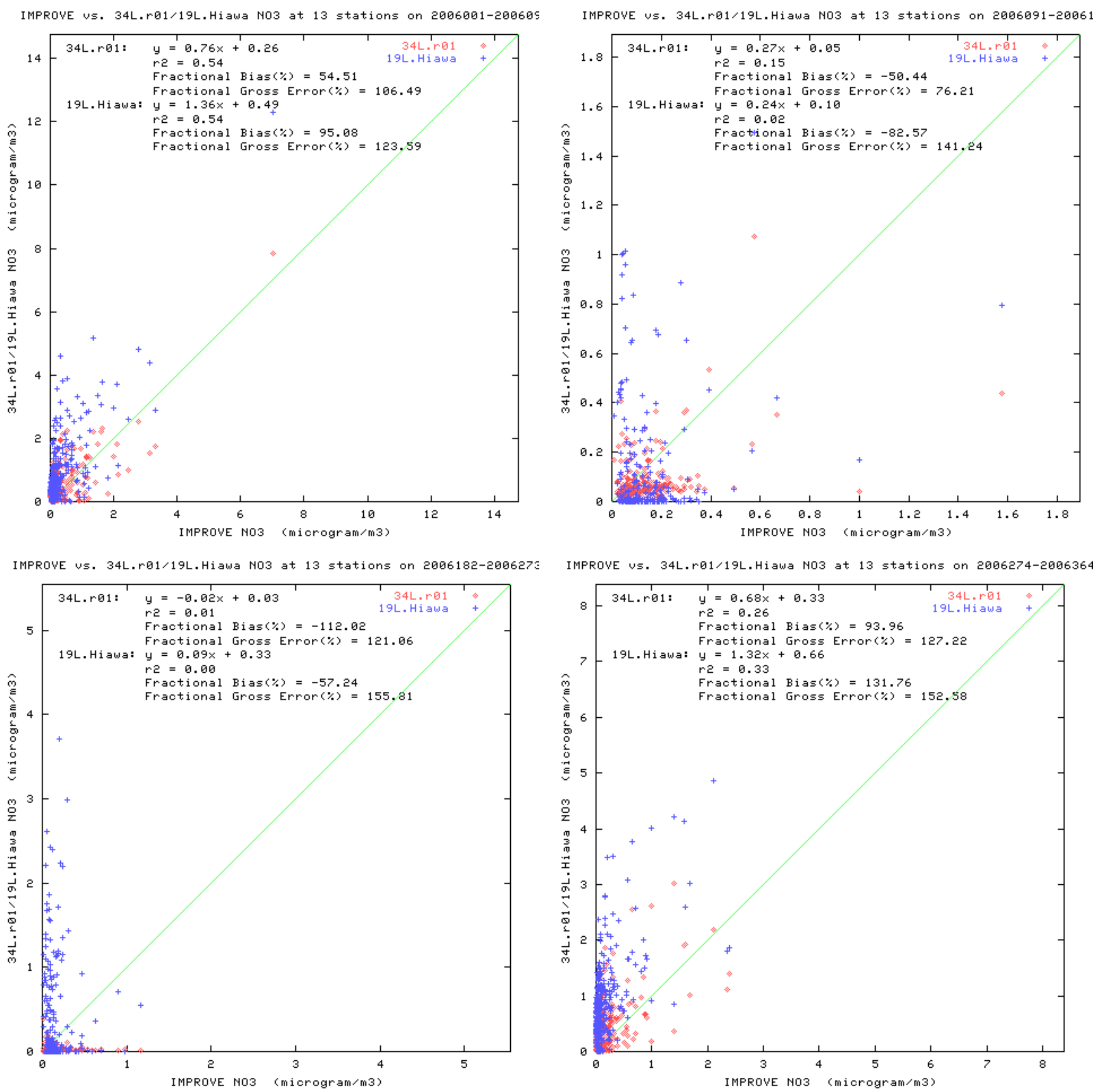


Figure A5-6a. Comparison of predicted and observed 24-hour average NO3 concentration for IMPROVE sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – NO3

CD-C

Hiawatha

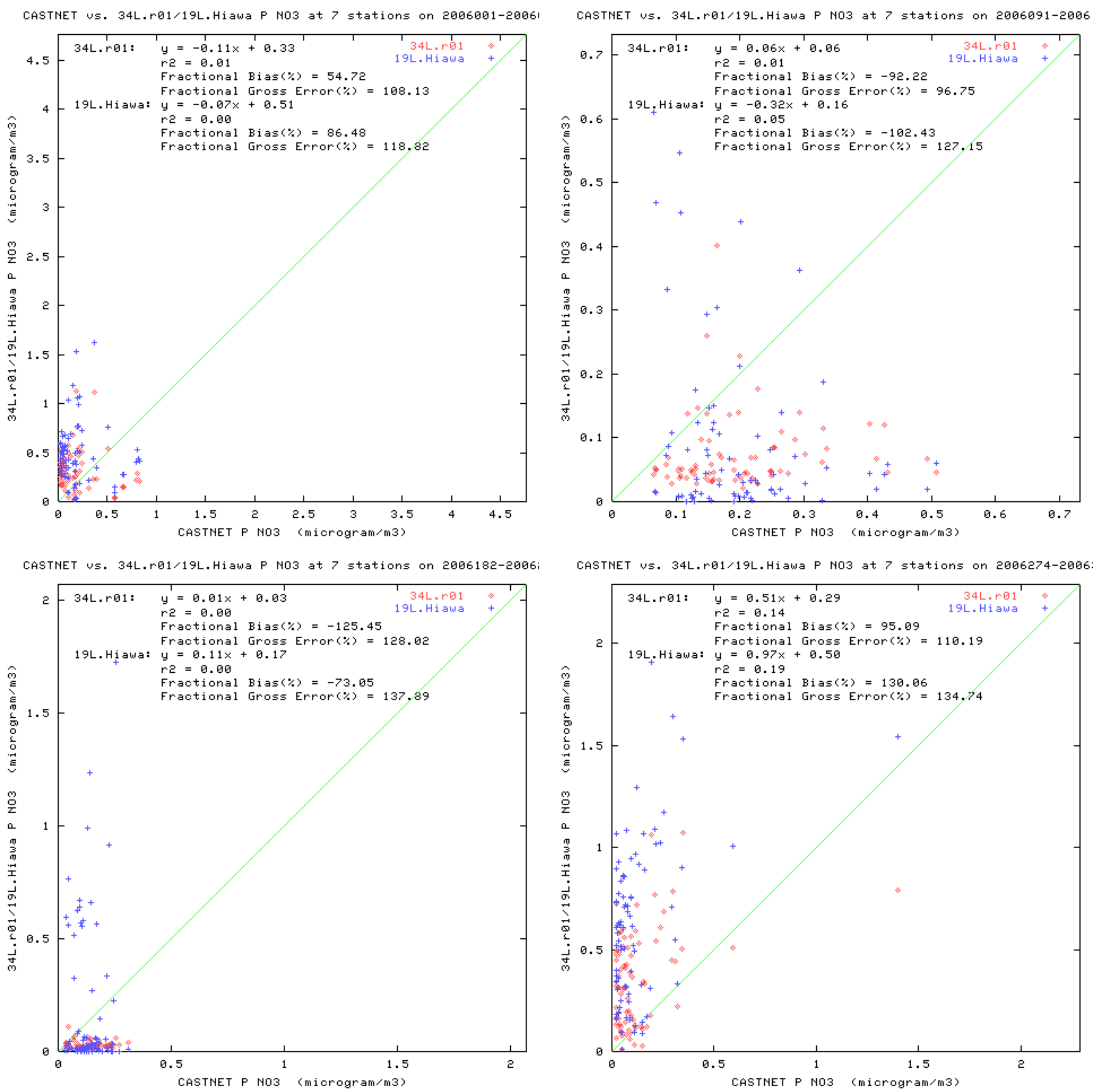


Figure A5-6b. Comparison of predicted and observed 24-hour average NO3 concentration for CASTNet sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – NO3

CD-C

Hiawatha

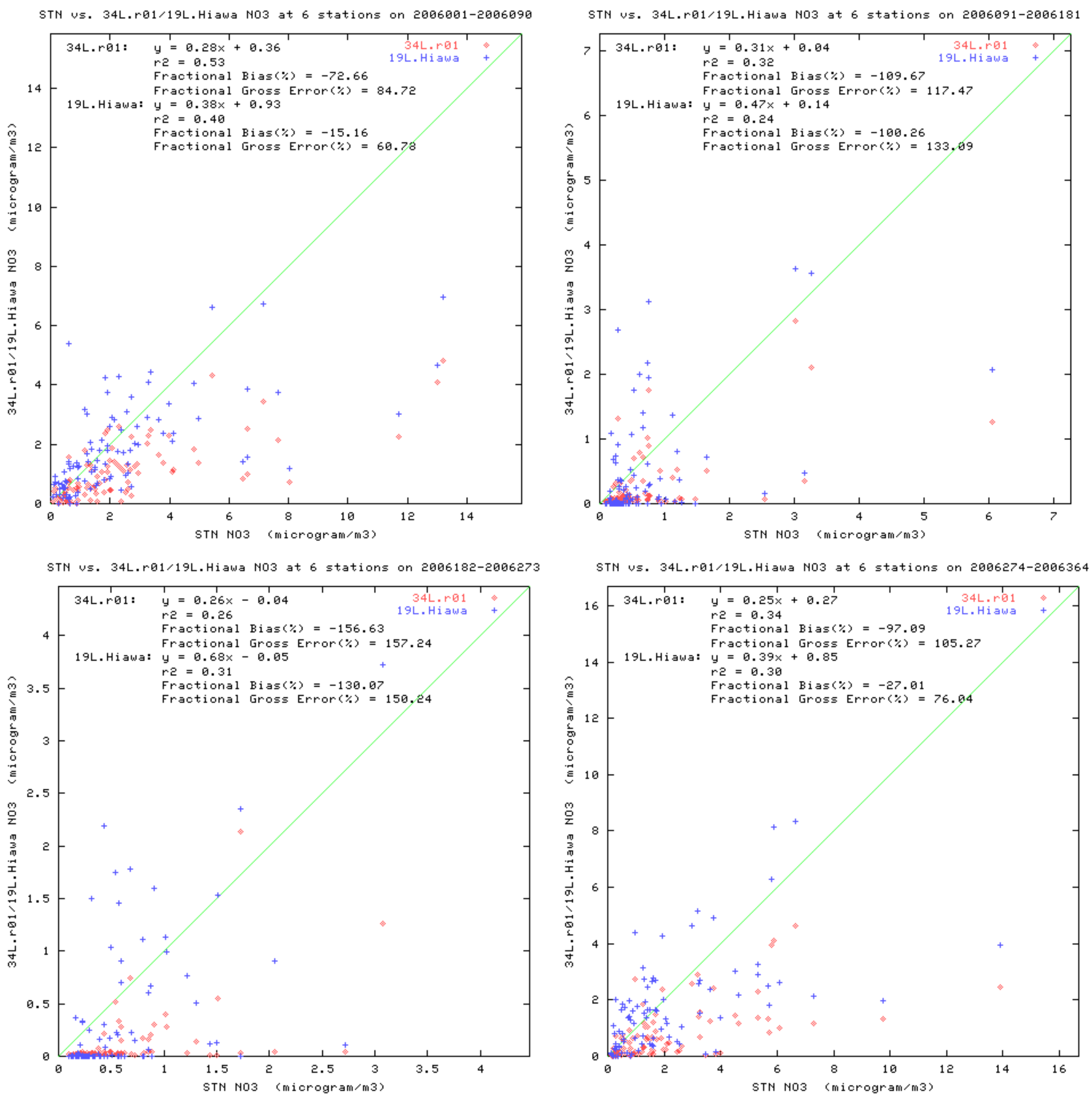


Figure A5-6c. Comparison of predicted and observed 24-hour average NO3 concentration for STN sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – HNO3

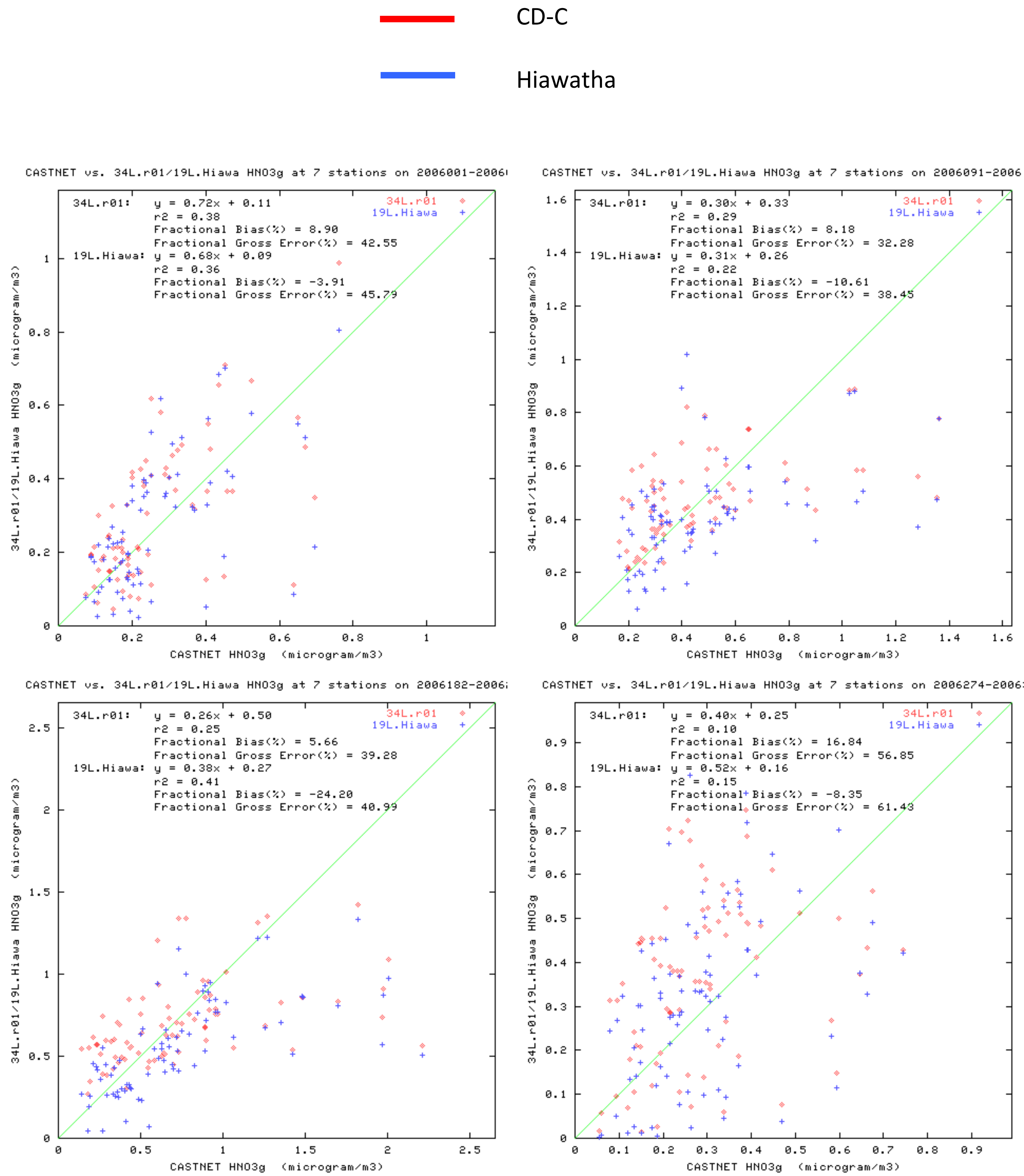


Figure A5-6d. Comparison of predicted and observed 24-hour average HNO3 concentration for CASTNet sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – Total Nitrate

CD-C

Hiawatha

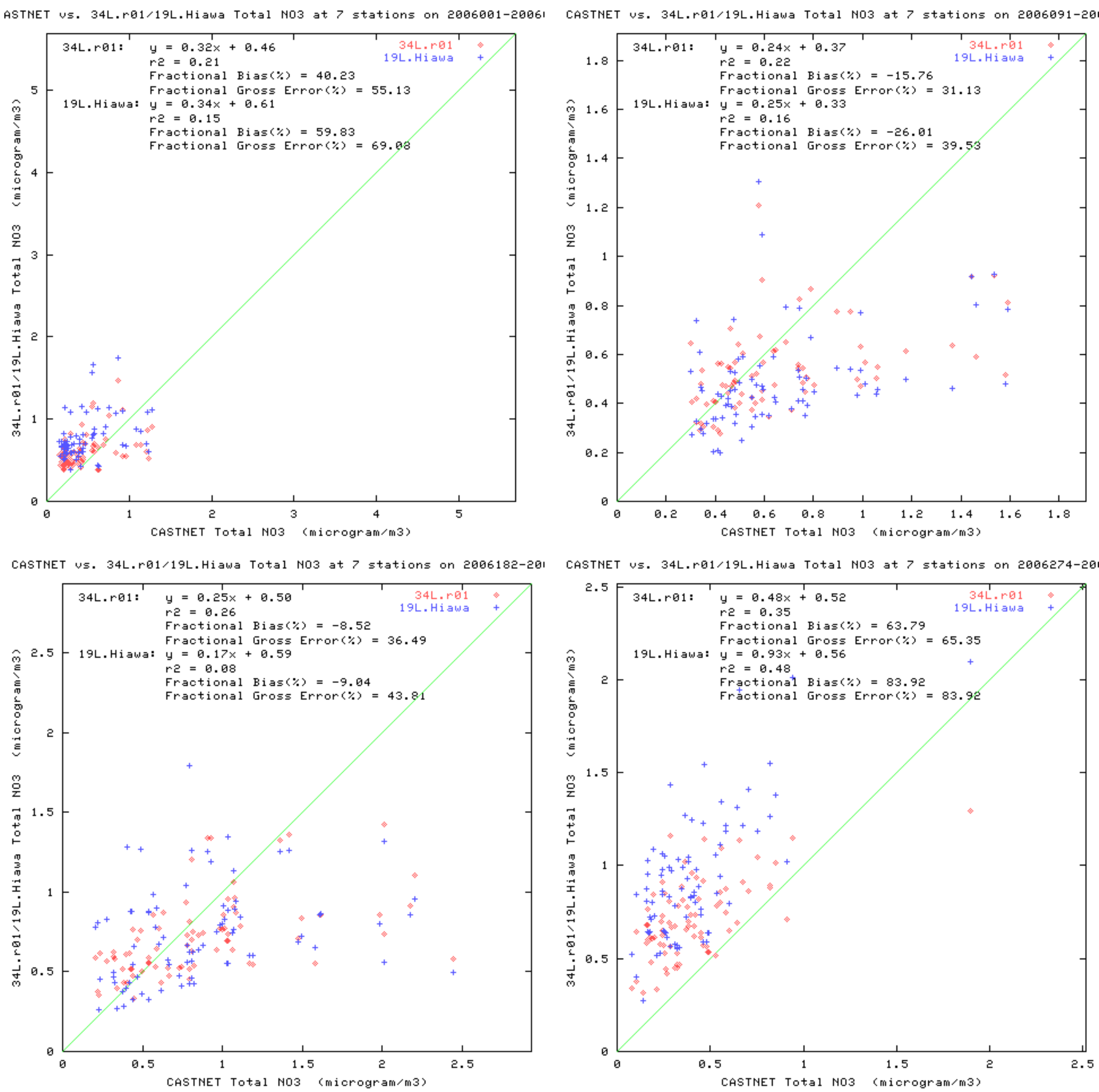


Figure A5-6e. Comparison of predicted and observed 24-hour average Total Nitrate (NO3+HNO3) concentration for CASTNet sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

CASTNet – NH4

CD-C

Hiawatha

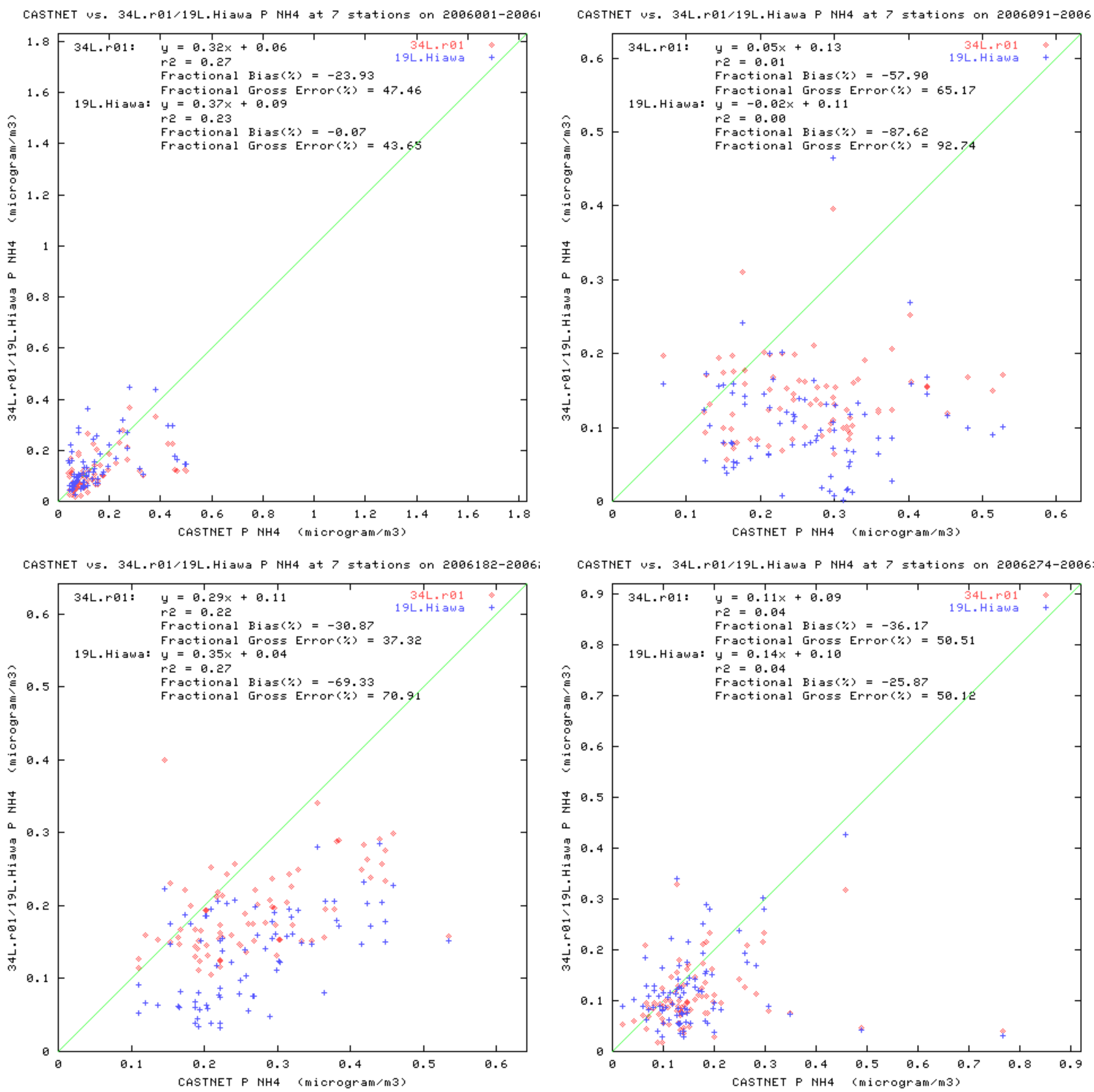


Figure A5-6f. Comparison of predicted and observed 24-hour average NH4 concentration for CASTNet sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – NH4

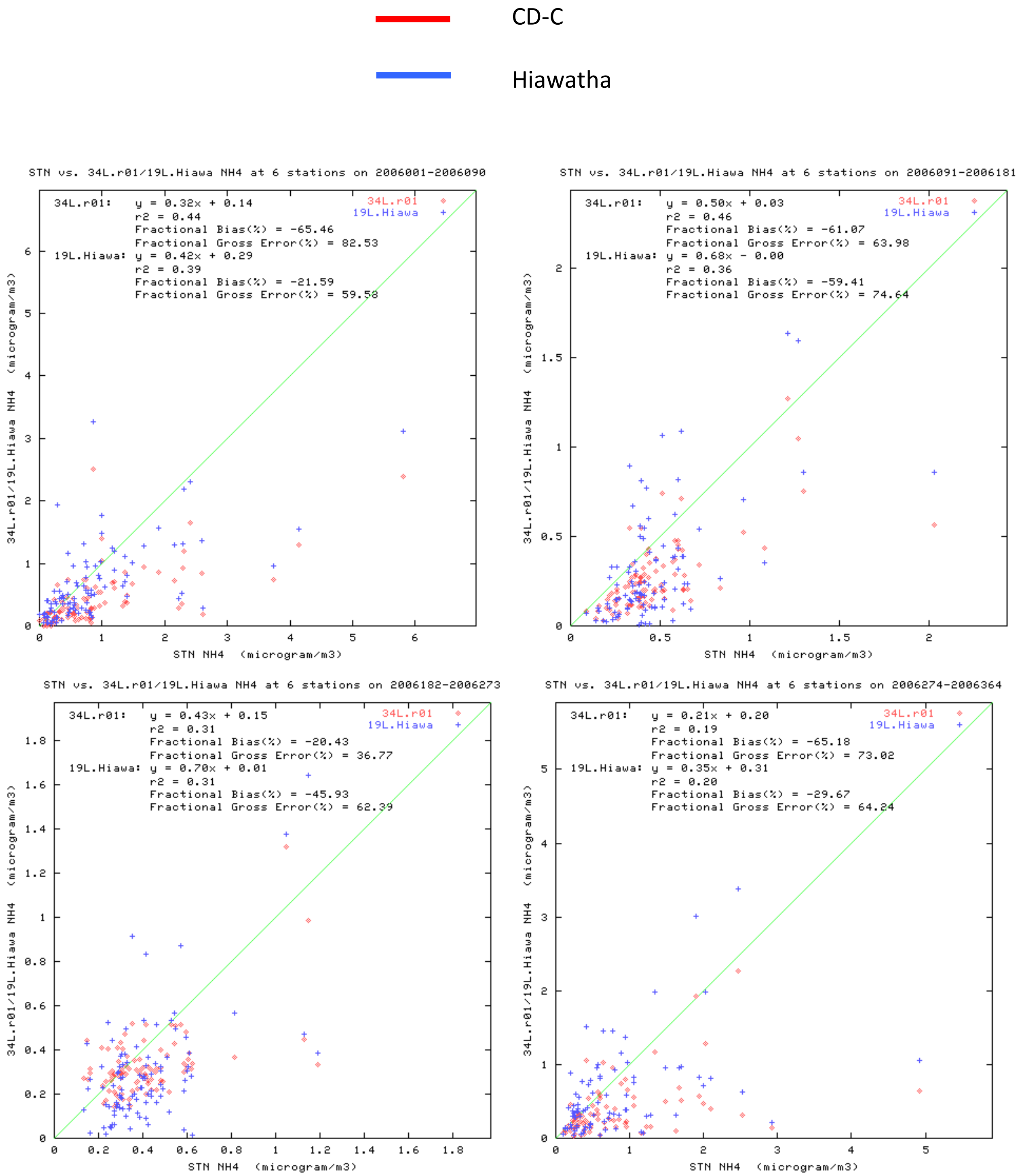


Figure A5-6g. Comparison of predicted and observed 24-hour average NH4 concentration for STN sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

NADP – NO3 wet deposition

CD-C

Hiawatha

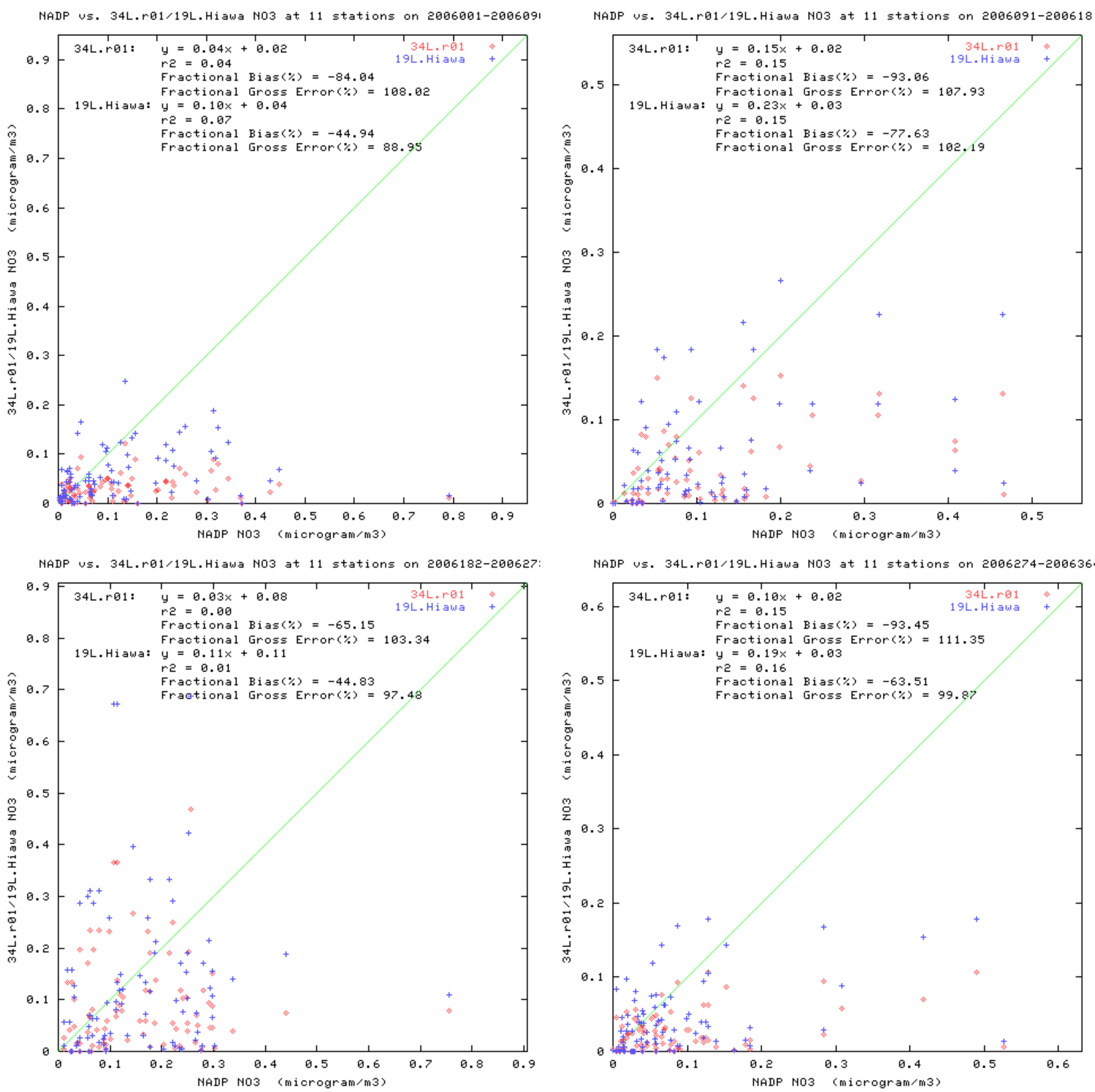


Figure A5-6h. Comparison of predicted and observed weekly average NO3 wet deposition for NADP sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

NADP – NH4 wet deposition

CD-C

Hiawatha

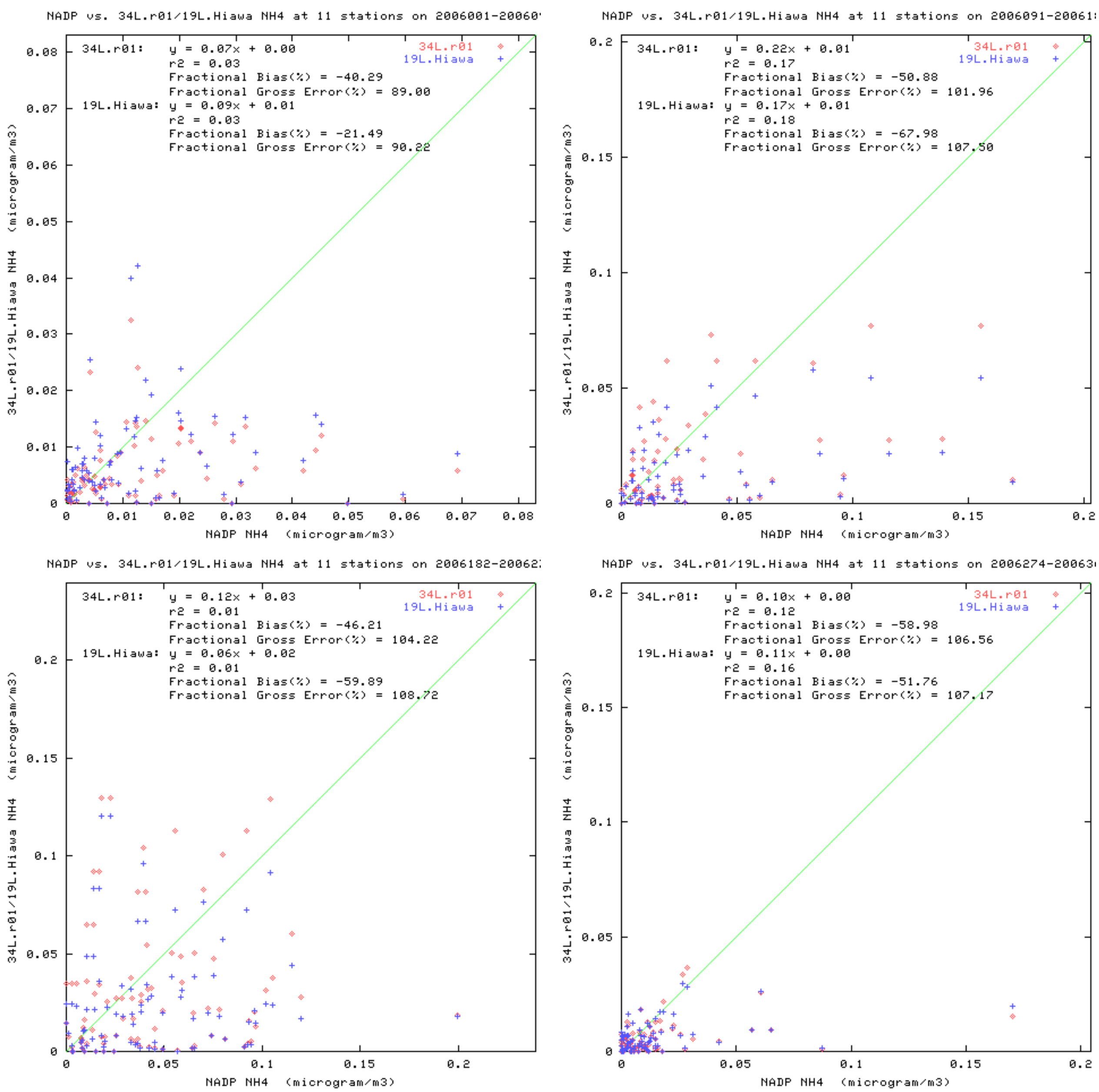


Figure A5-6i. Comparison of predicted and observed weekly average NH4 wet deposition for NADP sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

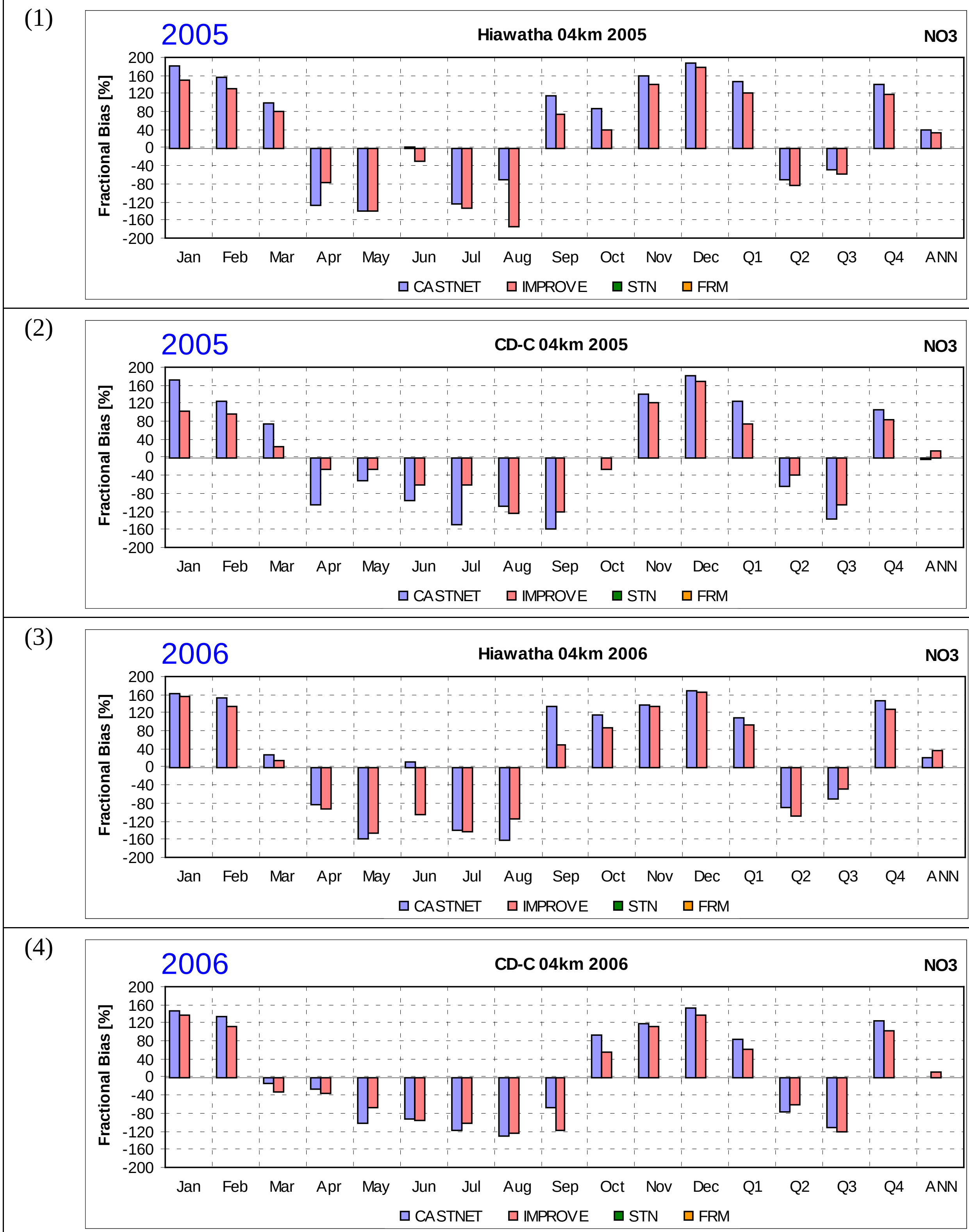


Figure A5-7a. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for NO3 in 4 km grid.

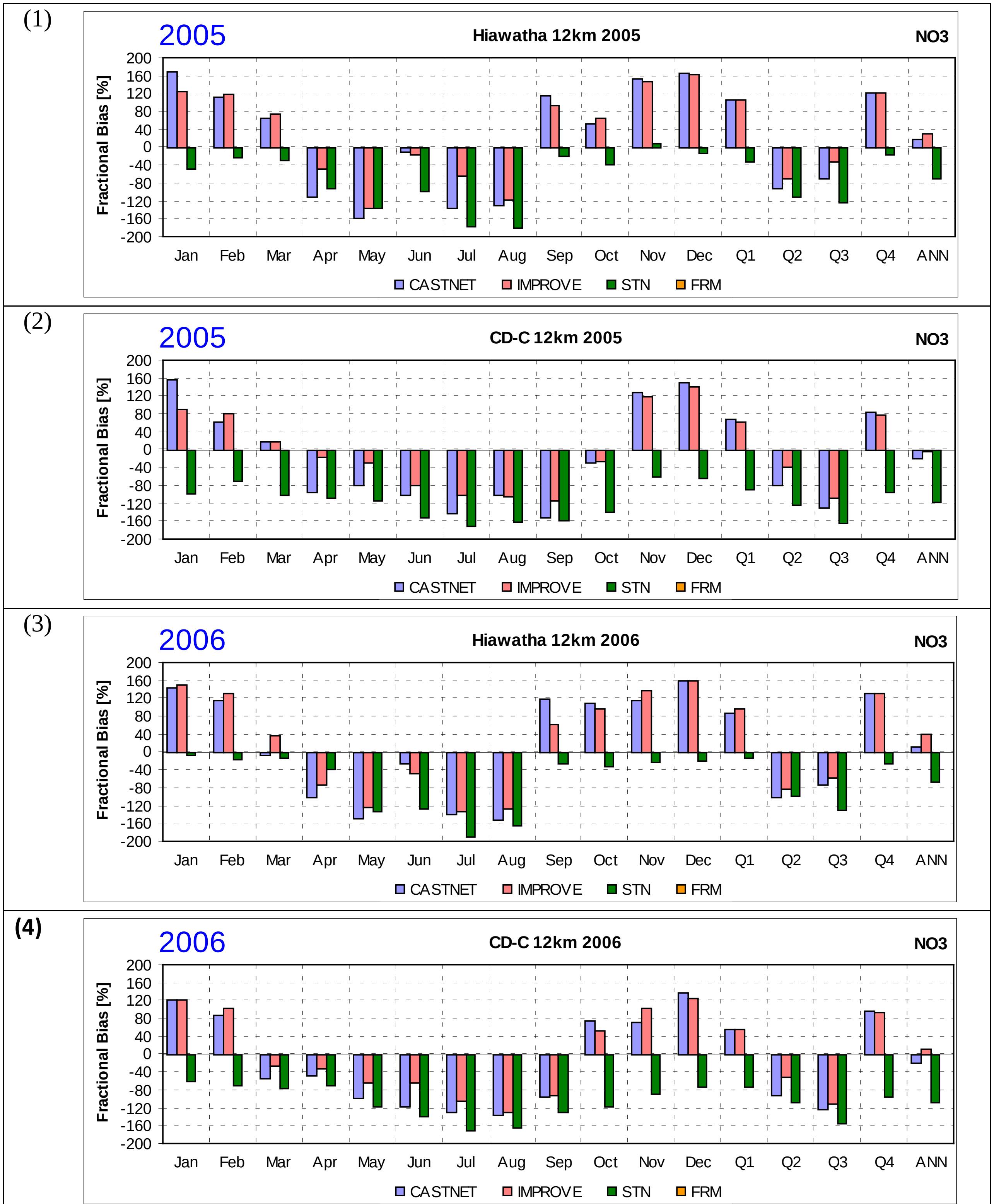


Figure A5-7b. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for NO3 in 12 km grid.

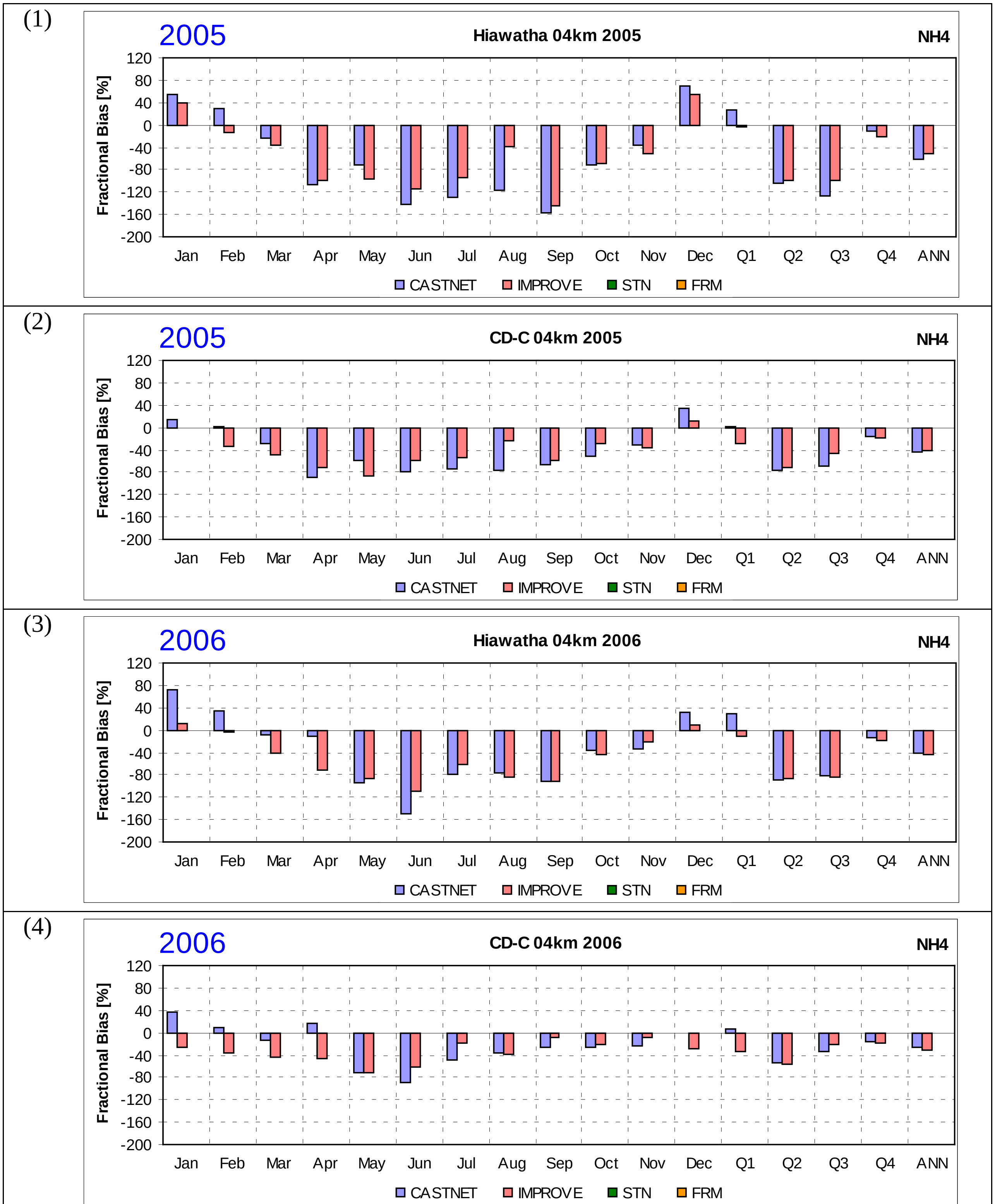
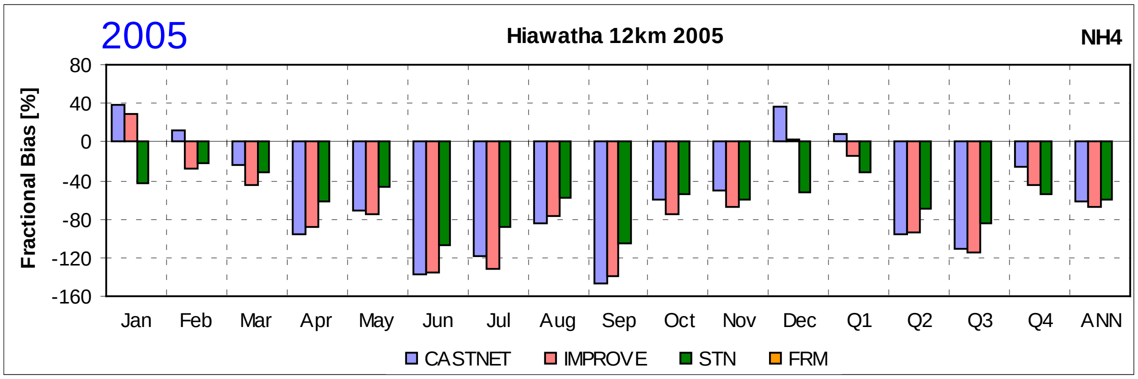
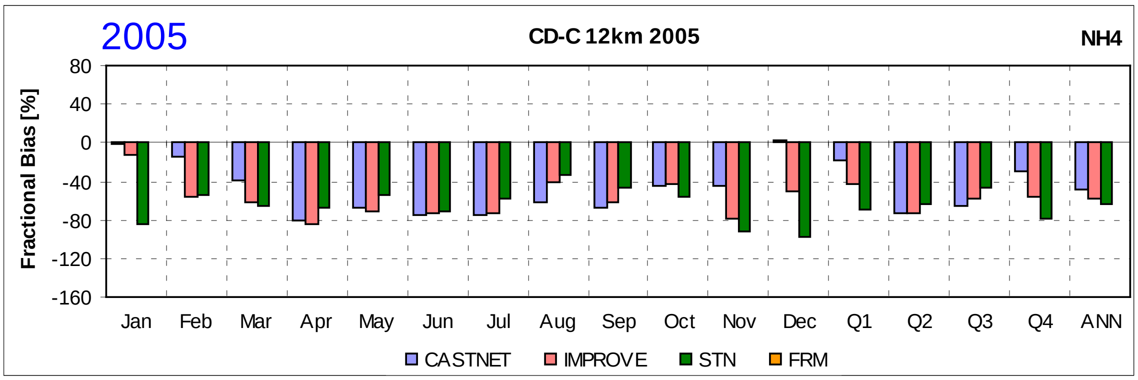


Figure A5-8a. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for NH4 in 4 km grid.

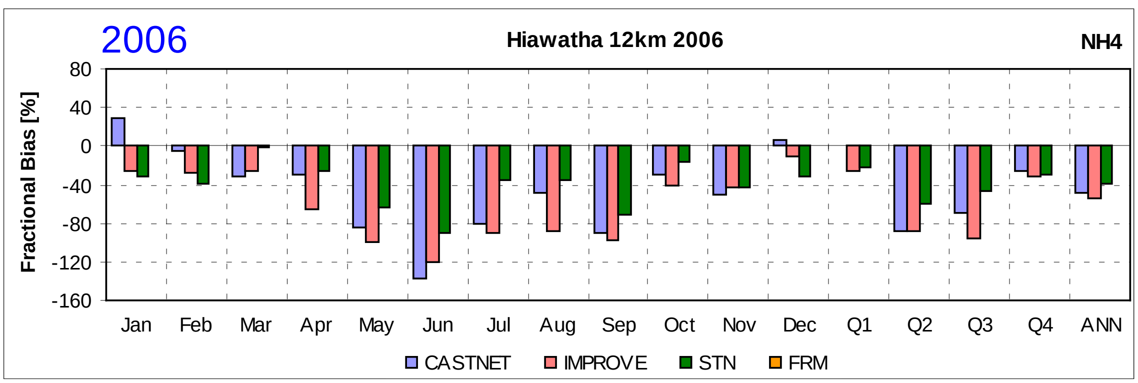
(1)



(2)



(3)



(4)

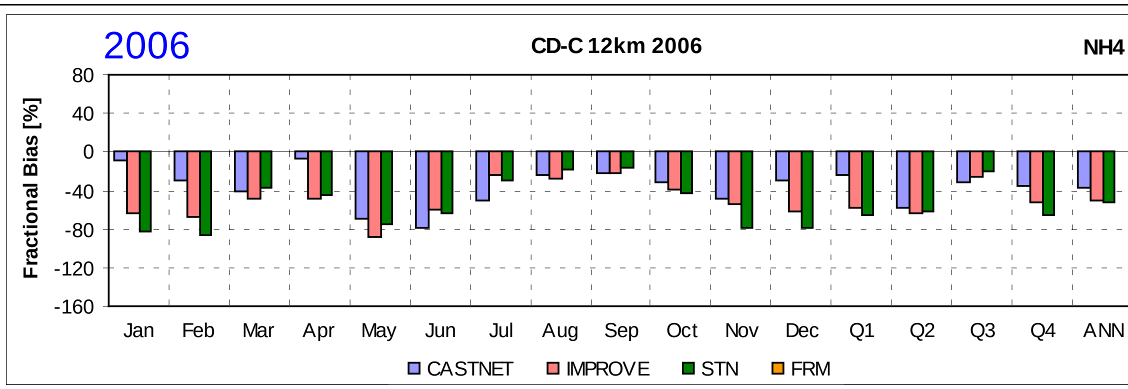


Figure A5-8b. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for NH4 in 12 km grid.

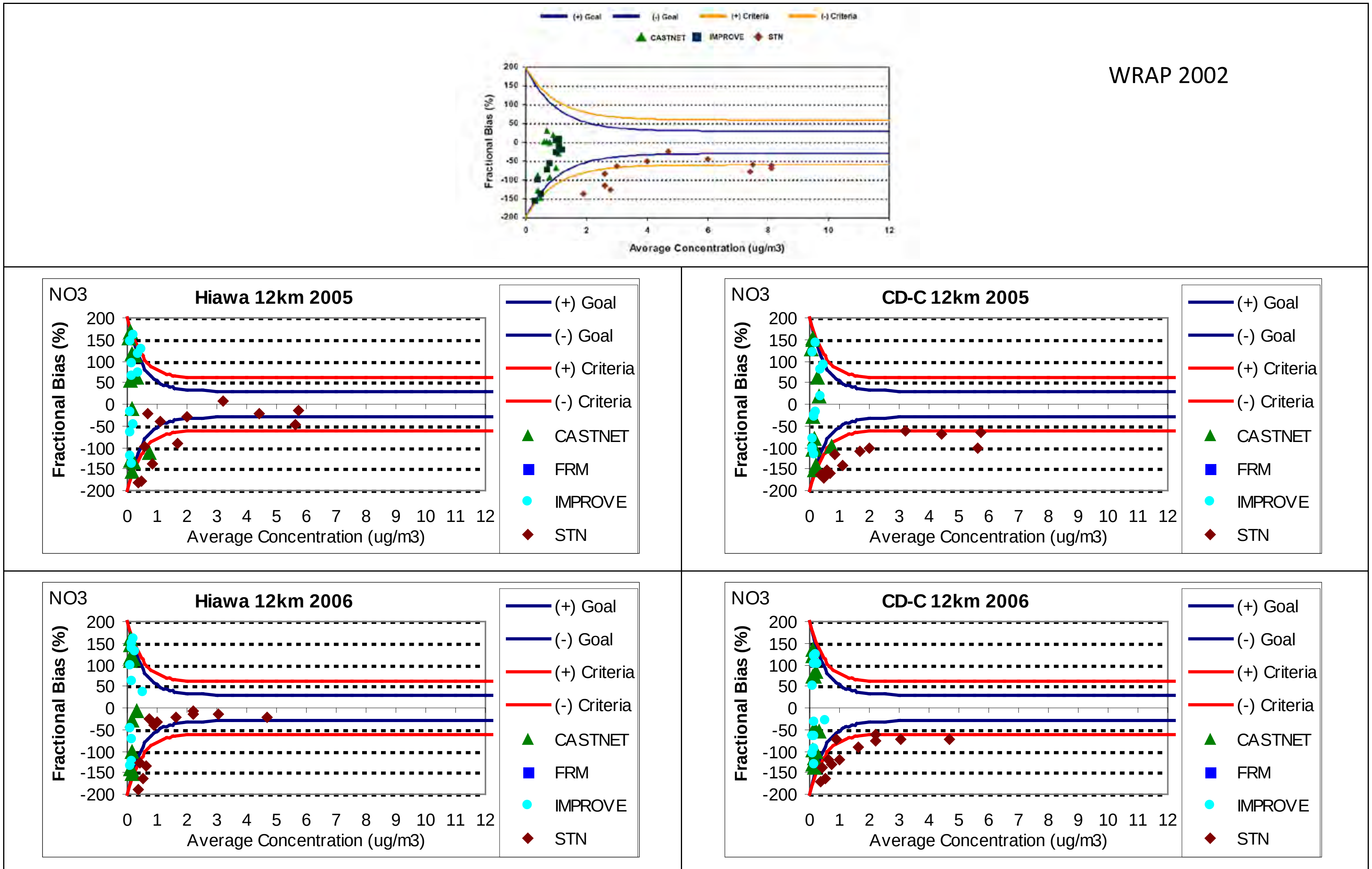


Figure A5-9a. Bugle Plots of NO3 model performance comparing mean fractional bias for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

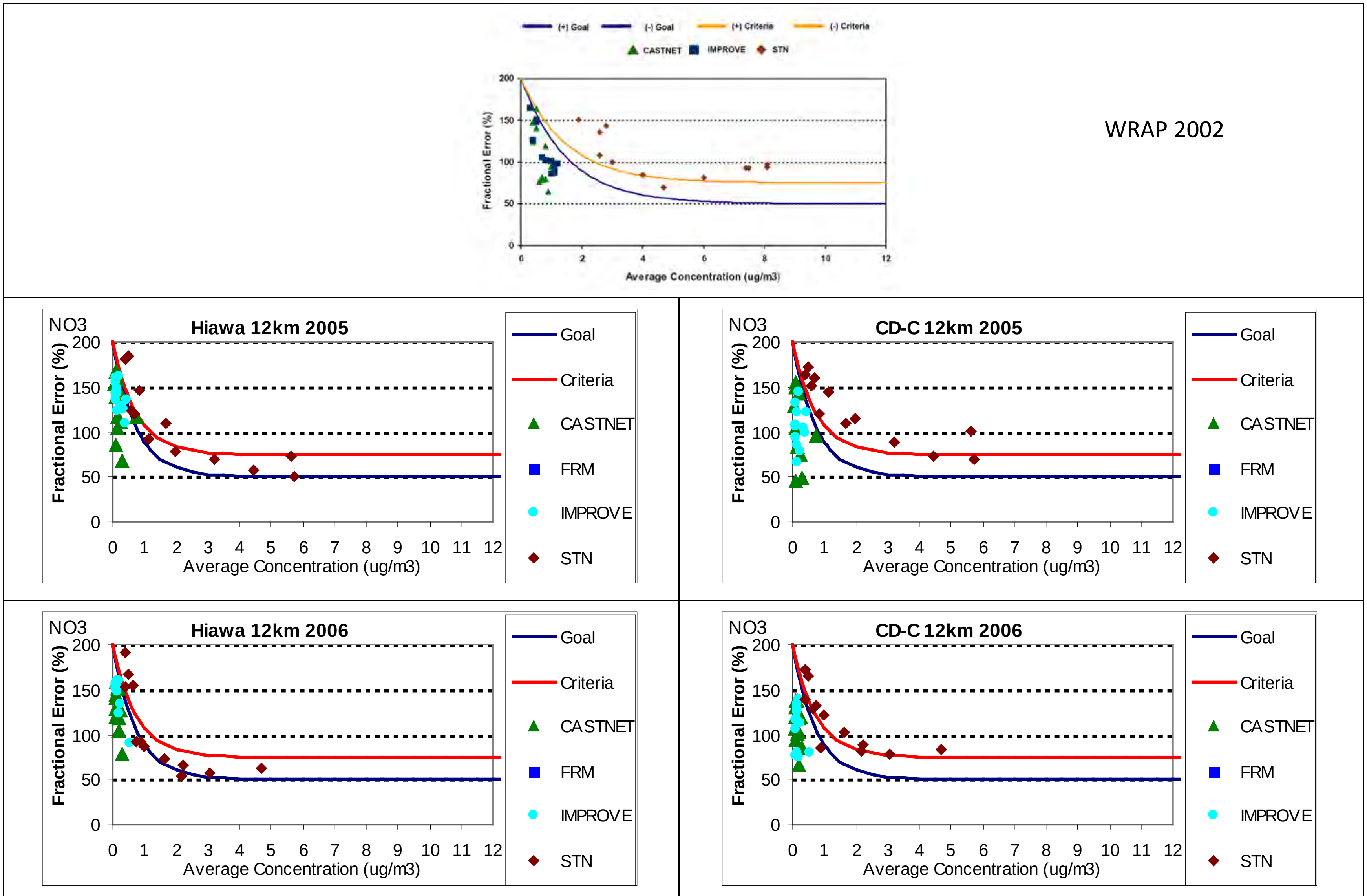


Figure A5-9b. Bugle Plots of NO3 model performance comparing mean fractional error for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

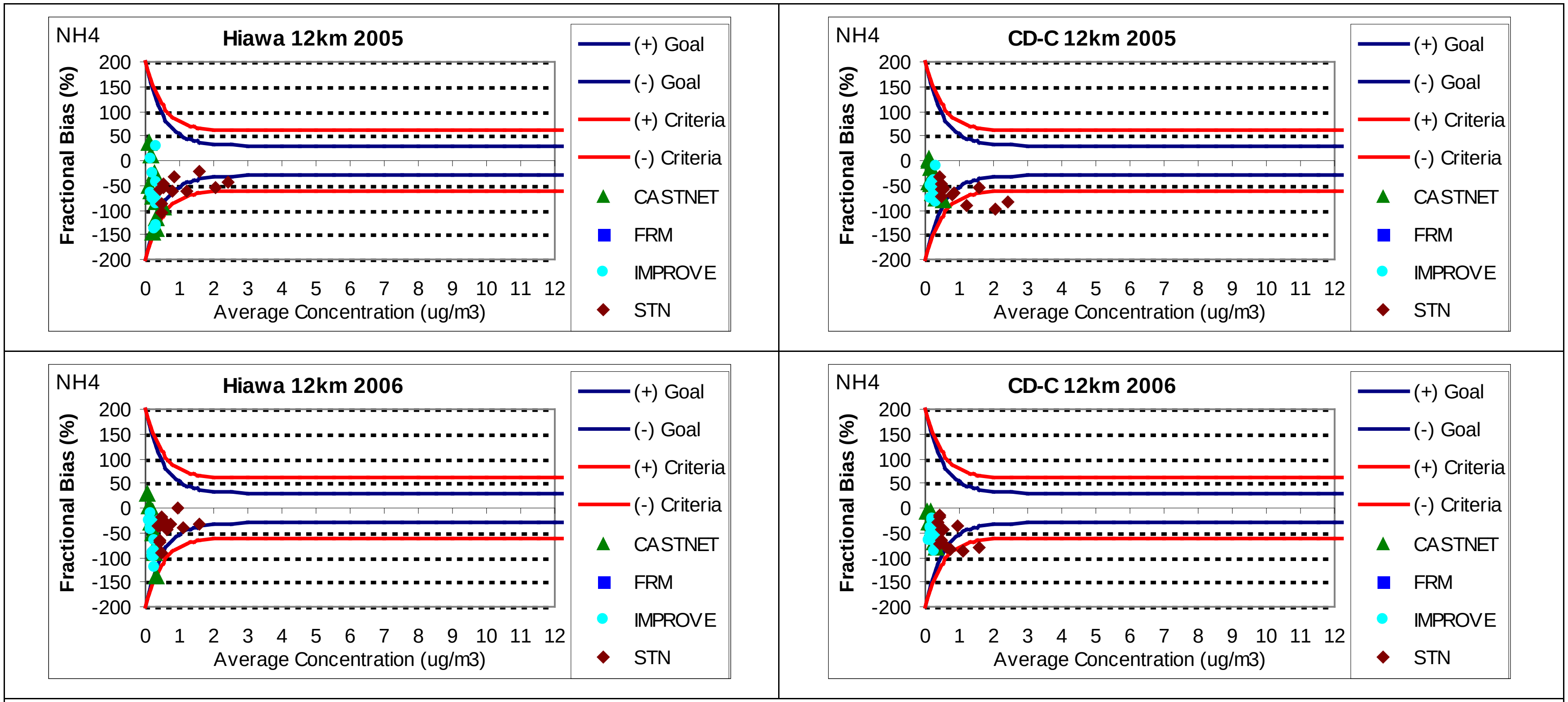


Figure A5-10a. Bugle Plots of NH4 model performance comparing mean fractional bias for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

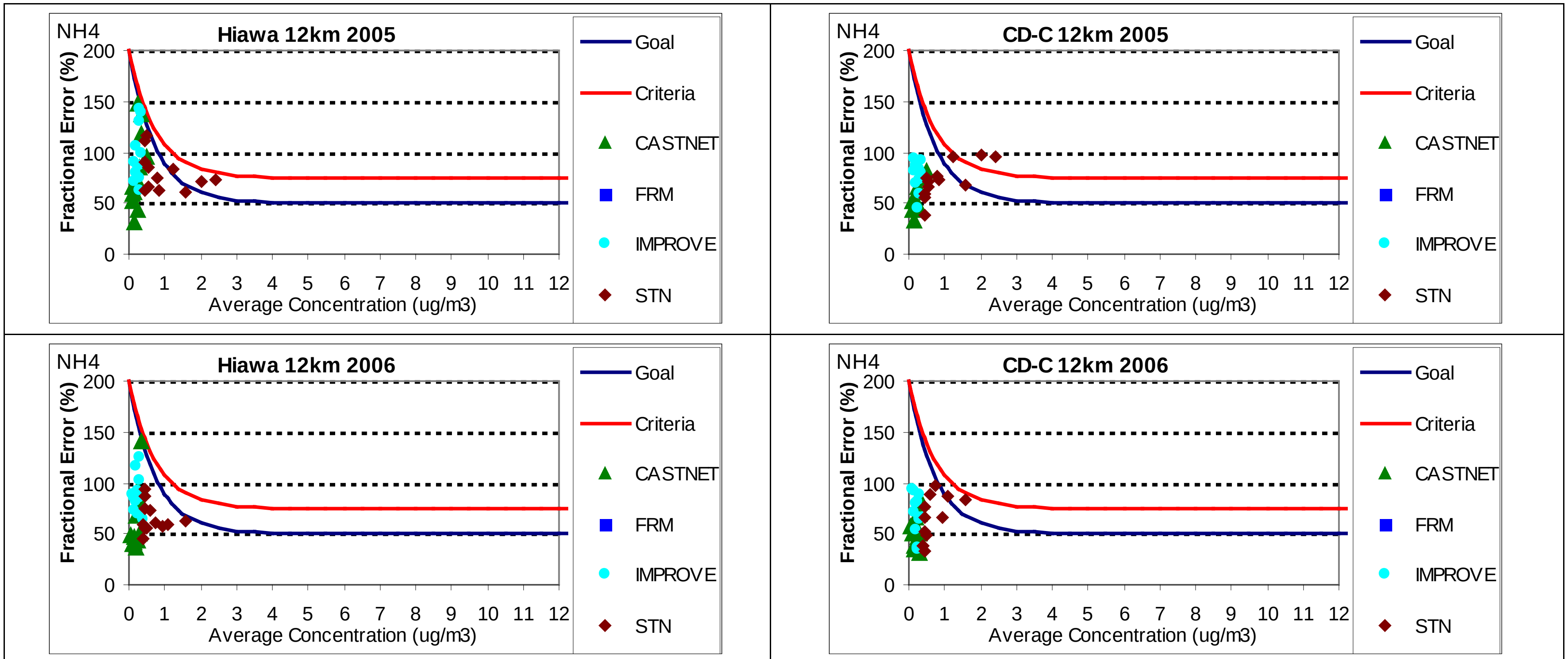


Figure A5-10b. Bugle Plots of NH4 model performance comparing mean fractional error for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

A5.3 ORGANICCARBON MASS (OCM) MODEL PERFORMANCE

Organic Carbon (OC) is measured at the IMPROVE and STN monitoring sites. It must be converted to Organic Carbon Mass (OCM, also called Organic Aerosolor OA) for comparisons with the modeled $PM_{2.5}$ concentrations. OCM/OC ratios tend to range from 1.2 to 2.4, with lower values associated with fresh OCM emissions and higher values associated with aged OA that has undergone photochemical processing. For the CD-C and Hiawatha OCM evaluation, we used an OCM/OC ratio of 1.8 for the rural IMPROVE sites, as 1.8 is the value used in the New IMPROVE equation, and is the best available and most current estimate of this quantity for rural areas. For the more urban STN sites, a OCM/OC ratio value of 1.2 was used, reflecting the fact that the urban STN sites are more influenced by fresh OCM emissions.

Figures A5-11 through A5-15 display the CAMx/OCM performance for 2005 and 2006 for the CD-C and Hiawathabase case simulations. The OCM model performance is characterized by systematic underprediction with monthly fractional bias values that range from approximately -30% to -130%. The two base case simulations fail to achieve the criteria for any quarter for 2005 and 2006 across the IMPROVE and STN monitors. Temporal patterns in bias arenot readily apparent in the model performance.

When the OCM performance of the CD-C and Hiawatha base case simulations is compared with the WRAP 2002 36 km run performance in Bugle Plots (Figure A5-15), the WRAP run shows marginally better performance at both the IMPROVE and the STN sites, but modeled concentrations do not reproduce ambient OCM well in any of the simulations. As for NO3 and SO4, the ambient OCM concentrations were somewhat lower in 2005-2006 than in 2002. Differences in OCM performance may also be related to different observed OCM/OC ratio assumptions. (WRAP used an OCM/OC ratio of 1.4 for all monitors.) Comparison of the CD-C and Hiawatha runs shows that the results of the two runs are very similar.

The development of OCM emissions, simulation of OCM in the atmosphere, and the monitoring of OC are all areas of current research. Although the measurement of OCM is very uncertain, use of different measurement techniques (e.g., IMPROVE vs. STN) can produce large differences (e.g., 50%), the emissions inventories also have several deficiencies that are known to produce an underprediction bias:

- Current mobile source OCM emissions estimates (MOBILE6) fail to account for temperature and speed effects that can have large influences on the primary OCM emissions.
  - Recent comparisons between EPA's new MOVES mobile source emissions model and MOBILE6 suggest that on-road mobile source particulate matter emissions are underestimated by MOBILE6 buy a factor of approximately 3 (Beardsley and Dolce, 2009).
- MOBILE6 fails to account for semi-volatile organic compound (SVOC) emissions from gasoline and diesel combustion. Recent SVOC emission measurements from gasoline vehicles were 3 times higher than the primary OCM emissions; if only a third of the SVOC emissions were to condense to particulate secondary organic aerosol (SOA) that would double the amount of OCM due to mobile sources.

- Other combustion sources (e.g., fires) also have SVOC emissions that are not accounted for in the current emission inventories.
- Given these important missing OCM processes, we are not surprised by the OCM underprediction tendency in the CAMx base case runs. Fortunately, most of these deficiencies in OCM have little effect on the AQ and AQRV impacts due tothe oil and gas emission sources that are the focus of the CD-C impact assessment.

IMPROVE – OCM

CD-C

Hiawatha

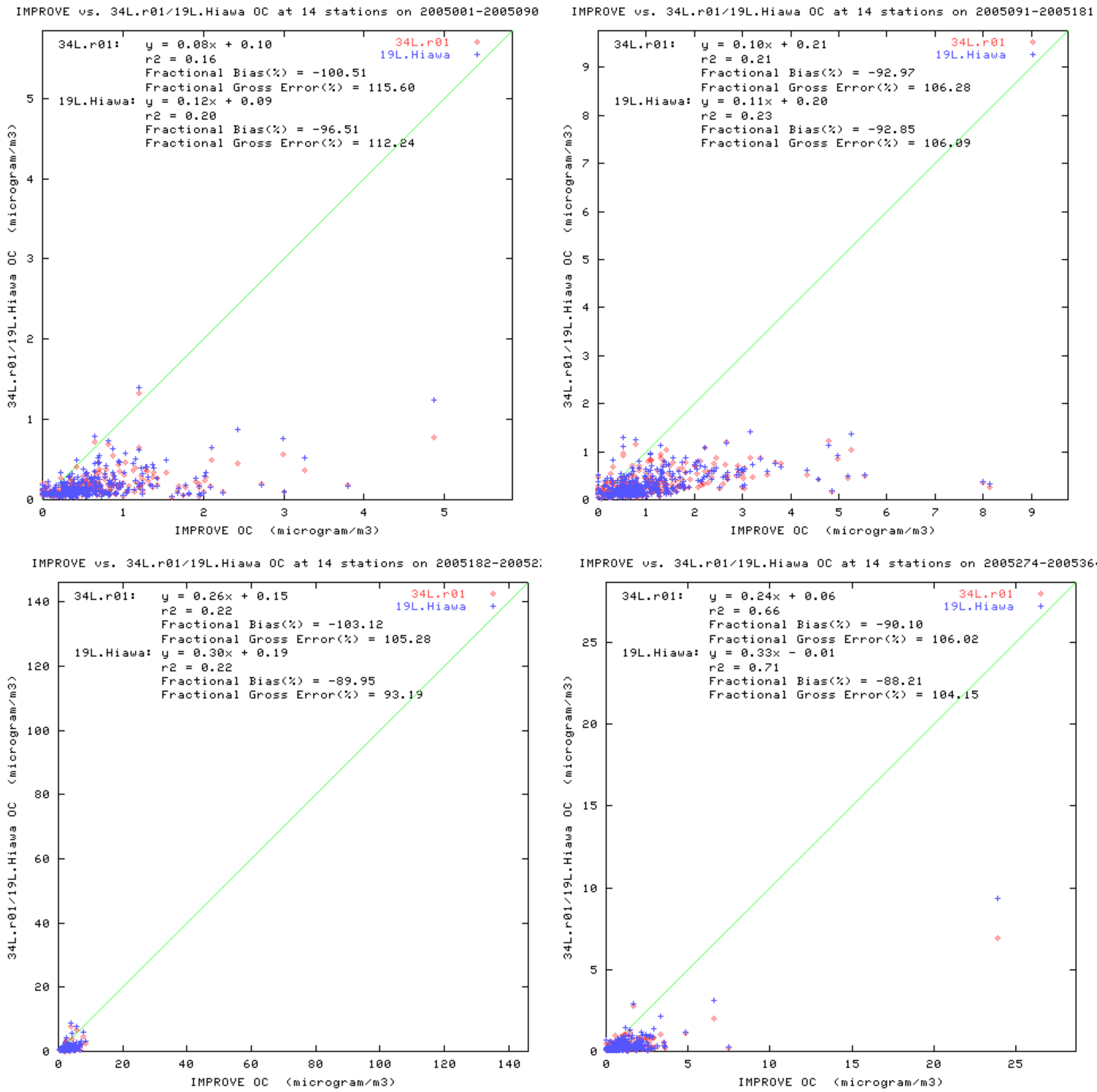


Figure A5-11a. Comparison of predicted and observed 24-hour average OCM concentration for IMPROVE sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – OCM

CD-C

Hiawatha

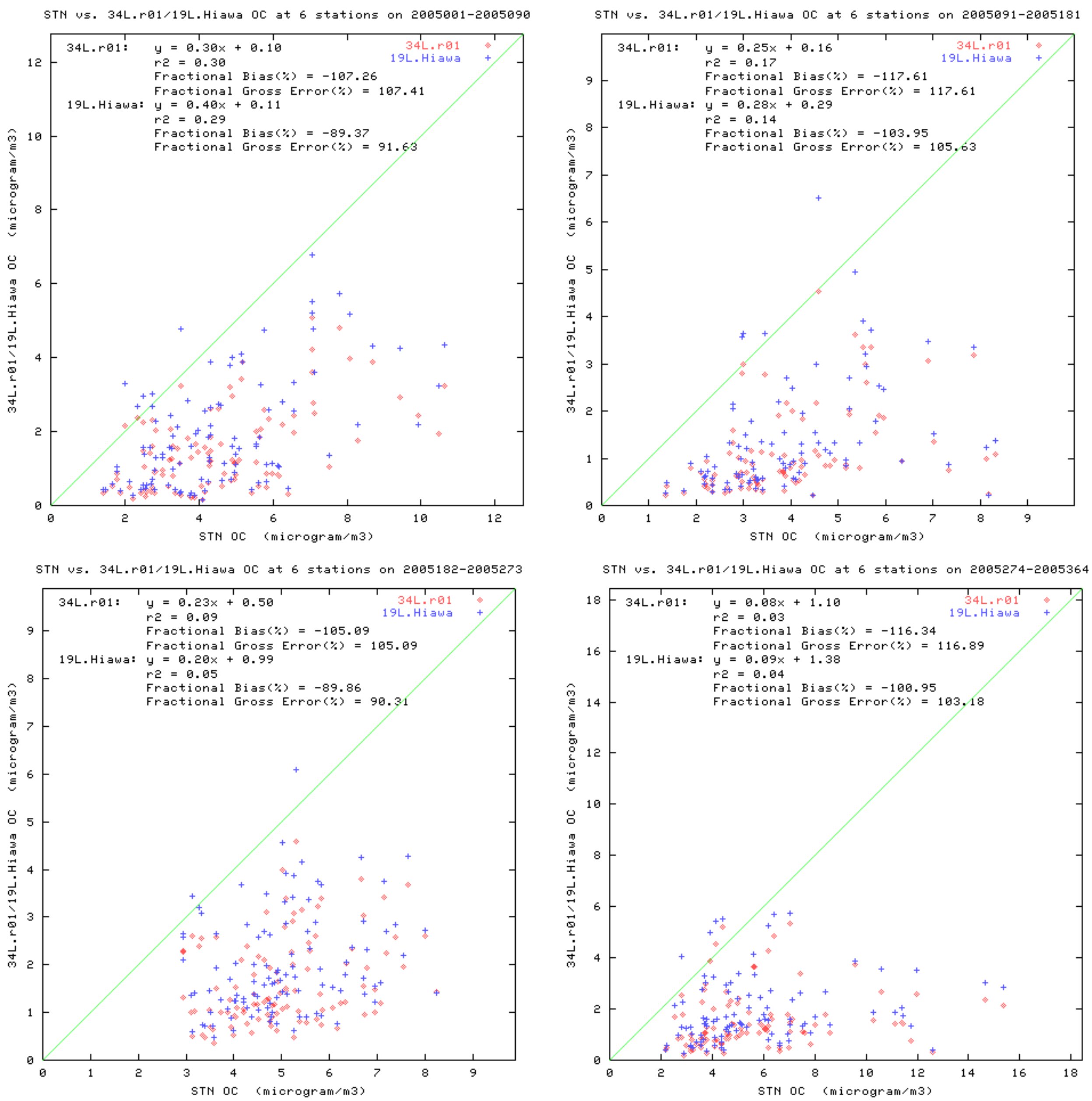


Figure A5-11b. Comparison of predicted and observed 24-hour average OCM concentration for STN sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – OCM

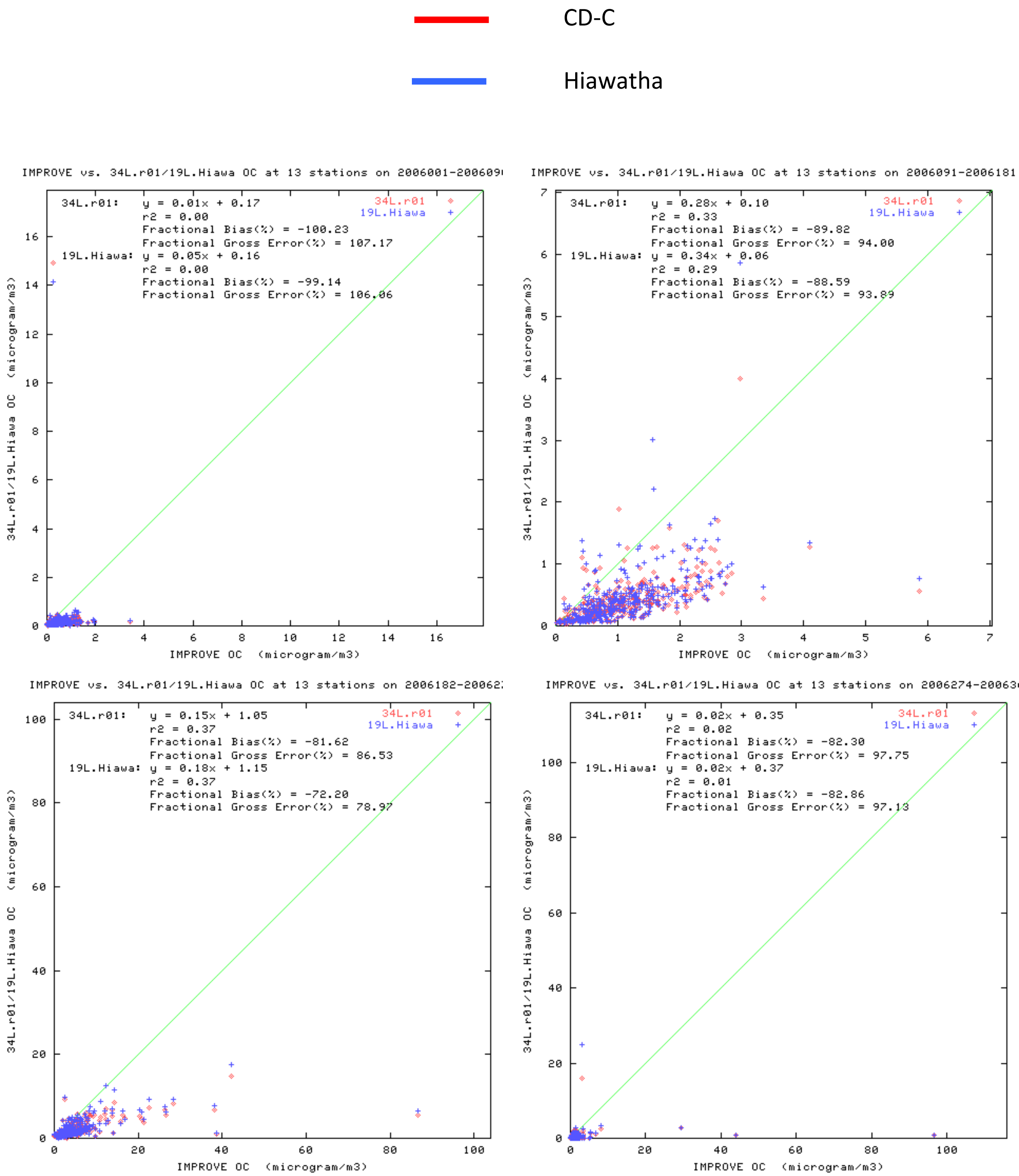


Figure A5-12a. Comparison of predicted and observed 24-hour average OCM concentration for IMPROVE sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – OCM

CD-C

Hiawatha

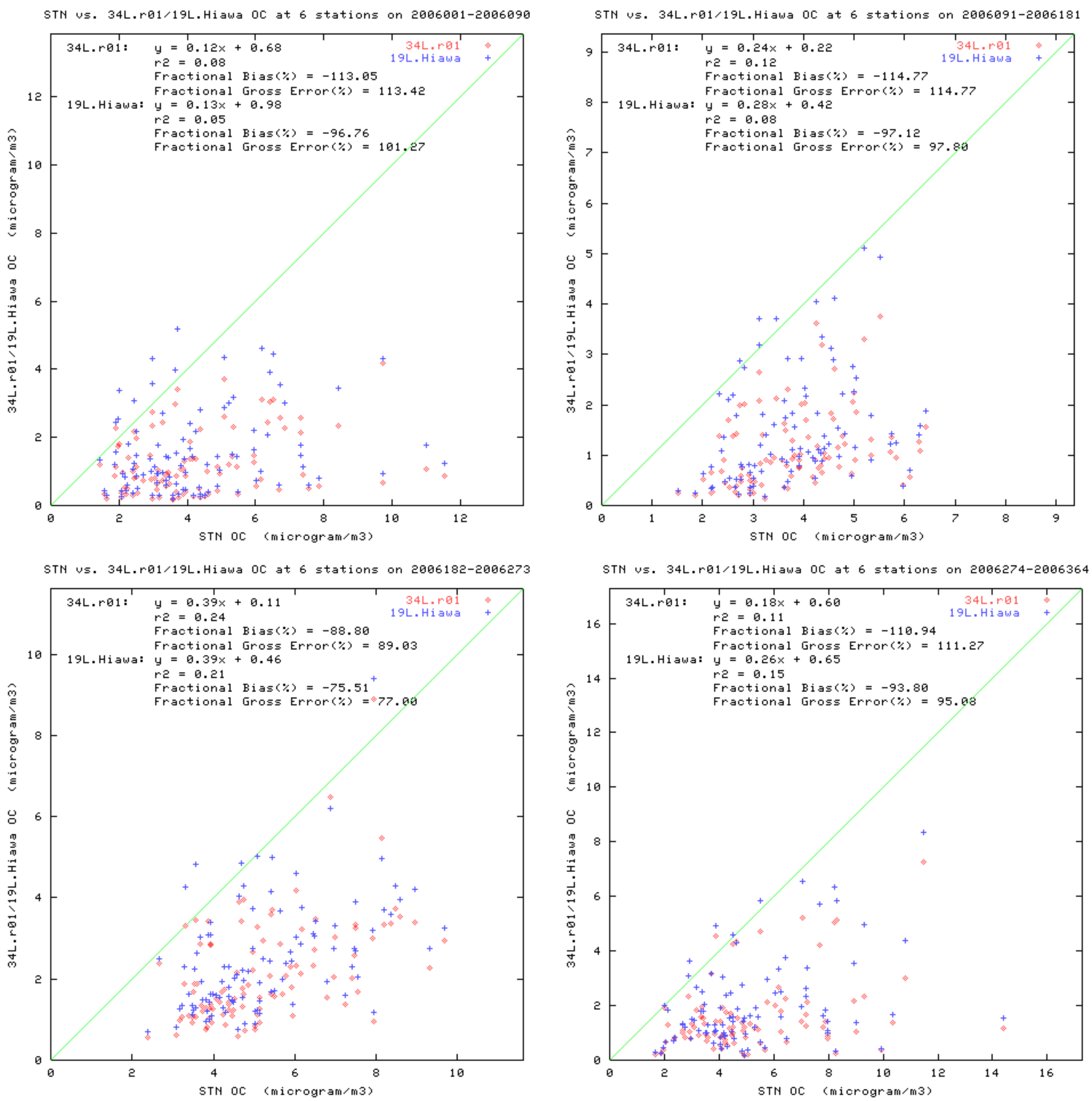


Figure A5-12b. Comparison of predicted and observed 24-hour average OCM concentration for STN sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

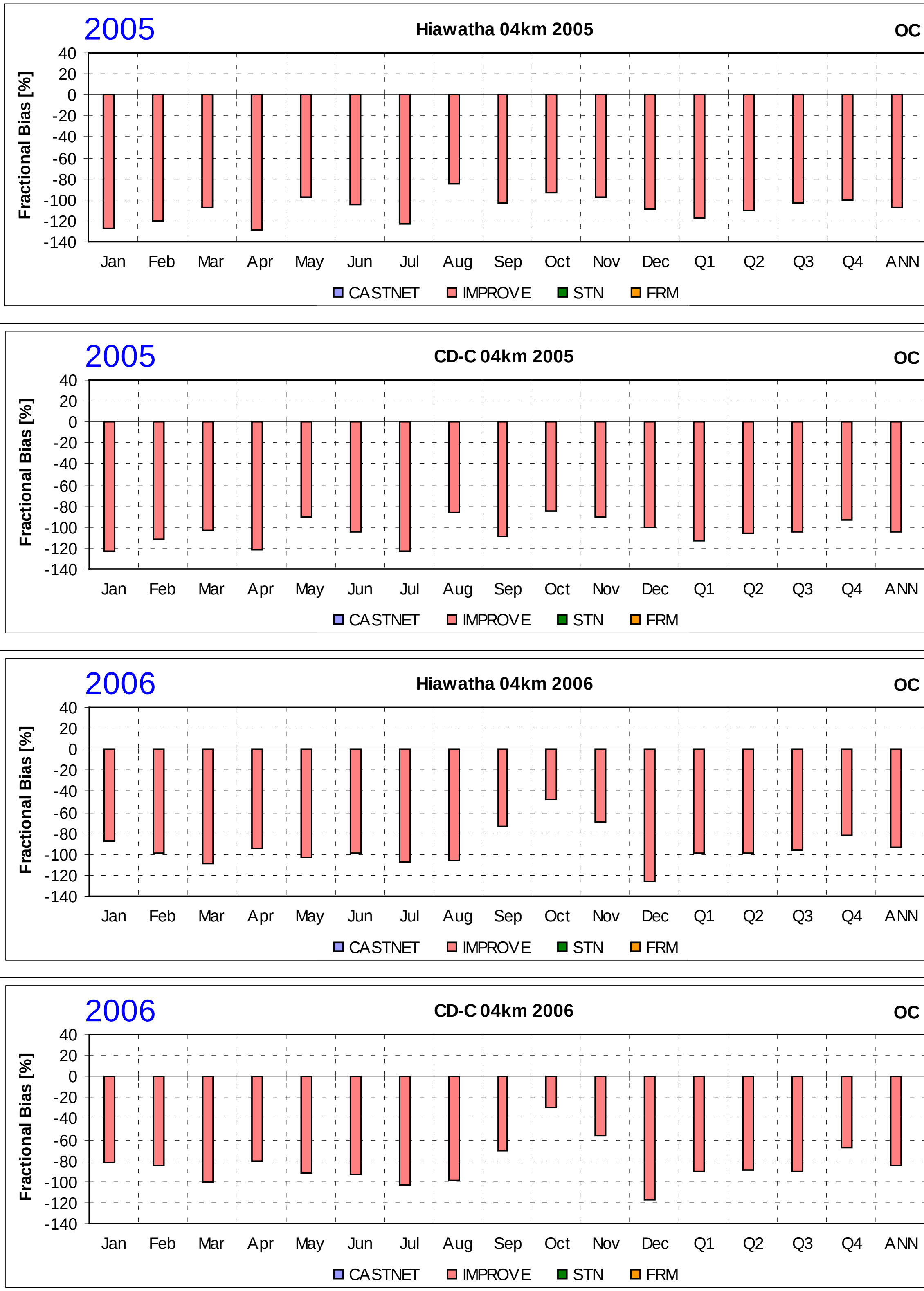


Figure A5-13. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for OCM in the 4 km grid.

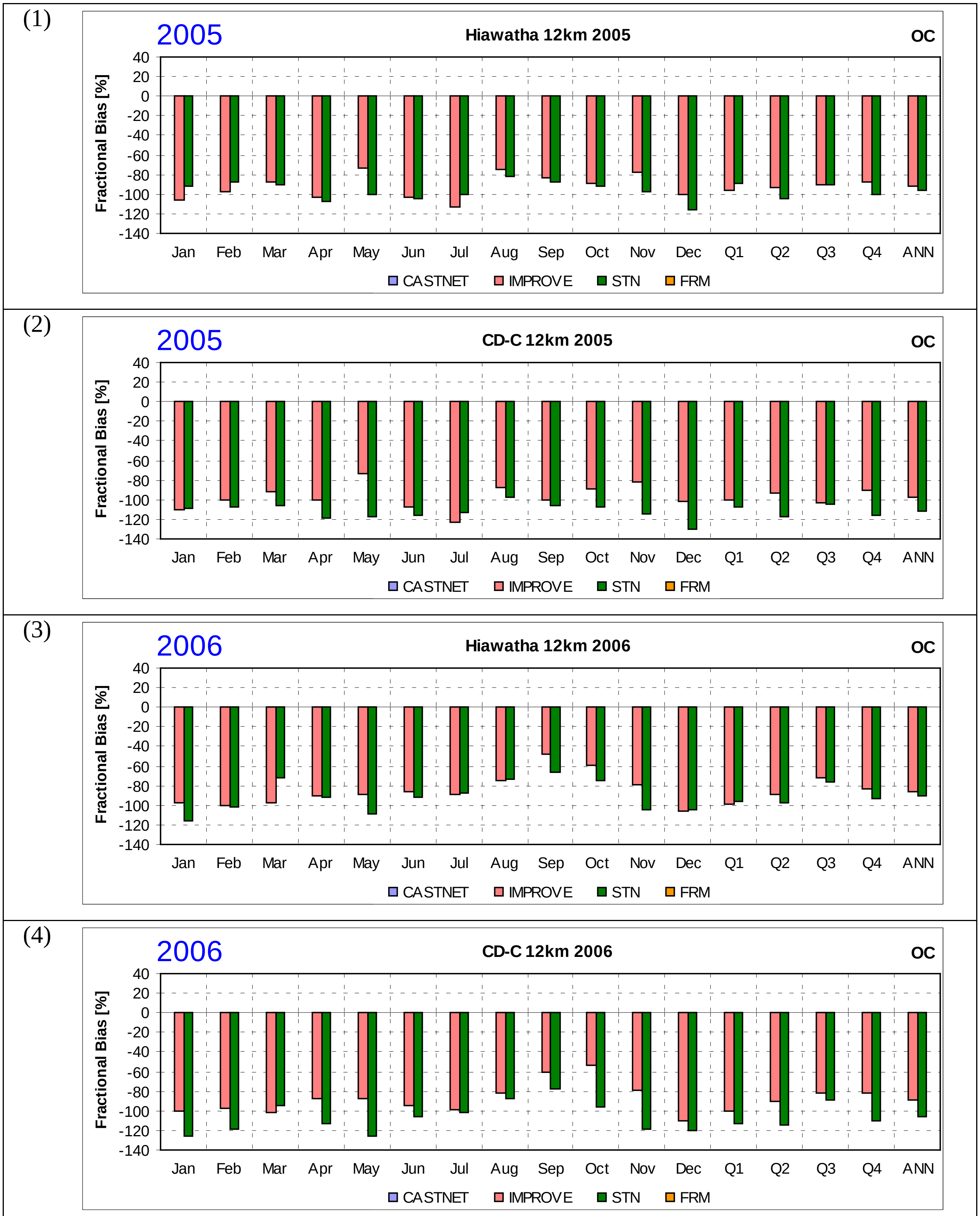


Figure A5-14. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for OCM in the 12 km grid.

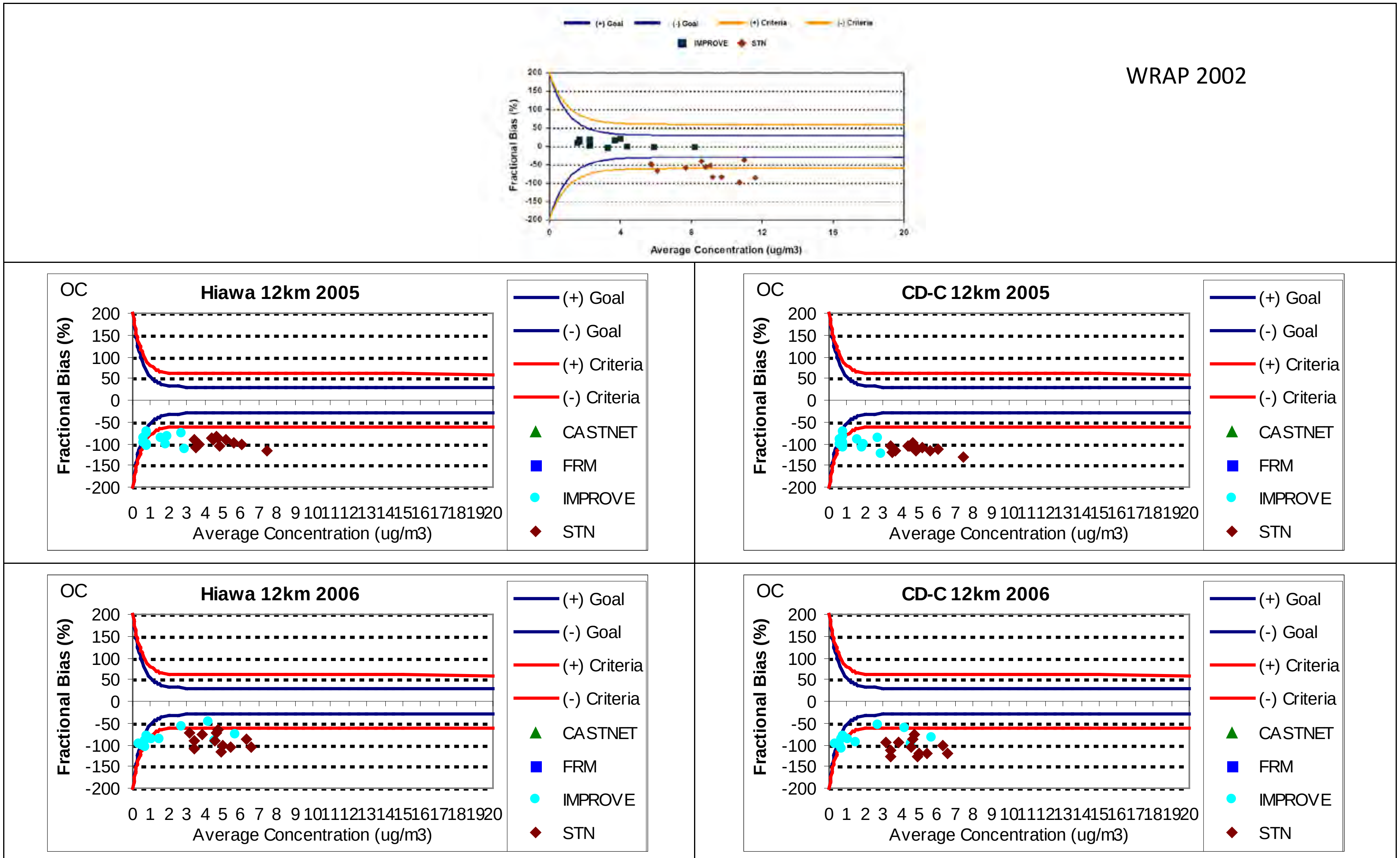


Figure A5-15a. Bugle Plots of OCM model performance comparing mean fractional bias for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

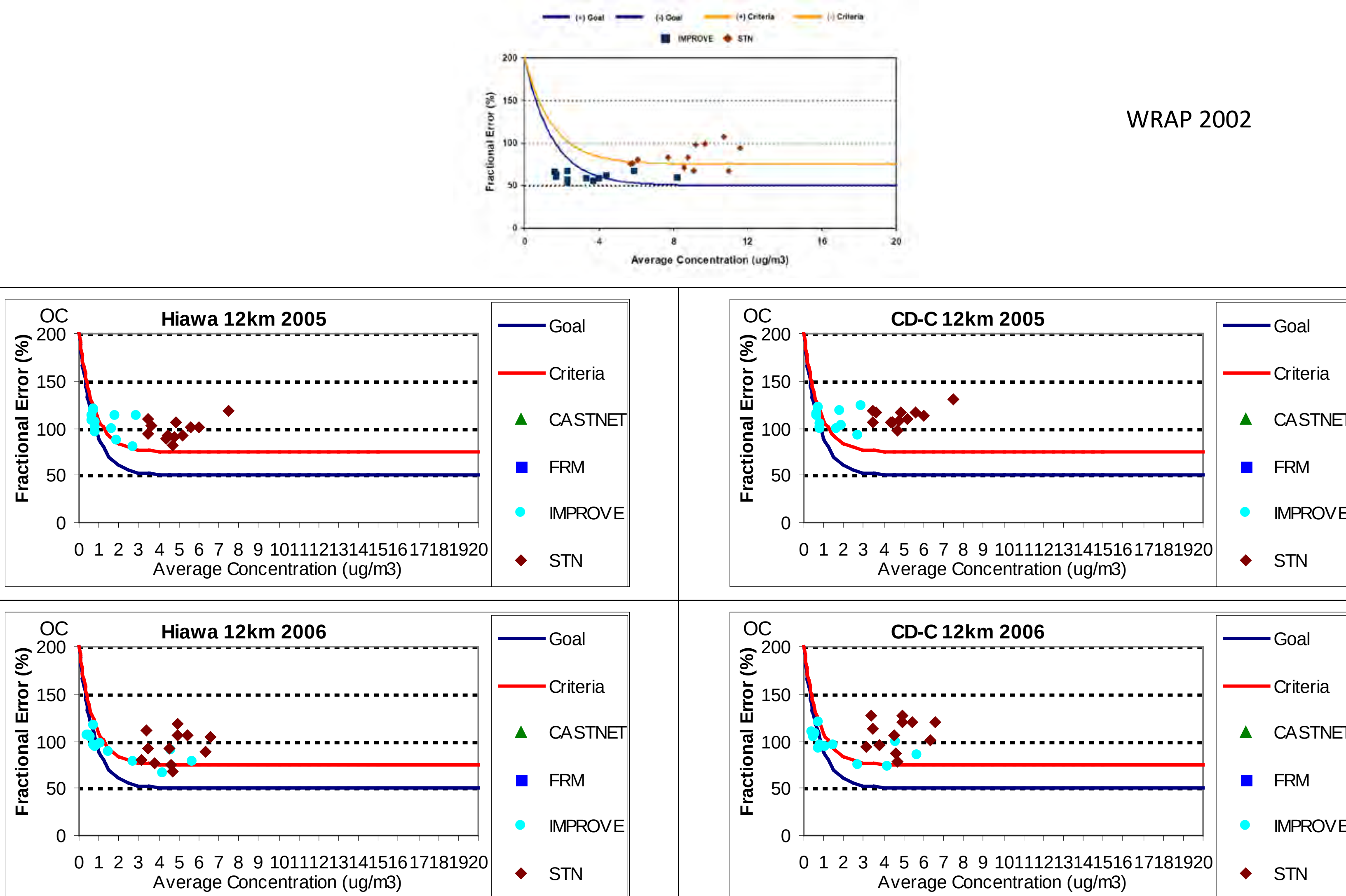


Figure A5-15b. Bugle Plots of OCM model performance comparing mean fractional error for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

A5.4 ELEMENTAL CARBON (EC) MODEL PERFORMANCE

The scatter plots and bias and error plots for Elemental Carbon (EC) model performance are shown in Figures A5-16 through A5-20. Across the IMPROVE network, both the modeled and observed EC are typically just a few tenths of a µg/m^3. However, there are some exceptions to this that are likely due to impacts from wildfires that impacted monitors in the CAMx simulations but did not impact the monitor during the actual fire event and vice versa. The bias performance statistics in the 4 km(FigureA5-18) and 12 km (Figure A5-19) domains indicate that the model generally underestimates EC during winter, spring, and early summer and overestimates EC during late summer and fall across the IMPROVE network. Higher predicted and observed EC concentrations are seen in the STN network (Figure A5-16b, 6-17b and 6-19), where the model exhibits much lower bias that achieves the PM performance goal for all quarters for 2005 and 2006, except Q2 of 2006. There is however, sufficient scatter that the error does not achieve the PM performance goal except for Q3 of 2005. The overall EC underprediction bias across the IMPROVE network is apparent in the monthly bias time series plots (FiguresA5-18 and A5-19).

The Bugle Plots of bias and error in Figure A5-21 put the EC performance into context. Because EC concentrations are so low across the IMPROVE network, the bias and error are well within the flared portion of the PM performance goal for bias and error for these sites, so the CD-C and Hiawatha base case simulations achieve the PM performance goals. Therefore, the errors in prediction of EC at the IMPROVE sites are not expected to introduce significant bias into the Hiawatha impact assessment. EC is generally larger at the STN sites, and performance across this network is nearly always within the goal and always within the criteria. EC performance in the WRAP simulation of 2002 was comparable to that in the Hiawatha 2005-2006 runs. Note that the WRAP Bugle Plots used a different and more lax definition of the flare in the goals and criteria, whereas we followed the definitions of their developers (Dr. James Boylan, see Boylan, 2004 or Morris et al., 2009a,b).

IMPROVE – EC

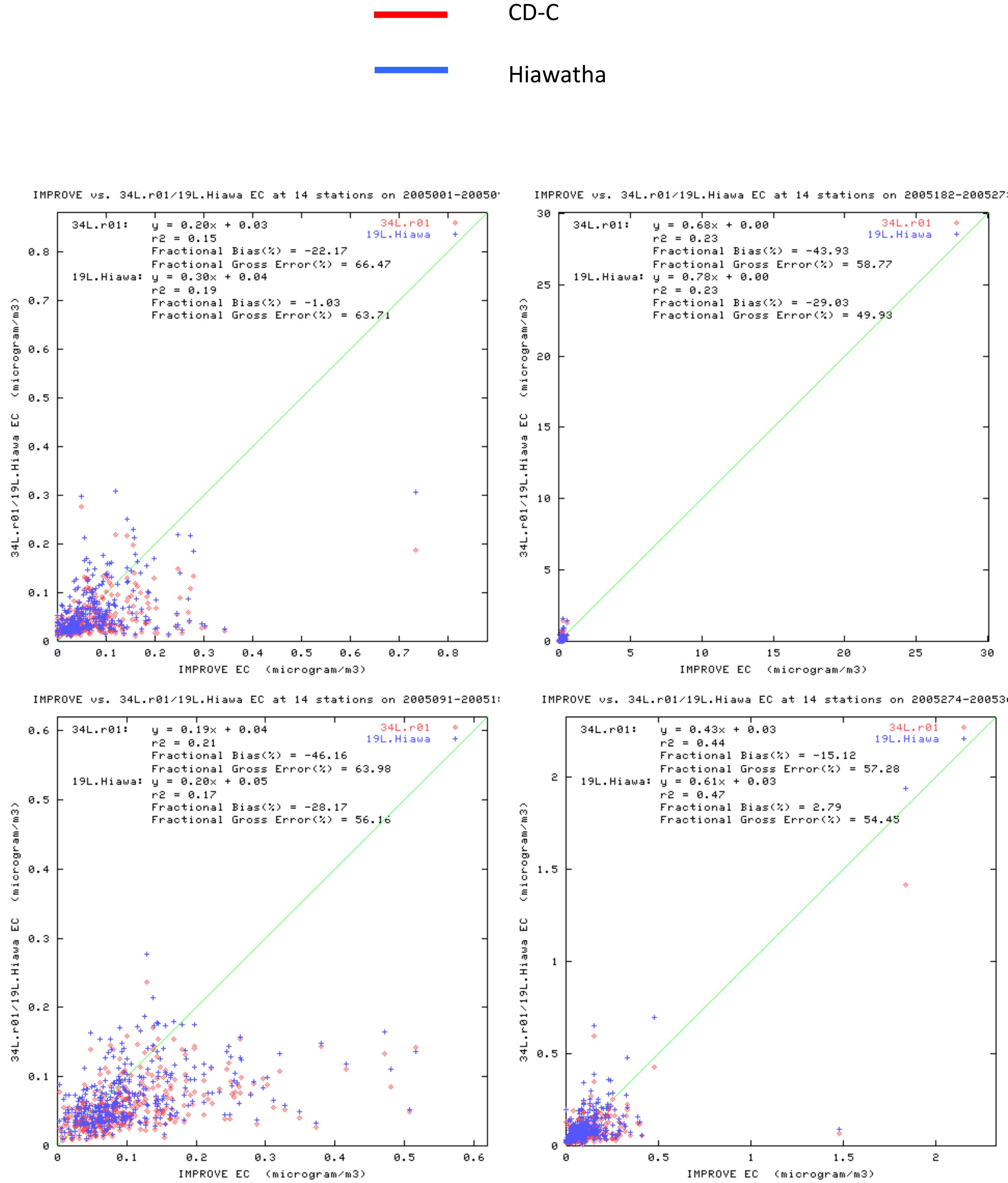


Figure A5-16a. Comparison of predicted and observed 24-hour average EC concentration for IMPROVE sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – EC

CD-C

Hiawatha

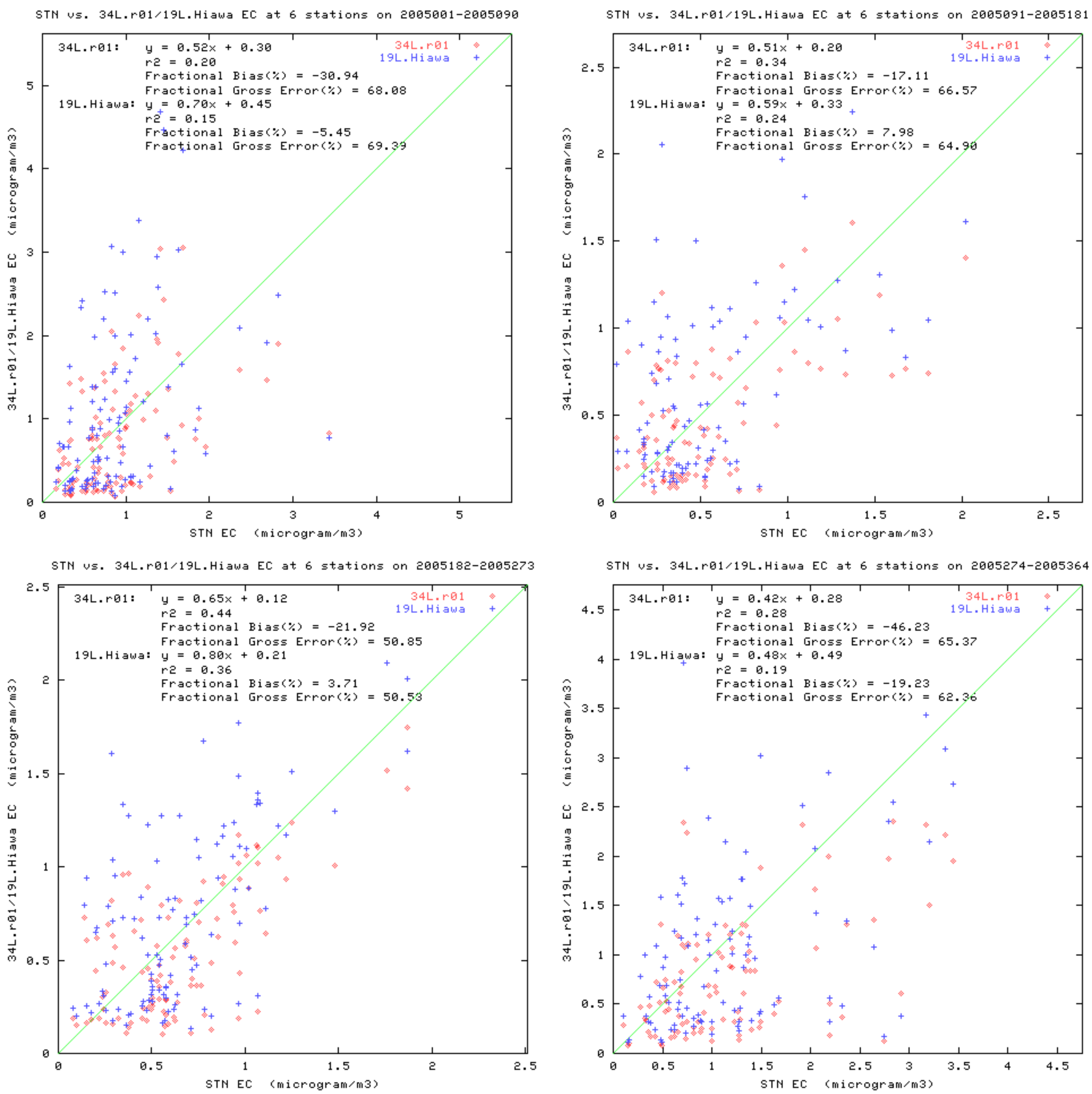


Figure A5-16b. Comparison of predicted and observed 24-hour average EC concentration for STN sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – EC

CD-C

Hiawatha

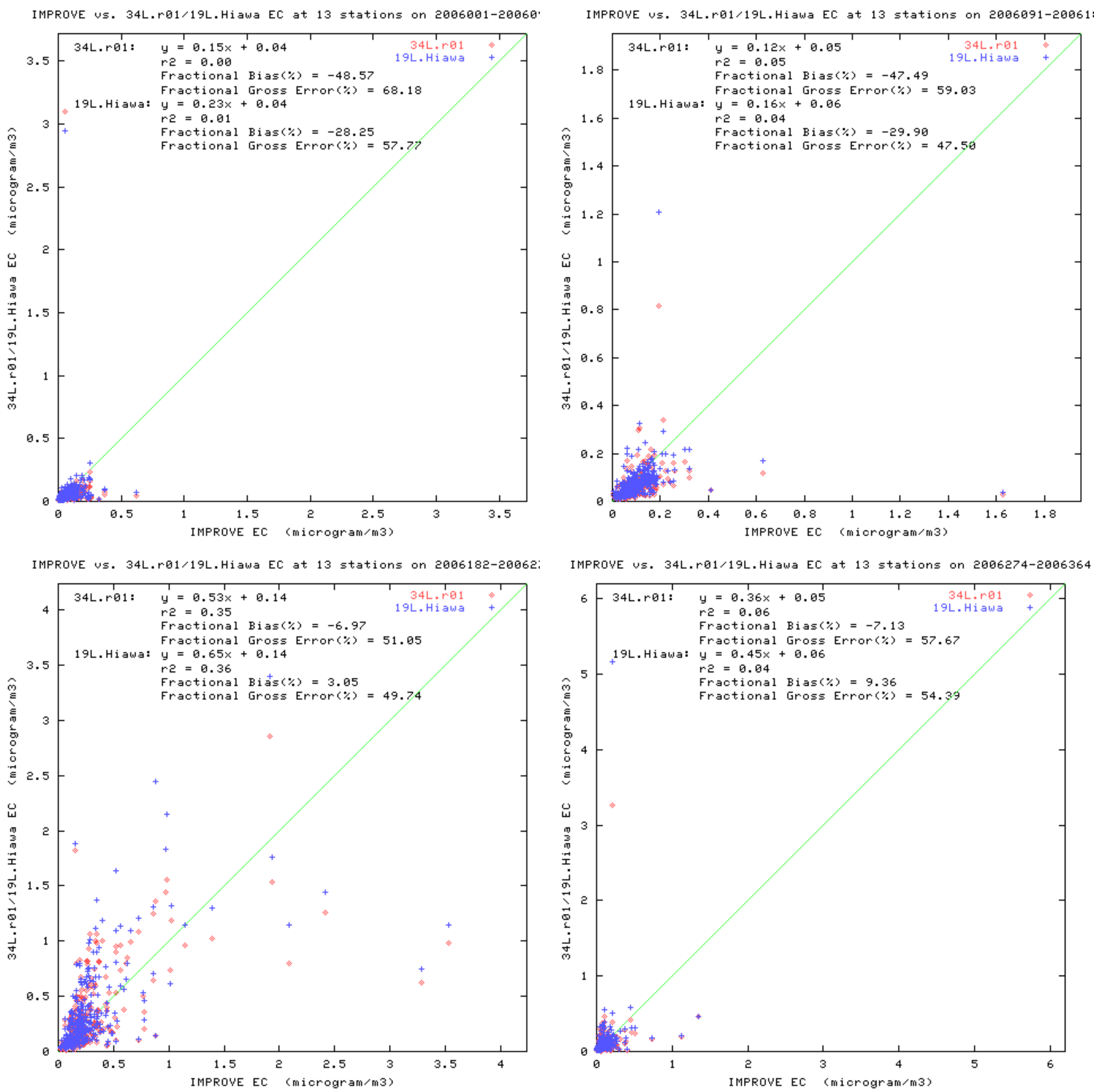


Figure A5-17a. Comparison of predicted and observed 24-hour average EC concentration for IMPROVE sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

STN – EC

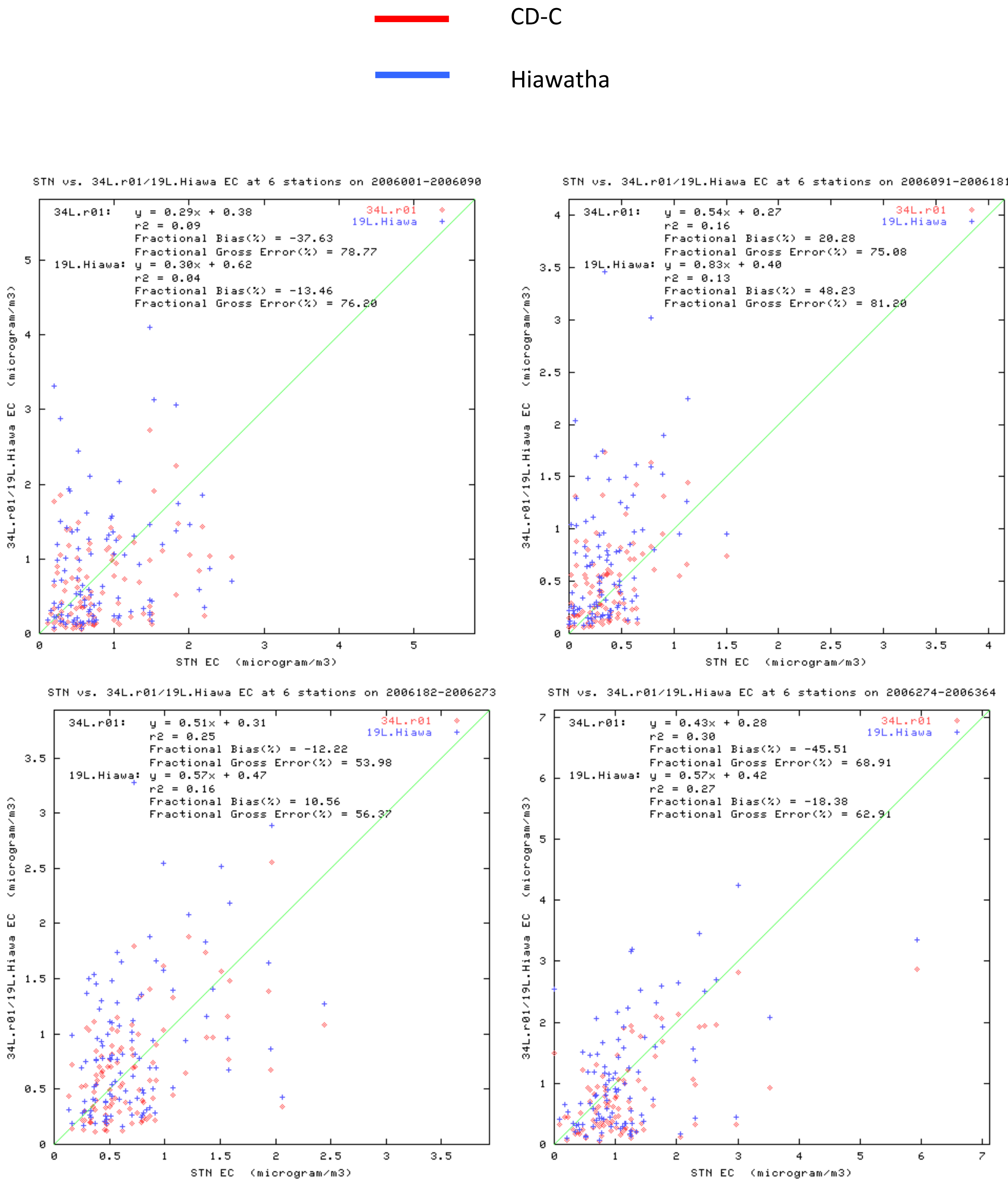
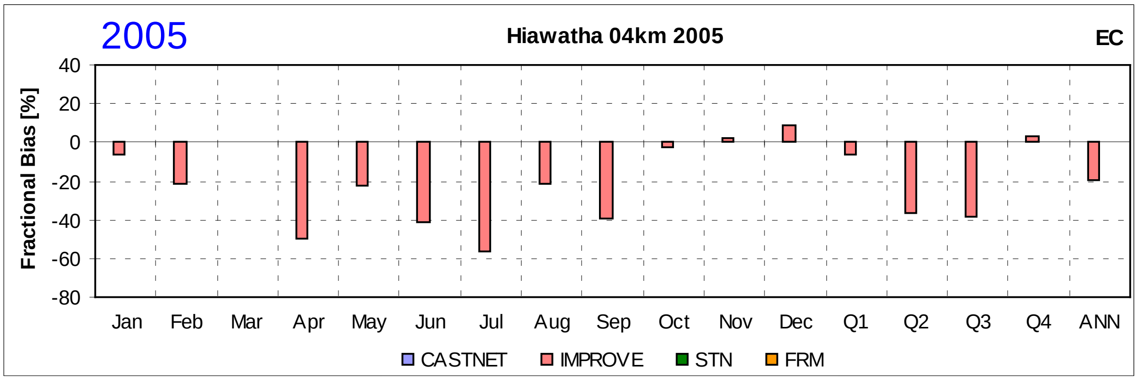
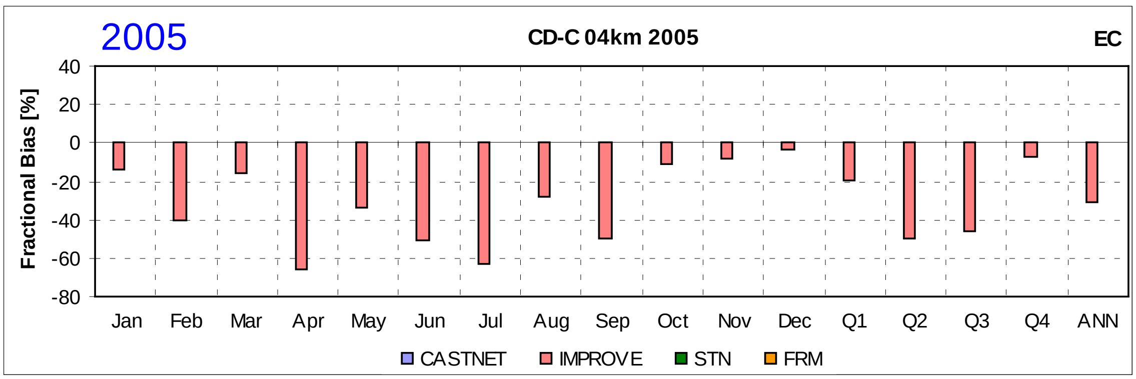


Figure A5-17b. Comparison of predicted and observed 24-hour average EC concentration for STN sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

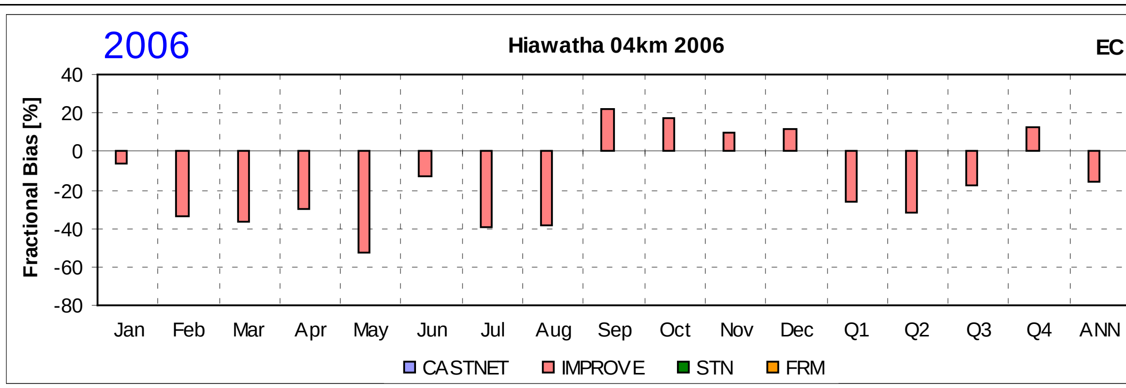
(1)



(2)



(3)



(4)

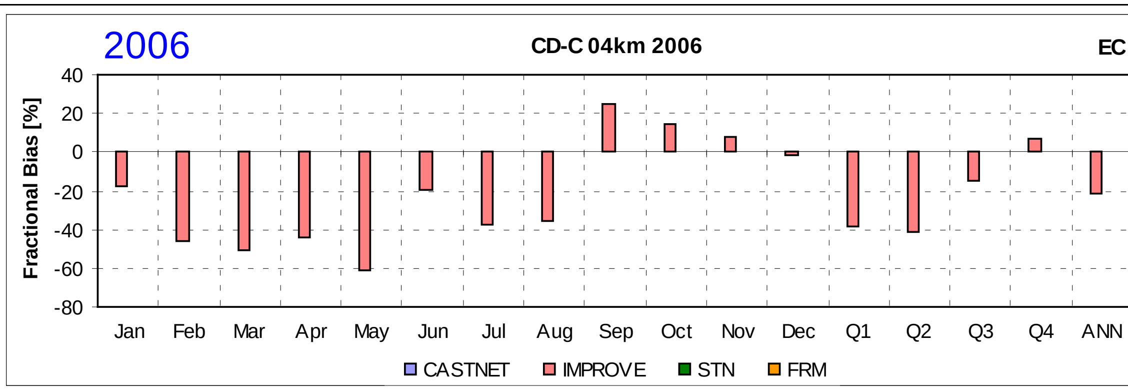
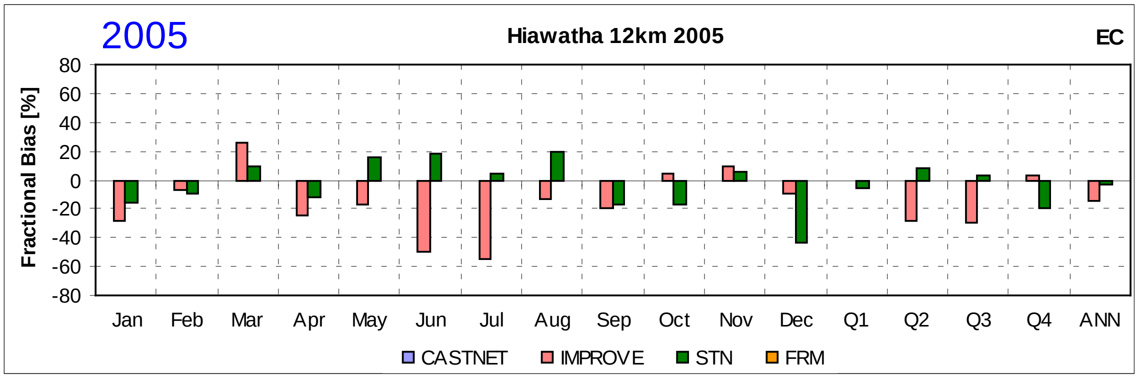
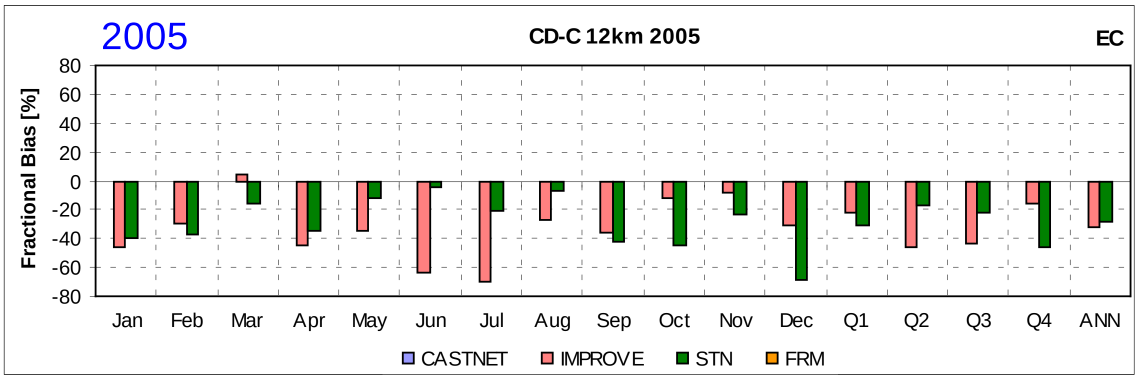


Figure A5-18. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for EC in 4 km grid.

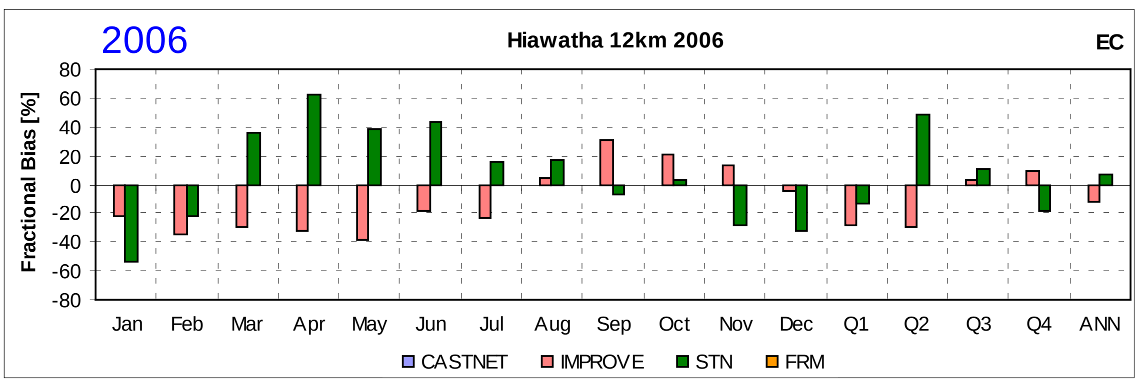
(1)



(2)



(3)



(4)

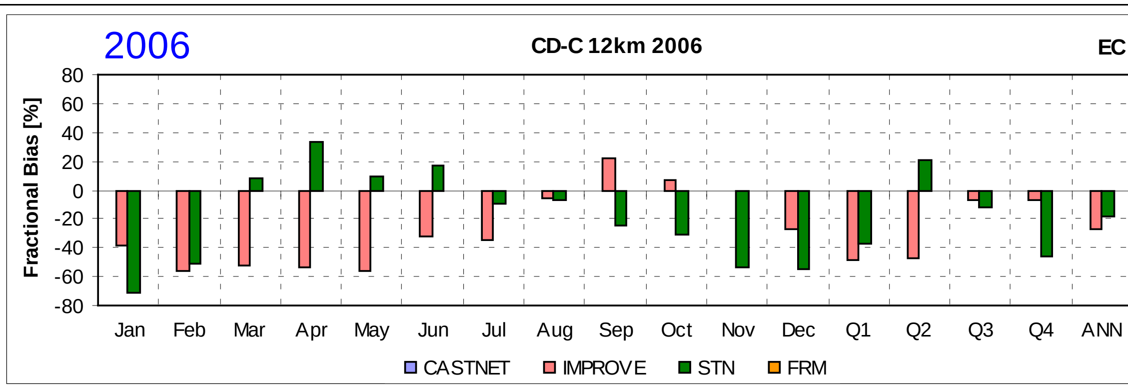
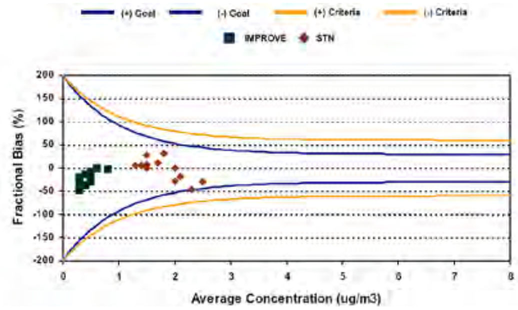
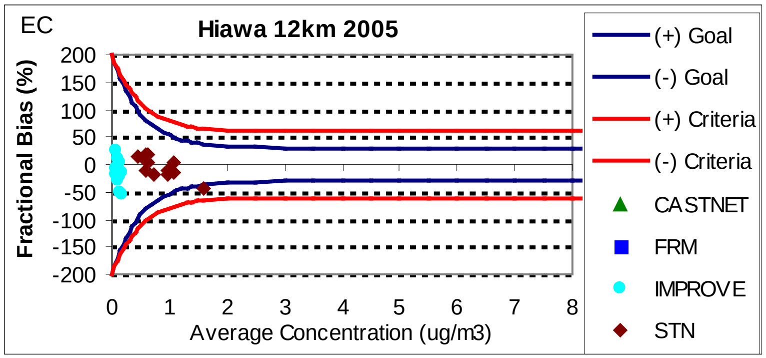
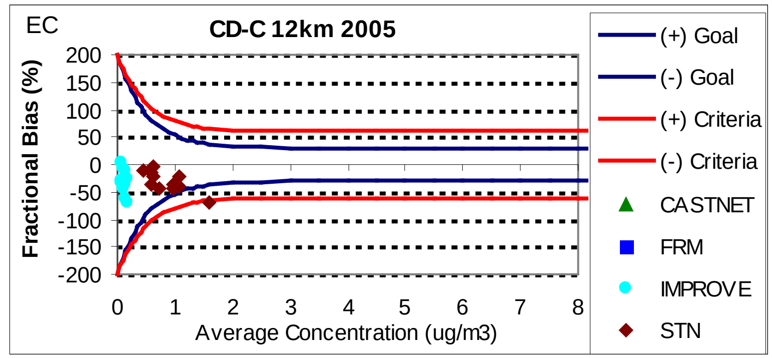


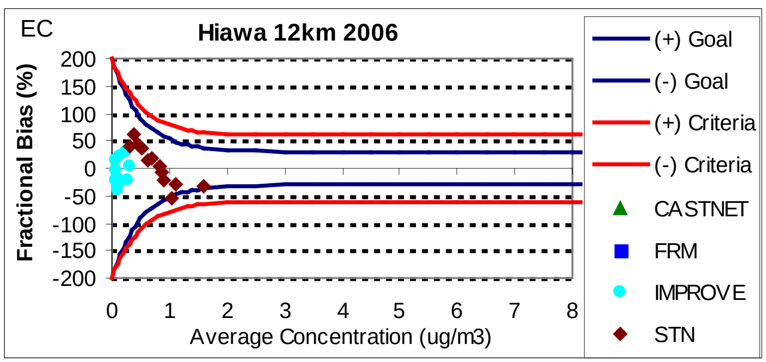
Figure A5-19. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for EC in 12 km grid.



WRAP 2002







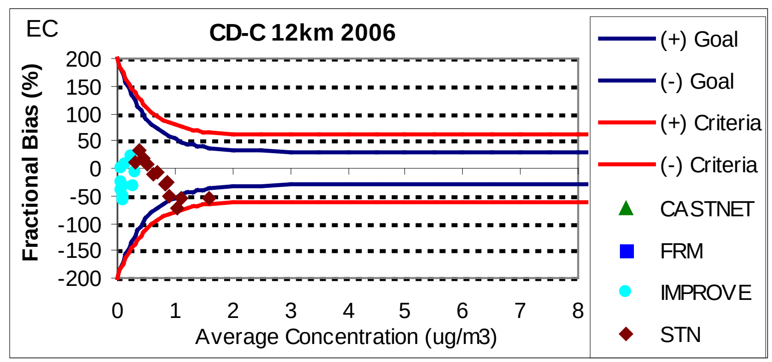
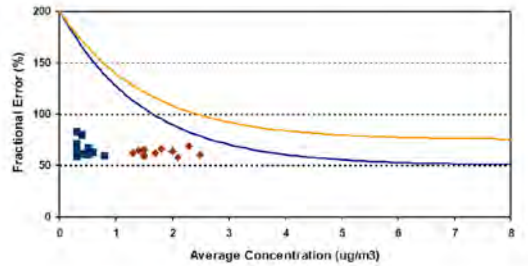
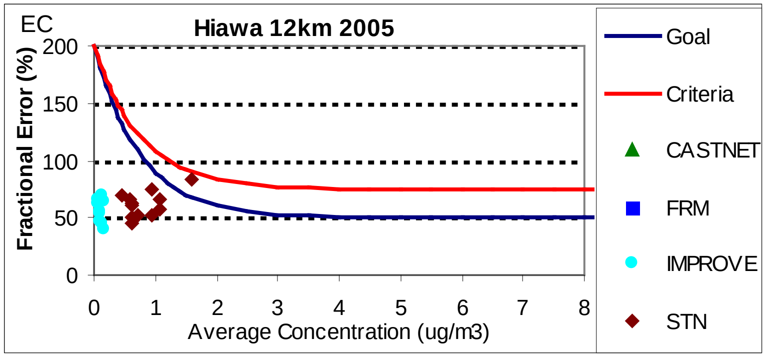
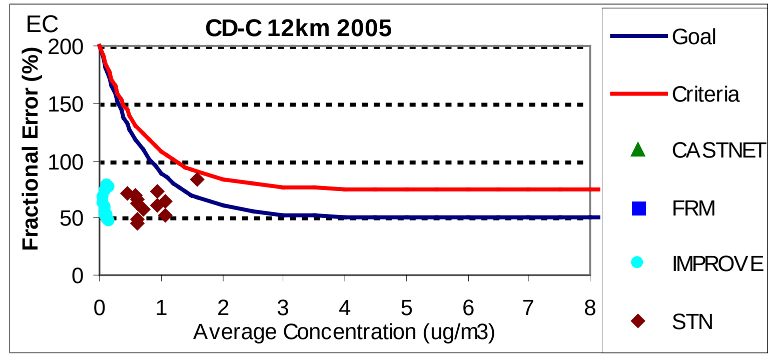


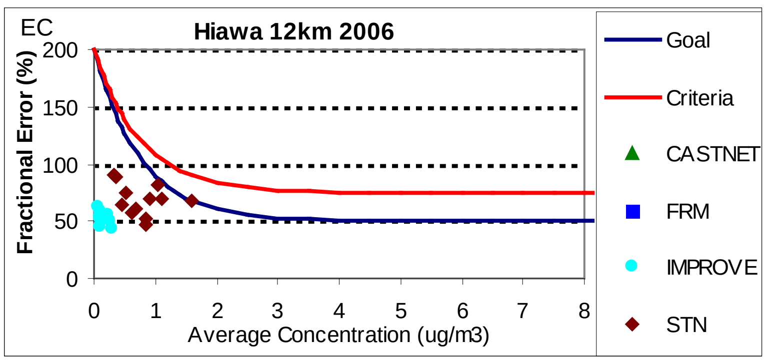
Figure A5-20a. Bugle Plots of EC model performance comparing mean fractional bias for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).



WRAP 2002







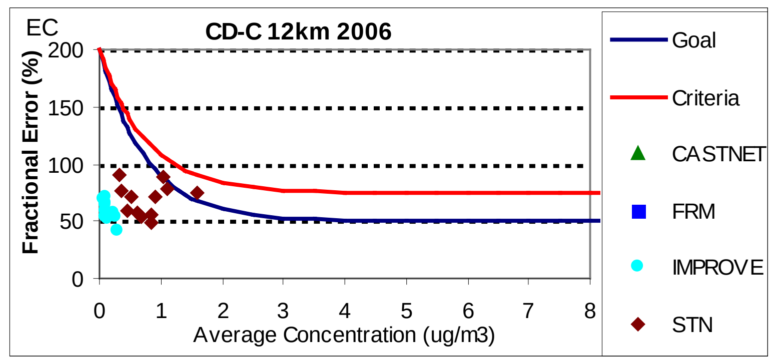


Figure A5-20b. Bugle Plots of EC model performance comparing mean fractional error for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

A5.5 SOIL MODEL PERFORMANCE

IMPROVE Soil observations are composed of a weighted linear combination of elements, whereas the CAMx Soil species consists of PM emissions that have not been explicitly speciated as SO4, NO3, OCM, EC or CM and therefore actually define an "other" $PM_{2.5}$ species. Thus, the modeled and observed Soil species are not directly comparable. The CAMx 2005 and 2006 Soil model performance for the CD-C and Hiawatha base case simulations are summarized in Figures A56-21 through A5-25. Most of the predicted and observed 24-hour average Soil concentrations are less than 2 $\mu g/m^3$ and agree reasonably well. The exception to this are a few predicted Soil values that exceed 2 $\mu g/m^3$, when the observed values do not and vice versa. In both 2005 and 2006, the Hiawatha base case underestimates Soil concentrations in April and May on the 4 km and 12 km domains by a large margin, whereas the CD-C base case has an overestimation bias for these two months that is closer to zero. Both models overestimate Soil at the end of the year (Oct-Dec) in both years (Figures A5-23 and A5-24). Because the observed Soil concentrations at the IMPROVE sites tend to be low, the CD-C and Hiawatha base case Soil fractional bias and error generally fall within the range of the PM performance goal in the Bugle Plots (Figure A5-25) and always fall within the PM performance criteria.

IMPROVE – Soil

CD-C

Hiawatha

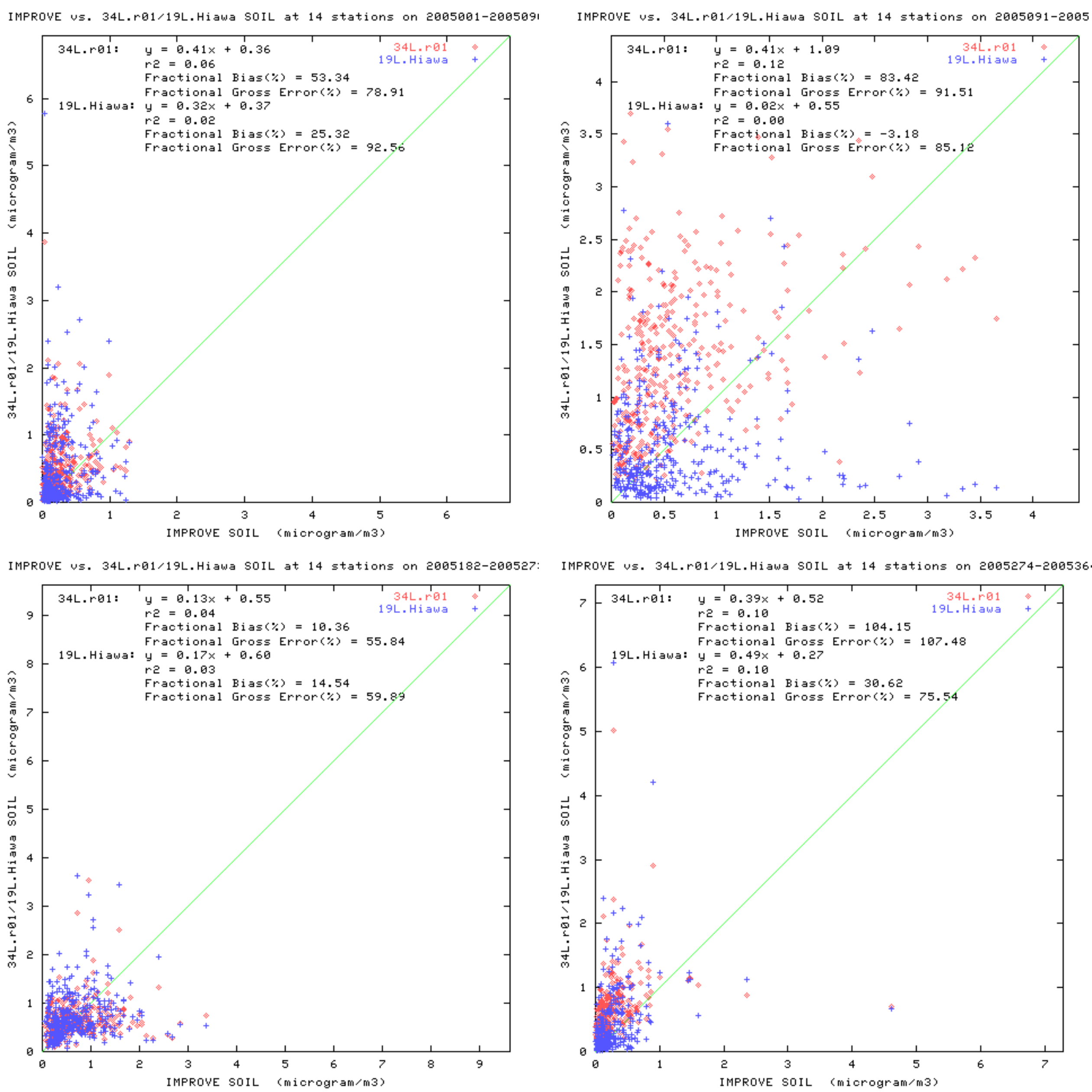


Figure A5-21. Comparison of predicted and observed 24-hour average Soil concentration for IMPROVE sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – Soil

CD-C

Hiawatha

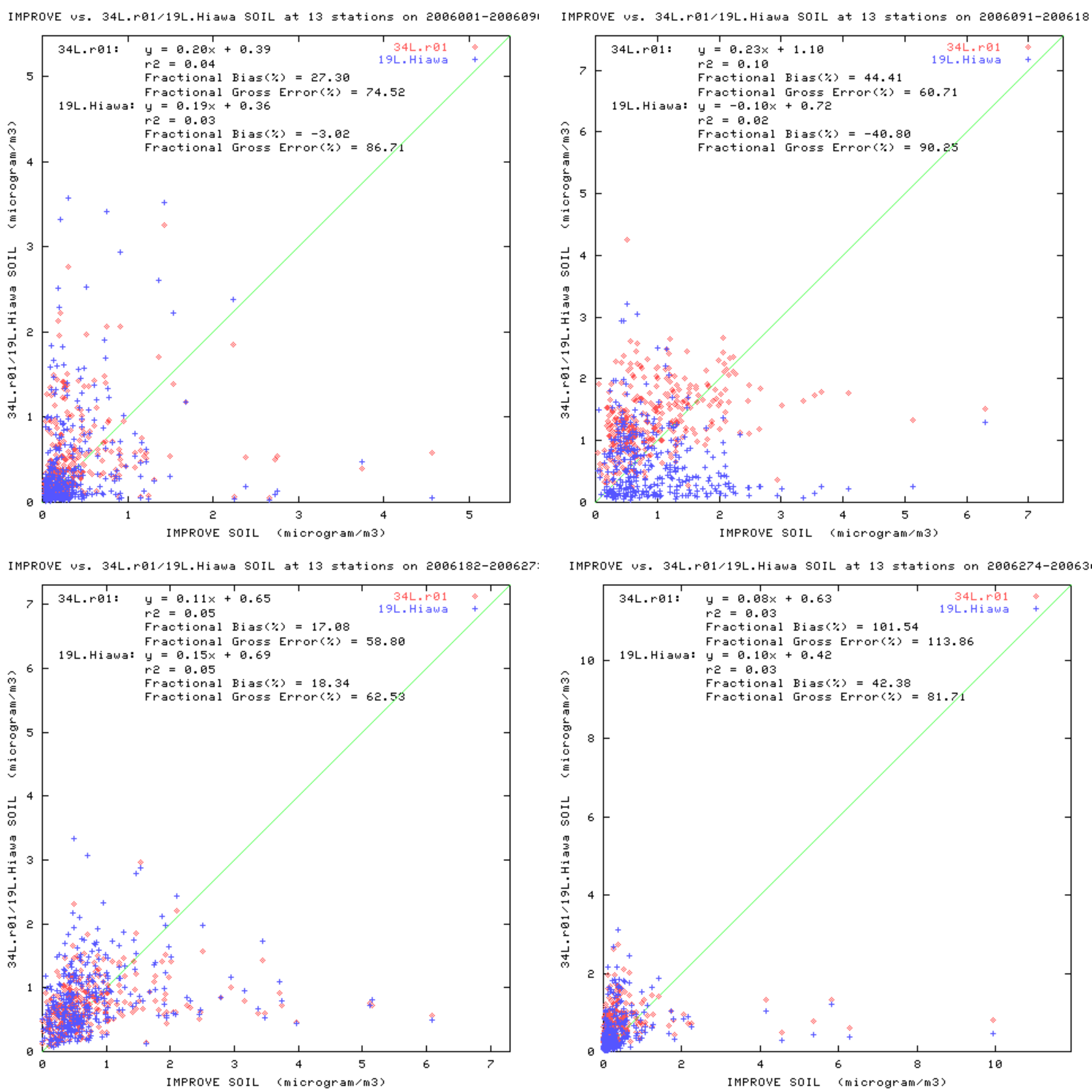
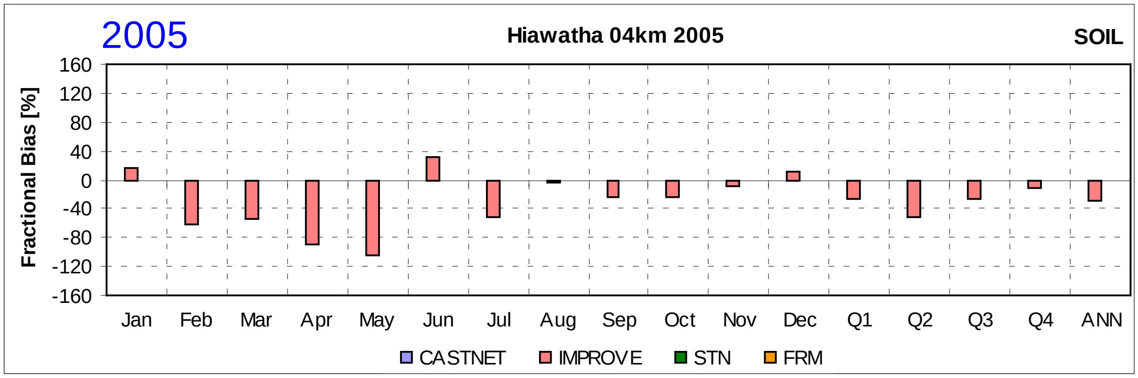
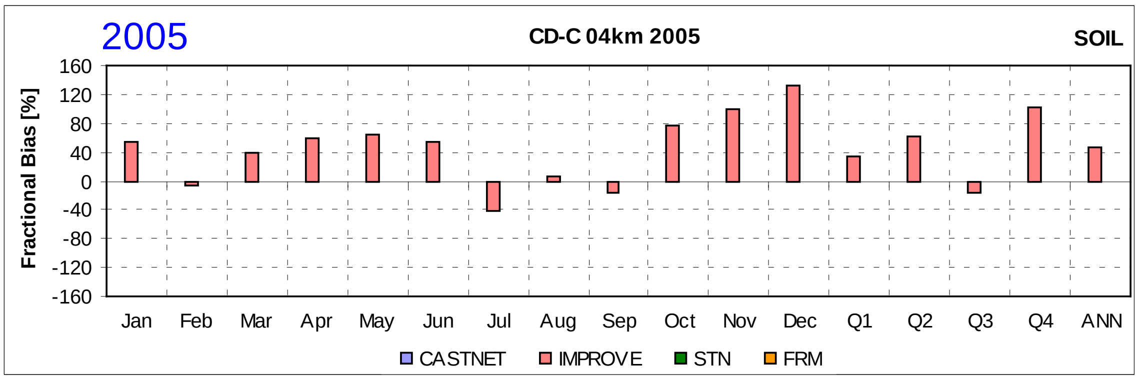


Figure A5-22. Comparison of predicted and observed 24-hour average Soil concentration for IMPROVE sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

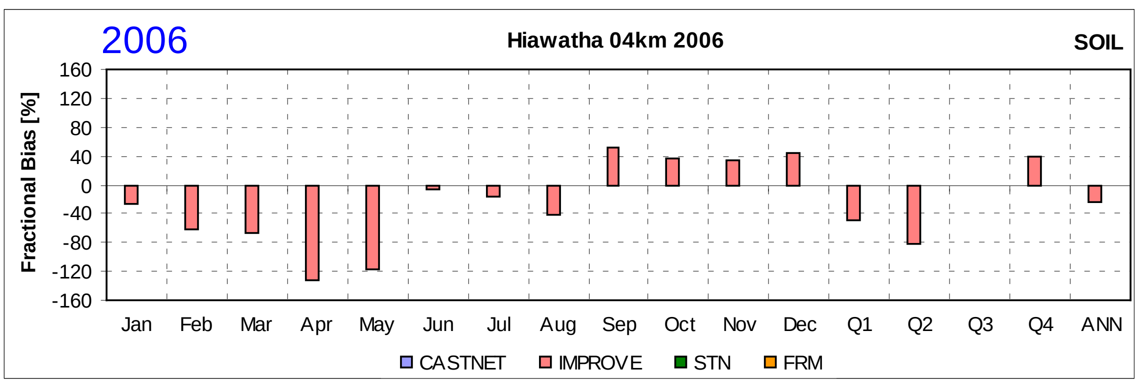
(1)



(2)



(3)



(4)

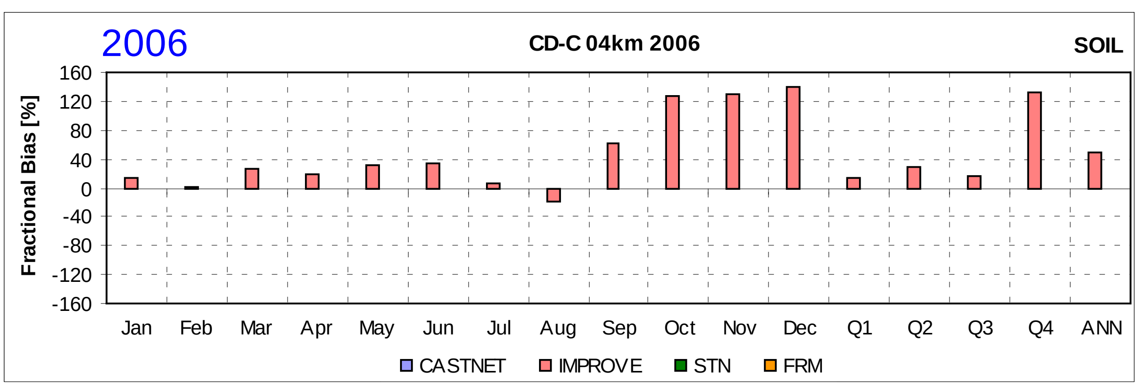
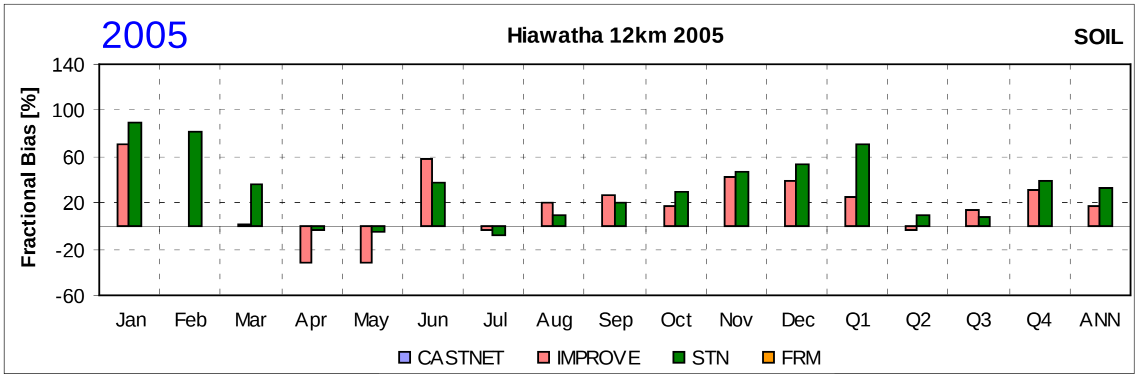
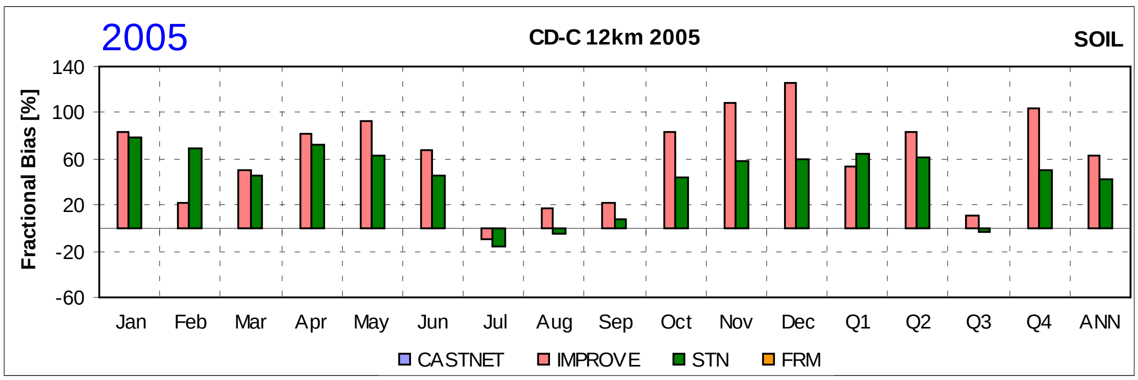


Figure A5-23. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for Soil in 4 km grid.

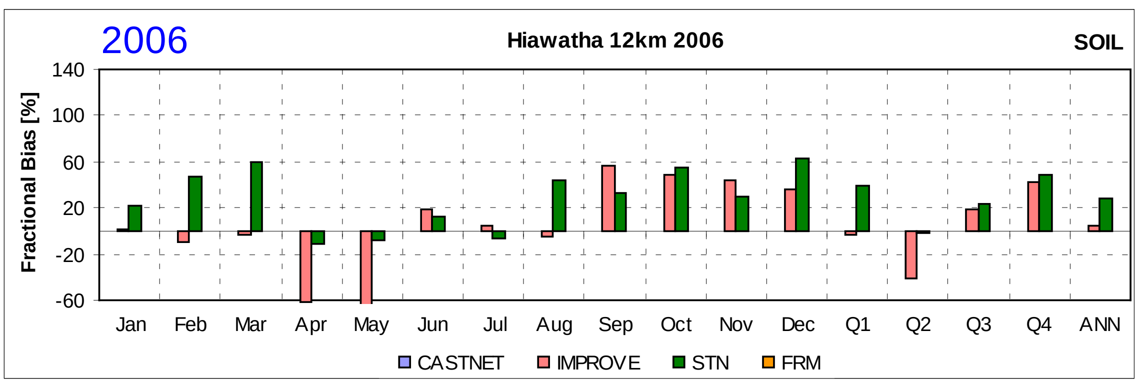
(1)



(2)



(3)



(4)

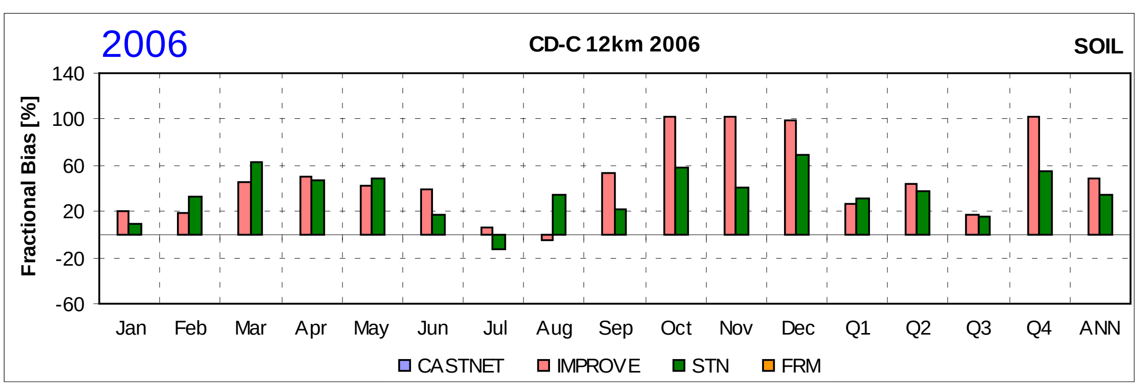


Figure A5-24. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for Soil in 12 km grid.

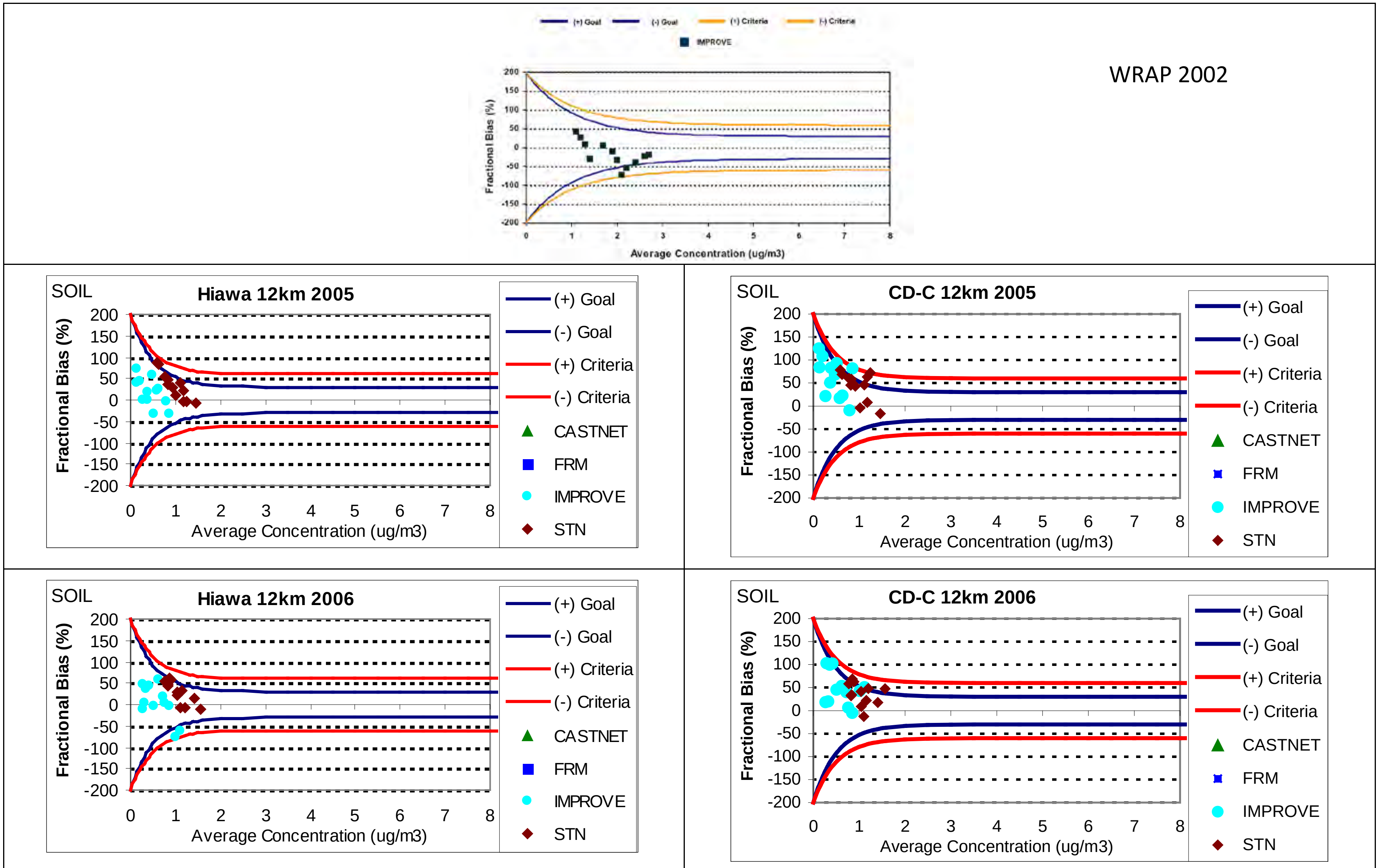


Figure A5-25a. Bugle Plots of Soil model performance comparing mean fractional bias for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

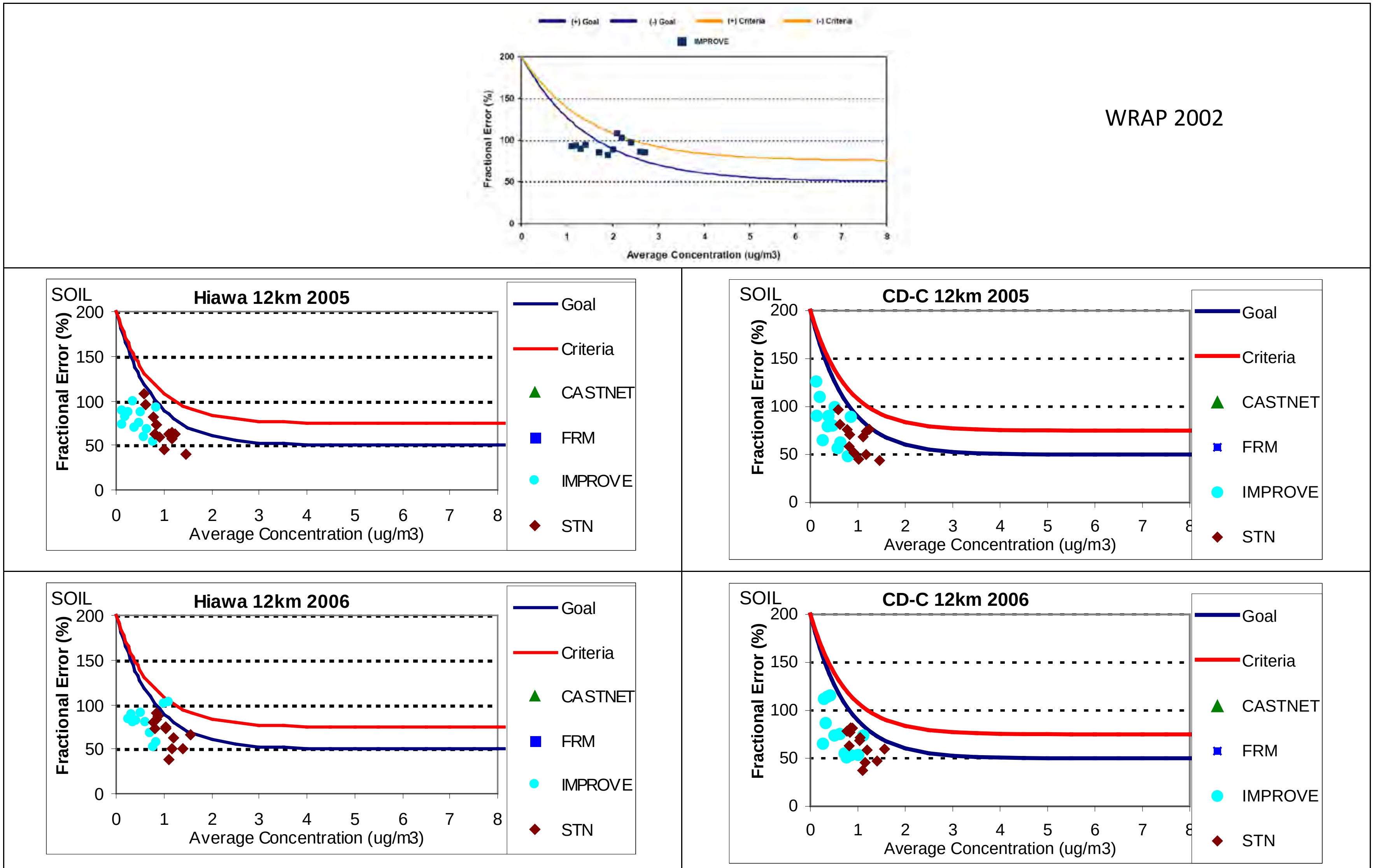


Figure A5-25b. Bugle Plots of Soil model performance comparing mean fractional error for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

A5.6 COARSE MASS (CM) MODEL PERFORMANCE

The CAMx IMPROVE Coarse Mass (CM, i.e., $PM_{2.5-10}$) model performance is summarized in Figures A5-26 through A5-30. The CM model performance for both base case simulations is characterized by an underprediction bias that is greatest in the summer. The Hiawatha base case CM underprediction bias is much greater than is seen for the CD-C base case underprediction bias which is near zero for several fall and winter months in 2005 and 2006. CM has a much shorter transport distance than fine particulate matter. CM tends to be dominated by crustal material that comes mainly from dust sources. For CAMx and other photochemical grid models, EPA has developed fugitive dust transport factors (FDTF) that represent the fraction of fugitive dust emissions that is transported aloft in the air and does not get deposited near the source. The FDTFs are applied to the fugitive dust emissions so they only represent the amount that gets transported out of the grid cell where they are emitted. FDTFs are land use dependent and can vary from 5% for grid cells that are heavily forested (i.e., 95% of the fugitive dust emissions in a forest are deposited locally and are not included in the modeling emissions inventory) to 95% for barren ground where very little (5%) of the fugitive dust is deposited locally. Although the use of FDTF is appropriate for regional modeling, if there are local source impacts at the monitor (e.g., wind-blown dust), then these will be underestimated in the model. Thus, the underestimation bias of CM is expected as the contributions of these local source impacts are not being fully accounted for in the model. As such local source impacts will be higher in the summer when dust emissions are more frequent, the higher underprediction bias in the summer than winter is also expected.

IMPROVE – CM

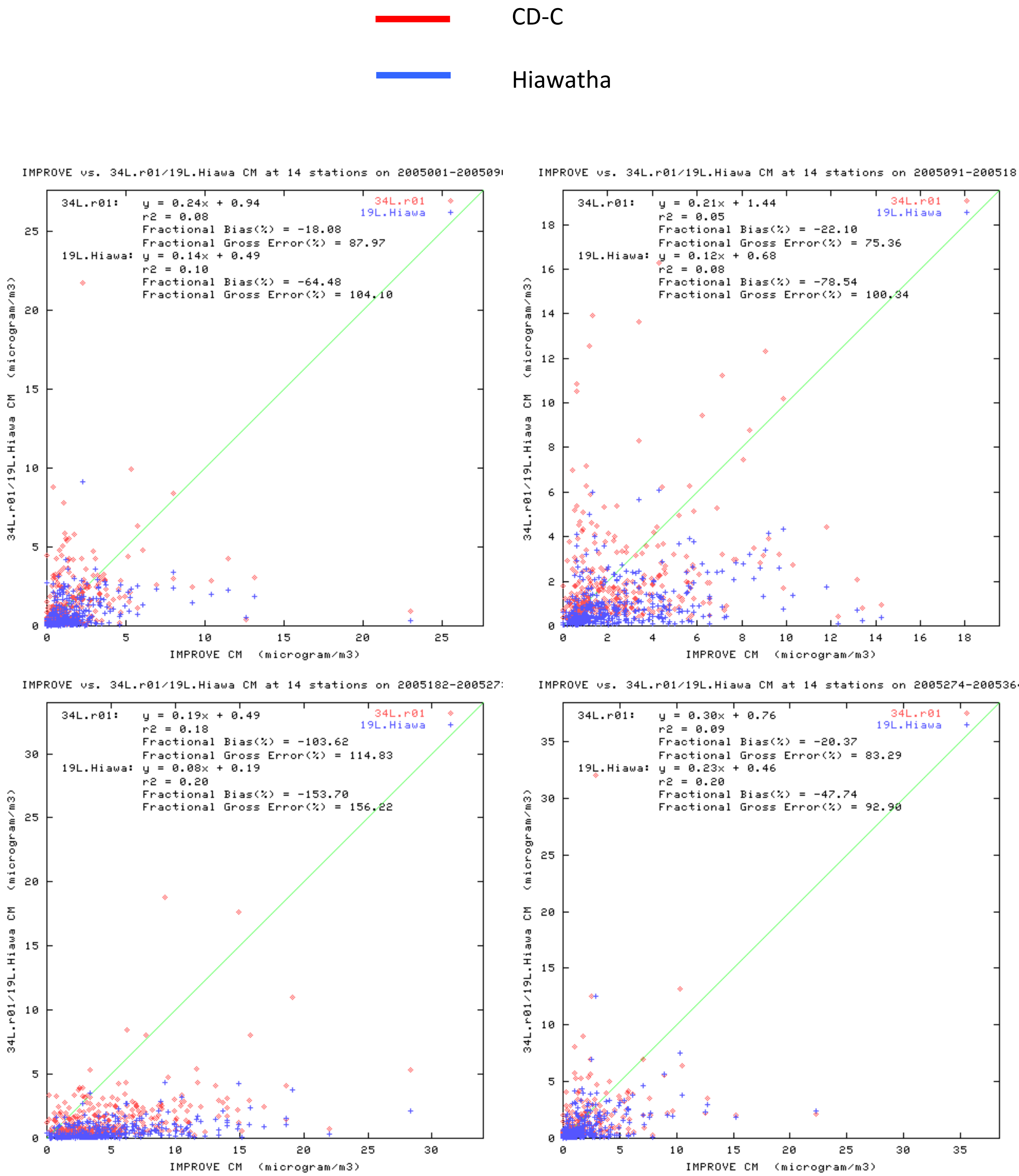


Figure A5-26. Comparison of predicted and observed 24-hour average CM concentration for IMPROVE sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – CM

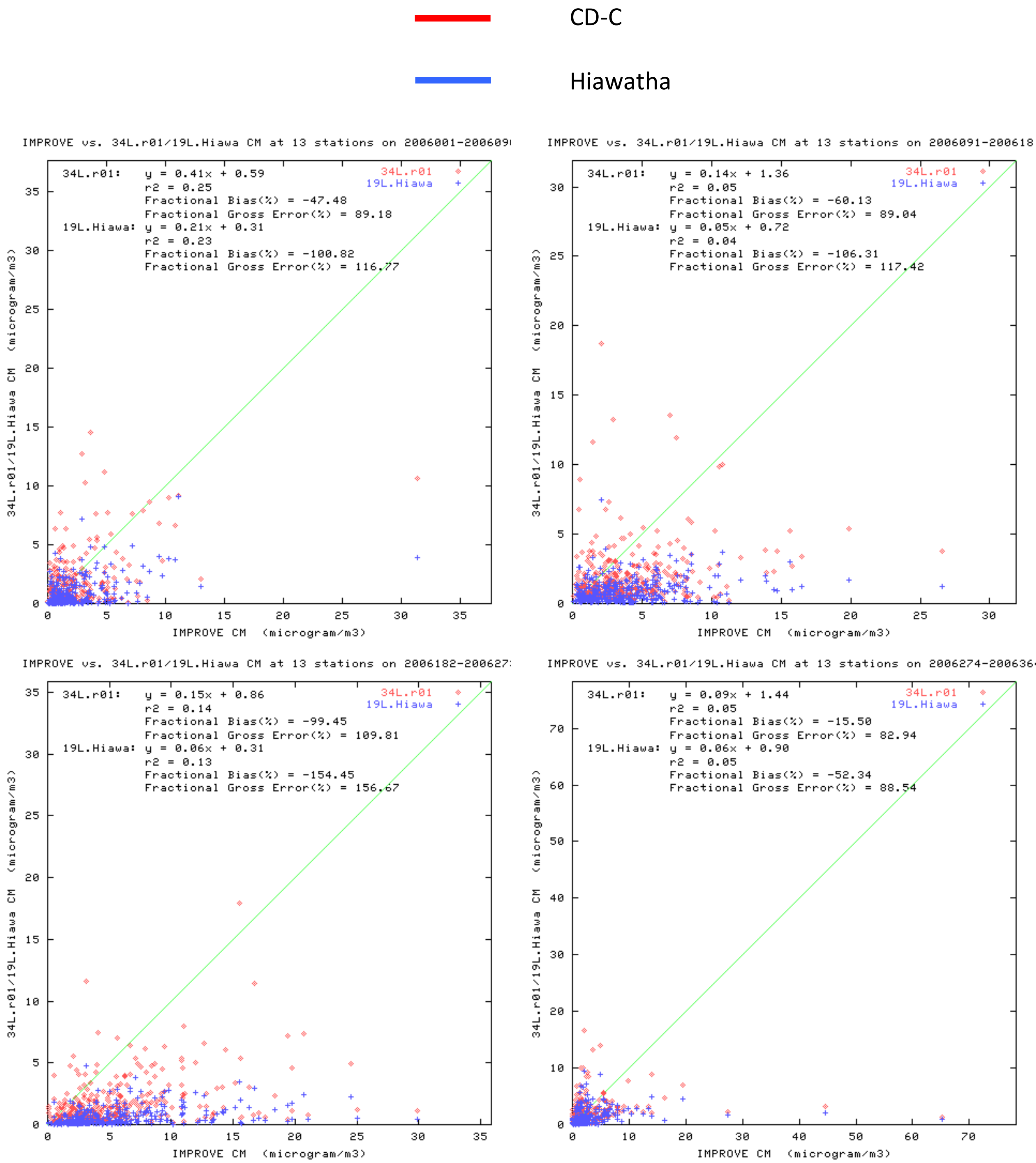
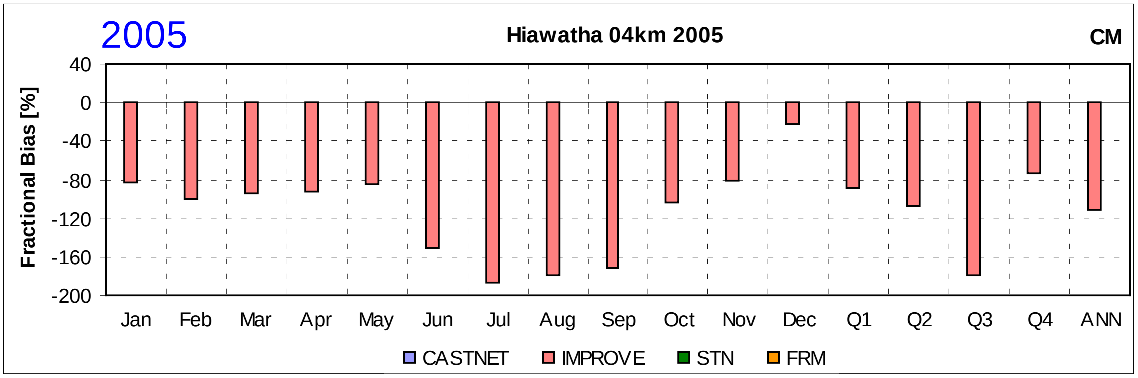
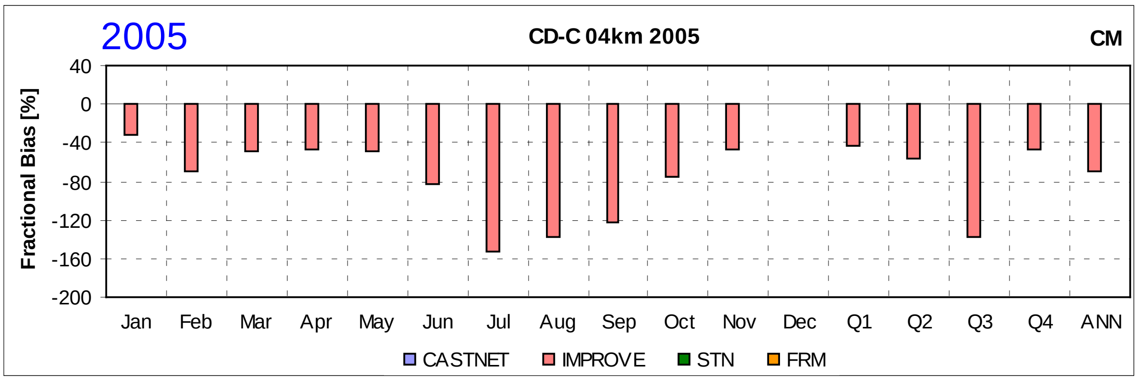


Figure A5-27. Comparison of predicted and observed 24-hour average CM concentration for IMPROVE sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

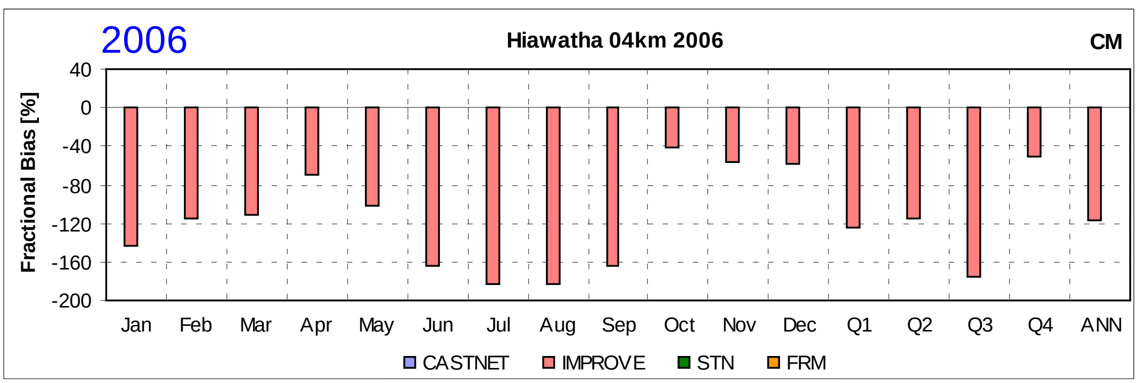
(1)



(2)



(3)



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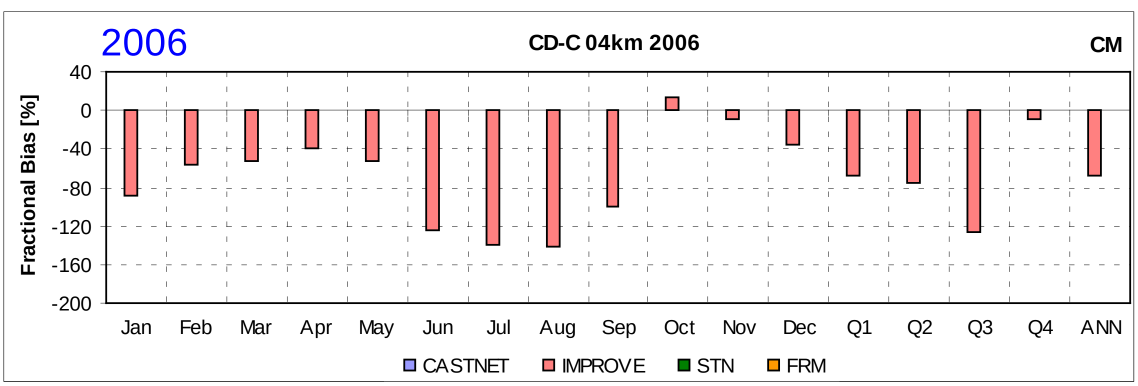
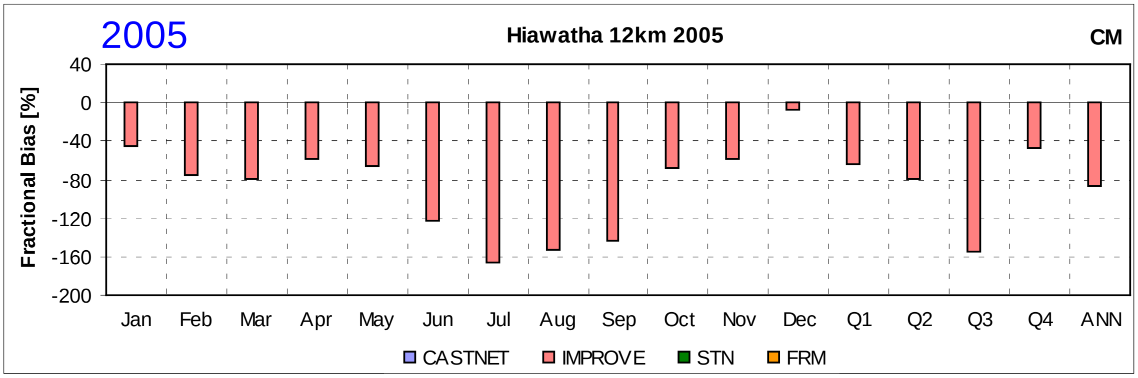
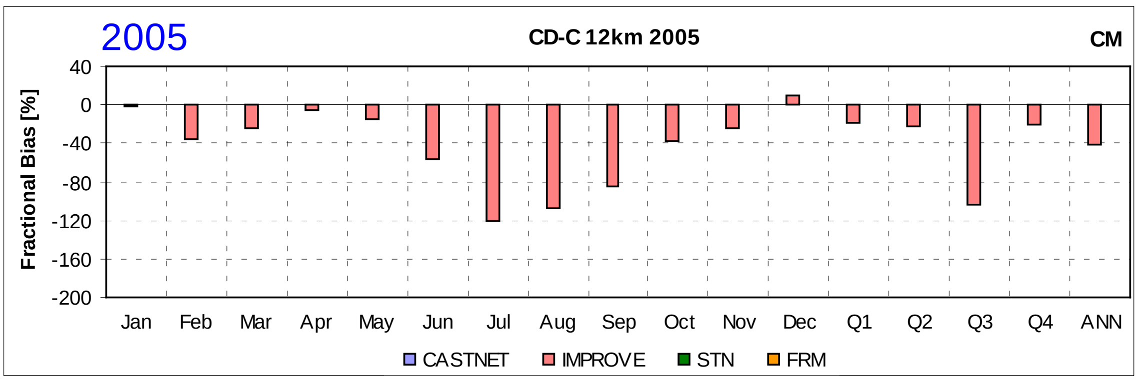


Figure A5-28. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for CM in 4 km grid.

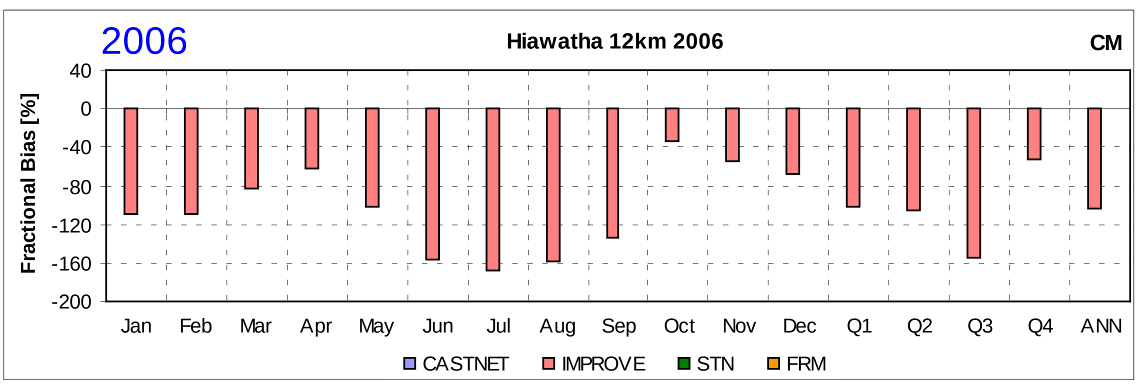
(1)



(2)



(3)



(4)

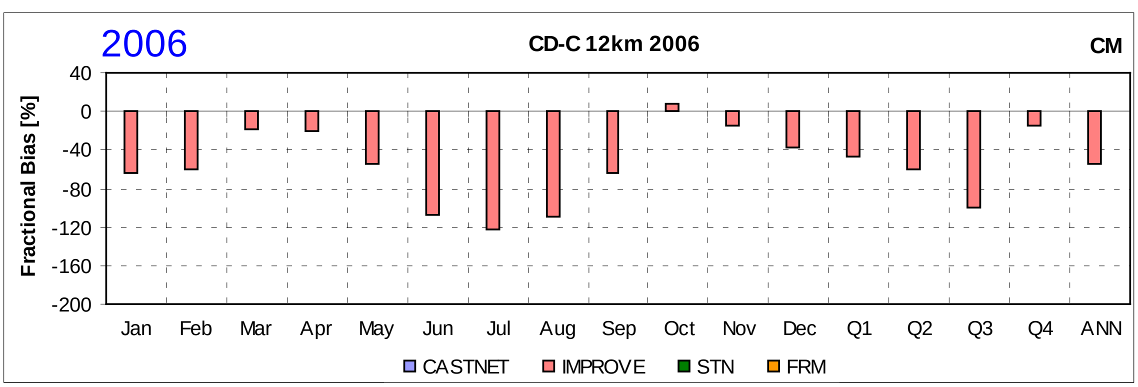


Figure A5-29. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for CM in 12 km grid.

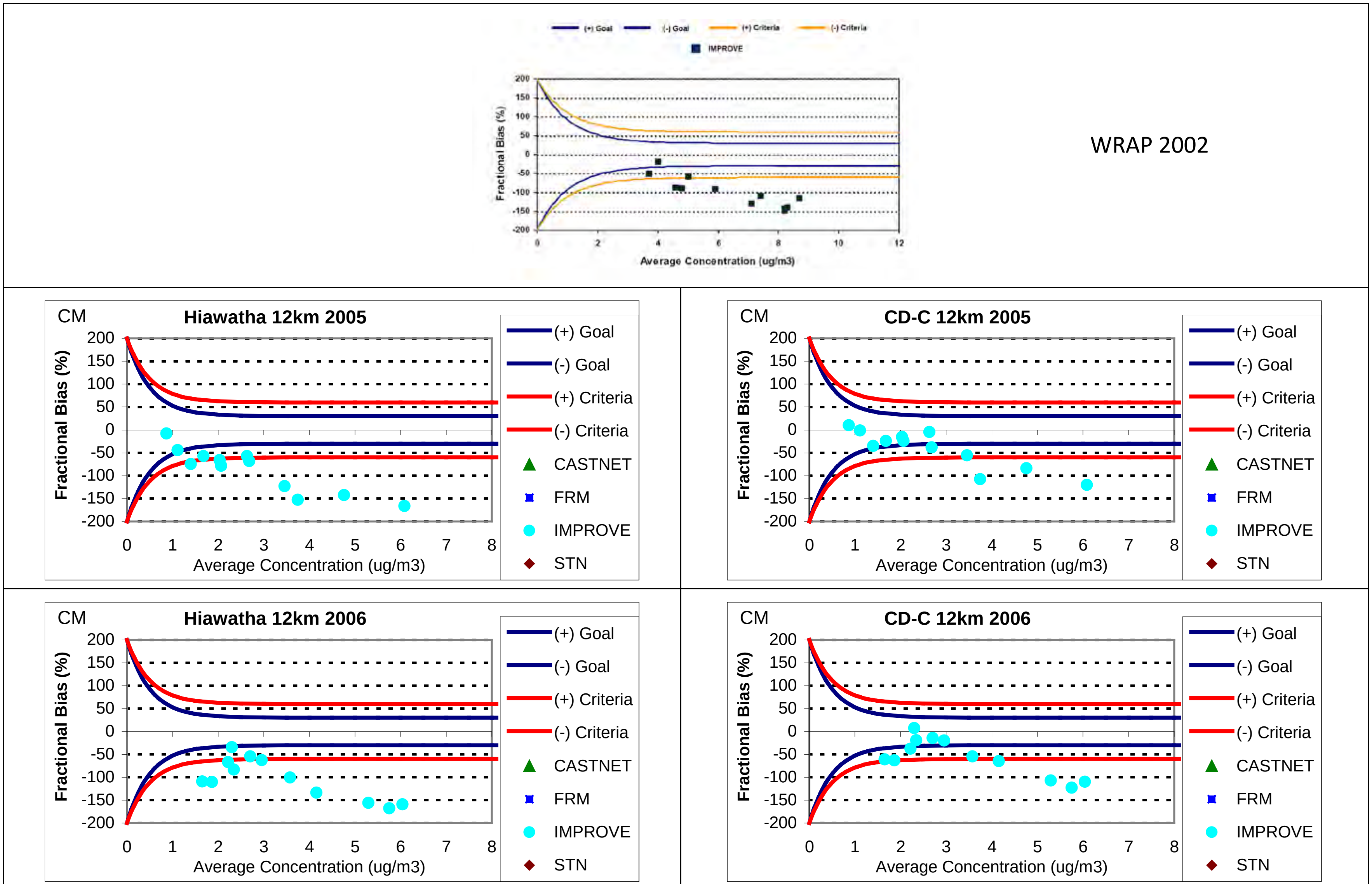


Figure A5-30a. Bugle Plots of CM model performance comparing mean fractional bias for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

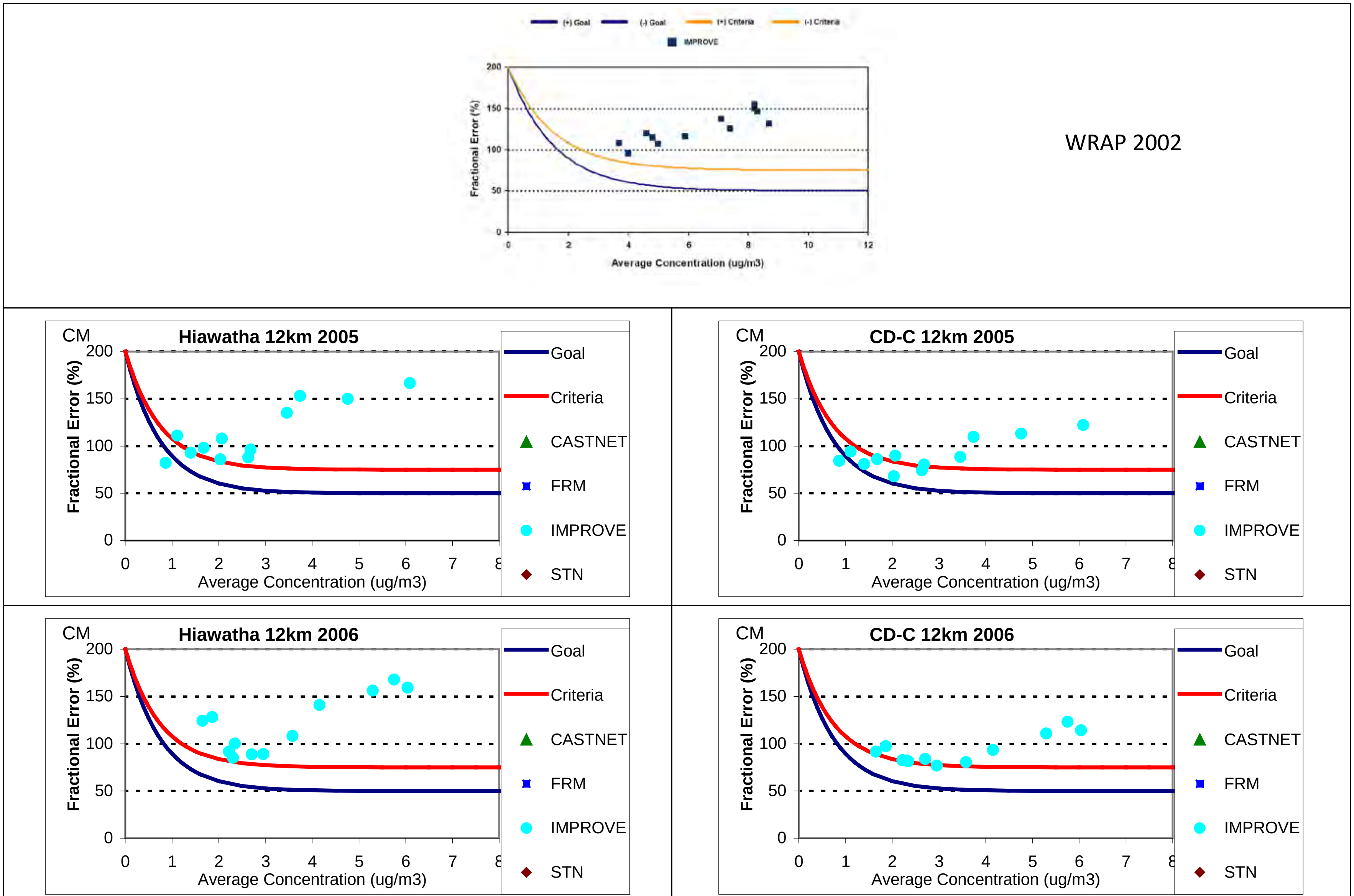


Figure A5-30b. Bugle Plots of CM model performance comparing mean fractional error for the WRAP 2002 CMAQ 36 km simulation (top), Hiawatha (middle), and CD-C (bottom) 12 km CAMx 2005 (left)and 2006 (right) simulation with PM model performance goals (blue) and criteria (orange).

A5.7 PARTICULATE MATTER (PM) MODEL PERFORMANCE

Figures A5-31 through A5-40 display model performance summaries for total fine particulate ($PM_{2.5}$) and PM_{10} mass concentrations. Across the IMPROVE network (Figures A5-31a and A5-32b), $PM_{2.5}$ is overestimated in the winter and underestimated in the summer for both 2005 and 2006 and both base case simulations. However, across the FRM monitoring network the two base case simulations exhibit an underestimation bias that is year round. This is shown more clearly in the monthly fractional bias Bar Charts across monitors in the 4 km and 12 km domains in Figures A5-35 and A5-36, respectively. Across the IMPROVE network the two base cases $PM_{2.5}$ model performance achieves the PM performance criteria for most months in the summer and during the transition periods, but the winter overestimation bias exceeds the PM performance criteria. At the more urban FRM monitoring sites, many months achieve the PM performance criteria, with some months even achieving the PM performance goal, albeit with an underestimation bias (Figures A5-35 and A5-36). However, most of the FRM sites lie in the 12 km portion of the modeling domain and we would not expect a 12 km coarse grid spacing to capture the urban $PM_{2.5}$ concentrations at the FRM monitoring sites. The Bugle Plots for $PM_{2.5}$ (Figure A5-37) indicate that for both 2005 and 2006 the CD-C and Hiawatha base case model performance is generally within the criteria for bias, and nearly always within the criteria for error.

The CD-C base case PM_{10} performance achieves the PM performance criteria in Q1, Q2 and Q4 in 2005 (Figure A5-32c) and 2006 (Figure 4-33c) and exhibits slightly better performance than the Hiawatha base case, whose PM_{10} bias does not achieve the PM performance goal in Q2 in either 2005 or 2006. However, both base case simulations exhibit a large summer underestimation bias in PM_{10} such that neither simulation's bias achieves the PM performance criteria in Q3 in either year. The Bar Charts of PM_{10} monthly fractional bias in the 4 km and 12 km domains (Figures A5-38 and A5-39) show that PM_{10} exhibits the same pattern of summer underprediction and winter overprediction as $PM_{2.5}$. The PM_{10} bugle plots show the same pattern of increasing negative bias with increasing ambient concentration as the coarse matter Bugle Plots. The Bugle Plots for $PM_{2.5}$ (Figure A5-40)show that performance is generally within the criteria for 2005, but more months lie outside the criteria in 2006, with error increasing as ambient concentration increases.

IMPROVE – $PM_{2.5}$

CD-C

Hiawatha

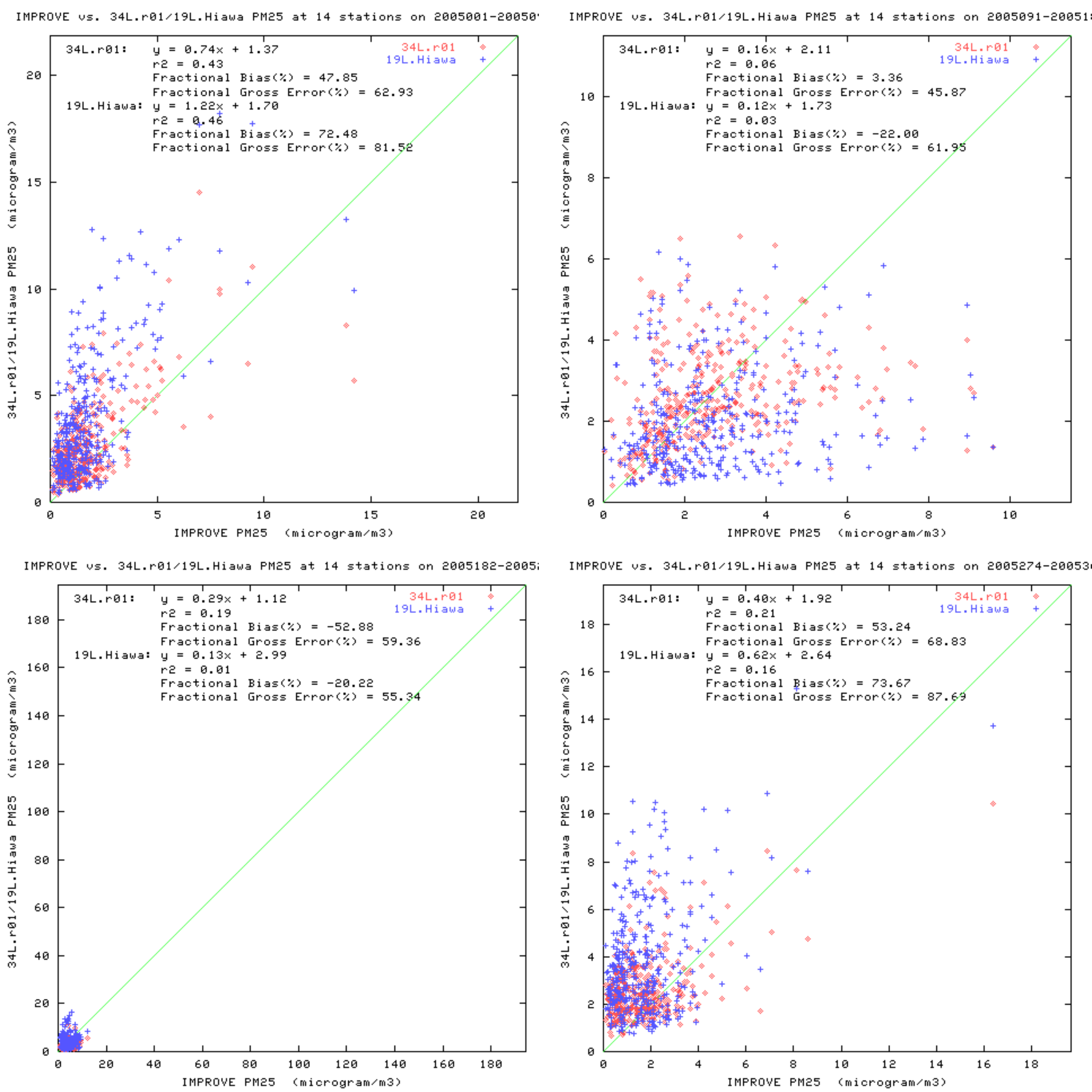


Figure A5-31a. Comparison of predicted and observed 24-hour average $PM_{2.5}$ concentration for IMPROVE sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

FRM – $PM_{2.5}$

CD-C

Hiawatha

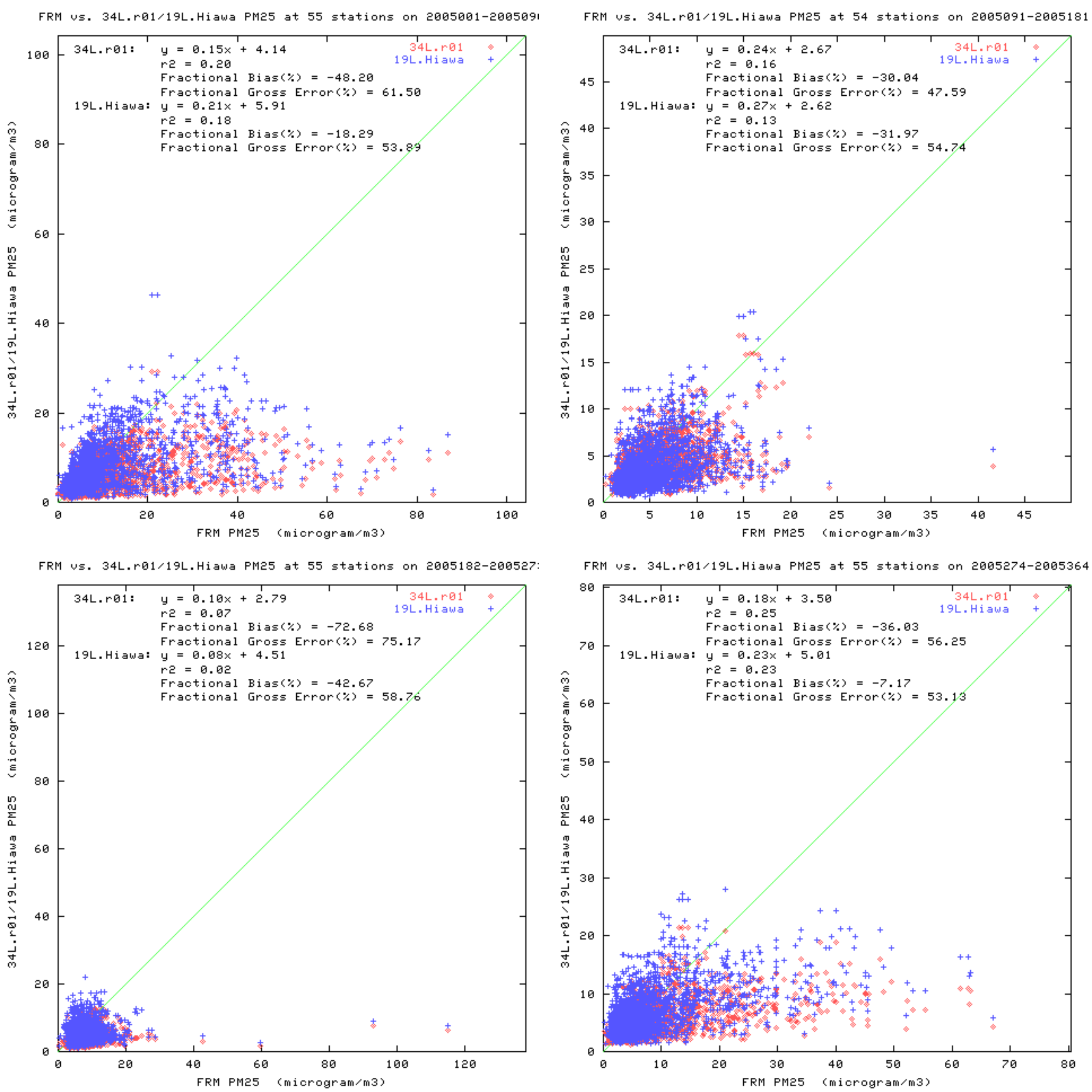


Figure A5-31b. Comparison of predicted and observed 24-hour average $PM_{2.5}$ concentration for FRM sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – PM_{10}

CD-C

Hiawatha

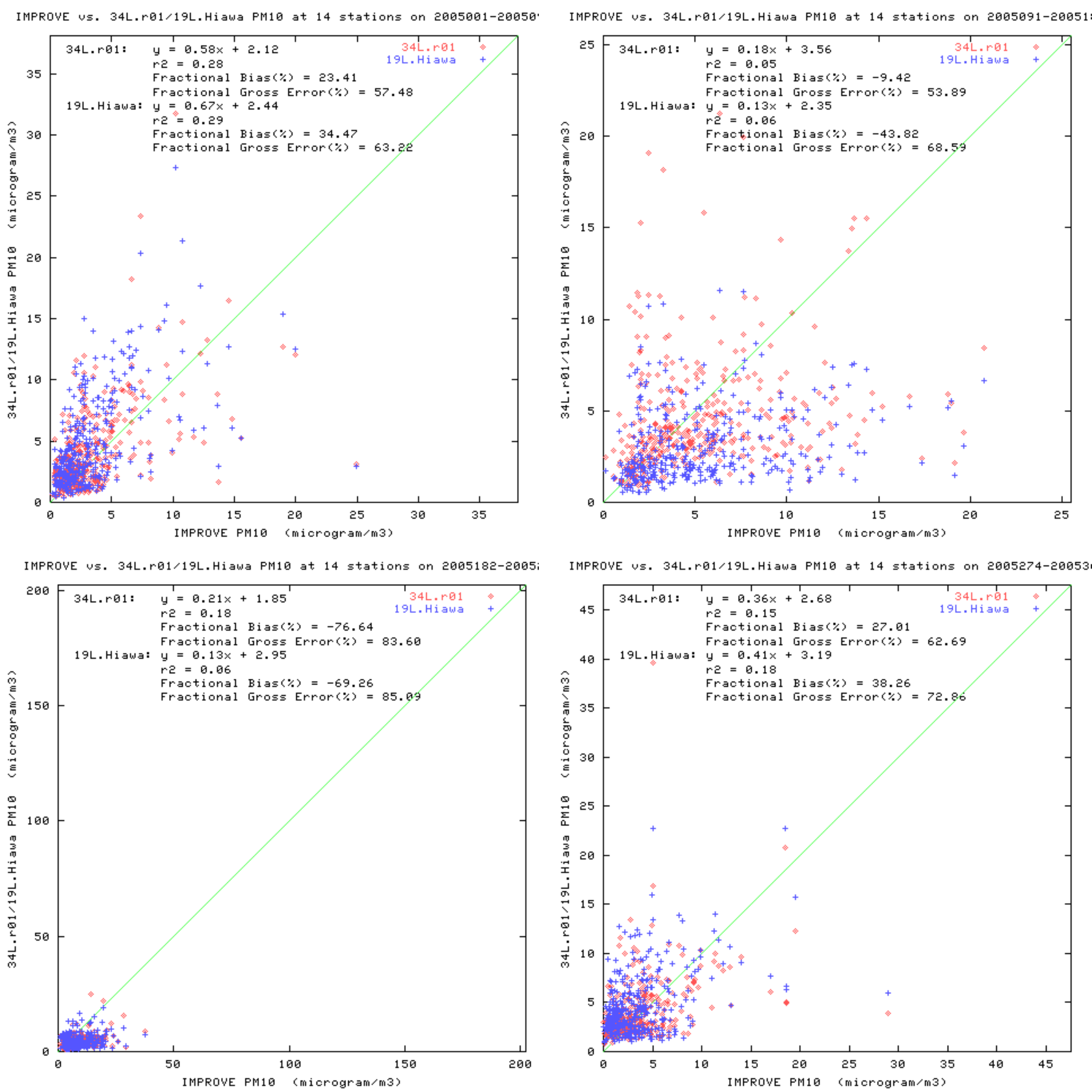


Figure A5-31c. Comparison of predicted and observed 24-hour average PM_{10} concentration for FRM sites in the CD-C 12 km domain for 2005 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – $PM_{2.5}$

CD-C

Hiawatha

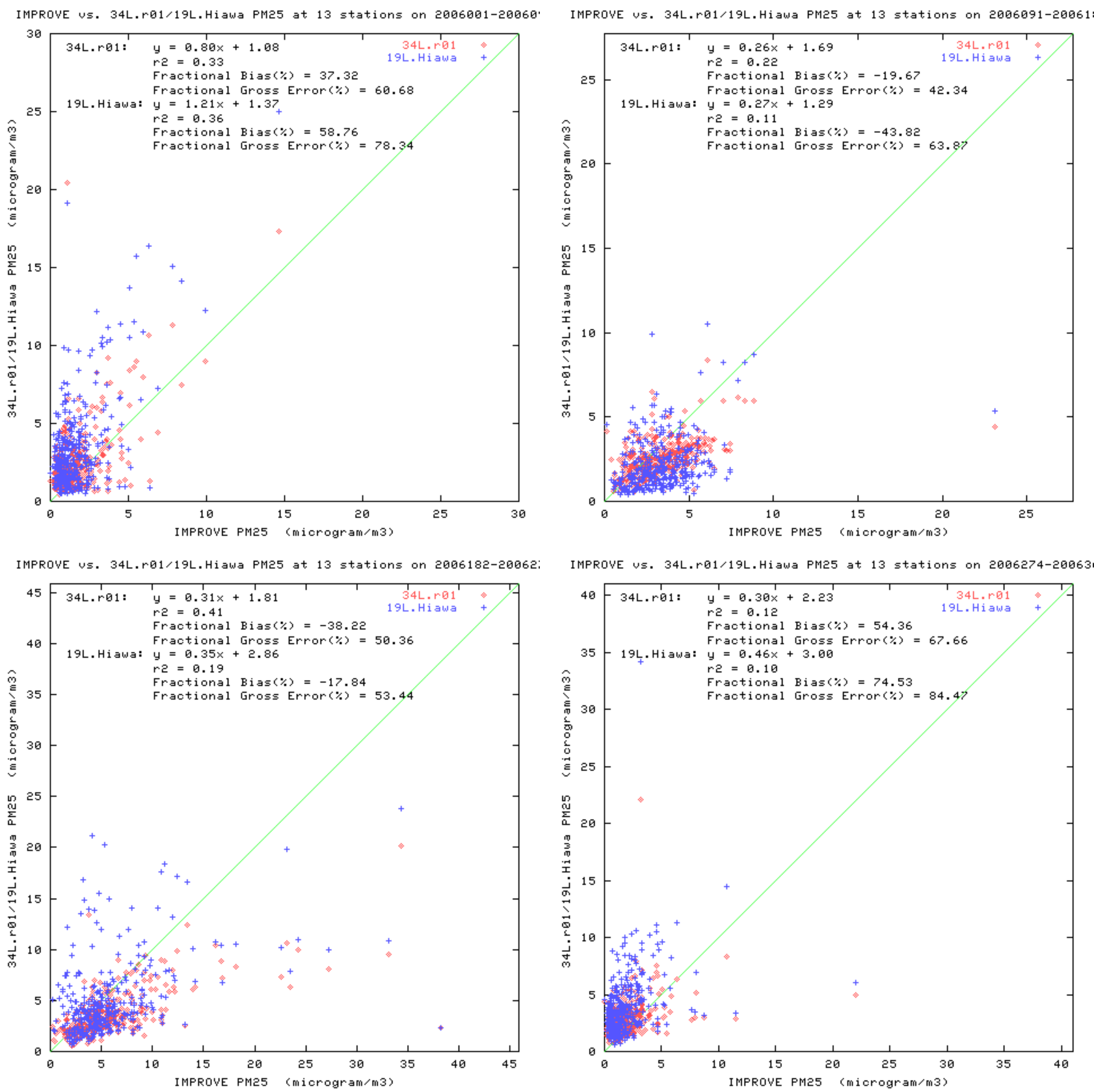


Figure A5-32a. Comparison of predicted and observed 24-hour average $PM_{2.5}$ concentration for IMPROVE sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

FRM – $PM_{2.5}$

CD-C

Hiawatha

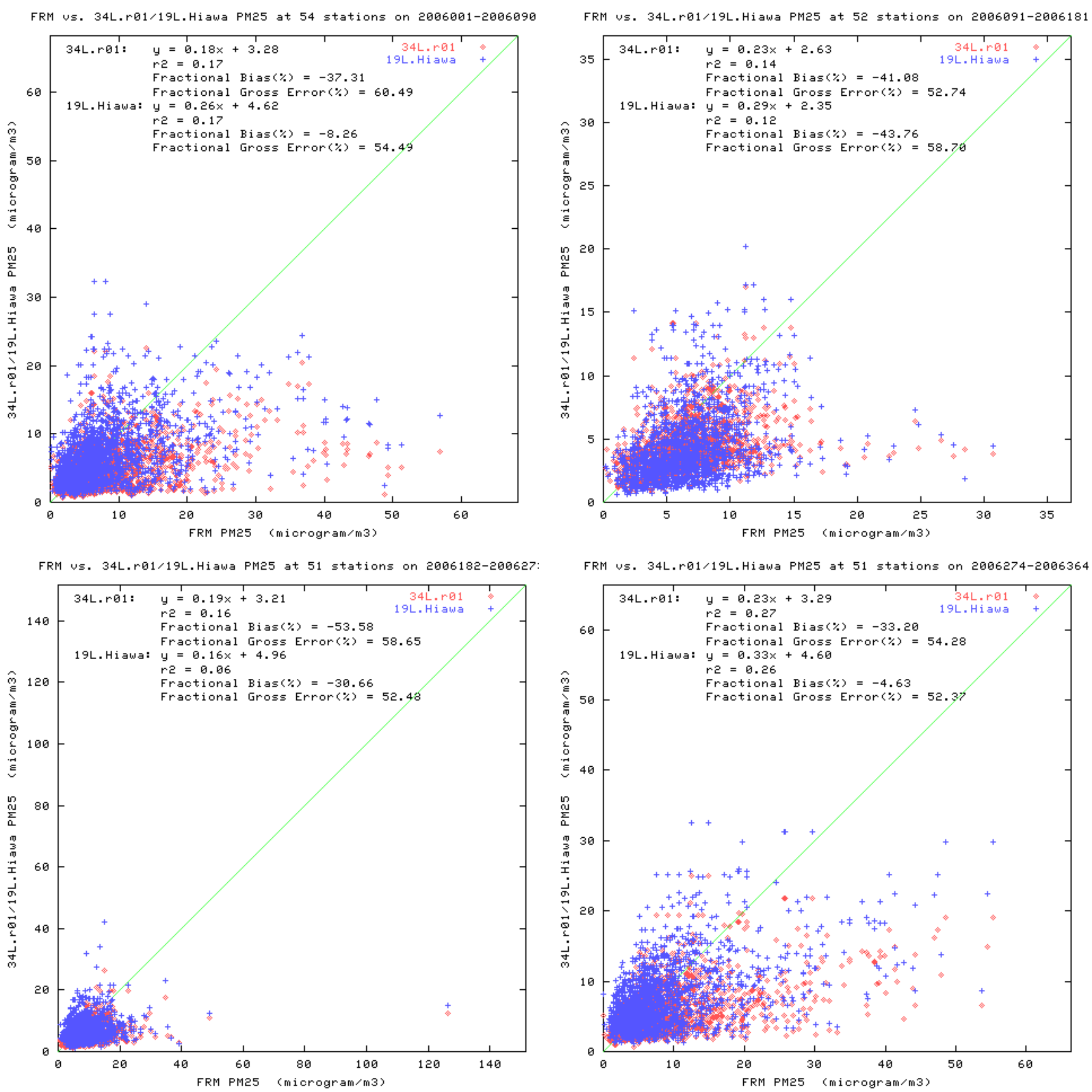


Figure A5-32b. Comparison of predicted and observed 24-hour average $PM_{2.5}$ concentration for FRM sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

IMPROVE – PM_{10}

CD-C

Hiawatha

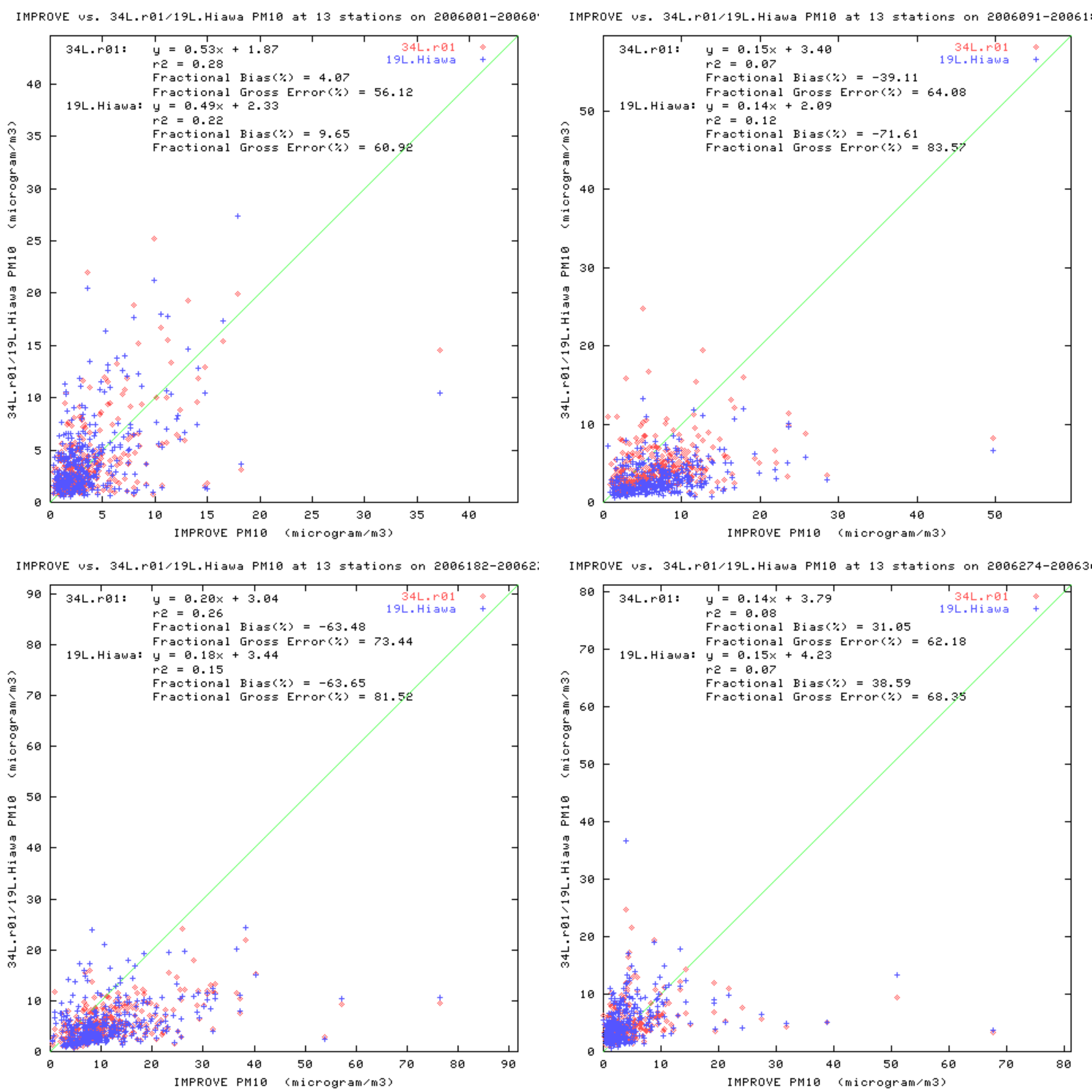
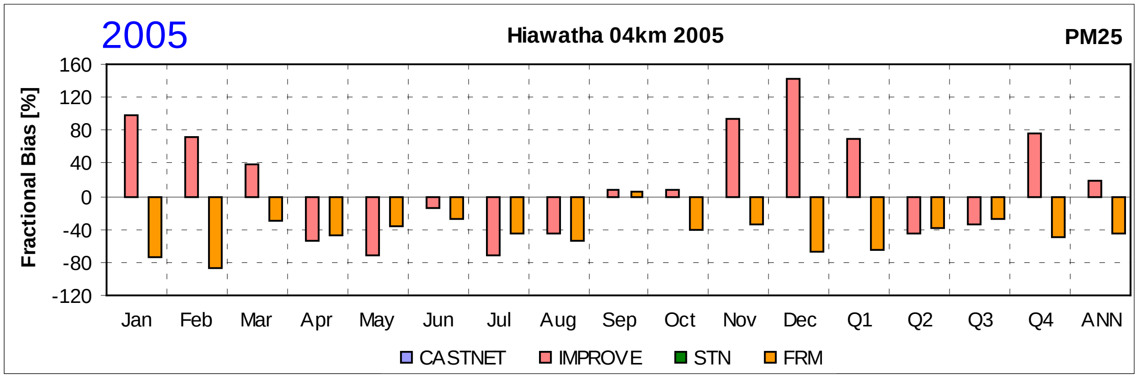
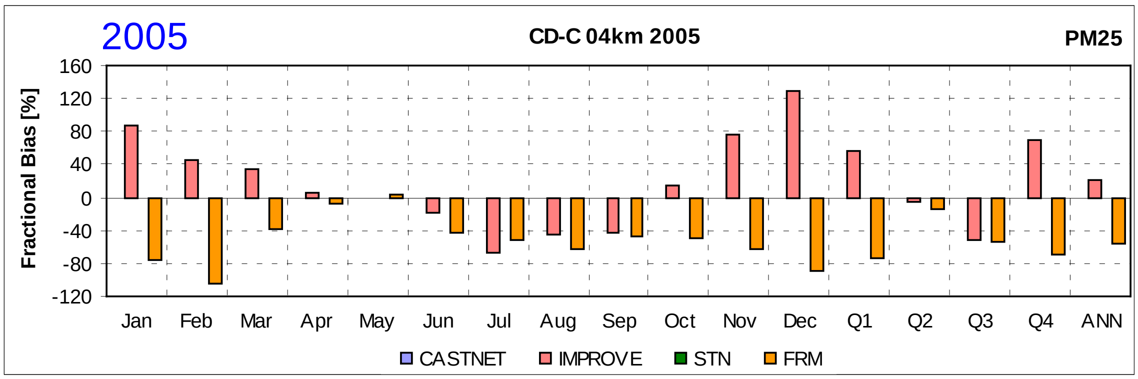


Figure A5-32c. Comparison of predicted and observed 24-hour average PM_{10} concentration for FRM sites in the CD-C 12 km domain for 2006 and Q1 (top left), Q2 (top right), Q3 (bottom left) and Q4 (bottom right).

(1)



(2)



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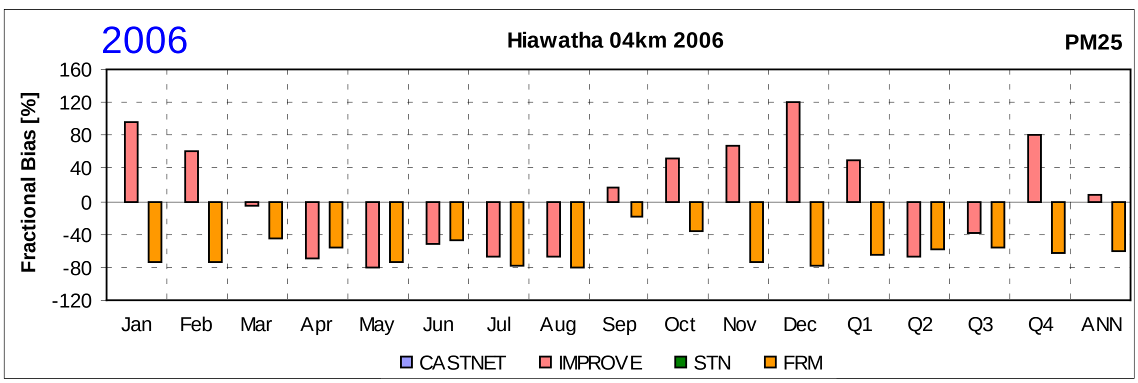

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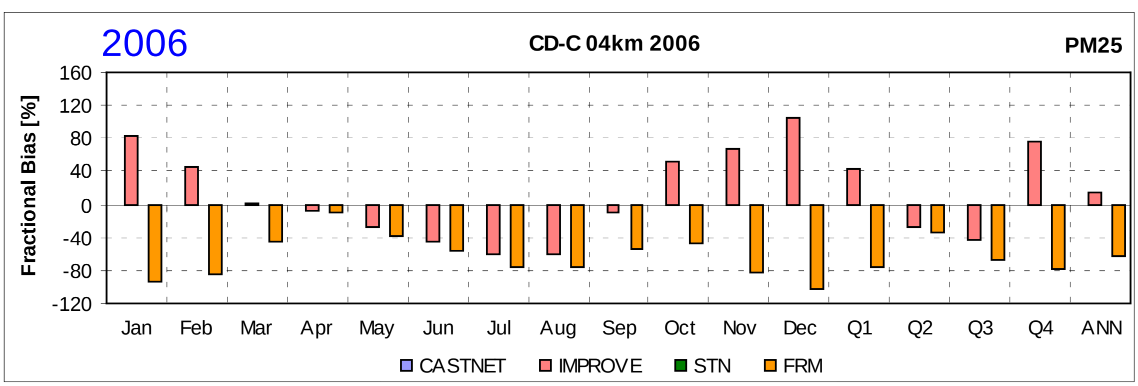


Figure A5-35. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for PM2.5 in 4 km grid.

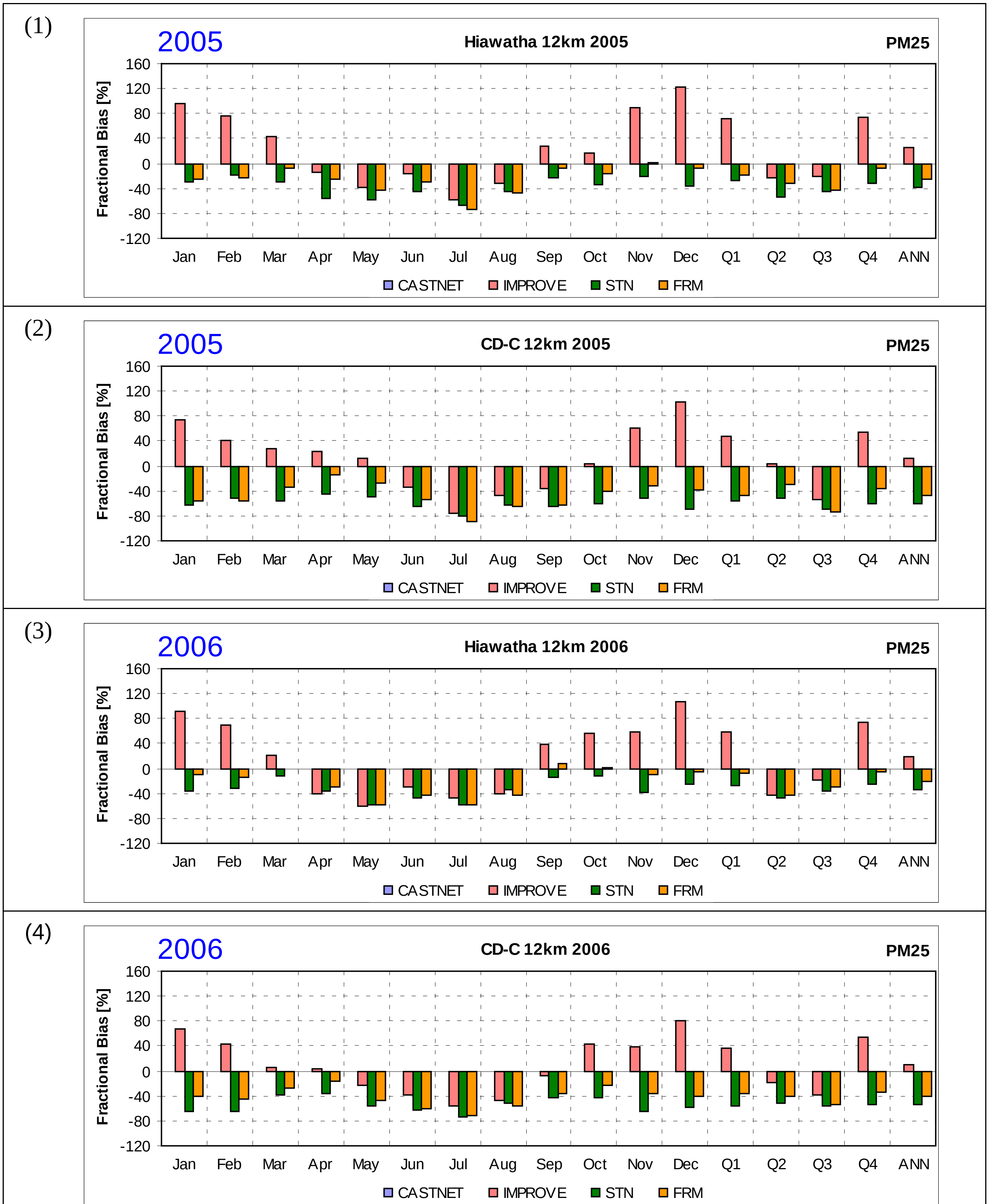


Figure A5-36. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for $PM_{2.5}$ in 12 km grid.

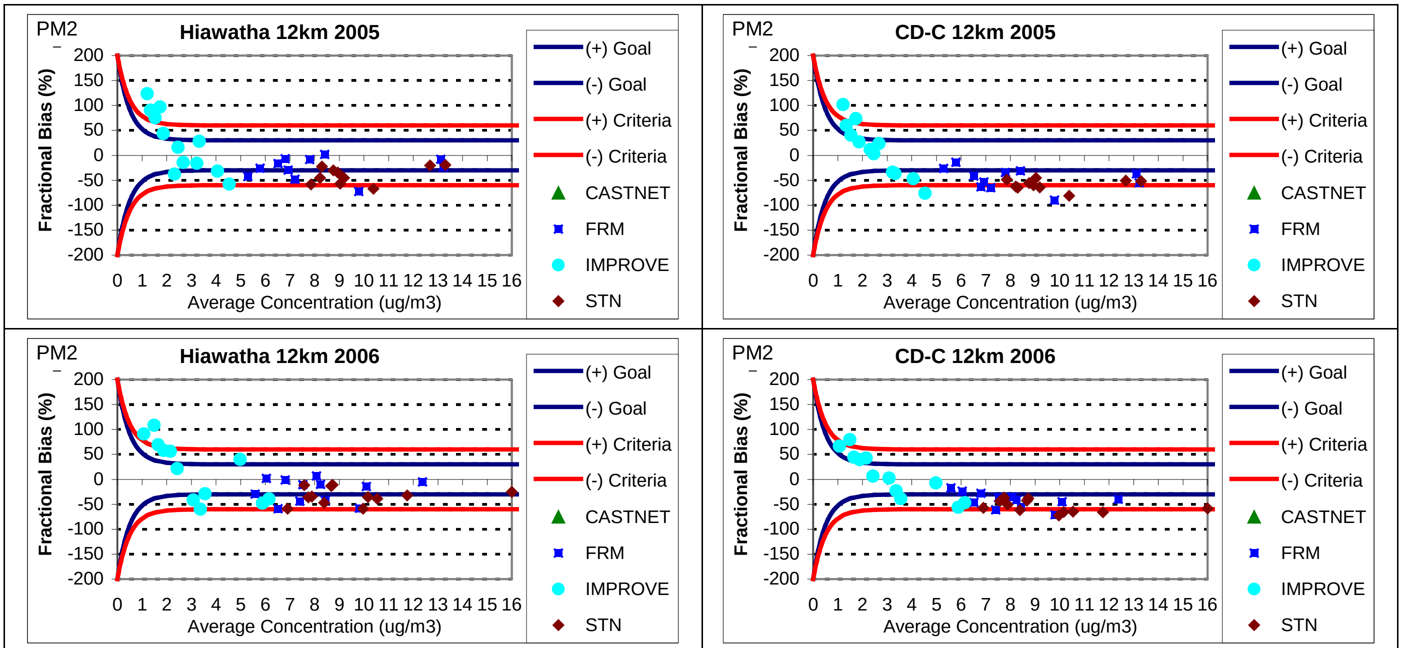


Figure A5-37a. Bugle Plots of PM$_{2.5}$model performance that compare mean fractional bias for the Hiawatha (left) and CD-C (right) CAMx 2005 (top) and 2006 (bottom) base case simulations in the 12 km domain with PM model performance goals (blue) and criteria (orange) (Note: WRAP did not generate Bugle Plots for PM$_{2.5}$).

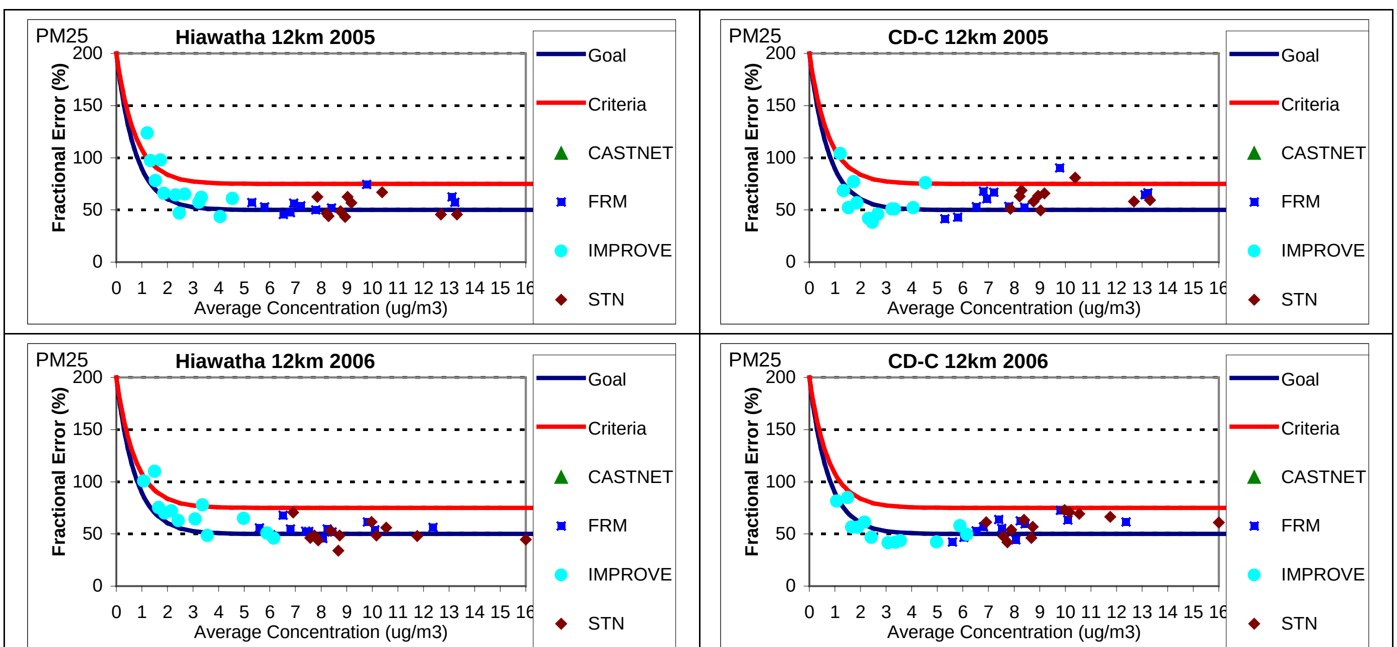


Figure A5-37b. Bugle Plots of PM$_{2.5}$model performance that compare mean fractional error for the Hiawatha (left) and CD-C (right) CAMx 2005 (top) and 2006 (bottom) base case simulations in the 12 km domain with PM model performance goals (blue) and criteria (orange) (Note: WRAP did not generate Bugle Plots for PM$_{2.5}$).

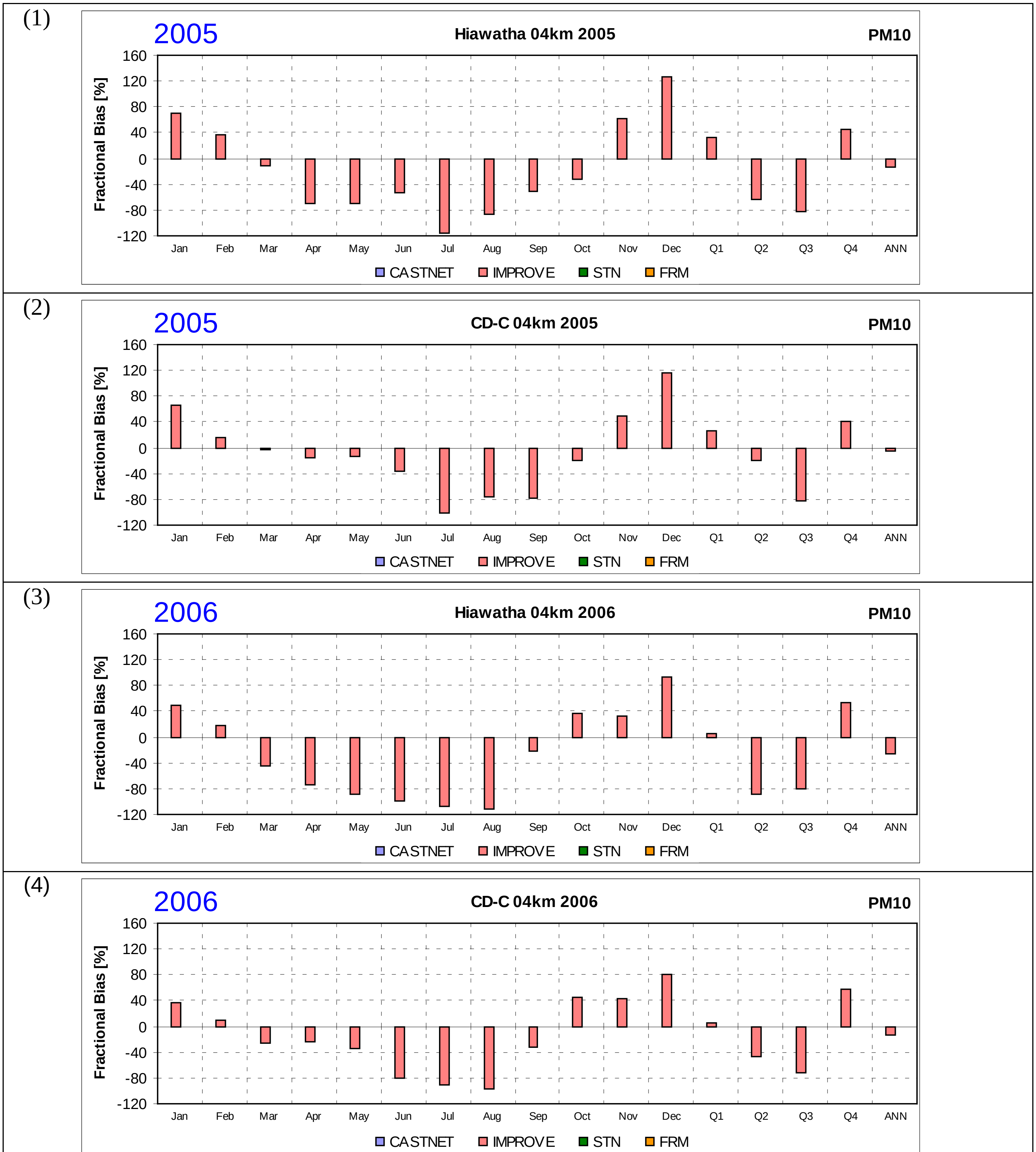
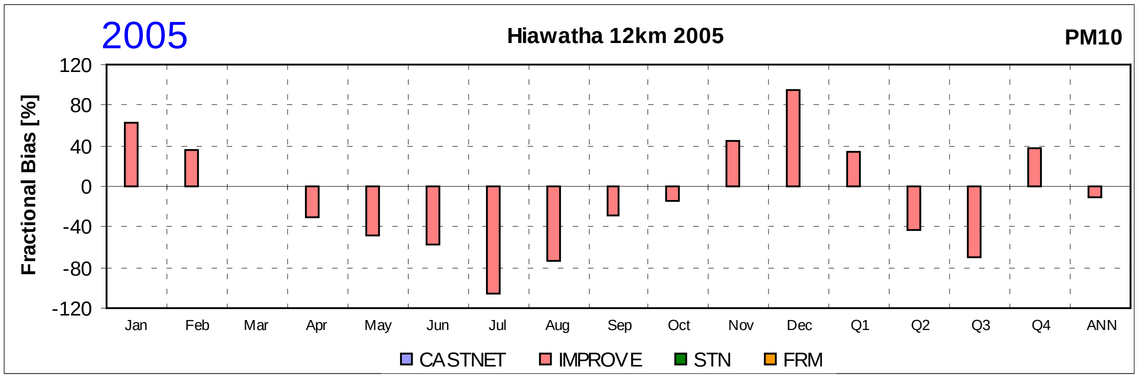
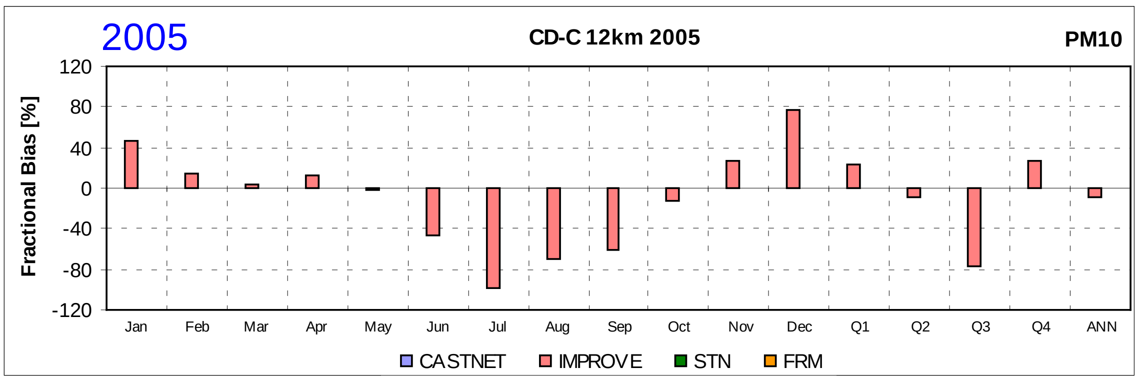


Figure A5-38. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for PM_{10} in 4 km grid.

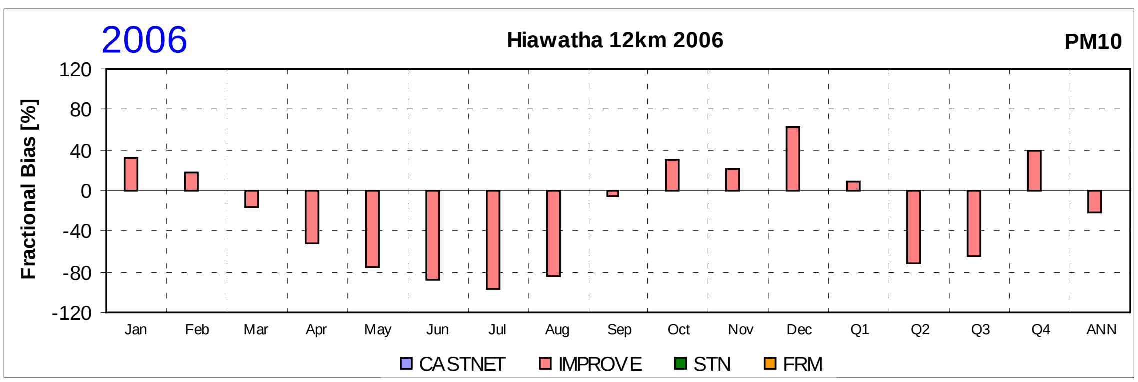
(1)



(2)



(3)



(4)

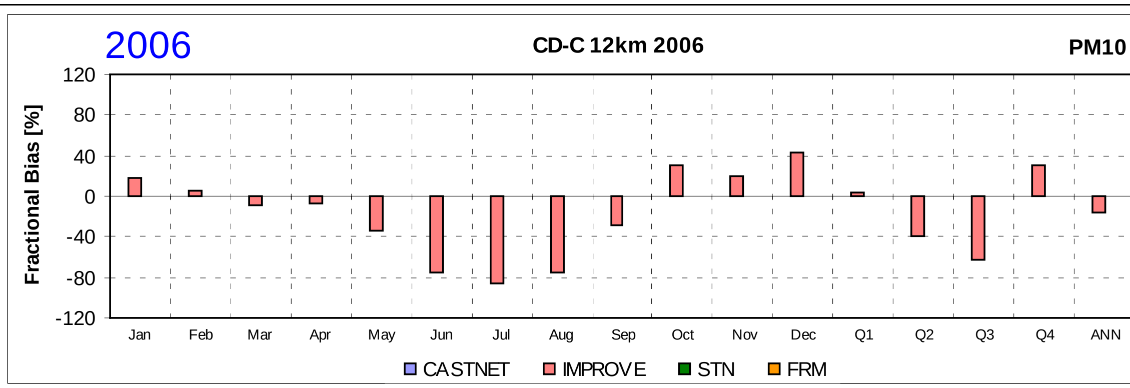


Figure A5-39. Monthly mean fractional bias performance metrics for Hiawatha 2005(1), CD-C 2005(2), Hiawatha 2006(3) and CD-C 2006(4) for PM_{10} in 12 km grid.

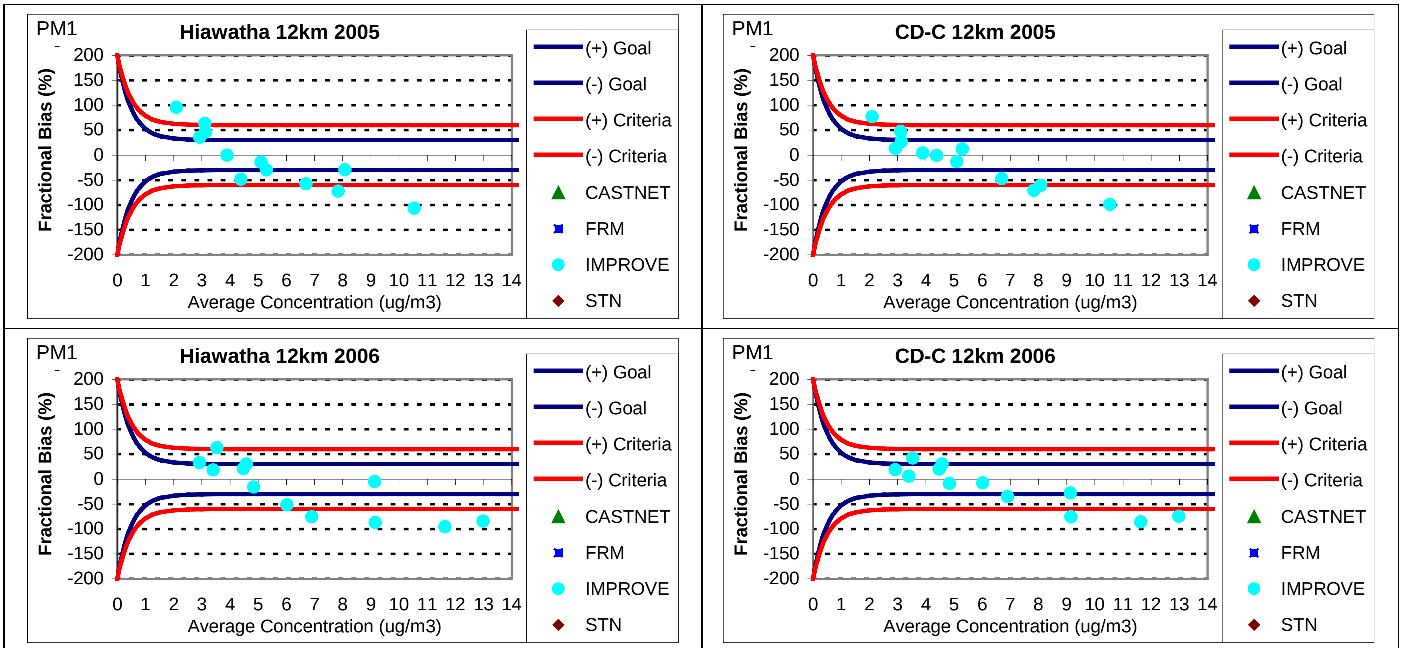


Figure A5-40a. Bugle Plots of PM_{10}model performance that compare mean fractional bias for the Hiawatha (left) and CD-C (right) CAMx 2005 (top) and 2006 (bottom) base case simulations in the 12 km domain with PM model performance goals (blue) and criteria (orange) (Note: WRAP did not generate Bugle Plots for PM_{10}).

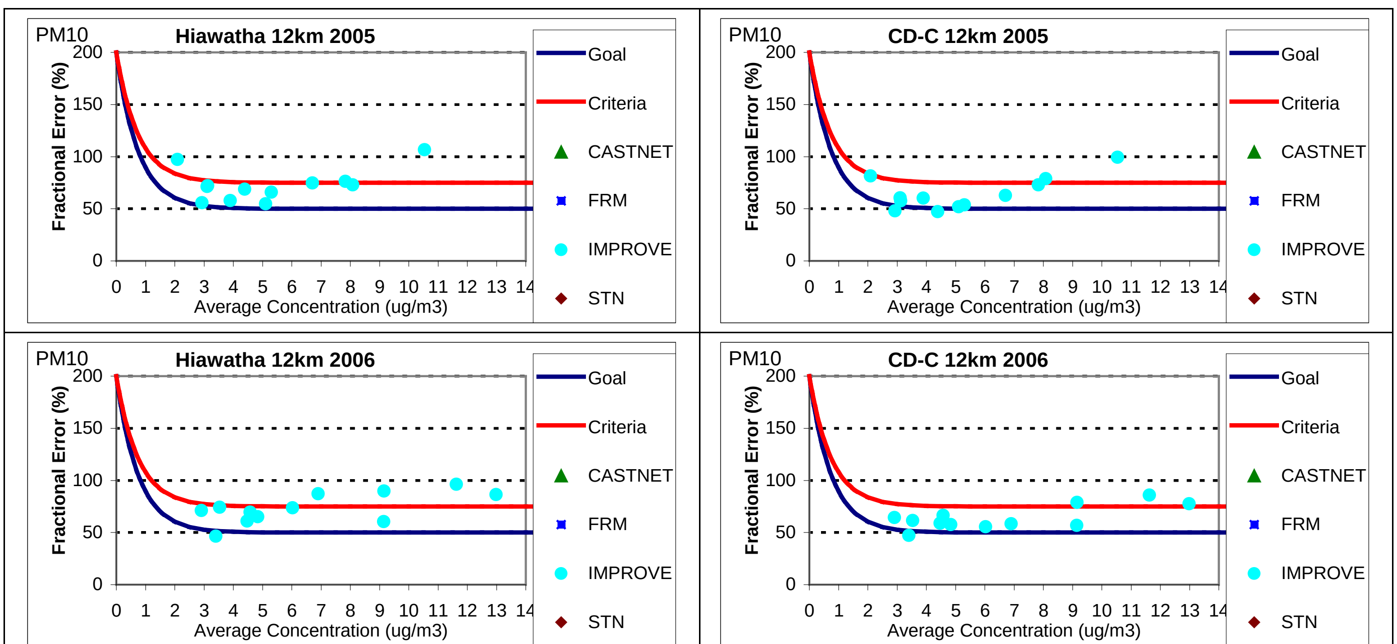


Figure A5-40b. Bugle Plots of PM_{10}model performance that compare mean fractional error for the Hiawatha (left) and CD-C (right) CAMx 2005 (top) and 2006 (bottom) base case simulations in the 12 km domain with PM model performance goals (blue) and criteria (orange) (Note: WRAP did not generate Bugle Plots for PM_{10}).

A5.8 NITRATE(NO3) PERFORMANCE ASSESSMENT

The largest emissions associated with oil and gas emissions sources, such as those associated with the CD-C project, are Volatile Organic Compounds (VOC) and oxides of nitrogen (NO_X), both of which are ozone precursors. In Section 4 of this Appendix, we addressed the CD-C CAMx base case ozone performance and showed much improvement on ozone model performance over the Hiawatha base case simulation. However, nitrate (NO3) represents a major potential contributor to visibility impairment at Class I areas due to O&G emissions in the 12/4 km modeling domain. The NO3 evaluation presented in Section A5.2 indicated that both the CD-C and Hiawatha CAMx 2005 and 2006 base case simulations overpredicted NO3 in the winter and underpredicted NO3 in the summer. In this section we discuss the implications of the NO3 performance issues and their potential effects on the calculation of O&G visibility impacts at Class I areas.

Figures A5-41and A5-42 displays time series plots of predicted and observed 24-hour average NO3 concentrations during 2005 and 2006 at the Bridger (BIRD) and Mount Zirkel (MOZI) IMPROVE monitoring sites in Wyoming and Colorado within the 4 km domain. These time series plots clearly show the seasonal dependence of NO3 concentrations in the observations and model predictions with much higher values in the winter and much lower values in the summer, when the modeled values approach zero. There are questions regarding the accuracy of the low observed NO3 values in the summer and whether the handling and transport of the filters could contaminate the samples producing small nitrate values when in reality the real atmosphere had none because the high summer temperatures volatilize the particulate NO3. In any event, both the observed and modeled summer nitrate are extremely low and not an important component of the $PM_{2.5}$ mass and visibility impairment during the summer.

Figures A5-41and A5-42 also compare the predicted and observed frequency distribution of 24-hour NO3 concentrations at each IMPROVE monitoring site during 2005 and 2006. When the measured NO3 concentration is above approximately 0.1 $\mu g/m^3$, both CAMx base case simulations have a marked overprediction bias of 50% to 100%, and even more for the highest model estimated NO3 concentrations. Thus, the CD-C and Hiawatha CAMx modeling systems will overestimate the maximum NO3 impacts and consequently overestimate the maximum visibility impacts due to O&G emissions at Class I areas.

The formation of particulate nitrate depends on the ambient concentration of ammonia, which reacts preferentially with SO4. If ambient concentrations of ammonia are not well-represented in the model, nitrate formation will not be simulated correctly. Routine measurements of NH3 within the modeling domain for 2005-6 were not available, however, Shell sponsored ammonia monitoring during 2007-2008 at the Boulder monitoring site southwest of the Wind River Range in Sublette County, WY. No direct comparison of the 2005-2006 modeled NH3 and the 2007-8 measured NH3 is possible, but this data set offers a unique observational database for use in general evaluation of the CAMx ammonia performance, which is critical to nitrate performance. Figure A5-43 displays the observed monthly frequency distribution of ammonia (NH3) concentrations during 2007 at the Boulder monitoring site using box and whisker plots from

Molenar and co-workers (2008)6 as well as similar plots using the CD-C and Hiawatha CAMx model predictions in 2005 and 2006 at the Boulder site. The amplitude of the modeled seasonal cycle is smaller in the two model simulations than in the observations, with the model estimating a fairly flat monthly average NH3 profile of approximately 0.05 to 0.20 ppb whereas the observed monthly average NH3 profile ranges from near zero in the winter to ~0.8 ppb in July and August. The underestimate of summer NH3 in the model may contribute to the general low bias in model nitrate predictions during summer. Ammonia emissions are highly uncertain, and better representation of ammonia within the model may improve nitrate performance.

As a final test of the implications of using the CD-C CAMx modeling database to make AQRV assessment at Class I areas, we examined the number of predicted and observed days during 2005 and 2006, and each Quarter in 2005 and 2006, that visibility impairment due to NO3 exceeds a 0.5 and 1.0 deciview (dv) thresholds. For each of the 1:3 sampling days from 2005 and 2006 and the two IMPROVE monitors in the 4 km domain (Mount Zirkel and Bridger), the observed and CD-C and Hiawatha base case predicted 24-hour NO3 concentrations were converted to light extinction using the IMPROVE extinction equation and monthly average relative humidity adjustment factors [f(RH)] and then converted to deciview assuming a change in deciview over clean natural background conditions. The number of days that the observed and predicted visibility impairment exceeded the 0.5 and 1.0 dv thresholds at Mount Zirkel and Bridger are tabulated in Table A5-1. At Mount Zirkel there were 49 days during 2005 that the observed visibility impairment due to NO3 exceeded the 0.5 dv threshold compared to 77 days and 67 days for the Hiawatha and CD-C base case simulations respectively. That is, the Hiawatha and CD-C base cases overestimate the number of days that NO3 visibility impairment exceeds 0.5 dv at Mount Zirkel in 2005 by 57% and 37%, respectively. The conservatism in the modeling systems in regards to NO3 AQRVs using the 1.0 dv threshold is even greater with the model estimating over 2 times as many days than observed at Mount Zirkel (Table A5-1a). The results at Mount Zirkel in 2006 are similar with over 10 more modeled days in 2006 (~25% more days) than observed having NO3 visibility impairment > 0.5 dv (Table A5-1b). And there were over 2.5 times more modeled days at Mount Zirkel in 2006 than observed days with NO3 visibility impairment exceeding the 1.0 dv threshold.

The conservatism of the Hiawatha and CD-C CAMx base case simulations in estimating NO3 visibility impairment at Class I areas is even greater at the Bridger IMPROVE monitoring site. In 2005, there are over twice as many modeled days than observed that the NO3 visibility impairment exceeds the 0.5 dv threshold at Bridger and over 5 times as many modeled days than observed days that the 1.0 dv threshold is exceeded (Table A5-1c). In 2006, the CD-C base case has 24 more days (45% more days) when the 0.5 dv threshold is exceeded due to NO3 than are observed and there are over 2.5 more modeled days than observed days that the 1.0 dv threshold is exceeded due to NO3 (Table A5-1d).

[6] Available at:
http://wrapair.org/forums/toc/meetings/080515m/NH3_Monitoring_in_the_Upper_Green_River_Basin.ppt#309,25,Neutralization

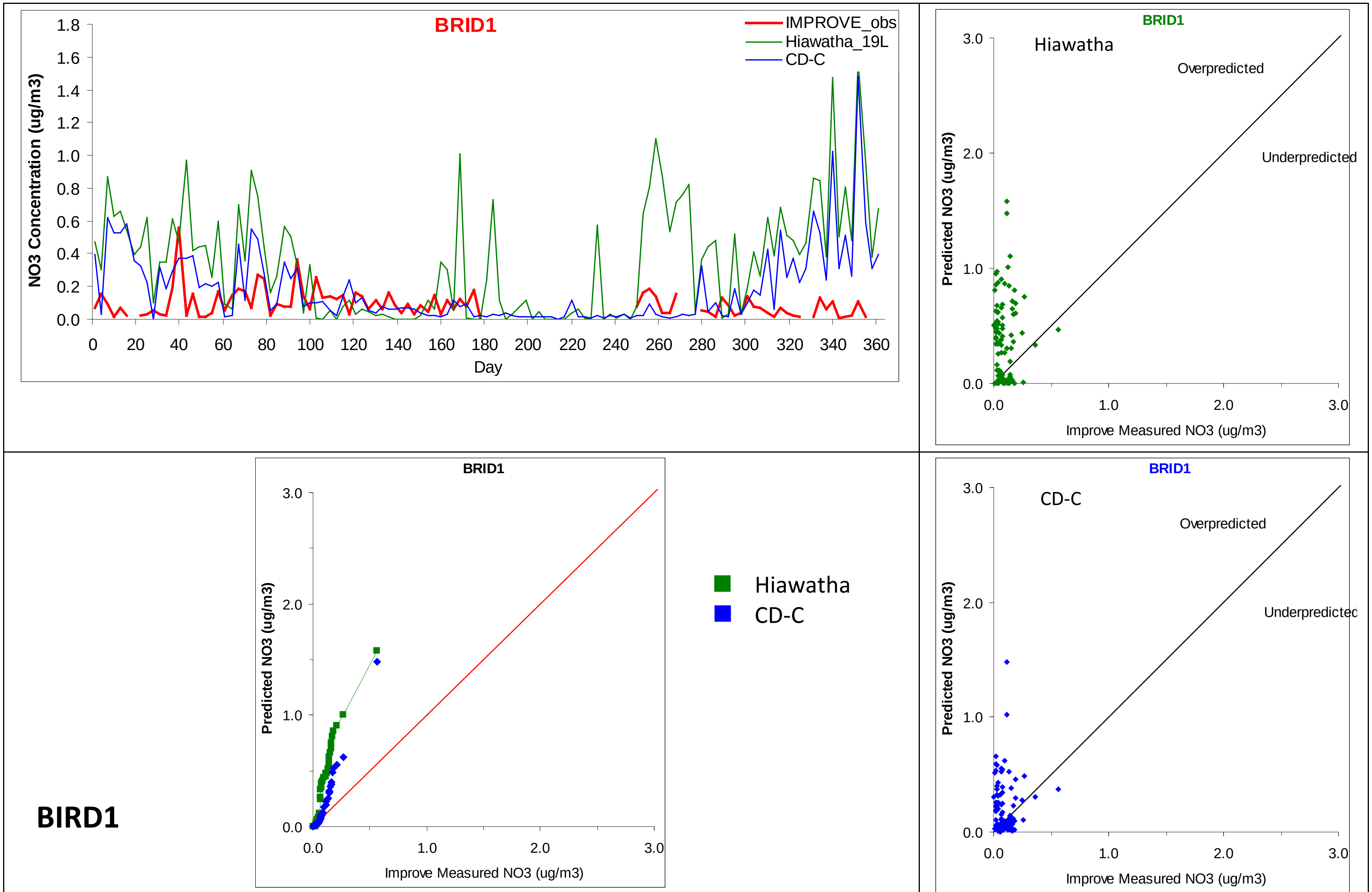


Figure A5-41a. Time series of 2005 predicted and observed 24-hour average NO3 concentrations at the Bridger IMPROVE monitoring site (top left panel). Cumulative frequency distribution of predicted and observed 24-hour NO3 concentrations unpaired in space and time for Hiawatha (top right panel) and CD-C (bottom right panel) and paired in time (bottom left panel) for the Bridger IMPROVE monitoring site for 2005.

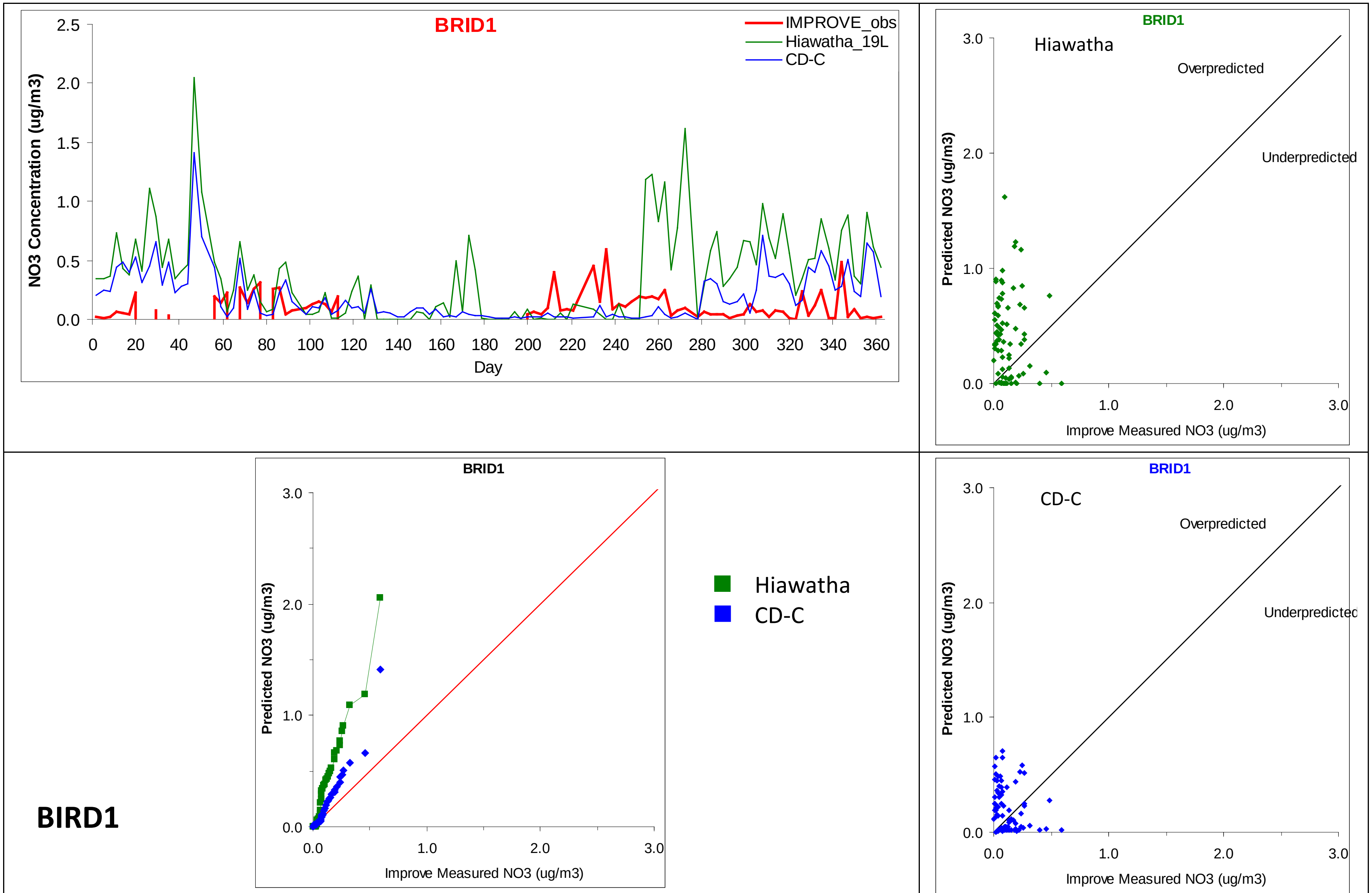


Figure A5-41b. Time series of 2006 predicted and observed 24-hour average NO3 concentrations at the Bridger IMPROVE monitoring site (top left panel). Cumulative frequency distribution of predicted and observed 24-hour NO3 concentrations unpaired in space and time for Hiawatha (top right panel) and CD-C (bottom right panel) and paired in time (bottom left panel) for the Bridger IMPROVE monitoring site for 2006.

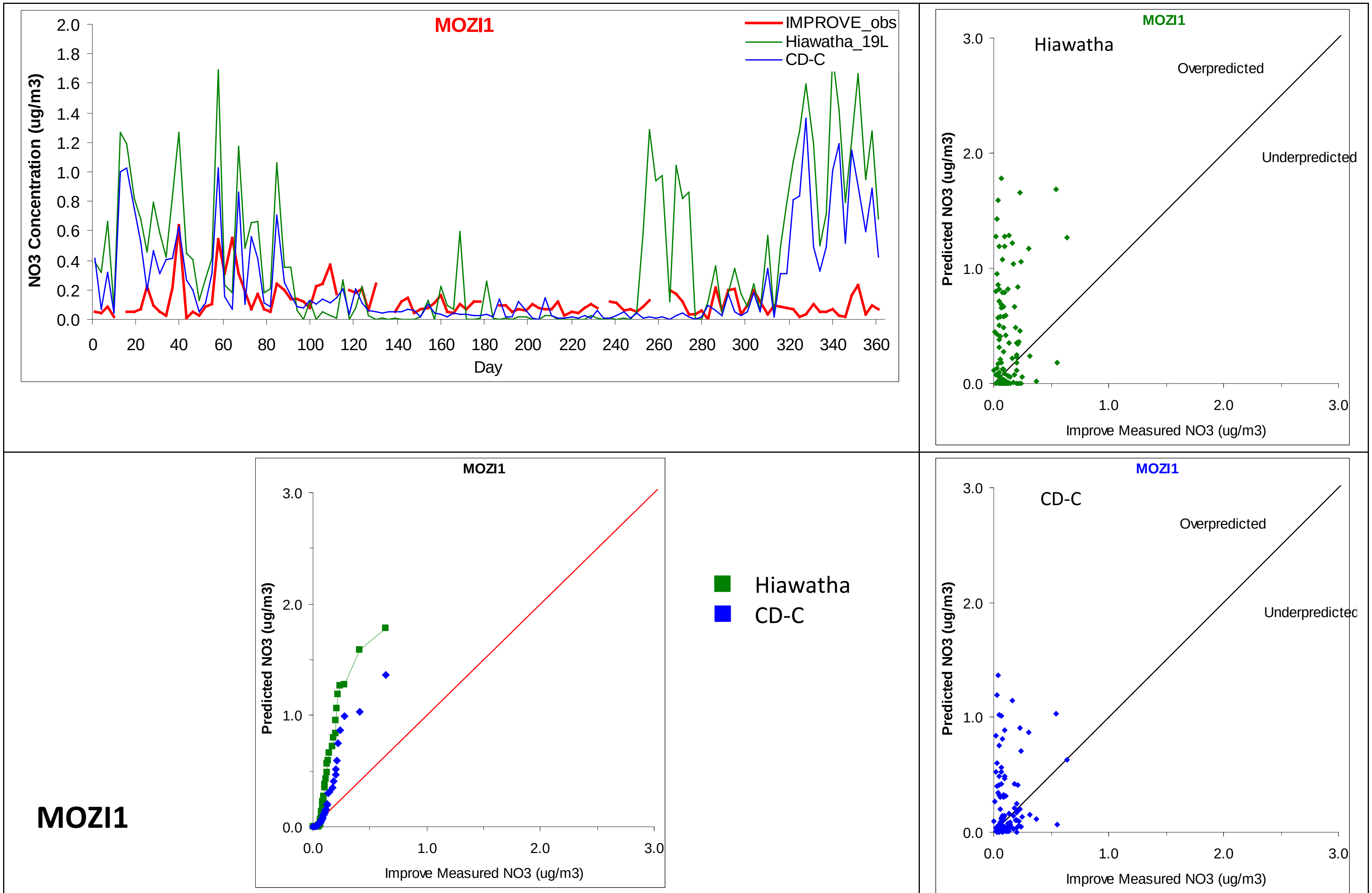


Figure A5-42a. Time series of 2005 predicted and observed 24-hour average NO3 concentrations at the Mount Zirkel IMPROVE monitoring site (top left panel). Cumulative frequency distribution of predicted and observed 24-hour NO3 concentrations unpaired in space and time for Hiawatha (top right panel) and CD-C (bottom right panel) and paired in time (bottom left panel) for the Bridger IMPROVE monitoring site for 2005.

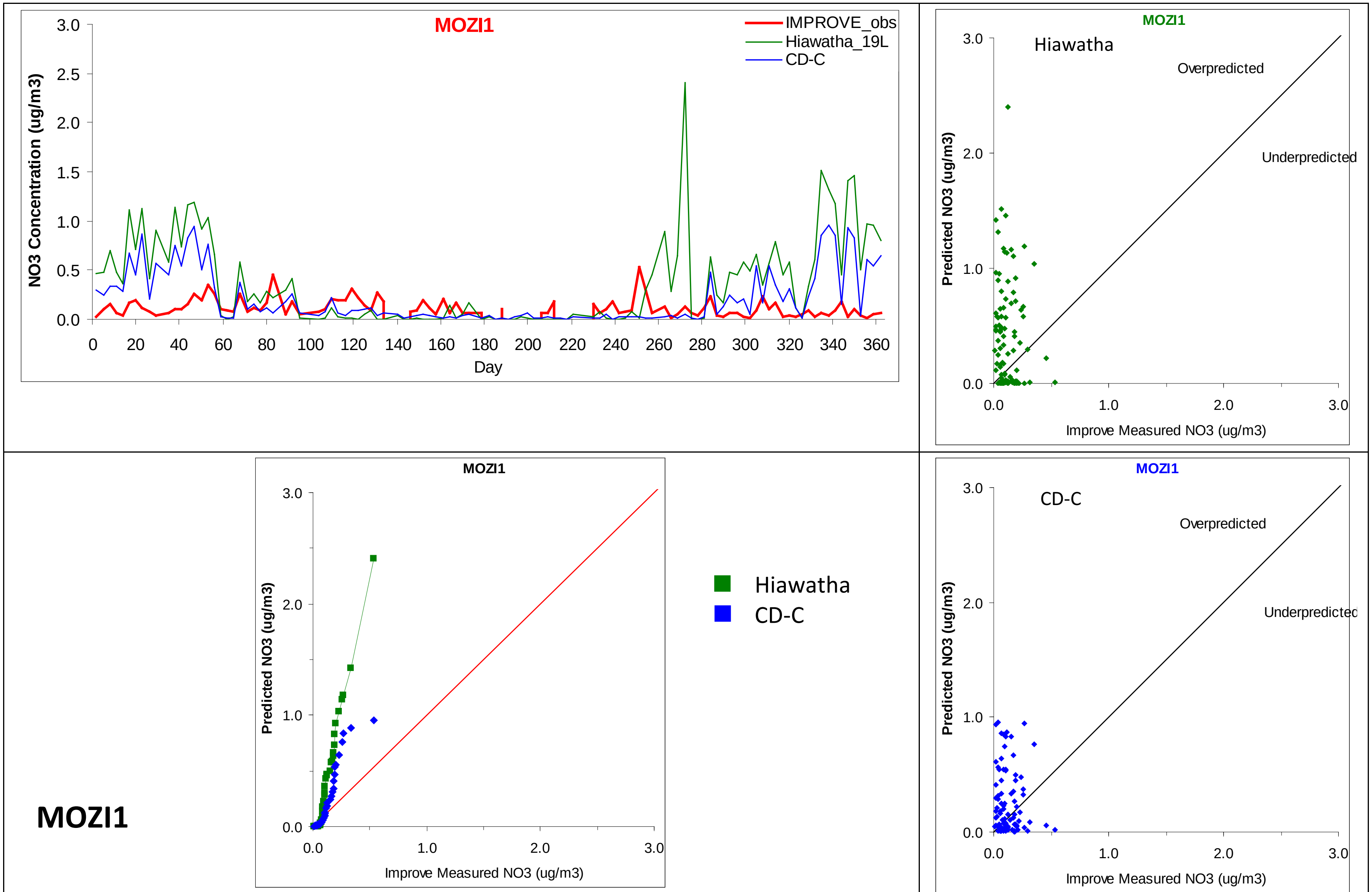


Figure A5-42b. Time series of 2006 predicted and observed 24-hour average NO3 concentrations at the Mount Zirkel IMPROVE monitoring site (top left panel). Cumulative frequency distribution of predicted and observed 24-hour NO3 concentrations unpaired in space and time for Hiawatha (top right panel) and CD-C (bottom right panel) and paired in time (bottom left panel) for the Bridger IMPROVE monitoring site for 2006.

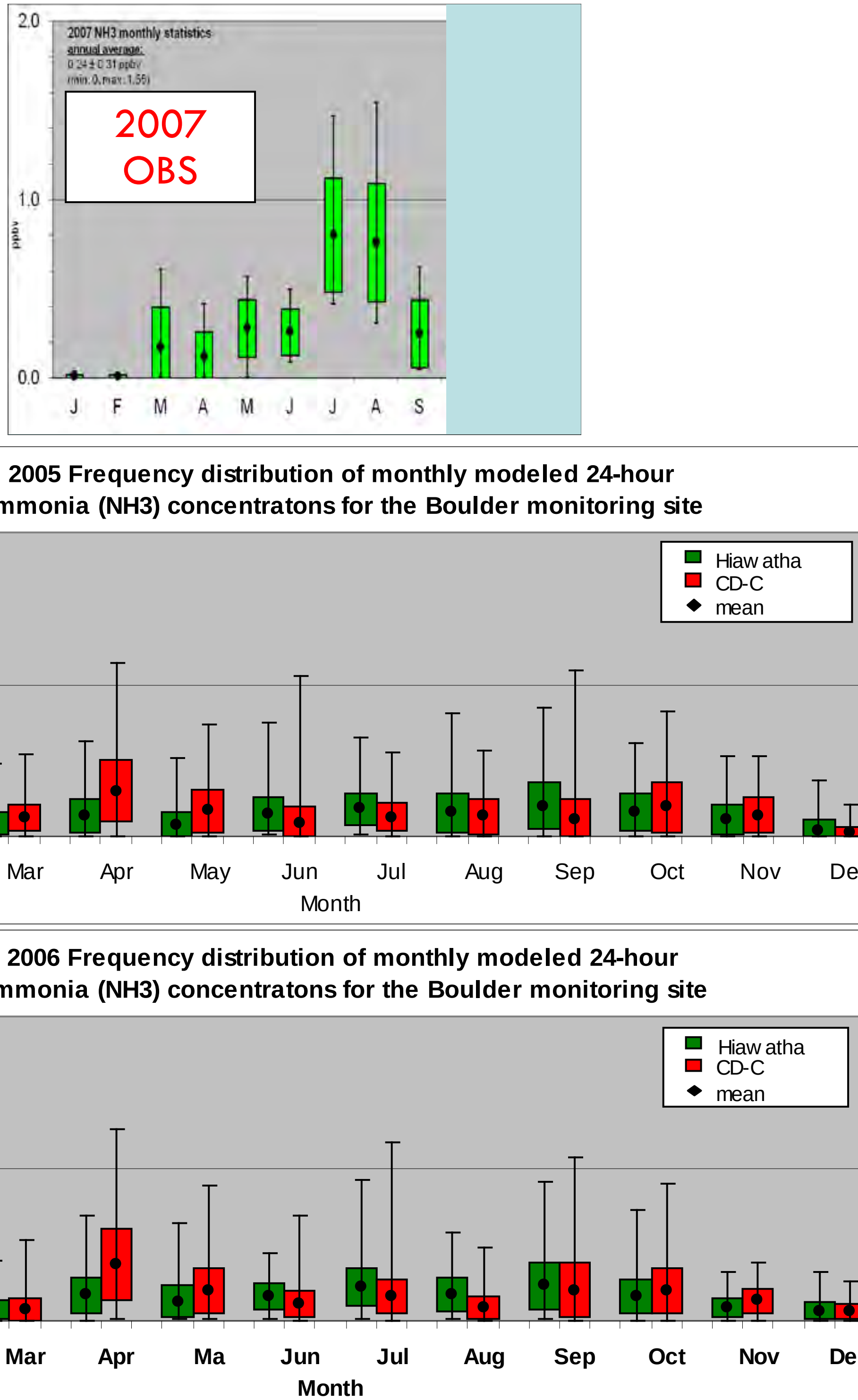


Figure A5-43. Observed and modeled ammonia concentrations. Upper left panel: monthly mean and standard deviation of ammonia measurements taken at the Shell site in Boulder, WY. Upper (lower) right panel: monthly mean and standard deviation of modeled ammonia for the 4 km grid cell that contains the Boulder monitoring site for the year 2005 (2006).

Table A5-1a. Number of days during 2005 that predicted and observed visibility impairment due NO3 exceeds a 0.5 and 1.0 deciview (dv) threshold at the Mount Zirkel IMPROVE monitoring site using the same 1:3 day sampling frequency for the CD-C and Hiawatha base case simulations.

	Number Days NO3 Visibility > 0.5 dv			Number Days NO3 Visibility > 1.0 dv		
	Observed	Hiawatha	CD-C	Observed	Hiawatha	CD-C
2005 Q1	12	30	27	9	27	24
2005 Q2	18	10	15	6	7	4
2005 Q3	10	8	4	1	7	1
2005 Q4	9	29	21	5	22	19
All 2005	49	77	67	21	63	48

Table A5-1b. Number of days during 2006 that predicted and observed visibility impairment due NO3 exceeds a 0.5 and 1.0 deciview (dv) threshold at the Mount Zirkel IMPROVE monitoring site using the same 1:3 day sampling frequency for the CD-C and Hiawatha base case simulations.

	Number Days NO3 Visibility > 0.5 dv			Number Days NO3 Visibility > 1.0 dv		
	Observed	Hiawatha	CD-C	Observed	Hiawatha	CD-C
2005 Q1	17	27	26	5	24	21
2005 Q2	17	5	10	7	2	1
2005 Q3	11	9	4	3	7	0
2005 Q4	7	26	25	2	25	21
All 2005	52	67	65	17	58	43

Table A5-1c. Number of days during 2005 that predicted and observed visibility impairment due NO3 exceeds a 0.5 and 1.0 deciview (dv) threshold at the Bridger IMPROVE monitoring site using the same 1:3 day sampling frequency for the CD-C and Hiawatha base case simulations.

	Number Days NO3 Visibility > 0.5 dv			Number Days NO3 Visibility > 1.0 dv		
	Observed	Hiawatha	CD-C	Observed	Hiawatha	CD-C
2005 Q1	12	30	29	6	29	26
2005 Q2	18	18	22	3	13	10
2005 Q3	8	13	10	2	9	0
2005 Q4	5	29	28	0	27	23
All 2005	43	90	89	11	78	59

Table A5-1d. Number of days during 2006 that predicted and observed visibility impairment due NO3 exceeds a 0.5 and 1.0 deciview (dv) threshold at the Bridger IMPROVE monitoring site using the same 1:3 day sampling frequency for the CD-C and Hiawatha base case simulations.

	Number Days NO3 Visibility > 0.5 dv			Number Days NO3 Visibility > 1.0 dv		
	Observed	Hiawatha	CD-C	Observed	Hiawatha	CD-C
2005 Q1	14	30	29	11	29	26
2005 Q2	16	18	16	3	12	9
2005 Q3	17	10	4	7	7	1
2005 Q4	6	28	28	3	28	27
All 2005	53	86	77	24	76	63

A5.9 PM MODEL PERFORMANCE EVALUATION CONCLUSIONS

The CD-C and HiawathaCAMx 2005 and 2006 base case simulations exhibited overall PM performance comparable to that of the WRAP's 2002 CMAQ simulations that were judged suitable for use in developing regional haze State Implementation Plans (SIPs). Sulfate (SO4) performance was fairly good, whereas nitrate (NO3) performance had a winter overestimation and summer underestimation bias. The elemental carbon performance was variable, but because concentrations were low it achieved the PM performance goals and criteria in the Bugle Plots. Organic Carbon Mass (OCM) was underestimated throughout the year which is a common issue in PM modeling. The reasons for the OCM underestimation bias are: missing emissions of primary OCM, insufficient formation of Secondary Organic Aerosols (SOA) and missing Semi-Volatile Organic Compound (SVOC) in the current generation of emissions and air quality modeling systems.

Probably the biggest concern regarding the assessment of the potential impacts of O&G emissions in southwestern Wyoming on air quality and AQRVs is the NO3 model performance and the effects that the winter overestimation and summer underestimation will have on visibility impacts at Class I areas. A focused analysis was performed that found the model predicted many more days than observed in which visibility impacts due to nitrate exceeded the 0.5 and 1.0 dv thresholds at the two Class I areas in the 4 km domain. Based on these results, we conclude that the CD-C CAMx base case simulation will provide a conservative estimate for assessing visibility impacts at Class I areas.

A6. MODEL PERFORMANCE EVALUATION CONCLUSIONS

The CD-C 12/4 km CAMx ozone performance at the rural CASTNet monitors and Wyoming industrial sites in southwestern Wyoming generally achieved EPA's performance goals for hourly and 8-hour ozone concentrations and ozone performance at these monitors was comparable to ozone performance seen in ozone SIP modeling, such as for the Denver 8-hour ozone EAC and more recent SIP modeling (Morris et al., 2008a,b). Ozone performance was not as good at Wyoming industrial sites monitors within areas of O&G development, however there was marked improvements in the ozone performance at these sites in the CD-C CAMx base case over what was obtained previously with the preliminary Hiawatha CAMx base case simulation (Kemball-Cook et al., 2009). There are numerous uncertainties in the O&G emissions, including the occurrence of episodic emissions that are currently modeled as continuous releases.

The CD-C CAMx 36/12/4 km 2005 and 2006 base case simulations exhibited PM performance comparable to that of the RPO 2002 CMAQ simulations that were judged suitable for use in developing regional haze State Implementation Plans (SIPs). The main PM performance issue in the CD-C base case simulations in regards to using the modeling system to evaluate the potential air quality and AQRV impacts of the CD-C Project is the overestimation of nitrate during winter and underestimation of nitrate during summer. There is a concern that the nitrate underestimation bias may result in the model understating the potential visibility impacts of the CD-C Project at Class I areas. This issue was evaluated by comparing the number of days of observed versus predicted that the visibility impairment due to NO3 was above 0.5 dv and 1.0 dv and found that the CD-C CAMx modeling system was sufficiently conservative.

The model also underestimates wet deposition of sulfate, nitrate, and ammonium. Wet deposition is particularly challenging for the model to simulate because it requires skillful prediction of the timing and amount of the precipitation as well as accurate representation of the nitrate, sulfate and ammonium fields. Note that the model will be used to predict incremental changes in deposition due to future year CD-C Project impacts, and that the effects of the underestimation of wet deposition will be minimized because the model will be used in a relative sense.

Because the CD-C CAMx base case PM and ozone performance were comparable to similar applications used in regional haze and ozone regulatory modeling, and because it meets most of the relevant performance benchmarks, the model is judged to be suitable for use in the CD-C Project AQ/AQRV impact assessment.

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