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

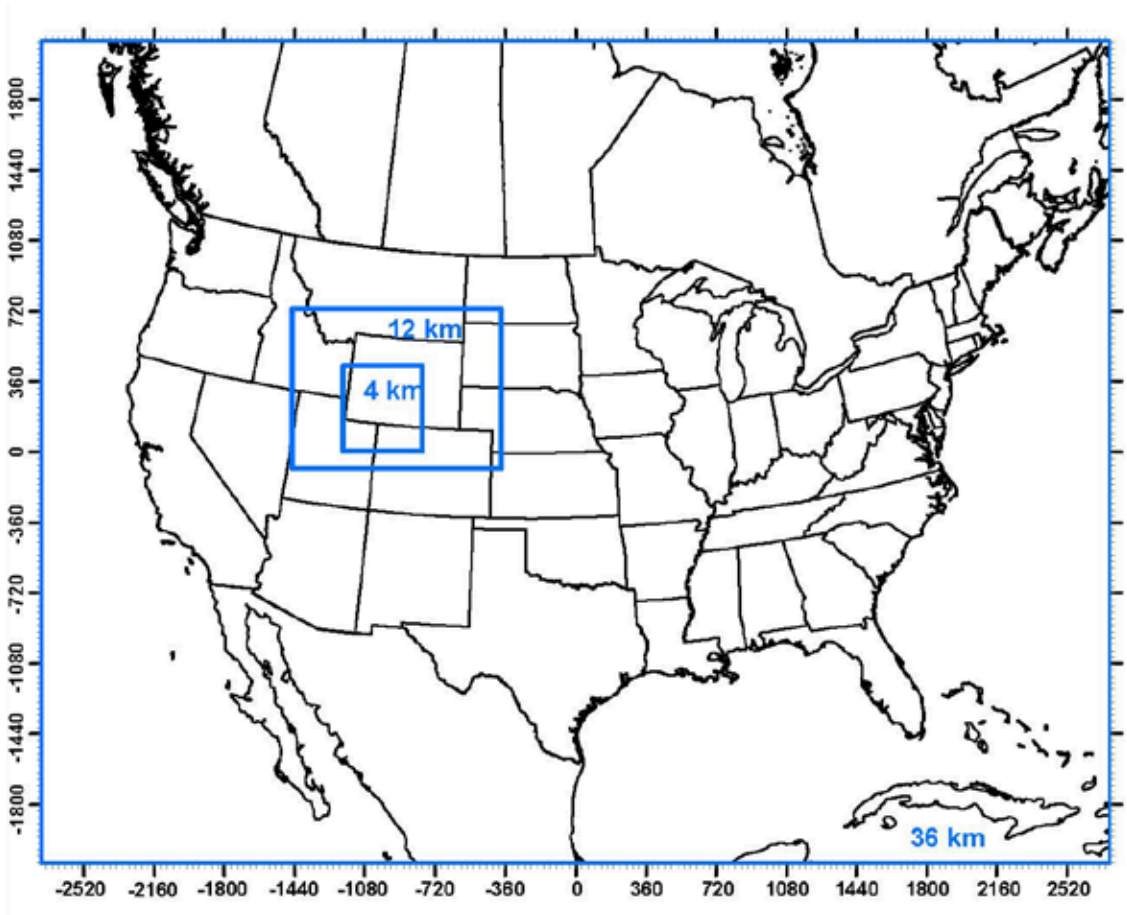


Figure A1-1. 36 km, 12 km, and 4 km modeling domains.

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:

- **Operational Evaluation**: 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
- **Diagnostic Evaluation:** 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

[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.

CAMx base case model performance with the preliminary CAMx 2005 and 2006 base case model performance performed under the Hiawatha EIS study.

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.

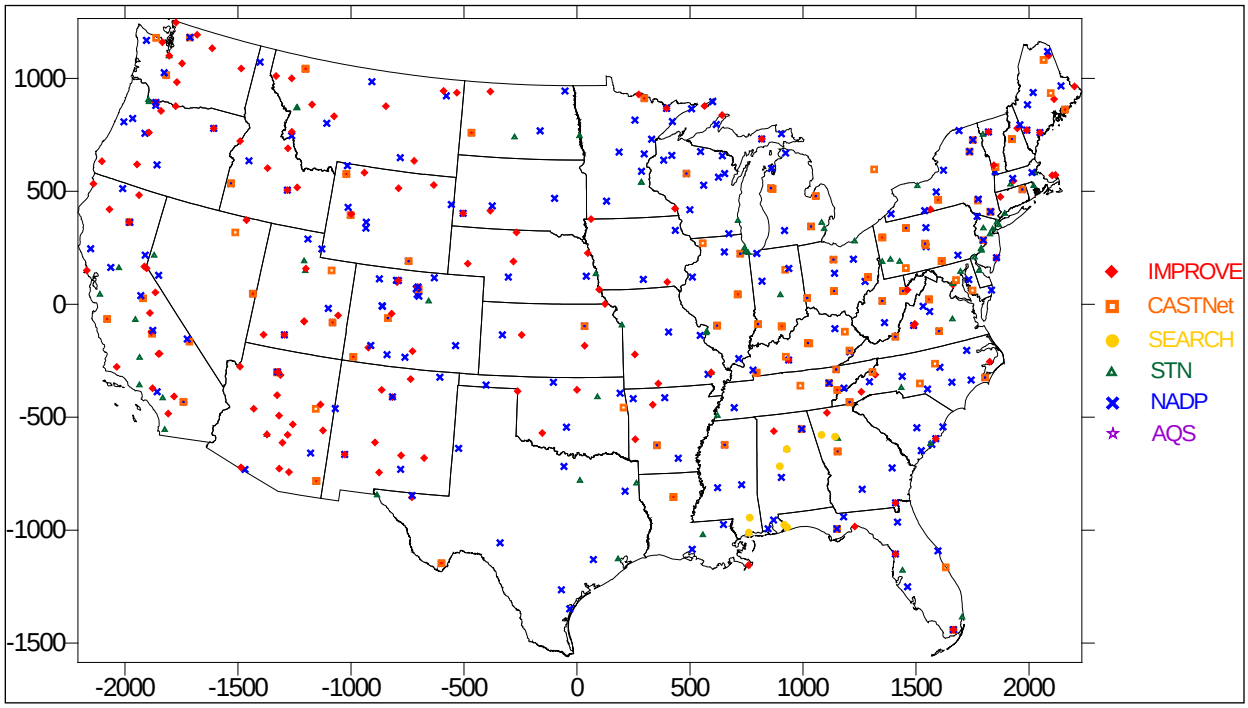


Figure A2-1. Locations of sites in each of the PM ambient monitoring networks and the 36 km modeling domain.

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

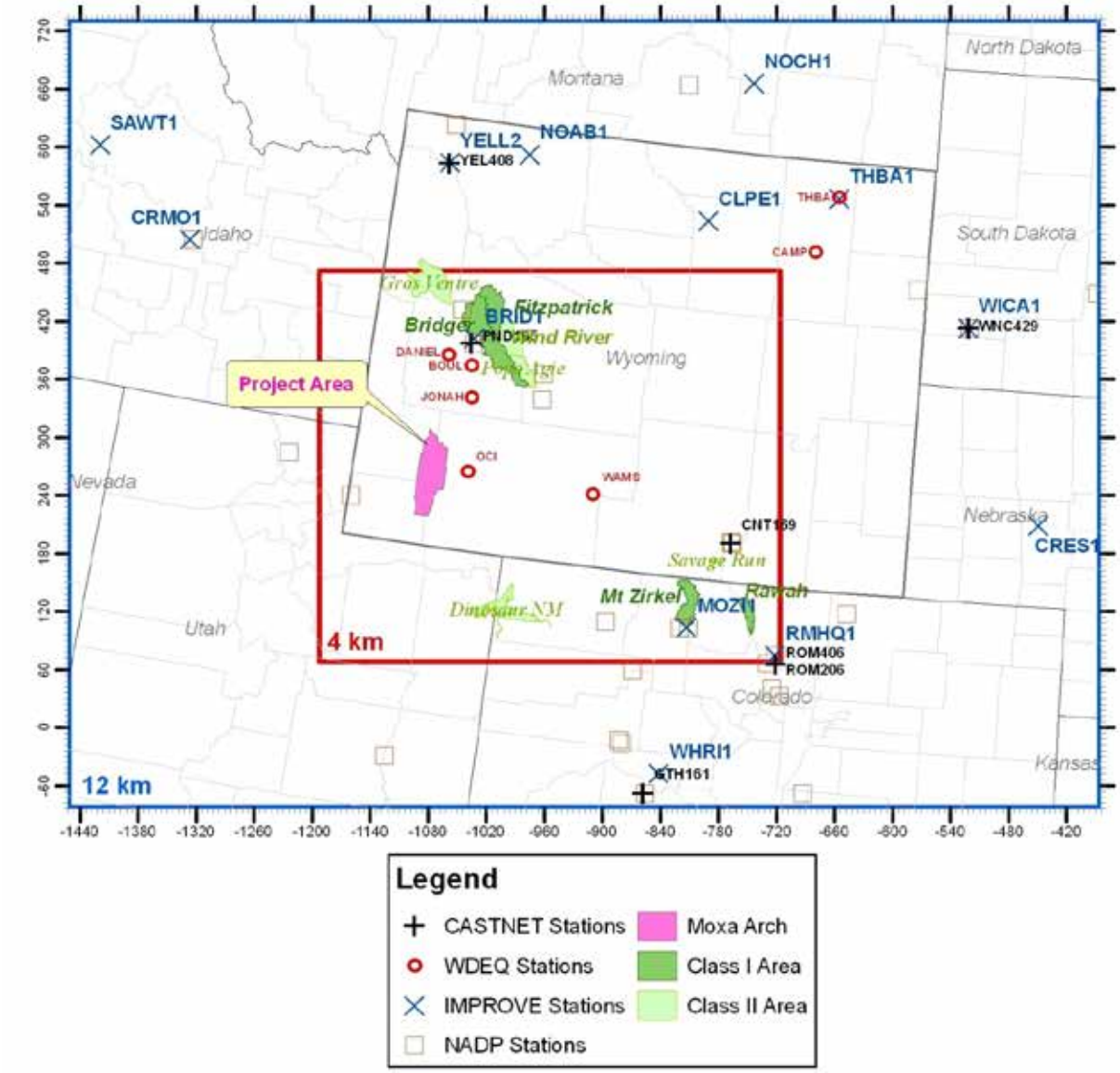


Figure A2-2. Locations of monitoring sites within the 12/4 km grid domain.

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.

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.

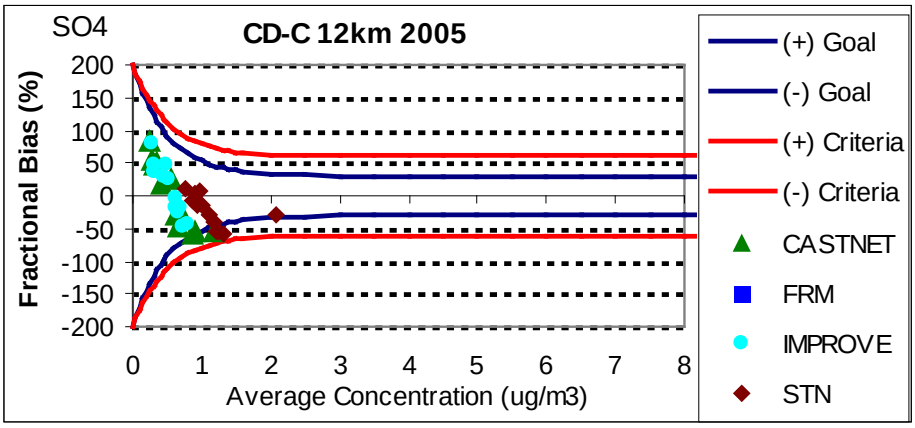
Fractional Bias	Fractional Error	Comment
≤±15%	≤35%	Goal for PM model performance based on ozone model performance, considered excellent performance
≤±30%	≤50%	Goal for PM model performance, considered good performance
≤±60%	≤75%	Criteria for PM model performance, considered average performance. Exceeding 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 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.



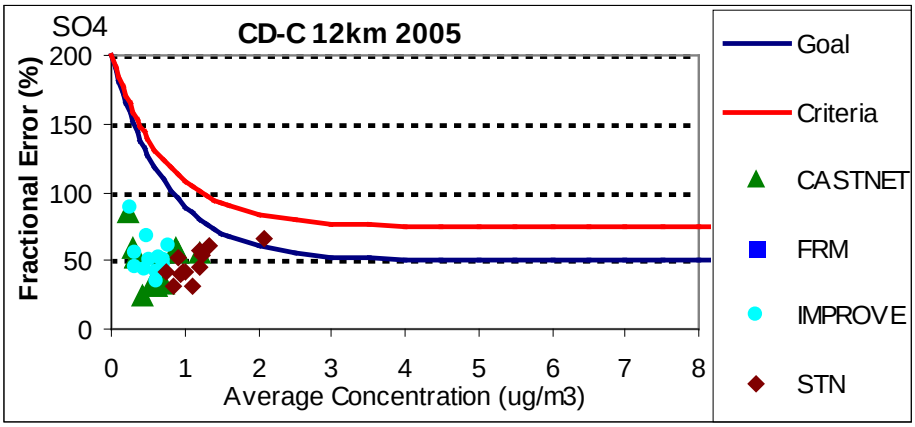


Figure A2-3.Example Bugle Plots used for evaluation of model PM performance. Shown are monthly fractional bias (top) and error (bottom) for sulfate (SO4) performance for the CAMx 2005 base case across CASTNet, IMPROVE and STN monitoring sites in 12 km modeling domain that are compared against the PM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

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

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 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.

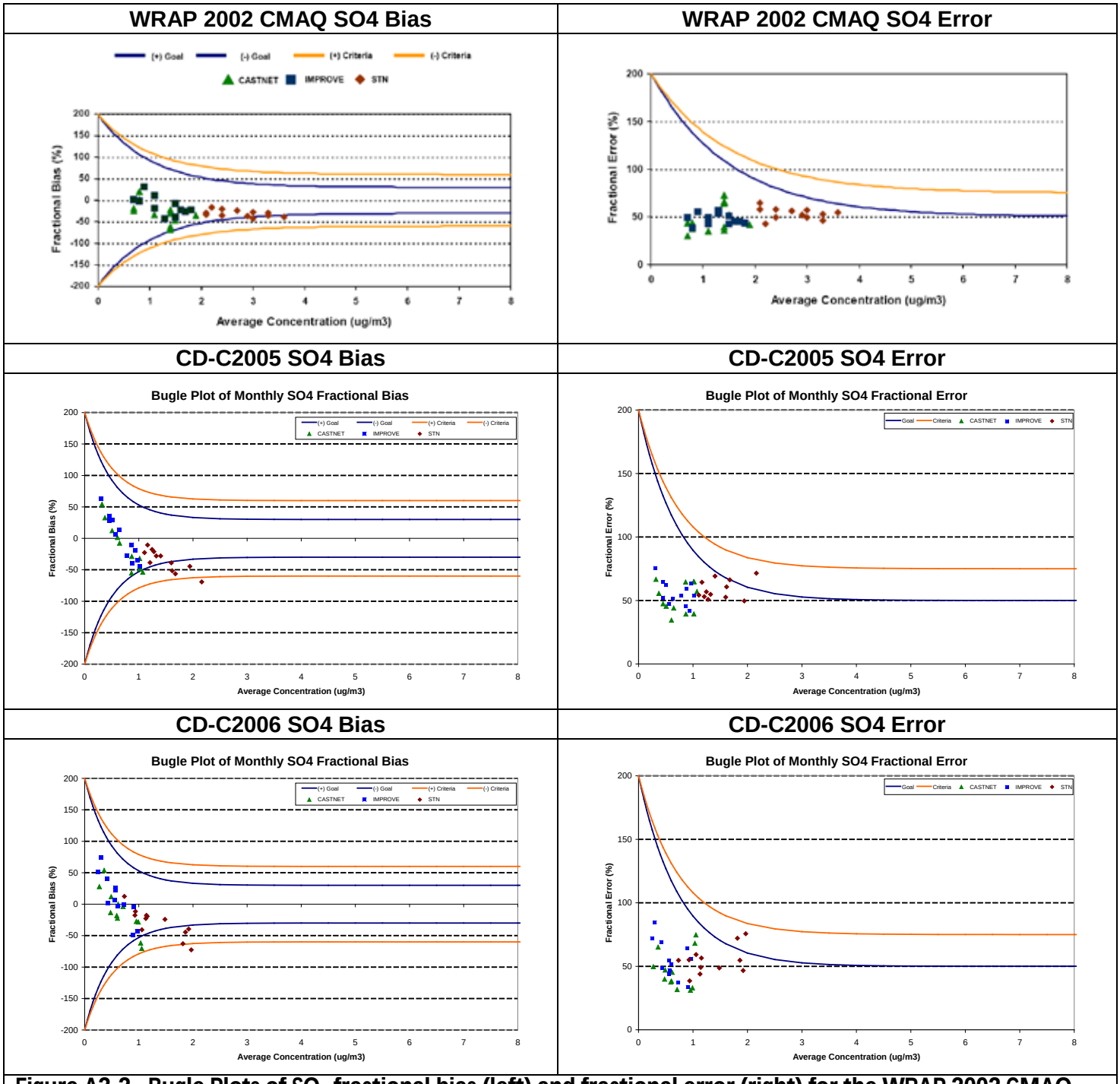


Figure A3-2. Bugle Plots of SO_4 fractional bias (left) and fractional error (right) for the WRAP 2002 CMAQ

(top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

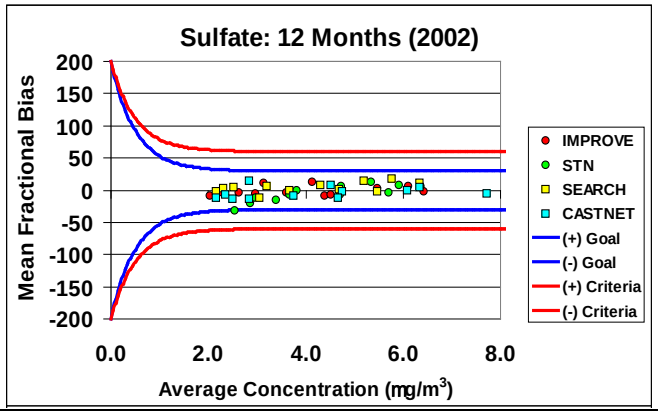
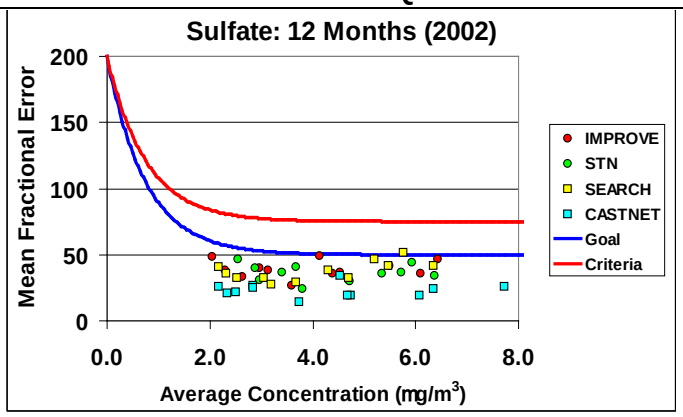
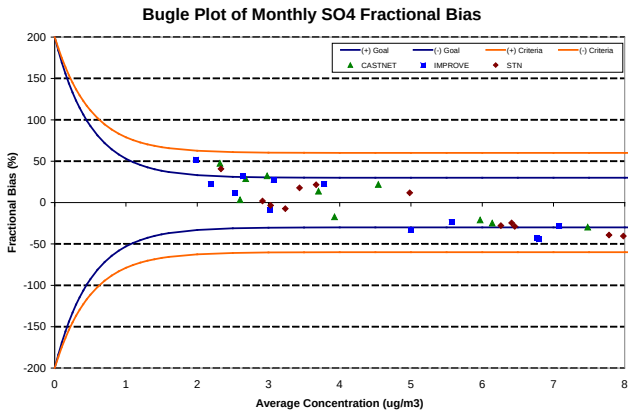
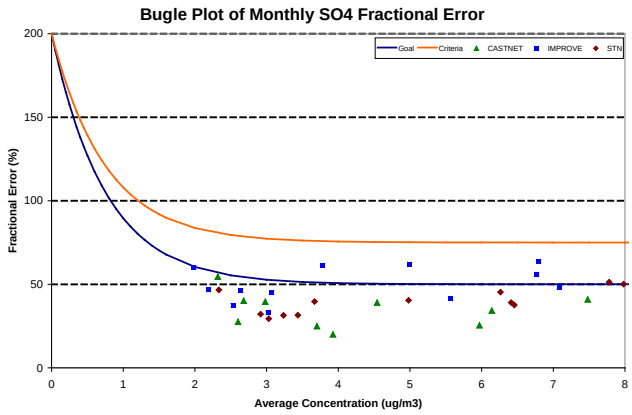
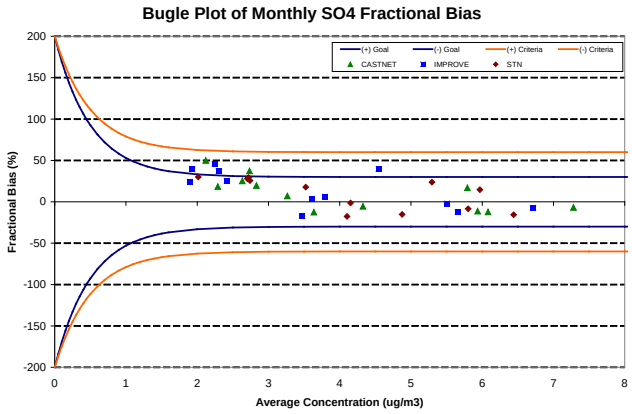
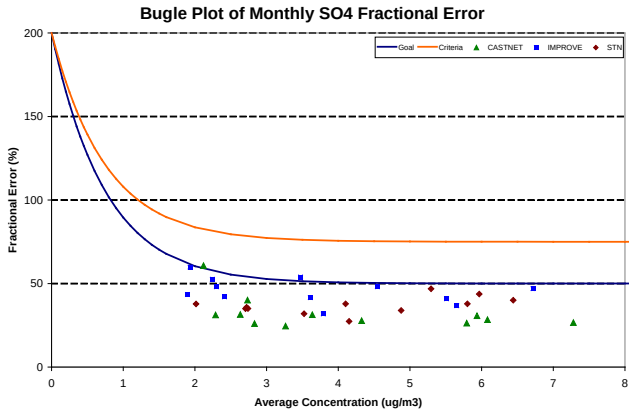
VISTAS 2002 CMAQ SO4 Bias	VISTASA 2002 CMAQ SO4 Error
	
CD-C2005 SO4 Bias	**CD-C2005 SO4 Error**
	
CD-C2006 SO4 Bias	**CD-C2006 SO4 Error**
	

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.

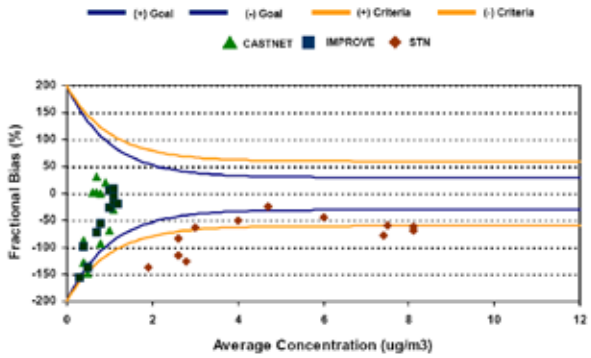
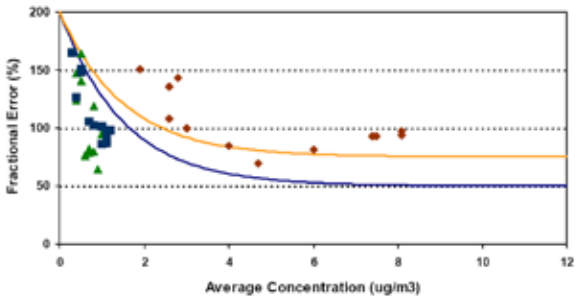
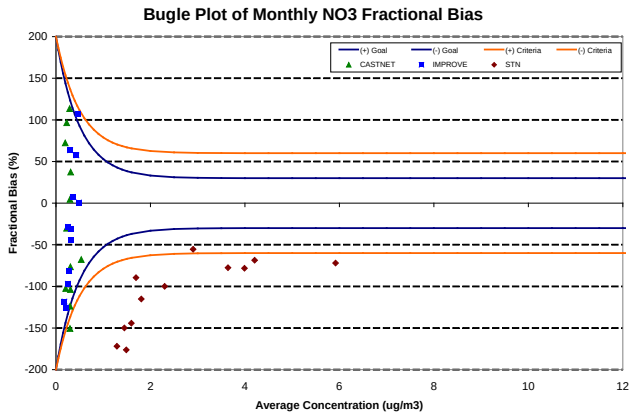
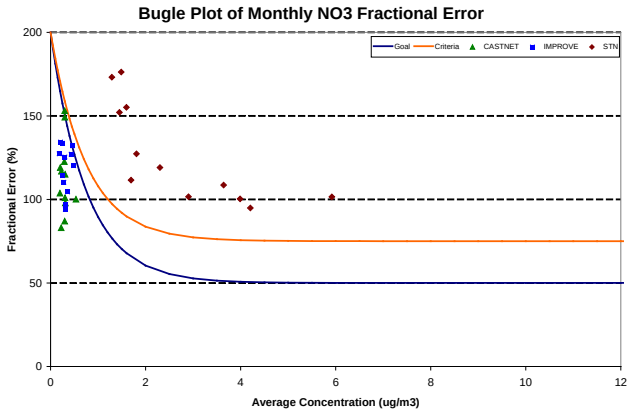
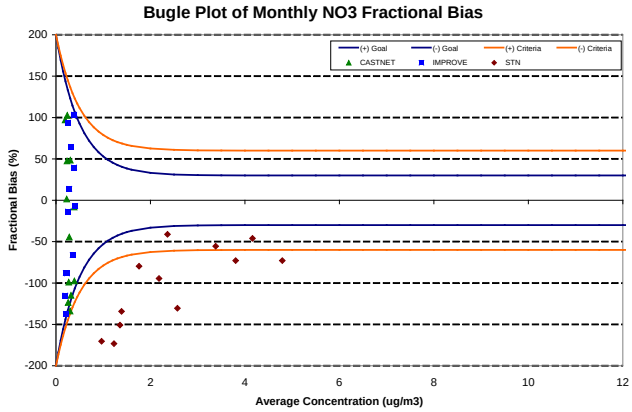
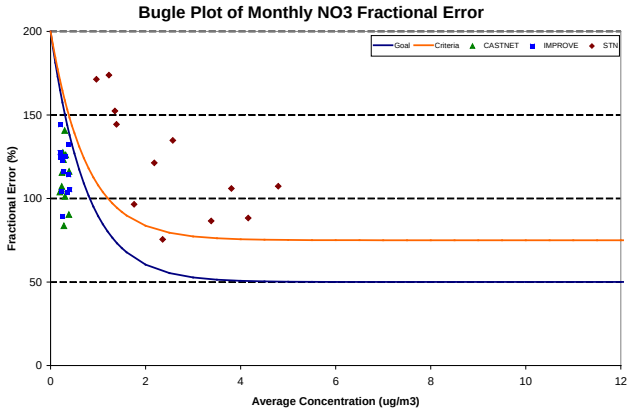
WRAP 2002 CMAQ NO3 Bias	WRAP 2002 CMAQ NO3 Error
	
CD-C 2005 NO3 Bias	**CD-C 2005 NO3 Error**
	
CD-C 2006 NO3 Bias	**CD-C 2006 NO3 Error**
	

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.

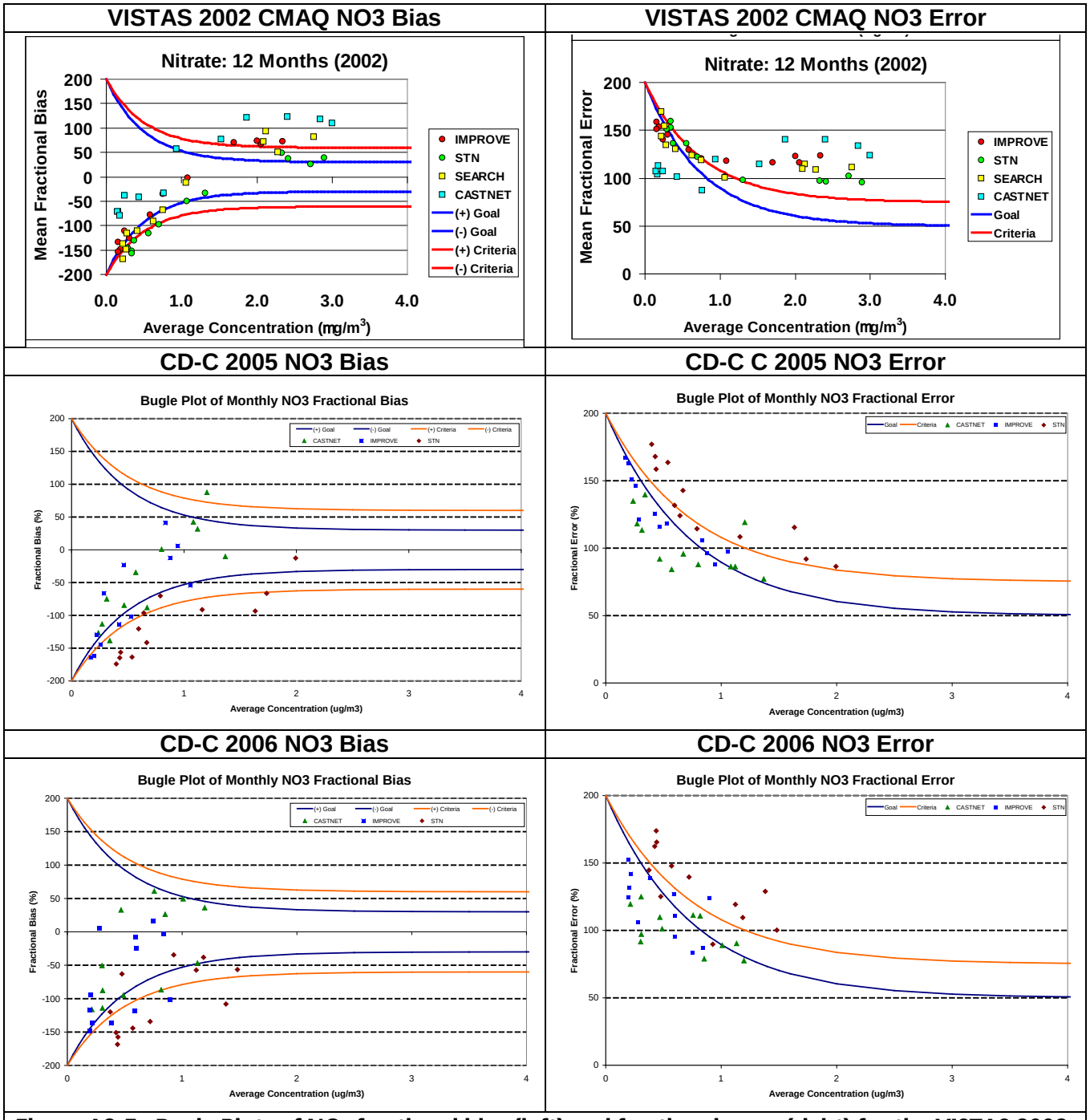


Figure A3-5. Bugle Plots of NO_3 fractional bias (left) and fractional error (right) for the VISTAS 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

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.

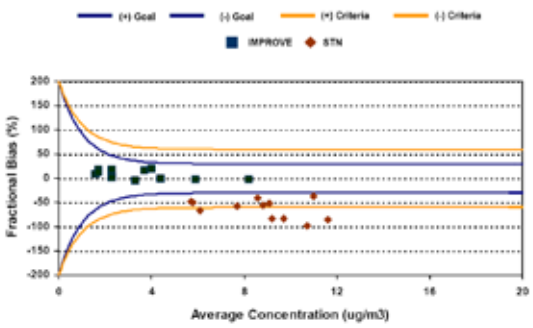
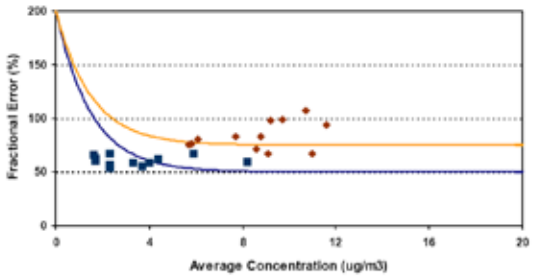
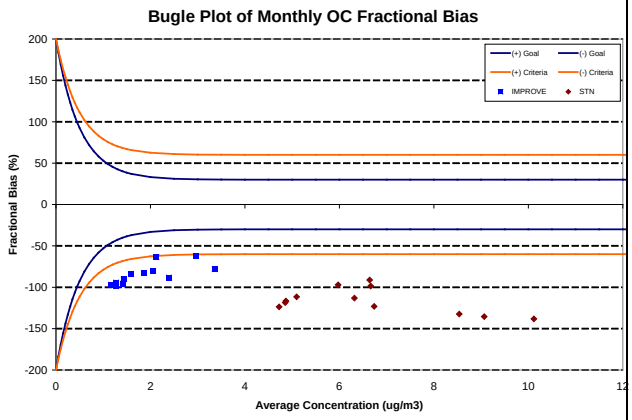
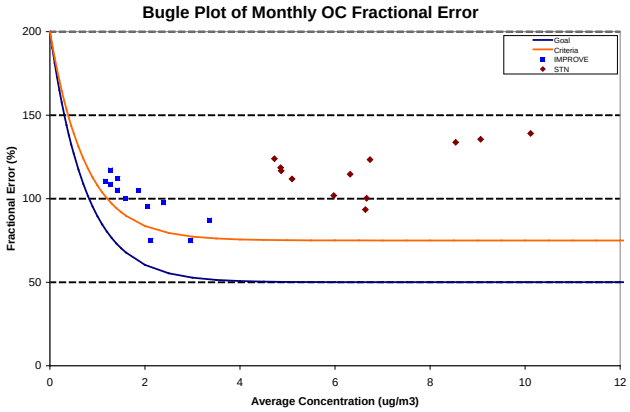
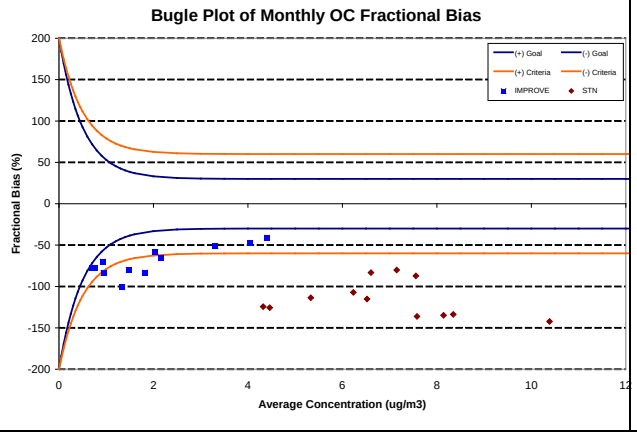
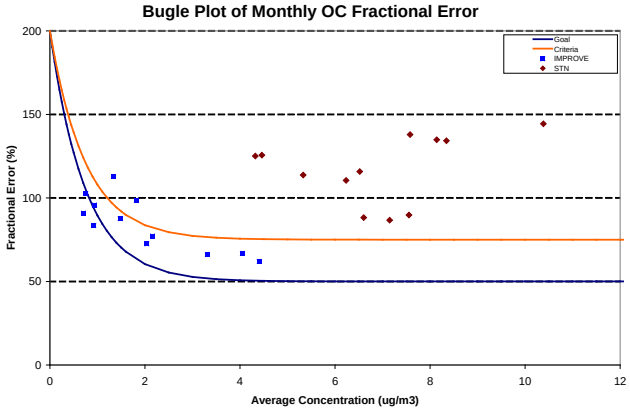
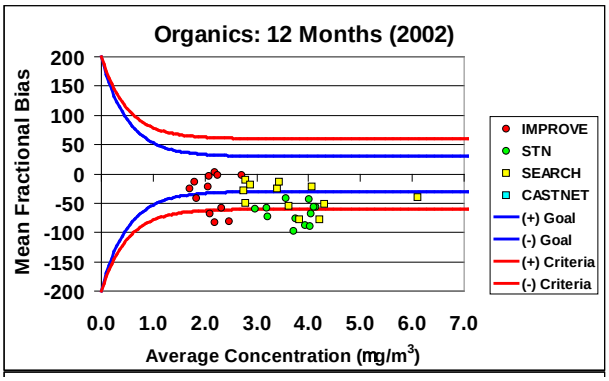
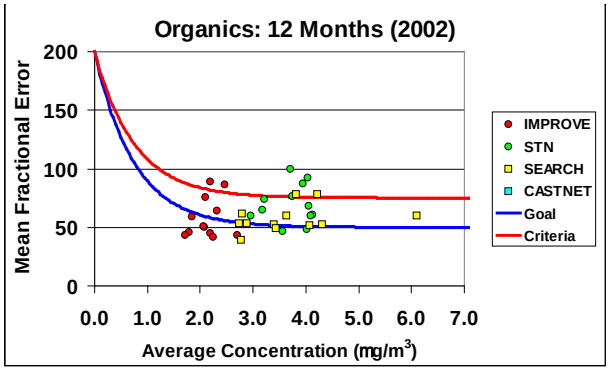
WRAP 2002 CMAQ OCM Bias	WRAP 2002 CMAQ OCM Error
	
CD-C 2005 OCM Bias	**CD-C 2005 OCM Error**
	
CD-C 2006 OCM Bias	**CD-C 2006 OCM Error**
	

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.

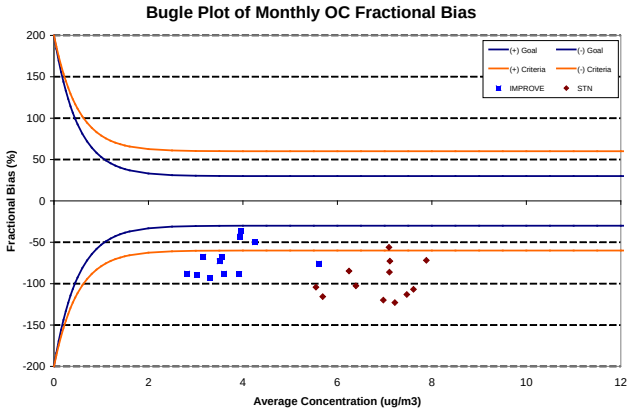
VISTAS 2002 CMAQ OCM Bias



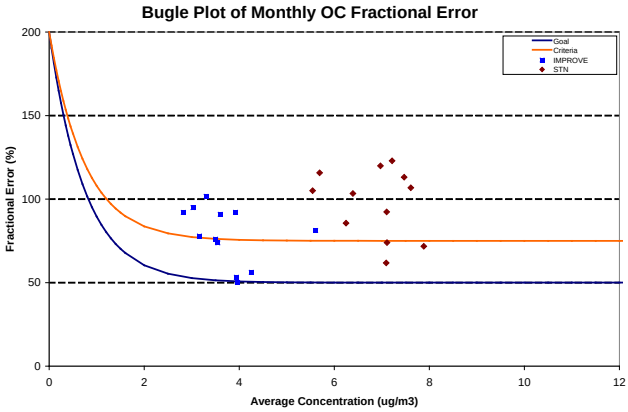
VISTAS 2002 CMAQ OCM Error



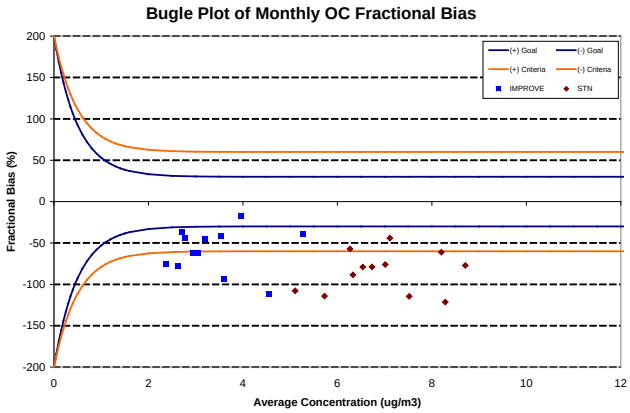
CD-C 2005 OCM Bias



CD-C 2005 OCM Error



CD-C 2006 OCM Bias



CD-C 2006 OCM Error

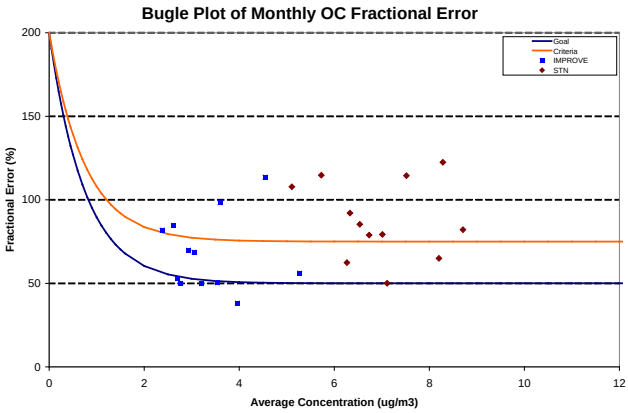
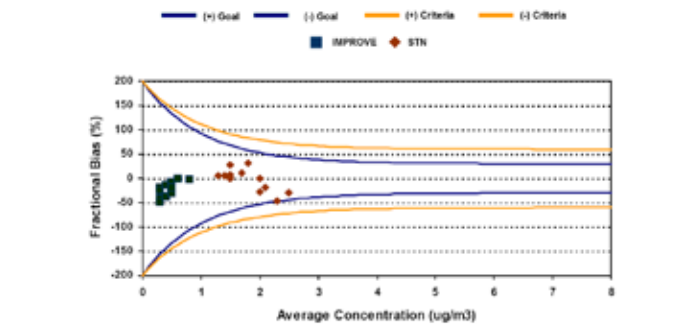


Figure A3-7. Bugle Plots of OCM fractional bias (left) and fractional error (right) for the VISTAS 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the VISTA region.

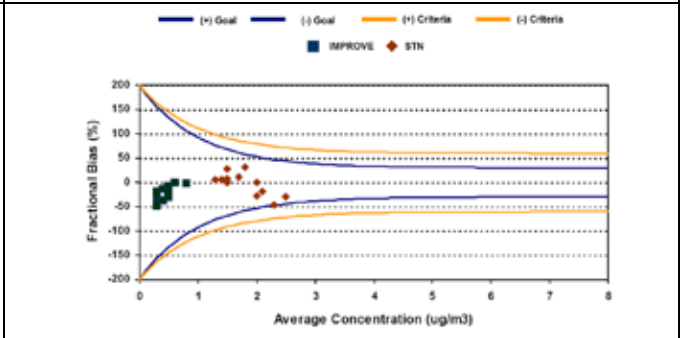
A3.4 ELEMENTAL CARBON (EC) PERFORMANCE

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).

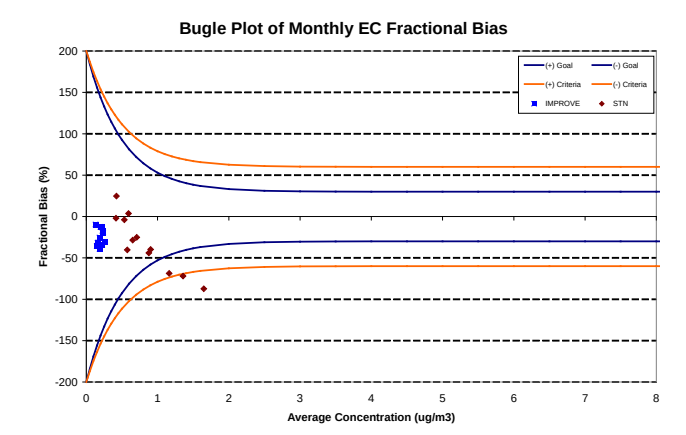
WRAP 2002 CMAQ EC Bias



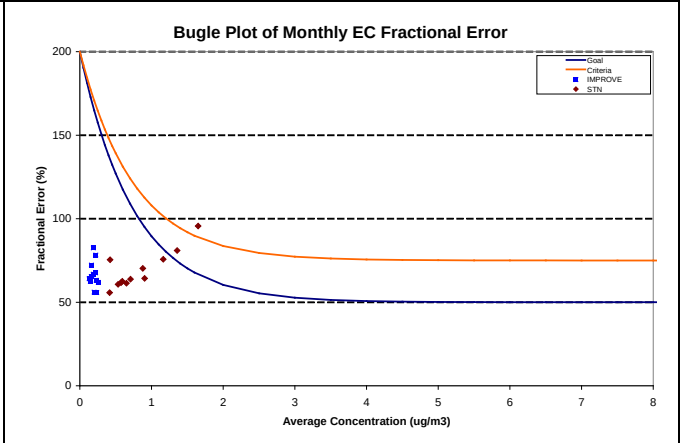
WRAP 2002 CMAQ EC Error



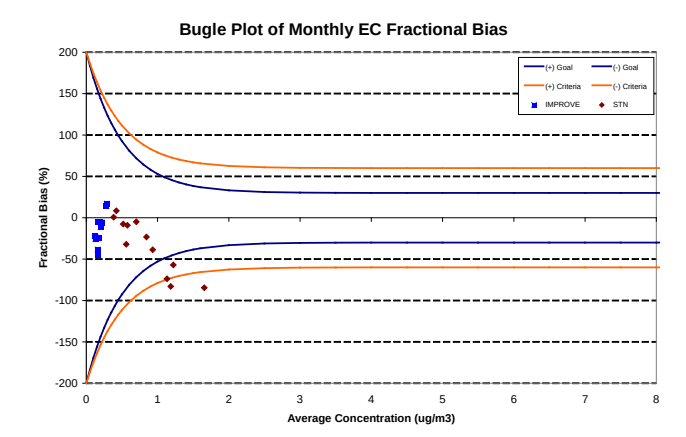
CD-C 2005 EC Bias



CD-C 2005 EC Error



CD-C 2006 EC Bias



CD-C 2006 EC Error

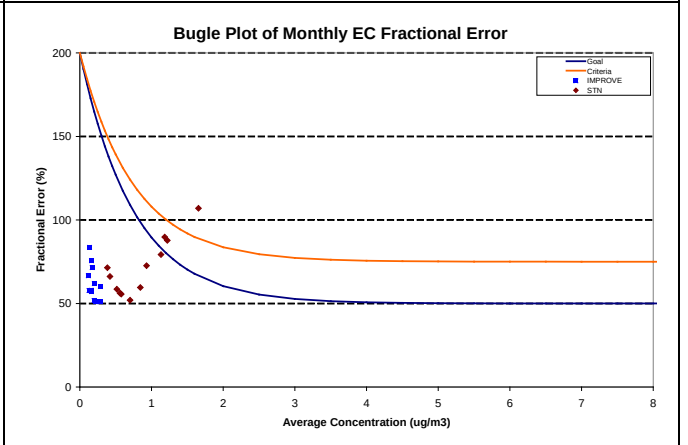
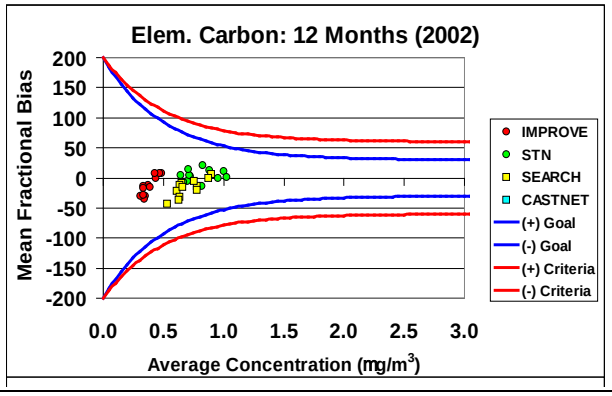
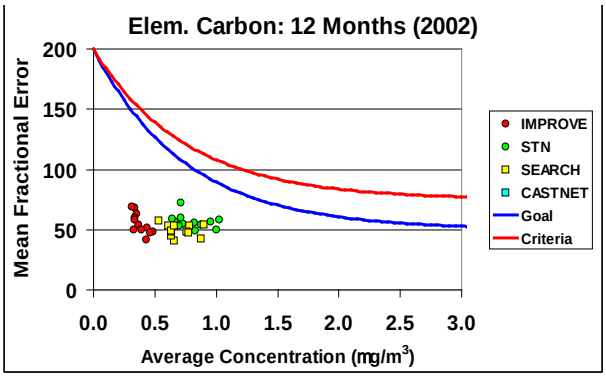


Figure A3-8. Bugle Plots of EC fractional bias (left) and fractional error (right) for the WRAP 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the WRAP region.

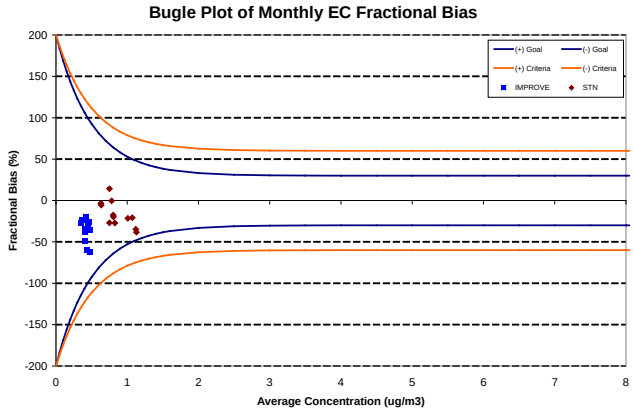
VISTAS 2002 CMAQ EC Bias



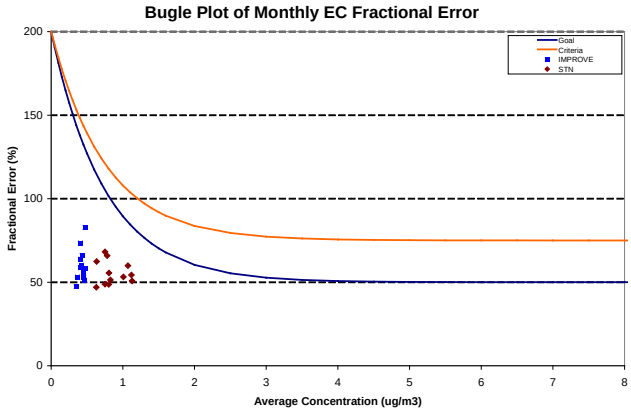
VISTAS 2002 CMAQ EC Error



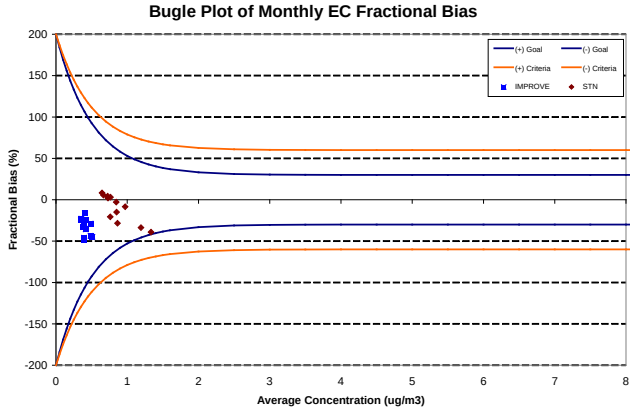
CD-C 2005 EC Bias



CD-C 2005 EC Error



CD-C 2006 EC Bias



CD-C 2006 EC Error

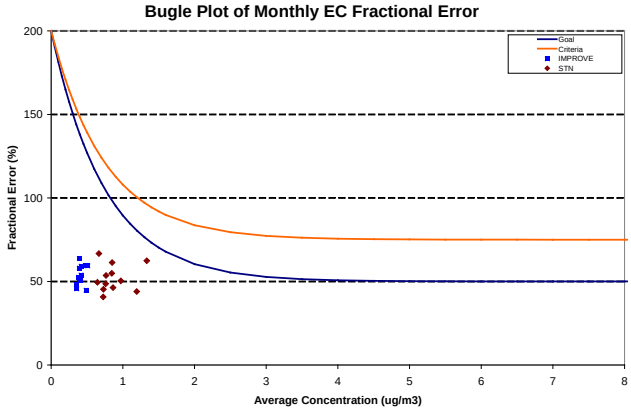


Figure A3-9. Bugle Plots of EC fractional bias (left) and fractional error (right) for the VISTAS 2002 CMAQ (top), CD-C 2005 CAMx (middle) and CD-C 2006 CAMx (bottom) 36 km base case simulations for monitoring sites within the VISTAS region.

A3.5 COARSE MASS (CM OR $PM_{2.5-10}$) 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 µg/m^3 in the winter to almost 7 µg/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.

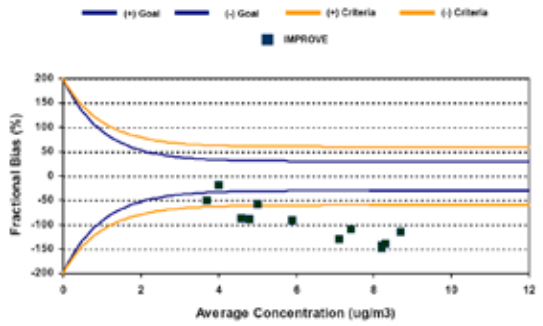
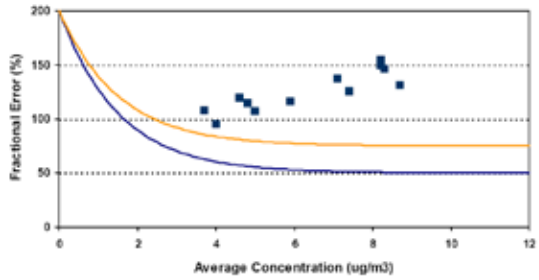
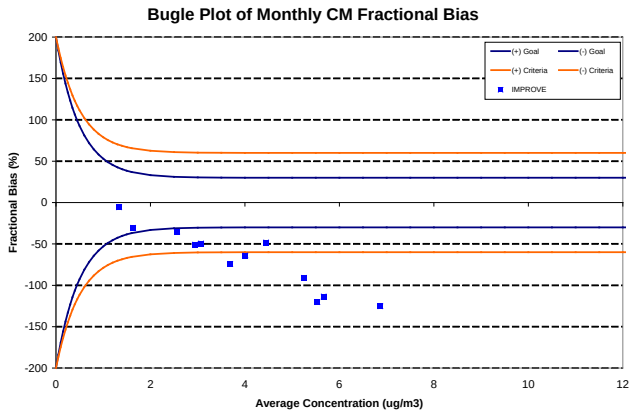
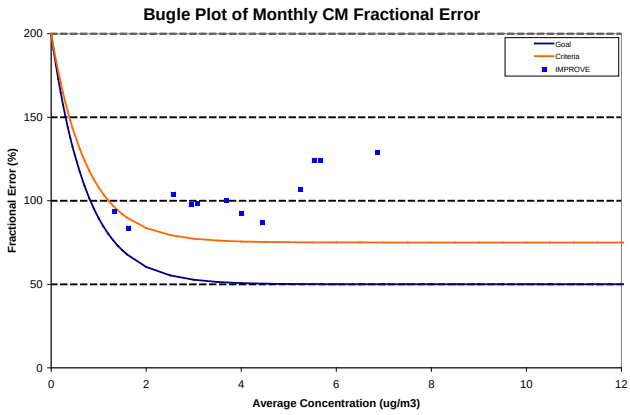
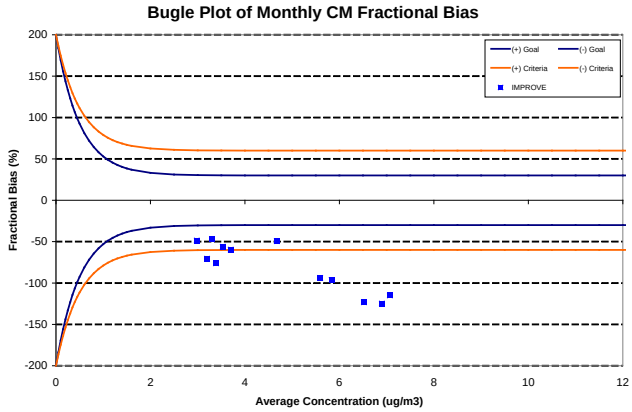
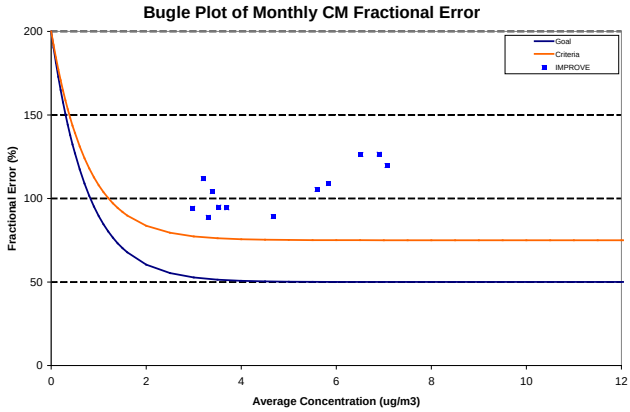
WRAP 2002 CMAQ CM Bias	WRAP 2002 CMAQ CM Error
	
CD-C 2005 CM Bias	**CD-C 2005 CM Error**
	
CD-C 2006 CM Bias	**CD-C 2006 CM Error**
	

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

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

(EPA, 1991). However, this guidance was developed almost two decades ago for urban ozone 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 Sublette County. 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

Observation
CD-C
Hiawatha

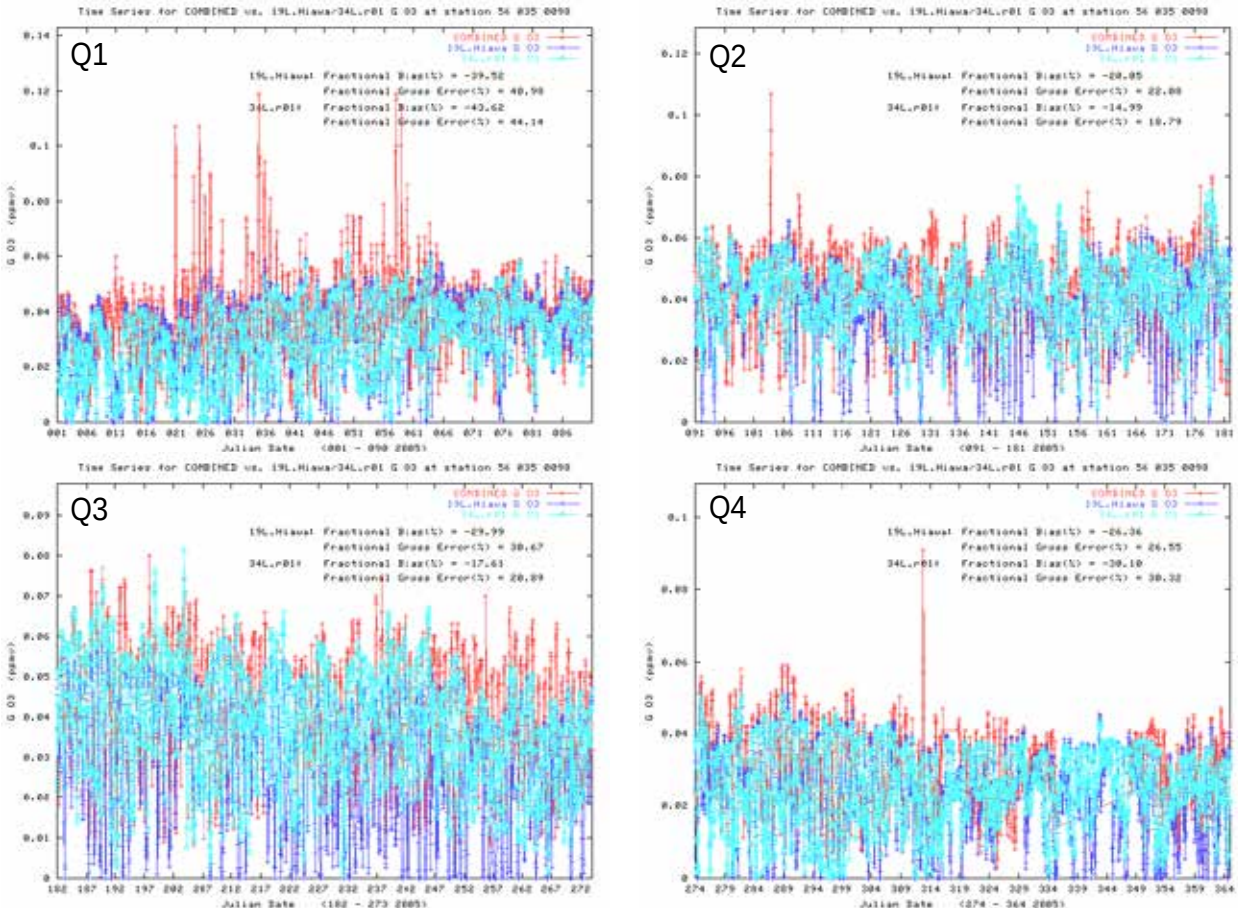


Figure A4-1a. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Jonah monitoring sites. Ozone units are ppm and statistics are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

Boulder

Observation
CD-C
Hiawatha

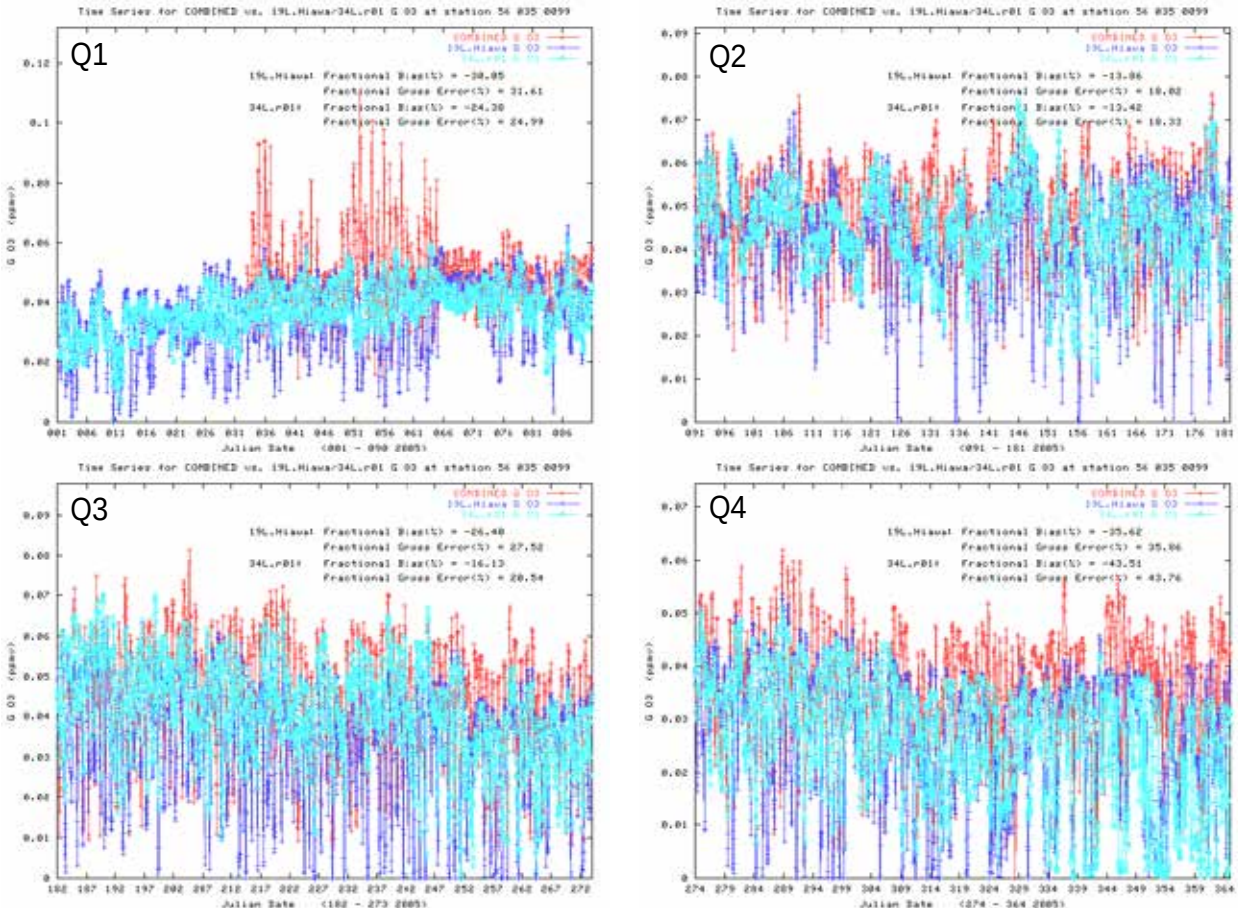


Figure A4-1b. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Boulder monitoring sites. Ozone units are ppm and statistics are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

Daniel

Observation
CD-C
Hiawatha

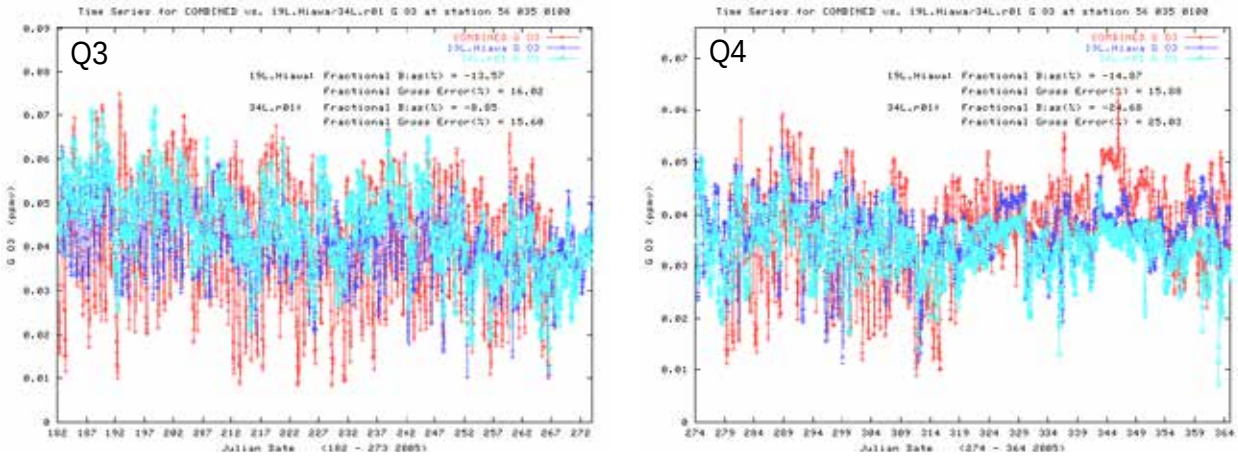


Figure A4-1c. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 3 (left column), and Quarter 4 (right column) at the Daniel monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed ozone cutoff concentration.

Pinedale

Observation
CD-C
Hiawatha

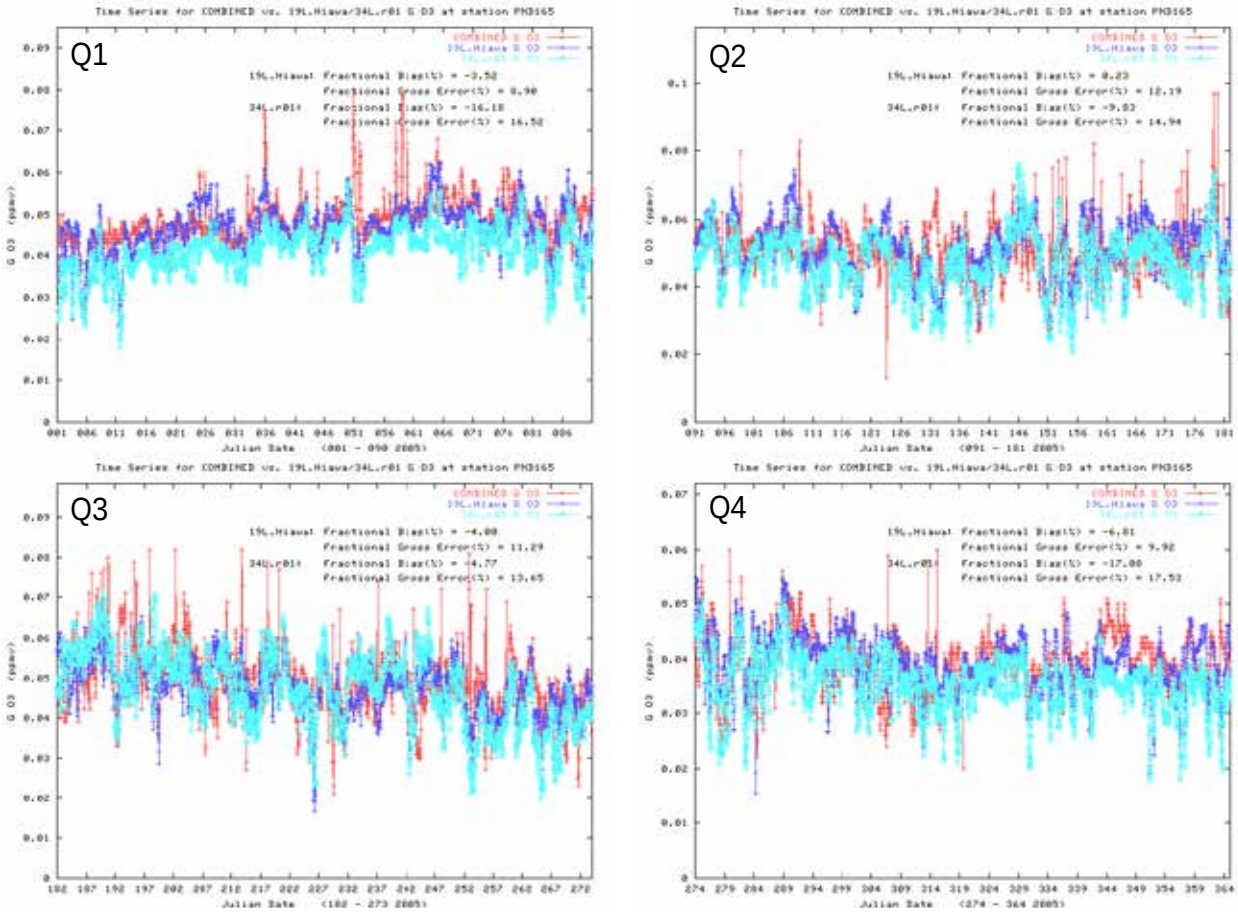


Figure A4-1d. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Pinedale monitoring sites. Ozone units are ppm and statistics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

Centennial

Observation
CD-C
Hiawatha

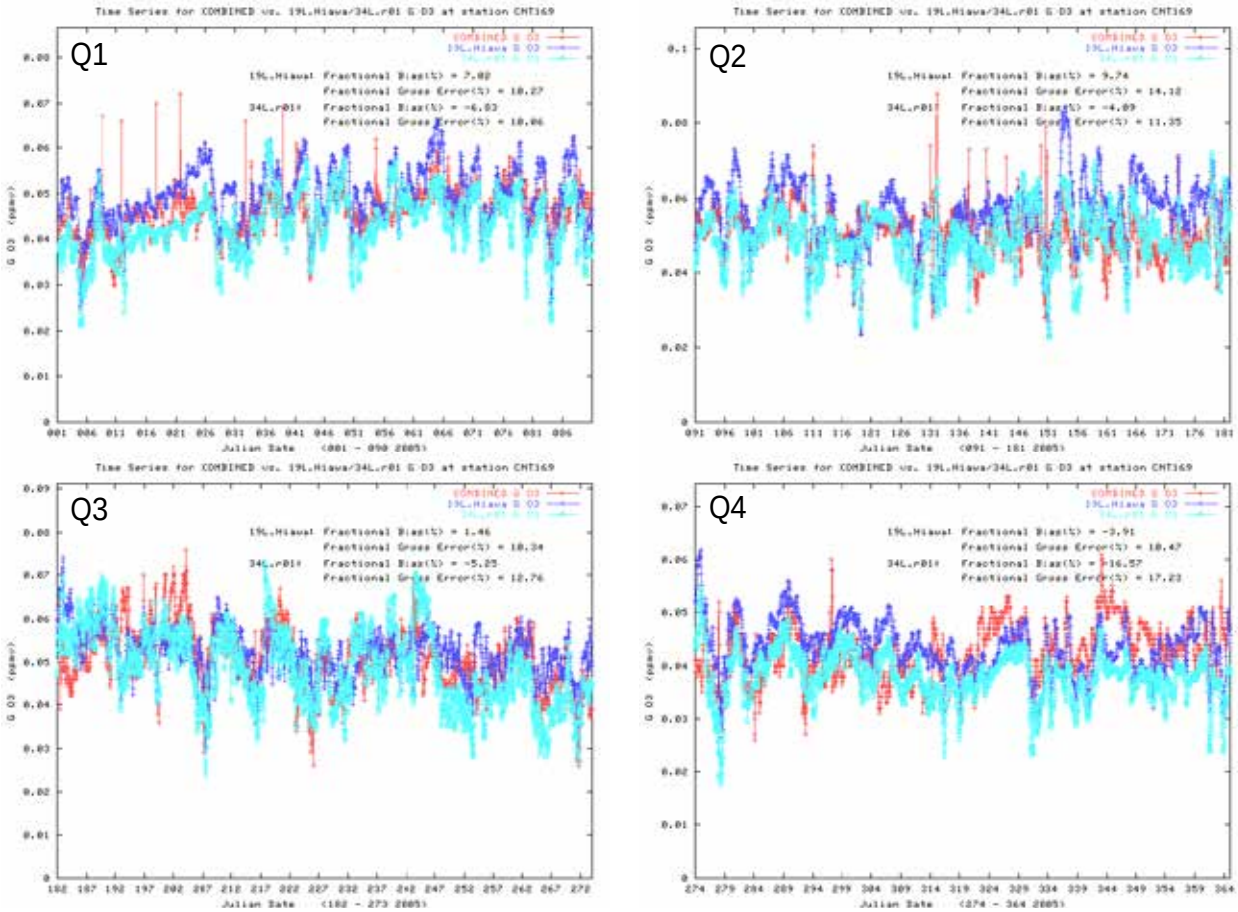


Figure A4-1e. Time series of predicted and observed hourly ozone concentrations for 2005 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Centennial monitoring sites. Ozone units are ppm and statistics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

Jonah

Observation
CD-C
Hiawatha

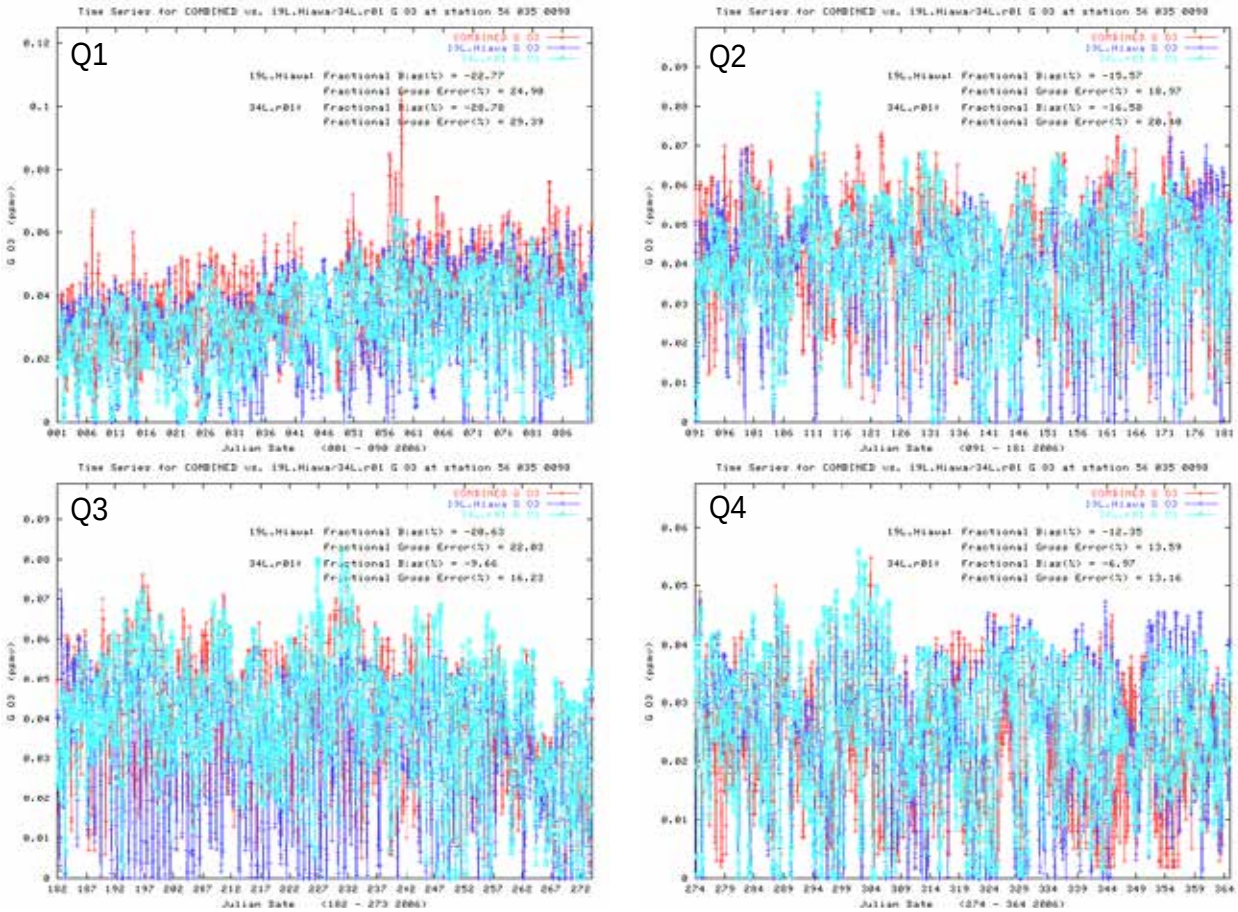


Figure A4-2a. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Jonah monitoring sites. Ozone units are ppm and statistics are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

Boulder

Observation
CD-C
Hiawatha

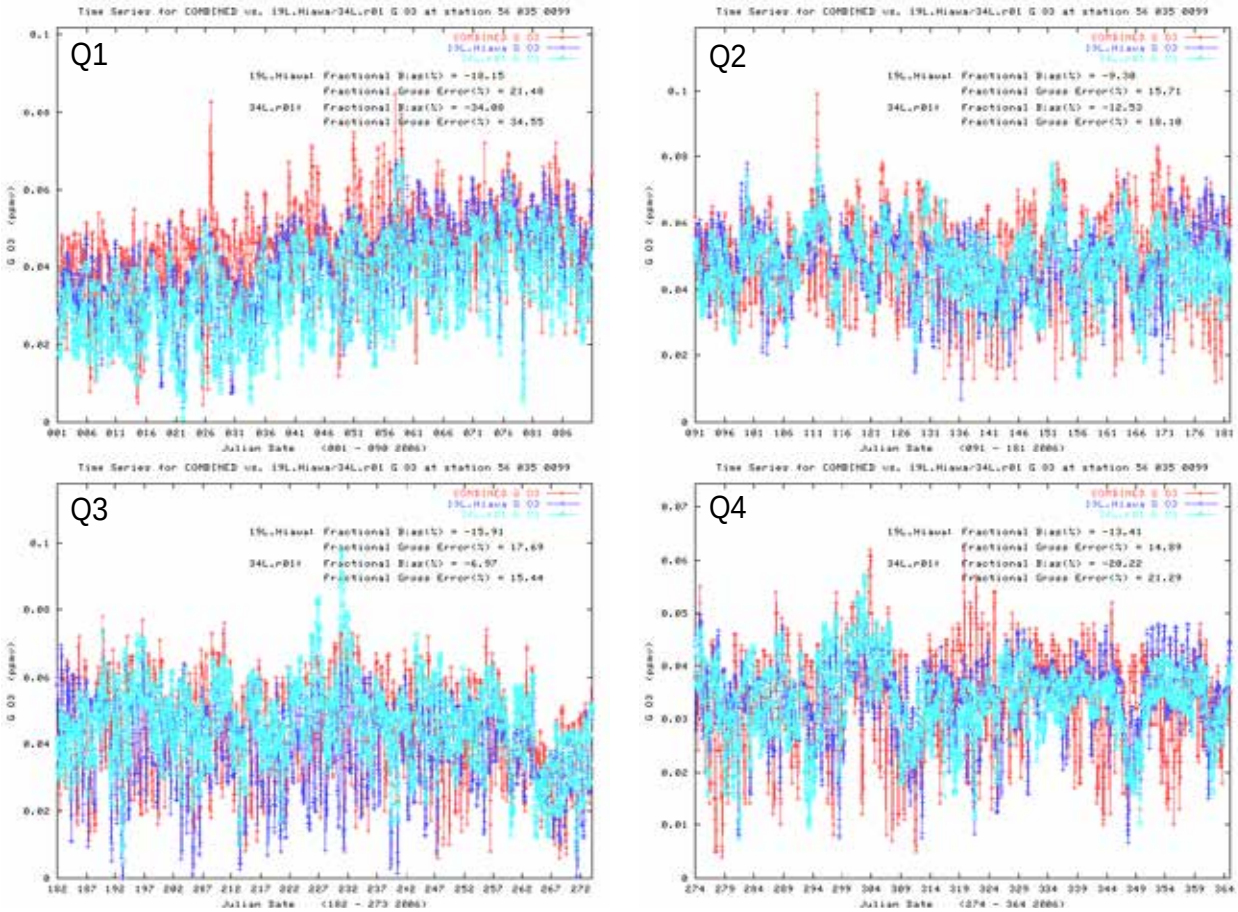


Figure A4-2b. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Boulder monitoring sites. Ozone units are ppm and statistics are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

Daniel

Observation
CD-C
Hiawatha

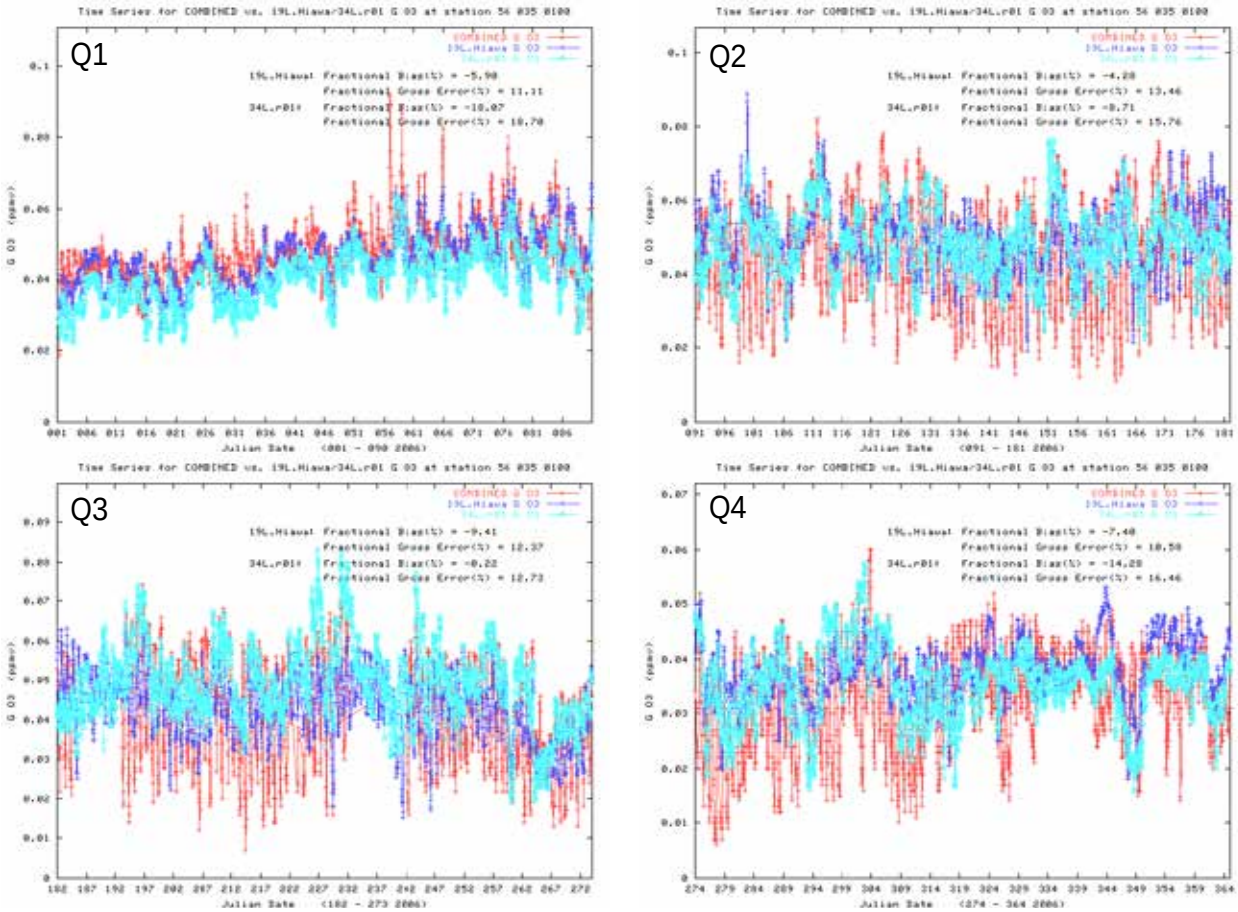


Figure A4-2c. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Daniel monitoring sites. Ozone units are ppm and statistics are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

Pinedale

Observation
CD-C
Hiawatha

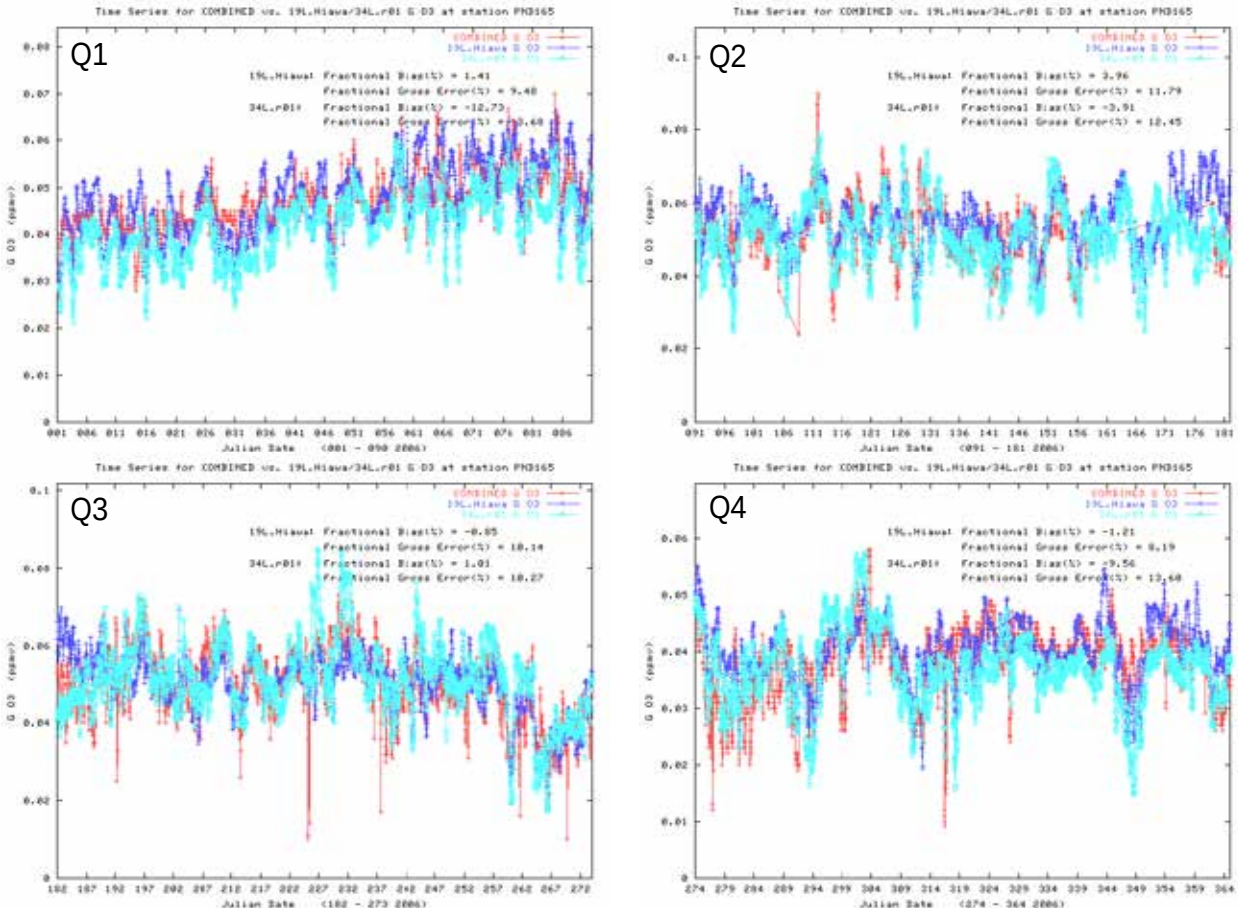


Figure A4-2d. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Pinedale monitoring sites. Ozone units are ppm and statistics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

Centennial

Observation
CD-C
Hiawatha

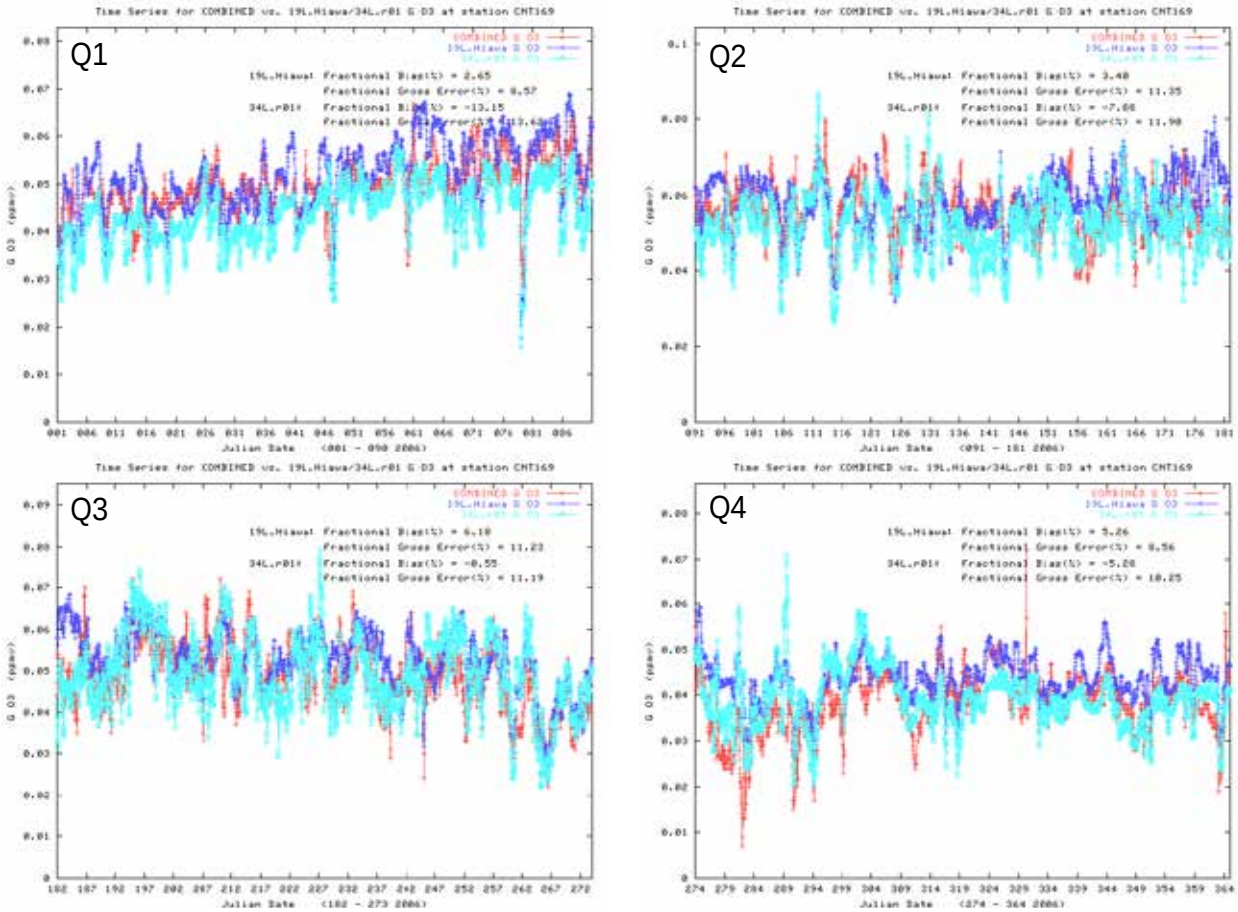


Figure A4-2e. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Centennial monitoring sites. Ozone units are ppm and statistics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

Wamsutter

Observation
CD-C
Hiawatha

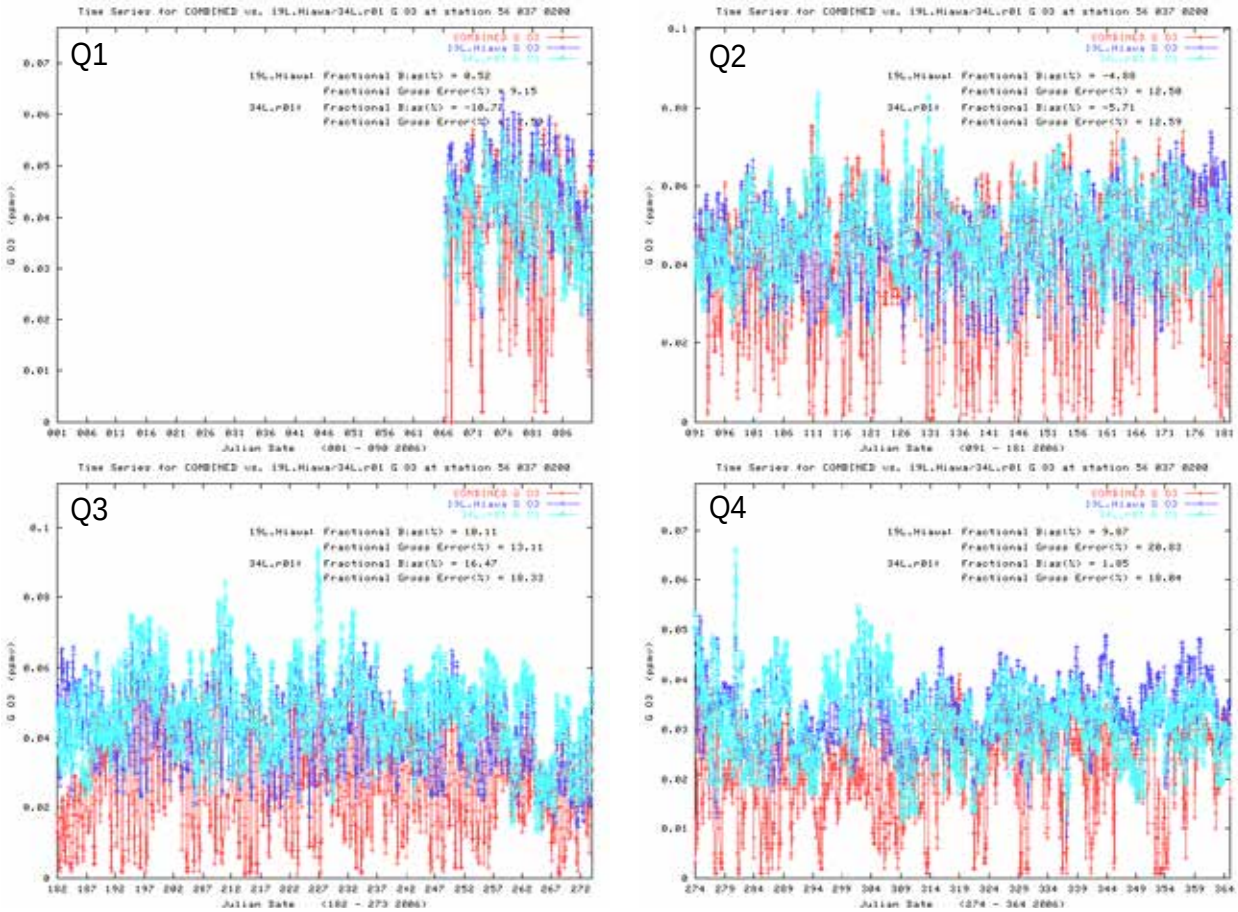


Figure A4-2f. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 1 (top row left column), Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the Wamsutter monitoring sites. Ozone units are ppm and statistics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

OCI

Observation
CD-C
Hiawatha

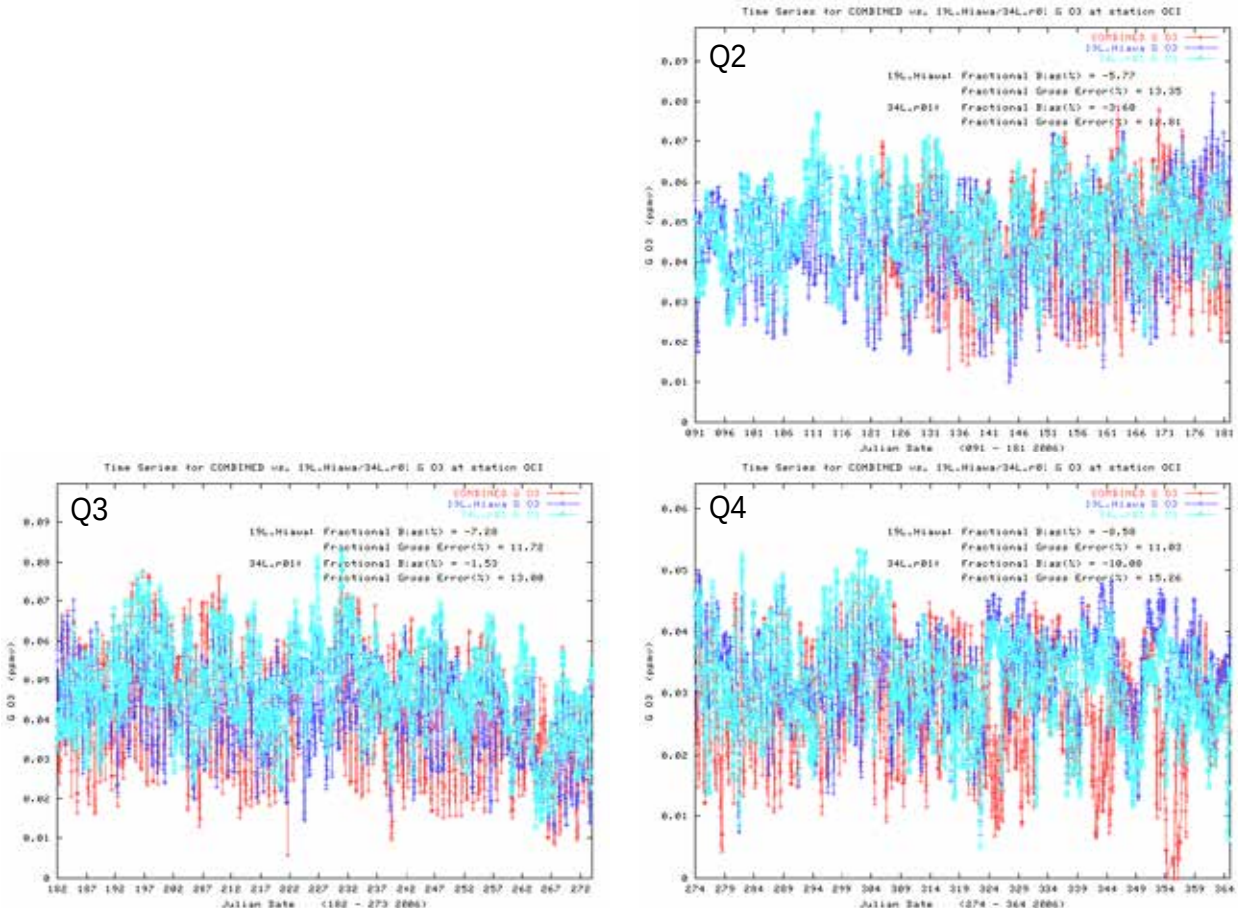


Figure A4-2g. Time series of predicted and observed hourly ozone concentrations for 2006 Quarter 2 (top row right column), Quarter 3 (bottom row left column), and Quarter 4 (bottom row right column) at the OCI monitoring sites. Ozone units are ppm and statistics are calculated using a 40 ppb observed 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	2005 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	2005 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 Month	2005 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
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 Month	2005 Day	Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
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		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
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		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
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		Daily Maximum Observed	Daily Maximum Predicted Hiawatha	Daily Maximum Predicted CD-C
	Month	Day			
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	2006 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.

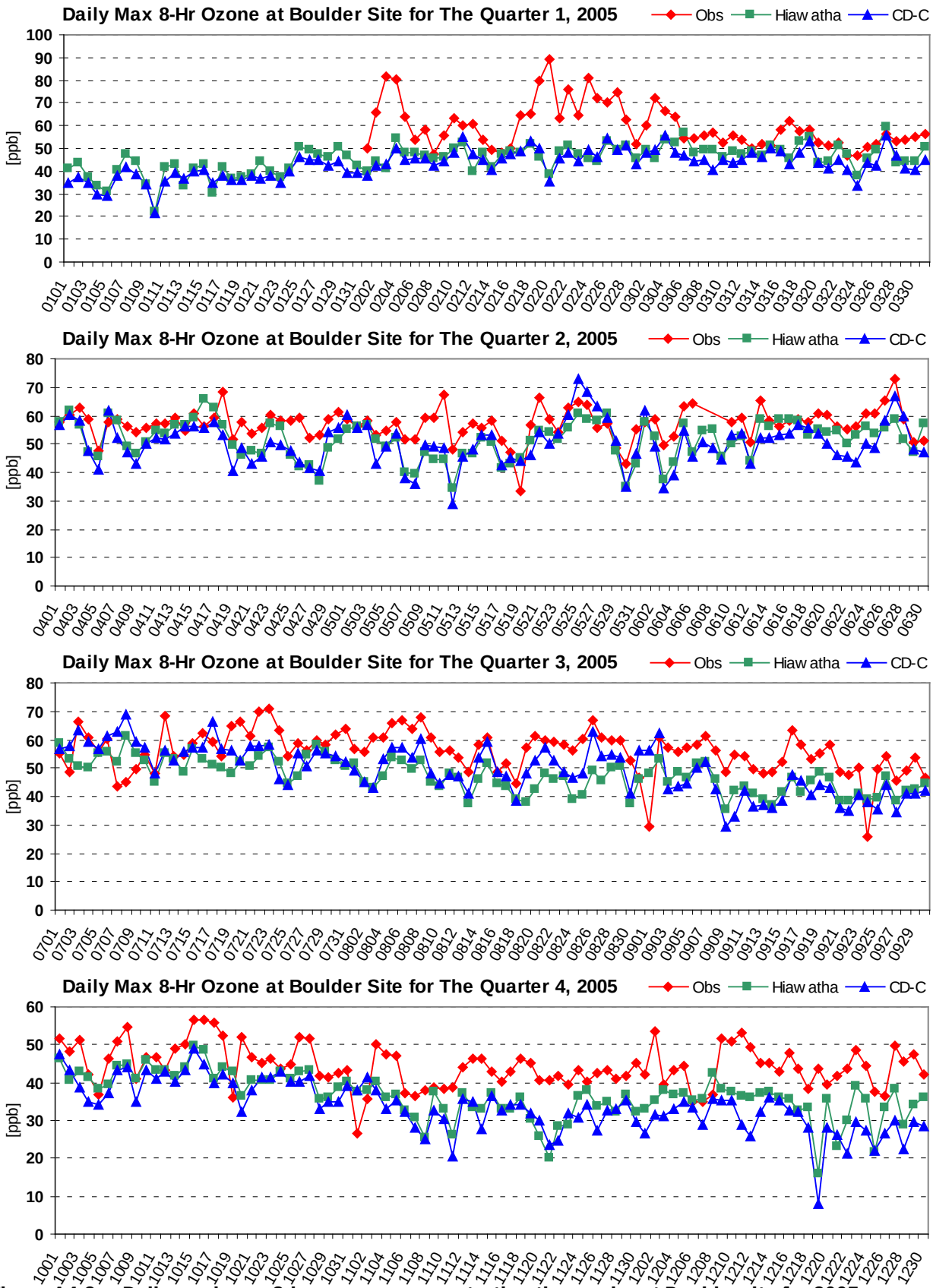


Figure A4-3a. Daily maximum 8-hour ozone concentration time series at Boulder site for 2005.

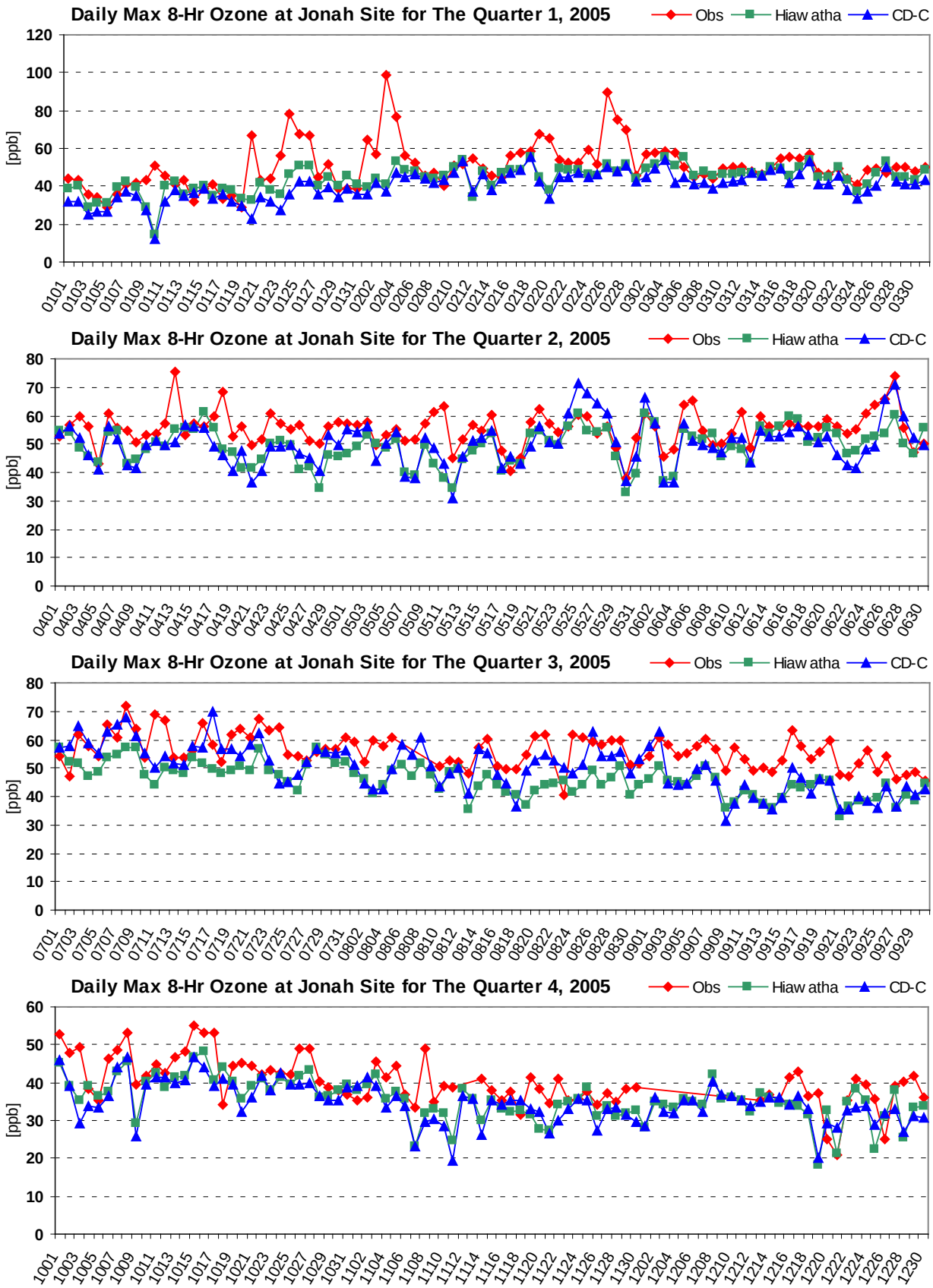


Figure A4-3b. Daily maximum 8-hour ozone concentration time series at Jonah site for 2005.

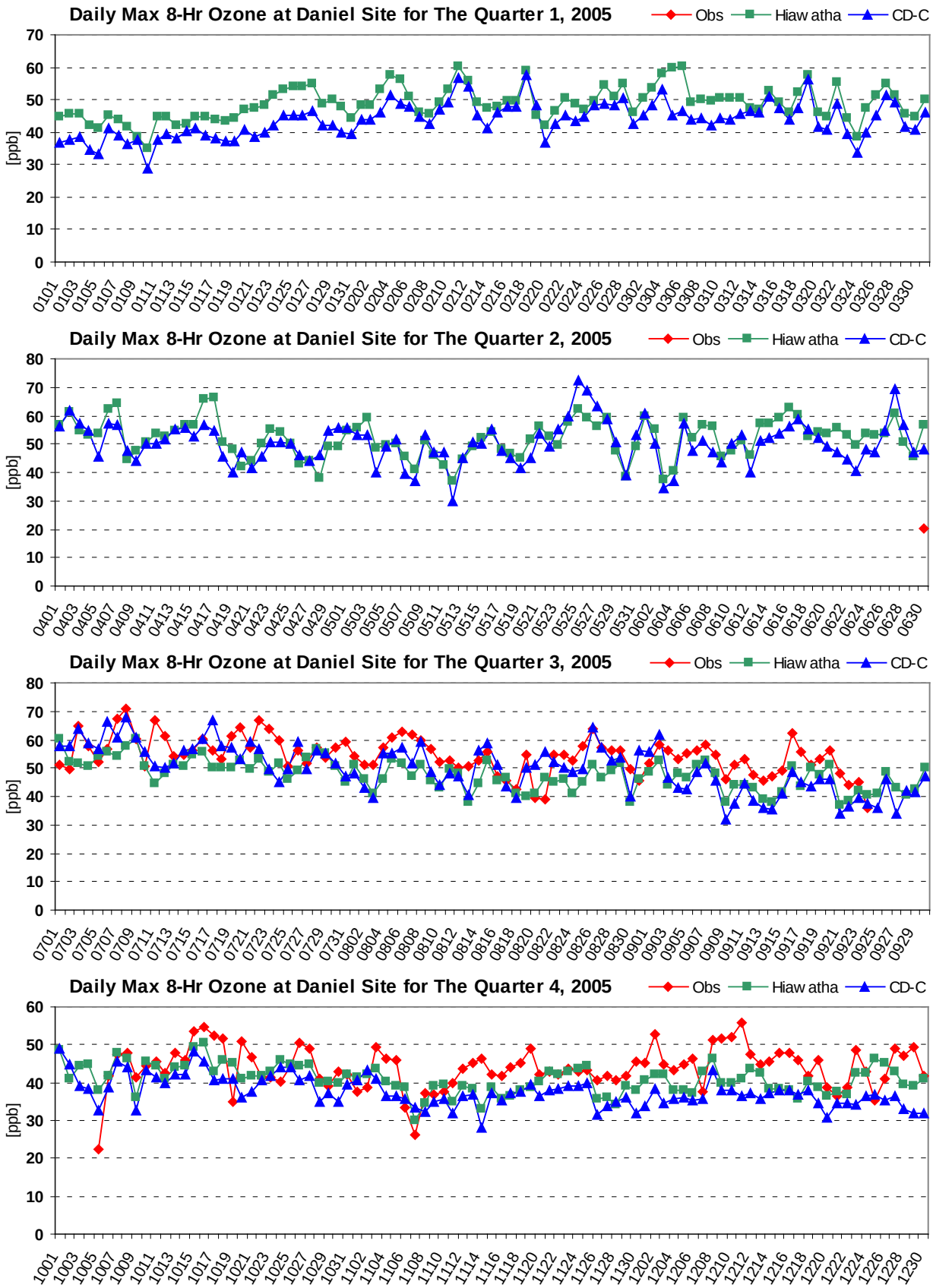


Figure A4-3c. Daily maximum 8-hour ozone concentration time series at Daniel site for 2005.

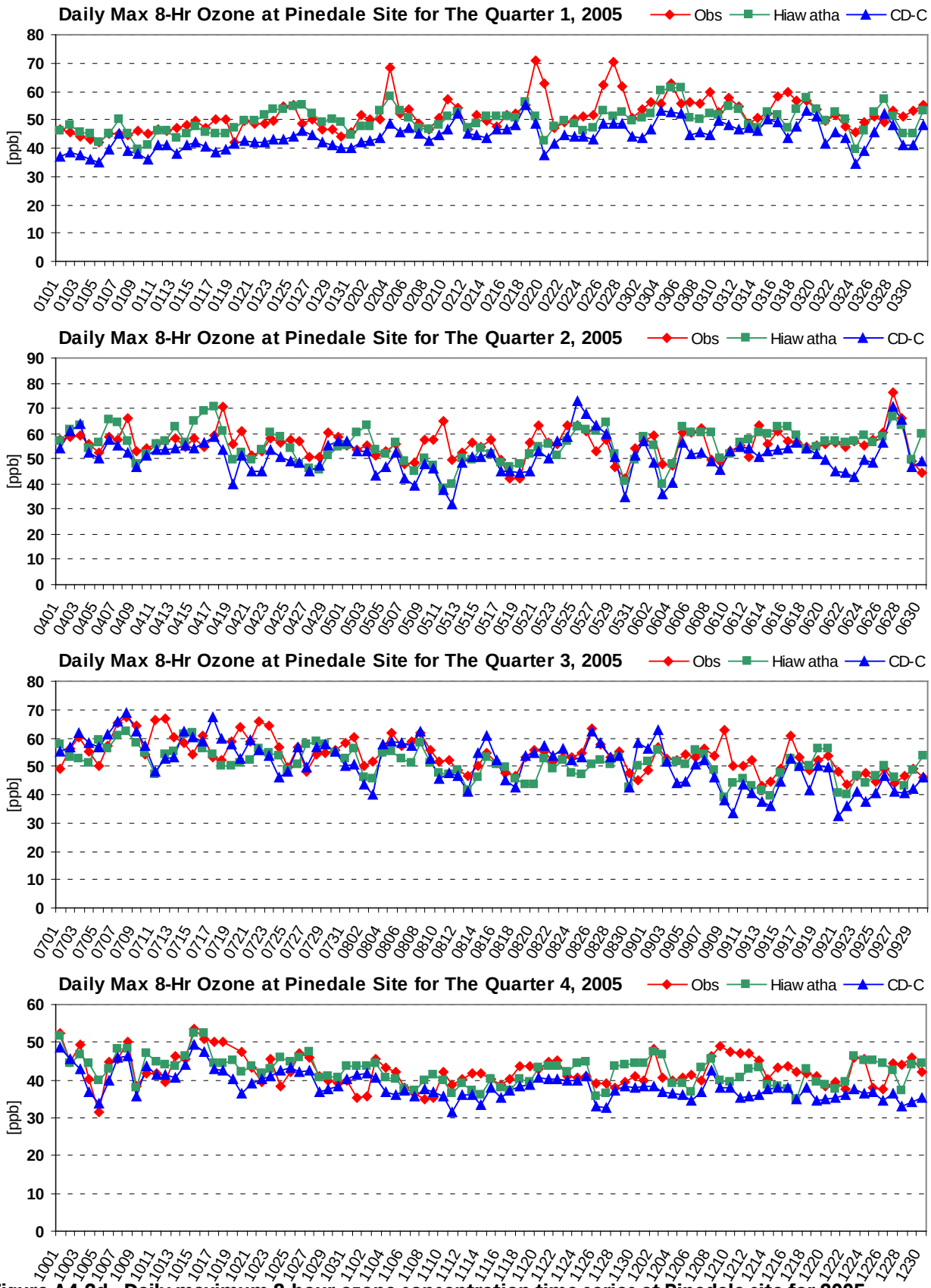


Figure A4-3d. Daily maximum 8-hour ozone concentration time series at Pinedale site for 2005.

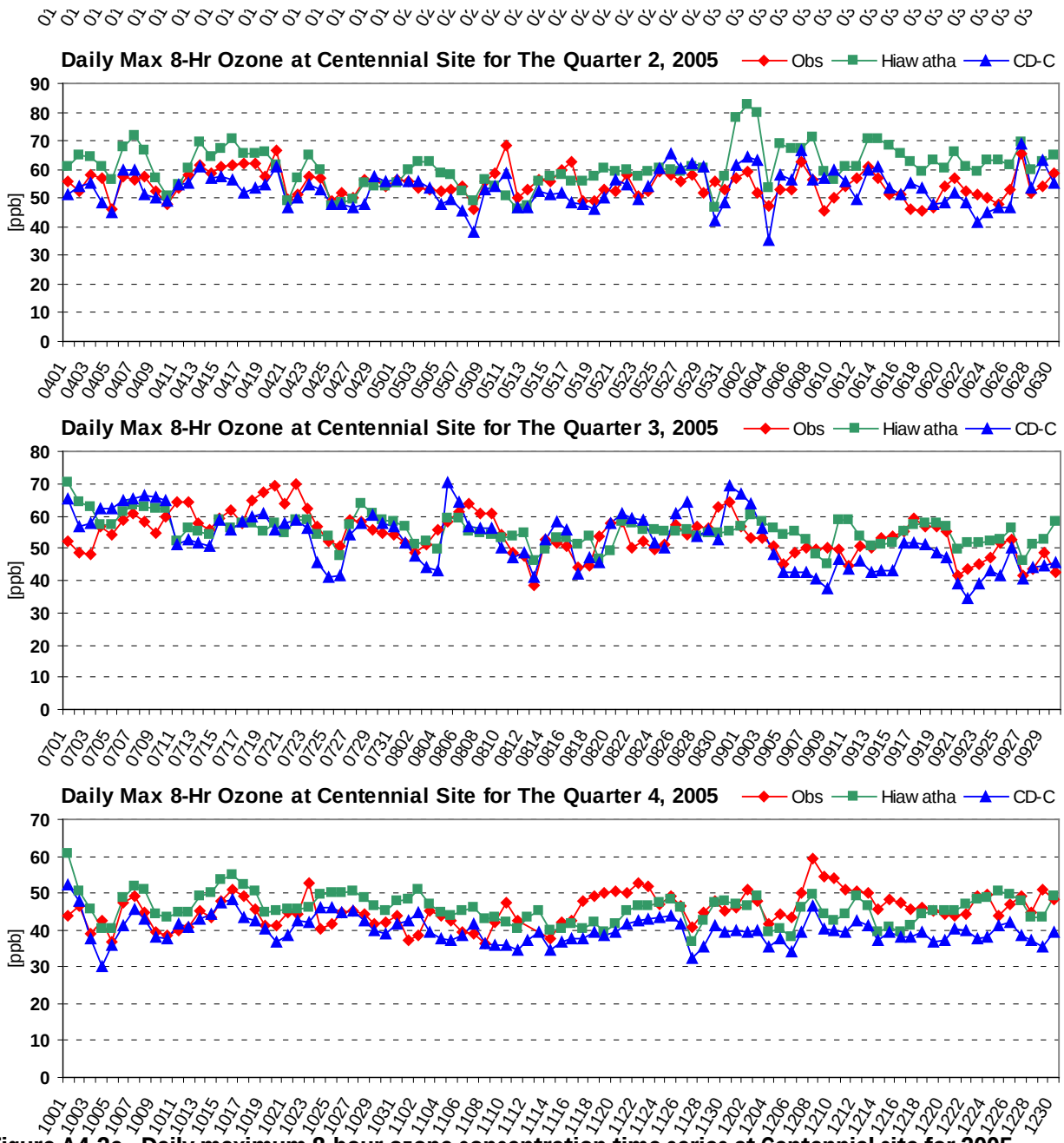


Figure A4-3e. Daily maximum 8-hour ozone concentration time series at Centennial site for 2005.

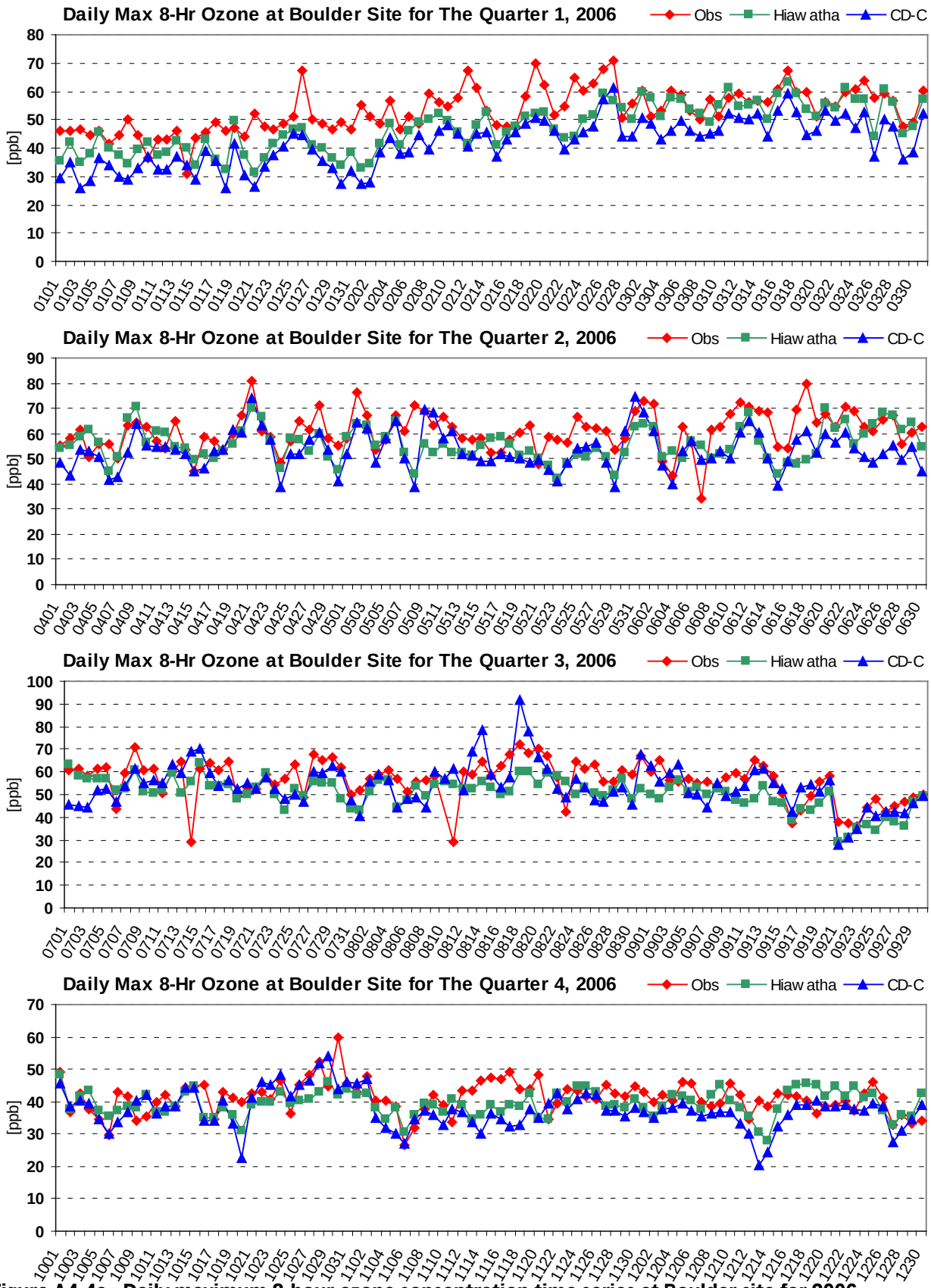


Figure A4-4a. Daily maximum 8-hour ozone concentration time series at Boulder site for 2006.

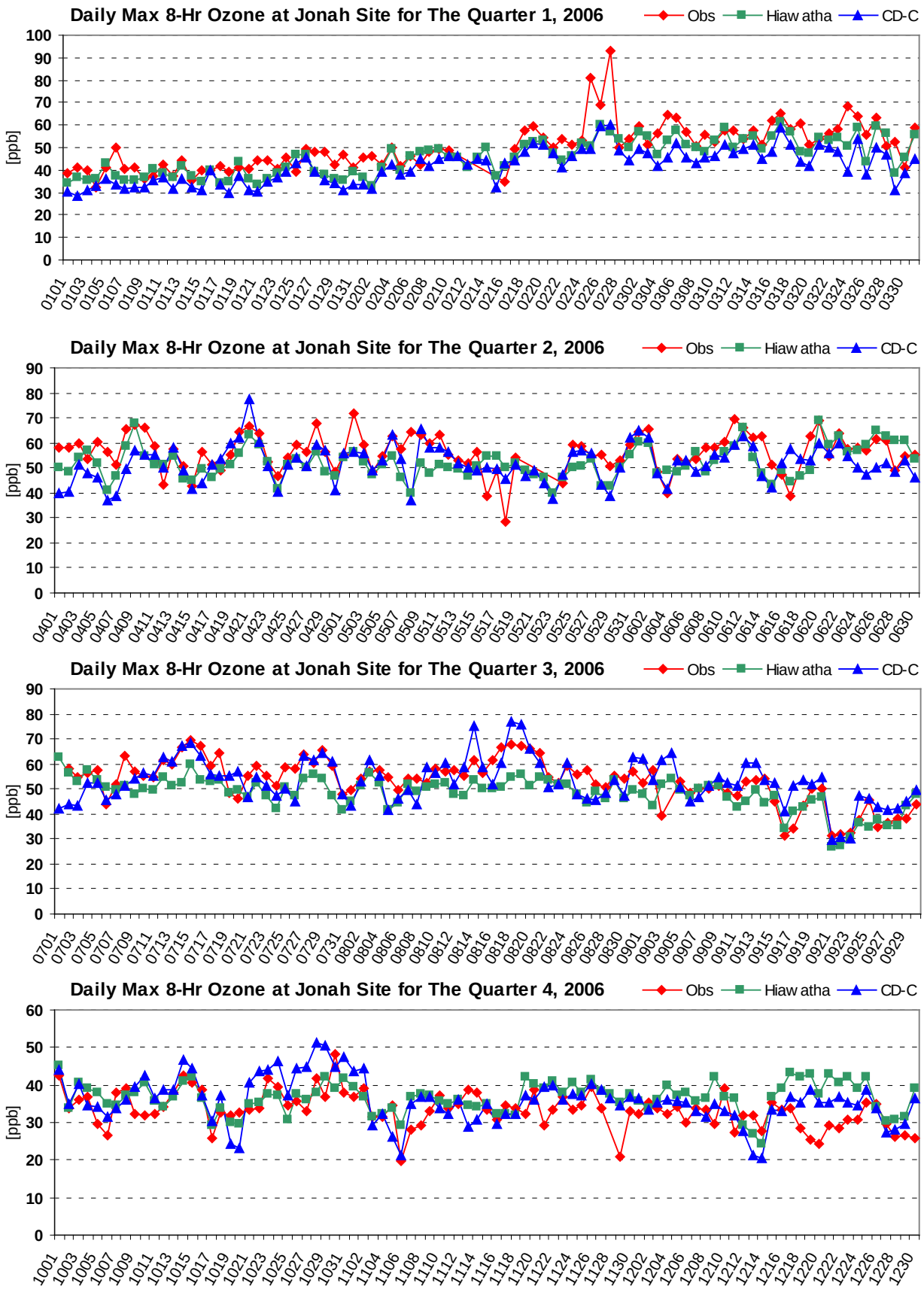


Figure A4-4b. Daily maximum 8-hour ozone concentration time series at Jonah site for 2006.

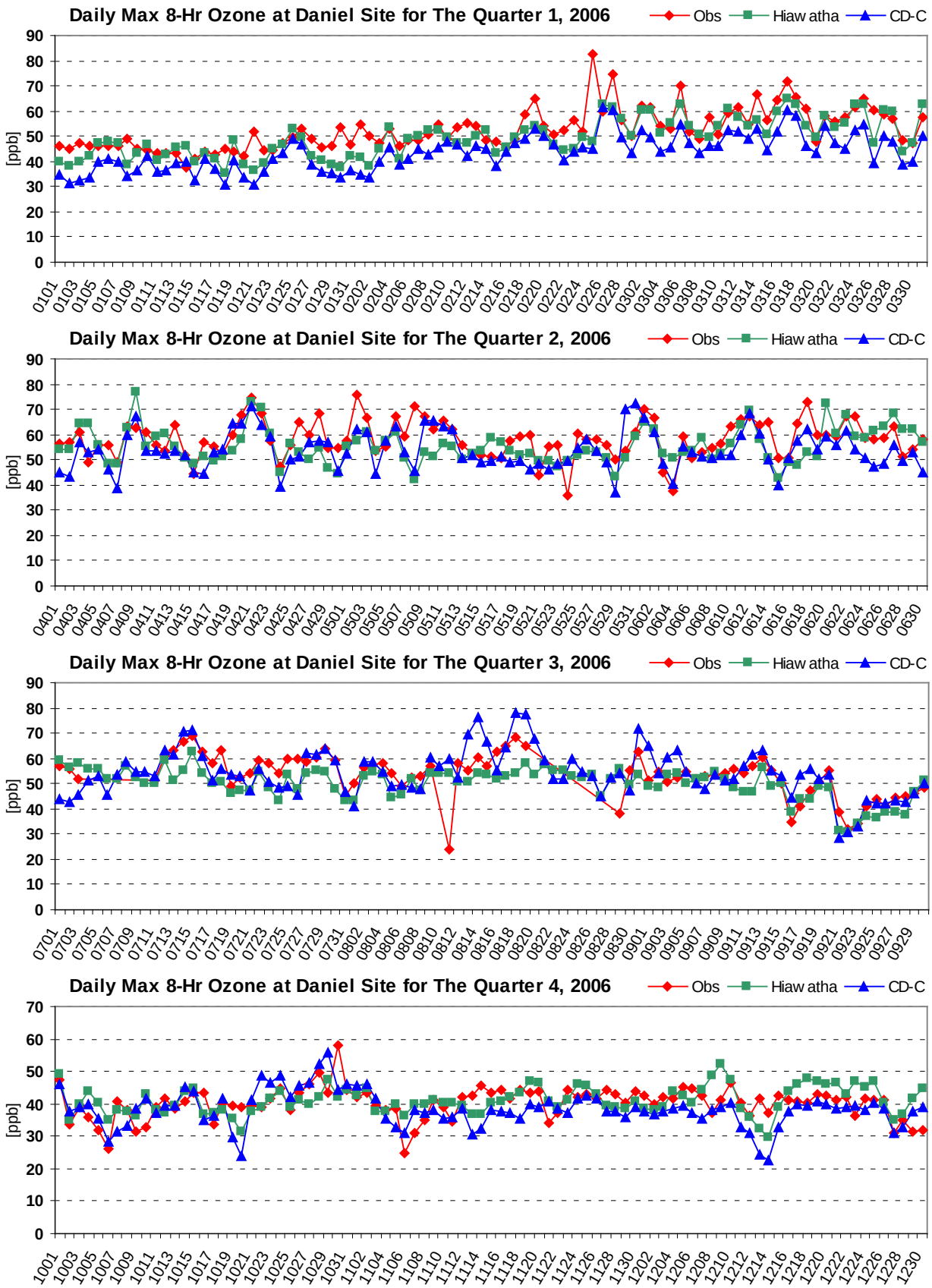


Figure A4-4c. Daily maximum 8-hour ozone concentration time series at Daniel site for 2006.

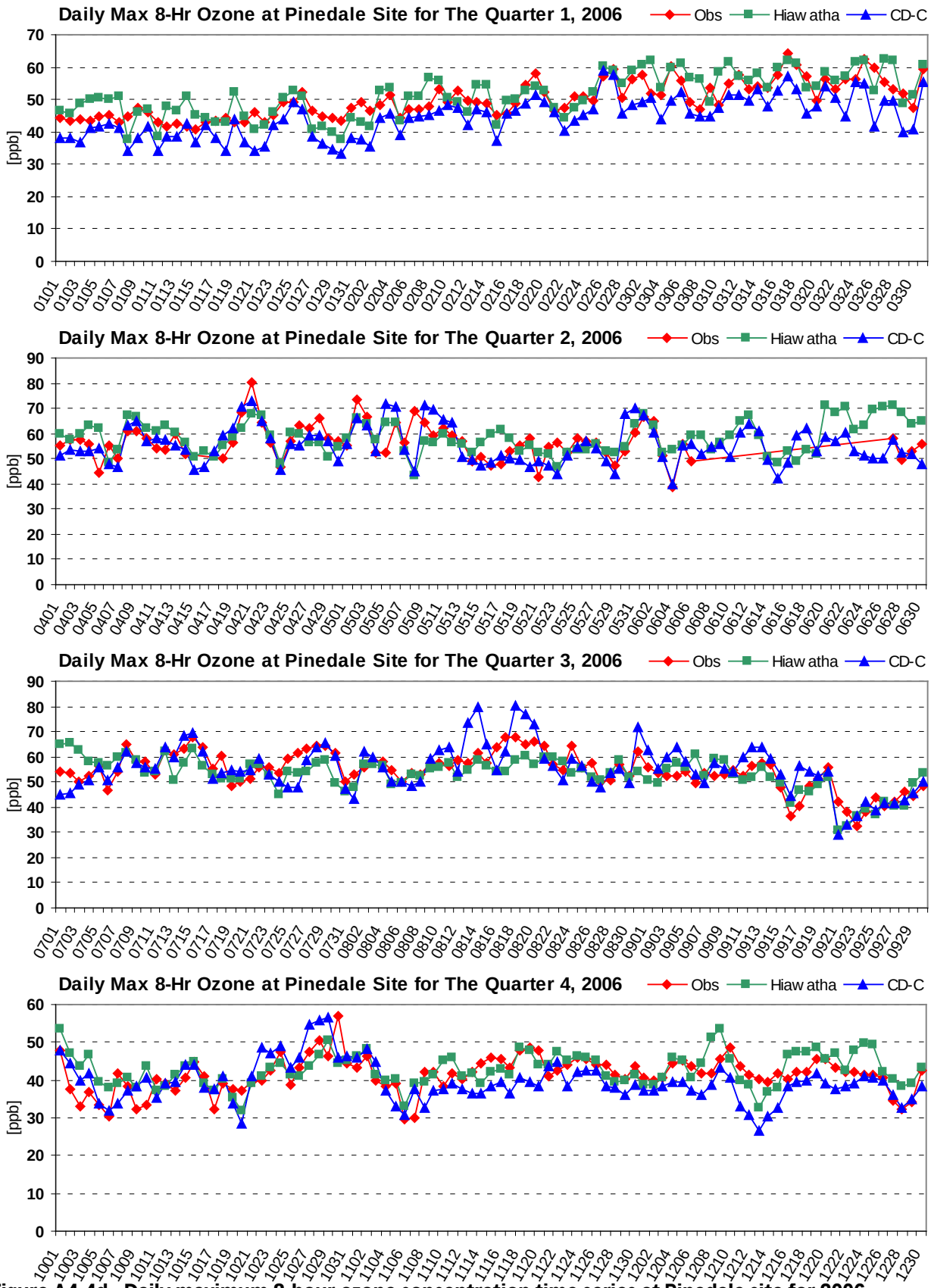


Figure A4-4d. Daily maximum 8-hour ozone concentration time series at Pinedale site for 2006.

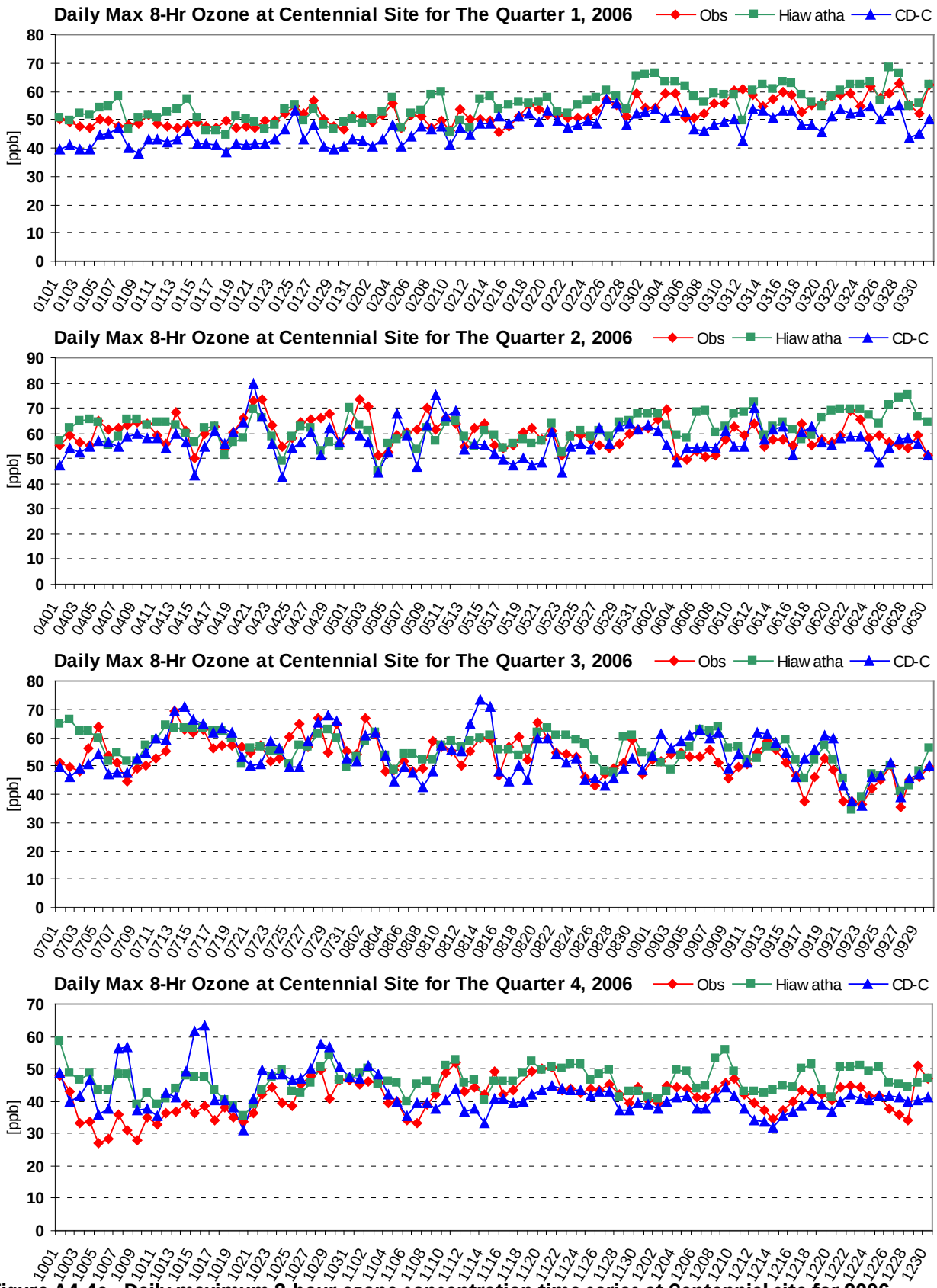


Figure A4-4e. Daily maximum 8-hour ozone concentration time series at Centennial site for 2006.

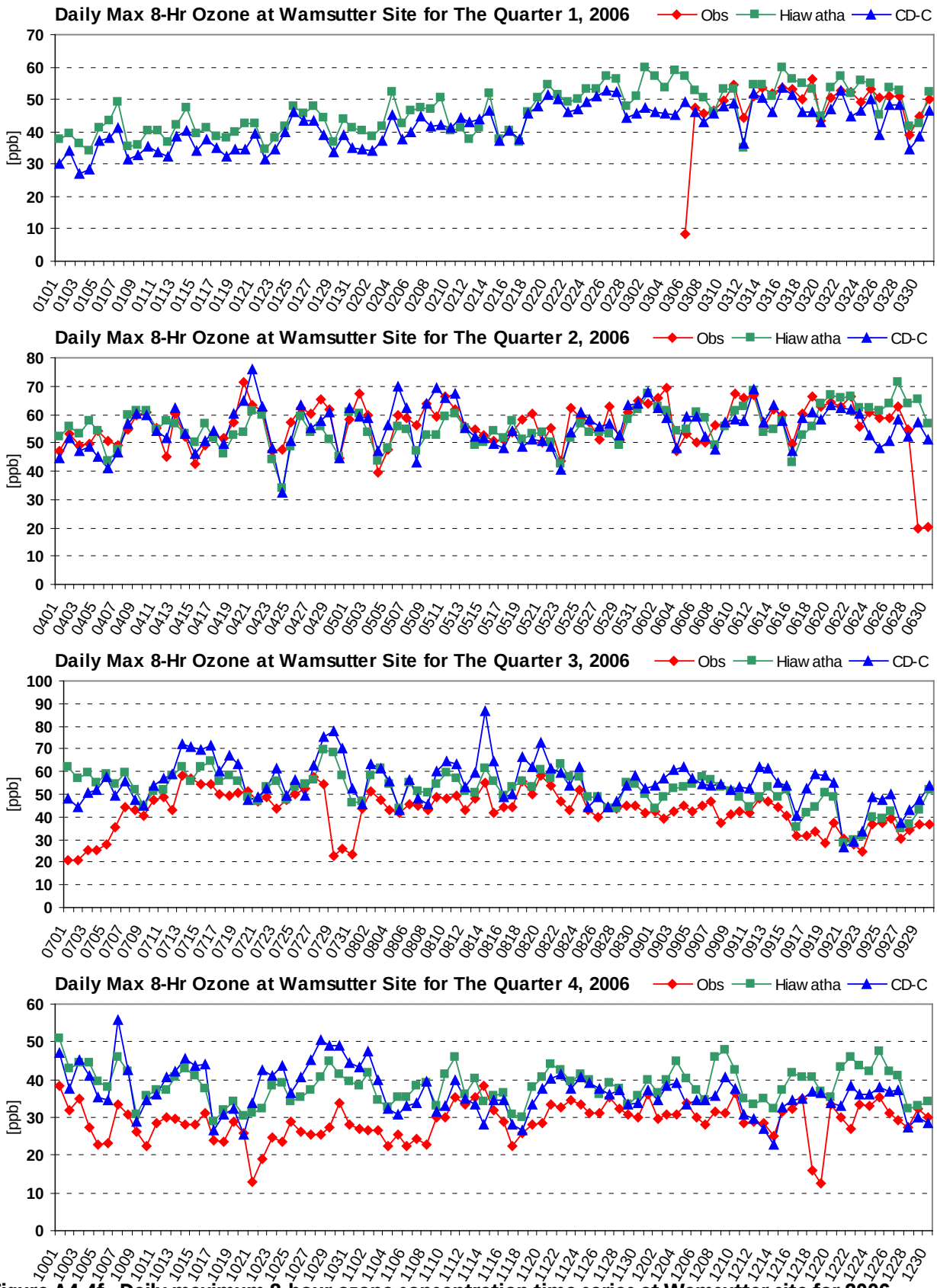


Figure A4-4f. Daily maximum 8-hour ozone concentration time series at Wamsutter site for 2006.

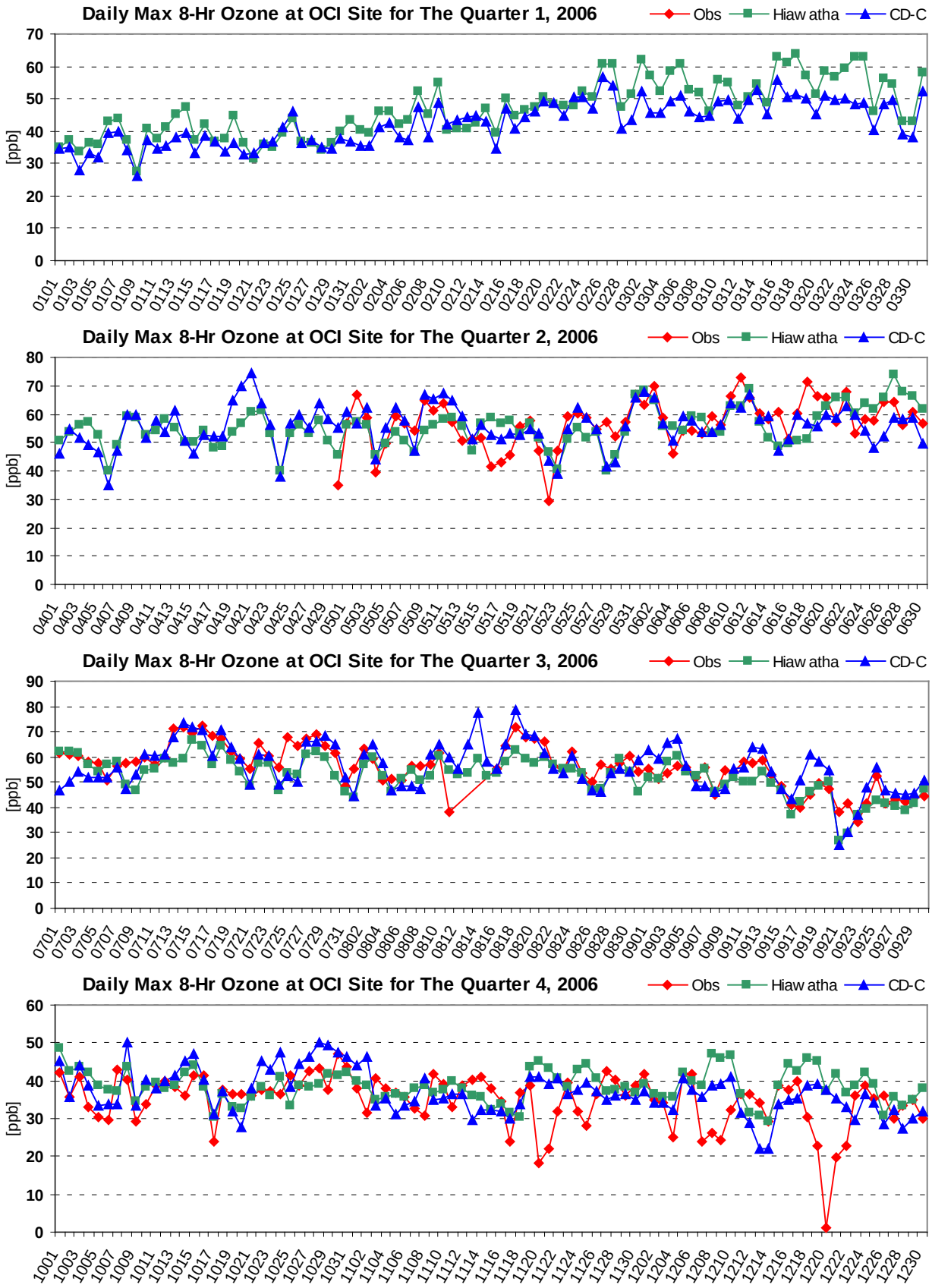


Figure A4-4g. Daily maximum 8-hour ozone concentration time series at OCI site for 2006.

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

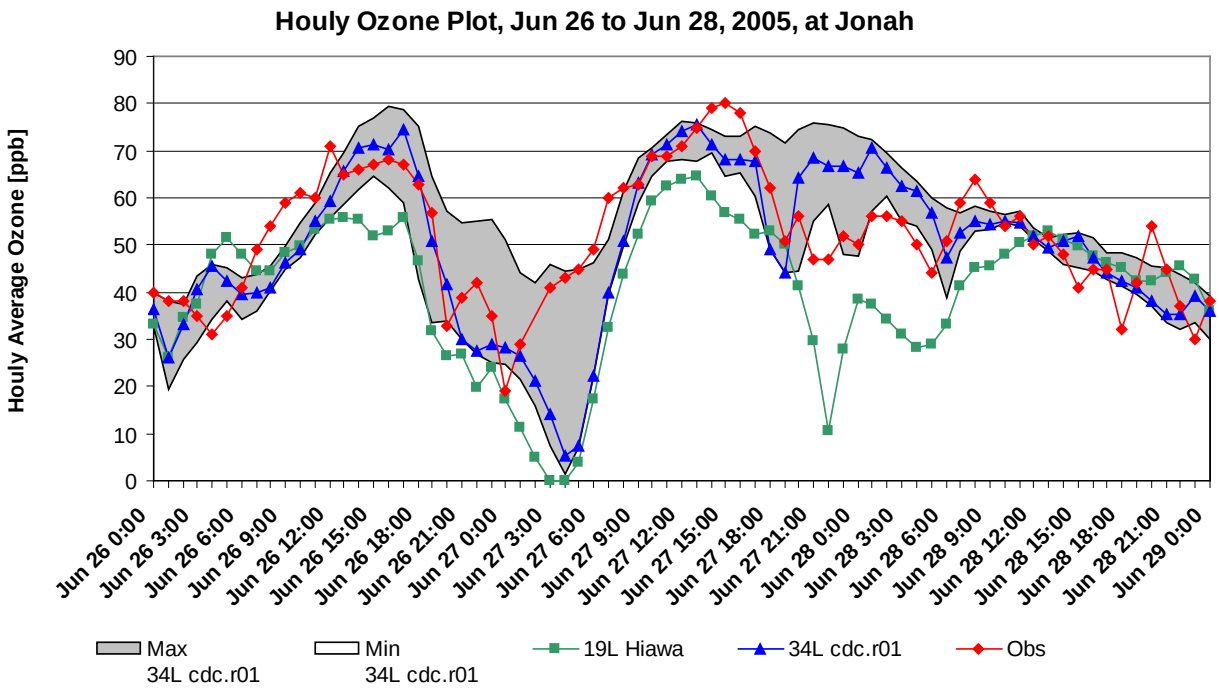
The two base case simulations have a tendency to underestimate the observed ozone peaks for all monitors except Centennial during June 10-19, 2006 (Figure A4-10). This suggests that the regional background ozone is well simulated but that the underprediction of peak ozone may be due insufficient ozone 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.



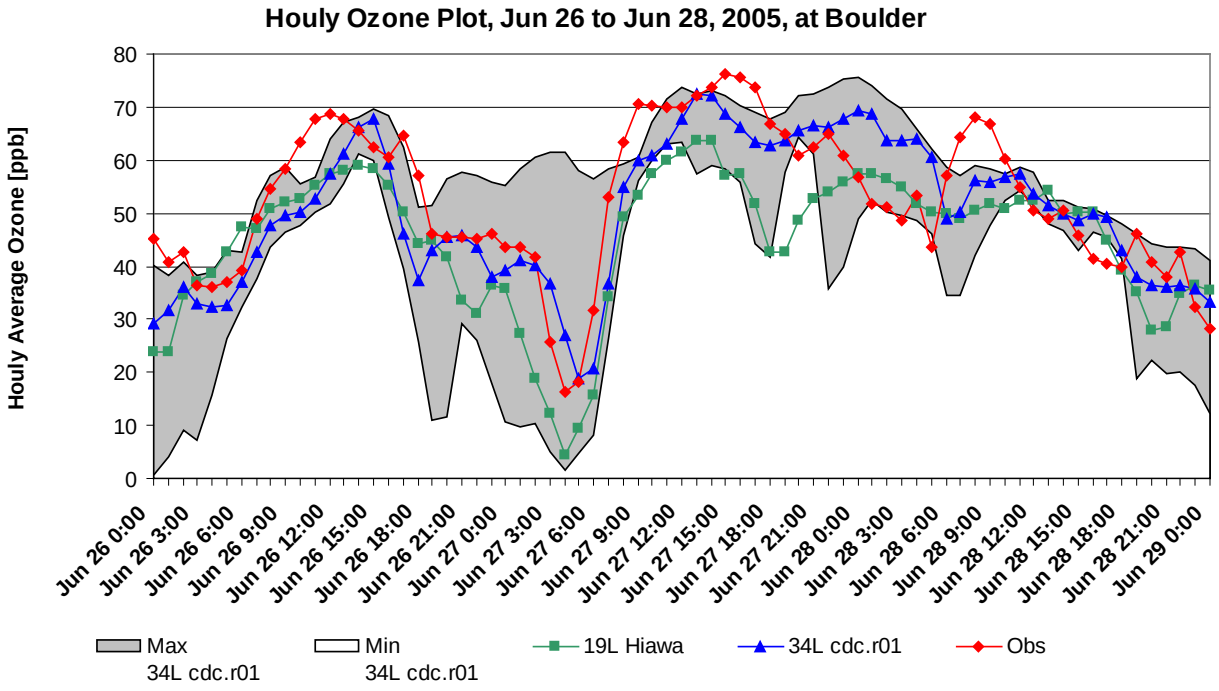
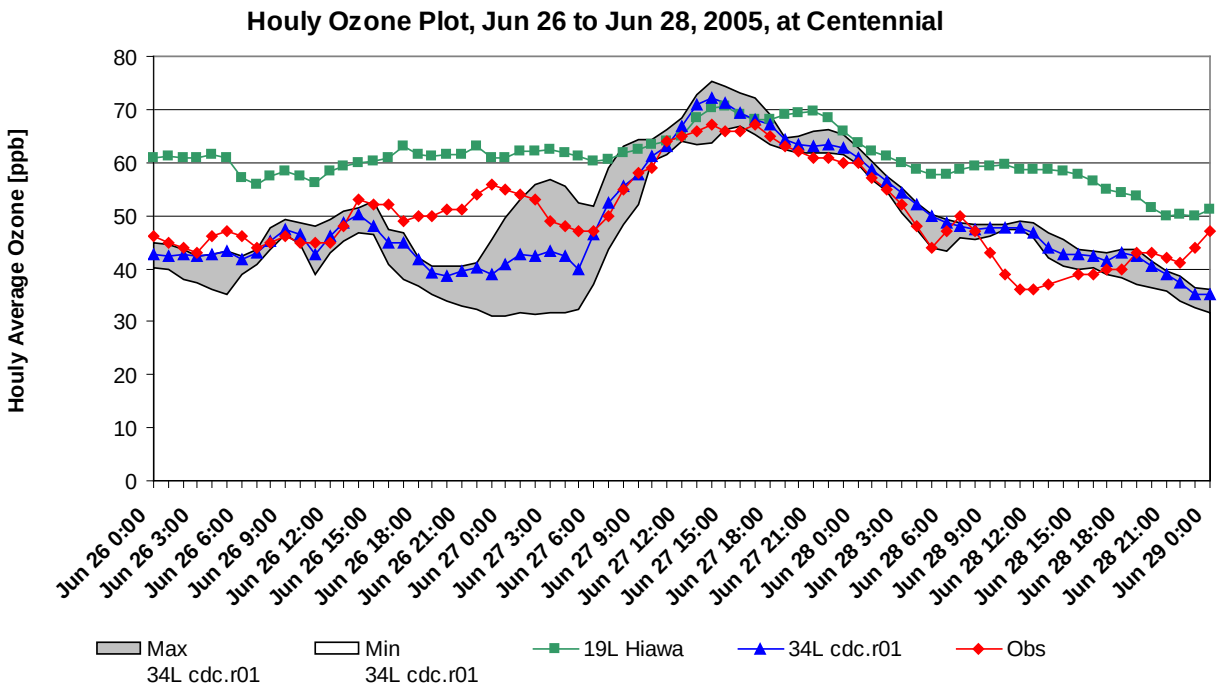


Figure A4-5a. 1-hour ozone time series for June 26-28, 2005.



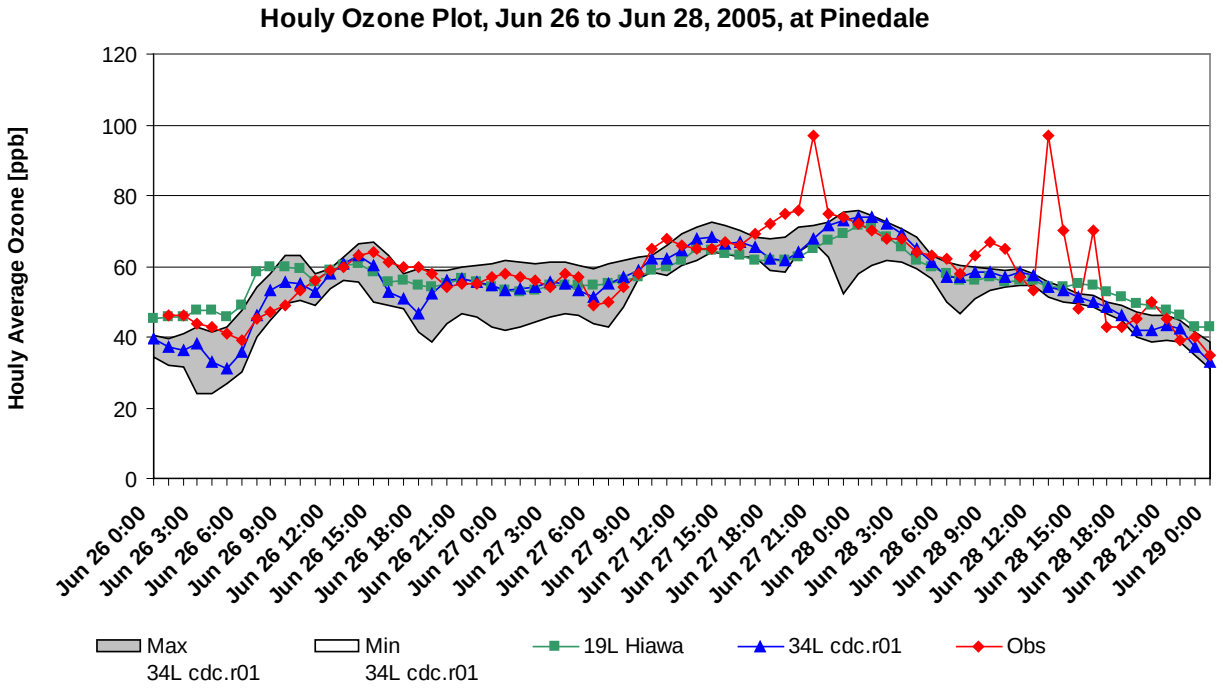
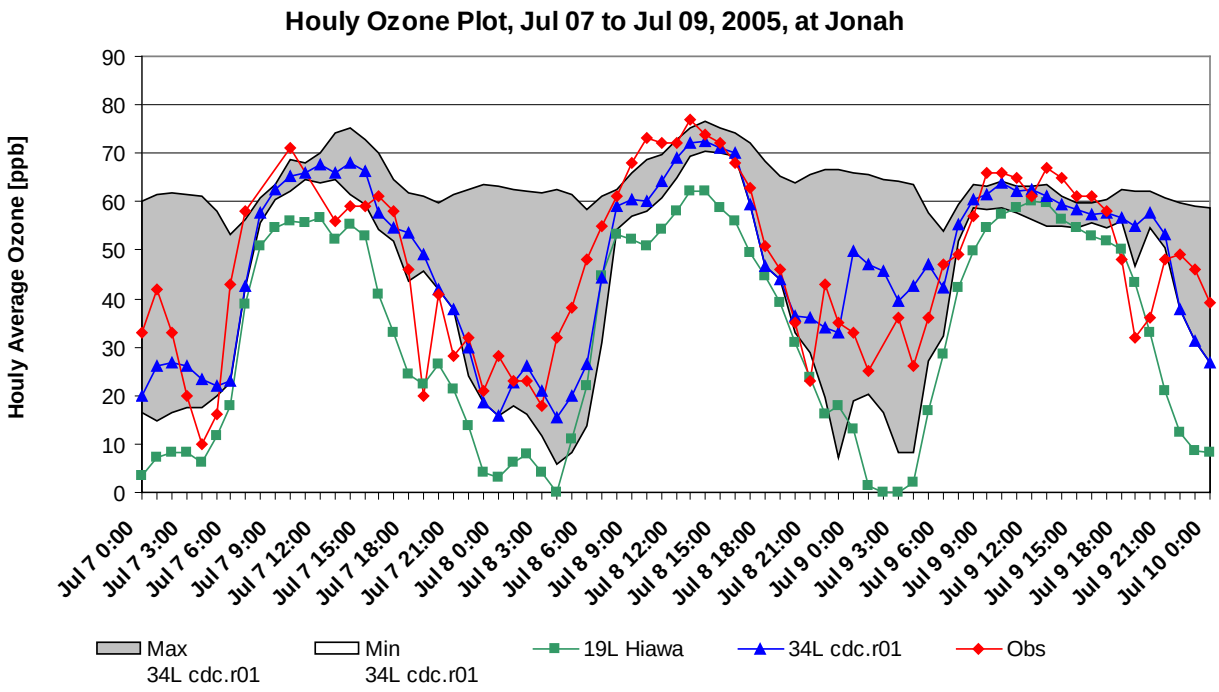


Figure A4-5b. 1-hour ozone time series for June 26-28, 2005.



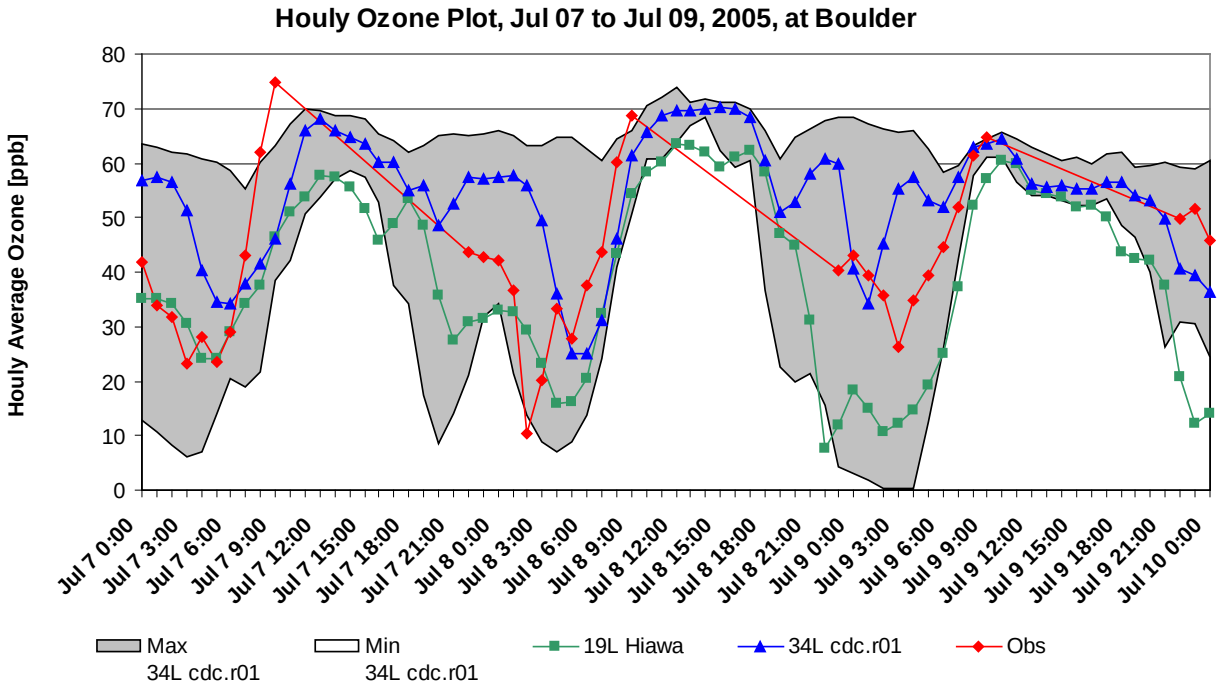
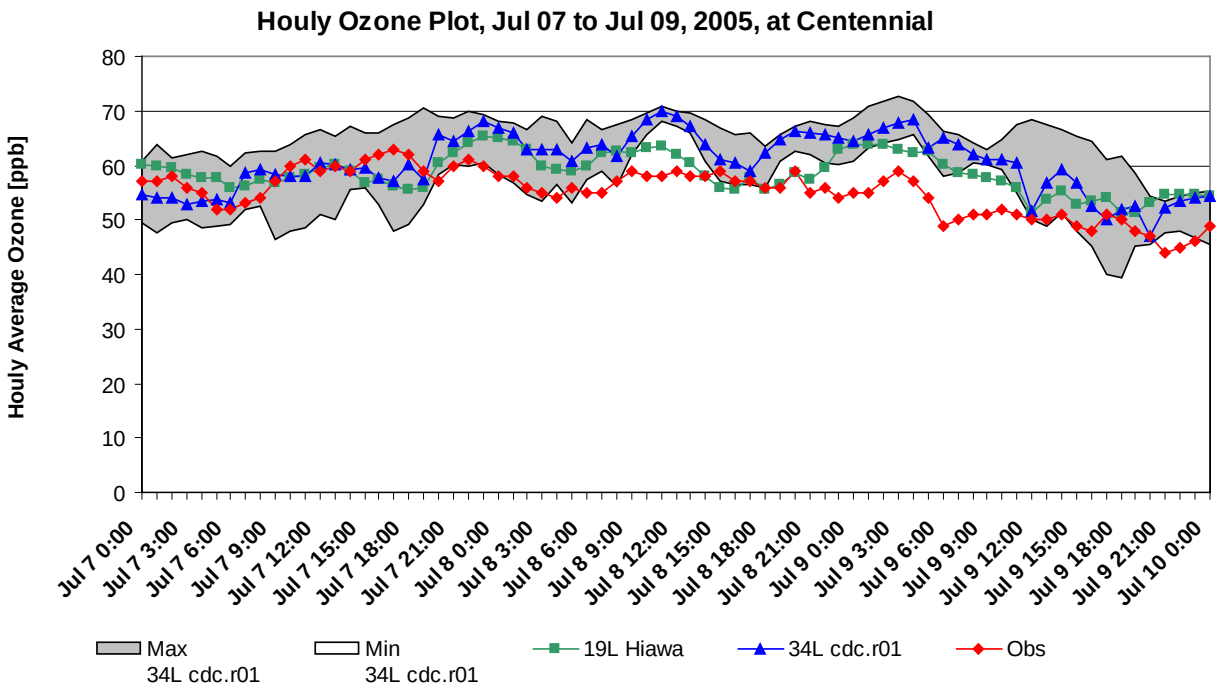


Figure A4-6a. 1-hour ozone time series for Jul7-9, 2005.



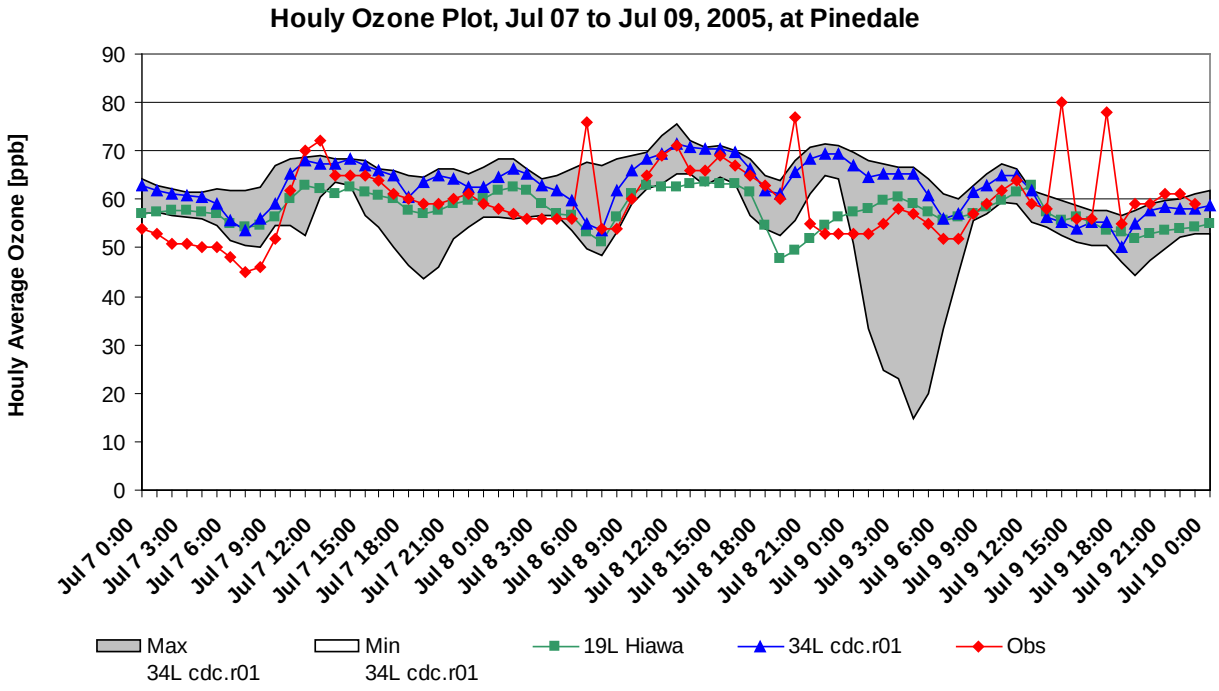


Figure A4-6b. 1-hour ozone time series for July7-9, 2005.

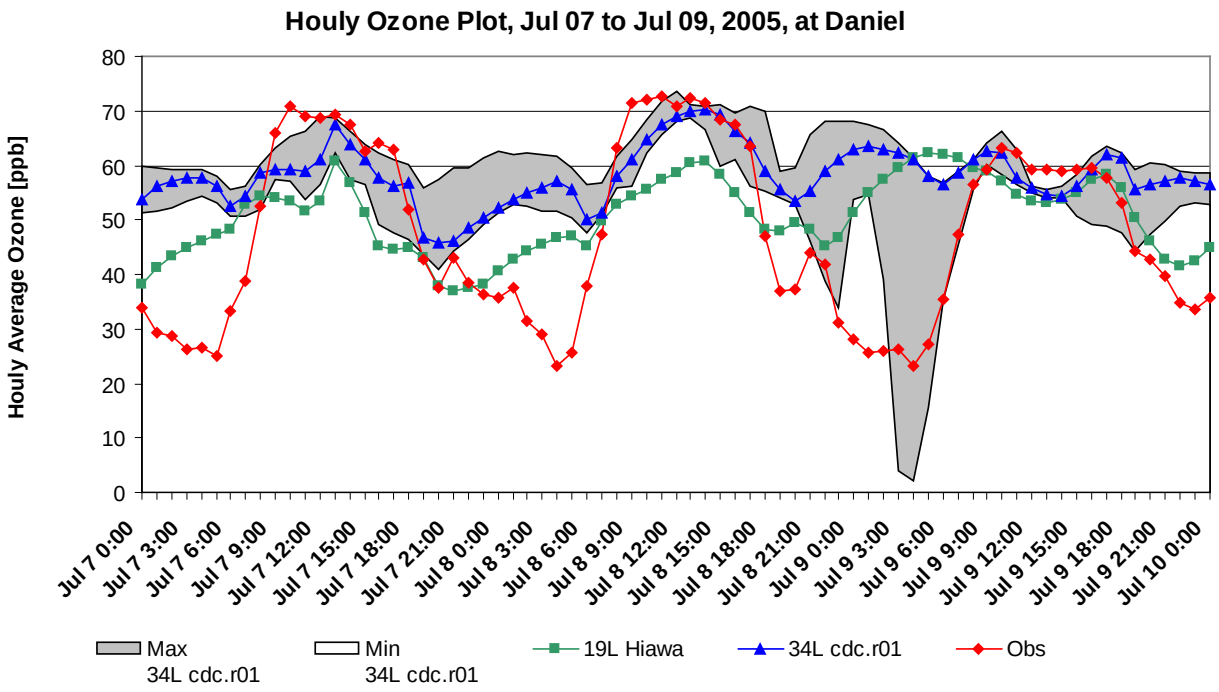
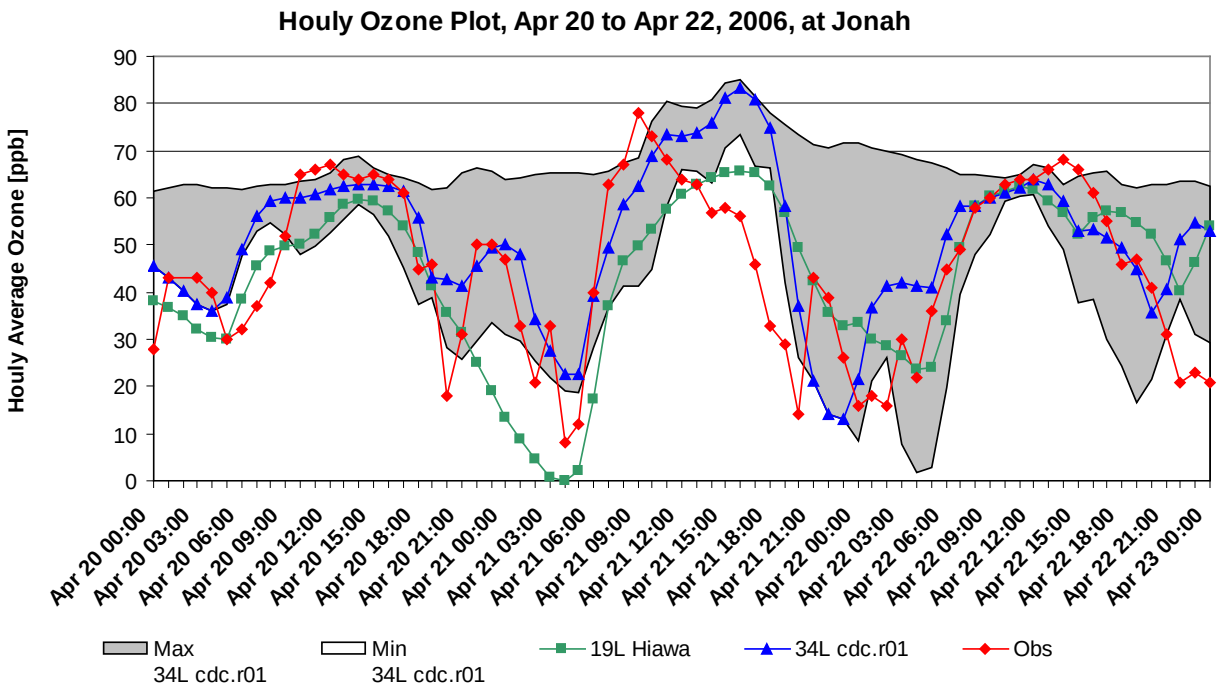


Figure A4-6c.1-hour ozone time series for July7-9, 2005.



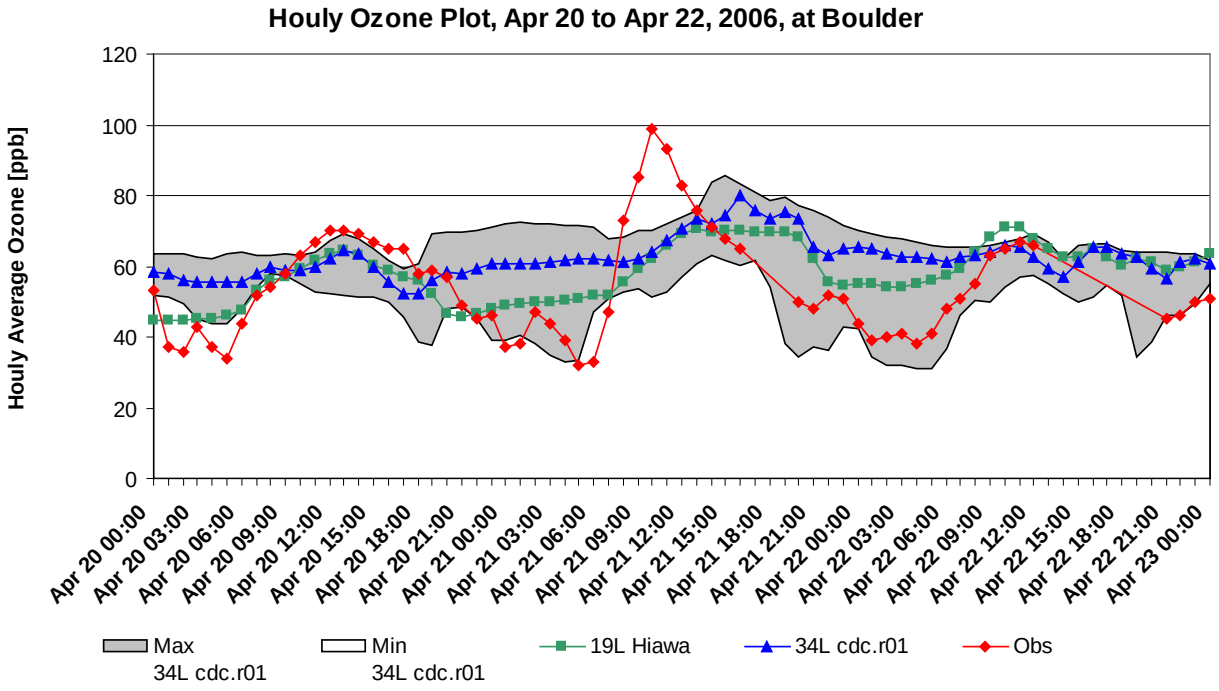
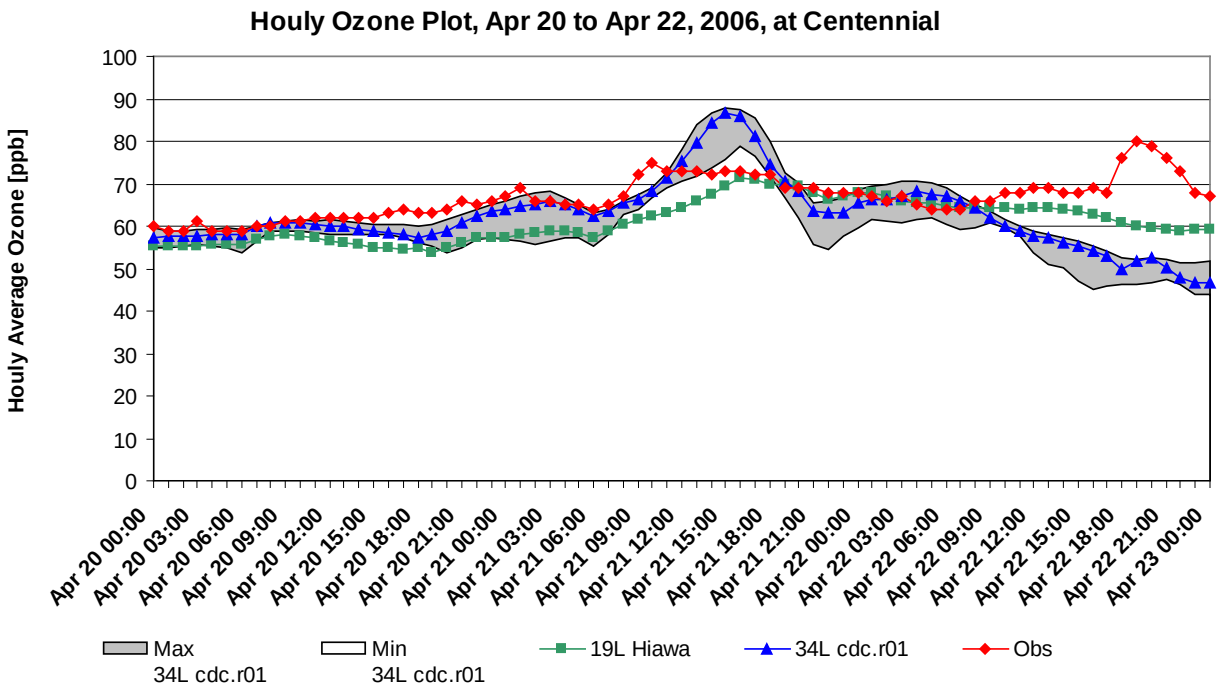


Figure A4-7a. 1-hour ozone time series for April20-22, 2006.



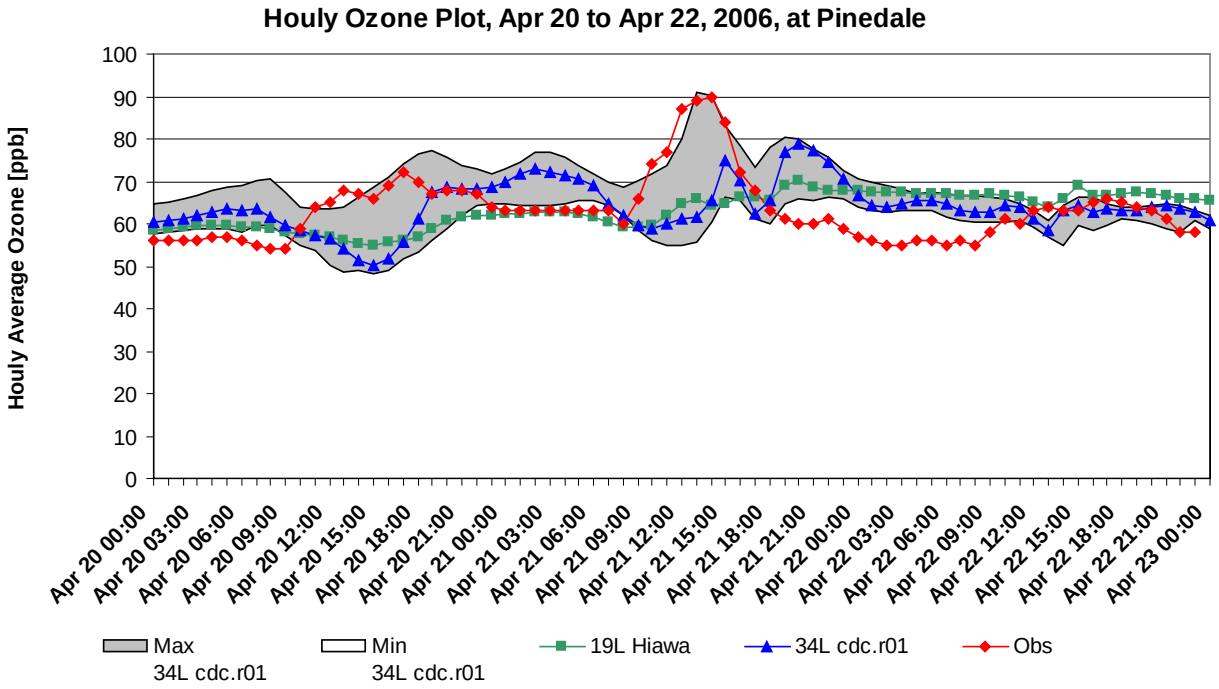
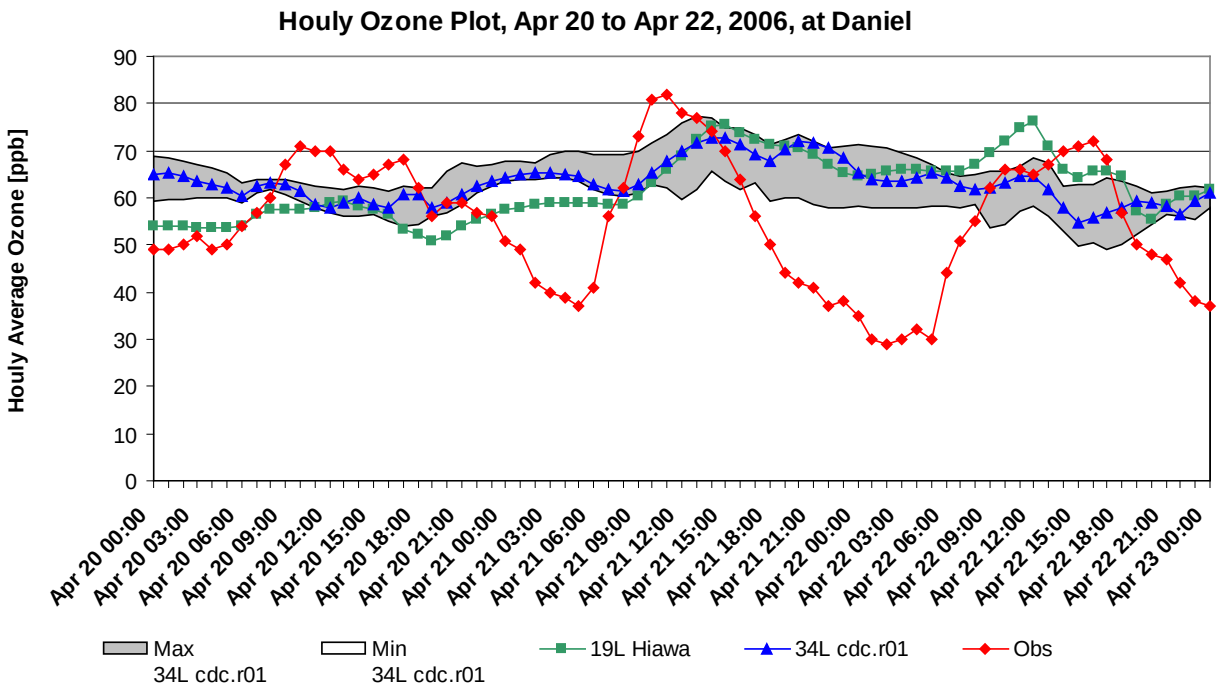


Figure A4-7b. 1-hour ozone time series for April20-22, 2006.



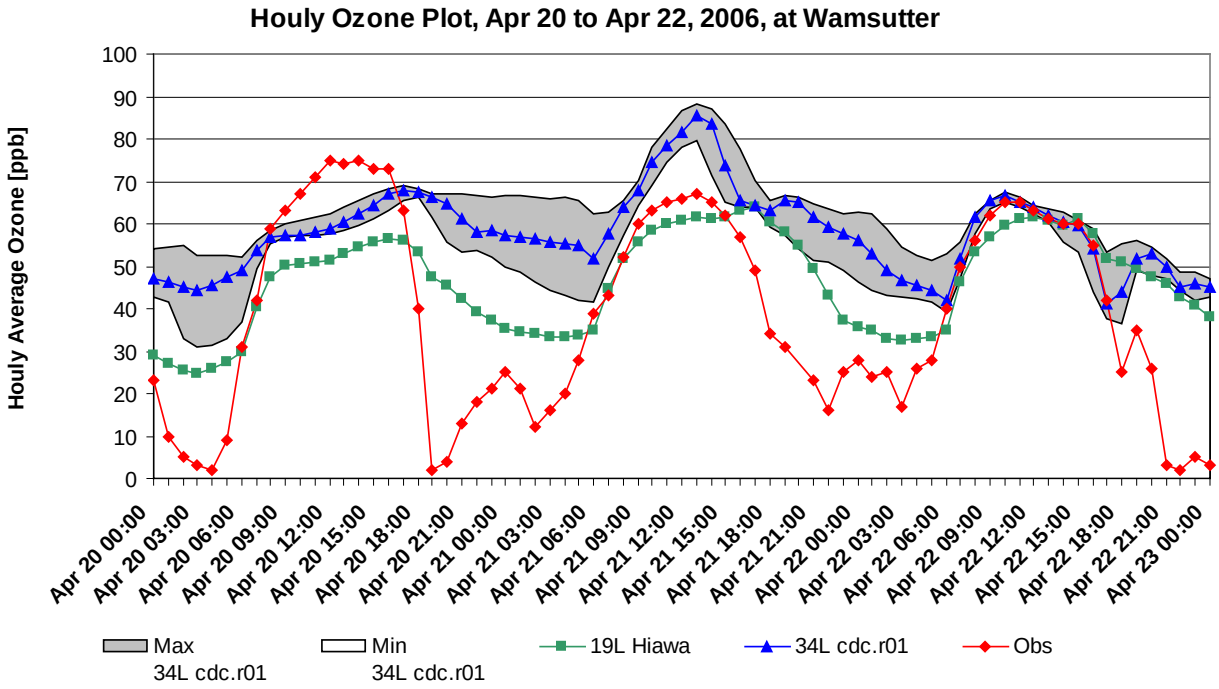
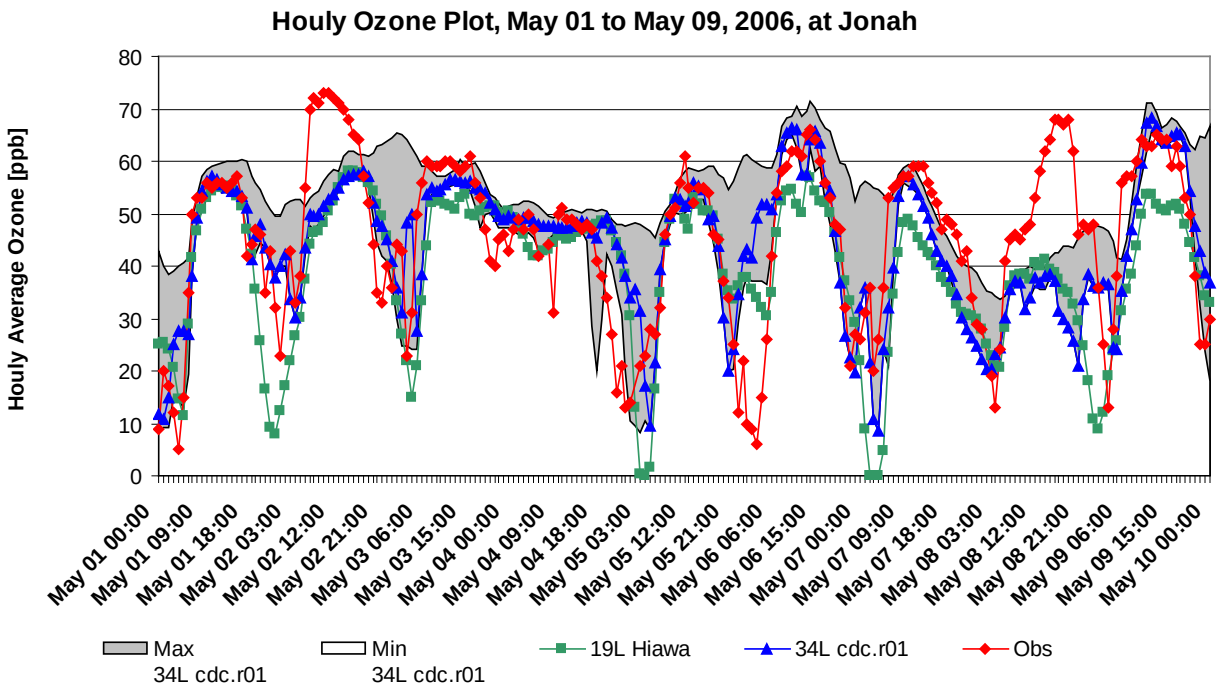


Figure A4-7c.1-hour ozone time series for April20-22, 2006.



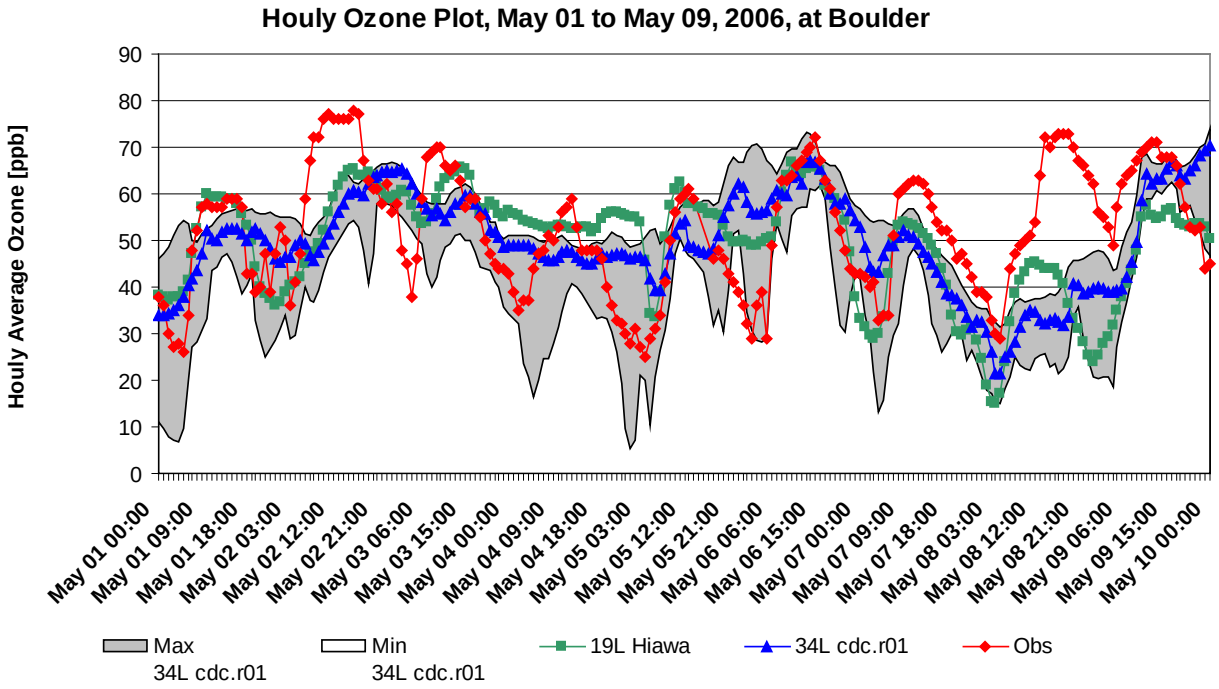
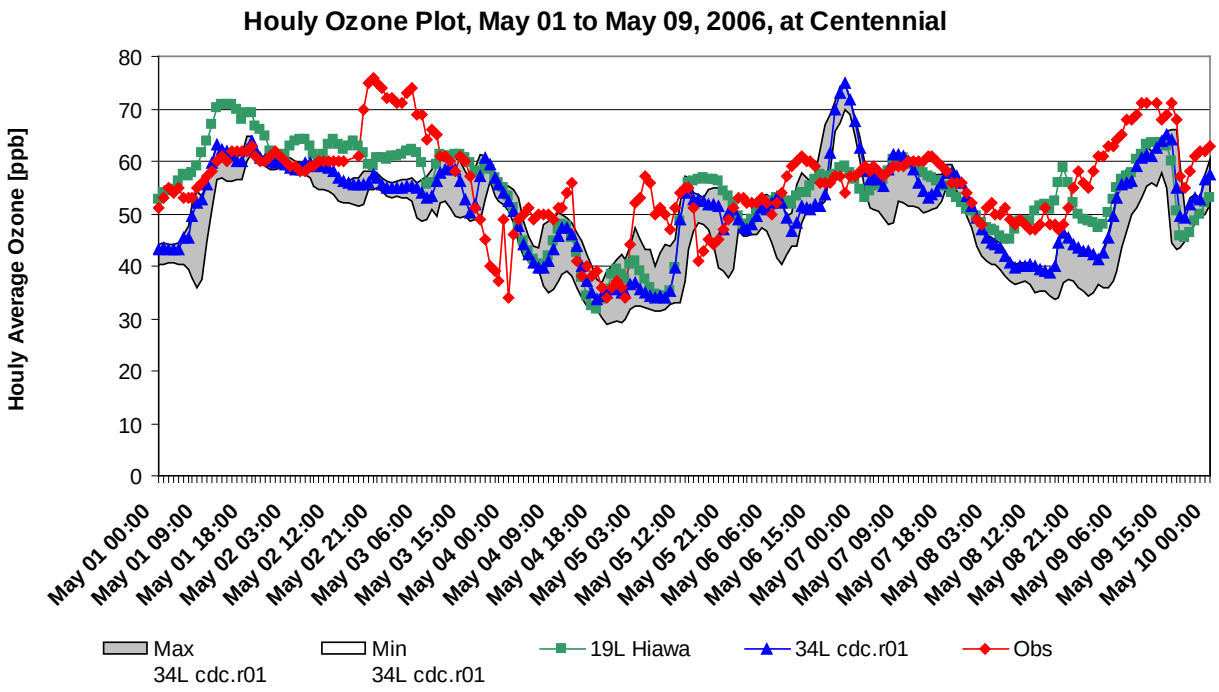


Figure A4-8a. 1-hour ozone time series for May 1-9, 2006.



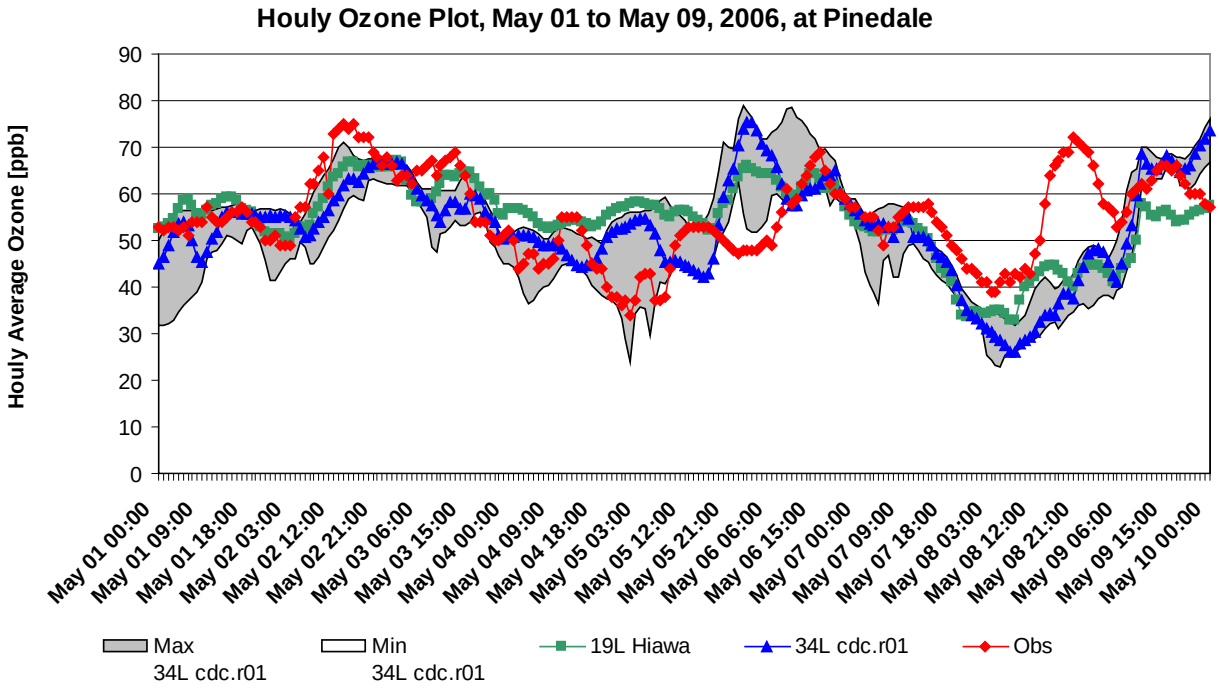
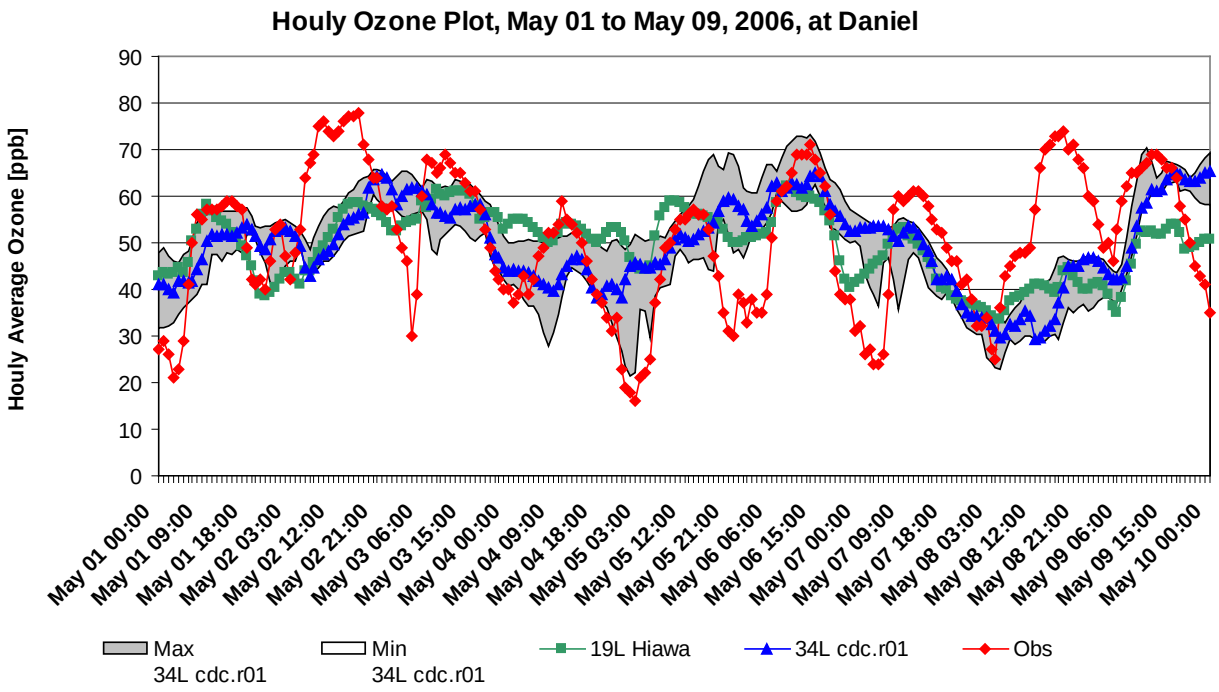


Figure A4-8b. 1-hour ozone time series for May 1-9, 2006.



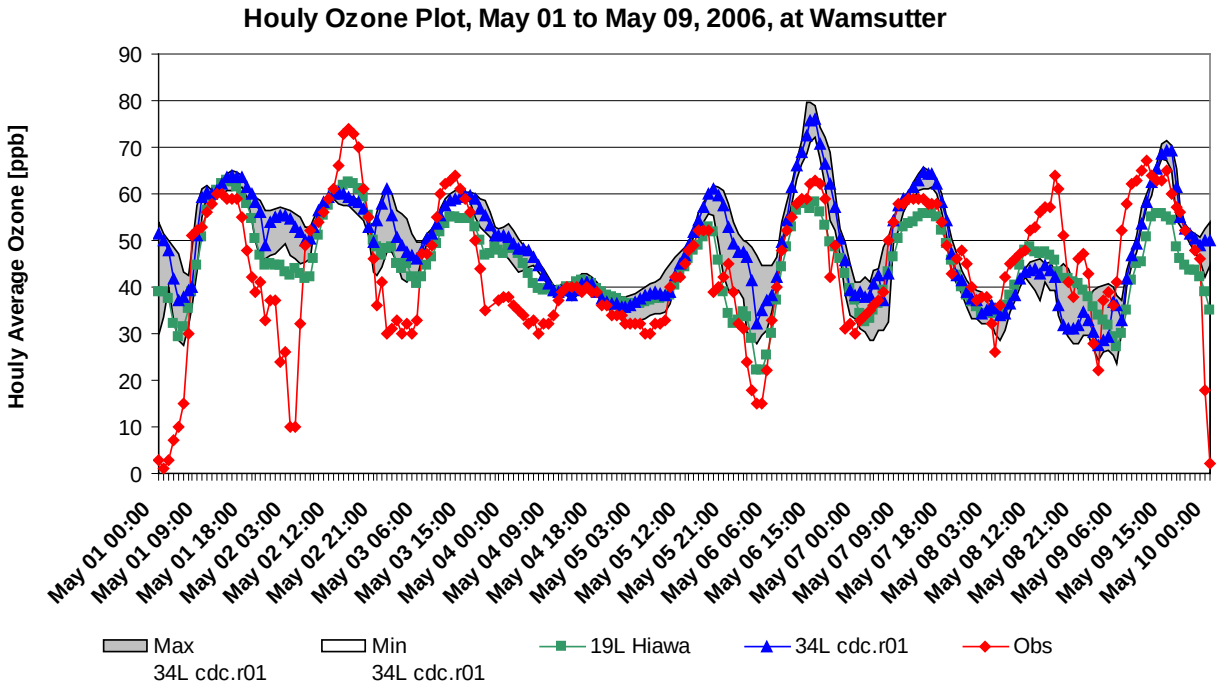


Figure A4-8c.1-hour ozone time series for May 1-9, 2006.

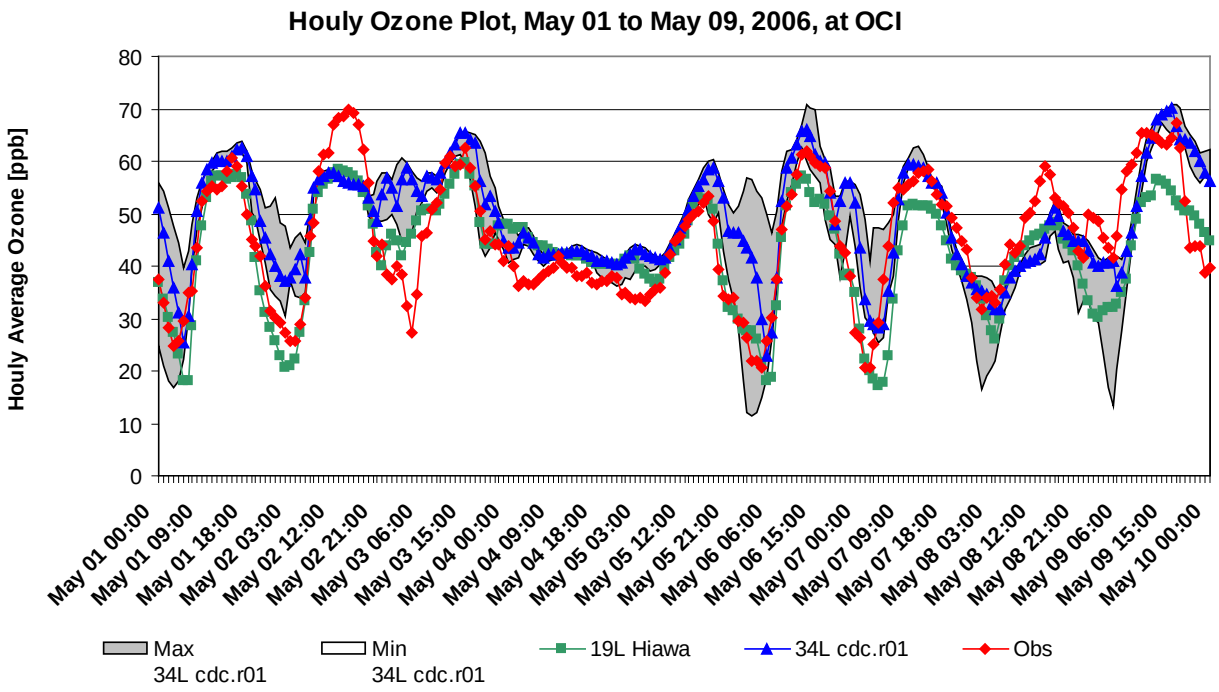
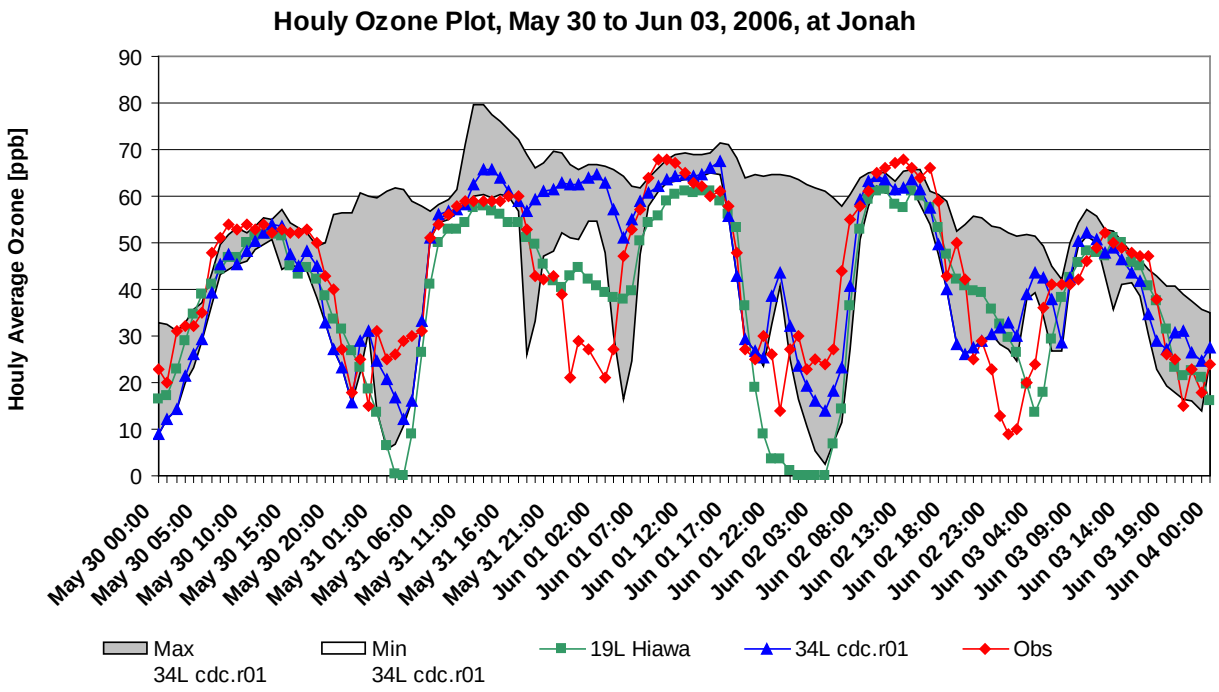


Figure A4-8d. 1-hour ozone time series for May 1-9, 2006.



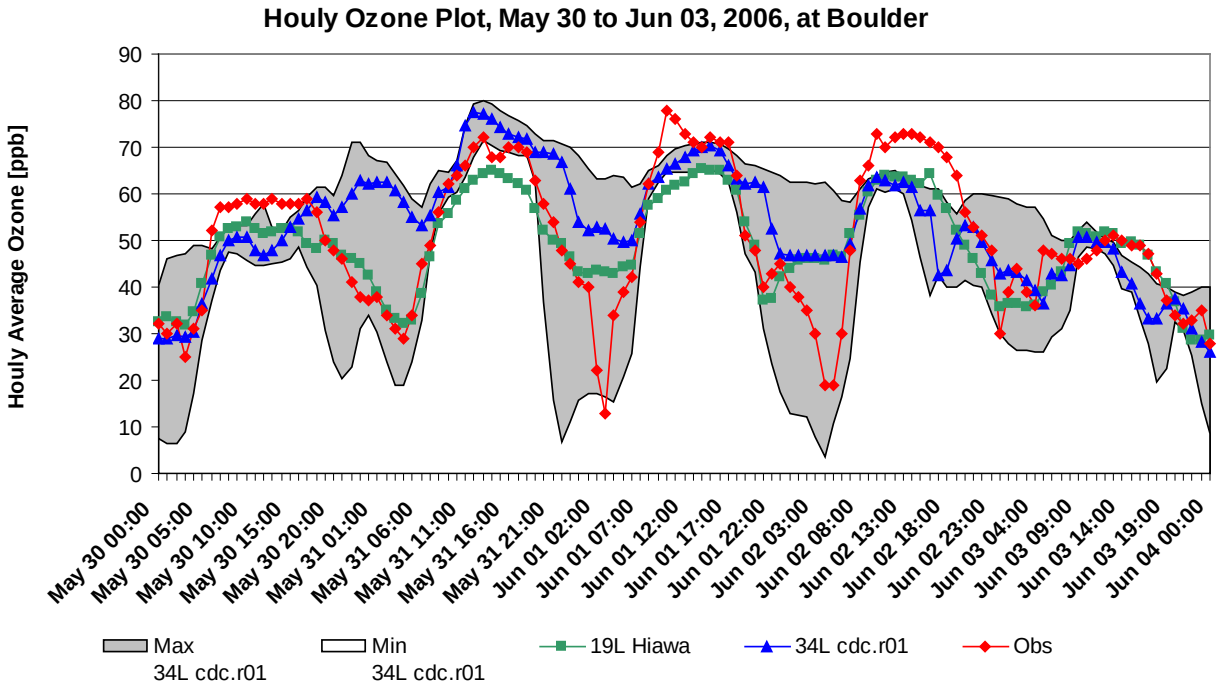
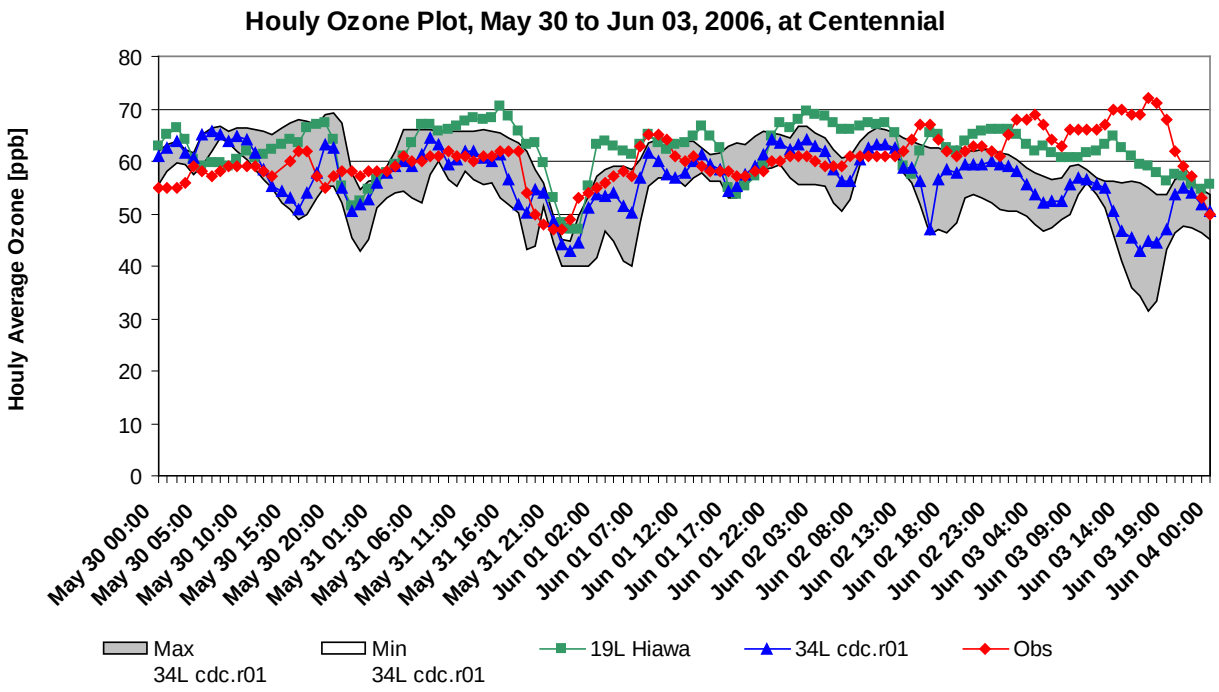


Figure A4-9a. 1-hour ozone time series for May 30-June 3, 2006.



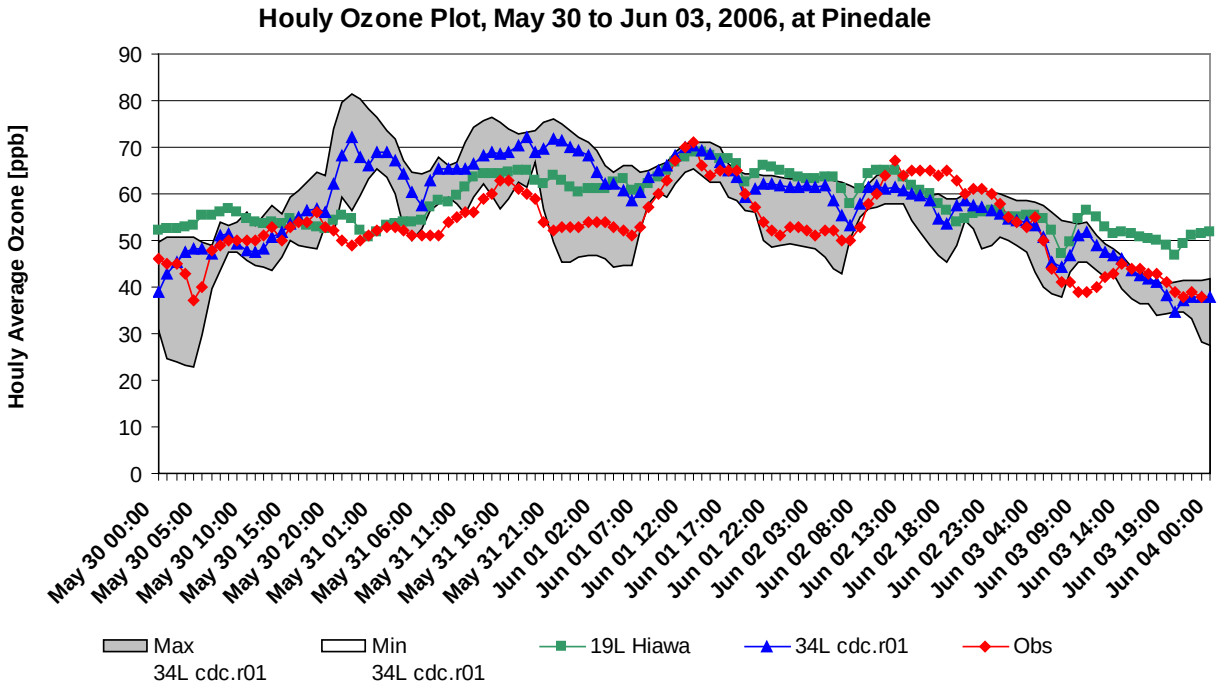
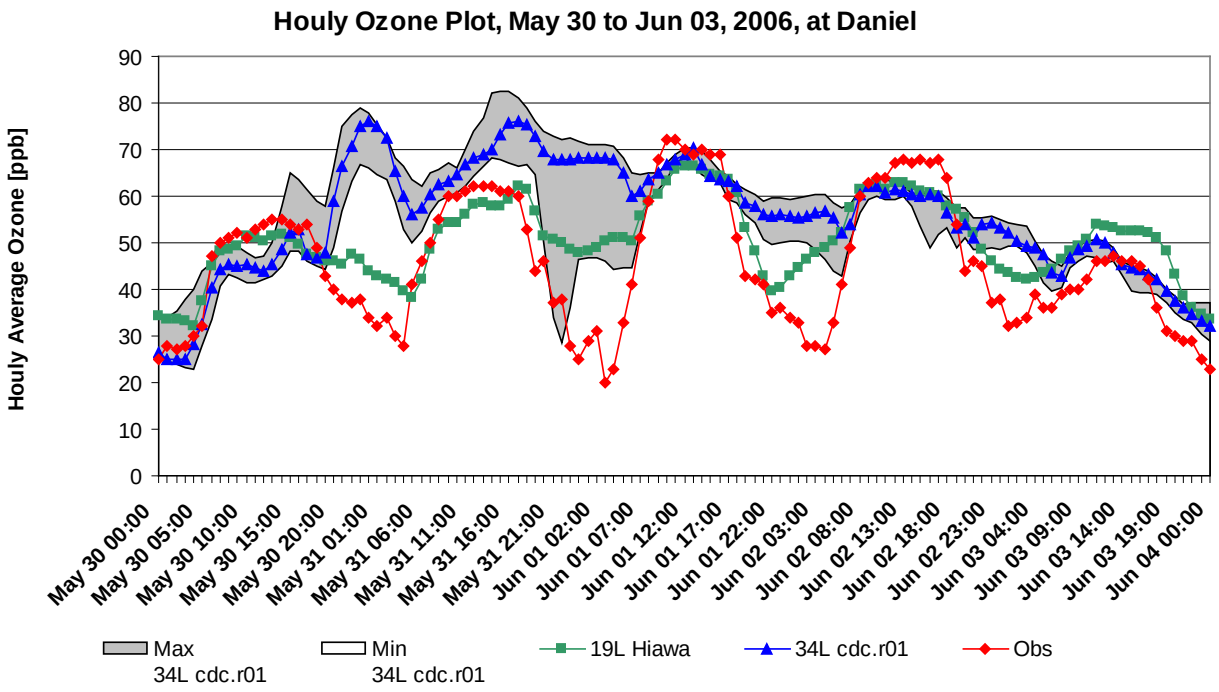


Figure A4-9b. 1-hour ozone time series for May 30-June 3, 2006.



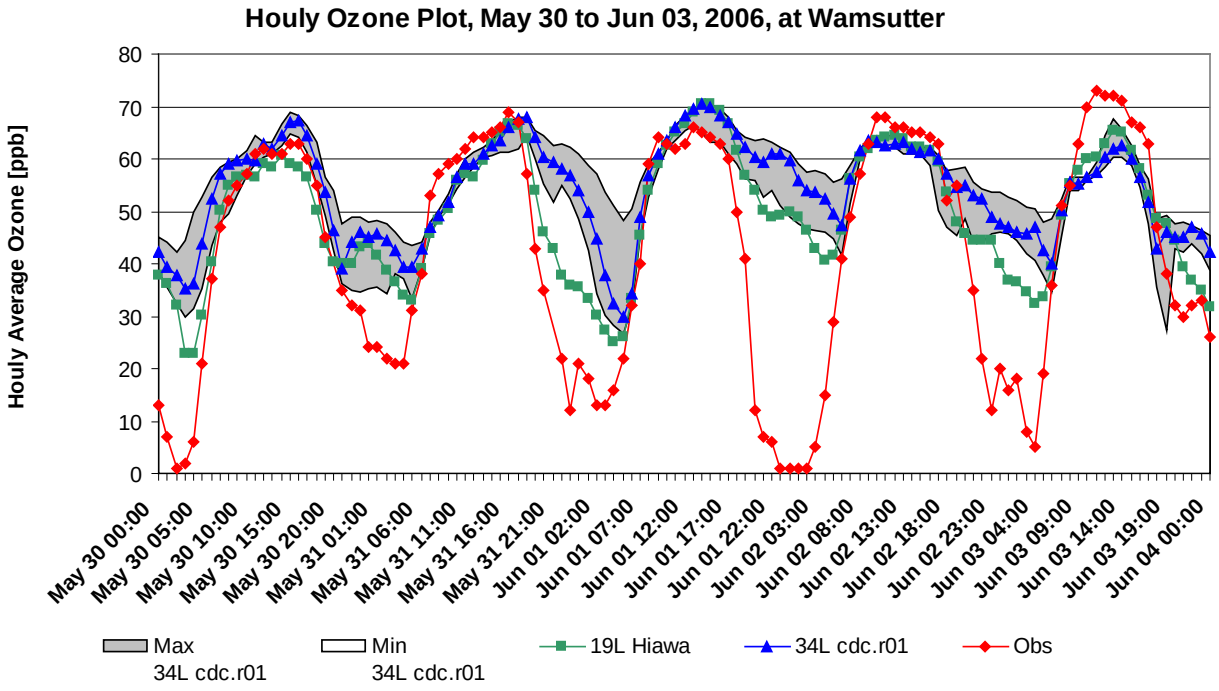


Figure A4-9c.1-hour ozone time series for May 30-June 3, 2006.

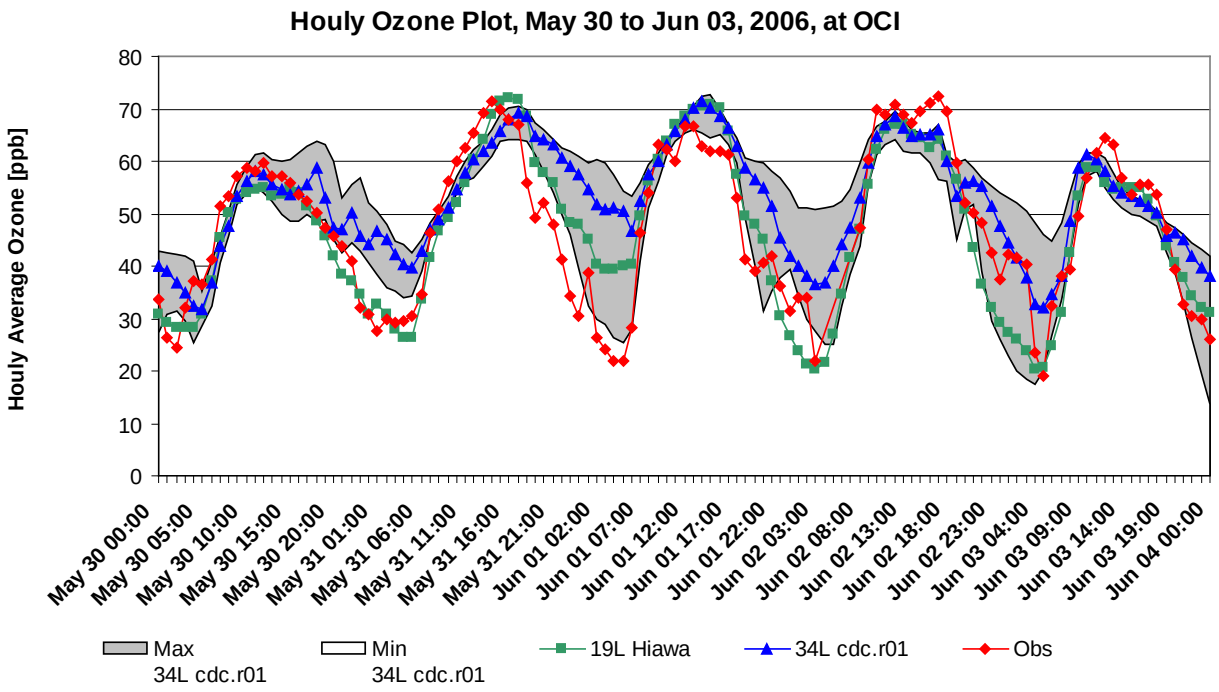
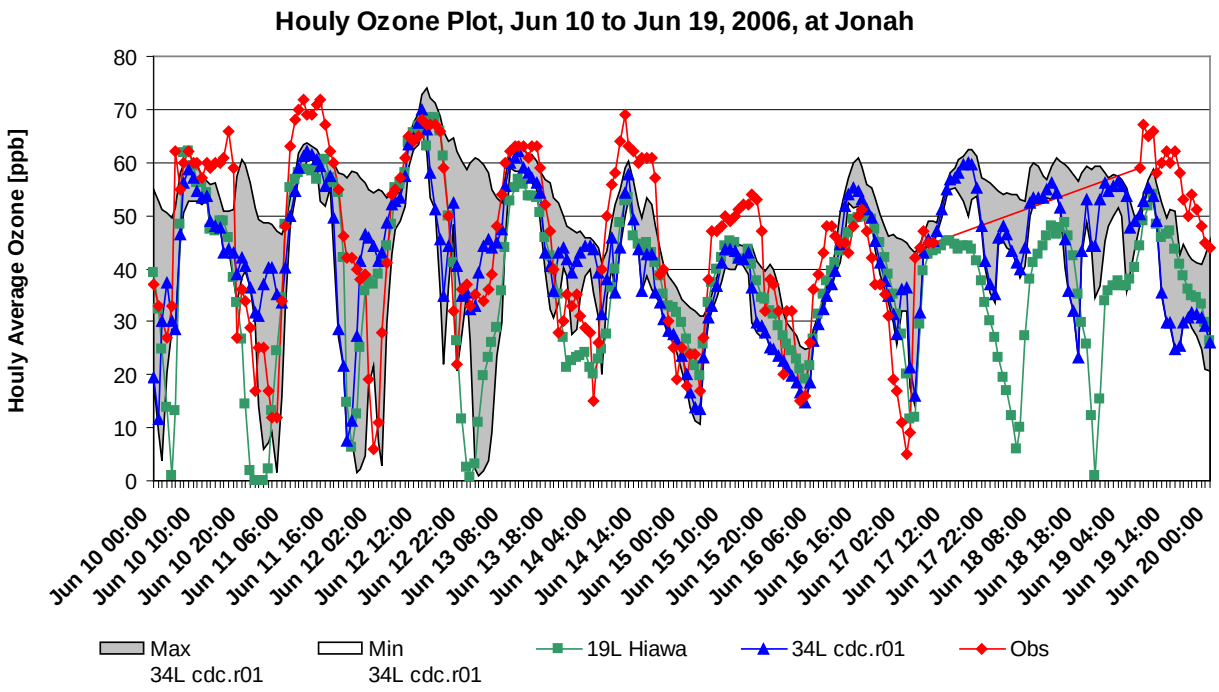


Figure A4-9d. 1-hour ozone time series for May 30-June 3, 2006.



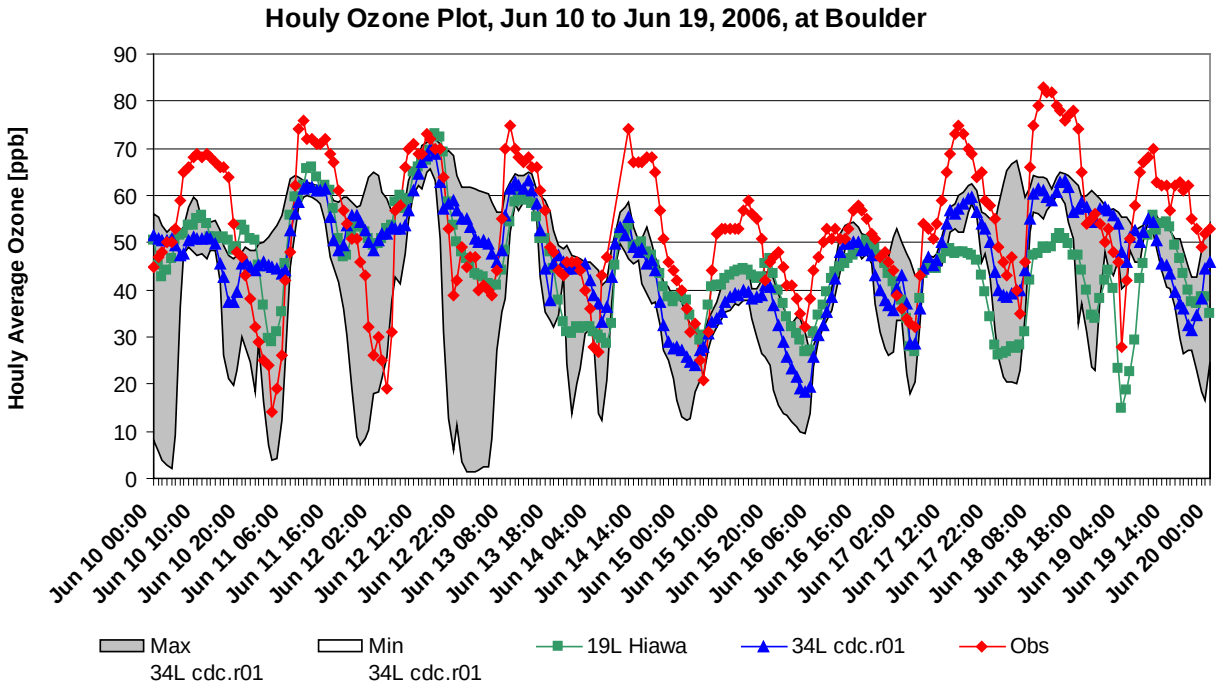
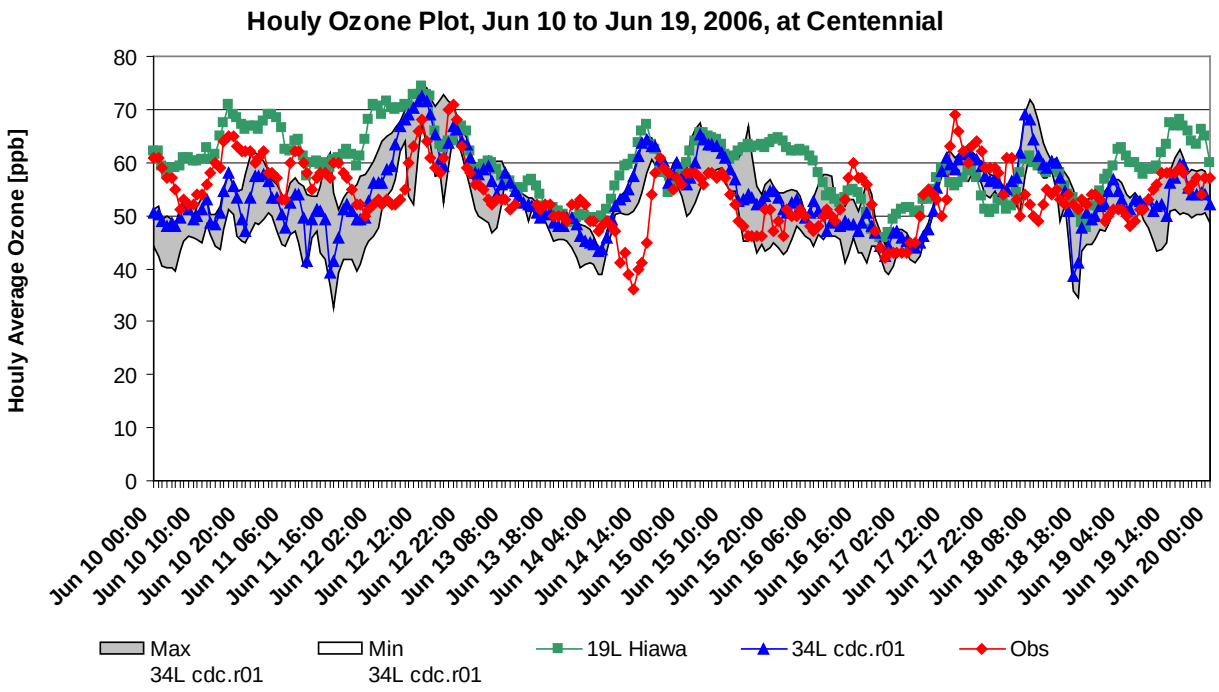


Figure A4-10a. 1-hour ozone time series for June 10-19, 2006.



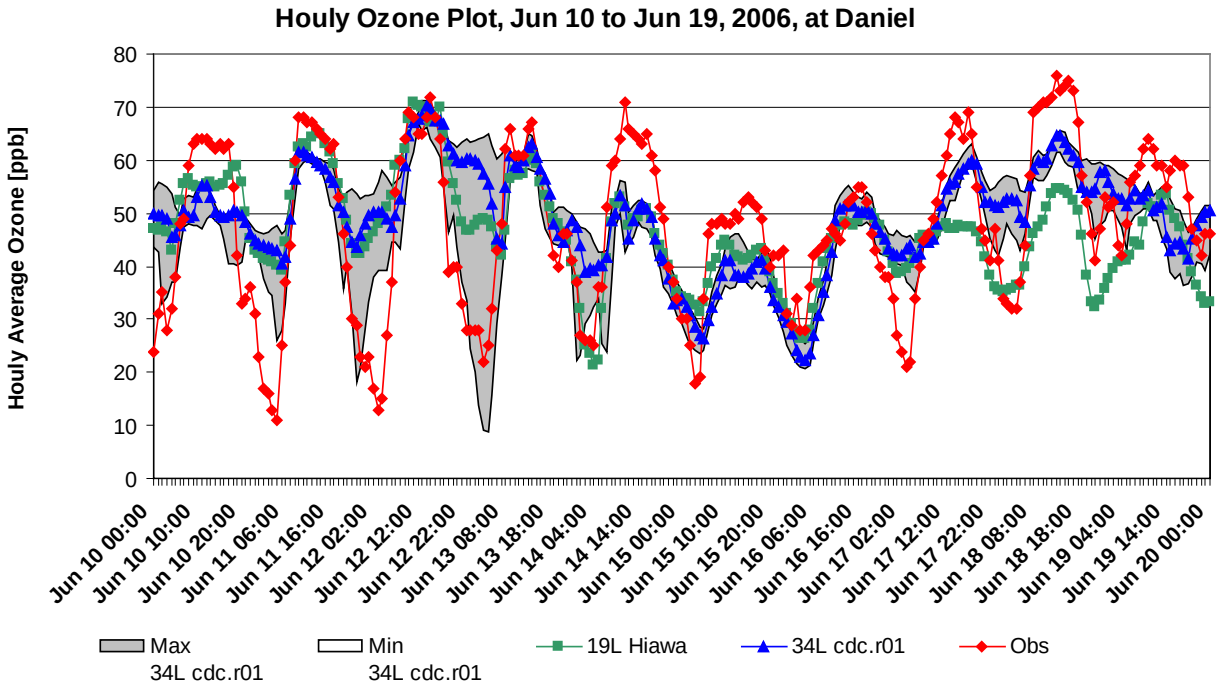
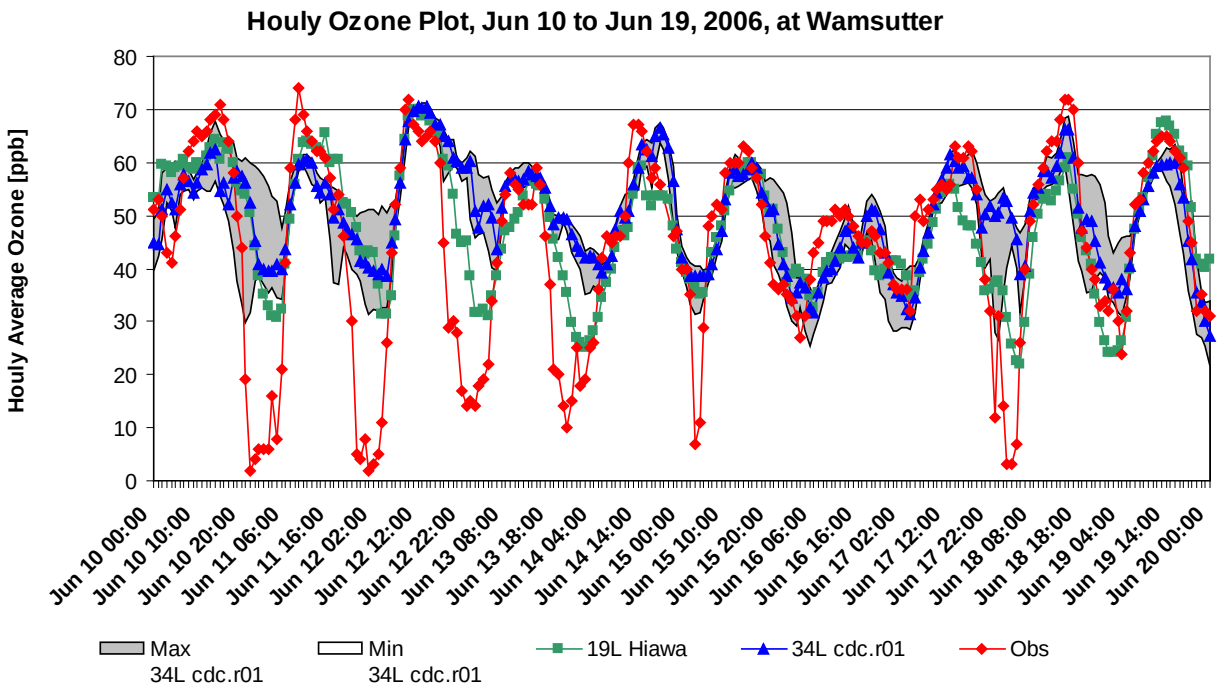


Figure A4-10b. 1-hour ozone time series for June 10-19, 2006.



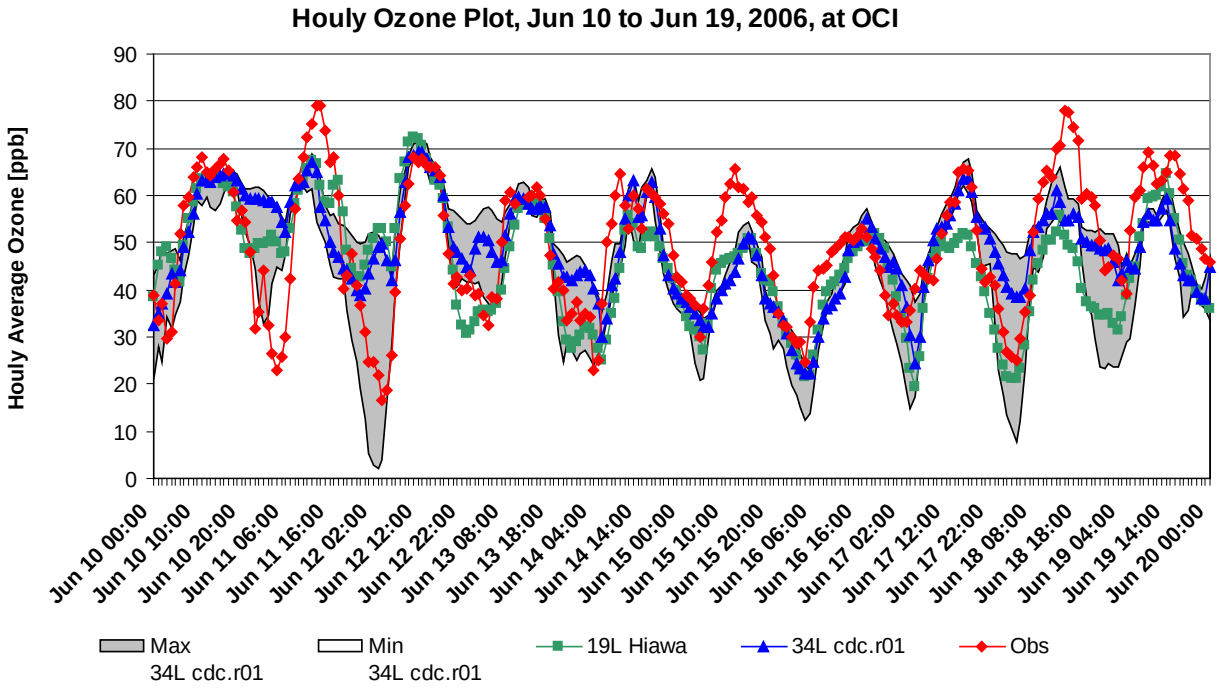
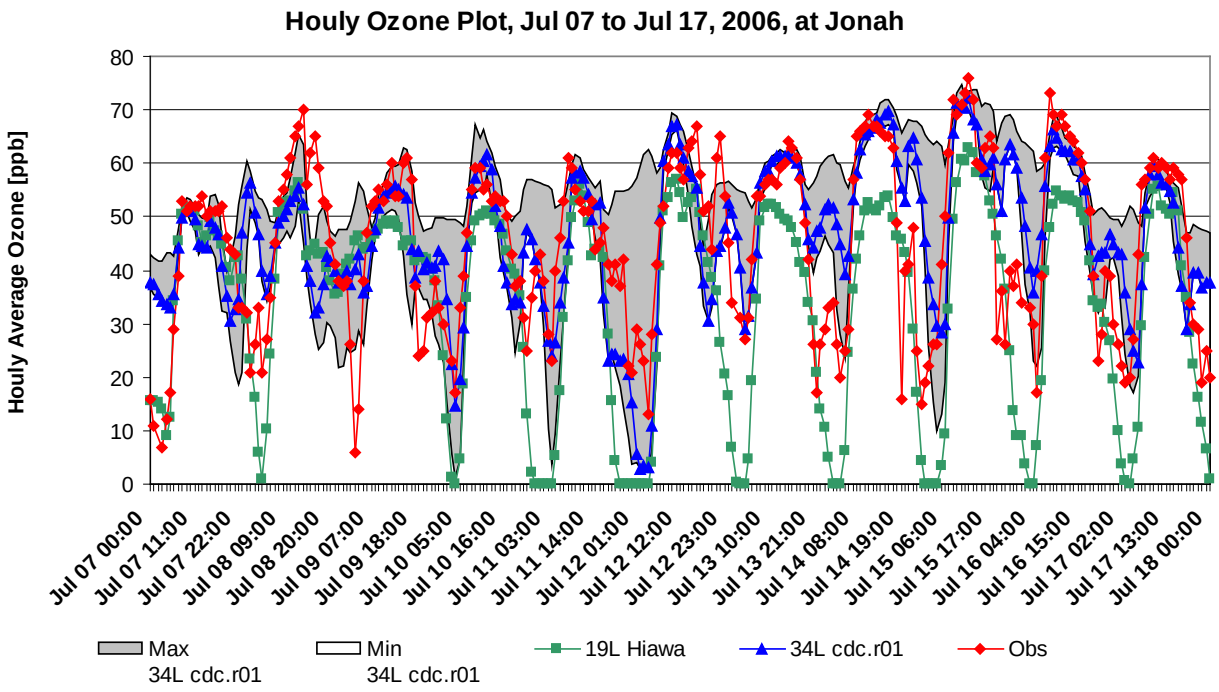


Figure A4-10c.1-hour ozone time series for June 10-19, 2006.



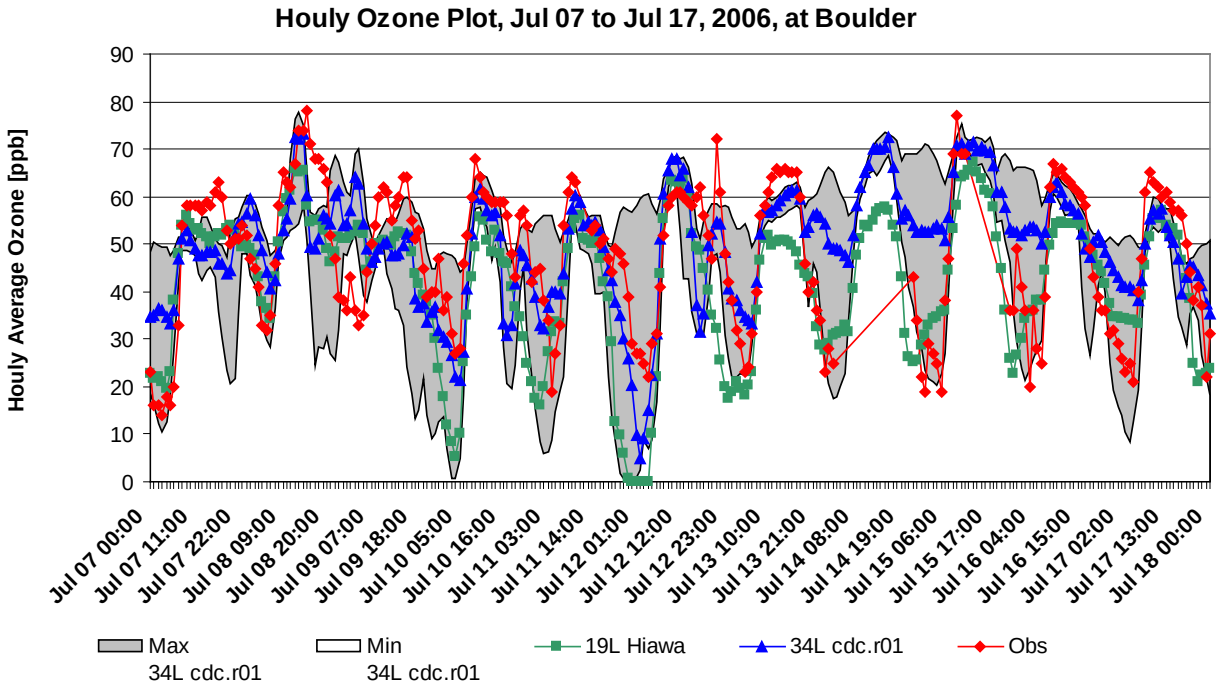
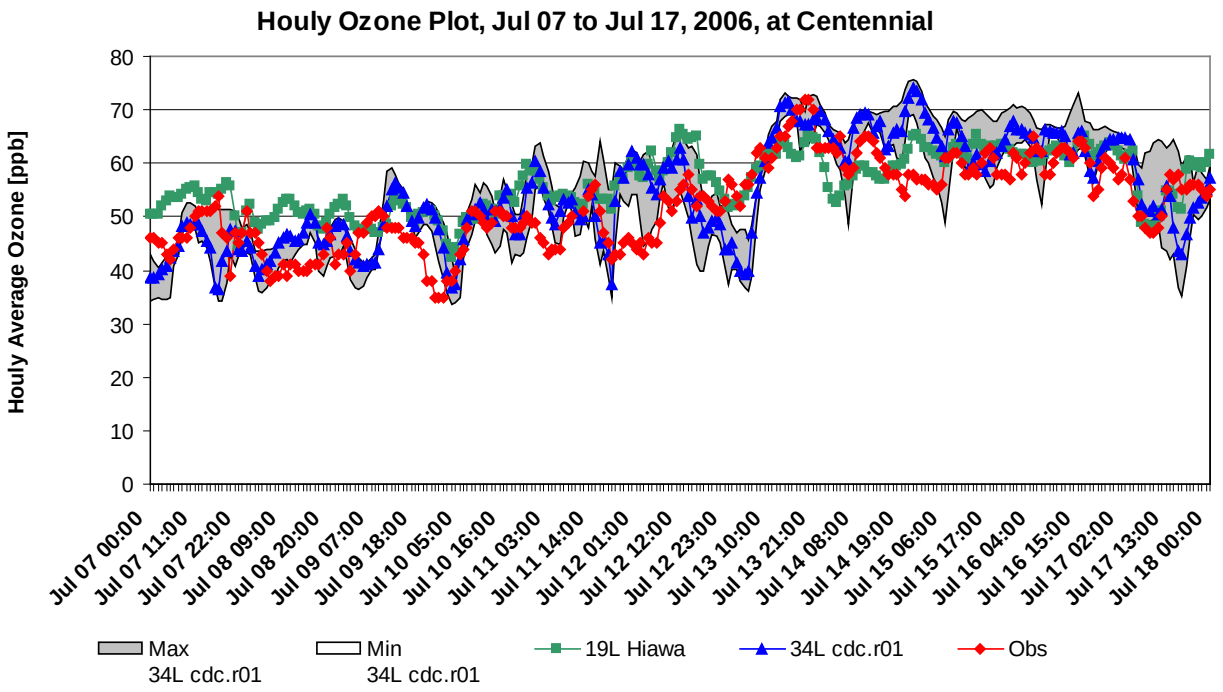


Figure A4-11a. 1-hour ozone time series for July 7-17, 2006.



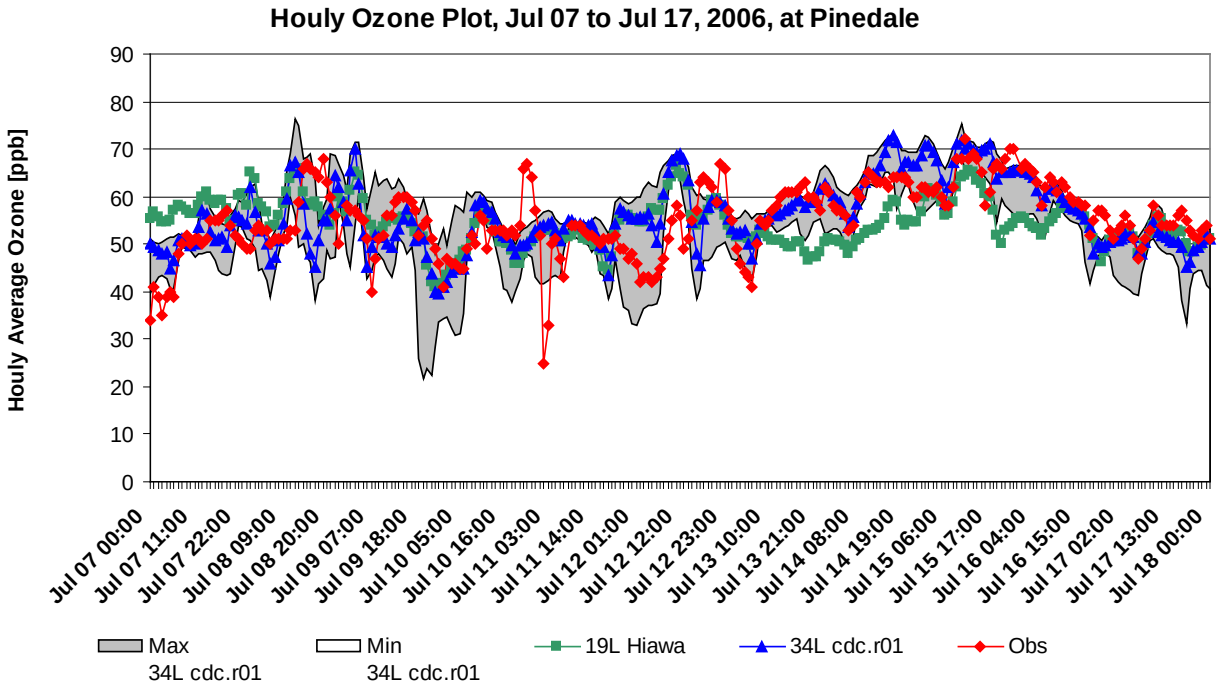
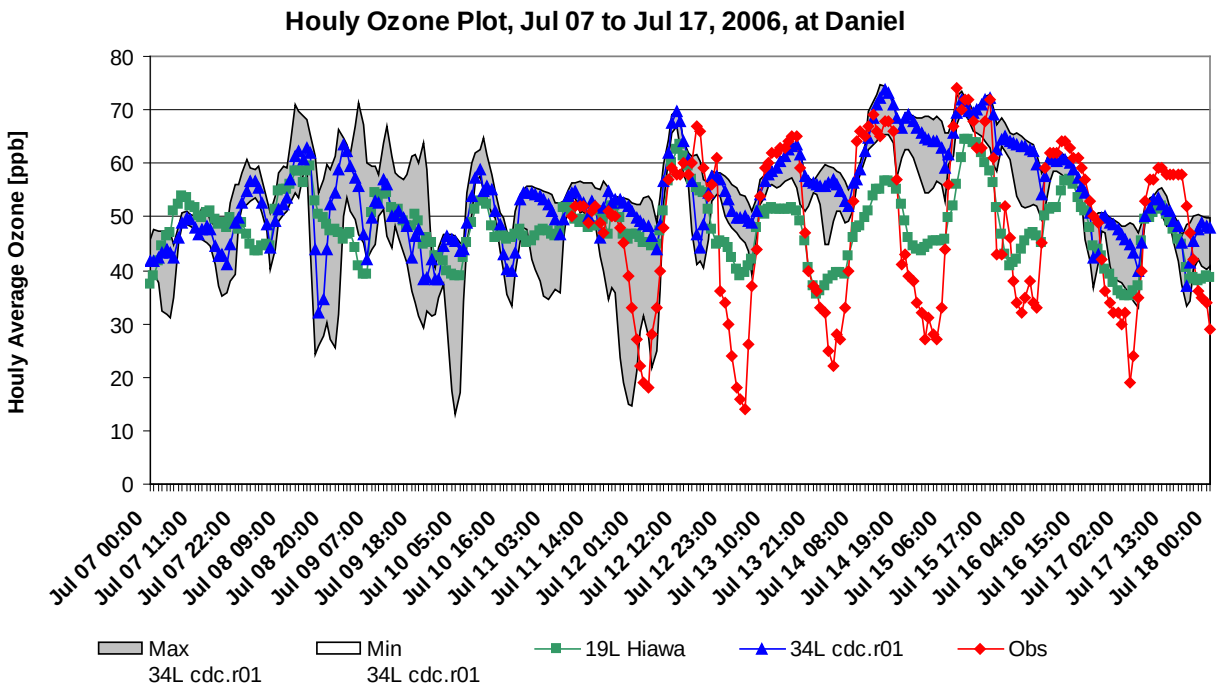


Figure A4-11b. 1-hour ozone time series for July 7-17, 2006.



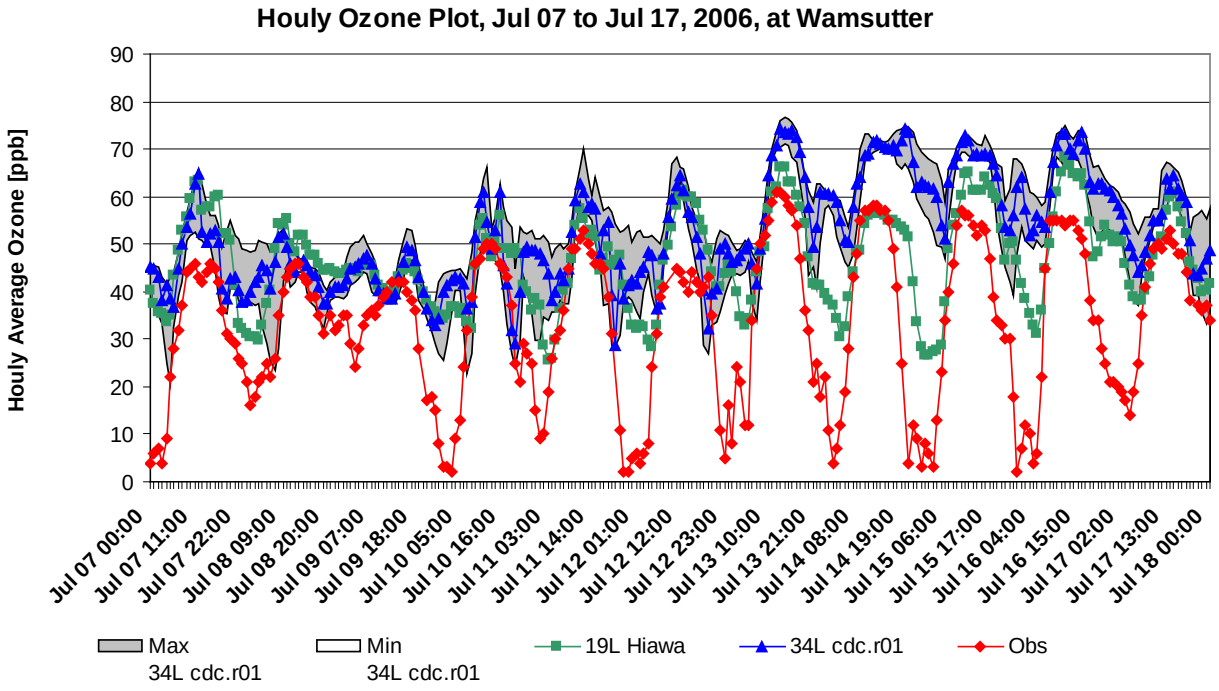


Figure A4-11c.1-hour ozone time series for July 7-17, 2006.

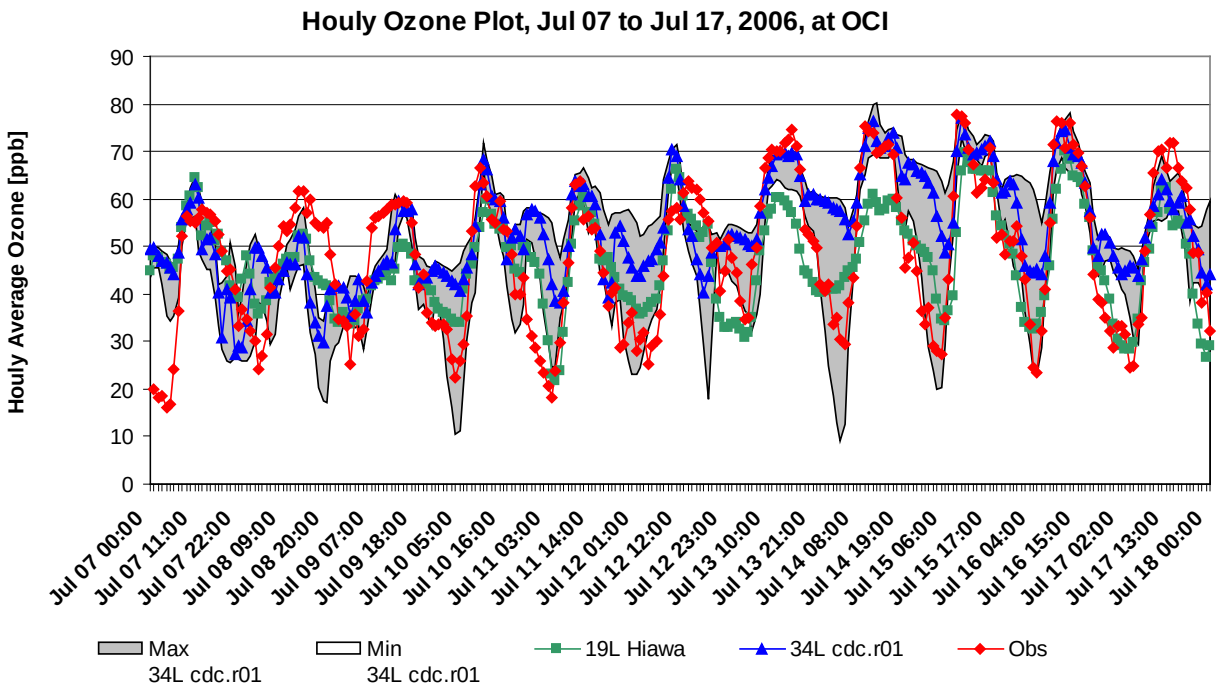
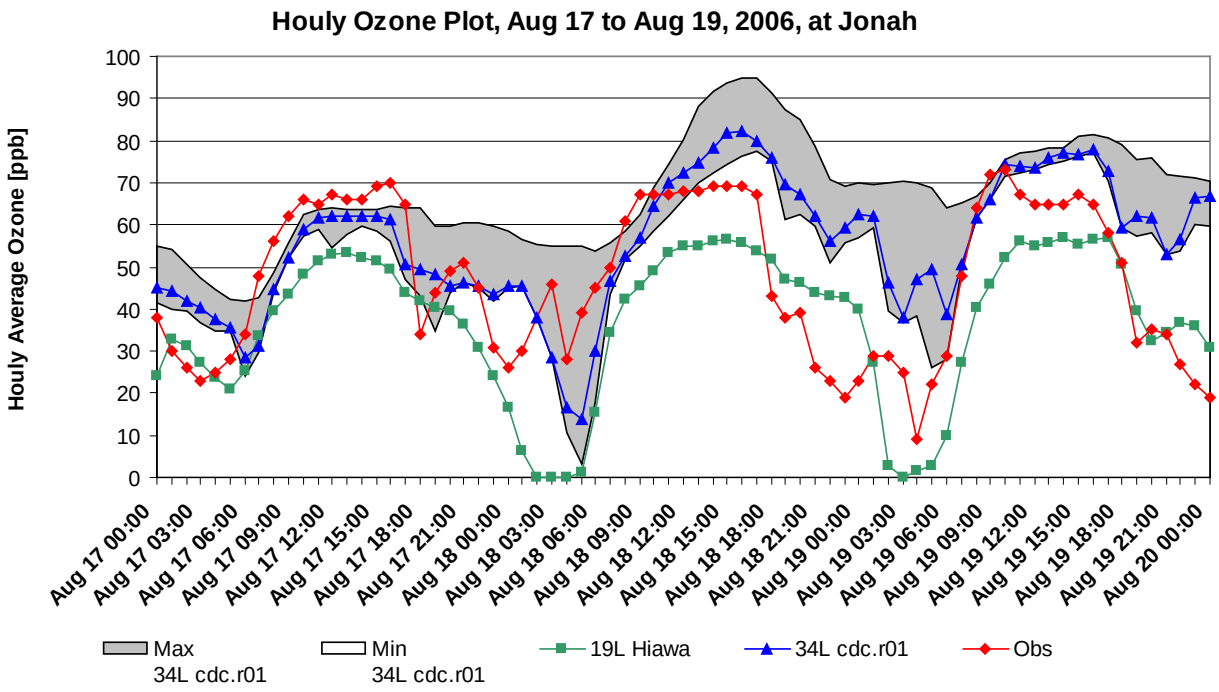


Figure A4-11d. 1-hour ozone time series for July 7-17, 2006.



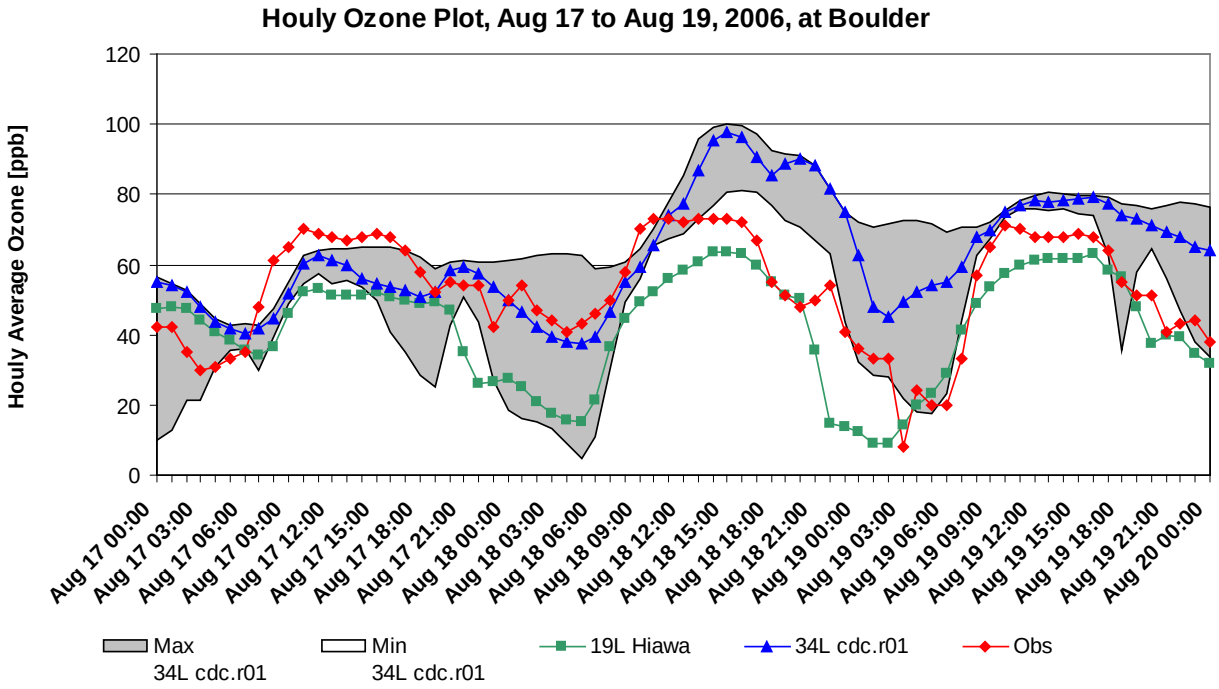
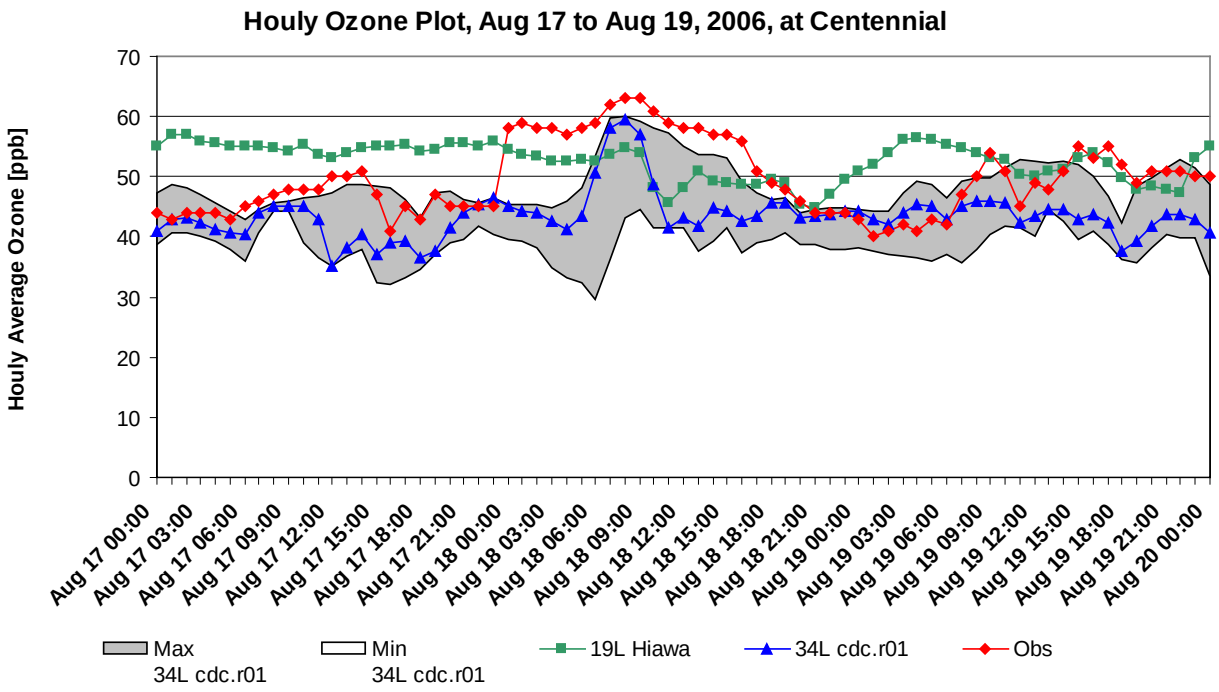


Figure A4-12a. 1-hour ozone time series for August 17-19, 2006.



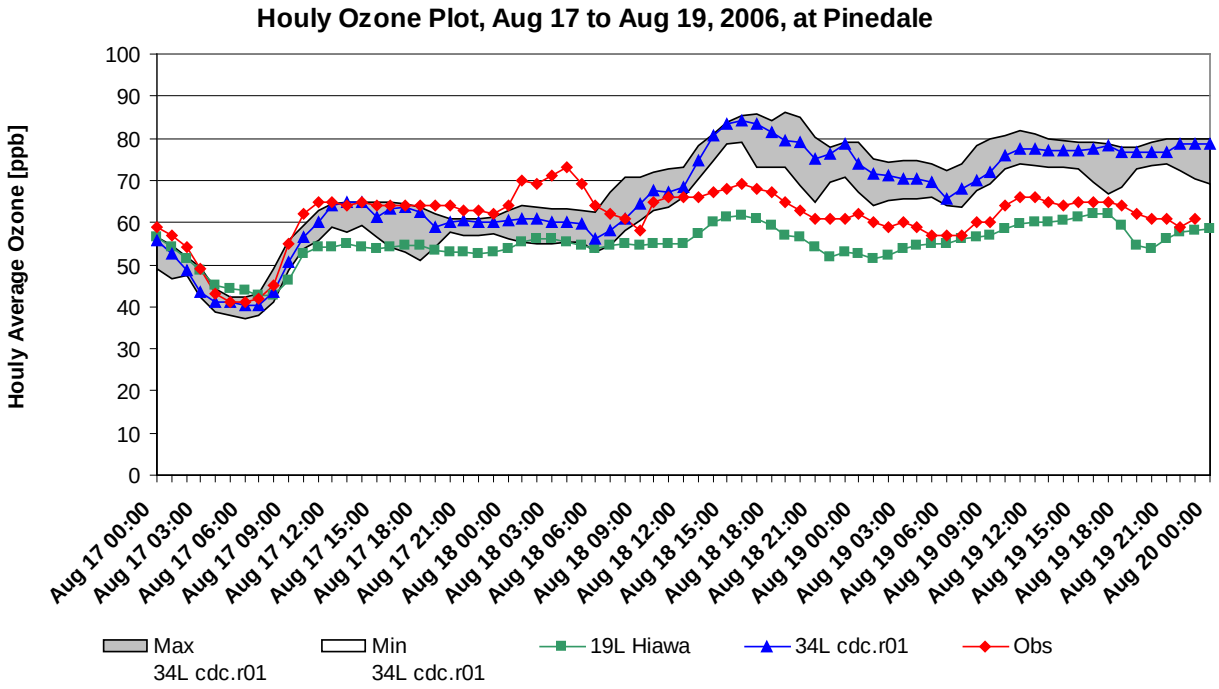
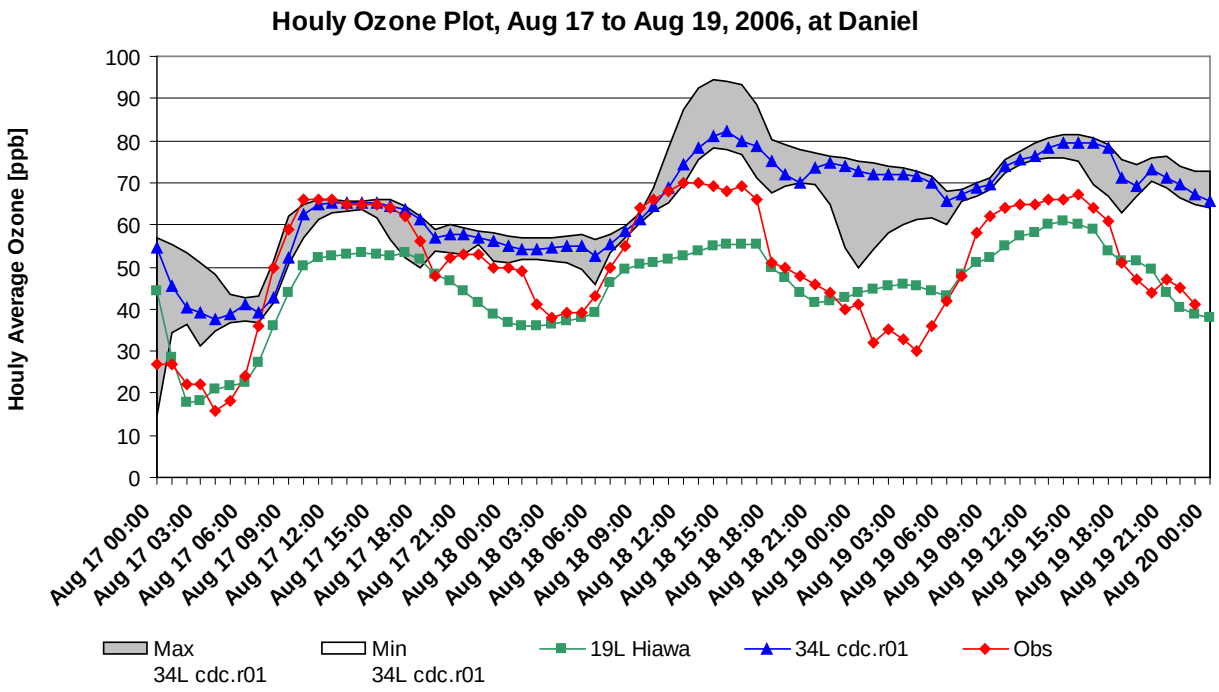


Figure A4-12b. 1-hour ozone time series for August 17-19, 2006.



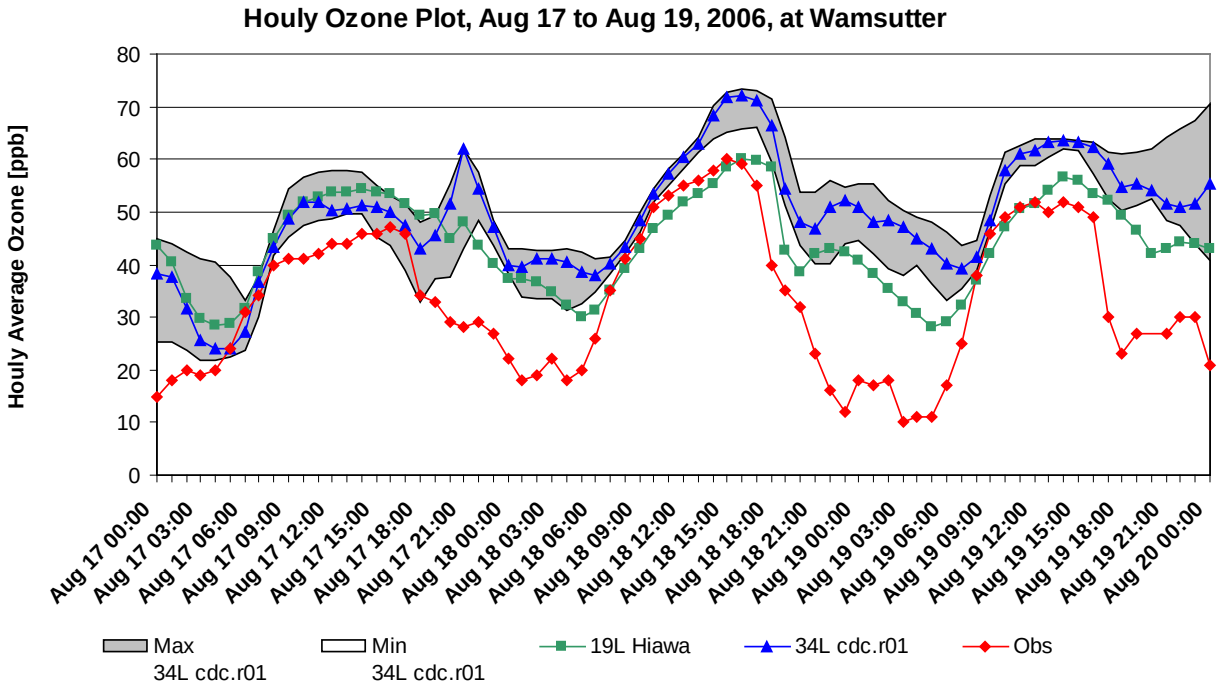


Figure A4-12c.1-hour ozone time series for August 17-19, 2006.

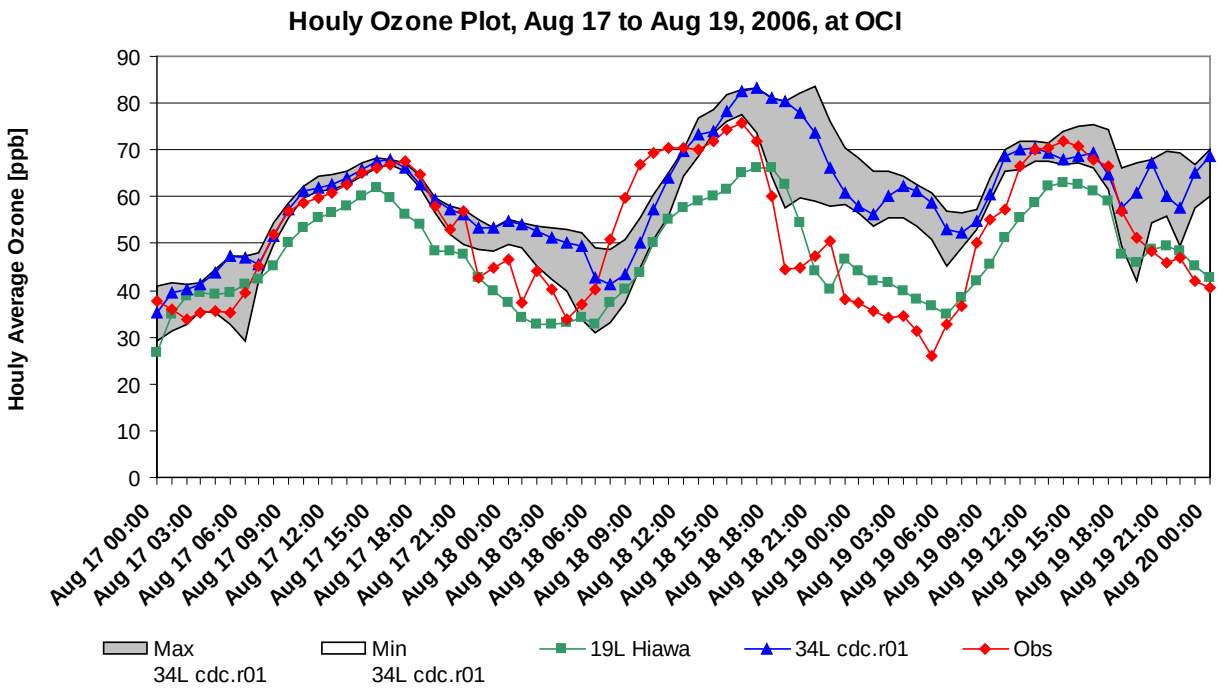


Figure A4-12d. 1-hour ozone time series for August 17-19, 2006.