# CMAQ Model Performance Evaluation

**conducted by**

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# Introduction

This document describes the evaluation of the 2001 modeling platform developed by EPA for use in support of the Clean Air Interstate Rule (CAIR). This platform consists of year-specific meteorology, anthropogenic and biogenic emissions, and boundary conditions representative of 2001 and the Community Multiscale Air Quality Model (CMAQ). Additional information on each component of this platform can be found in the CAIR docket (OAR-2003-0053).

CMAQ was run for 2001 and the resulting predictions were compared to corresponding observed data in order to evaluate the predictive capabilities of this plaform for use in simulating the various future-year scenarios examined for CAIR. This evaluation covers sulfate, nitrate, elemental carbon, organic carbon, ozone and deposition of ammonium, nitrate, and sulfate. However, sulfate and nitrate are the key species relevant to the use of this modeling system for CAIR since SO2 and NOx emissions, which are fundamental to the formation of these species, are the focus of the CAIR control program. In general, the results show that predictions of sulfate correspond closely with observations, particularly in the East. For nitrate, the modeling platform shows greatly improved performance compared to the 1996 modeling platform used in the CAIR proposal modeling (EPA, 2004). The remainder of this report describes the procedures and results of the evaluation of the 2001 modeling platform. The scope of this evaluation is greatly expanded compared to the evaluation of the 1996 platform. Specifically, for PM2.5 species this evaluation includes measurements from the **C**lean **A**ir **S**tatus and **T**rends **Net**work (CASTNet) and the **S**peciation **T**rend **N**etwork (STN) in addition to measurements from the **I**nteragency **M**onitoring of **PRO**tected **V**isual **E**nvironments (IMPROVE). This evaluation includes ozone, which was not part of the evaluation of the 1996 platform. Observed ozone data were obtained from the **A**erometric **I**nformation **R**etrieval **S**ystem (AIRS). Finally, measurements from the **N**ational **A**cid **D**eposition **P**rogram (NADP) were used to evaluate predictions of ammonium, nitrate, and sulfate deposition. Maps showing the location of the measurement sites for each network which were used in this evaluation are provided in Appendix A.

## 1. Procedures for Mapping Model Predictions to Observed Data

The IMPROVE network is a cooperative visibility monitoring effort between EPA, federal land management agencies, and state air agencies. Data is collected at Class I areas across the United States mostly at National Parks, National Wilderness Areas, and other protected pristine areas. There were approximately 134 IMPROVE rural/remote sites that had complete annual PM2.5 mass and/or PM2.5 species data for 2001. Eighty six sites were in the West[1] and forty eight sites were in the East. IMPROVE data is collected once in every three days. Thus, for each site there is a total of 104 possible samples per year or 26 samples per

[1]The dividing line between the West and East was defined as the 100th meridian.

season. For this analysis, a 50% completeness criteria was used[2]. That is, in order to be counted in the statistics a site had to have > 50% complete data in all 4 seasons. If any season was missing, an annual average was not calculated for the site.

The EPA STN network began operation in 1999 to provide nationally consistent speciated PM2.5 data for the assessment of trends at representative sites in urban areas. STN reports mass concentrations and PM2.5 constituents, including sulfate, nitrate, ammonium, and elemental and organic carbon. STN data is collected 1 in every 3 days, whereas some supplemental site are collected 1 in every 6 days. For the 2001 analysis, CMAQ predictions were evaluated against 133 STN sites (105 sites in the East and 28 sites in the West).

Model performance was also calculated using data from the CASTNet dry deposition monitoring network (total of 79 sites in 2001). The total number of sites for the East and West are 56 and 23, respectively. The sulfate and total nitrate data was used in the evaluation. CASTNet data are collected and reported as weekly average data. The data are collected in filter packs that sample the ambient air continuously during the week. The sulfate data are of high quality since sulfate is a stable compound. However, the particulate nitrate concentration data collected by CASTNet are known to be problematic and subject to volatility due to the length of the sampling period. Therefore, we chose to use the total nitrate data and not to use the particulate nitrate data in this evaluation. CASTNet also reports a total nitrate measurement, which is the combination of particulate nitrate and nitric acid. Since the total nitrate measurement is not affected by the partitioning between particulate nitrate and nitric acid, it is considered a more reliable measurement.

Wet deposition data from the NADP was also used in the model evaluation. There were a total of 225 NADP sites (144 in the East and 81 in the West) evaluated against modeled annual data for 2001. The Model results were compared to observed values of ammonium, sulfate, and nitrate wet deposition. NADP data is collected and reported as weekly average data.

Ozone data from the AIRS was used in the model evaluation where we compared 1-hour and 8-hour daily maximum observations to model predictions. There were a total of 1156 AIRS sites for which model ozone results were compared in 2001. Ozone data is collected and reported on an hourly basis. The total number of ozone sites for the East and West are 822 and 334, respectively.

The observed data used for the performance evaluation was PM2.5 mass, sulfate ion, nitrate ion, elemental carbon, organic aerosols, crustal material (soils), and ozone. The CMAQ model output species were postprocessed in order to achieve compatibility with the observation species. The following is the translation of CMAQ output species into PM2.5 and related species:

Sulfate Ion: PM_SULF = ASO4I + ASO4J

[2]The same completeness criteria was used for all of the monitoring networks.

| | |
|---|---|
| Nitrate Ion: | PM_NITR = ANO3I + ANO3J |
| Total Nitrate: | TNO3 = ANO3I + ANO3J + (2140*HNO3*DENS) |
| Organic aerosols: | PM_ORG_TOT = AORGAI + AORGAJ + 1.167*AORGPAI + 1.167*AORGPAJ + AORGBI + AORGBJ |
| Elemental Carbon: | PM_EC = AECI + AECJ |
| Crustal Material (soils): | PM_OTH = A25I +A25J |
| PM2.5: | PM2.5 = ASO4I + ASO4J + ANH4I + ANH4J + ANO3I +ANO3J + AORGAI + AORGAJ + 1.167*AORGPAI + 1.167*AORGPAJ+ AORGBI + AORGBJ + AECI + AECJ + A25I + A25J |
| Ozone: | O3 = O3 |

where, PM_SULF is particulate sulfate ion, ASO4J is accumulation mode sulfate mass, ASO4I is aitken mode sulfate mass, PM_NITR is particulate nitrate ion, ANO3J is accumulation mode nitrate mass, ANO3I is aitken mode aerosol nitrate mass, ANH4J is accumulation mode ammonium mass, ANH4I is aitken mode ammonium mass, TNO3 is total nitrate, HNO3 is nitric acid, DENS is air density, PM_ORG_TOT is total organic aerosols, AORGAJ is accumulation mode anthropogenic secondary organic mass, AORGAI is aitken mode anthropogenic secondary organic mass, AORGPAJ is accumulation mode primary organic mass, AORGPAI is aitken mode primary organic mass, AORGBJ is accumulation mode secondary biogenic organic mass, AORGBI is aitken mode biogenic secondary biogenic organic mass, PM_EC is primary elemental carbon, AECJ is accumlation mode elemental carbon mass, AECI is aitken mode elemental carbon mass, PM_OTH is primary fine particles (other unspeciated primary PM2.5), A25J is accumulation mode unspecified anthropogenic mass, A25I is aitken mode unspecified anthropogenic mass, and O3 is ozone. PM2.5 is defined as the sum of the individual species. Note that a factor of 1.167 was applied to AORGPAI and AORGPAJ since the CMAQ model assumed the conversion factor between organic carbon to organic mass is 1.2 for primary organic aerosol emission, while we assumed a 1.4 factor for the IMPROVE and STN ambient data.

## 2. Statistical Definitions

Below are the definitions of statistics used for the evaluation. The format of all the statistics is such that negative values indicate model predictions that were less than their observed counterparts. Positive statistics indicate model overestimation of observed PM and negative ones indicate model underestimation. The statistics were calculated for the entire CMAQ domain and separatately for the East and the West. The dividing line between East and West is the 100th meridian.

**Mean Observation:** The mean observed value (in μg/m$^3$) averaged over all monitored days in the year and then averaged over all sites in the region.

$$OBS = \frac{1}{N} \sum_{i=1}^{N} Obs_{x,t}^{i}$$

**Mean CMAQ Prediction:** The mean predicted value (in μg/m$^3$) paired in time and space with the observations and then averaged over all sites in the region.

$$PRED = \frac{1}{N} \sum_{i=1}^{N} Pred_{x,t}^{i}$$

**Ratio of the Means**: Ratio of the predicted over the observed values. A ratio of greater than 1 indicates on overprediction and a ratio of less than 1 indicates an underprediction.

$$RATIO = \frac{1}{N} \sum_{i=1}^{N} \frac{Pred_{x,t}^{i}}{Obs_{x,t}^{i}}$$

**Mean Bias (μg/m$^3$):** This performance statistic averages the difference (model - observed) over all pairs in which the observed values were greater than zero. A mean bias of zero indicates that the model over predictions and model under predictions exactly cancel each other out. Note that the model bias is defined such that it is a positive quantity when model prediction exceeds the observation, and vice versa. This model performance estimate is used to make statements about the absolute or unnormalized bias in the model simulation.

$$BIAS = \frac{1}{N} \sum_{i=1}^{N} (Pred_{x,t}^{i} - Obs_{x,t}^{i})$$

**Mean Fractional Bias (percent):** Normalized bias can become very large when a minimum threshold is not used. Therefore fractional bias is used as a substitute. The fractional bias for cases with factors of 2 under- and over-prediction are -67 and + 67 percent, respectively (as

opposed to -50 and +100 percent, when using normalized bias, which is not presented here). Fractional bias is a useful model performance indicator because it has the advantage of equally weighting positive and negative bias estimates. The single largest disadvantage in this estimate of model performance is that the estimated concentration (i.e., prediction, Pred) is found in both the numerator and denominator.

$$FBIAS = \frac{2}{N} \sum_{i=1}^{N} \frac{(Pred_{x,t}^{i} - Obs_{x,t}^{i})}{(Pred_{x,t}^{i} + Obs_{x,t}^{i})} * 100$$

**Mean Error ( μg/m$^3$):** This performance statistic averages the absolute value of the difference (model - observed) over all pairs in which the observed values were greater than zero. It is similar to mean bias except that the absolute value of the difference is used so that the error is always positive.

$$ERR = \frac{1}{N} \sum_{i=1}^{N} |Pred_{x,t}^{i} - Obs_{x,t}^{i}|$$

**Mean Fractional Error (percent):** Normalized error can become very large when a minimum threshold is not used. Therefore fractional error is used as a substitute. It is similar to the fractional bias except the absolute value of the difference is used so that the error is always positive.

$$FERROR = \frac{2}{N} \sum_{i=1}^{N} \frac{|Pred_{x,t}^{i} - Obs_{x,t}^{i}|}{Pred_{x,t}^{i} + Obs_{x,t}^{i}} * 100$$

**Correlation Coefficient ($R^2$):** This performance statistic measures the degree to which two variables are linearly related. A correlation coefficient of 1 indicates a perfect linear relationship, whereas a correlation coefficient of 0 means that there is no linear relationship

$$CORRCOEFF = \frac{\sum_{i=1}^{N} (Pred_i - \overline{Pred})\,(Obs_i - \overline{Obs})}{\sqrt{\sum_{i=1}^{N} (Pred_i - \overline{Pred})^2 \sum_{i=1}^{N} (Obs_i - \overline{Obs})^2}}$$

between the variables.

## 3. Results of CMAQ Performance Evaluation

The statistics described above are presented separately for the entire domain, the East, and the West. These statistics were calculated for observations and model predictions that were paired in time and space on a daily or weekly basis, depending on the sampling period of each network. Additional statistics tables are provided in Appendix B. The statistics are supplemented with scatterplots of seasonal average and annual average predictions versus observations paired by site. The scatter plots are annotated with the correlation coefficients for the data shown on the plot. Finally, a spatial analysis is provided for sulfate and nitrate to examine how well the platform predicts spatial patterns and gradients evident from the observations.

### a. Sulfate Performance

#### *a.1. IMPROVE Performance*

Table 1 lists the performance statistics for particulate sulfate at the IMPROVE sites. Domainwide, sulfate is overpredicted by 2%. The annual average sulfate for the East is overpredicted by 9% and underpredicted 13% in the West. The annual sulfate performance (especially in the East) is better than most of the other PM2.5 species. The annual fractional error in the East is ~46% and the $R^2$ is 0.74**.**

**Table 1.** Annual mean sulfate ion performance at IMPROVE sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 13447 | 1.72 | 1.68 | 1.02 | 0.04 | 0.94 | 0.67 | 45.67 | 0.74 |
| East | 4771 | 3.62 | 3.34 | 1.09 | 0.29 | 7.00 | 1.22 | 39.56 | 0.68 |
| West | 8676 | 0.67 | 0.77 | 0.87 | -0.10 | -2.39 | 0.36 | 49.02 | 0.28 |

Figures 1 and 2 show the annual and seasonal average sulfate 2001 IMPROVE observations versus CMAQ predictions respectively. The scatterplots and linear regressions displayed strong correlations (annual: $R^2 = 0.96$; summer: $R^2 = 0.94$; fall: $R^2 = 0.96$; spring: $R^2 = 0.94$; and winter: $R^2 = 0.80$).

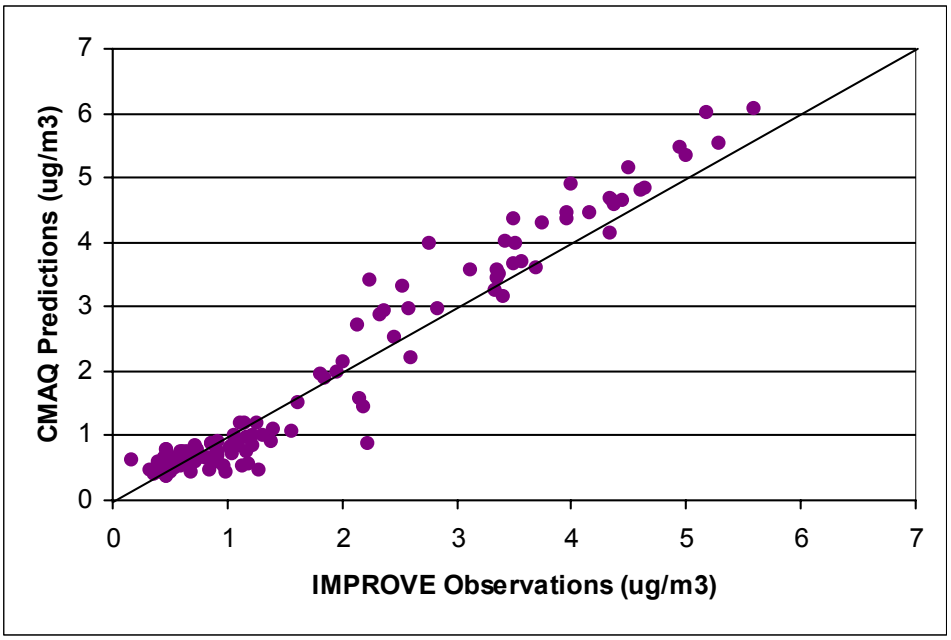



**Figure 1.** Annual average sulfate 2001 IMPROVE observations versus CMAQ predictions.

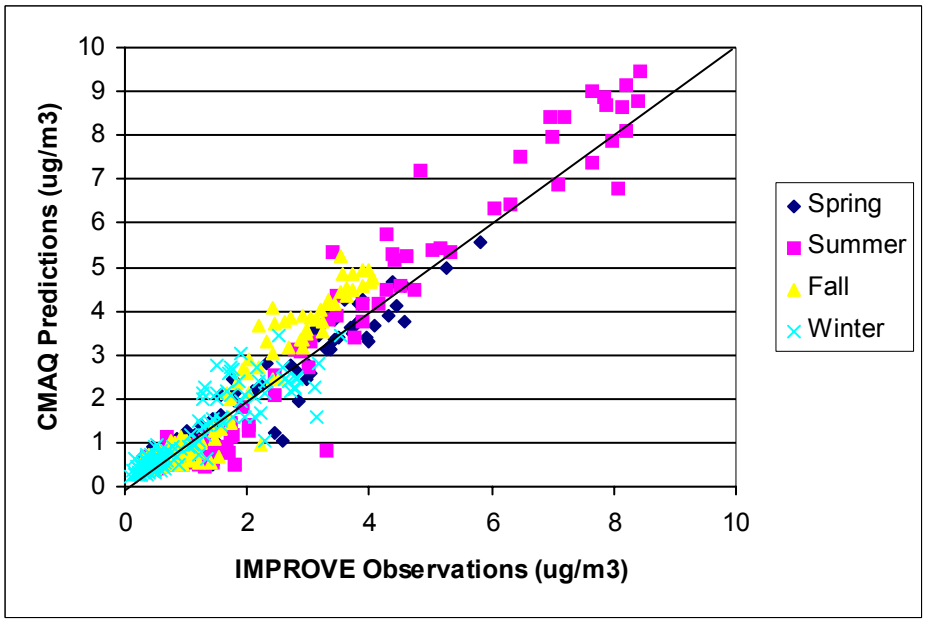



**Figure 2.** Seasonal average sulfate 2001 IMPROVE observations versus CMAQ predictions.

*a.2. STN Performance*

Table 2 lists the performance statistics for particulate sulfate at the STN sites. Nationally, CMAQ overpredicted sulfate by only 6% compared to the STN network. The annual average sulfate for the East is overpredicted by 11% and underpredicted by 36% in the West. The annual sulfate performance is encouraging (similar to IMPROVE SO4 performance) and better than most of the other PM2.5 species. The annual fractional error in the East is ~46% and the $R^2$ is 0.61**.**

**Table 2.** Annual mean sulfate ion performance at STN sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 6970 | 3.40 | 3.40 | 1.06 | 0.22 | -0.54 | 1.47 | 46.15 | 0.61 |
| East | 5414 | 4.37 | 3.93 | 1.11 | 0.44 | 8.43 | 1.67 | 44.53 | 0.59 |
| West | 1556 | 1.00 | 1.56 | 0.64 | -0.55 | -31.74 | 0.78 | 51.78 | 0.16 |

Figures 3 and 4 show the annual and seasonal average sulfate 2001 STN observations versus CMAQ predictions respectively. The scatterplots and linear regressions displayed strong correlations (annual: $R^2 = 0.83$; summer: $R^2 = 0.82$; fall: $R^2 = 0.67$; spring: $R^2 = 0.54$; and winter: $R^2 = 0.56$).

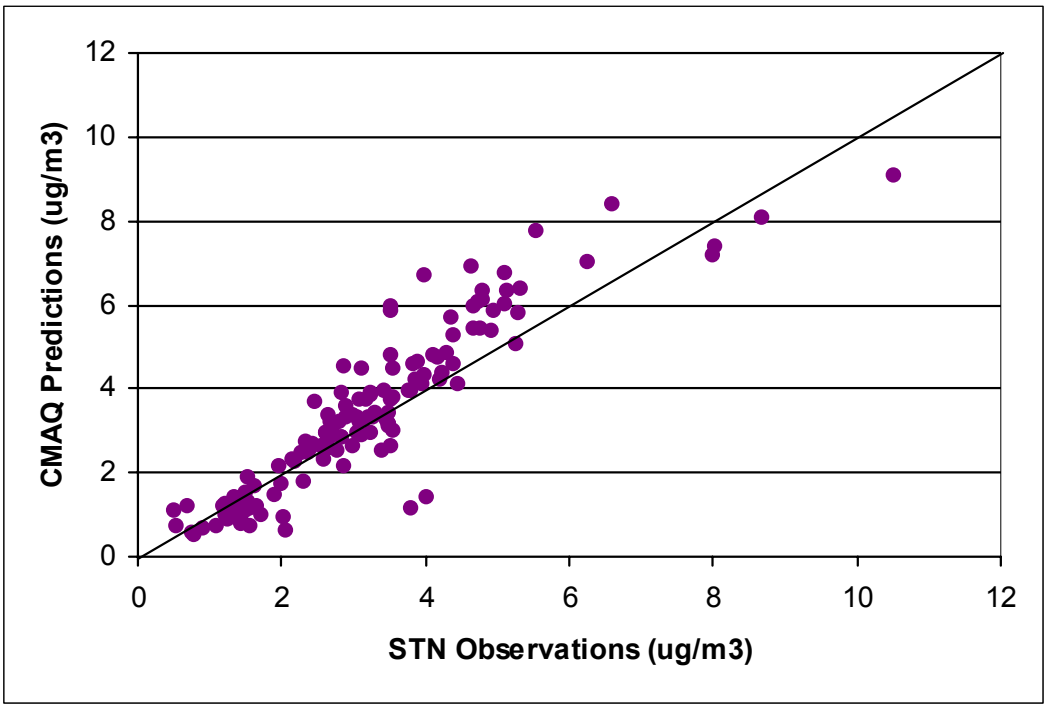



**Figure 3.** Annual total sulfate ($SO_4$) 2001 STN observations versus CMAQ predictions.

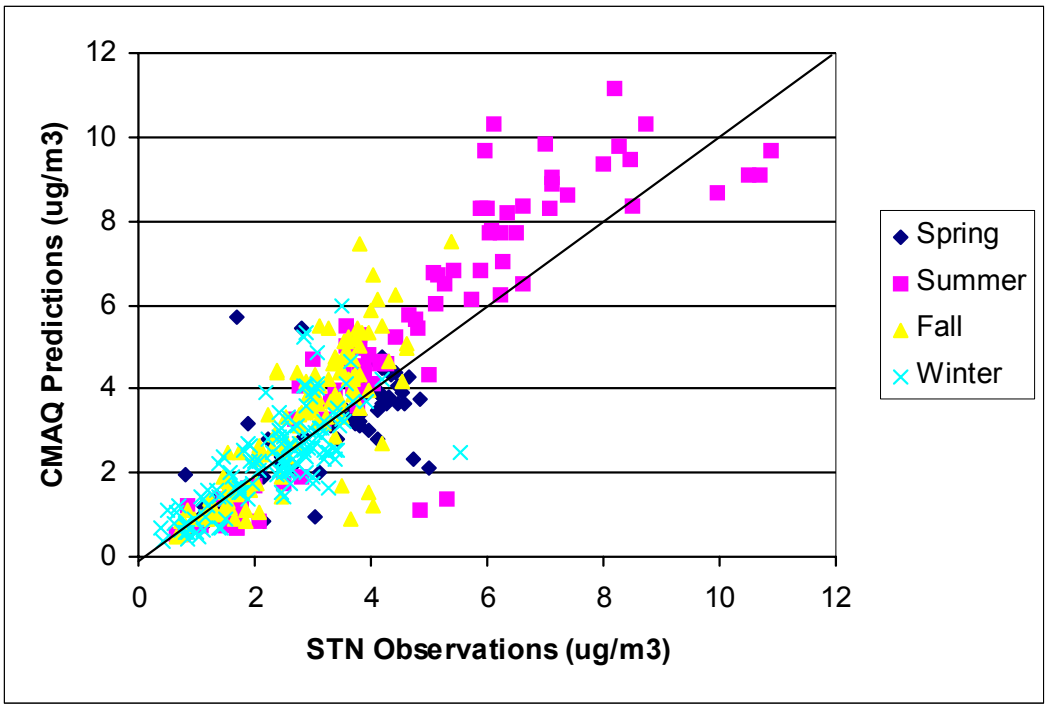



**Figure 4.** Seasonal total sulfate ($SO_4$) 2001 STN observations versus CMAQ predictions.

*a.3. CASTNet Performance*

Figure 5 shows the seasonal 2001 CASTNet observations versus CMAQ predictions for total sulfate. The scatterplot and linear regression of sulfate showed very good agreement, with strong correlations among all seasons (annual: $R^2 = 0.97$; summer: $R^2 = 0.95$; fall: $R^2 = 0.95$; spring: $R^2 = 0.95$; winter: $R^2 = 0.89$). The performance of sulfate at the CASTNet sites looks better than at the IMPROVE sites, as well better than the performance results from the CAIR proposal modeling. The CASTNet sites measure data on a weekly average basis as compared to the IMPROVE one in three day sampling schedule. There are also more CASTNet sites in the high sulfate region of the East (e.g. the Ohio Valley). The CASTNet long term averaging of data seems particularly well suited for comparisons to seasonal average modeled concentrations.

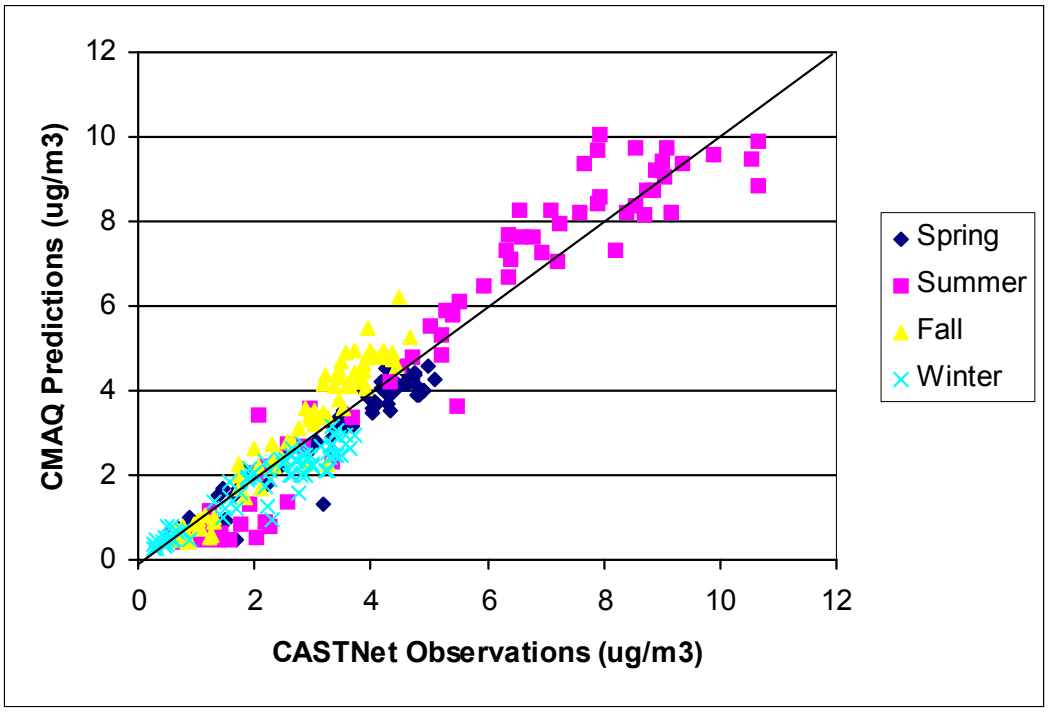



**Figure 5.** Seasonal average sulfate ($SO_4$) 2001 CASTNet observations versus CMAQ predictions.

*a.4. NADP Wet Deposition Performance*

Figure 6 shows the annual 2001 NADP observations versus CMAQ predictions for sulfate wet deposition. The scatterplot and linear regression show some scatter (underprediction bias sulfate wet deposition), but good agreement, with good correlation: $R^2 = 0.78$.

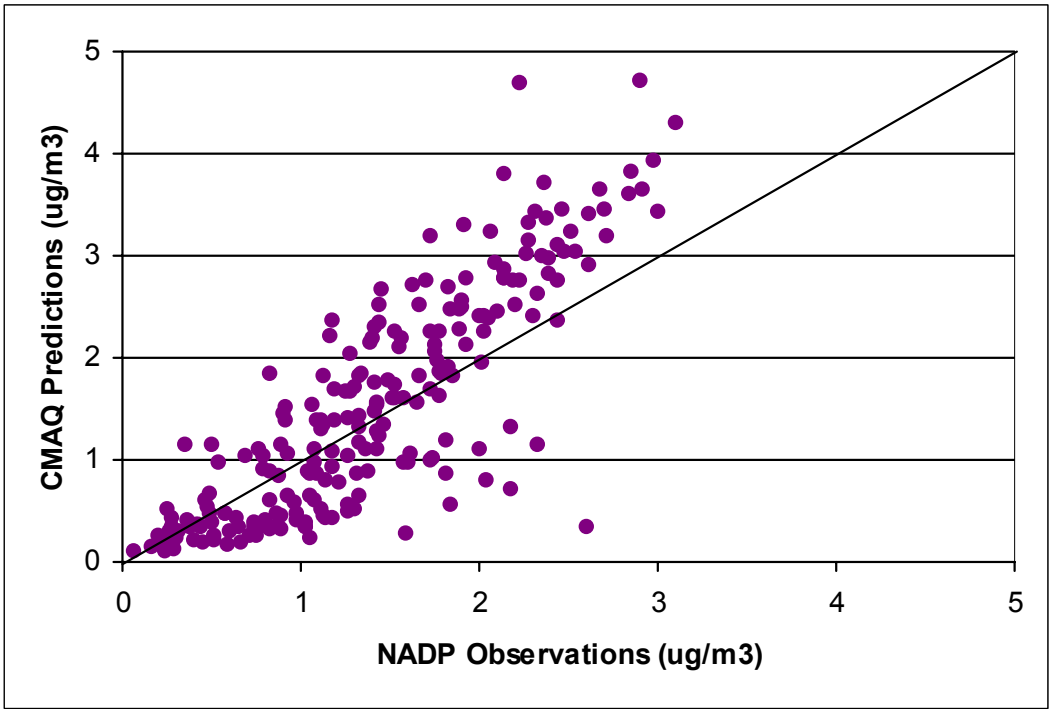



**Figure 6.** Annual total sulfate ($SO_4$) wet deposition 2001 NADP observations versus CMAQ predictions.

b. Nitrate Performance

*b.1. IMPROVE Performance*

Table 3 lists the performance statistics for nitrate ion at the IMPROVE sites. Nitrate is overpredicted by 27% domainwide. Nitrate is generally overpredicted in the East (58%) and underpredicted in the West (2%).

**Table 3.** Annual mean nitrate ion performance at IMPROVE sites.

| | No. of Obs | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 13398 | 0.61 | 0.48 | 1.27 | 0.13 | -39.71 | 0.49 | 112.04 | 0.35 |
| East | 4755 | 1.04 | 0.66 | 1.58 | 0.38 | -31.90 | 0.74 | 107.04 | 0.44 |
| West | 8643 | 0.37 | 0.38 | 0.98 | -0.01 | -44.01 | 0.36 | 114.79 | 0.23 |

Likewise, this overprediction is depicted in Figures 7 and 8, which show the scatterplots of the annual ($R^2$= 0.63) and seasonal (summer: $R^2$= 0.49; fall: $R^2$= 0.43; spring: $R^2$= 0.77; winter: $R^2$= 0.50) average nitrate ion for 2001 IMPROVE observations versus CMAQ predictions.

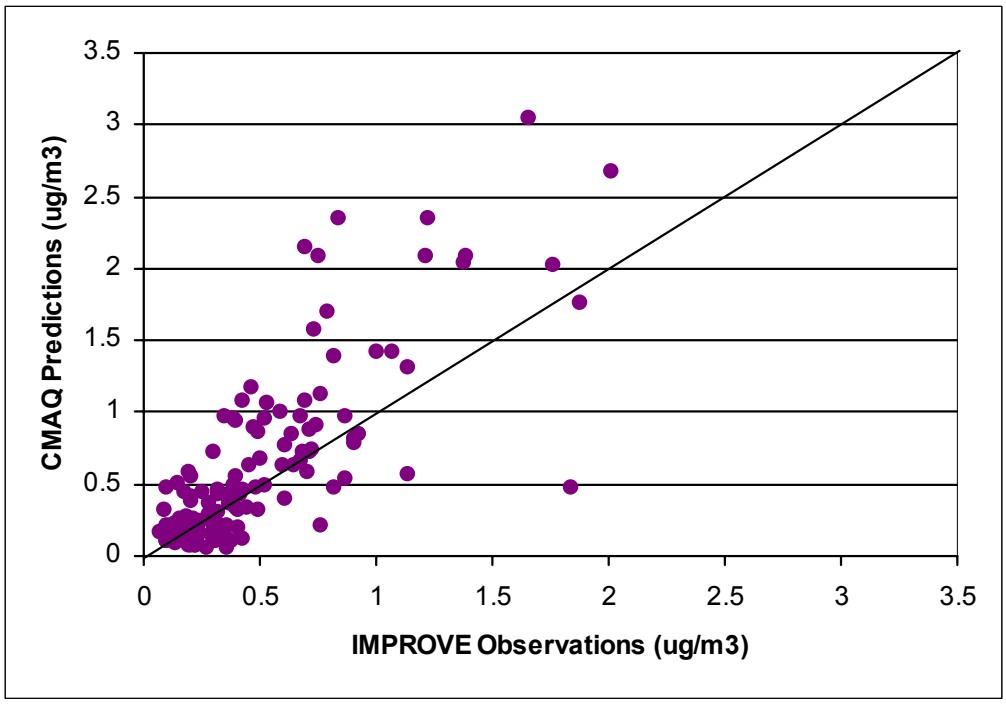



**Figure 7.** Annual average nitrate ion 2001 IMPROVE observations versus CMAQ predictions.

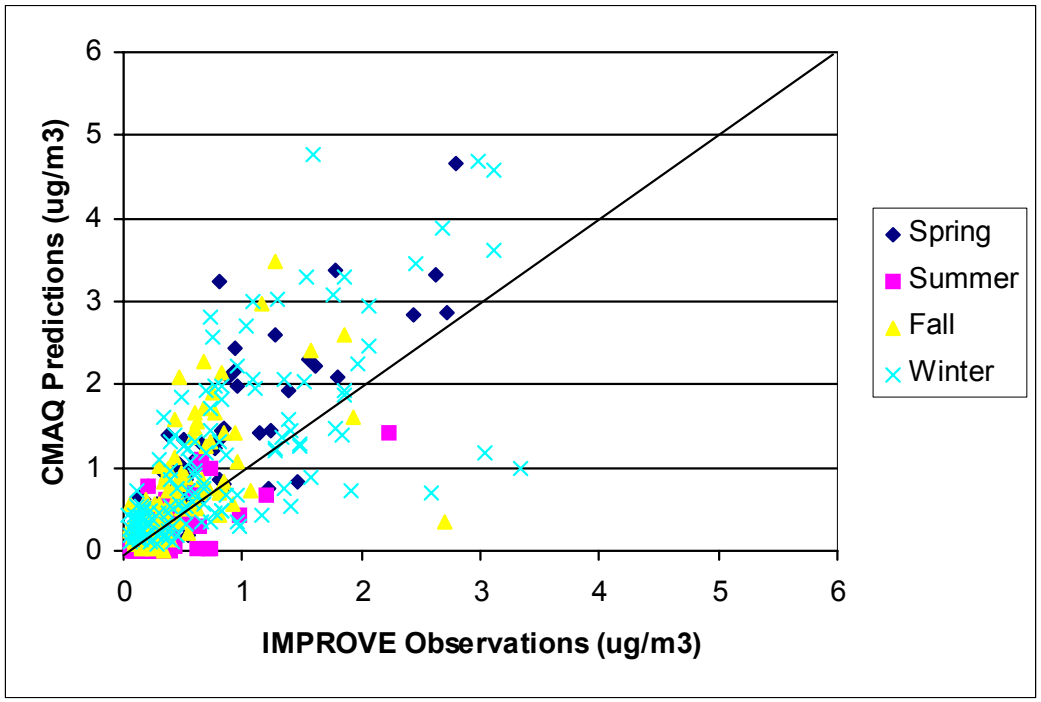



**Figure 8.** Seasonal average nitrate ion 2001 IMPROVE observations versus CMAQ predictions.

It is important to consider these results in the context that the observed nitrate concentrations at the IMPROVE sites are very low. The mean nationwide observations are only 0.48 $\mu g/m^3$. It is often difficult for models to replicate very low concentrations of secondarily formed pollutants. Nitrate is generally a small percentage of the measured PM2.5 at almost all of the IMPROVE sites. Nonetheless, it has been recognized that the current generation of PM air quality models generally overpredict particulate nitrate. Numerous improvements have been made to the CMAQ modeling system and nitrate performance has continued to improve, Additional ongoing efforts are expected to further improve nitrate predictions over time.

*b.2. STN Performance*

Table 4 lists the performance statistics for nitrate ion at the STN sites. Nitrate is underpredicted by 5% domainwide. Nitrate is generally overpredicted in the East (28%) and underpredicted in the West (66%).

**Table 4.** Annual mean nitrate ion performance at STN sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 6130 | 1.69 | 1.77 | 0.95 | -0.08 | -31.19 | 1.41 | 93.02 | 0.18 |
| East | 4662 | 1.94 | 1.52 | 1.28 | 0.42 | -11.90 | 1.23 | 86.03 | 0.38 |
| West | 1468 | 0.86 | 2.55 | 0.34 | -1.68 | -92.44 | 1.99 | 115.22 | 0.21 |

Figures 9 and 10, which show the scatterplots of the annual ($R^2$= 0.12) and seasonal (summer: $R^2$= 0.16; fall: $R^2$= 0.08; spring: $R^2$= 0.63; winter: $R^2$= 0.13) average nitrate ion for 2001 STN observations verus CMAQ predictions.

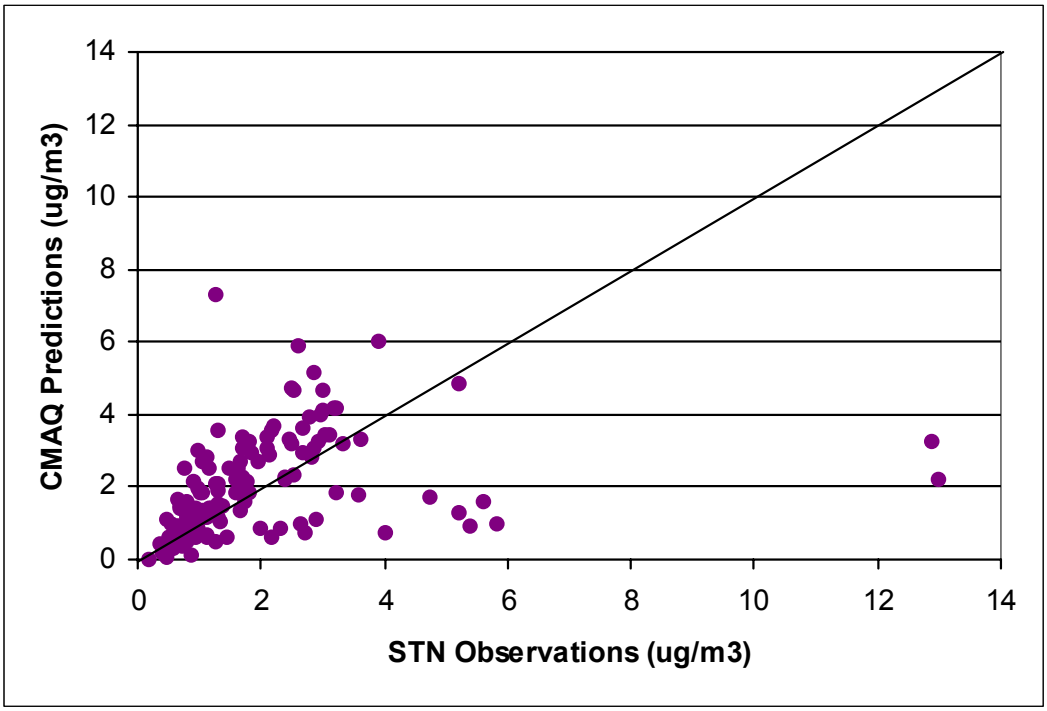



**Figure 9.** Annual average nitrate ion 2001 STN observations versus CMAQ predictions.

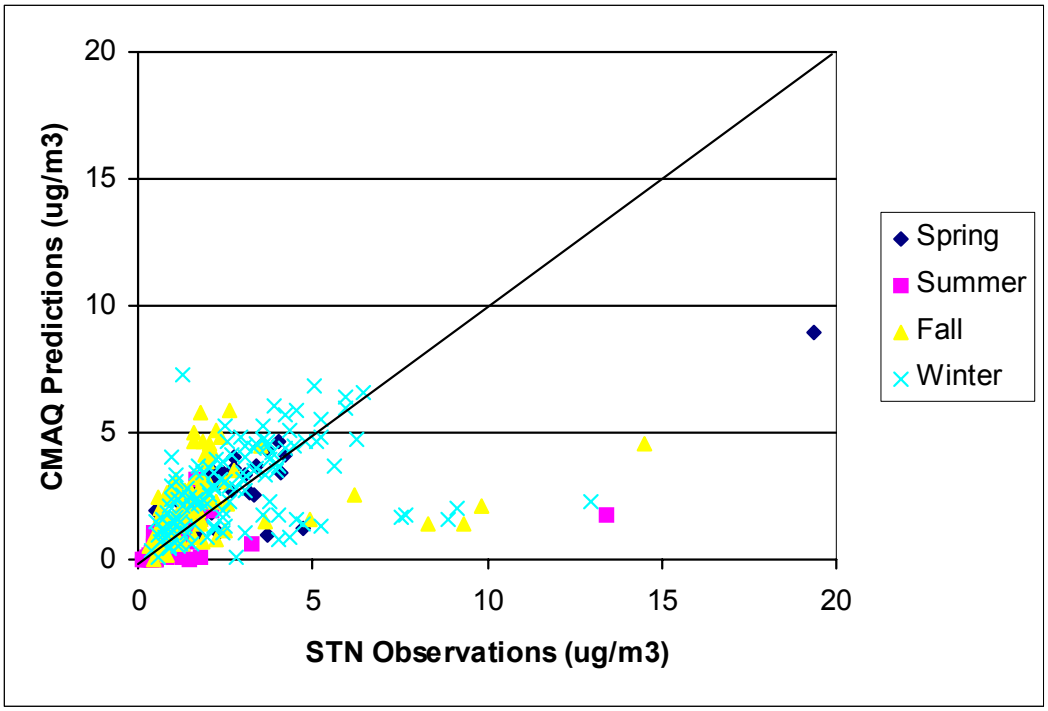



**Figure 10.** Seasonal average nitrate ion 2001 STN observations versus CMAQ predictions.

*b.3. CASTNet Performance*

Figure 11 show the seasonal 2001 CASTNet observations versus CMAQ predictions for total nitrate, respectively. The scatterplot and linear regression of total nitrate showed modest agreement, with weaker correlations within each season (annual: $R^2 = 0.53$; summer: $R^2 = 0.02$; fall: $R^2 = 0.43$; spring: $R^2 = 0.48$; winter: $R^2 = 0.60$). There is an indication of an overprediction bias nationwide of 25%. This is not surprising given the overprediction bias of modeled particulate nitrate. The overprediction of total nitrate indicates that nitric acid concentrations may be overpredicted. This may be one of the reasons for the general overprediction of particulate nitrate. Model developers are continuing to examine the nitric acid production and destruction pathways. There are continuing improvements being made to the daytime and nighttime nitric acid formation reactions. Dry deposition of nitric acid is also being studied as a possible cause of overprediction.

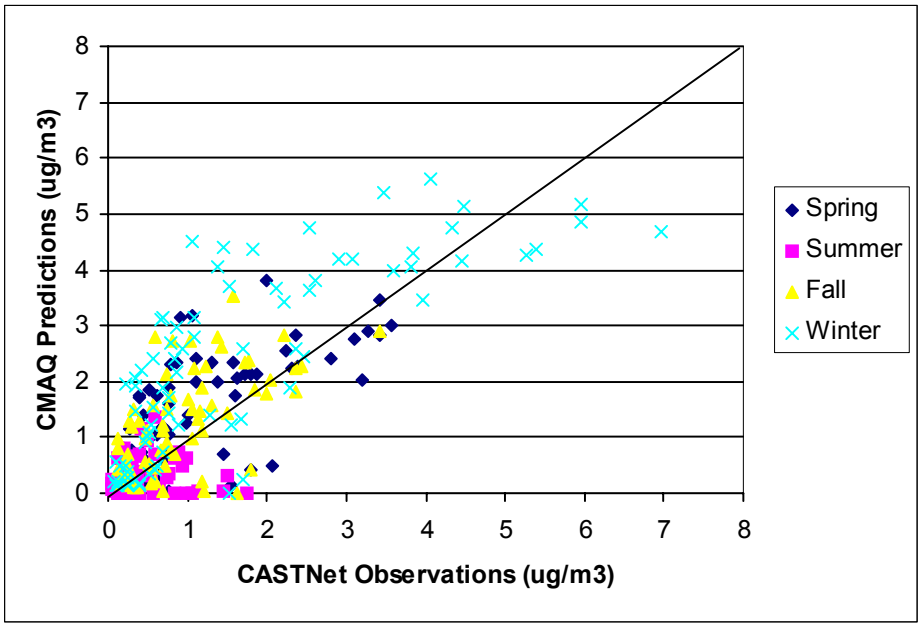



**Figure 11.** Seasonal average total nitrate ($NO_3 + HNO_3$) 2001 CASTNet observations versus CMAQ predictions.

*b.4. NADP Wet Deposition Performance*

Figure 12 show the annual 2001 NADP observations versus CMAQ predictions for total nitrate wet deposition. The scatterplot and linear regressions show an underprediction bias for nitrate with a good correlation, $R^2 = 0.78$.

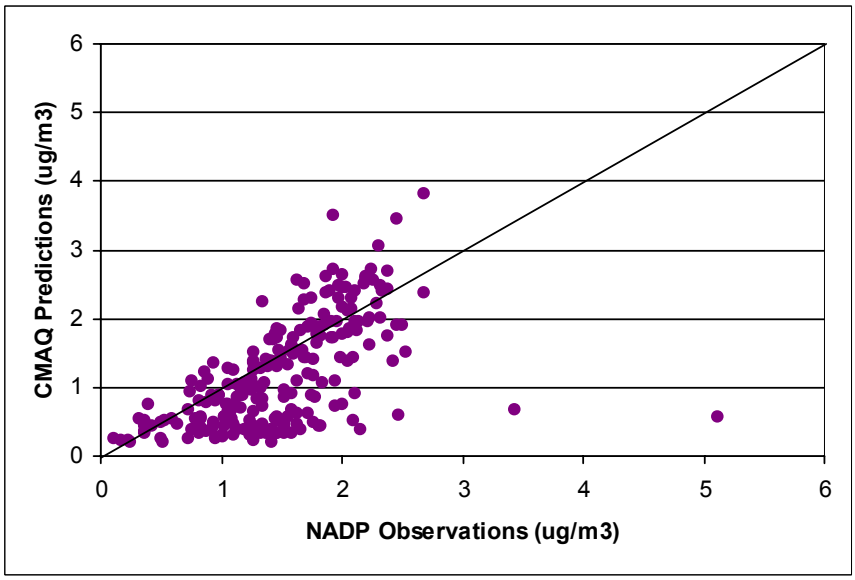



**Figure 12.** Annual total nitrate ($NO_3$) wet deposition 2001 NADP observations versus CMAQ predictions**.**

c. Spatial Analysis of Sulfate and Total Nitrate

In addition to the statistical assesssment, a spatial analysis was conducted on sulfate and total nitrate for comparison of spatially derived predictions versus observations. We select to show a summer case (July 17 - August 13, 2001) for sulfate and a winter case (January 2-29, 2001) for total nitrate, given the fact that particulate sulfate is greater in the summer and particulate nitrate is greater in the winter. The four week running average shown here is to be consistent with the CASTNet observed frequency although STN daily observed data are also included in these comparisons. A comparison of the observed and predicted fields indicates that predictions from the modeling platform closely replicate the observed patterns of sulfate and nitrate concentrations.

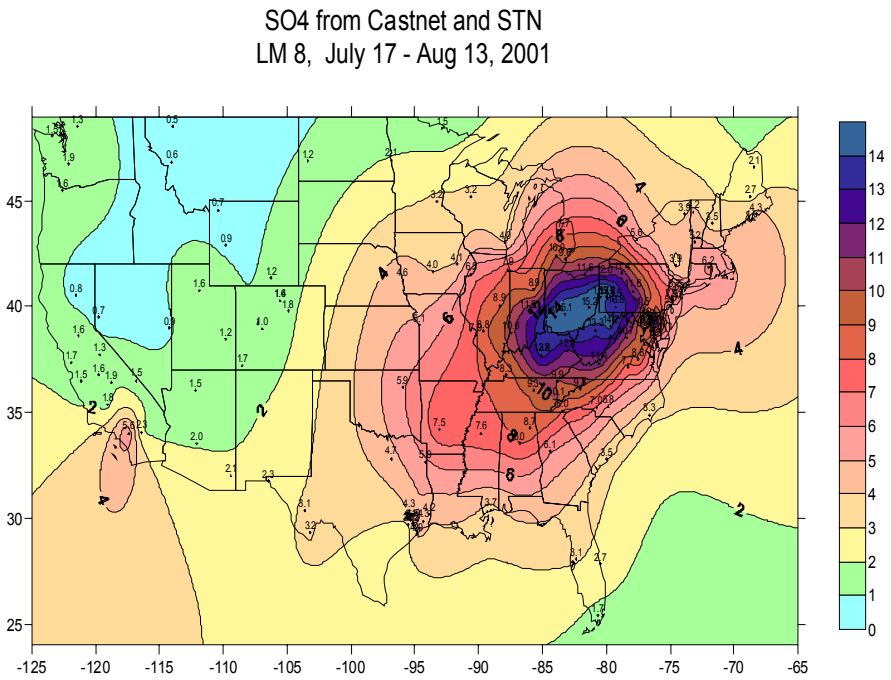



**Figure 13.** Sulfate ($SO_4$) based on average of the period July 17 - August 13, 2001 CASTNet and STN observations.

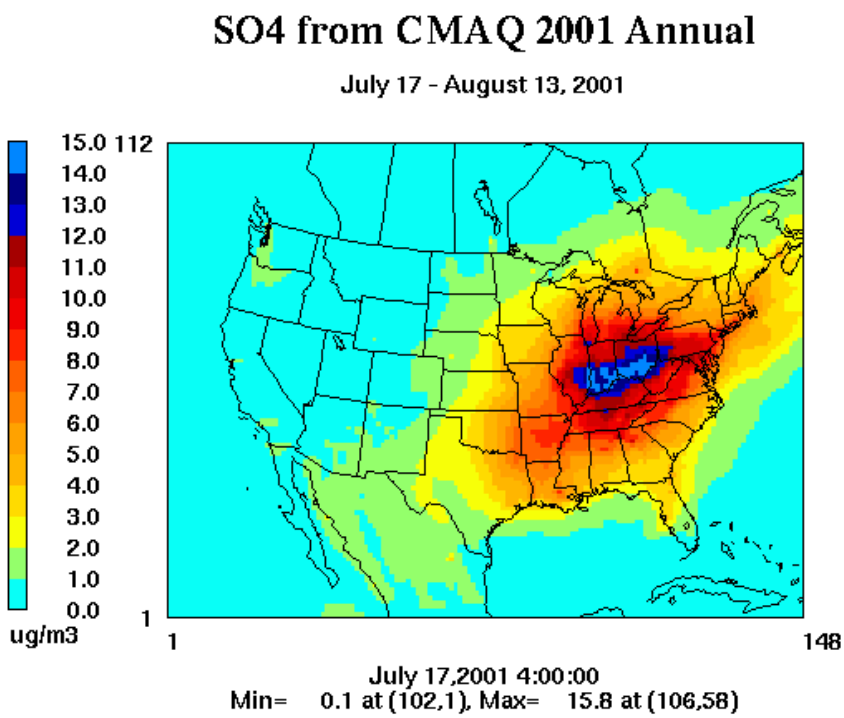



**Figure 14.** Sulfate ($SO_4$) based on average of the period July 17 - August 13, 2001 CMAQ predictions.

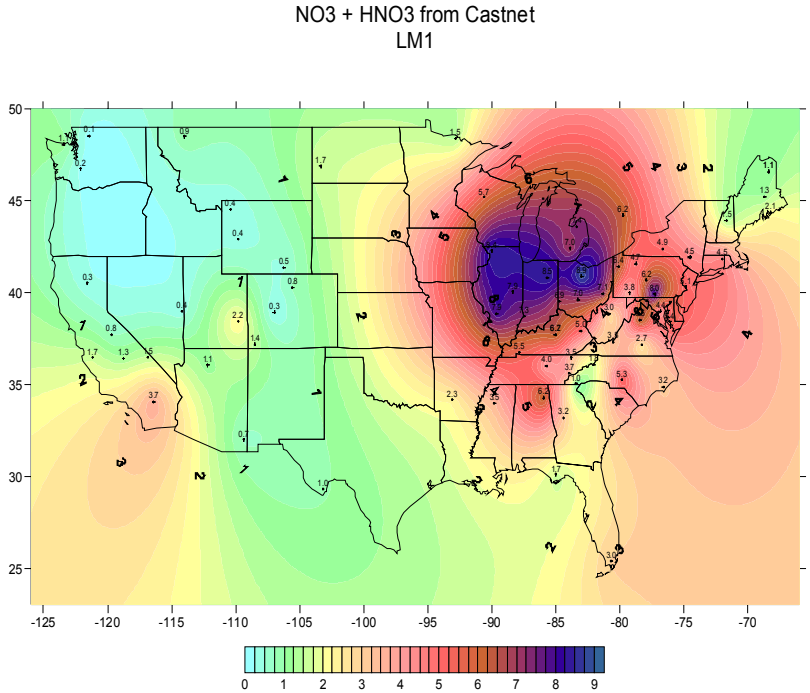



**Figure 15.** Total nitrate ($NO_3$ + $HNO_3$) based on average of the period January 2- 29, 2001 CASTNet observations.

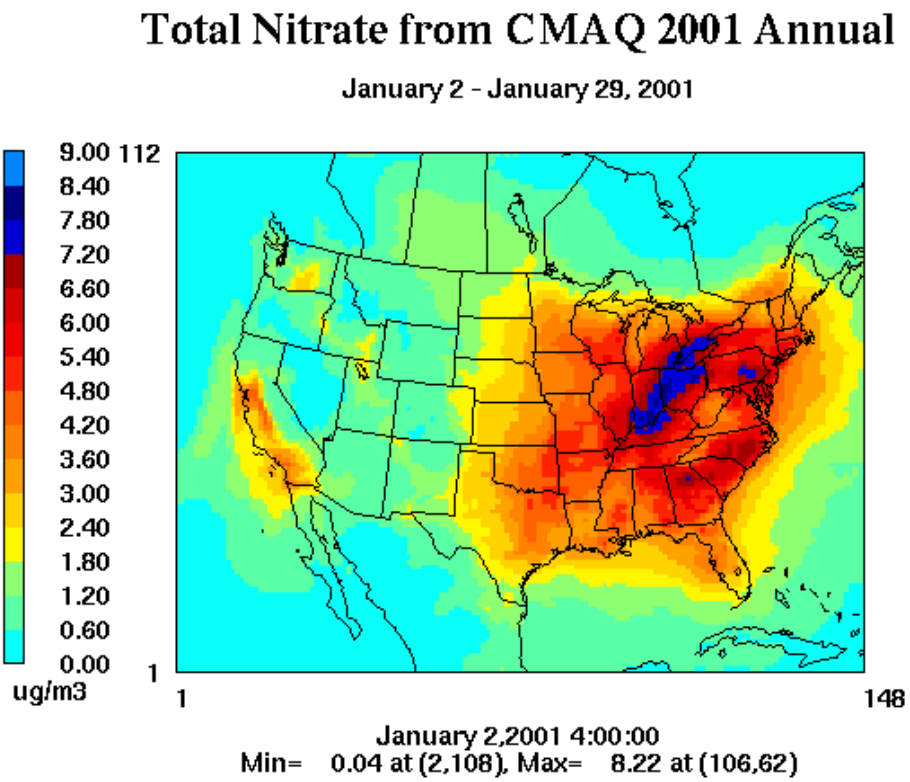



**Figure 16.** Total nitrate ($NO_3$ + $HNO_3$) based on average of the period January 2- 29, 2001 CMAQ predictions.

d. Elemental Carbon Performance

*d.3. IMPROVE Performance*

Table 5 lists the performance statistics for primary elemental carbon at the IMPROVE sites. Elemental carbon concentrations at IMPROVE sites are relatively low, but performance is generally good. There is a domainwide underprediction of only 2% with a western overprediction of 9%.

**Table 5.** Annual mean elemental carbon performance at IMPROVE sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 13441 | 0.23 | 0.24 | 0.98 | -0.01 | -16.26 | 0.15 | 60.77 | 0.22 |
| East | 4759 | 0.31 | 0.35 | 0.87 | -0.04 | -22.57 | 0.16 | 50.74 | 0.28 |
| West | 8682 | 0.19 | 0.17 | 1.09 | 0.02 | -12.81 | 0.13 | 66.25 | 0.14 |

Figures 17 and 18 show scatterplots of annual and seasonal average elemental carbon 2001 IMPROVE observations versus CMAQ predictions respectively. The annual scatterplot and linear regression displayed some scatter, however good agreement with a $R^2$ of 0.42. Overall, spring and fall linear regressions had relatively good agreement (spring: $R^2 = 0.47$; fall: $R^2 = 0.49$), whereas winter and summer had the weakest correlations (winter: $R^2 = 0.38$; and spring: $R^2 = 0.19$).

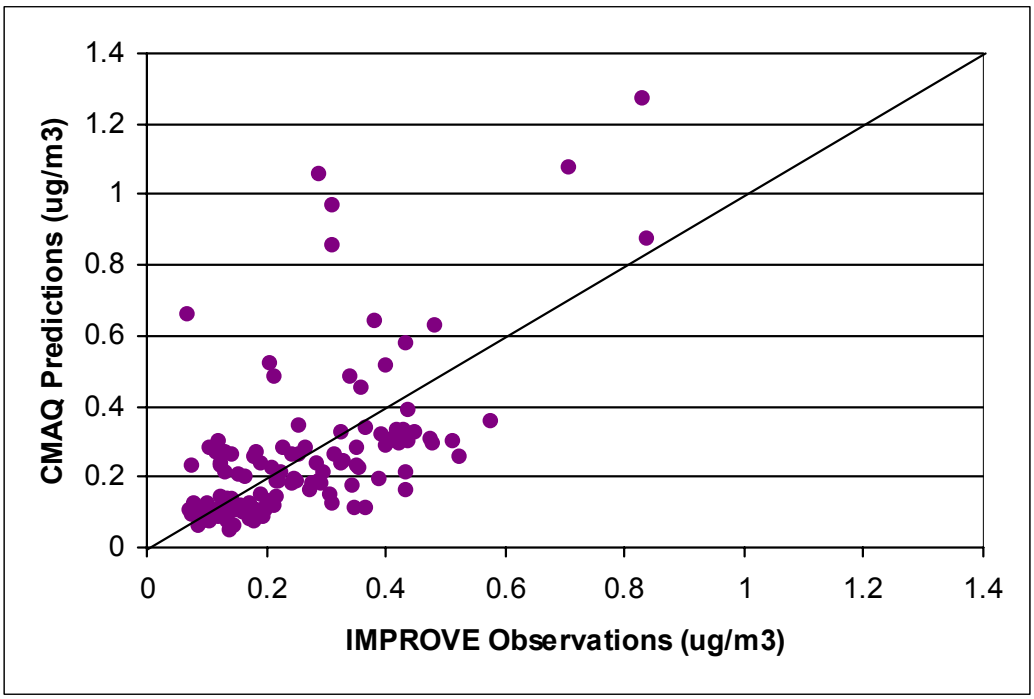



**Figure 17.** Annual average elemental carbon 2001 IMPROVE observations versus CMAQ predictions.

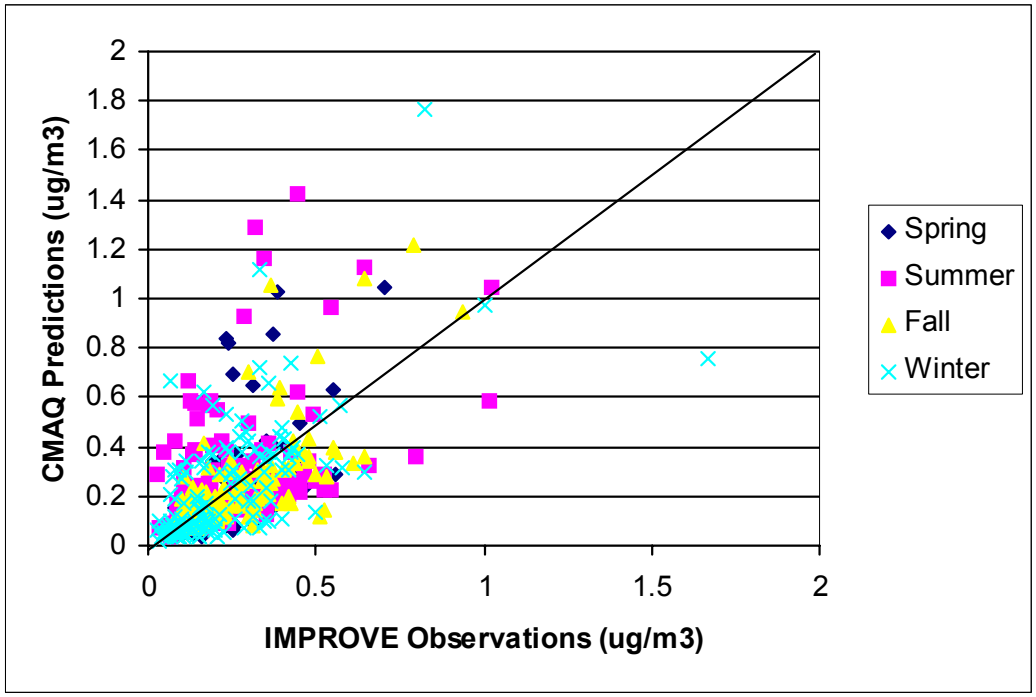



**Figure 18.** Seasonal average elemental carbon 2001 IMPROVE observations versus CMAQ predictions.

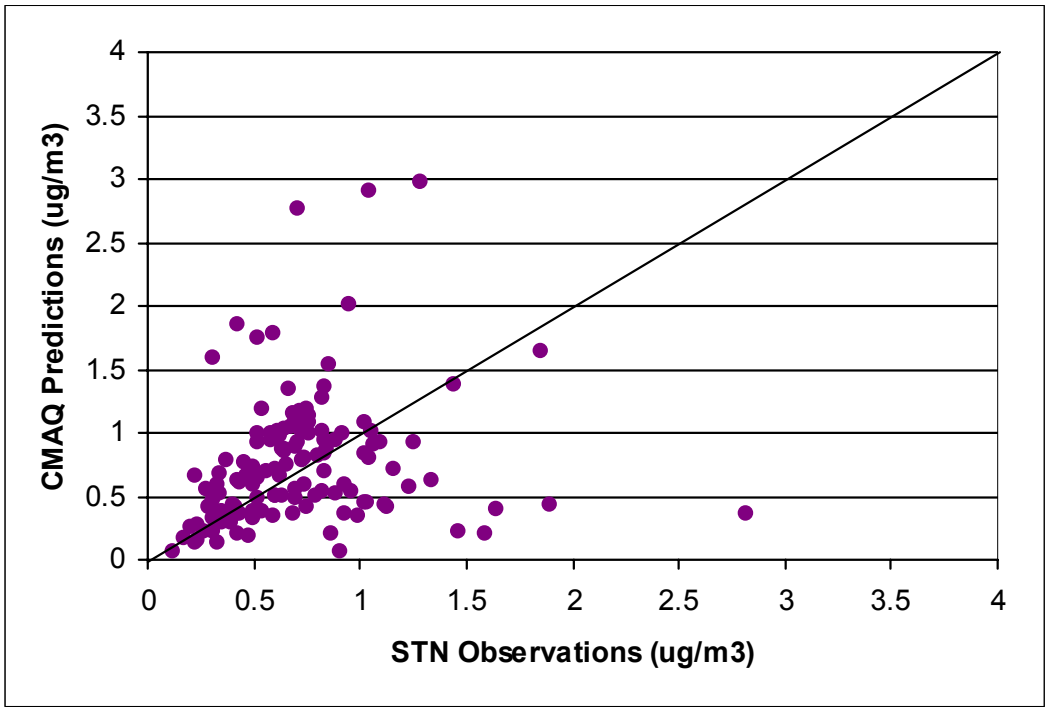
*d.3. STN Performance*

Table 6 lists the performance statistics for primary elemental carbon (EC) at the STN sites. Observed EC concentrations are extremely low, which CMAQ predicts domainwide an overprediction of 30%, 56% overprediction in the East and 23% underprediction in the West.

**Table 6.** Annual mean elemental carbon performance at STN sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 7108 | 0.85 | 0.65 | 1.30 | 0.20 | 20.24 | 0.52 | 64.22 | 0.09 |
| East | 5483 | 0.91 | 0.59 | 1.53 | 0.31 | 32.06 | 0.51 | 63.35 | 0.15 |
| West | 1625 | 0.65 | 0.85 | 0.77 | -0.20 | -19.63 | 0.52 | 67.16 | 0.08 |

Figures 19 and 20 show scatterplots of annual and seasonal average elemental carbon 2001 STN observations versus CMAQ predictions respectively. The annual scatterplot and linear regression displayed scatter with a poor $R^2$ of 0.03. Summer and spring seasons had the best regressions: summer: $R^2 = 0.21$; spring: $R^2 = 0.18$), whereas winter and fall had the weakest correlations (winter: $R^2 = 0.01$; and fall: $R^2 = 0.09$).




**Fgure 19.** Annual average elemental carbon 2001 STN observations versus CMAQ predictions.

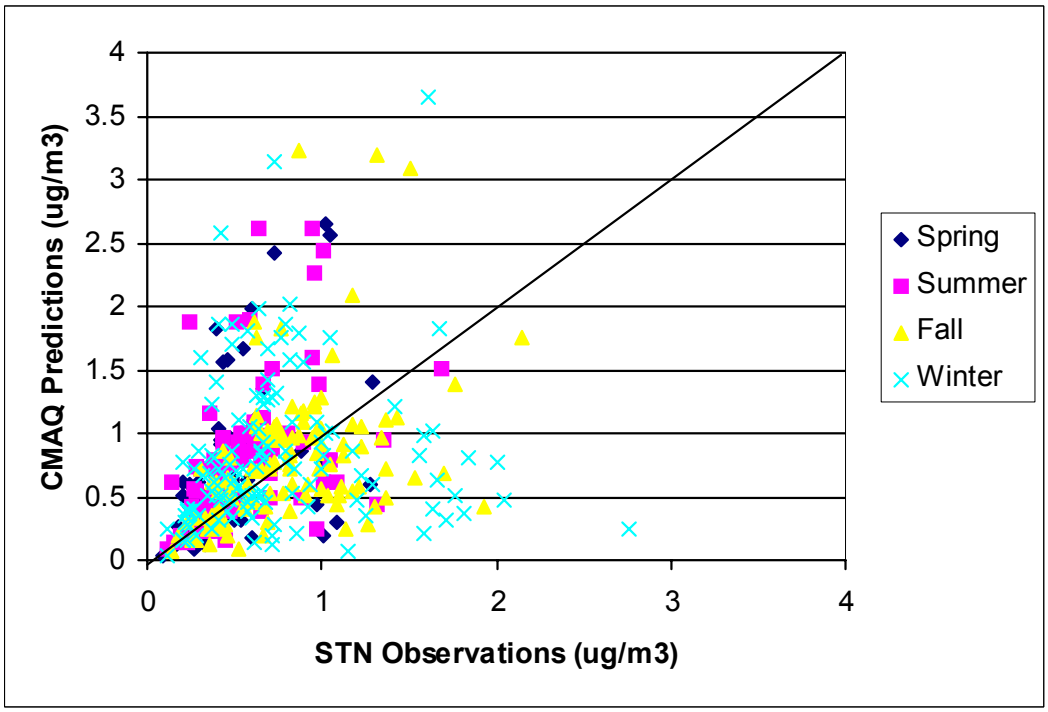



**Figure 20.** Seasonal average elemental carbon 2001 STN observations versus CMAQ predictions.

e. Organic Aerosol Performance

*e.1. IMPROVE Performance*

Table 7 lists the performance statistics for organic aerosols at the IMPROVE sites. Organic aerosols performance is generally good with a nationwide overprediction of 11%. The result of this overprediction is due to a 75% overprediction in the West, however performance was relatively good in the East with an underprediction of 7%. But the correlation coefficients are also low in the East and West. There is much uncertainty in the predictions of organic carbon. There are several different forms of organic carbon predicted in the model. There is primary organic carbon, secondary biogenic organic carbon, and secondary anthropogenic organic carbon. Both the model and the ambient data contains a mix of these different types of organics which all originate from different sources. Unfortunately, given limitations in measurement techniques, it is currently not possible to quantify the different types of organic carbon in the ambient air.

This latest version of CMAQ (v4.3) contains science updates and code fixes that result in inreased predictability in concentrations of secondary organic carbon. The performance for organics should be viewed relative to the uncertainties in the measurements and the emissions inventories.

**Table 7.** Annual mean organic aerosol performance at IMPROVE sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 13427 | 1.50 | 1.11 | 1.35 | 0.39 | 29.62 | 0.92 | 67.68 | 0.11 |
| East | 4764 | 1.45 | 1.56 | 0.93 | -0.10 | -9.73 | 0.77 | 51.78 | 0.23 |
| West | 8663 | 1.52 | 0.87 | 1.75 | 0.65 | 51.26 | 1.00 | 76.37 | 0.09 |

Annual and seasonal scatterplots (Figures 21 and 22) of average organic aerosol for 2001 IMPROVE observations versus CMAQ predictions displayed scatter, with a low annual $R^2$ = 0.11 and seasonal correlations of: summer: $R^2$ = 0.01; fall: $R^2$ = 0.12; spring: $R^2$ = 0.22; and winter: $R^2$ = 0.28.

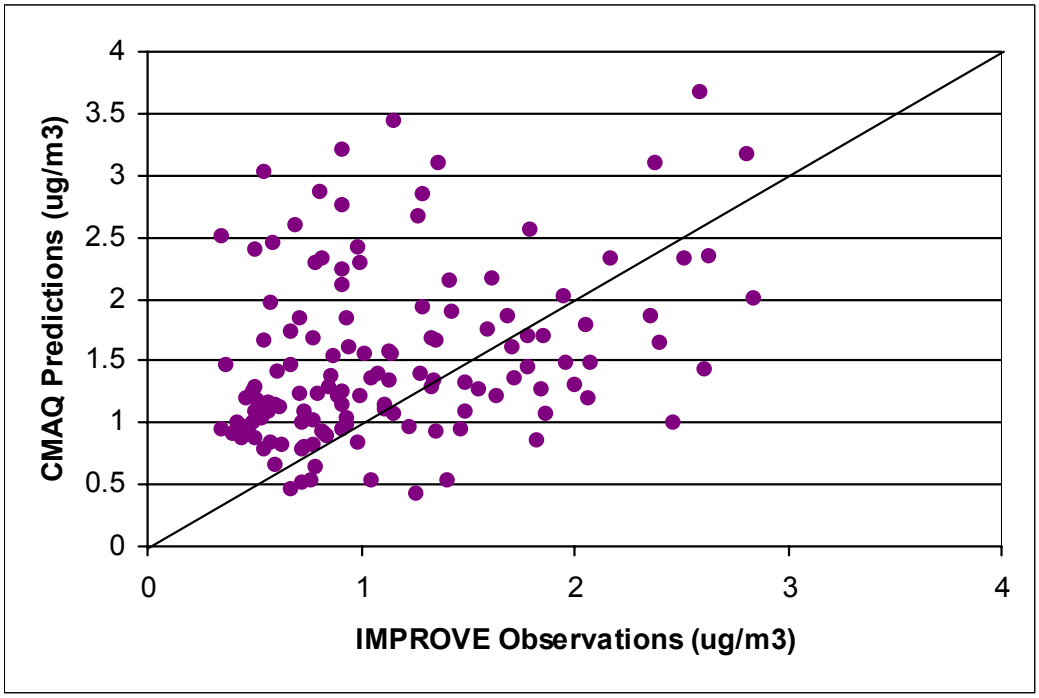



**Figure 21.** Annual average organic aerosol 2001 IMPROVE observations versus CMAQ predictions.

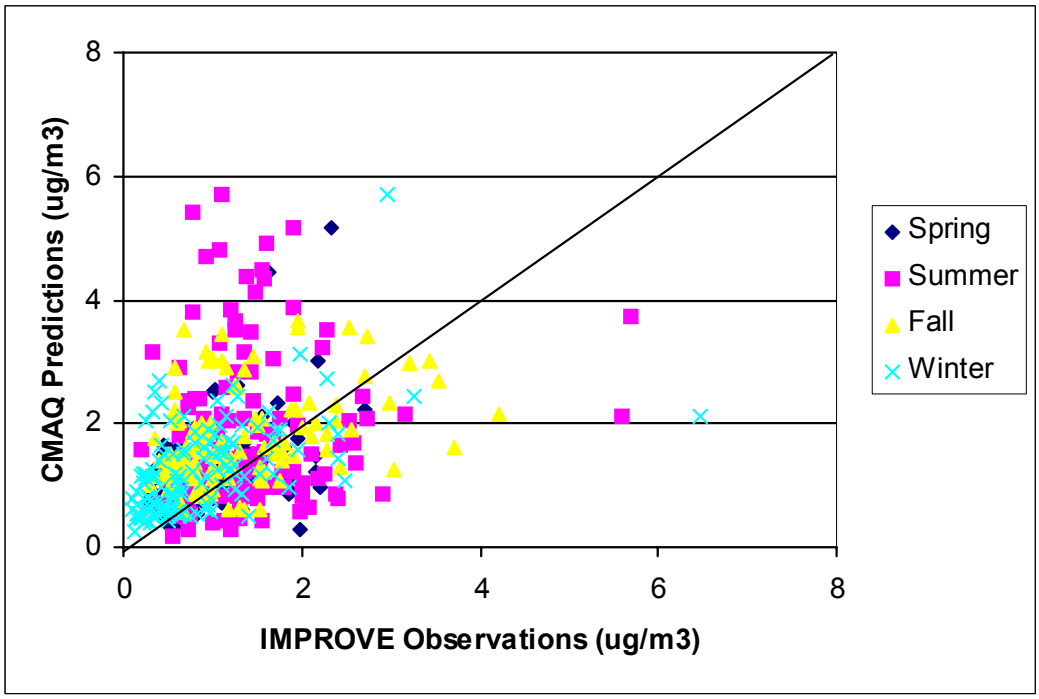



**Figure 22.** Seasonal average organic aerosol 2001 IMPROVE observations versus CMAQ predictions.

*e.2. STN Performance*

The performance statistics for organic aerosols at the STN sites are listed in Table 8. Organic aerosols performance has a nationwide underprediction of 25%. The result of this underprediction is due mostly to a 41% underprediction in the West, however performance was relatively good in the East with an underprediction of 18%. Correlation coefficients are low domainwide and consistently in the East and West.

**Table 8.** Annual mean organic carbon performance at STN sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 6947 | 2.40 | 3.20 | 0.75 | -0.86 | -9.58 | 1.75 | 73.13 | 0.11 |
| East | 5339 | 2.39 | 2.93 | 0.82 | -0.60 | -3.21 | 1.55 | 75.11 | 0.13 |
| West | 1608 | 2.44 | 4.12 | 0.59 | -1.72 | -31.05 | 2.42 | 66.44 | 0.11 |

Annual and seasonal scatterplots (Figures 23 and 24) of average organic aerosol for 2001 IMPROVE observations versus CMAQ predictions displayed scatter, with a low annual $R^2$ = 0.02 and seasonal correlations of: summer: $R^2$ = 0.23; fall: $R^2$ = 0.03; spring: $R^2$ = 0.22; and winter: $R^2$ = 0.01.

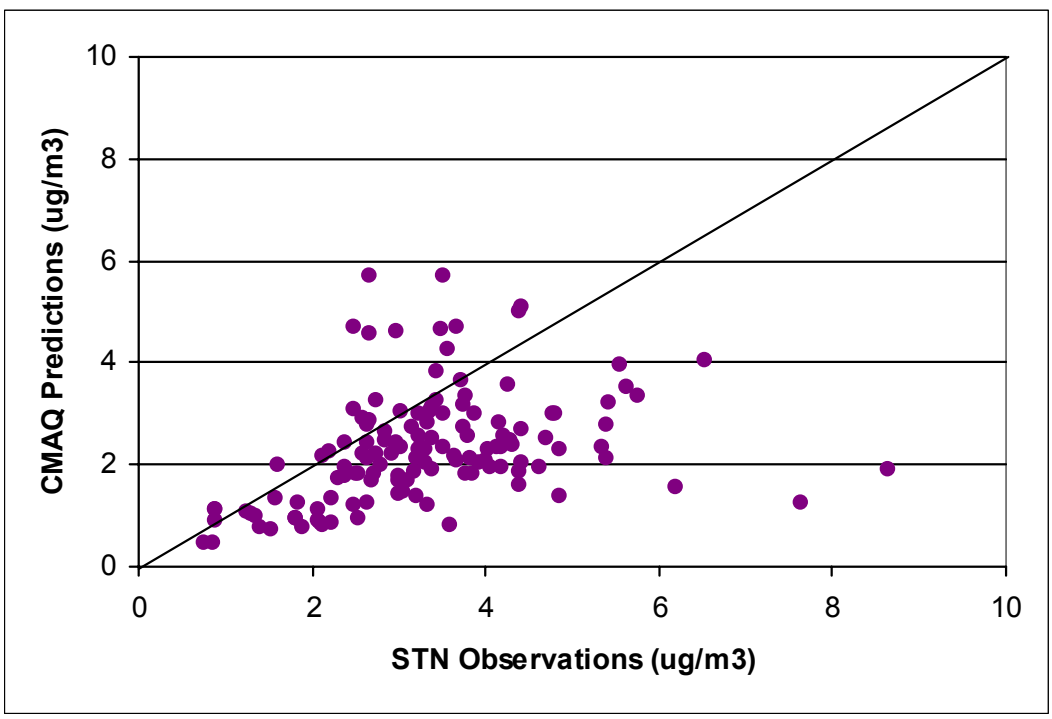



**Figure 23.** Annual average organic carbon 2001 STN observations versus CMAQ predictions.

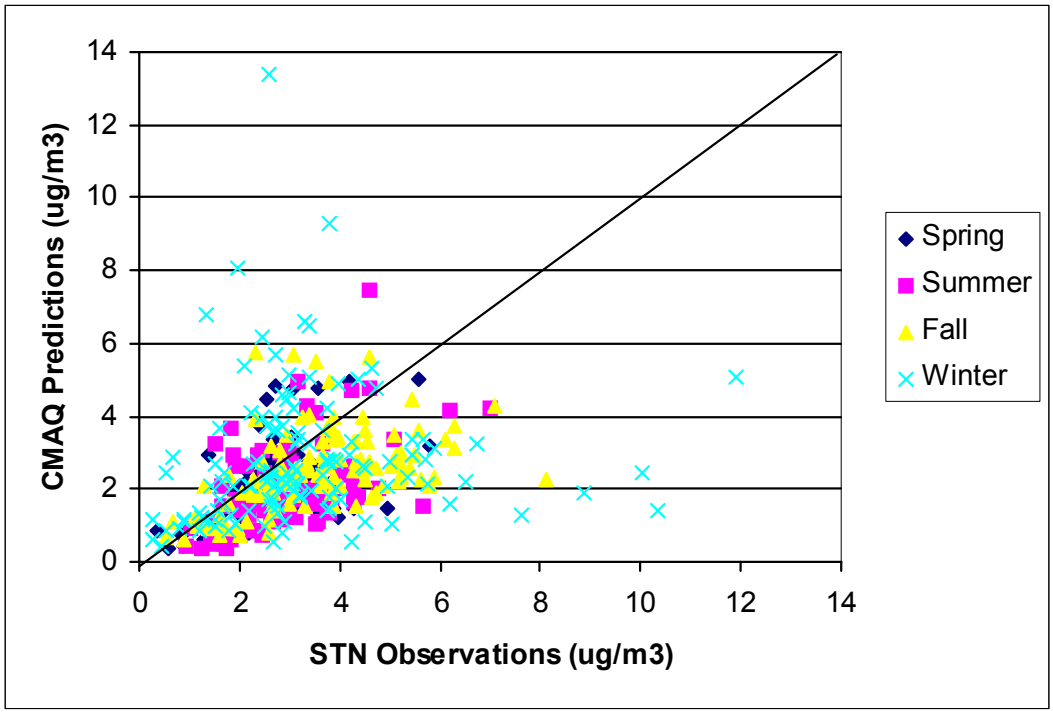



**Figure 24.** Seasonal average organic carbon 2001 STN observations versus CMAQ predictions.

f. Ammonium Performance

*f.1. NADP Wet Deposition Performance*

The annual 2001 NADP observations versus CMAQ predictions for ammonium wet deposition is shown in Figure 25. The $NH_4$ annual scatterplot and linear regression show some scatter,but good agreement, with a correlation of $R^2 = 0.65$.

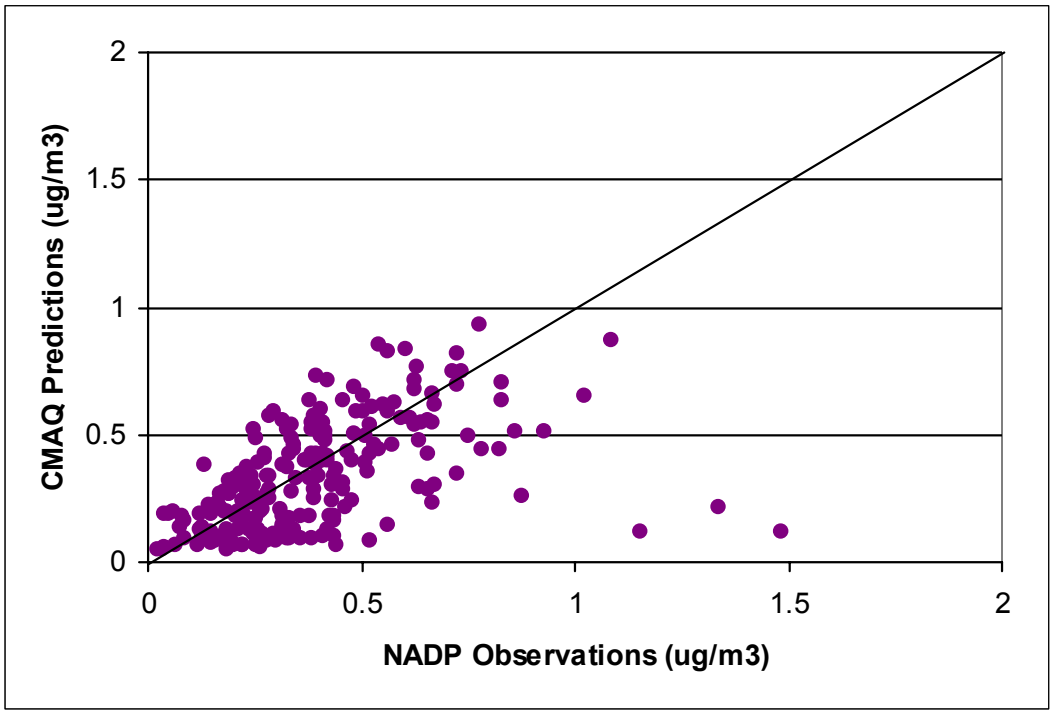



**Figure 25.** Annual total ammonium ($NH_4$) wet deposition 2001 NADP observations versus CMAQ predictions.

g. PM2.5 Performance

*g.1. IMPROVE Performance*

Table 9 lists the performance statistics for annual mean PM2.5 at the IMPROVE sites versus CMAQ (v4.3) predictions. For the full domain, PM2.5 is overpredicted by only 9%. The ratio of the means is 1.09 with a bias of 0.54 $\mu g/m^3$. It can be seen that this overprediction is similar in both the East and West. The West is overpredicted by 10% while the East is overpredicted by 9%. The fractional bias is ~8% in the East, while the fractional error is 43%. The fractional bias and error in the West is ~14% and 57% respectively. The observed PM2.5 concentrations in the East are relatively high compared to the West. CMAQ displays an ability to differentiate between generally high and low PM2.5 areas seen in the East and West.

**Table 9.** Annual mean PM2.5 performance at IMPROVE sites.

| | No. of Obs. | Mean CMAQ Predictions ($\mu g/m^3$) | Mean Observations ($\mu g/m^3$) | Ratio of Means (pred/obs) | Bias ($\mu g/m^3$) | Fractional Bias (%) | Error ($\mu g/m^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 13217 | 6.32 | 5.77 | 1.09 | 0.54 | 11.94 | 2.89 | 51.93 | 0.47 |
| East | 4724 | 9.86 | 9.04 | 1.09 | 0.82 | 8.32 | 3.80 | 43.27 | 0.48 |
| West | 8493 | 4.36 | 3.96 | 1.10 | 0.38 | 13.94 | 2.39 | 56.70 | 0.17 |

Figures 26 and 27 show the annual and seasonal average PM2.5 2001 IMPROVE observations versus CMAQ predictions respectively. The annual and seasonal scatterplots showed some scatter, but good agreement, with correlations (annual: $R^2 = 0.72$; summer: $R^2 = 0.65$; fall: $R^2 = 0.64$; spring: $R^2 = 0.72$; and winter: $R^2 = 0.60$).

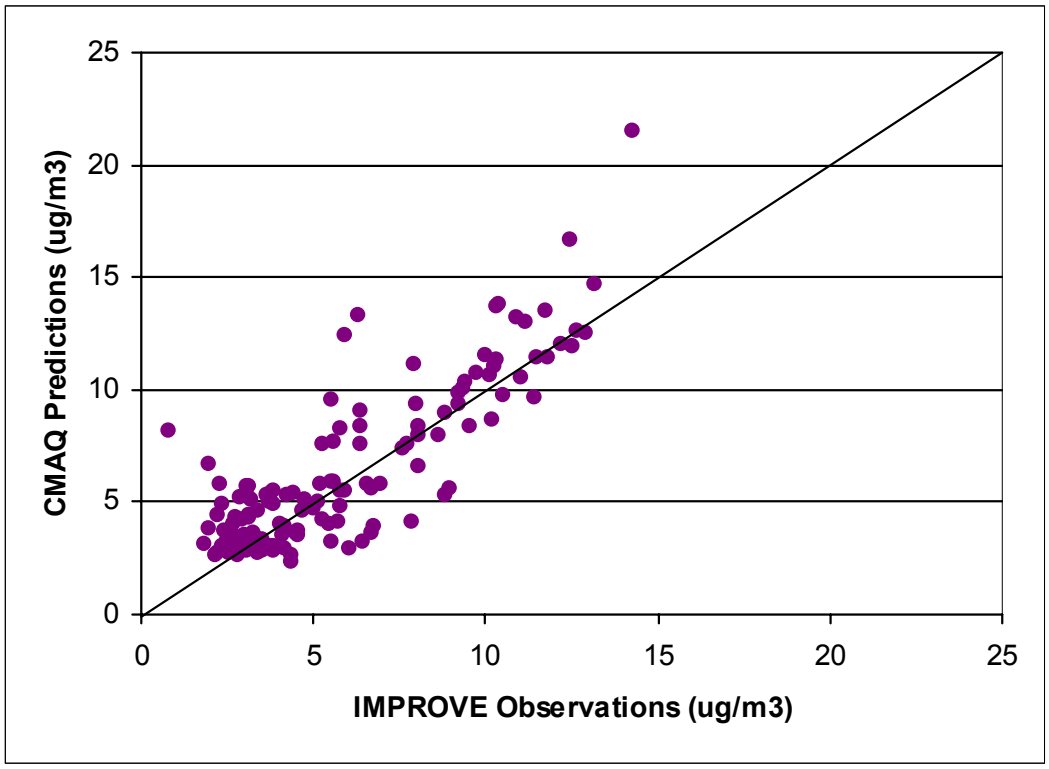



**Figure 26.** Annual average PM2.5 2001 IMPROVE observations versus CMAQ predictions.

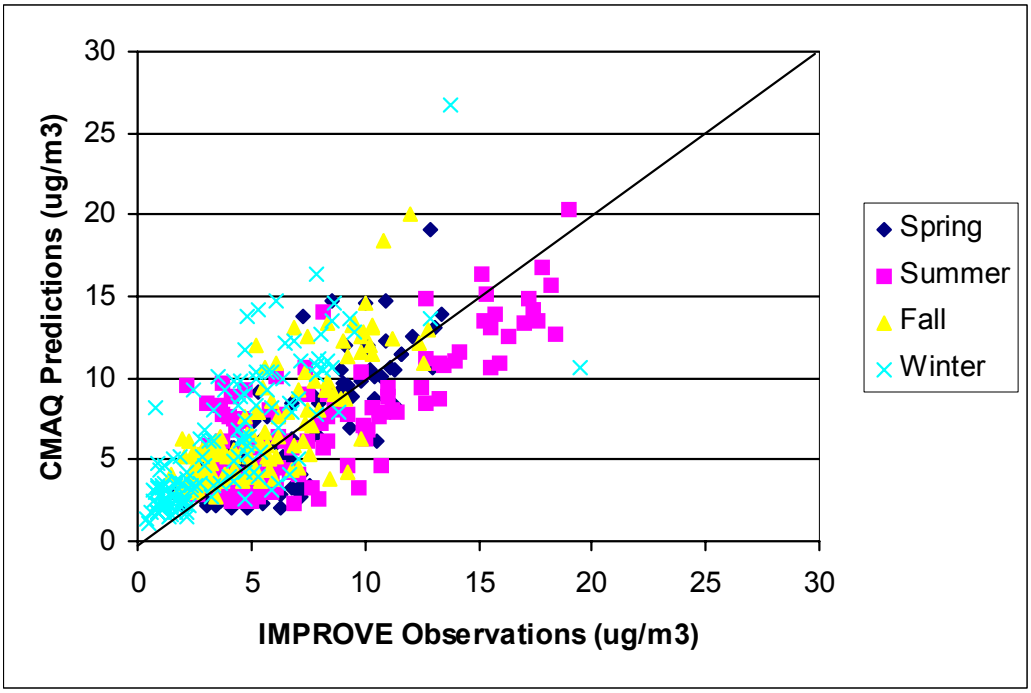



**Figure 27.** Seasonal average PM2.5 2001 IMPROVE observations versus CMAQ predictions.

*g.2. STN Performance*

Table 10 lists the performance statistics for annual mean PM2.5 at the STN sites. Nationally, CMAQ underpredicted PM2.5 by 16%. The ratio of the means is 0.84 with a bias of -2.10 µg/m$^3$. It can be seen that this underprediction is greater in the West (49%), whereas the East underpredicts by only 7%. The fractional bias is approximately 21% in the East, while the fractional error is 49%. The fractional bias and error is higher in the West with ~51% and 64% respectively.

**Table 10.** Annual mean PM2.5 performance at STN sites.

| | No. of Obs. | Mean CMAQ Predictions (µg/m$^3$) | Mean Observations (µg/m$^3$) | Ratio of Means (pred/obs) | Bias (µg/m$^3$) | Fractional Bias (%) | Error (µg/m$^3$) | Fractional Error (%) | Correlation Coefficient |
|---|---|---|---|---|---|---|---|---|---|
| National | 6419 | 10.79 | 12.89 | 0.84 | -2.10 | -21.11 | 5.48 | 48.54 | 0.29 |
| East | 4944 | 12.13 | 13.07 | 0.93 | -0.94 | -12.08 | 5.03 | 43.90 | 0.41 |
| West | 1475 | 6.29 | 12.30 | 0.51 | -6.02 | -51.33 | 6.96 | 64.09 | 0.19 |

Figures 28 and 29 show the annual and seasonal average PM2.5 2001 STN observations versus CMAQ predictions respectively. The annual and seasonal scatterplots showed some scatter, with correlations: annual: $R^2 = 0.28$; summer: $R^2 = 0.58$; fall: $R^2 = 0.19$; spring: $R^2 = 0.40$; and winter: $R^2 = 0.09$.

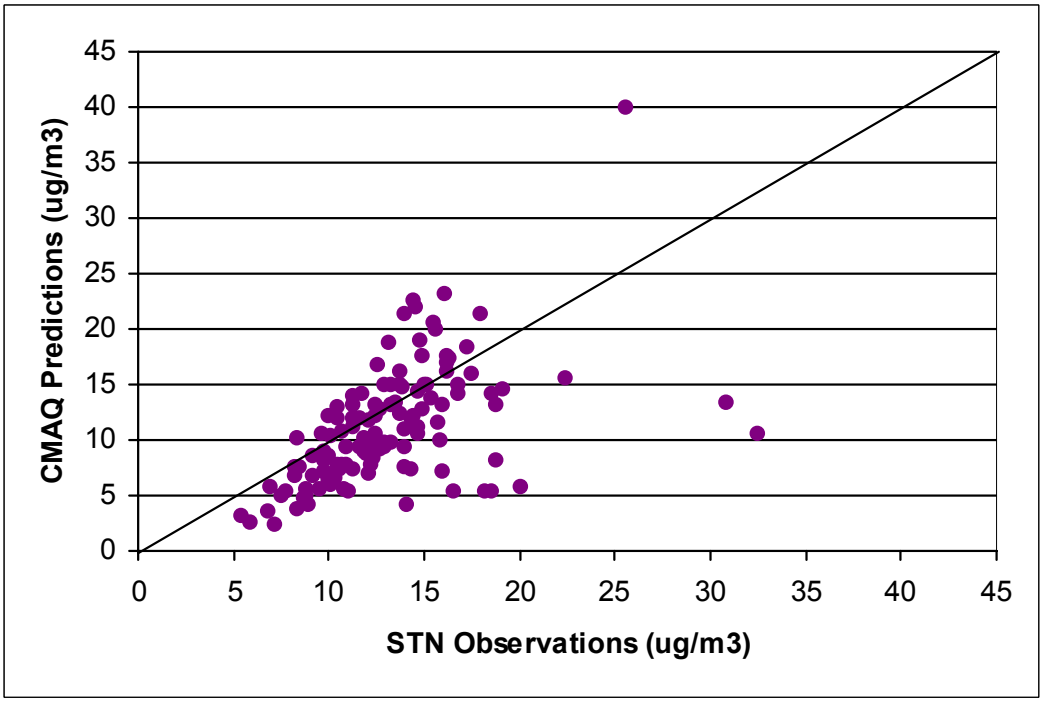



**Figure 28.** Annual average PM2.5 2001 STN observations versus CMAQ predictions.

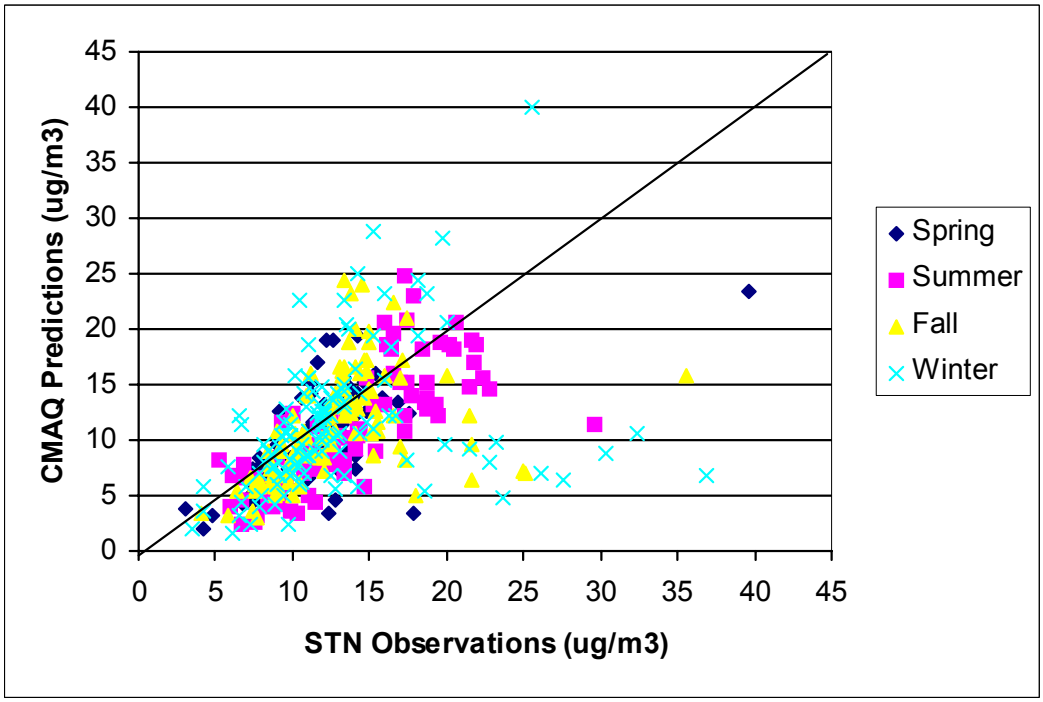



**Figure 29.** Seasonal average PM2.5 2001 STN observations versus CMAQ predictions.

h. AIRS Ozone Performance

Figures 30 and 31 show the annual 2001 AIRS observations versus CMAQ predictions for 8-hour maximum ozone ($O_3$) and 1-hour maximum ozone, respectively. The scatterplot and linear regression of 8-hour and 1-hour maximum ozone observations versus CMAQ ozone predictions showed good agreement. Correlations of 8-hour $O_3$: annual: $R^2 = 0.59$; summer: $R^2 = 0.49$; fall: $R^2 = 0.51$; spring: $R^2 = 0.39$; winter: $R^2 = 0.41$. Correlations of 1-hour $O_3$: annual: $R^2 = 0.60$; summer: $R^2 = 0.48$; fall: $R^2 = 0.54$; spring: $R^2 = 0.39$; winter: $R^2 = 0.49$.

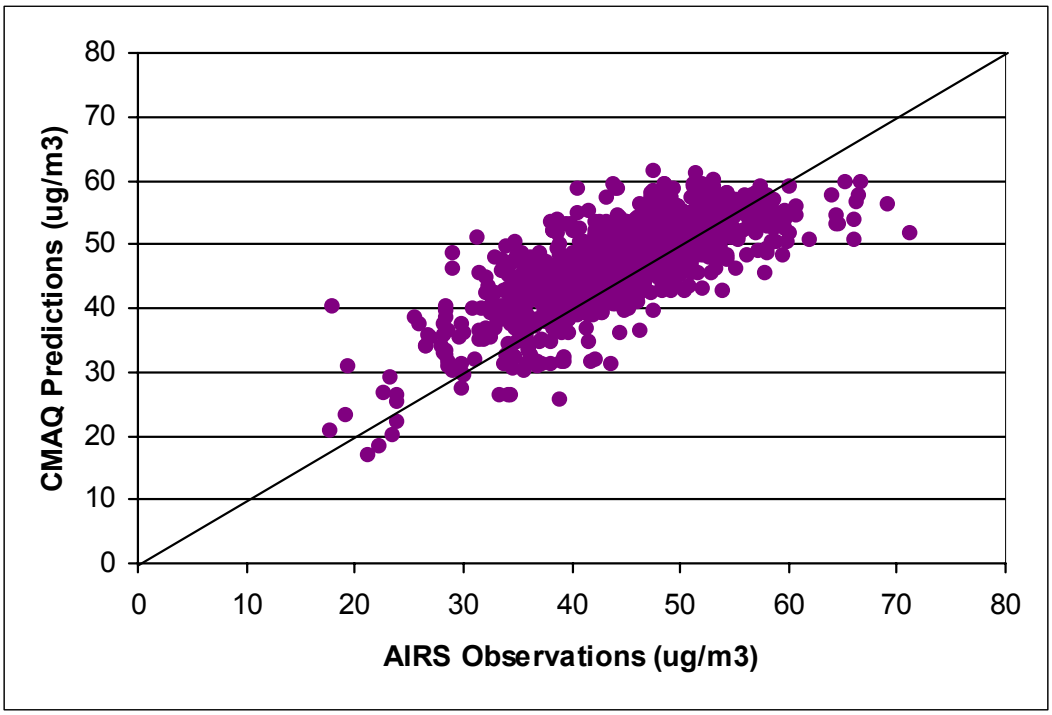



**Figure 30.** Annual 8-hour maximum average ozone 2001 AIRS observations versus CMAQ predictions.

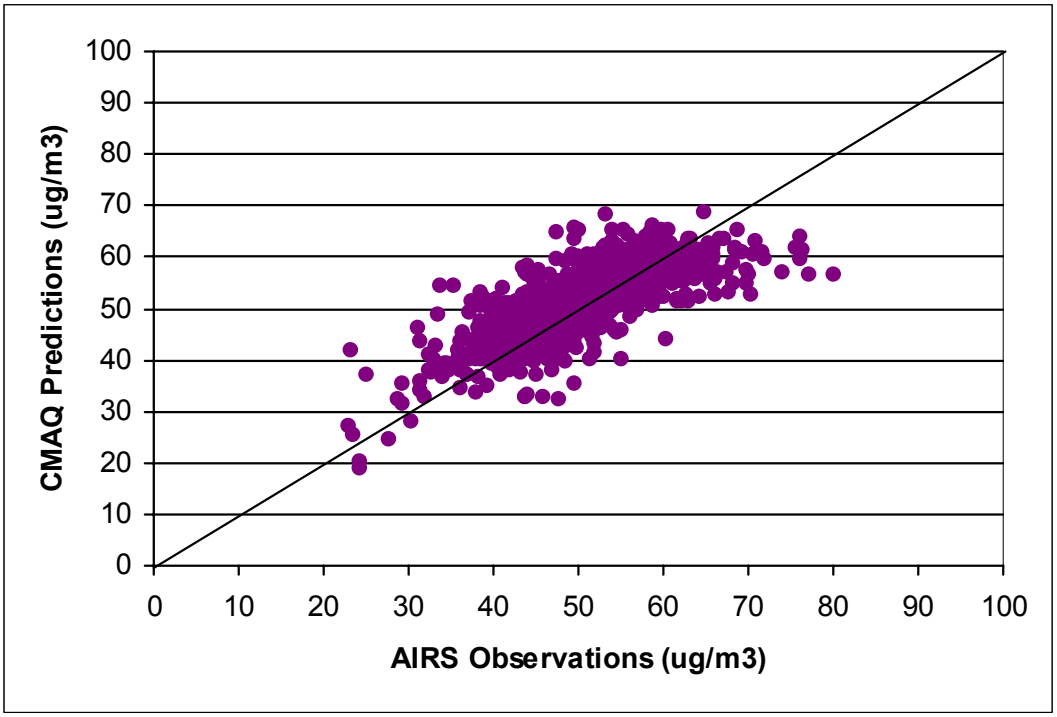



**Figure 31.** Annual 1-hour maximum average ozone 2001 AIRS observations versus CMAQ predictions.

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EPA, 1999: Office of Air Quality Planning and Standards, Emissions, Modeling and Analysis Division, Monitoring and Quality Assurance Group. *Particulate Matter (PM2.5) Speciation Guidance, Final Draft, Edition 1*; October 17, 1999.

EPA, 2002: Clean Air Status and Trends Network (CASTNet), 2001annual report.

EPA, 2004: Technical Support Document in the Interstate Air Quality Rule, Air Quality Modeling Analysis, United States Environmental Protection Agency, Research Triangle Park, 27711, January 2004. Docket No. OAR-2003-0053-0162.

IMPROVE, 2001: Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States: Report III. Cooperative Institute for Research in the Atmosphere, ISSN: 0737-5352-47. IMPROVE Web Site: http://vista.cira.colostate.edu/improve/.

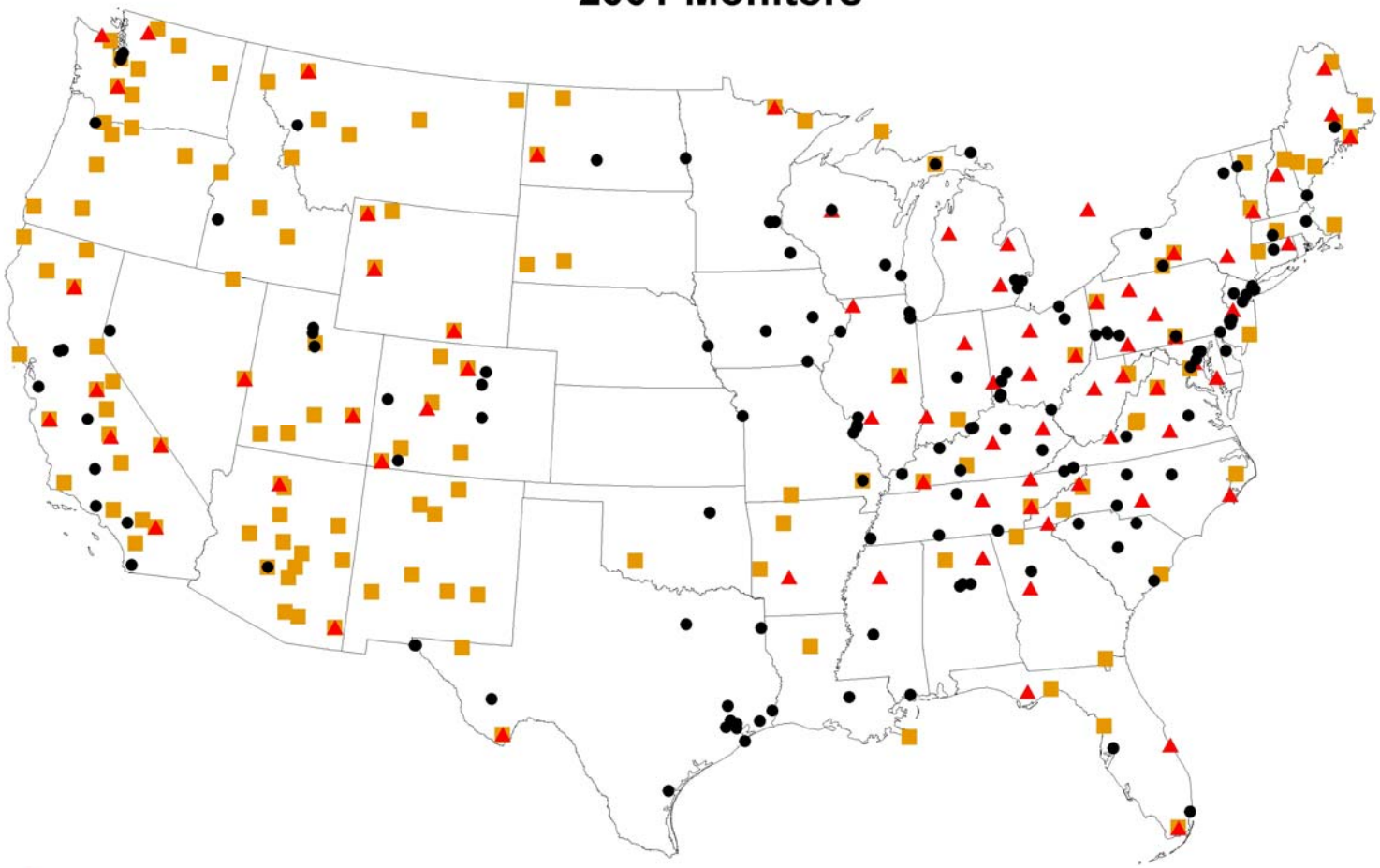
NADP, 2002: National Acid Deposition Program 2002 Annual Summary.

# Appendix A

# 2001 Monitoring Networks:

# IMPROVE, STN, CASTNet, NADP, and AIRS

# 2001 Monitors

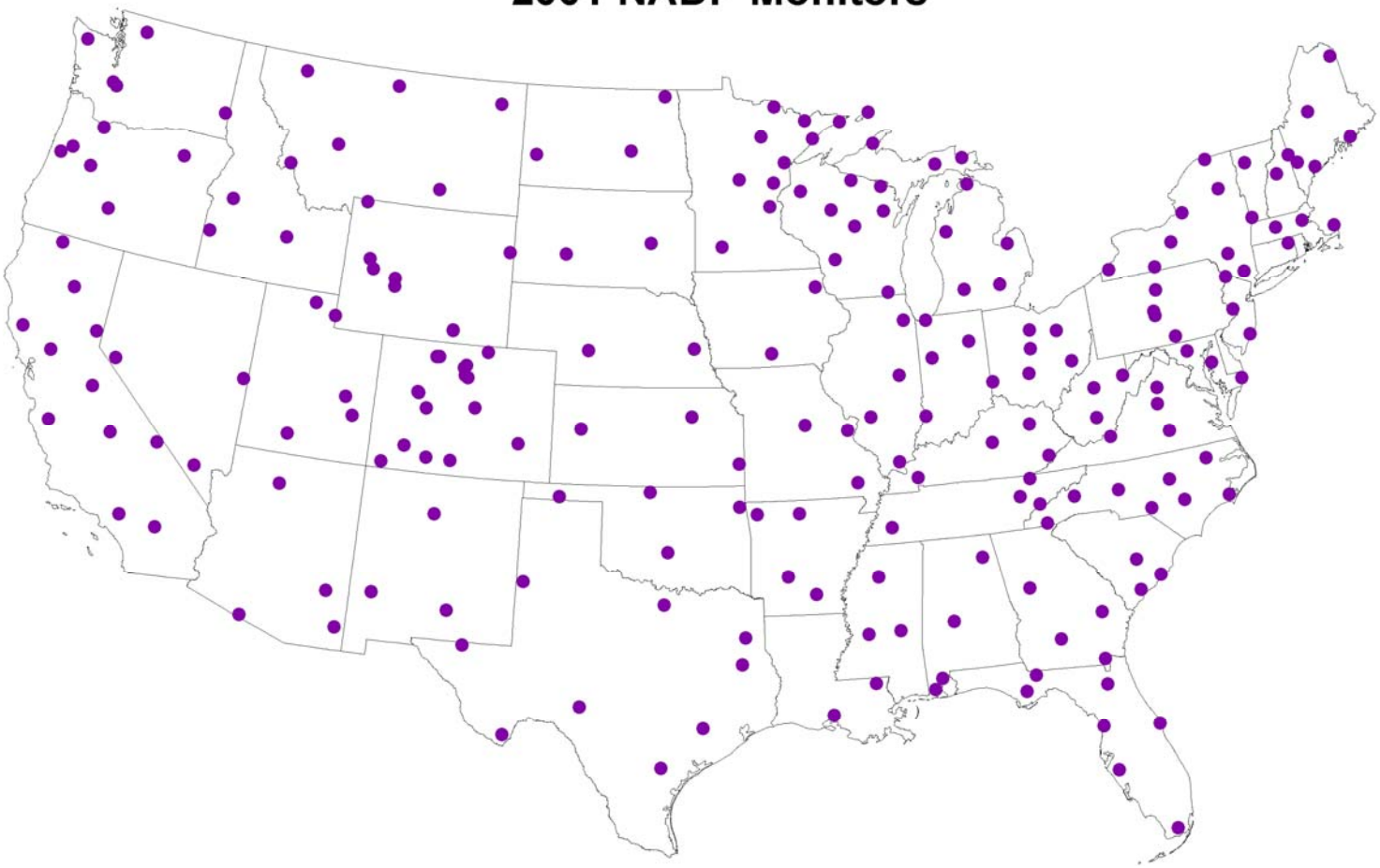


IMPROVE (145 sites)

CASTNET (83 sites)

STN (139 sites)

# 2001 NADP Monitors



NADP (225 sites)

# 2001 AIRS Monitors

AIRS sites (1161 sites)

# Appendix B

# 2001 CMAQ Statistical Assessments based on: IMPROVE, STN, CASTNet, NADP, and AIRS monitoring networks

**Description and notes about statistics calculated**

Statistics were performed for all non-zero observations.
**n_obs** refers to the total number of observations plotted and used in calculating pred, obs, and r2.
**obs** is the average observed value.
**nzero_obs** is the number of observations used to calculate bias, nbias, err, and nerr.
**pred** is the average model value.
**bias** is the mean bias.
**nbias** is the normalized bias percentage.
**fbias** is the fractional bias percentage.
**err** is the mean error.
**nerr** is the normalized error percentage.
**ferror** is the fractional error percentage.
**r2** is the correlation coefficient r sqare.

**EC_STN_CMAQ: Comparison of STN elemental carbon observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 7108 | 7108 | 7108 | 0.65 | 0.85 | 1.30 | 0.20 | 103.63 | 20.24 | 0.52 | 134.47 | 64.22 | 0.09 |
| | east | 5483 | 5483 | 5483 | 0.59 | 0.91 | 1.53 | 0.31 | 128.17 | 32.06 | 0.51 | 150.91 | 63.35 | 0.15 |
| | west | 1625 | 1625 | 1625 | 0.85 | 0.65 | 0.77 | -0.20 | 20.81 | -19.63 | 0.52 | 78.99 | 67.16 | 0.08 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1424 | 1424 | 1424 | 0.50 | 0.81 | 1.61 | 0.31 | 132.02 | 33.70 | 0.50 | 157.06 | 69.17 | 0.11 |
| | east | 1082 | 1082 | 1082 | 0.49 | 0.89 | 1.82 | 0.40 | 163.39 | 46.11 | 0.55 | 181.54 | 70.99 | 0.14 |
| | west | 342 | 342 | 342 | 0.54 | 0.54 | 1.00 | 0.00 | 32.79 | -5.54 | 0.34 | 79.64 | 63.41 | 0.05 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2147 | 2147 | 2147 | 0.53 | 0.81 | 1.52 | 0.28 | 113.93 | 31.74 | 0.44 | 135.88 | 61.78 | 0.11 |
| | east | 1698 | 1698 | 1698 | 0.52 | 0.84 | 1.61 | 0.32 | 128.80 | 36.54 | 0.45 | 147.42 | 61.47 | 0.13 |
| | west | 449 | 449 | 449 | 0.55 | 0.68 | 1.24 | 0.13 | 57.70 | 13.57 | 0.40 | 92.22 | 62.95 | 0.05 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2201 | 2201 | 2201 | 0.80 | 0.83 | 1.04 | 0.04 | 47.27 | -0.70 | 0.49 | 88.62 | 58.68 | 0.15 |
| | east | 1691 | 1691 | 1691 | 0.73 | 0.88 | 1.21 | 0.15 | 62.57 | 11.03 | 0.47 | 94.59 | 55.63 | 0.20 |
| | west | 510 | 510 | 510 | 1.02 | 0.66 | 0.65 | -0.35 | -3.47 | -39.59 | 0.57 | 68.82 | 68.77 | 0.13 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1336 | 1336 | 1336 | 0.77 | 0.99 | 1.28 | 0.22 | 149.66 | 21.92 | 0.69 | 183.65 | 72.01 | 0.04 |
| | east | 1012 | 1012 | 1012 | 0.60 | 1.08 | 1.81 | 0.48 | 199.10 | 44.65 | 0.66 | 218.13 | 71.25 | 0.14 |
| | west | 324 | 324 | 324 | 1.31 | 0.70 | 0.53 | -0.61 | -4.76 | -49.11 | 0.80 | 75.96 | 74.41 | 0.08 |

**EC_IMPROVE_CMAQ: Comparison of IMPROVE elemental carbon observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 13492 | 13441 | 13492 | 0.24 | 0.23 | 0.98 | -0.01 | 51.41 | -16.26 | 0.15 | 105.60 | 60.77 | 0.22 |
| | east | 4765 | 4759 | 4765 | 0.35 | 0.31 | 0.87 | -0.04 | 0.08 | -22.57 | 0.16 | 53.40 | 50.74 | 0.28 |
| | west | 8727 | 8682 | 8727 | 0.17 | 0.19 | 1.09 | 0.02 | 79.55 | -12.81 | 0.13 | 134.21 | 66.25 | 0.14 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3367 | 3363 | 3367 | 0.20 | 0.18 | 0.91 | -0.02 | -4.31 | -30.42 | 0.11 | 58.12 | 58.45 | 0.25 |
| | east | 1190 | 1190 | 1190 | 0.32 | 0.31 | 0.98 | -0.01 | 8.03 | -17.52 | 0.17 | 57.17 | 49.97 | 0.17 |
| | west | 2177 | 2173 | 2177 | 0.14 | 0.11 | 0.81 | -0.03 | -11.07 | -37.47 | 0.09 | 58.64 | 63.08 | 0.16 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3411 | 3385 | 3411 | 0.26 | 0.28 | 1.10 | 0.03 | 156.60 | 1.40 | 0.19 | 201.37 | 62.86 | 0.10 |
| | east | 1273 | 1267 | 1273 | 0.36 | 0.25 | 0.68 | -0.12 | -12.08 | -39.47 | 0.16 | 58.17 | 57.56 | 0.43 |
| | west | 2138 | 2118 | 2138 | 0.19 | 0.30 | 1.59 | 0.11 | 257.50 | 25.73 | 0.20 | 287.04 | 66.01 | 0.09 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3751 | 3740 | 3751 | 0.27 | 0.24 | 0.89 | -0.03 | 16.30 | -17.87 | 0.14 | 68.85 | 56.73 | 0.33 |
| | east | 1379 | 1379 | 1379 | 0.37 | 0.31 | 0.84 | -0.06 | -8.39 | -25.16 | 0.16 | 45.40 | 48.75 | 0.38 |
| | west | 2372 | 2361 | 2372 | 0.20 | 0.19 | 0.94 | -0.01 | 30.72 | -13.63 | 0.13 | 82.55 | 61.36 | 0.23 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **id** | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2963 | 2953 | 2963 | 0.21 | 0.22 | 1.02 | 0.00 | 38.77 | -18.46 | 0.14 | 96.43 | 66.13 | 0.30 |
| | east | 923 | 923 | 923 | 0.35 | 0.38 | 1.10 | 0.03 | 19.17 | -1.92 | 0.17 | 53.94 | 45.29 | 0.33 |
| | west | 2040 | 2030 | 2040 | 0.15 | 0.14 | 0.95 | -0.01 | 47.68 | -25.95 | 0.12 | 115.75 | 75.56 | 0.14 |

**NH4_CASTNET_CMAQ: Comparison of CASTNet NH4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3736 | 3736 | 3736 | 1.16 | 1.24 | 1.07 | 0.08 | 20.66 | 5.85 | 0.39 | 45.67 | 37.97 | 0.67 |
| | east | 2639 | 2639 | 2639 | 1.49 | 1.63 | 1.09 | 0.14 | 25.77 | 13.91 | 0.48 | 41.50 | 32.94 | 0.54 |
| | west | 1097 | 1097 | 1097 | 0.38 | 0.32 | 0.83 | -0.06 | 8.37 | -13.54 | 0.18 | 55.70 | 50.06 | 0.12 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 953 | 953 | 953 | 1.12 | 1.25 | 1.11 | 0.13 | 23.09 | 9.27 | 0.36 | 42.66 | 33.93 | 0.68 |
| | east | 676 | 676 | 676 | 1.42 | 1.61 | 1.14 | 0.19 | 28.86 | 16.67 | 0.43 | 40.25 | 30.13 | 0.57 |
| | west | 277 | 277 | 277 | 0.40 | 0.37 | 0.92 | -0.03 | 9.01 | -8.79 | 0.19 | 48.53 | 43.20 | 0.05 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 937 | 937 | 937 | 1.51 | 1.26 | 0.83 | -0.26 | -17.87 | -26.92 | 0.42 | 31.75 | 38.04 | 0.75 |
| | east | 654 | 654 | 654 | 1.97 | 1.69 | 0.86 | -0.28 | -7.90 | -13.62 | 0.50 | 25.80 | 27.97 | 0.60 |
| | west | 283 | 283 | 283 | 0.46 | 0.25 | 0.54 | -0.21 | -40.91 | -57.66 | 0.23 | 45.49 | 61.32 | 0.20 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 980 | 980 | 980 | 0.93 | 1.18 | 1.27 | 0.25 | 36.93 | 19.68 | 0.42 | 53.88 | 41.12 | 0.64 |
| | east | 687 | 687 | 687 | 1.17 | 1.54 | 1.31 | 0.37 | 44.36 | 28.64 | 0.52 | 53.33 | 39.42 | 0.53 |
| | west | 293 | 293 | 293 | 0.36 | 0.34 | 0.93 | -0.02 | 19.52 | -1.33 | 0.16 | 55.17 | 45.12 | 0.18 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 866 | 866 | 866 | 1.09 | 1.29 | 1.18 | 0.20 | 41.27 | 21.88 | 0.37 | 54.75 | 38.77 | 0.74 |
| | east | 622 | 622 | 622 | 1.40 | 1.67 | 1.19 | 0.27 | 37.28 | 23.57 | 0.45 | 46.30 | 34.07 | 0.63 |
| | west | 244 | 244 | 244 | 0.28 | 0.30 | 1.09 | 0.02 | 51.42 | 17.56 | 0.15 | 76.30 | 50.74 | 0.25 |

**SO4_NADP_CMAQ: Comparison of NADP SO4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 7619 | 7619 | 7619 | 1.46 | 1.68 | 1.15 | 0.22 | 42.05 | -4.40 | 1.02 | 87.13 | 63.09 | 0.17 |
| | east | 5299 | 5299 | 5299 | 1.77 | 2.21 | 1.25 | 0.44 | 52.46 | 8.61 | 1.24 | 86.17 | 57.51 | 0.12 |
| | west | 2320 | 2320 | 2320 | 0.74 | 0.47 | 0.64 | -0.26 | 18.27 | -34.13 | 0.53 | 89.32 | 75.85 | 0.03 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1955 | 1955 | 1955 | 1.47 | 1.60 | 1.09 | 0.13 | 26.98 | -8.80 | 0.94 | 73.38 | 59.99 | 0.18 |
| | east | 1304 | 1304 | 1304 | 1.80 | 2.12 | 1.18 | 0.33 | 38.94 | 5.33 | 1.12 | 72.63 | 53.76 | 0.14 |
| | west | 651 | 651 | 651 | 0.82 | 0.55 | 0.66 | -0.28 | 3.03 | -37.10 | 0.59 | 74.88 | 72.49 | 0.02 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1949 | 1949 | 1949 | 1.83 | 1.61 | 0.88 | -0.22 | 19.07 | -23.00 | 1.09 | 77.31 | 62.42 | 0.15 |
| | east | 1441 | 1441 | 1441 | 2.10 | 2.00 | 0.95 | -0.10 | 22.14 | -10.66 | 1.20 | 68.62 | 55.06 | 0.12 |
| | west | 508 | 508 | 508 | 1.04 | 0.51 | 0.49 | -0.53 | 10.36 | -57.99 | 0.77 | 101.94 | 83.32 | 0.00 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1805 | 1805 | 1805 | 1.35 | 2.01 | 1.48 | 0.65 | 78.82 | 12.33 | 1.26 | 114.93 | 67.74 | 0.17 |
| | east | 1255 | 1255 | 1255 | 1.65 | 2.69 | 1.63 | 1.04 | 103.88 | 29.17 | 1.60 | 127.43 | 64.59 | 0.11 |
| | west | 550 | 550 | 550 | 0.68 | 0.45 | 0.66 | -0.23 | 21.63 | -26.08 | 0.48 | 86.42 | 74.93 | 0.12 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1910 | 1910 | 1910 | 1.17 | 1.53 | 1.31 | 0.36 | 46.19 | 3.26 | 0.82 | 84.97 | 62.55 | 0.35 |
| | east | 1299 | 1299 | 1299 | 1.51 | 2.07 | 1.37 | 0.56 | 50.00 | 13.43 | 1.06 | 79.39 | 57.14 | 0.27 |
| | west | 611 | 611 | 611 | 0.44 | 0.38 | 0.86 | -0.06 | 38.07 | -18.38 | 0.31 | 96.83 | 74.05 | 0.14 |

**SO4_IMPROVE_CMAQ: Comparison of IMPROVE SO4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 13458 | 13447 | 13458 | 1.68 | 1.72 | 1.02 | 0.04 | 45.01 | 0.94 | 0.67 | 78.29 | 45.67 | 0.74 |
| | east | 4771 | 4771 | 4771 | 3.34 | 3.62 | 1.09 | 0.29 | 24.78 | 7.00 | 1.22 | 49.14 | 39.56 | 0.68 |
| | west | 8687 | 8676 | 8687 | 0.77 | 0.67 | 0.87 | -0.10 | 56.13 | -2.39 | 0.36 | 94.31 | 49.02 | 0.28 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3374 | 3372 | 3374 | 1.61 | 1.54 | 0.96 | -0.07 | 61.95 | -3.79 | 0.58 | 95.72 | 40.81 | 0.72 |
| | east | 1194 | 1194 | 1194 | 3.07 | 3.03 | 0.99 | -0.04 | 11.43 | -0.88 | 0.99 | 38.57 | 34.54 | 0.62 |
| | west | 2180 | 2178 | 2180 | 0.80 | 0.72 | 0.89 | -0.09 | 89.65 | -5.38 | 0.35 | 127.05 | 44.24 | 0.21 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3390 | 3384 | 3390 | 2.54 | 2.51 | 0.99 | -0.03 | 8.70 | -11.58 | 0.97 | 52.15 | 47.56 | 0.76 |
| | east | 1273 | 1273 | 1273 | 5.09 | 5.50 | 1.08 | 0.41 | 30.92 | 9.53 | 1.79 | 54.43 | 41.93 | 0.67 |
| | west | 2117 | 2111 | 2117 | 1.01 | 0.72 | 0.71 | -0.29 | -4.70 | -24.28 | 0.47 | 50.77 | 50.94 | 0.22 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3712 | 3711 | 3712 | 1.51 | 1.73 | 1.14 | 0.22 | 33.43 | 8.94 | 0.65 | 60.24 | 44.75 | 0.77 |
| | east | 1380 | 1380 | 1380 | 2.78 | 3.44 | 1.23 | 0.65 | 35.06 | 16.08 | 1.15 | 53.13 | 40.03 | 0.73 |
| | west | 2332 | 2331 | 2332 | 0.76 | 0.72 | 0.95 | -0.04 | 32.47 | 4.72 | 0.35 | 64.44 | 47.55 | 0.33 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2982 | 2980 | 2982 | 1.01 | 1.01 | 1.01 | 0.01 | 81.47 | 10.56 | 0.45 | 110.72 | 50.16 | 0.51 |
| | east | 924 | 924 | 924 | 2.10 | 2.08 | 0.99 | -0.02 | 18.21 | 0.12 | 0.84 | 49.56 | 42.09 | 0.28 |
| | west | 2058 | 2056 | 2058 | 0.52 | 0.53 | 1.03 | 0.02 | 109.90 | 15.25 | 0.27 | 138.21 | 53.78 | 0.32 |

**SO4_CASTNET_CMAQ: Comparison of CASTNetSO4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3736 | 3736 | 3736 | 3.21 | 3.09 | 0.96 | -0.12 | -2.31 | -11.61 | 0.77 | 31.22 | 31.43 | 0.85 |
| | east | 2639 | 2639 | 2639 | 4.11 | 4.10 | 1.00 | -0.01 | 5.17 | -2.09 | 0.89 | 26.72 | 23.77 | 0.81 |
| | west | 1097 | 1097 | 1097 | 1.04 | 0.66 | 0.64 | -0.38 | -20.29 | -34.51 | 0.46 | 42.03 | 49.84 | 0.34 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 953 | 953 | 953 | 3.01 | 2.64 | 0.88 | -0.37 | -5.67 | -18.48 | 0.71 | 33.08 | 30.65 | 0.77 |
| | east | 676 | 676 | 676 | 3.77 | 3.43 | 0.91 | -0.34 | 4.62 | -7.79 | 0.80 | 30.08 | 22.18 | 0.68 |
| | west | 277 | 277 | 277 | 1.16 | 0.70 | 0.61 | -0.46 | -30.79 | -44.58 | 0.52 | 40.40 | 51.33 | 0.16 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 937 | 937 | 937 | 5.05 | 5.00 | 0.99 | -0.05 | -7.30 | -17.11 | 1.10 | 31.74 | 35.70 | 0.87 |
| | east | 654 | 654 | 654 | 6.65 | 6.88 | 1.03 | 0.23 | 8.82 | 3.19 | 1.26 | 24.01 | 21.83 | 0.81 |
| | west | 283 | 283 | 283 | 1.35 | 0.67 | 0.50 | -0.68 | -44.54 | -64.01 | 0.71 | 49.60 | 67.77 | 0.29 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 980 | 980 | 980 | 2.58 | 2.85 | 1.10 | 0.27 | 8.21 | 0.59 | 0.68 | 30.79 | 29.40 | 0.83 |
| | east | 687 | 687 | 687 | 3.27 | 3.75 | 1.15 | 0.49 | 16.78 | 10.99 | 0.82 | 27.51 | 24.01 | 0.77 |
| | west | 293 | 293 | 293 | 0.96 | 0.71 | 0.74 | -0.25 | -11.86 | -23.80 | 0.35 | 38.48 | 42.04 | 0.59 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 866 | 866 | 866 | 2.14 | 1.78 | 0.83 | -0.36 | -5.10 | -11.89 | 0.56 | 29.09 | 29.95 | 0.71 |
| | east | 622 | 622 | 622 | 2.73 | 2.27 | 0.83 | -0.46 | -10.87 | -15.88 | 0.69 | 25.06 | 27.30 | 0.44 |
| | west | 244 | 244 | 244 | 0.64 | 0.55 | 0.86 | -0.09 | 9.62 | -1.72 | 0.25 | 39.36 | 36.73 | 0.34 |

**PM25_STN_CMAQ: Comparison of STN PM25 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **id** | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 6420 | 6419 | 6420 | 12.89 | 10.79 | 0.84 | -2.10 | 1.71 | -21.11 | 5.48 | 51.73 | 48.54 | 0.29 |
| | east | 4944 | 4944 | 4944 | 13.07 | 12.13 | 0.93 | -0.94 | 11.45 | -12.08 | 5.03 | 52.78 | 43.90 | 0.41 |
| | west | 1476 | 1475 | 1476 | 12.30 | 6.29 | 0.51 | -6.02 | -30.95 | -51.33 | 6.96 | 48.22 | 64.09 | 0.19 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1309 | 1308 | 1309 | 11.49 | 9.93 | 0.86 | -1.56 | -1.75 | -19.81 | 4.83 | 47.41 | 48.49 | 0.30 |
| | east | 995 | 995 | 995 | 12.29 | 11.31 | 0.92 | -0.98 | 5.47 | -12.99 | 4.96 | 48.30 | 45.65 | 0.30 |
| | west | 314 | 313 | 314 | 8.96 | 5.55 | 0.62 | -3.42 | -24.71 | -41.44 | 4.41 | 44.55 | 57.50 | 0.13 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1922 | 1922 | 1922 | 13.75 | 10.77 | 0.78 | -2.98 | -8.84 | -29.20 | 5.29 | 47.36 | 47.98 | 0.46 |
| | east | 1489 | 1489 | 1489 | 14.98 | 12.22 | 0.82 | -2.76 | -4.36 | -24.94 | 5.37 | 46.99 | 44.27 | 0.47 |
| | west | 433 | 433 | 433 | 9.53 | 5.81 | 0.61 | -3.72 | -24.25 | -43.84 | 5.01 | 48.65 | 60.77 | 0.17 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2005 | 2005 | 2005 | 12.61 | 10.91 | 0.87 | -1.70 | -1.80 | -17.62 | 5.24 | 44.08 | 45.81 | 0.31 |
| | east | 1541 | 1541 | 1541 | 12.20 | 12.07 | 0.99 | -0.13 | 7.86 | -6.68 | 4.46 | 43.13 | 40.36 | 0.52 |
| | west | 464 | 464 | 464 | 13.99 | 7.07 | 0.50 | -6.93 | -33.92 | -53.98 | 7.83 | 47.24 | 63.92 | 0.20 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1184 | 1184 | 1184 | 13.51 | 11.55 | 0.85 | -1.97 | 28.62 | -15.30 | 6.89 | 76.55 | 54.12 | 0.11 |
| | east | 919 | 919 | 919 | 12.28 | 12.98 | 1.06 | 0.70 | 49.58 | 0.66 | 5.52 | 83.18 | 47.35 | 0.32 |
| | west | 265 | 265 | 265 | 17.80 | 6.57 | 0.37 | -11.23 | -44.07 | -70.63 | 11.63 | 53.55 | 77.62 | 0.26 |

**PM25_IMPROVE_CMAQ: Comparison of IMPROVE PM2.5 versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 13317 | 13217 | 13317 | 5.77 | 6.32 | 1.09 | 0.54 | 43.41 | 11.94 | 2.89 | 73.03 | 51.93 | 0.47 |
| | east | 4729 | 4724 | 4729 | 9.04 | 9.86 | 1.09 | 0.82 | 27.32 | 8.32 | 3.80 | 53.46 | 43.27 | 0.48 |
| | west | 8588 | 8493 | 8588 | 3.96 | 4.36 | 1.10 | 0.38 | 52.36 | 13.94 | 2.39 | 83.92 | 56.70 | 0.17 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3281 | 3271 | 3281 | 5.85 | 5.71 | 0.98 | -0.14 | 16.51 | -3.62 | 2.69 | 54.50 | 48.20 | 0.44 |
| | east | 1174 | 1172 | 1174 | 8.68 | 9.36 | 1.08 | 0.68 | 21.69 | 6.19 | 3.54 | 47.73 | 40.61 | 0.42 |
| | west | 2107 | 2099 | 2107 | 4.28 | 3.69 | 0.86 | -0.60 | 13.62 | -9.09 | 2.22 | 58.28 | 52.43 | 0.15 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3379 | 3377 | 3379 | 7.77 | 6.96 | 0.90 | -0.81 | 9.68 | -10.50 | 3.16 | 51.32 | 45.89 | 0.53 |
| | east | 1263 | 1262 | 1263 | 12.42 | 10.12 | 0.81 | -2.31 | -10.95 | -20.54 | 3.84 | 32.62 | 37.69 | 0.64 |
| | west | 2116 | 2115 | 2116 | 4.99 | 5.08 | 1.02 | 0.09 | 21.99 | -4.51 | 2.76 | 62.48 | 50.78 | 0.10 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3717 | 3700 | 3717 | 5.51 | 6.75 | 1.23 | 1.24 | 46.36 | 19.91 | 2.80 | 67.99 | 48.89 | 0.53 |
| | east | 1369 | 1367 | 1369 | 7.90 | 9.81 | 1.24 | 1.92 | 35.29 | 17.85 | 3.44 | 54.23 | 43.06 | 0.65 |
| | west | 2348 | 2333 | 2348 | 4.12 | 4.97 | 1.21 | 0.85 | 52.85 | 21.11 | 2.43 | 76.05 | 52.28 | 0.20 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2940 | 2869 | 2940 | 3.70 | 5.69 | 1.54 | 1.99 | 109.98 | 45.04 | 2.90 | 126.22 | 66.89 | 0.46 |
| | east | 923 | 923 | 923 | 6.59 | 10.23 | 1.55 | 3.63 | 74.99 | 36.37 | 4.59 | 88.09 | 54.60 | 0.39 |
| | west | 2017 | 1946 | 2017 | 2.38 | 3.61 | 1.52 | 1.21 | 126.57 | 49.00 | 2.13 | 144.30 | 72.52 | 0.23 |

**OC_STN_CMAQ: Comparison of STN OC observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 7108 | 6947 | 7093 | 3.20 | 2.40 | 0.75 | -0.86 | 34.84 | -9.58 | 1.75 | 93.93 | 73.13 | 0.11 |
| | east | 5483 | 5339 | 5470 | 2.93 | 2.39 | 0.82 | -0.60 | 47.14 | -3.21 | 1.55 | 103.79 | 75.11 | 0.13 |
| | west | 1625 | 1608 | 1623 | 4.12 | 2.44 | 0.59 | -1.72 | -6.02 | -31.05 | 2.42 | 61.17 | 66.44 | 0.11 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 7108 | 6947 | 7093 | 3.20 | 2.40 | 0.82 | -0.86 | 34.84 | -9.58 | 1.75 | 93.93 | 73.13 | 0.11 |
| | east | 5483 | 5339 | 5470 | 2.93 | 2.39 | 0.86 | -0.60 | 47.14 | -3.21 | 1.55 | 103.79 | 75.11 | 0.13 |
| | west | 1625 | 1608 | 1623 | 4.12 | 2.44 | 0.69 | -1.72 | -6.02 | -31.05 | 2.42 | 61.17 | 66.44 | 0.11 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2147 | 2118 | 2146 | 2.94 | 1.98 | 0.67 | -0.99 | -1.64 | -32.74 | 1.49 | 67.79 | 65.07 | 0.17 |
| | east | 1698 | 1670 | 1697 | 2.94 | 1.84 | 0.62 | -1.15 | -4.25 | -38.08 | 1.49 | 70.84 | 67.80 | 0.16 |
| | west | 449 | 448 | 449 | 2.91 | 2.53 | 0.87 | -0.38 | 8.09 | -12.56 | 1.47 | 56.42 | 54.72 | 0.19 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2201 | 2137 | 2190 | 3.39 | 2.54 | 0.75 | -0.92 | 29.96 | 9.38 | 1.71 | 85.45 | 85.72 | 0.18 |
| | east | 1691 | 1631 | 1681 | 3.13 | 2.49 | 0.80 | -0.72 | 41.64 | 21.95 | 1.52 | 93.37 | 91.88 | 0.20 |
| | west | 510 | 506 | 509 | 4.23 | 2.69 | 0.64 | -1.57 | -7.72 | -32.13 | 2.36 | 59.93 | 65.37 | 0.11 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1336 | 1295 | 1334 | 3.79 | 3.00 | 0.79 | -0.91 | 114.54 | -1.27 | 2.60 | 169.14 | 76.75 | 0.03 |
| | east | 1012 | 976 | 1011 | 2.79 | 3.20 | 1.15 | 0.32 | 161.69 | 19.01 | 1.88 | 201.28 | 72.77 | 0.11 |
| | west | 324 | 319 | 323 | 6.94 | 2.39 | 0.34 | -4.66 | -29.71 | -64.74 | 4.86 | 70.80 | 89.20 | 0.18 |

**OC_IMPROVE_CMAQ: Comparison of IMPROVE OC observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 13492 | 13427 | 13492 | 1.11 | 1.50 | 1.35 | 0.39 | 132.57 | 29.72 | 0.92 | 159.76 | 67.68 | 0.11 |
| | east | 4765 | 4764 | 4765 | 1.56 | 1.45 | 0.93 | -0.10 | 15.03 | -9.73 | 0.77 | 58.97 | 51.78 | 0.23 |
| | west | 8727 | 8663 | 8727 | 0.87 | 1.52 | 1.75 | 0.65 | 197.20 | 51.26 | 1.00 | 215.18 | 76.37 | 0.09 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3367 | 3360 | 3367 | 0.95 | 1.21 | 1.27 | 0.25 | 86.55 | 24.78 | 0.67 | 112.35 | 60.42 | 0.14 |
| | east | 1190 | 1190 | 1190 | 1.39 | 1.52 | 1.09 | 0.13 | 34.08 | 0.77 | 0.78 | 70.95 | 51.64 | 0.21 |
| | west | 2177 | 2170 | 2177 | 0.71 | 1.04 | 1.46 | 0.32 | 115.32 | 37.91 | 0.60 | 135.06 | 65.22 | 0.05 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3411 | 3395 | 3411 | 1.38 | 1.81 | 1.31 | 0.43 | 106.56 | 15.94 | 1.24 | 145.35 | 71.25 | 0.04 |
| | east | 1273 | 1273 | 1273 | 1.77 | 1.17 | 0.66 | -0.60 | -25.13 | -43.50 | 0.83 | 46.55 | 58.94 | 0.23 |
| | west | 2138 | 2122 | 2138 | 1.15 | 2.20 | 1.92 | 1.05 | 185.56 | 51.34 | 1.49 | 204.62 | 78.59 | 0.06 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3751 | 3727 | 3751 | 1.27 | 1.73 | 1.36 | 0.45 | 151.34 | 35.26 | 1.04 | 175.52 | 68.77 | 0.13 |
| | east | 1379 | 1378 | 1379 | 1.64 | 1.53 | 0.93 | -0.12 | 13.92 | -5.26 | 0.71 | 51.77 | 46.93 | 0.32 |
| | west | 2372 | 2349 | 2372 | 1.06 | 1.84 | 1.74 | 0.79 | 231.95 | 58.82 | 1.24 | 248.11 | 81.46 | 0.10 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2963 | 2945 | 2963 | 0.78 | 1.18 | 1.51 | 0.40 | 191.30 | 44.19 | 0.68 | 210.50 | 70.45 | 0.25 |
| | east | 923 | 923 | 923 | 1.35 | 1.66 | 1.23 | 0.31 | 47.53 | 16.64 | 0.75 | 71.43 | 49.31 | 0.35 |
| | west | 2040 | 2022 | 2040 | 0.52 | 0.96 | 1.84 | 0.44 | 256.93 | 56.65 | 0.65 | 273.98 | 80.02 | 0.10 |

**HNO3_CASTNET_CMAQ: Comparison of CASTNET HNO3 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3738 | 3738 | 3738 | 1.49 | 1.67 | 1.12 | 0.18 | 42.78 | 10.30 | 0.68 | 70.85 | 47.58 | 0.50 |
| | east | 2640 | 2640 | 2640 | 1.76 | 2.02 | 1.15 | 0.26 | 41.41 | 10.58 | 0.81 | 68.36 | 46.89 | 0.41 |
| | west | 1098 | 1098 | 1098 | 0.83 | 0.82 | 0.99 | -0.01 | 46.08 | 9.62 | 0.37 | 76.83 | 49.25 | 0.57 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 952 | 952 | 952 | 1.47 | 1.44 | 0.98 | -0.03 | 27.55 | 2.18 | 0.59 | 59.36 | 44.36 | 0.48 |
| | east | 675 | 675 | 675 | 1.79 | 1.72 | 0.96 | -0.07 | 22.16 | -2.41 | 0.70 | 56.58 | 43.83 | 0.35 |
| | west | 277 | 277 | 277 | 0.68 | 0.74 | 1.09 | 0.06 | 40.67 | 13.36 | 0.31 | 66.13 | 45.67 | 0.61 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 938 | 938 | 938 | 1.87 | 2.29 | 1.22 | 0.41 | 39.34 | 14.94 | 0.78 | 59.75 | 40.68 | 0.64 |
| | east | 654 | 654 | 654 | 2.14 | 2.82 | 1.32 | 0.68 | 58.04 | 29.31 | 0.90 | 66.27 | 38.88 | 0.61 |
| | west | 284 | 284 | 284 | 1.26 | 1.06 | 0.84 | -0.20 | -3.73 | -18.16 | 0.52 | 44.72 | 44.82 | 0.57 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 980 | 980 | 980 | 1.35 | 1.82 | 1.35 | 0.47 | 73.68 | 28.70 | 0.74 | 90.53 | 49.83 | 0.48 |
| | east | 687 | 687 | 687 | 1.57 | 2.22 | 1.42 | 0.66 | 79.22 | 34.52 | 0.90 | 91.73 | 50.09 | 0.39 |
| | west | 293 | 293 | 293 | 0.84 | 0.87 | 1.03 | 0.03 | 60.69 | 15.04 | 0.37 | 87.73 | 49.20 | 0.56 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 868 | 868 | 868 | 1.26 | 1.08 | 0.86 | -0.18 | 28.34 | -6.59 | 0.61 | 73.22 | 56.04 | 0.29 |
| | east | 624 | 624 | 624 | 1.56 | 1.28 | 0.82 | -0.28 | 3.18 | -21.37 | 0.74 | 57.55 | 55.06 | 0.18 |
| | west | 244 | 244 | 244 | 0.49 | 0.57 | 1.16 | 0.08 | 92.67 | 31.20 | 0.27 | 113.29 | 58.54 | 0.33 |

**O3_1HRMAX_AIRS_CMAQ: Comparison of Ozone 1-hour maximum observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 404336 | 404205 | 404336 | 51.24 | 52.15 | 1.02 | 0.90 | 8.06 | 2.82 | 9.29 | 22.37 | 19.37 | 0.57 |
| | east | 274172 | 274098 | 274172 | 51.00 | 52.70 | 1.03 | 1.70 | 8.15 | 3.80 | 8.87 | 21.14 | 18.77 | 0.62 |
| | west | 130164 | 130107 | 130164 | 51.76 | 50.98 | 0.99 | -0.79 | 7.86 | 0.77 | 10.17 | 24.96 | 20.64 | 0.48 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 116795 | 116777 | 116795 | 55.17 | 56.54 | 1.02 | 1.37 | 7.09 | 3.50 | 8.71 | 18.55 | 16.40 | 0.48 |
| | east | 81810 | 81801 | 81810 | 54.58 | 56.63 | 1.04 | 2.05 | 7.89 | 4.73 | 8.36 | 18.07 | 16.12 | 0.53 |
| | west | 34985 | 34976 | 34985 | 56.55 | 56.35 | 1.00 | -0.22 | 5.22 | 0.63 | 9.54 | 19.69 | 17.06 | 0.39 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 102204 | 102198 | 102204 | 59.65 | 61.07 | 1.02 | 1.41 | 8.55 | 3.95 | 11.37 | 22.33 | 19.80 | 0.47 |
| | east | 73129 | 73128 | 73129 | 59.30 | 63.22 | 1.07 | 3.93 | 12.98 | 8.38 | 10.87 | 22.47 | 19.00 | 0.53 |
| | west | 29075 | 29070 | 29075 | 60.56 | 55.65 | 0.92 | -4.91 | -2.60 | -7.21 | 12.63 | 21.95 | 21.82 | 0.43 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 140122 | 140101 | 140122 | 47.47 | 48.00 | 1.01 | 0.52 | 7.89 | 2.62 | 8.86 | 22.59 | 19.50 | 0.50 |
| | east | 96091 | 96075 | 96091 | 46.13 | 46.96 | 1.02 | 0.83 | 7.26 | 3.01 | 8.14 | 20.94 | 18.58 | 0.55 |
| | west | 44031 | 44026 | 44031 | 50.41 | 50.26 | 1.00 | -0.15 | 9.28 | 1.78 | 10.44 | 26.18 | 21.52 | 0.40 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 45215 | 45129 | 45215 | 33.79 | 33.50 | 0.99 | -0.33 | 9.95 | -0.84 | 7.39 | 31.65 | 25.66 | 0.35 |
| | east | 23142 | 23094 | 23142 | 32.38 | 29.44 | 0.91 | -2.98 | -2.51 | -10.70 | 7.38 | 28.60 | 28.24 | 0.47 |
| | west | 22073 | 22035 | 22073 | 35.26 | 37.76 | 1.07 | 2.44 | 23.01 | 9.50 | 7.40 | 34.83 | 22.97 | 0.20 |

**O3_8HRMAX_AIRS_CMAQ: Comparison of Ozone 8-hour maximum observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 404156 | 404040 | 404156 | 44.95 | 47.41 | 1.05 | 2.45 | 14.62 | 6.72 | 8.80 | 27.19 | 21.31 | 0.57 |
| | east | 274076 | 274006 | 274076 | 44.96 | 47.88 | 1.06 | 2.91 | 12.92 | 6.94 | 8.57 | 24.80 | 20.75 | 0.61 |
| | west | 130080 | 130034 | 130080 | 44.93 | 46.42 | 1.03 | 1.47 | 18.21 | 6.25 | 9.29 | 32.23 | 22.48 | 0.49 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 116726 | 116713 | 116726 | 49.70 | 52.33 | 1.05 | 2.63 | 11.48 | 6.48 | 8.41 | 21.51 | 17.78 | 0.47 |
| | east | 81766 | 81757 | 81766 | 49.32 | 52.43 | 1.06 | 3.11 | 11.76 | 7.48 | 8.26 | 20.92 | 17.79 | 0.51 |
| | west | 34960 | 34956 | 34960 | 50.58 | 52.09 | 1.03 | 1.51 | 10.81 | 4.12 | 8.75 | 22.88 | 17.75 | 0.38 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 102147 | 102140 | 102147 | 52.17 | 55.68 | 1.07 | 3.50 | 13.99 | 8.26 | 10.47 | 25.11 | 21.01 | 0.49 |
| | east | 73095 | 73094 | 73095 | 51.98 | 57.73 | 1.11 | 5.75 | 18.96 | 12.74 | 10.50 | 26.43 | 21.09 | 0.54 |
| | west | 29052 | 29046 | 29052 | 52.66 | 50.50 | 0.96 | -2.16 | 1.46 | -3.01 | 10.40 | 21.77 | 20.81 | 0.45 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 140092 | 140072 | 140092 | 40.88 | 42.84 | 1.05 | 1.96 | 14.16 | 6.54 | 8.31 | 27.25 | 21.61 | 0.50 |
| | east | 96083 | 96069 | 96083 | 40.01 | 41.79 | 1.04 | 1.78 | 11.94 | 5.87 | 7.75 | 24.82 | 20.61 | 0.54 |
| | west | 44009 | 44003 | 44009 | 42.78 | 45.15 | 1.06 | 2.36 | 19.02 | 8.01 | 9.54 | 32.56 | 23.80 | 0.42 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 45191 | 45115 | 45191 | 28.98 | 30.14 | 1.04 | 1.13 | 25.63 | 4.38 | 7.54 | 46.42 | 30.15 | 0.33 |
| | east | 23132 | 23086 | 23132 | 27.92 | 25.92 | 0.93 | -2.03 | 1.99 | -8.90 | 6.94 | 33.25 | 30.73 | 0.46 |
| | west | 22059 | 22029 | 22059 | 30.09 | 34.57 | 1.15 | 4.45 | 50.40 | 18.31 | 8.17 | 60.22 | 29.54 | 0.23 |

**NO3_STN_CMAQ: Comparison of STN NO3 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 6130 | 6130 | 6130 | 1.77 | 1.69 | 0.95 | -0.08 | 180.38 | -31.19 | 1.41 | 254.27 | 93.02 | 0.18 |
| | east | 4662 | 4662 | 4662 | 1.52 | 1.94 | 1.28 | 0.42 | 248.66 | -11.90 | 1.23 | 308.39 | 86.03 | 0.38 |
| | west | 1468 | 1468 | 1468 | 2.55 | 0.86 | 0.34 | -1.68 | -36.45 | -92.44 | 1.99 | 82.38 | 115.22 | 0.21 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1377 | 1377 | 1377 | 1.65 | 1.81 | 1.10 | 0.16 | 159.57 | -23.18 | 1.27 | 227.74 | 90.44 | 0.37 |
| | east | 1050 | 1050 | 1050 | 1.73 | 2.12 | 1.23 | 0.39 | 215.00 | -9.80 | 1.35 | 274.47 | 87.74 | 0.40 |
| | west | 327 | 327 | 327 | 1.41 | 0.81 | 0.58 | -0.59 | -18.41 | -66.14 | 0.99 | 77.69 | 99.11 | 0.32 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1662 | 1662 | 1662 | 0.99 | 0.64 | 0.65 | -0.35 | -7.77 | -74.72 | 0.86 | 99.02 | 110.20 | 0.07 |
| | east | 1268 | 1268 | 1268 | 0.81 | 0.74 | 0.92 | -0.06 | 8.86 | -55.49 | 0.69 | 100.66 | 98.18 | 0.13 |
| | west | 394 | 394 | 394 | 1.57 | 0.30 | 0.19 | -1.27 | -61.28 | -136.64 | 1.41 | 93.74 | 148.92 | 0.24 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1856 | 1856 | 1856 | 1.82 | 1.86 | 1.02 | 0.04 | 204.55 | -14.60 | 1.63 | 266.95 | 89.37 | 0.10 |
| | east | 1410 | 1410 | 1410 | 1.33 | 2.09 | 1.57 | 0.76 | 278.77 | 7.83 | 1.32 | 324.93 | 82.64 | 0.33 |
| | west | 446 | 446 | 446 | 3.37 | 1.14 | 0.34 | -2.22 | -30.10 | -85.53 | 2.63 | 83.66 | 110.67 | 0.19 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1235 | 1235 | 1235 | 2.86 | 2.69 | 0.94 | -0.17 | 420.45 | -6.47 | 1.96 | 473.70 | 78.26 | 0.15 |
| | east | 934 | 934 | 934 | 2.55 | 3.16 | 1.24 | 0.61 | 566.58 | 15.11 | 1.67 | 603.58 | 72.74 | 0.38 |
| | west | 301 | 301 | 301 | 3.85 | 1.24 | 0.32 | -2.61 | -32.96 | -73.42 | 2.88 | 70.70 | 95.39 | 0.18 |

**NO3_NADP_CMAQ: Comparison of NADP NO3 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 7619 | 7619 | 7619 | 1.52 | 1.31 | 0.86 | -0.21 | 31.47 | -33.47 | 1.13 | 101.41 | 74.92 | 0.11 |
| | east | 5299 | 5299 | 5299 | 1.68 | 1.66 | 0.99 | -0.02 | 43.44 | -21.23 | 1.25 | 103.50 | 69.43 | 0.12 |
| | west | 2320 | 2320 | 2320 | 1.16 | 0.51 | 0.44 | -0.65 | 4.14 | -61.41 | 0.85 | 96.65 | 87.47 | 0.05 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1955 | 1955 | 1955 | 1.57 | 1.23 | 0.78 | -0.34 | 6.28 | -36.27 | 0.94 | 73.84 | 64.50 | 0.20 |
| | east | 1304 | 1304 | 1304 | 1.76 | 1.55 | 0.88 | -0.21 | 18.02 | -27.25 | 1.02 | 77.68 | 59.56 | 0.22 |
| | west | 651 | 651 | 651 | 1.18 | 0.59 | 0.50 | -0.59 | -17.25 | -54.36 | 0.78 | 66.15 | 74.38 | 0.12 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1949 | 1949 | 1949 | 1.79 | 0.71 | 0.40 | -1.08 | -42.49 | -80.80 | 1.24 | 66.77 | 91.83 | 0.03 |
| | east | 1441 | 1441 | 1441 | 1.78 | 0.82 | 0.46 | -0.96 | -39.85 | -72.50 | 1.15 | 61.37 | 83.04 | 0.04 |
| | west | 508 | 508 | 508 | 1.80 | 0.40 | 0.22 | -1.40 | -49.99 | -104.36 | 1.47 | 82.09 | 116.79 | 0.01 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1805 | 1805 | 1805 | 1.32 | 1.55 | 1.18 | 0.24 | 115.09 | -6.73 | 1.11 | 165.20 | 69.94 | 0.16 |
| | east | 1255 | 1255 | 1255 | 1.49 | 2.02 | 1.36 | 0.53 | 131.20 | 9.87 | 1.30 | 168.74 | 65.54 | 0.15 |
| | west | 550 | 550 | 550 | 0.94 | 0.50 | 0.53 | -0.44 | 78.32 | -44.60 | 0.66 | 157.13 | 79.97 | 0.05 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1910 | 1910 | 1910 | 1.40 | 1.78 | 1.28 | 0.38 | 53.73 | -7.55 | 1.22 | 104.70 | 73.06 | 0.20 |
| | east | 1299 | 1299 | 1299 | 1.67 | 2.37 | 1.42 | 0.70 | 76.58 | 11.62 | 1.53 | 113.11 | 68.01 | 0.17 |
| | west | 611 | 611 | 611 | 0.82 | 0.52 | 0.64 | -0.29 | 5.15 | -48.33 | 0.57 | 86.80 | 83.78 | 0.08 |

**NO3_IMPROVE_CMAQ: Comparison of IMPROVE NO3 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 13458 | 13398 | 13443 | 0.48 | 0.61 | 1.27 | 0.13 | 90.46 | -39.71 | 0.49 | 176.87 | 112.04 | 0.35 |
| | east | 4771 | 4755 | 4767 | 0.66 | 1.04 | 1.58 | 0.38 | 69.44 | -31.90 | 0.74 | 149.28 | 107.04 | 0.44 |
| | west | 8687 | 8643 | 8676 | 0.38 | 0.37 | 0.98 | -0.01 | 102.02 | -44.01 | 0.36 | 192.05 | 114.79 | 0.23 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3374 | 3356 | 3372 | 0.52 | 0.74 | 1.43 | 0.22 | 118.82 | -19.24 | 0.53 | 189.24 | 100.89 | 0.46 |
| | east | 1194 | 1191 | 1194 | 0.79 | 1.24 | 1.58 | 0.45 | 86.91 | -18.28 | 0.86 | 157.33 | 101.65 | 0.45 |
| | west | 2180 | 2165 | 2178 | 0.38 | 0.47 | 1.25 | 0.09 | 136.38 | -19.76 | 0.35 | 206.80 | 100.47 | 0.41 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3390 | 3378 | 3385 | 0.27 | 0.14 | 0.53 | -0.13 | -34.92 | -115.96 | 0.24 | 104.45 | 139.10 | 0.16 |
| | east | 1273 | 1263 | 1269 | 0.29 | 0.19 | 0.67 | -0.10 | -33.43 | -97.79 | 0.26 | 92.29 | 124.48 | 0.09 |
| | west | 2117 | 2115 | 2116 | 0.25 | 0.11 | 0.43 | -0.14 | -35.80 | -126.86 | 0.23 | 111.71 | 147.87 | 0.20 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3712 | 3706 | 3709 | 0.40 | 0.60 | 1.48 | 0.20 | 110.08 | -25.74 | 0.50 | 187.44 | 109.92 | 0.24 |
| | east | 1380 | 1380 | 1380 | 0.55 | 0.99 | 1.79 | 0.44 | 93.21 | -18.66 | 0.74 | 164.15 | 105.64 | 0.35 |
| | west | 2332 | 2326 | 2329 | 0.32 | 0.37 | 1.16 | 0.05 | 120.09 | -29.93 | 0.36 | 201.26 | 112.45 | 0.13 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2982 | 2958 | 2977 | 0.77 | 1.01 | 1.30 | 0.23 | 176.86 | 6.38 | 0.73 | 232.27 | 96.57 | 0.32 |
| | east | 924 | 921 | 924 | 1.17 | 2.02 | 1.73 | 0.85 | 152.30 | 21.24 | 1.25 | 194.72 | 92.16 | 0.41 |
| | west | 2058 | 2037 | 2053 | 0.59 | 0.55 | 0.93 | -0.05 | 187.96 | -0.30 | 0.50 | 249.25 | 98.55 | 0.23 |

**NO3_CASTNET_CMAQ: Comparison of CASTNet NO3 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 3735 | 3735 | 3735 | 0.99 | 1.25 | 1.26 | 0.26 | 98.13 | -6.40 | 0.75 | 154.67 | 88.11 | 0.53 |
| | east | 2638 | 2638 | 2638 | 1.20 | 1.64 | 1.36 | 0.43 | 131.73 | 15.84 | 0.90 | 172.52 | 81.14 | 0.53 |
| | west | 1097 | 1097 | 1097 | 0.48 | 0.32 | 0.66 | -0.16 | 17.31 | -59.89 | 0.39 | 111.73 | 104.87 | 0.09 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 953 | 953 | 953 | 1.10 | 1.35 | 1.22 | 0.25 | 95.35 | -4.36 | 0.82 | 149.15 | 81.05 | 0.48 |
| | east | 676 | 676 | 676 | 1.31 | 1.72 | 1.32 | 0.41 | 133.56 | 15.81 | 0.98 | 174.34 | 78.60 | 0.47 |
| | west | 277 | 277 | 277 | 0.60 | 0.44 | 0.73 | -0.16 | 2.10 | -53.57 | 0.42 | 87.69 | 87.01 | 0.12 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 937 | 937 | 937 | 0.37 | 0.23 | 0.60 | -0.15 | 17.36 | -62.21 | 0.33 | 115.82 | 111.87 | 0.01 |
| | east | 654 | 654 | 654 | 0.34 | 0.29 | 0.86 | -0.05 | 52.05 | -25.47 | 0.29 | 122.58 | 91.18 | 0.04 |
| | west | 283 | 283 | 283 | 0.45 | 0.07 | 0.16 | -0.38 | -62.79 | -147.11 | 0.43 | 100.20 | 159.70 | 0.00 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 980 | 980 | 980 | 0.86 | 1.13 | 1.32 | 0.27 | 109.86 | 6.39 | 0.73 | 156.78 | 84.37 | 0.37 |
| | east | 687 | 687 | 687 | 1.04 | 1.47 | 1.42 | 0.43 | 138.72 | 24.15 | 0.87 | 172.92 | 79.84 | 0.36 |
| | west | 293 | 293 | 293 | 0.43 | 0.34 | 0.77 | -0.10 | 42.19 | -35.26 | 0.39 | 118.93 | 95.00 | 0.03 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 865 | 865 | 865 | 1.68 | 2.38 | 1.41 | 0.70 | 175.38 | 37.31 | 1.16 | 200.42 | 74.37 | 0.55 |
| | east | 621 | 621 | 621 | 2.18 | 3.14 | 1.44 | 0.96 | 205.94 | 50.18 | 1.50 | 222.68 | 74.75 | 0.47 |
| | west | 244 | 244 | 244 | 0.43 | 0.44 | 1.03 | 0.01 | 97.61 | 4.54 | 0.31 | 143.77 | 73.41 | 0.29 |

**NH4_STN_CMAQ: Comparison of STN NH4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 6970 | 6970 | 6970 | 1.26 | 1.58 | 1.25 | 0.32 | 412.61 | 35.50 | 0.84 | 436.05 | 68.24 | 0.34 |
| | east | 5414 | 5414 | 5414 | 1.36 | 1.87 | 1.37 | 0.51 | 467.21 | 44.10 | 0.89 | 484.36 | 67.16 | 0.43 |
| | west | 1556 | 1556 | 1556 | 0.94 | 0.61 | 0.65 | -0.33 | 222.61 | 5.57 | 0.66 | 267.95 | 72.01 | 0.20 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1378 | 1378 | 1378 | 1.24 | 1.54 | 1.24 | 0.30 | 224.94 | 29.99 | 0.71 | 245.21 | 57.25 | 0.46 |
| | east | 1051 | 1051 | 1051 | 1.43 | 1.83 | 1.28 | 0.40 | 272.77 | 34.42 | 0.81 | 289.98 | 57.03 | 0.43 |
| | west | 327 | 327 | 327 | 0.62 | 0.61 | 0.99 | -0.01 | 71.21 | 15.74 | 0.38 | 101.32 | 57.96 | 0.31 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2106 | 2106 | 2106 | 1.51 | 1.64 | 1.08 | 0.13 | 162.95 | 13.50 | 0.78 | 193.46 | 55.38 | 0.44 |
| | east | 1677 | 1677 | 1677 | 1.69 | 1.95 | 1.15 | 0.26 | 198.79 | 22.90 | 0.84 | 222.02 | 53.70 | 0.47 |
| | west | 429 | 429 | 429 | 0.82 | 0.44 | 0.54 | -0.38 | 22.85 | -23.22 | 0.54 | 81.83 | 61.92 | 0.22 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2155 | 2155 | 2155 | 1.01 | 1.57 | 1.55 | 0.56 | 588.07 | 61.04 | 0.95 | 604.87 | 84.78 | 0.26 |
| | east | 1671 | 1671 | 1671 | 1.00 | 1.82 | 1.82 | 0.82 | 630.56 | 71.52 | 1.00 | 641.13 | 85.80 | 0.48 |
| | west | 484 | 484 | 484 | 1.05 | 0.70 | 0.66 | -0.36 | 441.38 | 24.86 | 0.80 | 479.66 | 81.26 | 0.20 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1331 | 1331 | 1331 | 1.31 | 1.57 | 1.20 | 0.26 | 717.84 | 34.65 | 0.88 | 744.14 | 73.18 | 0.23 |
| | east | 1015 | 1015 | 1015 | 1.33 | 1.84 | 1.39 | 0.51 | 843.13 | 44.02 | 0.87 | 860.99 | 69.16 | 0.41 |
| | west | 316 | 316 | 316 | 1.24 | 0.69 | 0.55 | -0.56 | 315.41 | 4.57 | 0.91 | 368.81 | 86.10 | 0.18 |

**NH4_NADP_CMAQ: Comparison of NADP NH4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 7619 | 7619 | 7619 | 0.38 | 0.35 | 0.93 | -0.02 | 56.22 | -11.20 | 0.28 | 110.06 | 70.70 | 0.10 |
| | east | 5299 | 5299 | 5299 | 0.40 | 0.43 | 1.07 | 0.03 | 64.67 | 0.76 | 0.29 | 107.53 | 63.17 | 0.11 |
| | west | 2320 | 2320 | 2320 | 0.32 | 0.17 | 0.54 | -0.15 | 36.93 | -38.53 | 0.25 | 115.86 | 87.90 | 0.07 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1955 | 1955 | 1955 | 0.44 | 0.38 | 0.88 | -0.05 | 41.37 | -11.96 | 0.29 | 93.14 | 65.65 | 0.16 |
| | east | 1304 | 1304 | 1304 | 0.47 | 0.46 | 0.97 | -0.01 | 41.01 | -3.24 | 0.29 | 83.80 | 58.70 | 0.19 |
| | west | 651 | 651 | 651 | 0.37 | 0.23 | 0.63 | -0.14 | 42.08 | -29.42 | 0.27 | 111.86 | 79.58 | 0.09 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1949 | 1949 | 1949 | 0.45 | 0.28 | 0.61 | -0.18 | 8.23 | -40.07 | 0.29 | 82.54 | 72.46 | 0.02 |
| | east | 1441 | 1441 | 1441 | 0.44 | 0.31 | 0.71 | -0.13 | 8.40 | -27.17 | 0.25 | 69.36 | 60.99 | 0.05 |
| | west | 508 | 508 | 508 | 0.50 | 0.16 | 0.33 | -0.33 | 7.73 | -76.63 | 0.40 | 119.93 | 105.00 | 0.00 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1805 | 1805 | 1805 | 0.36 | 0.43 | 1.17 | 0.06 | 89.60 | 3.64 | 0.31 | 133.65 | 70.76 | 0.10 |
| | east | 1255 | 1255 | 1255 | 0.40 | 0.54 | 1.34 | 0.14 | 107.45 | 18.46 | 0.36 | 139.44 | 65.22 | 0.11 |
| | west | 550 | 550 | 550 | 0.28 | 0.17 | 0.61 | -0.11 | 48.87 | -30.16 | 0.21 | 120.43 | 83.42 | 0.08 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1910 | 1910 | 1910 | 0.25 | 0.33 | 1.34 | 0.08 | 88.87 | 4.99 | 0.23 | 133.18 | 74.00 | 0.18 |
| | east | 1299 | 1299 | 1299 | 0.29 | 0.42 | 1.48 | 0.14 | 109.53 | 18.67 | 0.28 | 142.86 | 68.08 | 0.16 |
| | west | 611 | 611 | 611 | 0.16 | 0.12 | 0.78 | -0.03 | 44.97 | -24.08 | 0.12 | 112.62 | 86.57 | 0.22 |

**NH4_IMPROVE_CMAQ: Comparison of IMPROVE NH4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 330 | 330 | 330 | 1.38 | 1.72 | 1.25 | 0.35 | 177.10 | 26.19 | 0.69 | 193.07 | 47.10 | 0.36 |
| | east | 326 | 326 | 326 | 1.38 | 1.74 | 1.26 | 0.36 | 175.68 | 26.93 | 0.69 | 190.65 | 46.19 | 0.36 |
| | west | 4 | 4 | 4 | 0.82 | 0.46 | 0.57 | -0.36 | 292.66 | -34.31 | 0.92 | 390.27 | 121.54 | 0.22 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 90 | 90 | 90 | 1.35 | 1.67 | 1.24 | 0.32 | 39.58 | 20.52 | 0.61 | 54.75 | 39.74 | 0.34 |
| | east | 90 | 90 | 90 | 1.35 | 1.67 | 1.24 | 0.32 | 39.58 | 20.52 | 0.61 | 54.75 | 39.74 | 0.34 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 84 | 84 | 84 | 1.89 | 1.93 | 1.02 | 0.04 | 507.18 | 10.82 | 0.77 | 532.39 | 43.59 | 0.29 |
| | east | 84 | 84 | 84 | 1.89 | 1.93 | 1.02 | 0.04 | 507.18 | 10.82 | 0.77 | 532.39 | 43.59 | 0.29 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 94 | 94 | 94 | 1.23 | 1.69 | 1.38 | 0.47 | 58.86 | 33.18 | 0.66 | 69.98 | 47.06 | 0.52 |
| | east | 93 | 93 | 93 | 1.24 | 1.71 | 1.38 | 0.47 | 59.93 | 34.10 | 0.67 | 70.29 | 47.00 | 0.51 |
| | west | 1 | 1 | 1 | 0.14 | 0.08 | 0.59 | -0.06 | -41.35 | -52.13 | 0.06 | 41.35 | 52.13 | |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 62 | 62 | 62 | 0.96 | 1.58 | 1.65 | 0.62 | 108.78 | 44.65 | 0.75 | 120.74 | 62.63 | 0.38 |
| | east | 59 | 59 | 59 | 0.95 | 1.63 | 1.71 | 0.67 | 93.76 | 48.36 | 0.72 | 101.12 | 58.45 | 0.50 |
| | west | 3 | 3 | 3 | 1.05 | 0.59 | 0.56 | -0.46 | 404.00 | -28.37 | 1.20 | 506.57 | 144.67 | 0.93 |

**SO4_STN_CMAQ: Comparison of STN SO4 observations versus CMAQ predictions.**

| ANNUAL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 6970 | 6970 | 6970 | 3.40 | 3.62 | 1.06 | 0.22 | 55.36 | -0.54 | 1.47 | 89.70 | 46.15 | 0.61 |
| | east | 5414 | 5414 | 5414 | 3.93 | 4.37 | 1.11 | 0.44 | 75.58 | 8.43 | 1.67 | 102.51 | 44.53 | 0.59 |
| | west | 1556 | 1556 | 1556 | 1.56 | 1.00 | 0.64 | -0.55 | -14.97 | -31.74 | 0.78 | 45.16 | 51.78 | 0.16 |

| SPRING | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1378 | 1378 | 1378 | 3.22 | 2.96 | 0.92 | -0.26 | 35.33 | -11.79 | 1.23 | 75.85 | 42.44 | 0.48 |
| | east | 1051 | 1051 | 1051 | 3.78 | 3.56 | 0.94 | -0.21 | 50.37 | -6.94 | 1.42 | 86.49 | 41.24 | 0.39 |
| | west | 327 | 327 | 327 | 1.43 | 1.01 | 0.71 | -0.42 | -13.04 | -27.39 | 0.62 | 41.64 | 46.27 | 0.20 |

| SUMMER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2106 | 2106 | 2106 | 4.76 | 5.28 | 1.11 | 0.52 | 54.69 | 0.97 | 2.05 | 88.61 | 47.42 | 0.63 |
| | east | 1677 | 1677 | 1677 | 5.50 | 6.37 | 1.16 | 0.86 | 76.43 | 13.81 | 2.31 | 99.30 | 44.27 | 0.60 |
| | west | 429 | 429 | 429 | 1.87 | 1.03 | 0.55 | -0.85 | -30.31 | -49.25 | 1.01 | 46.80 | 59.75 | 0.15 |

| FALL | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 2155 | 2155 | 2155 | 2.81 | 3.25 | 1.16 | 0.44 | 53.84 | 6.14 | 1.27 | 82.51 | 44.83 | 0.62 |
| | east | 1671 | 1671 | 1671 | 3.15 | 3.88 | 1.23 | 0.73 | 73.65 | 16.59 | 1.41 | 93.96 | 43.50 | 0.63 |
| | west | 484 | 484 | 484 | 1.62 | 1.06 | 0.65 | -0.56 | -14.57 | -29.92 | 0.79 | 42.96 | 49.39 | 0.17 |

| WINTER | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **region** | **n_obs** | **nzero_obs** | **nzero_sum** | **obs** | **pred** | **means_ratio** | **bias** | **nbias** | **fbias** | **err** | **nerr** | **ferr** | **r2** |
| | nation | 1331 | 1331 | 1331 | 2.40 | 2.27 | 0.95 | -0.13 | 79.65 | -2.08 | 1.13 | 117.44 | 50.14 | 0.28 |
| | east | 1015 | 1015 | 1015 | 2.79 | 2.71 | 0.97 | -0.08 | 103.43 | 2.02 | 1.30 | 138.45 | 50.08 | 0.19 |
| | west | 316 | 316 | 316 | 1.15 | 0.87 | 0.75 | -0.29 | 3.24 | -15.26 | 0.60 | 49.96 | 50.34 | 0.12 |