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: $R^2 = 0.80$).

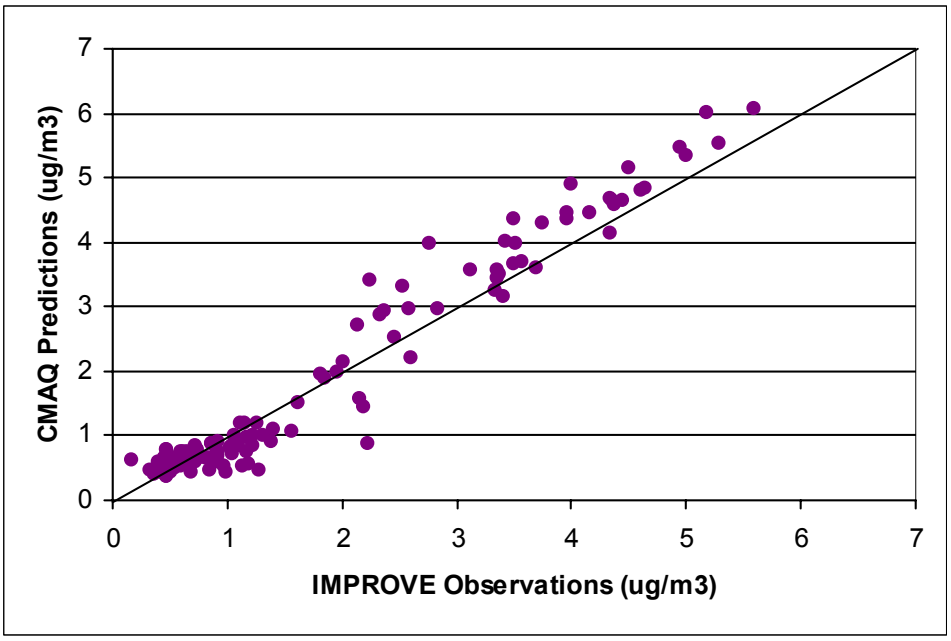


Figure 1. Annual average sulfate 2001 IMPROVE observations versus CMAQ predictions.

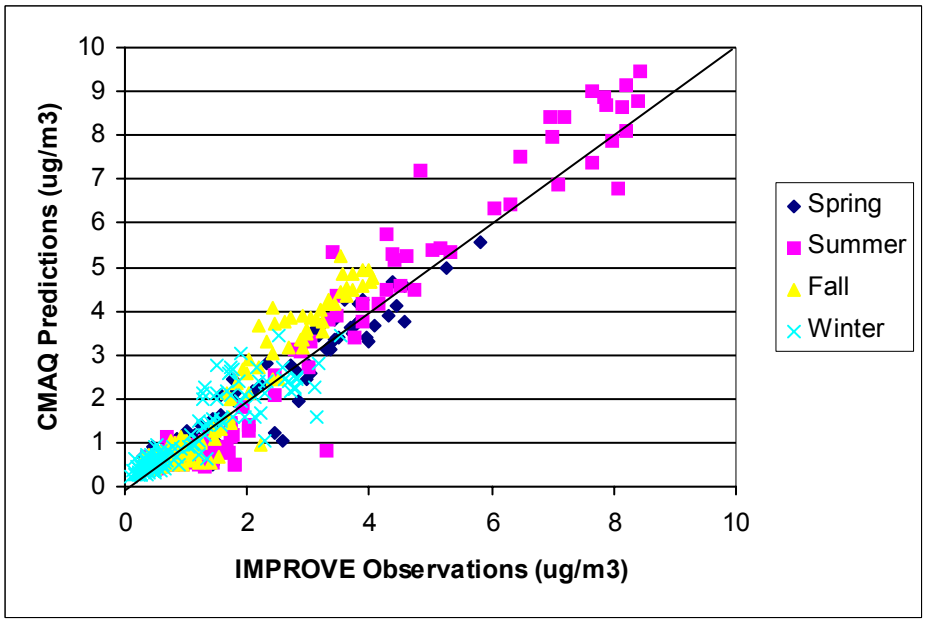


Figure 2. Seasonal average sulfate 2001 IMPROVE observations versus CMAQ predictions.

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: $R^2 = 0.56$).

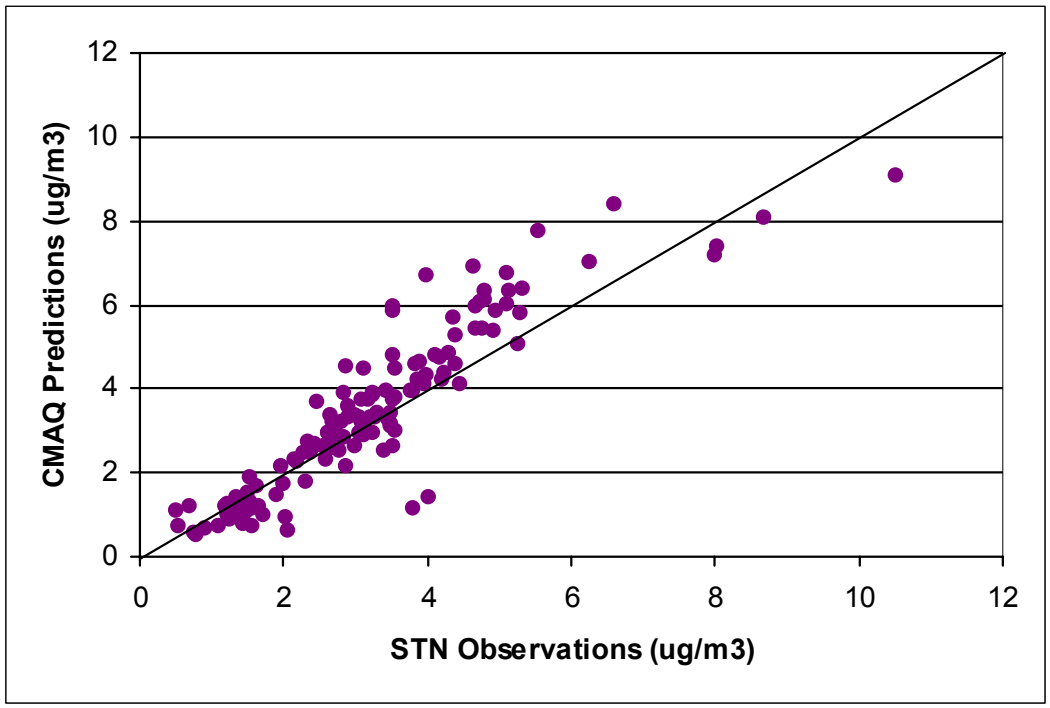


Figure 3. Annual total sulfate (SO_4) 2001 STN observations versus CMAQ predictions.

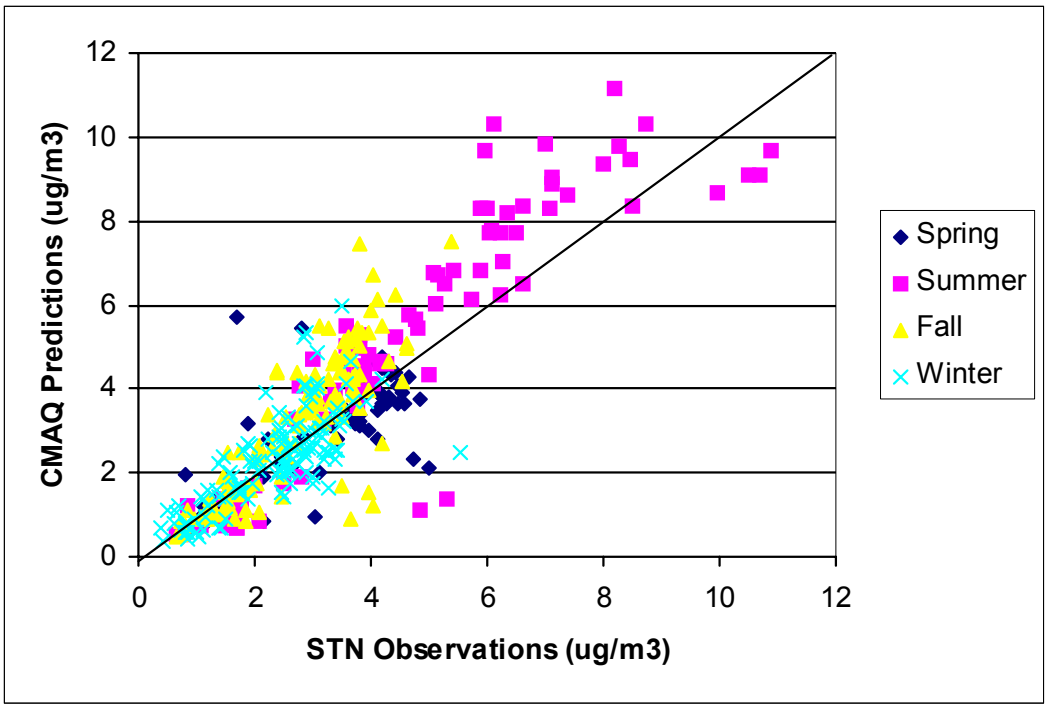


Figure 4. Seasonal total sulfate (SO_4) 2001 STN observations versus CMAQ predictions.

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.

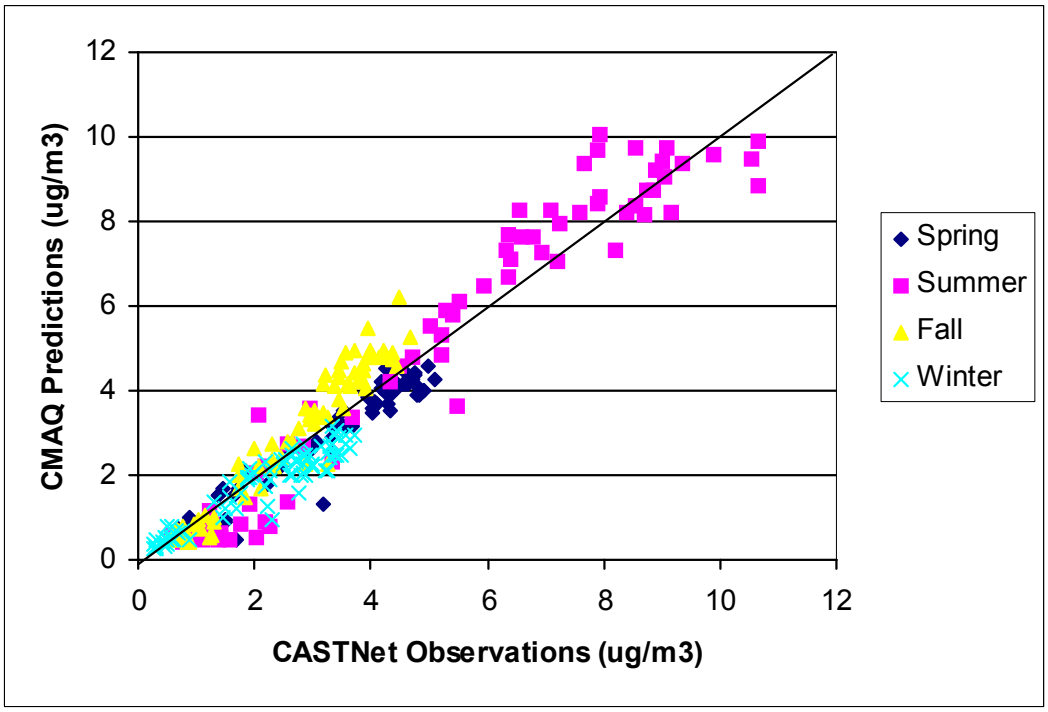


Figure 5. Seasonal average sulfate (SO_4) 2001 CASTNet observations versus CMAQ predictions.

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: $R^2 = 0.78$.

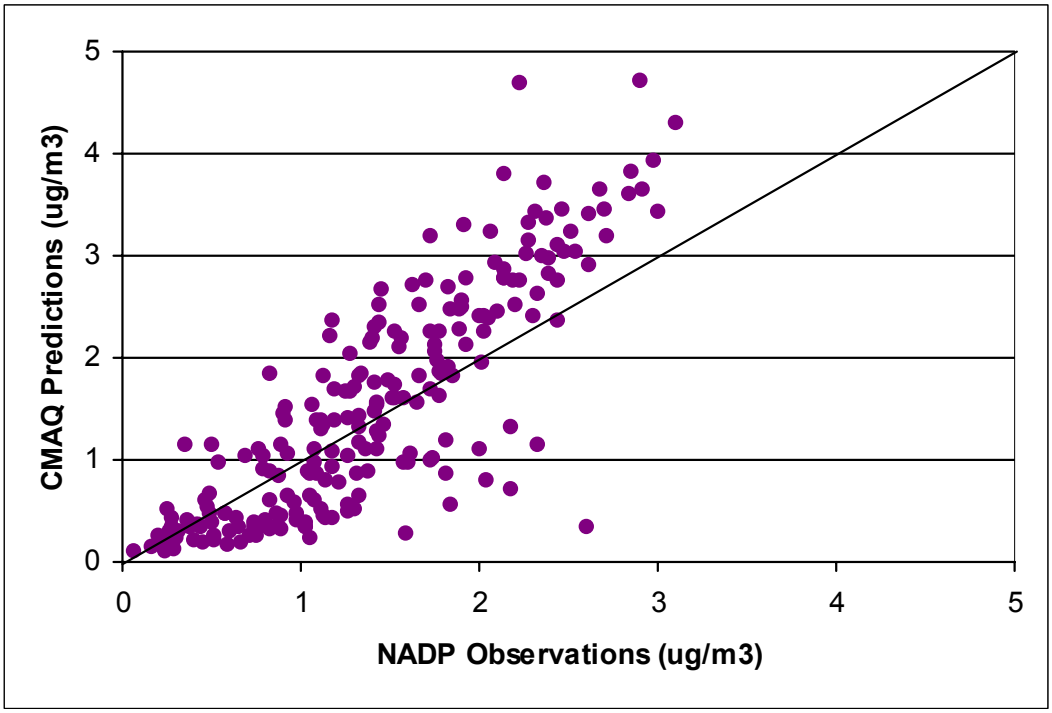


Figure 6. Annual total sulfate (SO_4) wet deposition 2001 NADP observations versus CMAQ predictions.

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.

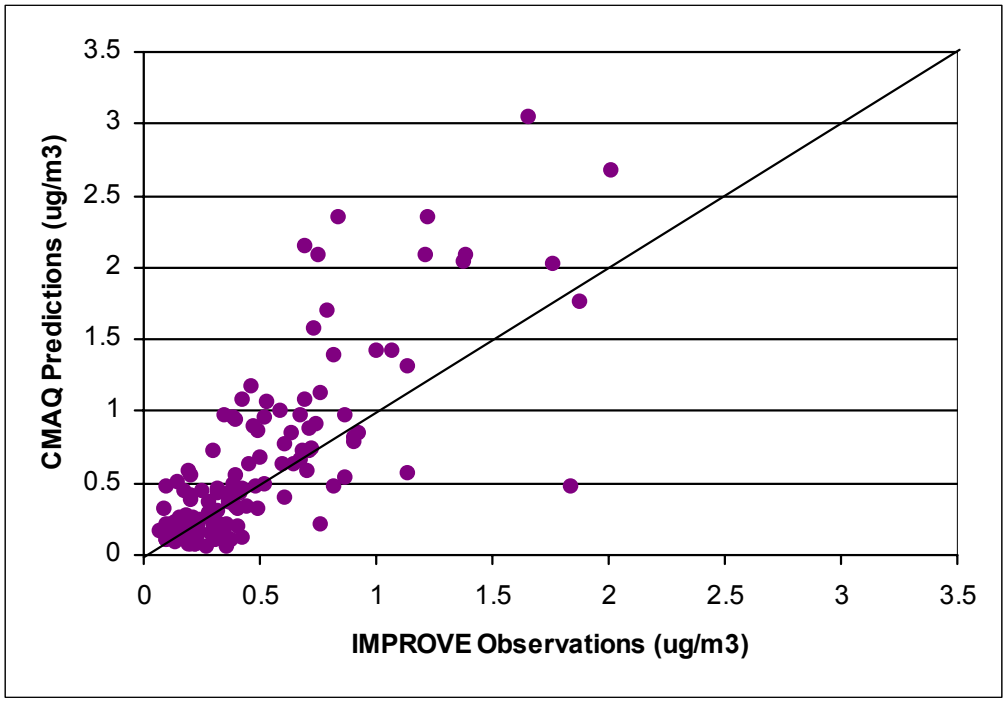


Figure 7. Annual average nitrate ion 2001 IMPROVE observations versus CMAQ predictions.

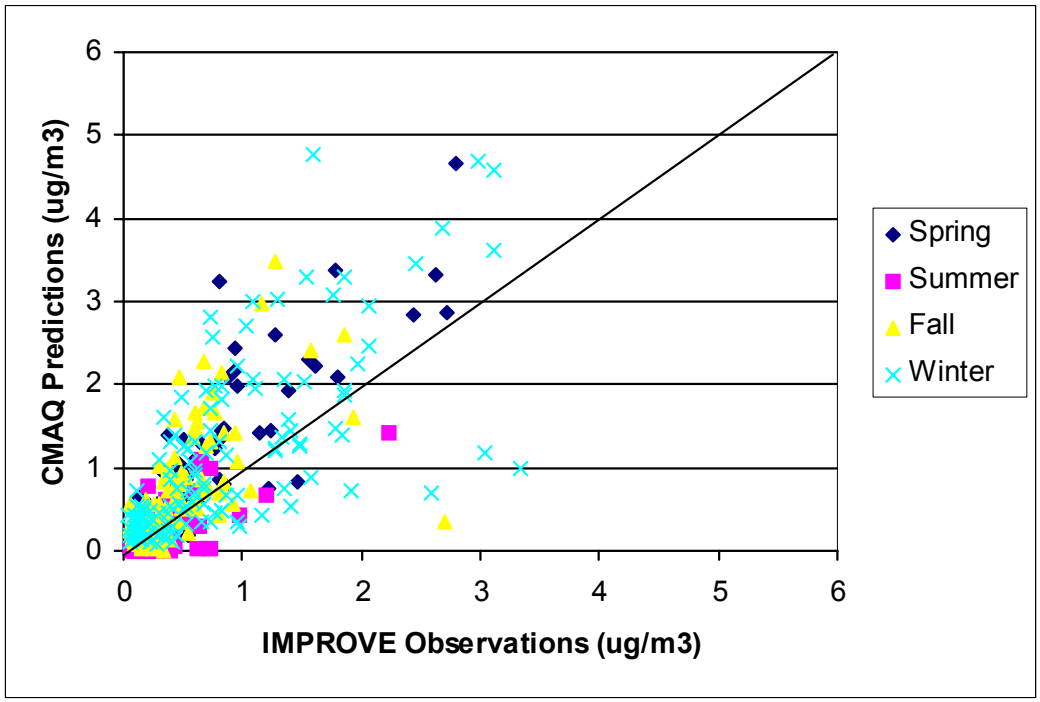


Figure 8. Seasonal average nitrate ion 2001 IMPROVE observations versus CMAQ predictions.

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.

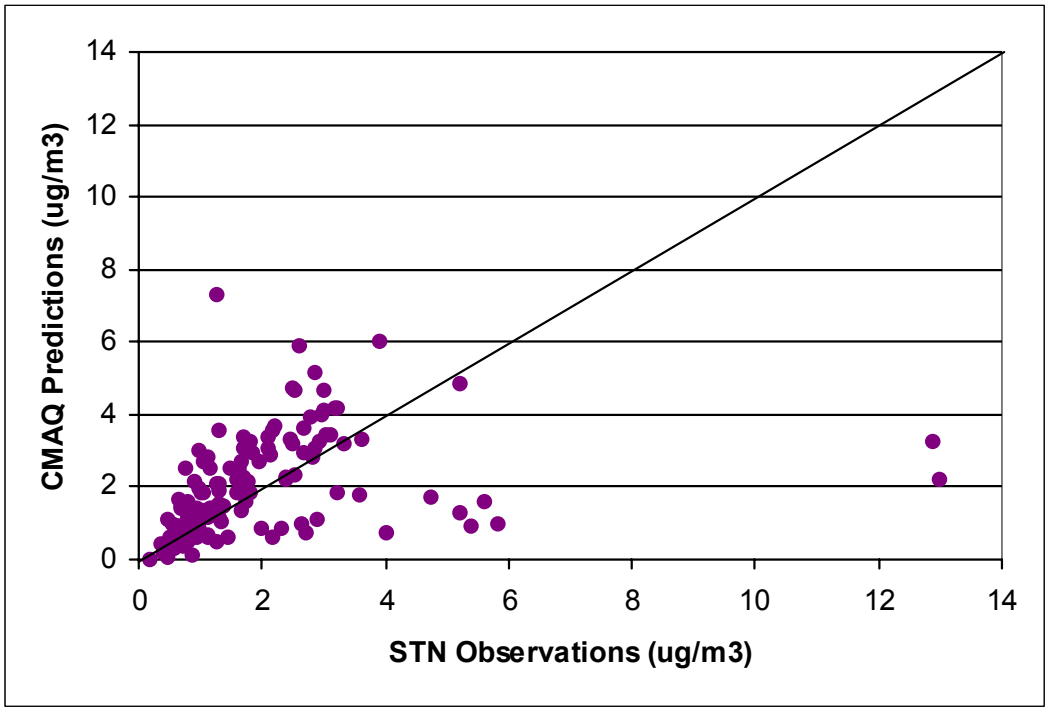


Figure 9. Annual average nitrate ion 2001 STN observations versus CMAQ predictions.

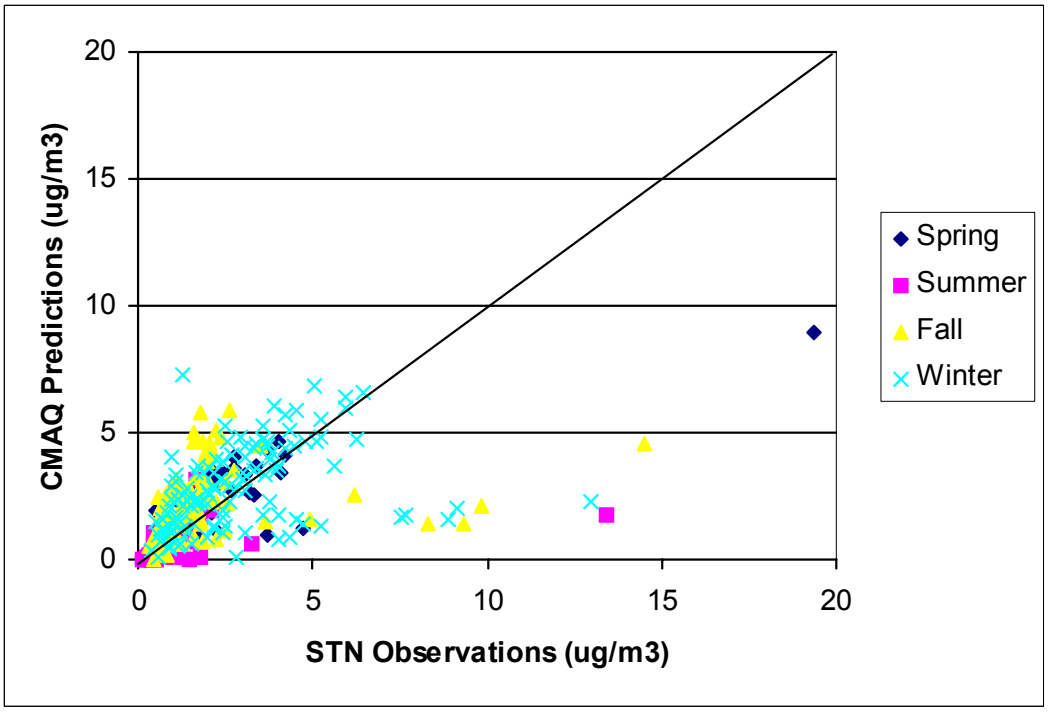


Figure 10. Seasonal average nitrate ion 2001 STN observations versus CMAQ predictions.

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.

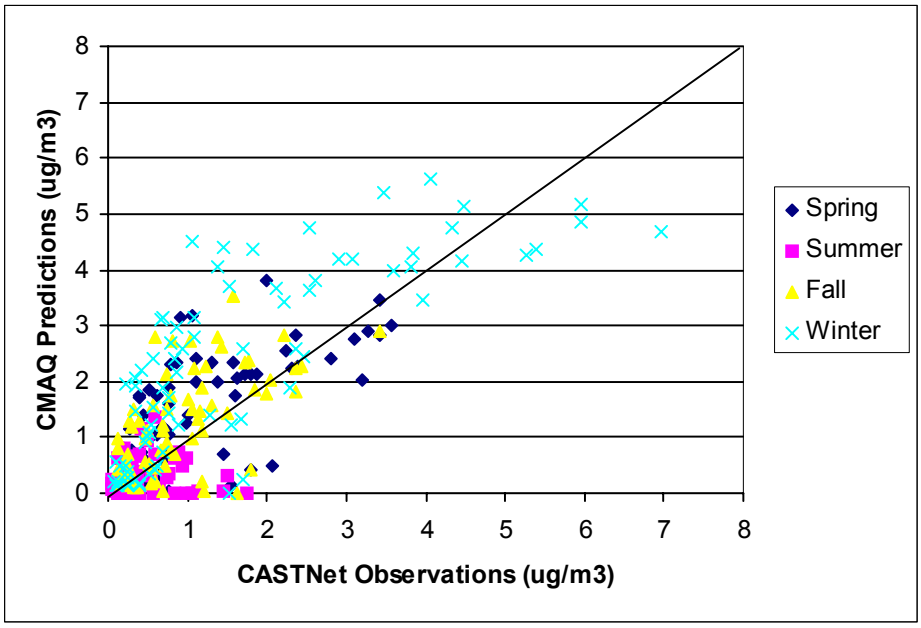


Figure 11. Seasonal average total nitrate ($NO_3 + HNO_3$) 2001 CASTNet observations versus CMAQ predictions.

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, $R^2 = 0.78$.

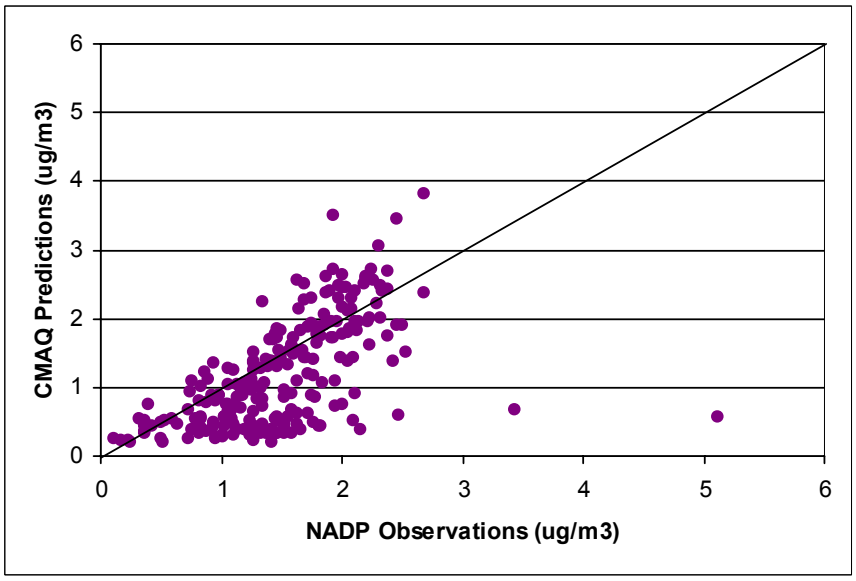


Figure 12. Annual total nitrate (NO_3) wet deposition 2001 NADP observations versus CMAQ predictions**.**

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.

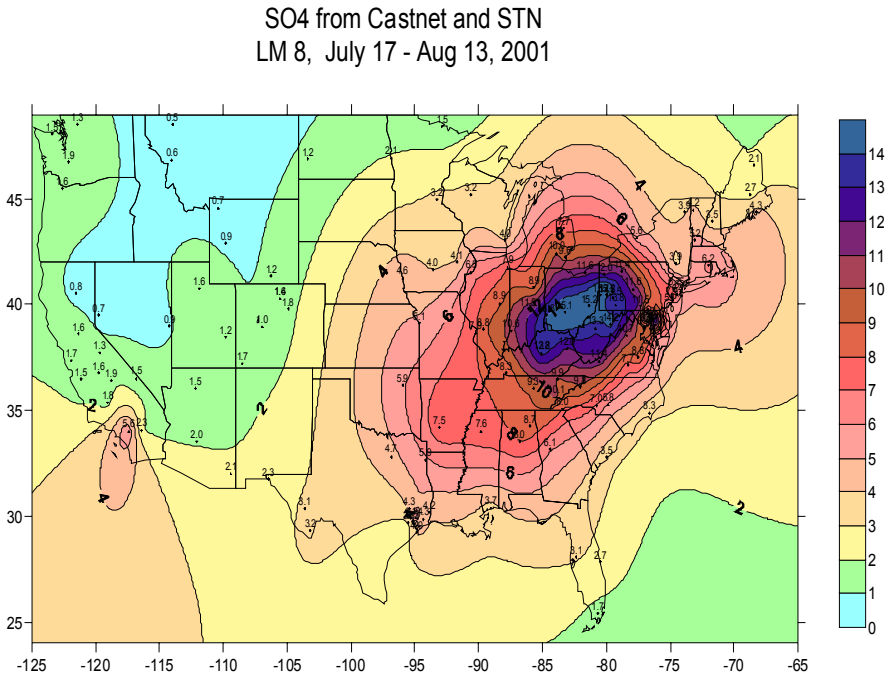


Figure 13. Sulfate (SO_4) based on average of the period July 17 - August 13, 2001 CASTNet and STN observations.

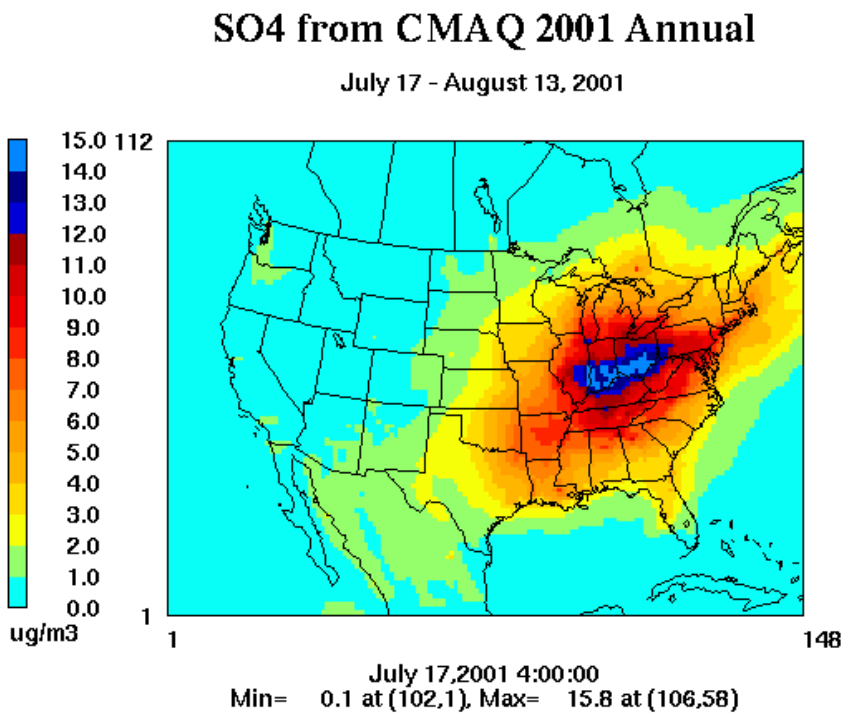


Figure 14. Sulfate (SO_4) based on average of the period July 17 - August 13, 2001 CMAQ predictions.

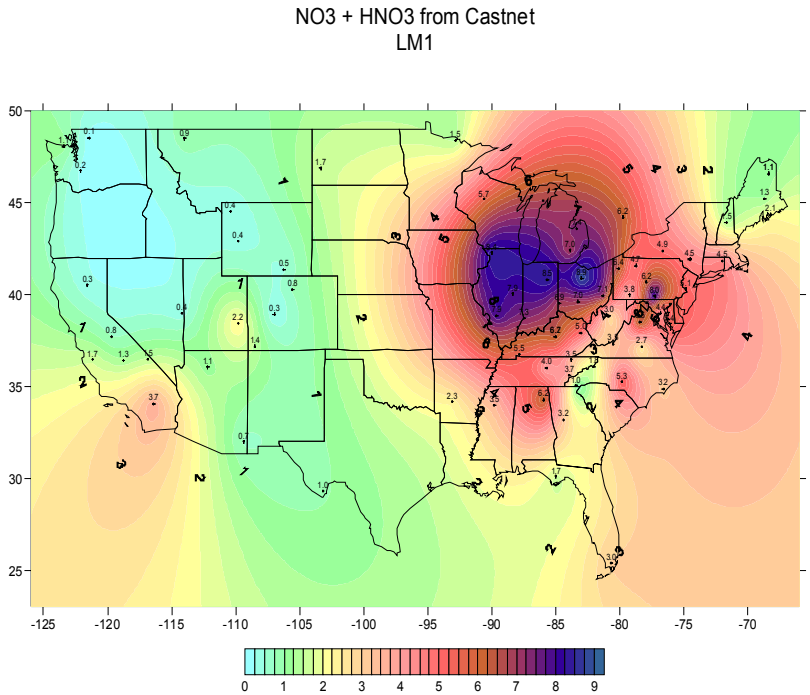


Figure 15. Total nitrate (NO_3 + HNO_3) based on average of the period January 2- 29, 2001 CASTNet observations.

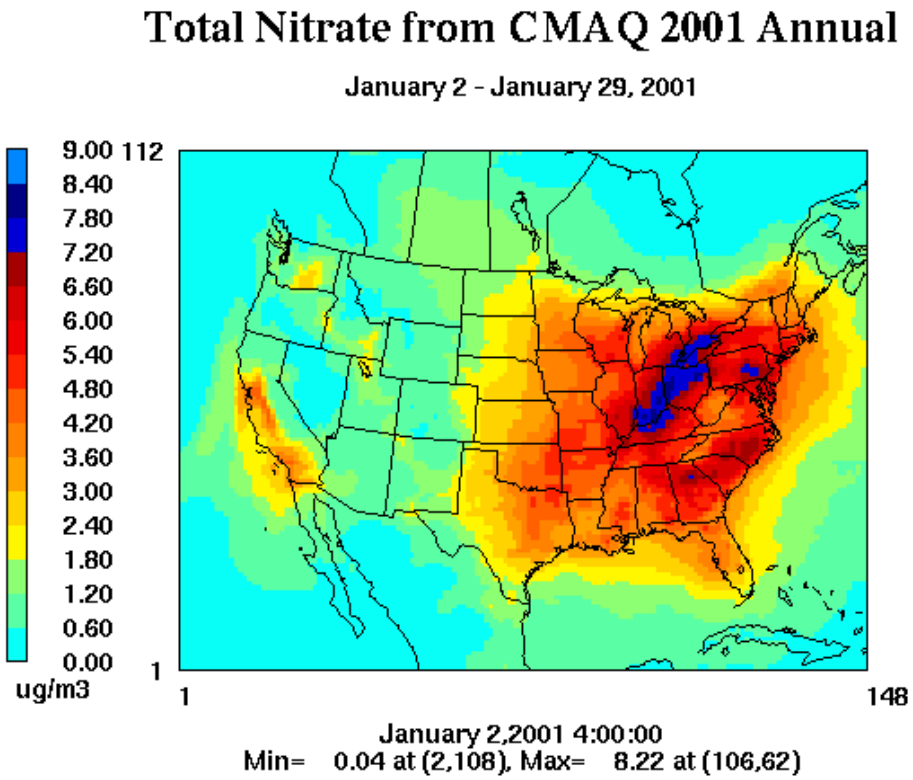


Figure 16. Total nitrate (NO_3 + HNO_3) based on average of the period January 2- 29, 2001 CMAQ predictions.

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: $R^2 = 0.19$).

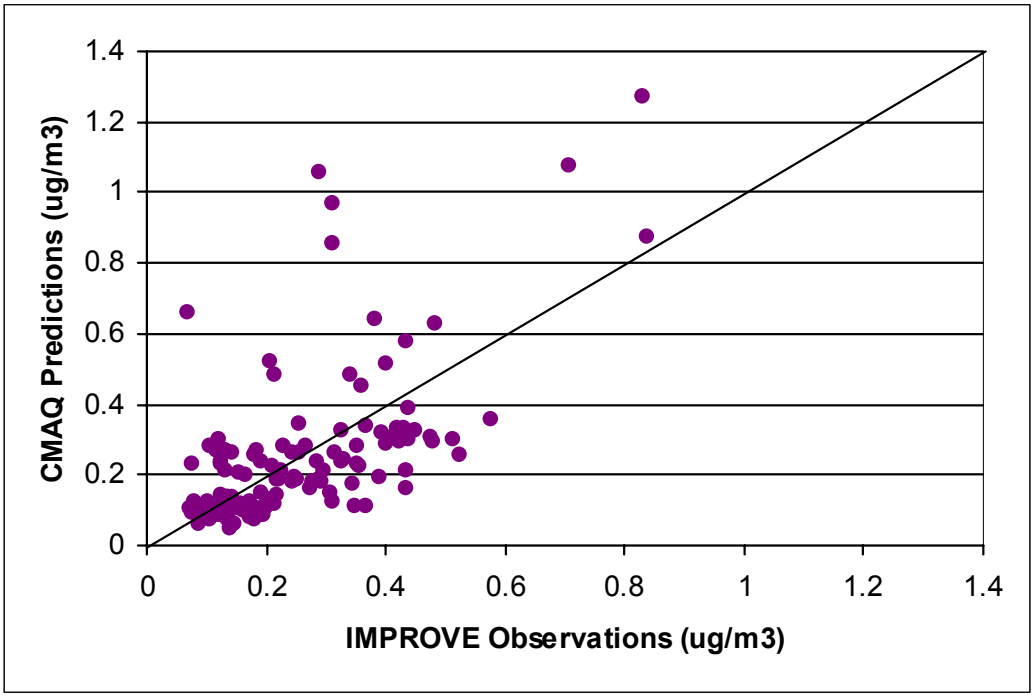


Figure 17. Annual average elemental carbon 2001 IMPROVE observations versus CMAQ predictions.

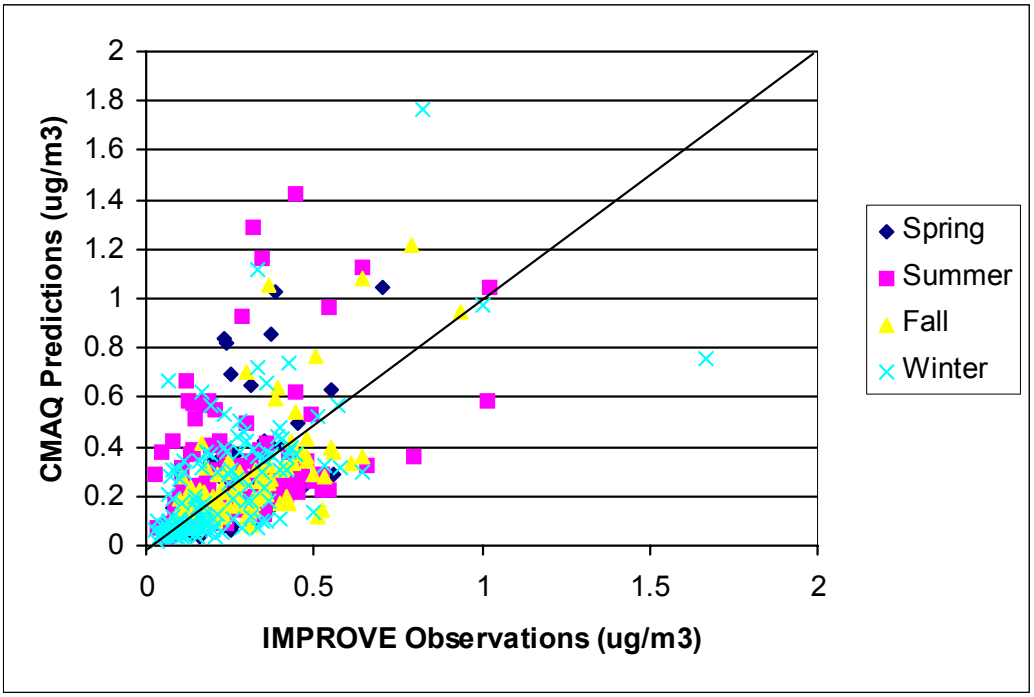


Figure 18. Seasonal average elemental carbon 2001 IMPROVE observations versus CMAQ predictions.

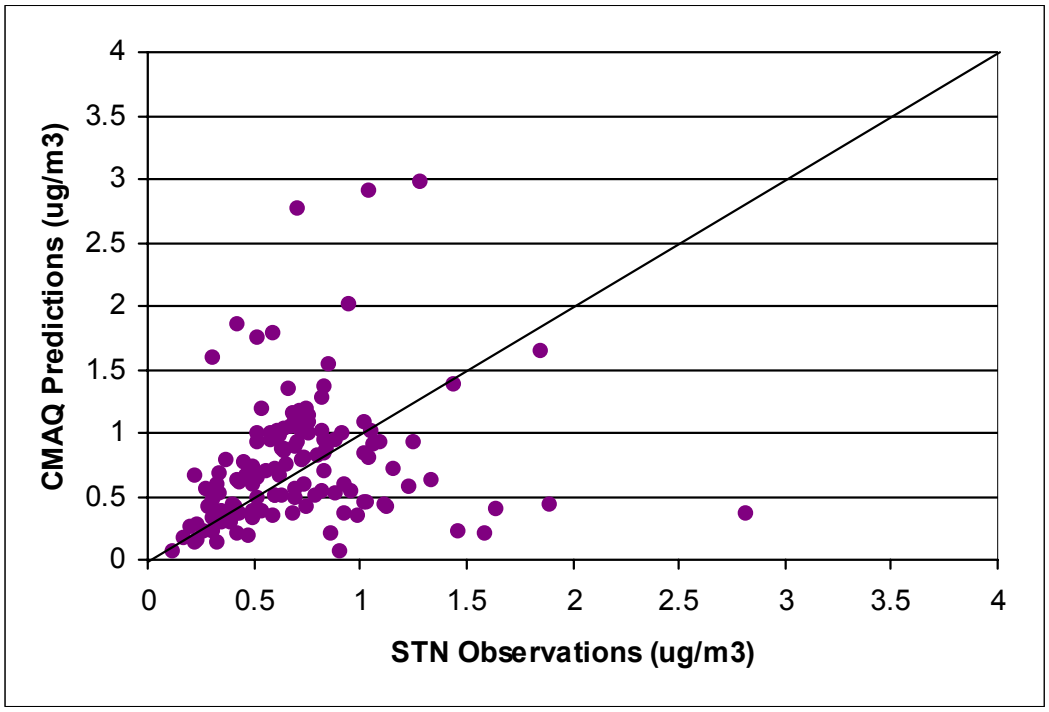
d.3. STN Performance

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.

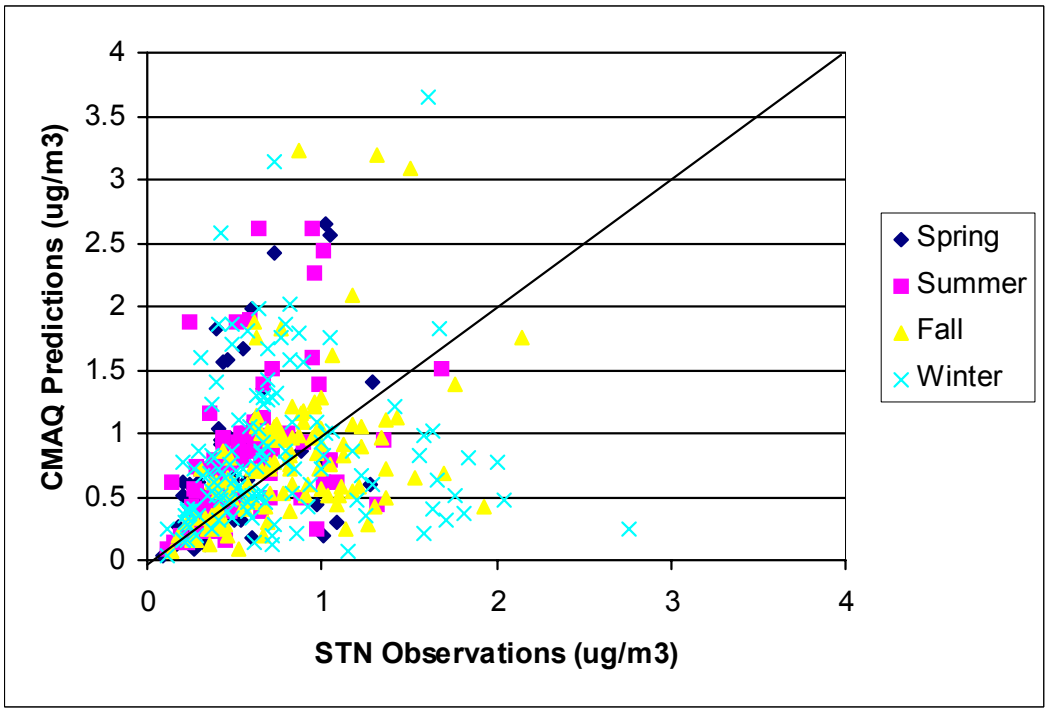


Figure 20. Seasonal average elemental carbon 2001 STN observations versus CMAQ predictions.

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.

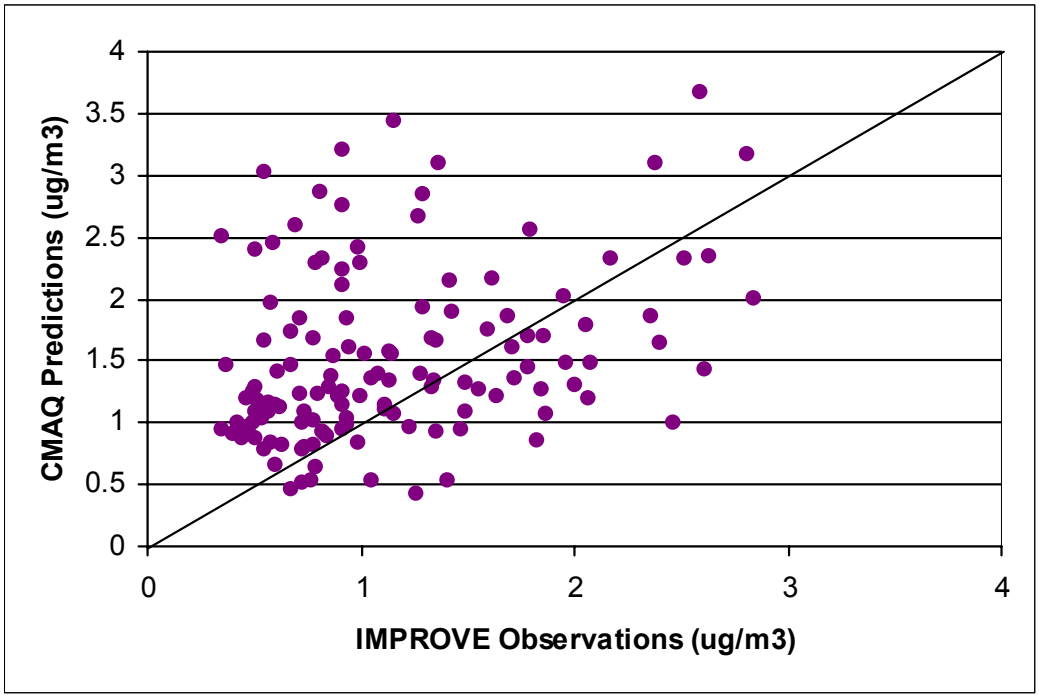


Figure 21. Annual average organic aerosol 2001 IMPROVE observations versus CMAQ predictions.

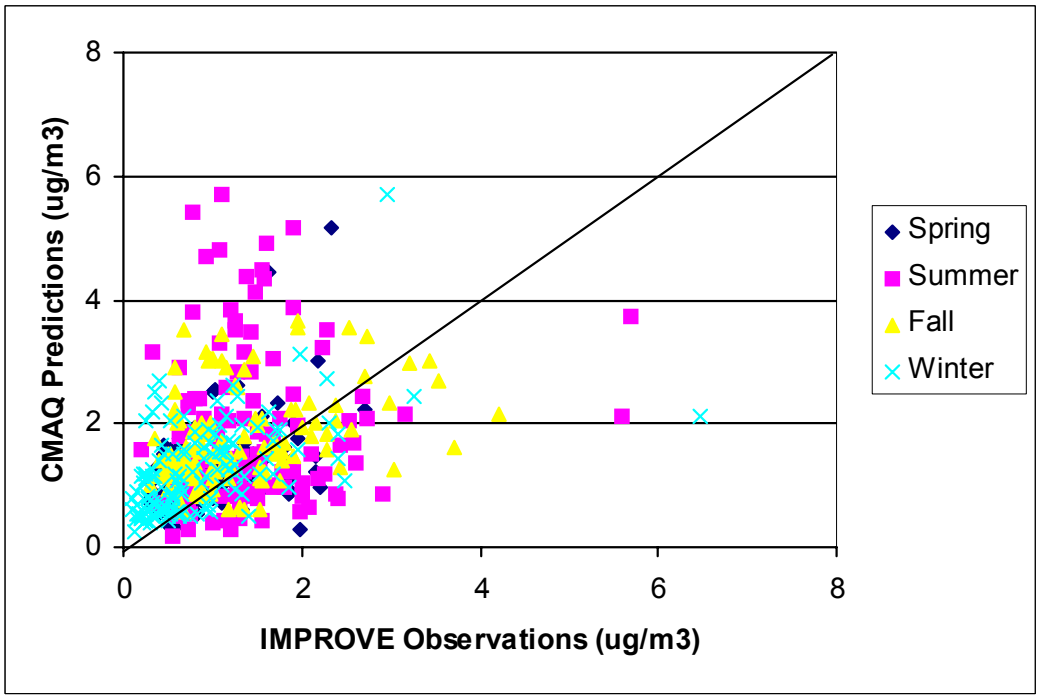


Figure 22. Seasonal average organic aerosol 2001 IMPROVE observations versus CMAQ predictions.

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.

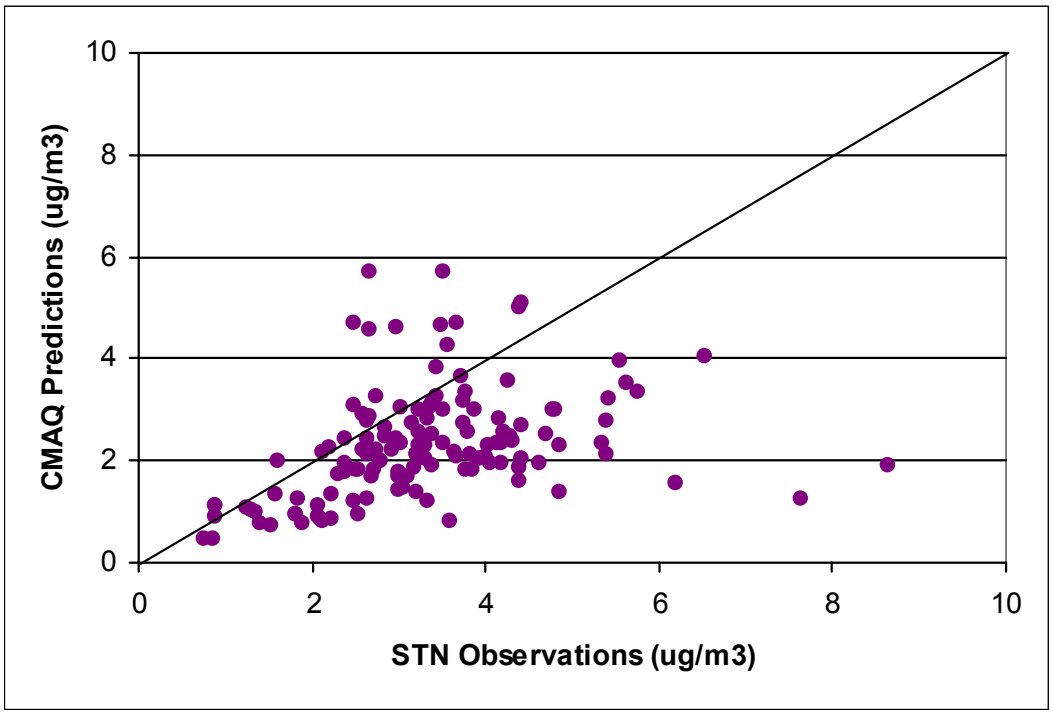


Figure 23. Annual average organic carbon 2001 STN observations versus CMAQ predictions.

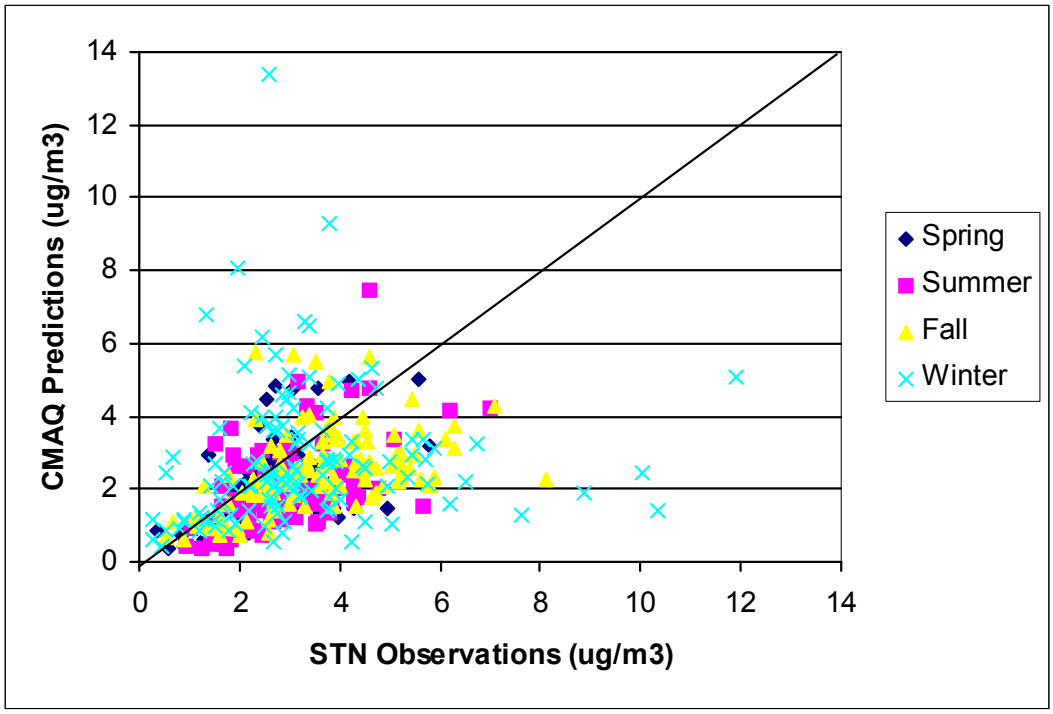


Figure 24. Seasonal average organic carbon 2001 STN observations versus CMAQ predictions.

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 $R^2 = 0.65$.

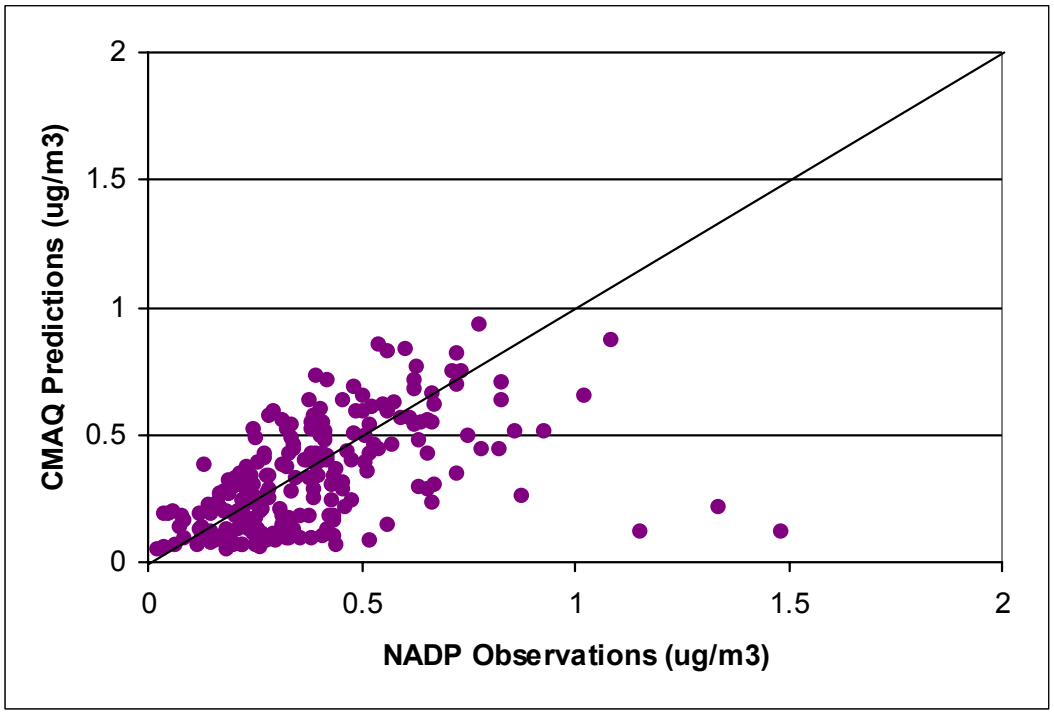


Figure 25. Annual total ammonium (NH_4) wet deposition 2001 NADP observations versus CMAQ predictions.

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: $R^2 = 0.60$).

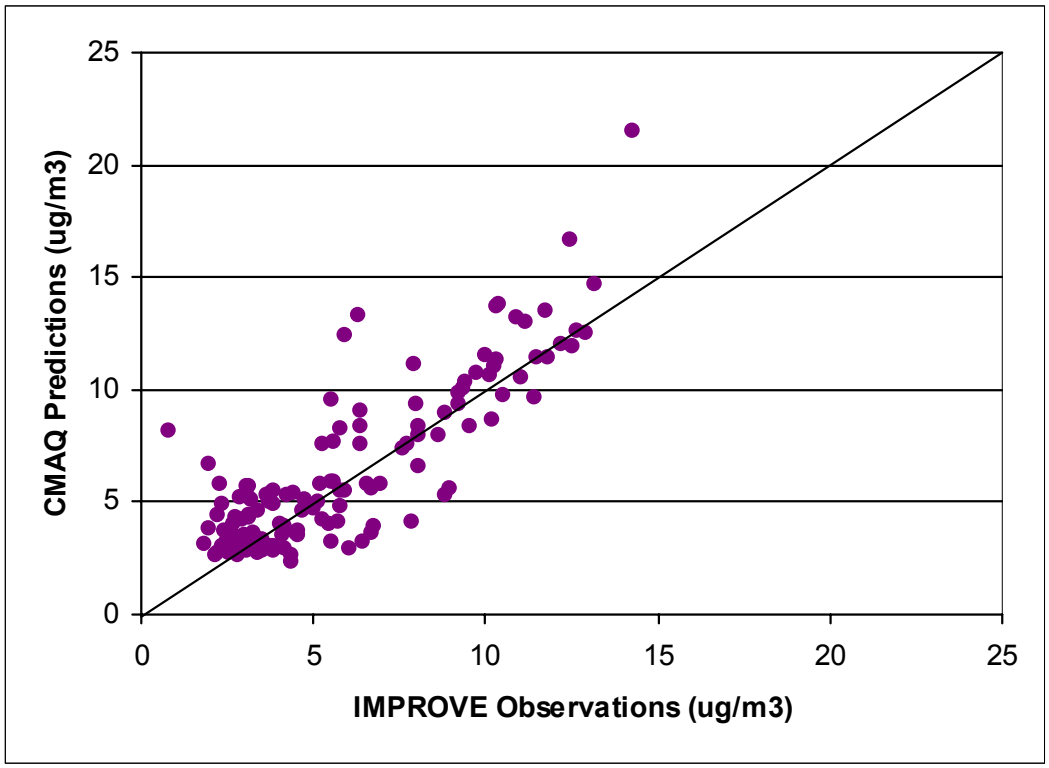


Figure 26. Annual average PM2.5 2001 IMPROVE observations versus CMAQ predictions.

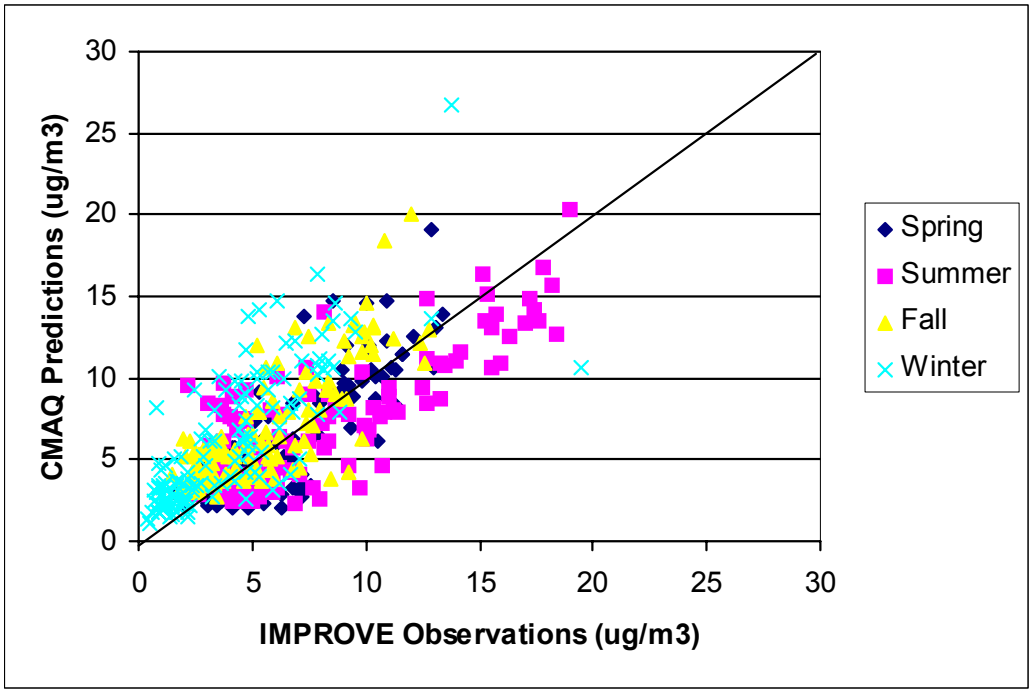


Figure 27. Seasonal average PM2.5 2001 IMPROVE observations versus CMAQ predictions.

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: $R^2 = 0.09$.

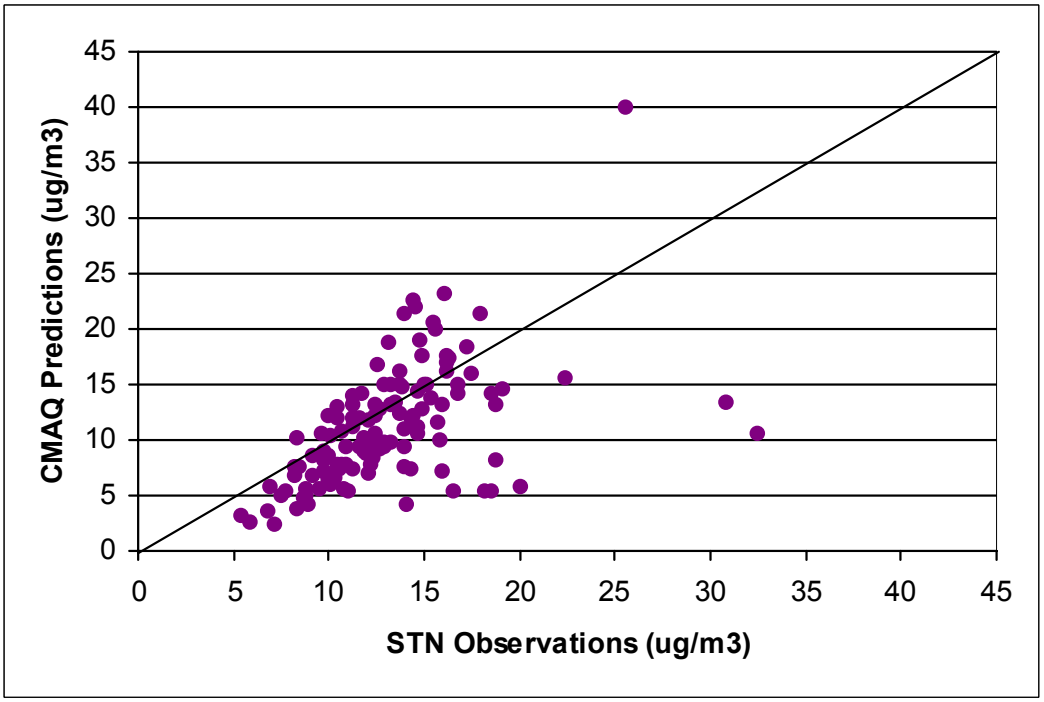


Figure 28. Annual average PM2.5 2001 STN observations versus CMAQ predictions.

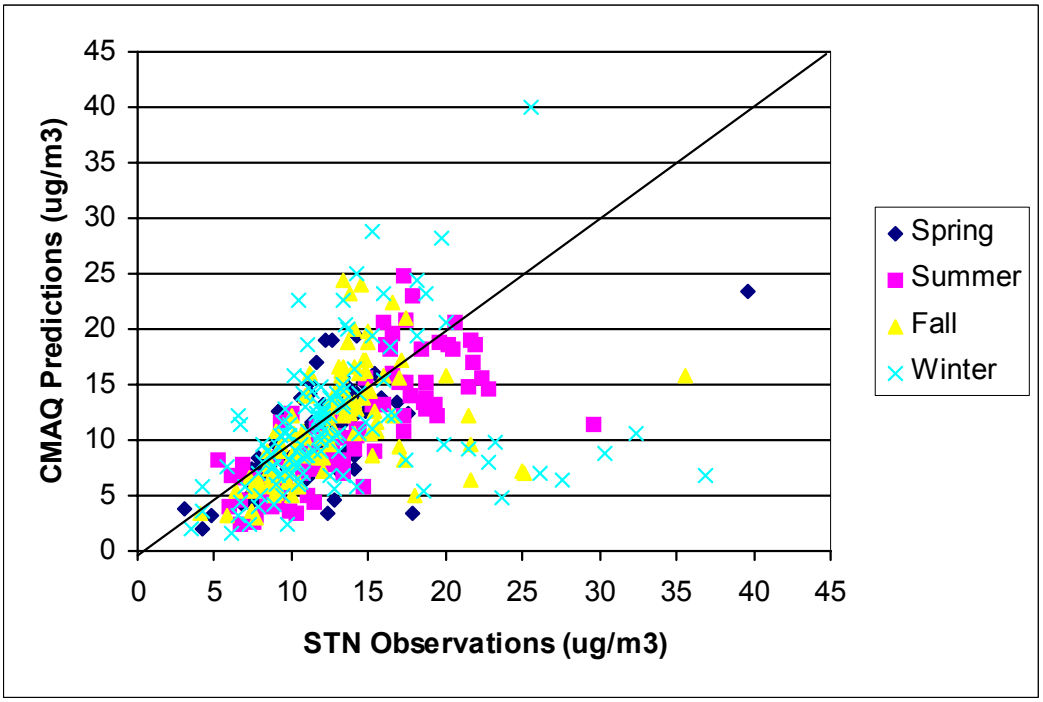


Figure 29. Seasonal average PM2.5 2001 STN observations versus CMAQ predictions.

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: $R^2 = 0.49$.

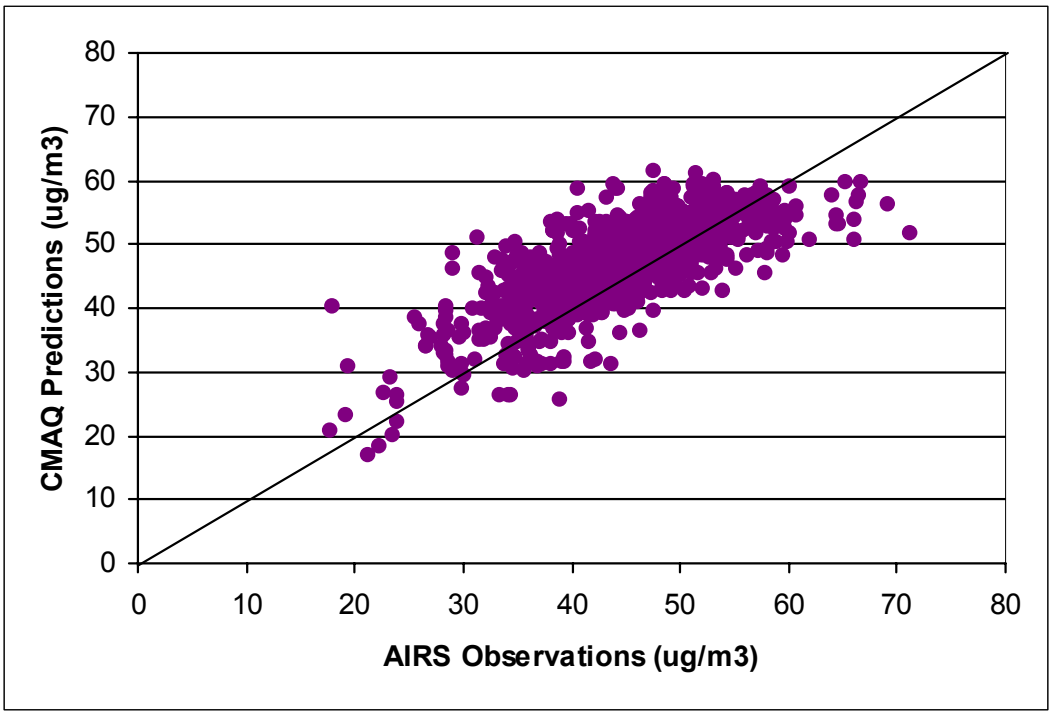


Figure 30. Annual 8-hour maximum average ozone 2001 AIRS observations versus CMAQ predictions.

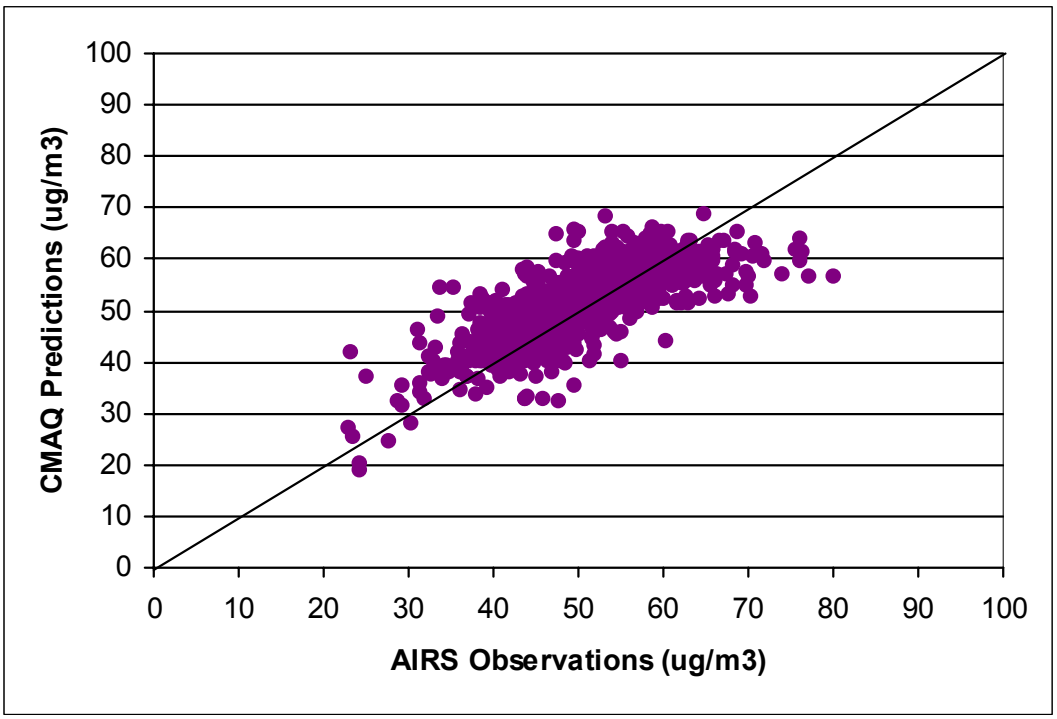


Figure 31. Annual 1-hour maximum average ozone 2001 AIRS observations versus CMAQ predictions.

4. References

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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/.

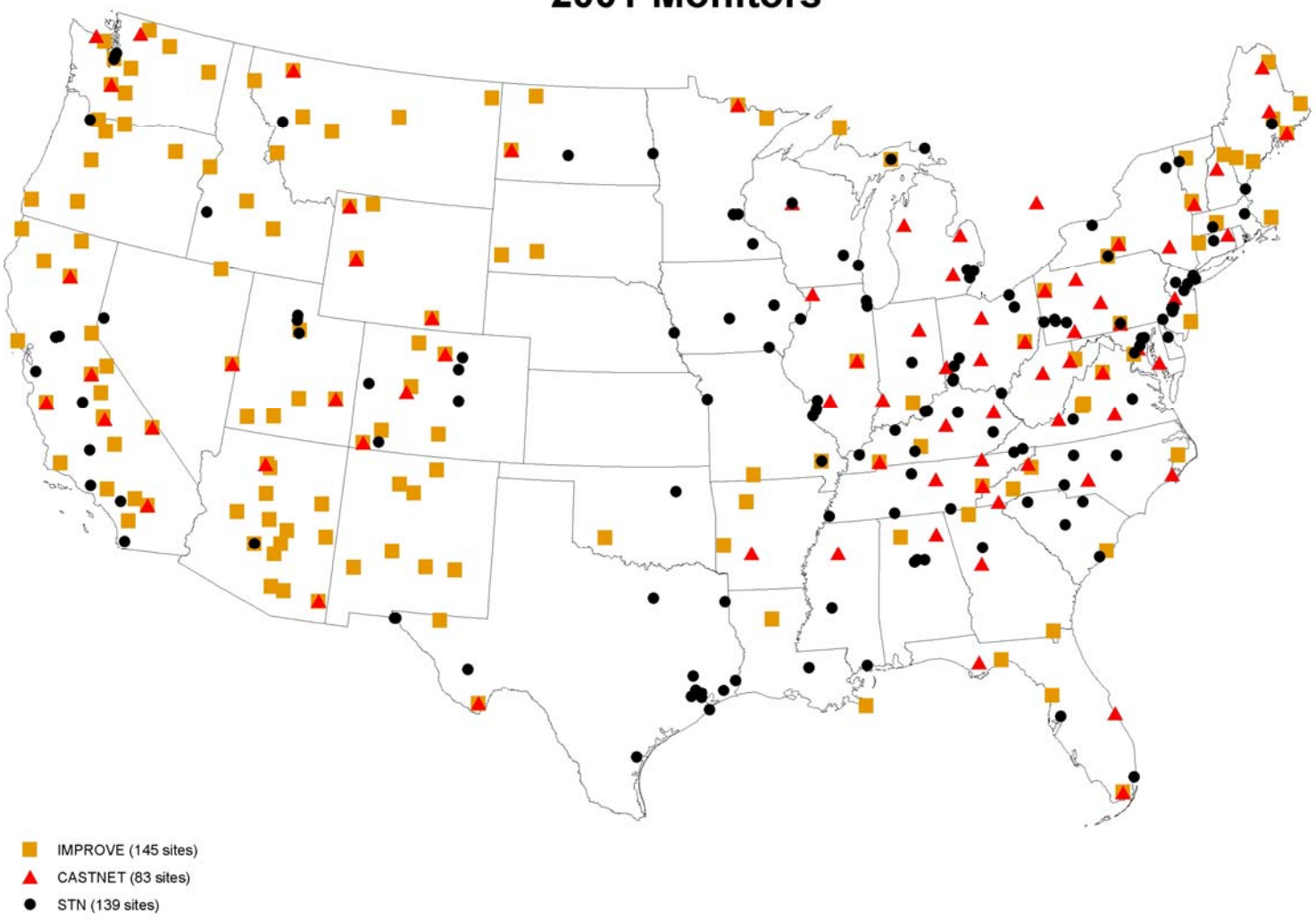
NADP, 2002: National Acid Deposition Program 2002 Annual Summary.

Appendix A

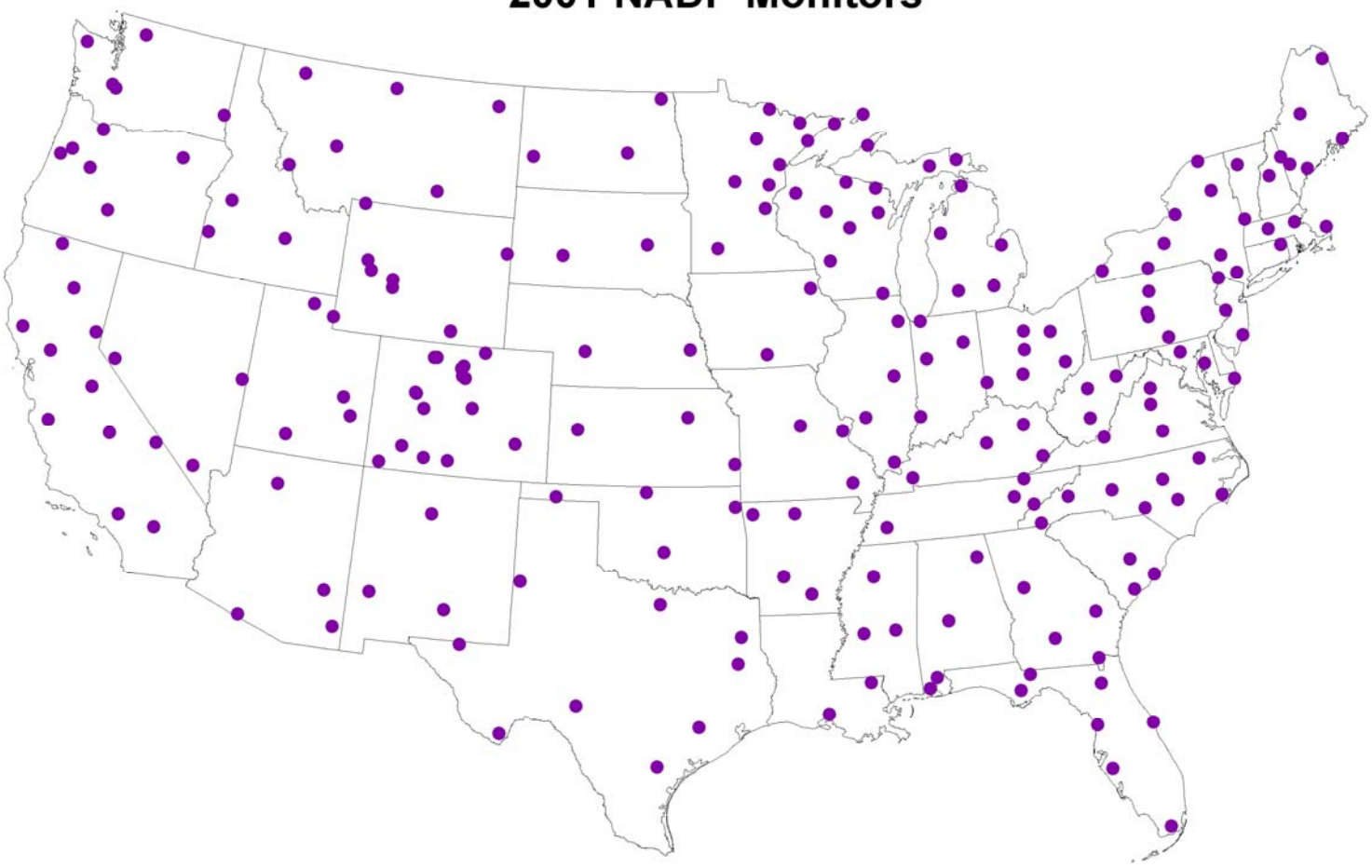
2001 Monitoring Networks:

IMPROVE, STN, CASTNet, NADP, and AIRS

2001 Monitors



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