

CMAQ MODEL PERFORMANCE IN GEORGIA AND MACON

There are many aspects of model performance. This section will focus primarily on the methods and techniques recommended by the USEPA for evaluating the performance of the air quality model. Before the air quality model can be fully evaluated, the meteorological modeling performance is needed to understand potential biases and errors that may be passed from the meteorological model directly into the air quality model. The meteorological modeling evaluations for VISTAS and Georgia are fully documented in Appendix K.1 and Appendix K.2, respectively. The air quality modeling evaluation for VISTAS is fully documented in Appendix G. The air quality modeling evaluation for Georgia and the Macon nonattainment area is fully documented here.

1 Meteorological Model Performance

Generally speaking, the meteorological modeling performance was quite good at both the 36-km and 12-km grid resolutions. Synoptic features were routinely accurately predicted and the meteorological model showed considerable skill in replicating the state variables (e.g. temperature, mixing ratio, relative humidity, wind speed and direction, cloud cover, and precipitation). The meteorological modeling performance statistics fell within expected and acceptable ranges of error during the majority of the 2002 modeled year.

The meteorological modeling performance for Georgia was very similar to the performance for the VISTAS/ASIP region for the 12-km modeling domain. Again, large-scale meteorological patterns were accurately predicted. The meteorological model demonstrated substantial skills throughout the entire year and was especially skillful during the summertime season from May through September.

U.S. EPA guidance (EPA, 2007) recognizes the complexity and importance of evaluating meteorological modeling results for air quality applications. Since MM5 algorithms and modules have undergone significant peer review and testing, an “operational” evaluation of the modeling system is sufficient to serve as the basis of evaluating if the system is operating with sufficient reliability to be used in support of SIP development. An operational evaluation can be defined as the process of evaluating how accurately a modeling simulation estimates observed quantities. In the case of a prognostic meteorological model, this amounts to a statistical analysis of model predictions and surface observations.

GA EPD used the software package METSTAT developed by ENVIRON corporation for calculating model performance statistics. METSTAT computes domain wide surface statistics for temperature, wind speed and direction, and humidity. The metrics include: Bias Error (B), Gross Error (E) and Root Mean Square Error (RMSE), Systematic Root Mean Square Error (RMSE_s), Unsystematic Root Mean Square Error (RMSE_u) and Index Of Agreement (IOA). Mathematical formulation of these variables is provided in Table 1-1. The surface meteorological data for this analysis was obtained from the CISL Research Data Archive (<http://dss.ucar.edu/datasets/ds472.0>).

While reviewing statistics, the reader is cautioned that summary statistics are useful in making only a general assessment about the adequacy of meteorological fields. For example, daily-mean performance statistics are likely to conceal important hour-to-hour variations. Also, the credibility of summary statistics depend upon the number of observation-prediction pairs and generally improve with larger sampling sizes and longer averaging periods. This is because the sensitivity of these summary statistics to extreme values is high in case of smaller

sample sizes. These and other concerns have lead U.S. EPA to recommend that benchmarks proposed in Table 1-2 (Emery *et al.*, 2001) should not be used in a “pass/fail” test for a model, but only as a means of assessing general confidence in meteorological model output.

A graphical summary of the daily and hourly mean performance statistics for the 12-km grid resolution modeling simulation is provided in Appendix K.2. Monthly averaged statistics have also been provided in Figure 1-1 and Table 1-3. Statistics have been computed at monitoring stations that are located in and around Georgia.

Table 1-1: Mathematical Formulation of Statistical Metrics Used for Evaluating Mesoscale Meteorological Model Performance

Metrics	Formulation
Bias	$B = \frac{1}{IJ} \sum_{j=1}^J \sum_{i=1}^I (P_j^i - O_j^i)$
Gross Error	$E = \frac{1}{IJ} \sum_{j=1}^J \sum_{i=1}^I P_j^i - O_j^i $
Root Mean Square Error	$RMSE = \left[\frac{1}{IJ} \sum_{j=1}^J \sum_{i=1}^I (P_j^i - O_j^i)^2 \right]^{1/2}$
Systematic Root Mean Square Error	$RMSE_s = \left[\frac{1}{IJ} \sum_{j=1}^J \sum_{i=1}^I (\hat{P}_j^i - O_j^i)^2 \right]^{1/2}$
Unsystematic Root Mean Square Error	$RMSE_u = \left[\frac{1}{IJ} \sum_{j=1}^J \sum_{i=1}^I (P_j^i - \hat{P}_j^i)^2 \right]^{1/2}$
Index of Agreement	$IOA = 1 - \left[\frac{IJ \cdot RMSE^2}{\sum_{j=1}^J \sum_{i=1}^I P_j^i - M_o + O_j^i - M_o } \right]$

Table 1-2: Statistical Benchmarks for Mesoscale Meteorological Models

Statistical Measure	Benchmark
Wind Speed Bias (m/s)	<±0.5
Wind Speed Total RMSE (m/s)	2.0
Wind Speed Index of Agreement	0.6
Wind Direction Gross Error (degree)	30.0
Wind Direction Bias (degree)	<±10.0
Temperature Bias (Kelvin)	<±0.5
Temperature Gross Error (degree)	2.0
Temperature Index of Agreement	0.8
Humidity Bias (g/kg)	<±1.0
Humidity Gross Error (g/kg)	2.0
Humidity Index of Agreement	0.6

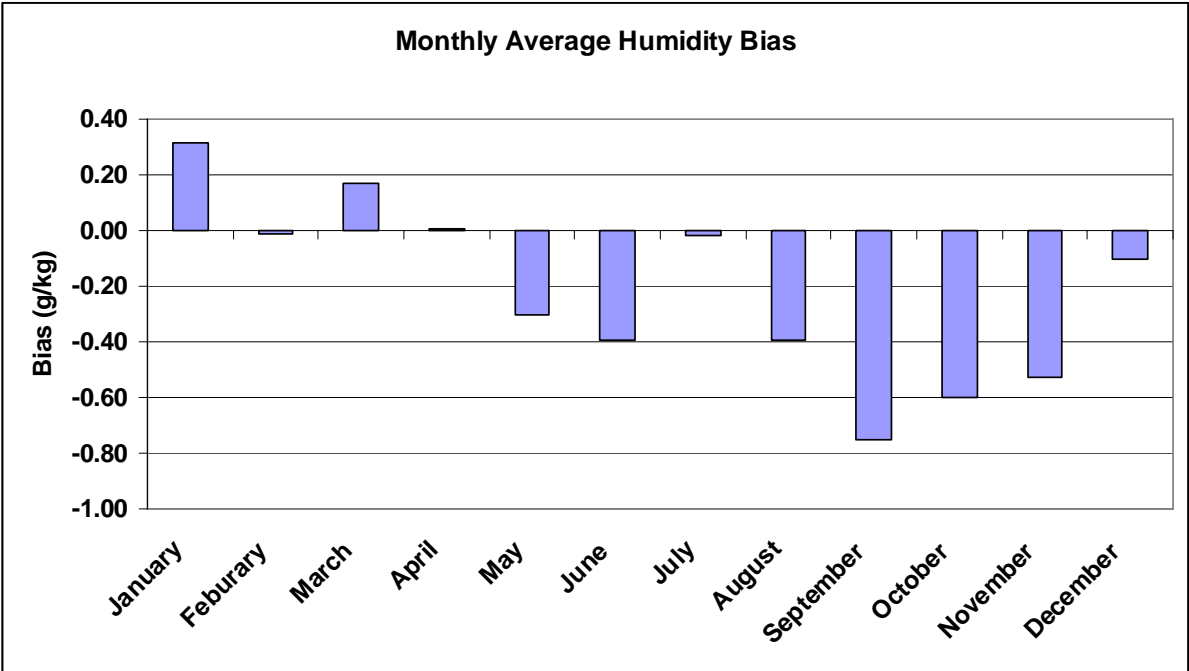
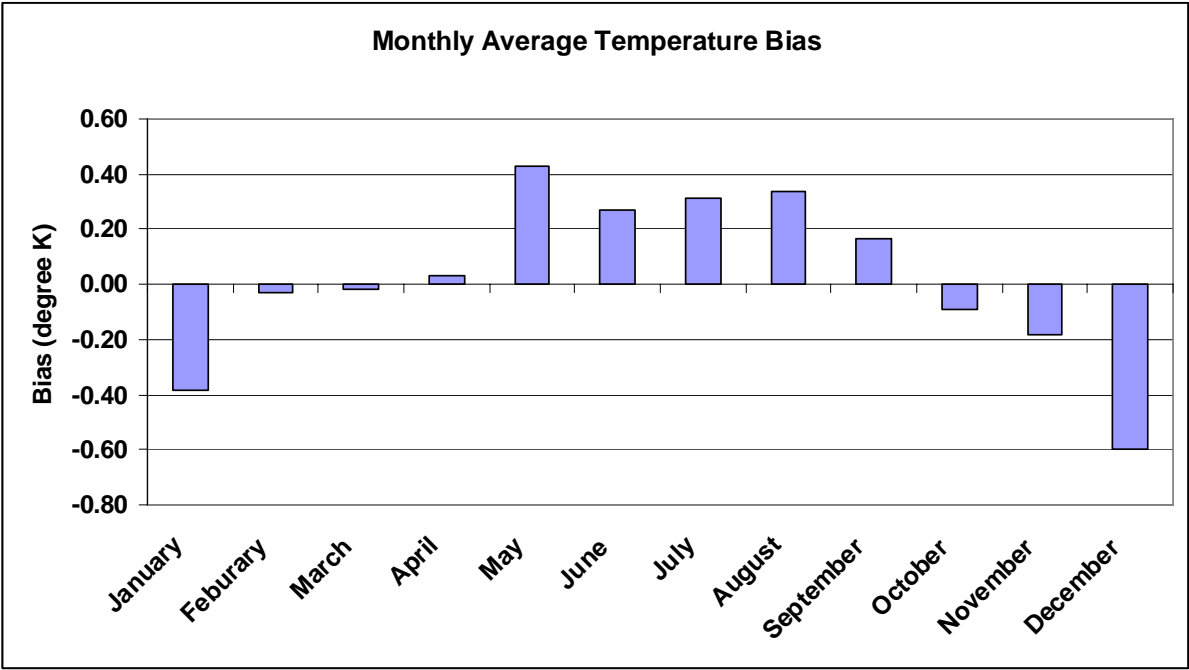


Figure 1-1: Monthly averaged Bias statistics for 2-m temperature and humidity

Table 1-3: Monthly averaged statistics for the region of the 12-km modeling domain in and around Georgia.

Statistics		Units	January	February	March	April	May	June	July	August	September	October	November	December
Wind Speed	Mean OBS	(m/s)	2.50	2.94	3.00	2.86	2.85	2.36	2.04	2.09	2.51	2.12	2.43	2.93
	Mean PRD	(m/s)	3.07	3.46	3.47	3.41	3.42	2.92	2.56	2.62	3.16	2.75	3.21	3.50
	Bias	(m/s)	0.56	0.52	0.46	0.56	0.56	0.57	0.52	0.54	0.65	0.63	0.78	0.57
	Gross Error	(m/s)	1.35	1.33	1.34	1.30	1.36	1.36	1.32	1.35	1.33	1.29	1.45	1.40
	RMSE	(m/s)	1.69	1.66	1.68	1.64	1.70	1.69	1.65	1.67	1.69	1.60	1.79	1.75
	Sys RMSE	(m/s)	1.36	1.29	1.31	1.25	1.27	1.33	1.35	1.37	1.31	1.28	1.46	1.38
	Unsys RMSE	(m/s)	0.98	1.02	1.04	1.04	1.12	1.04	0.94	0.94	1.05	0.95	1.02	1.04
IOA		0.66	0.72	0.70	0.70	0.71	0.64	0.61	0.62	0.66	0.64	0.63	0.66	
Wind Direction	Mean OBS	(deg)	210.79	217.36	193.44	183.67	132.25	159.26	210.72	145.09	106.11	155.27	255.71	209.07
	Mean PRD	(deg)	217.93	202.41	189.61	178.68	134.97	169.83	184.38	146.70	119.42	160.35	237.67	214.91
	Bias	(deg)	1.16	2.75	1.19	0.55	1.61	2.79	0.75	3.30	4.18	3.18	3.20	5.10
	Gross Error	(deg)	26.37	23.56	25.11	25.46	28.99	35.02	39.13	37.12	30.20	31.23	28.99	24.68
Temperature	Mean OBS	(K)	281.78	281.88	286.70	292.81	294.22	298.24	299.79	299.20	297.62	292.47	284.27	280.44
	Mean PRD	(K)	281.40	281.85	286.68	292.85	294.65	298.51	300.11	299.54	297.79	292.38	284.08	279.85
	Bias	(K)	-0.38	-0.03	-0.02	0.03	0.43	0.27	0.31	0.34	0.16	-0.09	-0.18	-0.60
	Gross Error	(K)	2.03	1.82	1.94	1.63	1.61	1.49	1.55	1.57	1.42	1.40	1.78	1.79
	RMSE	(K)	2.57	2.28	2.43	2.06	2.07	1.92	2.00	2.03	1.83	1.78	2.20	2.23
	Sys RMSE	(K)	1.64	1.36	1.60	1.22	1.19	0.94	1.00	0.90	0.66	0.75	1.20	1.26
	Unsys RMSE	(K)	1.90	1.78	1.78	1.63	1.65	1.64	1.72	1.78	1.68	1.58	1.80	1.80
IOA		0.92	0.94	0.94	0.94	0.95	0.93	0.92	0.93	0.93	0.94	0.94	0.93	
Humidity	Mean OBS	(g/kg)	5.62	4.58	7.23	10.05	11.33	14.48	16.49	15.46	15.30	12.38	6.76	4.93
	Mean PRD	(g/kg)	5.94	4.56	7.40	10.05	11.03	14.09	16.47	15.06	14.55	11.78	6.23	4.82
	Bias	(g/kg)	0.31	-0.01	0.17	0.01	-0.30	-0.40	-0.02	-0.39	-0.75	-0.60	-0.53	-0.10
	Gross Error	(g/kg)	0.73	0.67	0.91	1.05	1.20	1.48	1.59	1.59	1.43	1.10	0.87	0.66
	RMSE	(g/kg)	0.97	0.90	1.21	1.38	1.57	1.91	2.07	2.08	1.82	1.42	1.11	0.90
	Sys RMSE	(g/kg)	0.50	0.40	0.61	0.48	0.71	0.91	0.98	1.05	0.97	0.77	0.65	0.42
	Unsys RMSE	(g/kg)	0.82	0.79	1.00	1.27	1.38	1.65	1.77	1.75	1.51	1.16	0.86	0.78
	IOA		0.88	0.88	0.87	0.84	0.78	0.70	0.62	0.69	0.80	0.85	0.84	0.89

The MM5 simulation is able to capture meteorological conditions observed during the study period with an adequate level of accuracy. Performance statistics for most days are within the benchmarks proposed by Emery (2001). Monthly average statistics reveal under prediction in humidity from May through November, and an over prediction in temperature during the summer months (May through September). The simulation tends to over predict daytime and nighttime temperature, and consistently over-predicts nighttime wind speed. However, the magnitude of these under/over predictions remains small. It should also be pointed out that air quality model performance evaluation serves as an additional check on how accurately the meteorological model was able to capture the observed atmospheric dynamics during a particular time period. In an unlikely event of unusually poor air quality model performance, it is reasonable to further investigate the performance of meteorological model.

Overall, the GA EPD believes that the meteorological model performance is adequate for this modeling exercise and should produce credible inputs for the air quality modeling for the attainment demonstration for the Macon PM_{2.5} nonattainment area.

2 Air Quality Model Performance

The air quality model evaluation mostly focused on both the FRM and STN monitors across the state of Georgia, due to the nature of the attainment test. Designations were based on FRM monitors, and calculations of future design values are based on current design value information from these sites. Thus, model performance for these FRM sites should be evaluated. STN data was also utilized as this data is used to speciate the FRM data so component based relative response factors can be calculated for each FRM monitoring site. More detailed information on the model attainment test process is described in Appendix G.

Only a brief summary of the model performance evaluation for the VISTAS/ASIP 12-km grid domain will be discussed in the subsections to follow. For the full model performance evaluation for the VISTAS 12-km grid domain, please refer to Appendix G.

2.1 Modeling Performance Goals and Criteria

In 2004, VISTAS/ASIP established model performance “goal levels” and “criteria levels” for components of fine particle mass (Table 2.1-1) based on previous model performance for ozone and fine particles. The Attainment Modeling Guidance (EPA, 2007) for fine particulate matter at the time noted that PM models might not be able to achieve the same level of performance as ozone models. VISTAS’ evaluation considered several statistical performance measures and graphical performance measures. Fractional bias and mean fractional error were selected as the most appropriate metrics to summarize model performance (Boylan and Russell, 2006); other metrics were also calculated and are included for FRM and STN monitors.

Table 2.1-1. Established Model Performance Goals and Criteria for the PM_{2.5} Component Species

Mean Fractional Bias	Mean Fractional Error	Comment
≤15 percent	≤35 percent	Goal for PM _{2.5} model performance based on ozone model performance, considered “excellent performance”
≤30 percent	≤50 percent	Goal for PM _{2.5} model performance, considered good performance; hereafter, it is called “(performance) goal level”
≤60 percent	≤75 percent	Criteria for PM _{2.5} model performance, considered average performance; hereafter, it is called “(performance) criteria level”. Exceeding this level of performance indicates fundamental concerns with the modeling system and triggers diagnostic evaluation.

The statistical measures were calculated for all of the component species of particulate matter. For convenience, these statistical measures or metrics, along with a variety of additional statistical measures, are summarized in Table 2.1-2.

An additional way to evaluate model performance statistics is to visualize performance based on these fractional bias and mean fractional errors via “soccer plots” (e.g. Figure 2.2-1) and “bugle plots” (Figure 2.2-2). The soccer plot is so named because the dotted lines resemble a soccer goal. The soccer plot is useful as both bias and error are shown on a single plot. As bias and error approach zero, the points are plotted closer to or within the “performance criteria level”, the “performance goal level”, and/or the “excellent performance level”, represented here by the dashed boxes.

The bugle plot, named for the shape formed by the criteria and goal lines. The bugle plots are shaped as such because the goal and criteria lines are adjusted based on the average concentration of the observed species concentrations and the modeled species concentrations. As the average concentration becomes smaller, the criteria and goal lines become larger to adjust for the model’s poor ability to predict at low concentrations and for the over-sensitivity of normalized statistical measures to low concentration cases.

The analysis of bugle plots demonstrated that greater emphasis should be placed on performance of those components with the greatest contribution to PM_{2.5} mass (e.g. SO₄ and OC) and that greater bias and error could be accepted for components with smaller contributions to total PM_{2.5} mass (e.g. EC, NO₃, and SOIL). The soccer plots and bugle plots have been included as suggested in the Attainment Modeling Guidance.

Table 2.1-2 Statistical Metric Calculations

Statistical Measure	Shorthand Notation	Mathematical Expression	Notes
Accuracy of Paired Peak	A_p	$\frac{P - O_{peak}}{O_{peak}}$	
Coefficient of Determination	R^2	$\frac{\left[\sum_{i=1}^N (P_i - \bar{P})(O_i - \bar{O}) \right]^2}{\sum_{i=1}^N (P_i - \bar{P})^2 \sum_{i=1}^N (O_i - \bar{O})^2}$	P_i = prediction at time and location i ; O_i = observation at time and location i ; \bar{P} = arithmetic average of P_i , $i = 1, 2, \dots, N$; \bar{O} = arithmetic average of O_i , $i = 1, 2, \dots, N$;
Normalized Mean Error	NME	$\frac{\sum_{i=1}^N P_i - O_i }{\sum_{i=1}^N O_i}$	Reported as %
Root Mean Square Error	RMSE	$\left[\frac{1}{N} \sum_{i=1}^N (P_i - O_i)^2 \right]^{\frac{1}{2}}$	Reported as %
Mean Fractional Error	MFE	$\frac{2}{N} \sum_{i=1}^N \left \frac{P_i - O_i}{P_i + O_i} \right $	Reported as %
Mean Absolute Gross Error	MAGE	$\frac{1}{N} \sum_{i=1}^N P_i - O_i $	
Mean Normalized Gross Error	MNGE	$\frac{1}{N} \sum_{i=1}^N \frac{ P_i - O_i }{O_i}$	Reported as %
Mean Biased	MB	$\frac{1}{N} \sum_{i=1}^N (P_i - O_i)$	Reported as concentration
Mean Normalized Bias	MNB	$\frac{1}{N} \sum_{i=1}^N \frac{(P_i - O_i)}{O_i}$	Reported as %
Mean Fractionalized Bias (Fractional Bias)	MFB	$\frac{2}{N} \sum_{i=1}^N \left(\frac{P_i - O_i}{P_i + O_i} \right)$	Reported as %
Normalized Mean Bias	NMB	$\frac{\sum_{i=1}^N (P_i - O_i)}{\sum_{i=1}^N O_i}$	Reported as %
Bias Factor	BF	$\frac{1}{N} \sum_{i=1}^N \left(\frac{P_i}{O_i} \right)$	Reported as BF: 1 or 1:BF or in fractional notation (BF/1 or 1/BF)

2.2 Domain-Wide Model Performance

As a summary of model performance, soccer plots and bugle plots for the all of the VISTAS STN and FRM monitors are included here. Plots have been developed for the average monthly concentrations and the performance statistics for all of the PM_{2.5} component species (SO₄, NO₃, NH₄, OC, and EC) and reconstructed PM_{2.5} total mass from the STN monitoring sites (Figures 2.2-1 and 2.2-2), as well as the total FRM PM_{2.5} mass (Figures 2.2-3 and 2.2-4).

The soccer plots for monthly average component performance for all the VISTAS/ASIP STN sites shows generally good model performance for most species of PM_{2.5} and total PM_{2.5}. The exception is the prediction of NO₃ values, which most values fall outside the criteria level (Figure 2.2-1). There are a few months that the model's performance falls in the criteria level, which is better seen in the zoomed view presented in the image on the right in Figure 2.2-1. However, when the very low concentration of NO₃ is taken into consideration, as presented in the bugle plots (Figure 2.2-2), NO₃ performance largely falls within the criteria and goal levels. One can still note a general tendency for under prediction in NO₃, and other species (e.g. OC) in left hand image in Figure 2.2-2, which leads to a slight under prediction in total reconstructed PM_{2.5}.

Monthly total PM_{2.5} performance at all the VISTAS/ASIP FRM monitors largely falls within goal level thresholds, with only three months falling just outside goal level (Figure 2.2-3). Figure 2.2-4 suggests a slight negative bias in PM_{2.5} prediction for most of the year, with mean fractional error values remaining within goal levels across the base year.

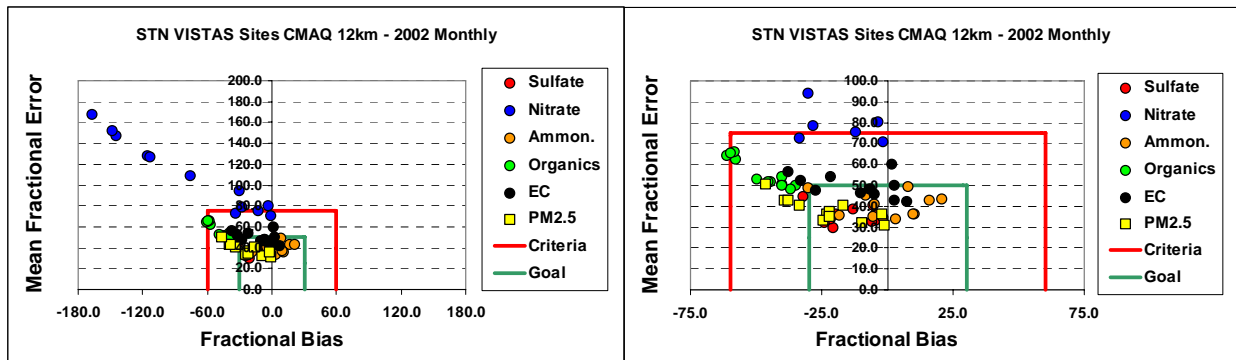


Figure 2.2-1. VISTAS STN Soccer Plots - The image on the left is a soccer plot depicting both the mean fractional error and fractional bias for component concentration for all VISTAS STN monitoring sites. The image on the right is a zoomed view of the soccer plot on the left to better depict the area inside the criteria/goal lines. Each point represents a monthly value as compared to the model performance criteria (red box) and modeling performance goals (green box).

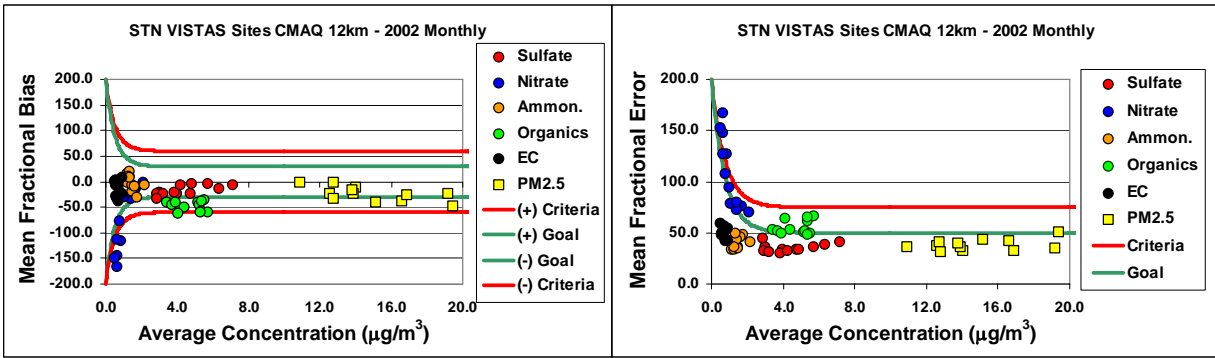


Figure 2.2-2. VISTAS STN Bugle Plots - The image on the left is a bugle plot of the mean fraction bias for particulate matter and its component concentrations for all VISTAS STN monitoring sites. The image on the right is a bugle plot of mean fraction error for particulate matter and its component species for all VISTAS STN monitoring sites. Each point represents a monthly mean fraction bias value as compared to the model performance criteria (red lines) and modeling performance goals (green lines).

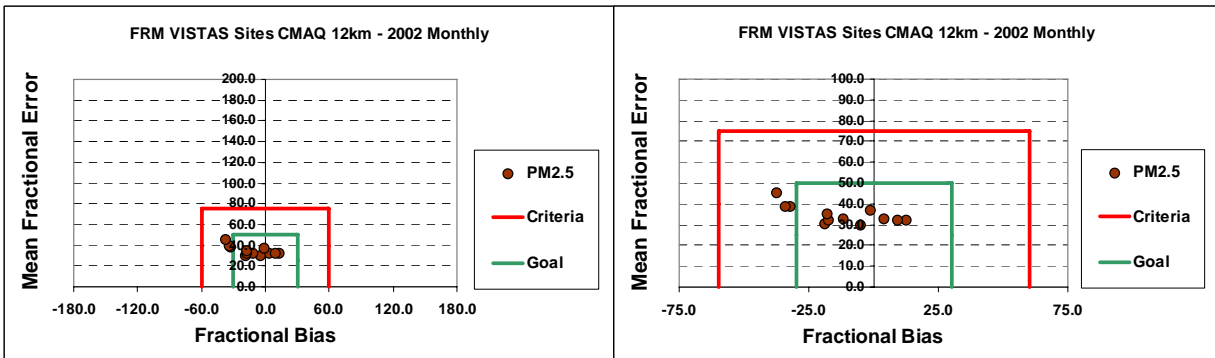


Figure 2.2-3. VISTAS FRM Soccer Plots - Soccer plots depicting both the mean fractional error and fractional bias for PM_{2.5} concentration for all the VISTAS FRM Monitoring sites. The image on the right is a zoomed view of the soccer plot on the left to better depict the area inside the criteria/goal lines. Each point represents a monthly value as compared to the model performance criteria (red box) and modeling performance goals (green box).

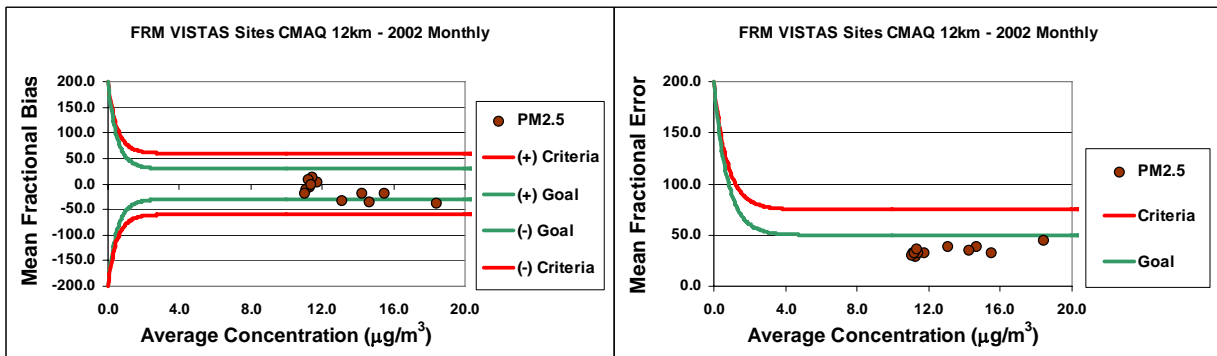


Figure 2.2-4. VISTAS FRM Bugle Plots - The image on the left is a bugle plot of the mean fraction bias for particulate matter for all the VISTAS FRM Monitoring sites. The image on the right is a bugle plot of mean fraction error for particulate matter for all the VISTAS FRM Monitoring sites. Each point represents a monthly mean fraction bias value as compared to the model performance criteria (red lines) and modeling performance goals (green lines).

The overall tendency of the model was that the model had some difficulties in predicting NO₃. For example, the monthly average values tend to fall outside the criteria levels in the soccer plots. Part of this under prediction lies in the fact that NO₃ are generally found in low concentrations across the southeast, and the model usually has difficulties representing any compound with low ambient concentrations. The bugle plots are more encouraging with NO₃ performance, as these plots take into account for absolute concentrations of PM_{2.5} components when evaluating performance. The bugle plots show all components and total PM_{2.5} falling within criteria levels, if not goal levels, of model performance. The under predictions of NO₃ and OC account for the slight negative bias in the modeled PM_{2.5} mass compared to the measurements.

2.3 Model Performance within Georgia and in the Macon nonattainment area

Statistical metrics and performance plots were developed for the entire state of Georgia as well as the Macon nonattainment area. For GA, the primary monitoring networks available to evaluate the CMAQ modeling were: (1) EPA Federal Reference Method (FRM) PM_{2.5} and PM₁₀ Mass Networks, (2) EPA Speciation Trends Network (STN) of PM_{2.5} species, (3) Interagency Monitoring of Protected Visual Environments (IMPROVE), (4) Clean Air Status and Trends Network (CASTNET), and (5) Southeastern Aerosol Research and Characterization (SEARCH). It should be noted that the STN monitor here refers to the combination of the official STN monitors and the CSN (Chemical Speciation Network) monitors. Table 2.3-1 and Figure 2.3-1 summarize the species data collected and locations of the monitoring sites for the FRM, IMPROVE, STN, CASTNET, and SEARCH monitoring networks used in this evaluation. The Macon nonattainment area contains two FRM monitors (13-021-0007 and 13-021-0012) and one STN monitor (13-021-0007).

Table 2.3-1. Ambient monitoring data available in 2002.

Monitoring Network	Chemical Species Measured	Sampling Frequency; Duration
FRM	Only total fine particulate mass (PM _{2.5})	Varies; 24 hr
IMPROVE	Speciated PM _{2.5} and PM ₁₀	1 in 3 days; 24 hr
STN	Speciated PM _{2.5}	Varies; Varies
CASTNET	Speciated PM _{2.5} and ozone	Hourly, Weekly; 1 hr, Week
SEARCH	24-hr PM _{2.5} (FRM Mass, OC, BC, SO ₄ , NO ₃ , NH ₄ , EC); 24-hr PM coarse (SO ₄ , NO ₃ , NH ₄ , elements); Hourly PM _{2.5} (Mass, SO ₄ , NO ₃ , NH ₄ , EC, TC); and Hourly gases (O ₃ , NO, NO ₂ , NO _y , HNO ₃ , SO ₂ , CO)	Daily, Hourly;

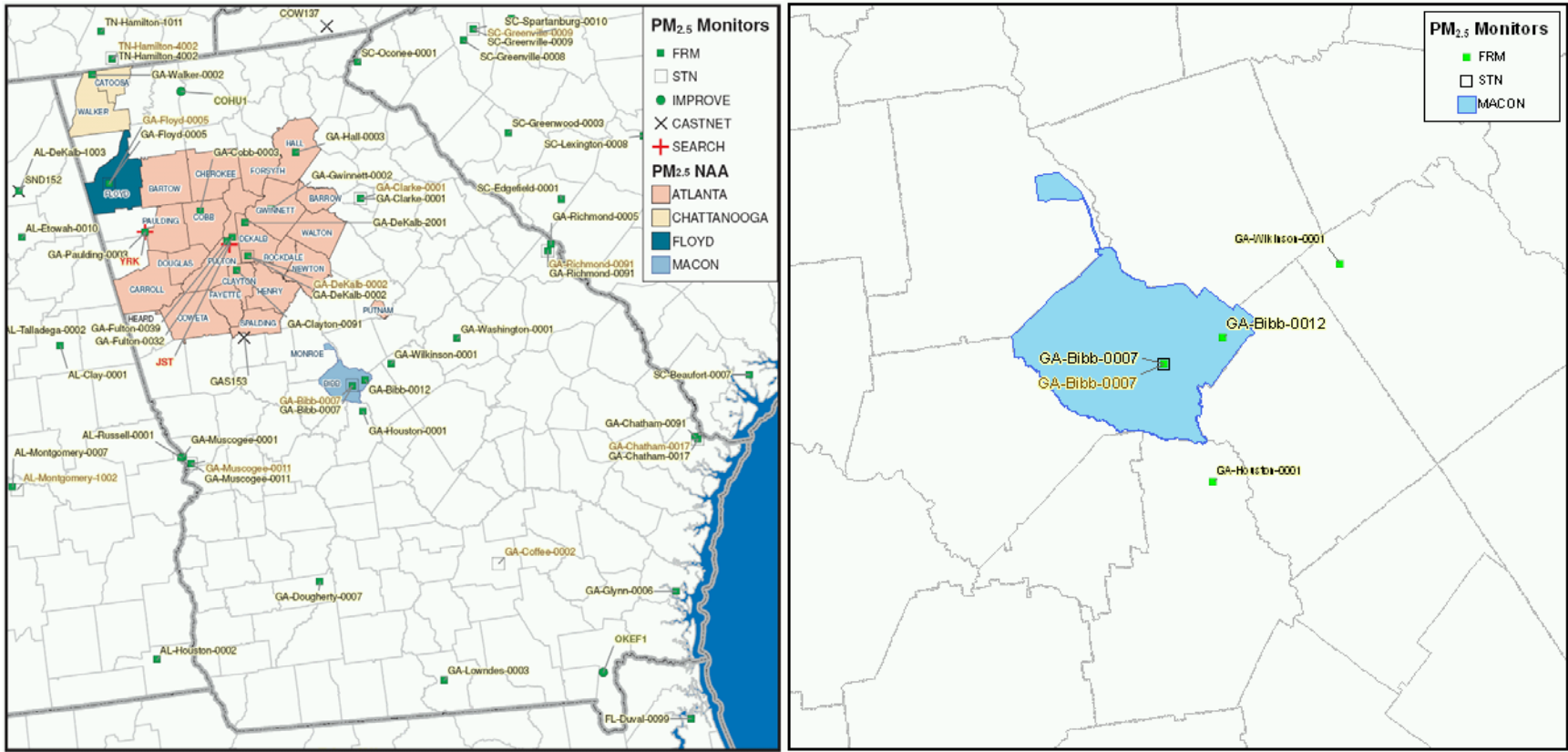


Figure 2.3-1. FRM, STN, IMPROVE, CASTNET, NADP, and SEARCH monitoring sites located in and near the GA PM_{2.5} nonattainment areas (left) and the Macon PM_{2.5} nonattainment area (right).

2.3.1 Model performance statistics

Model performance statistics were calculated collectively for the FRM monitors within Georgia, as well as individually for the two FRM monitors in the Macon nonattainment area to demonstrate the model's ability to replicate total PM_{2.5} mass at these sites. In addition, the same approach was taken to conduct model performance evaluation for the STN monitors within Georgia and for the Macon STN site on PM_{2.5} component species and total PM_{2.5} basis for the entire base year. The statistical measures selected were based on the recommendations outlined in section 18.4.1 of the USEPA's Guidance On The Use Of Models And Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM_{2.5}, and Regional Haze ("*Attainment Guidance*").

2.3.1.1 Model Performance Statistics for the FRM Sites

To examine the overall model performance, the annual model performance statistics were estimated for all FRM sites in GA and two FRM sites in the Macon nonattainment area. As shown in Table 2.3.1.1-1, the model's performance at two FRM monitors in the Macon nonattainment area is comparable with that of the all FRM monitors in GA. Exceptions are fractional bias, normalized mean bias, and mean bias. These bias statistics clearly indicate that the model tends to show more positive biases at the Macon FRM monitors than monitors across GA.

For more in-depth examinations, the model performance statistics are broken out by month at each of the FRM monitors in the Macon nonattainment area to see if there is any performance issue during the base year (Table 2.3.1.1-2 and Table 2.3.1.1-3). It was noted that the model had significant under prediction during summer. In addition, the model showed less significant under prediction in February. During months of under prediction, errors were in similar magnitude, which indicates these errors were dominated by model's under predictions. During the monthly performance evaluation, we found the model's mean predictions were comparable to the mean observed concentrations but the model could not replicate very high PM_{2.5} concentrations that were observed. For example, the model predicted mean PM_{2.5} concentration of 17.3 µg/m³ at 13-021-0012 in May while 43.2 µg/m³ was observed at the same monitor for the same period. More detailed performance evaluation was conducted with graphical measures and the results are presented in Section 2.3.2.1. Given the number of samples, however, these discrepancies may not be significant. In fact, other comparable statistics with less numbers of samples indicates the overall performance of model in the Macon nonattainment area can be equal or better than the model's overall performance across GA.

Table 2.3.1.1-1. Annual model performance statistics for PM_{2.5} at all FRM monitors in the State of Georgia and in the Macon nonattainment area.

Statistics	GA	13-021-0007	13-021-0012
MFB (%)	-5.7	-24.3	-11.6
MFE (%)	30.2	35.5	32.1
A _p	-0.1	-0.2	-0.2
NMB (%)	-2.7	-19.2	-9.1
NME (%)	27.4	28.5	28.9
MNB (%)	4.5	-15.4	-4.3
MNGE (%)	32.9	29.4	29.3
MB	-0.4	-2.8	-1.2
MAGE	4.0	4.2	3.8
Geometric Mean Bias	-0.1	-0.3	-0.1
Geometric Mean Error	0.3	0.4	0.3
RMSE	5.3	5.8	5.5
Max _{OBS}	52.0	41.0	43.2
Max _{PRE}	48.0	33.3	33.1
Mean Observations	14.5	14.7	13.3
Mean Predictions	14.1	11.9	12.1
Standard Deviation of Observations	6.6	6.6	6.2
Standard Deviation of Predictions	6.9	6.0	5.7
R ²	0.5	0.5	0.3
BF	1.0	0.8	1.0
Number of Samples	3166	90	112

Table 2.3.1.1-2. Monthly model performance statistics for PM_{2.5} at 13-021-0007.

Statistics	January	February	March	April	May	June	July	August	September	October	November	December
MFB (%)	12.2	-23.7	2.6	N/A	-36.7	-61.1	-60.6	-44.2	-27.9	5.4	-7.1	-8.1
MFE (%)	25.1	26.4	2.6	N/A	36.7	61.1	61.7	46.9	32.7	23.7	13.7	30.2
A _p	0.1	-0.3	0.0	N/A	-0.3	-0.3	-0.2	-0.2	-0.2	0.0	-0.1	-0.1
NMB (%)	11.8	-20.4	2.6	N/A	-31.0	-45.4	-46.0	-30.6	-16.0	6.1	-3.3	-7.1
NME (%)	26.3	21.7	2.6	N/A	31.0	45.4	47.1	33.7	19.7	23.5	9.8	24.8
MNB (%)	18.9	-19.3	2.6	N/A	-31.0	-43.4	-41.9	-33.6	-19.0	10.1	-4.5	-1.9
MNGE (%)	30.4	22.2	2.6	N/A	31.0	43.4	43.0	36.4	24.3	26.7	11.5	29.0
MB	1.3	-3.0	0.2	N/A	-7.3	-7.2	-7.2	-5.1	-3.0	0.9	-0.4	-0.8
MAGE	2.9	3.2	0.2	N/A	7.3	7.2	7.4	5.6	3.7	3.4	1.3	2.7
Geometric Mean Bias	0.1	-0.2	0.0	N/A	-0.4	-0.7	-0.7	-0.5	-0.3	0.1	-0.1	-0.1
Geometric Mean Error	0.3	0.3	0.0	N/A	0.4	0.7	0.7	0.5	0.4	0.2	0.1	0.3
RMSE	3.8	4.2	0.2	N/A	7.3	9.4	9.2	6.1	4.9	4.0	2.0	3.1
Max _{OBS}	16.4	30.0	7.0	N/A	23.4	29.3	25.5	27.7	41.0	21.1	20.2	22.2
Max _{PRE}	17.5	20.1	7.2	N/A	16.1	20.9	19.8	21.5	33.3	20.5	18.9	19.9
Mean Observations	11.1	14.6	7.0	N/A	23.4	15.9	15.7	16.7	18.6	14.3	13.4	10.9
Mean Predictions	12.4	11.6	7.2	N/A	16.1	8.7	8.5	11.6	15.6	15.2	12.9	10.1
Standard Deviation of Observations	3.5	7.2	N/A	N/A	N/A	8.1	5.7	5.5	10.7	4.6	3.8	5.2
Standard Deviation of Predictions	3.4	5.4	N/A	N/A	N/A	5.7	4.6	6.3	10.3	4.4	4.5	4.8
R ²	0.2	0.8	N/A	N/A	N/A	0.4	0.1	0.7	0.9	0.3	0.8	0.6
BF	1.2	0.8	1.0	N/A	0.7	0.6	0.6	0.7	0.8	1.1	1.0	1.0
Number of Samples	9	10	1	N/A	1	9	11	10	10	10	10	9

Table 2.3.1.1-3. Monthly model performance statistics for PM_{2.5} at 13-021-0012.

Statistics	January	February	March	April	May	June	July	August	September	October	November	December
MFB (%)	31.0	-6.4	16.9	0.9	-42.1	-43.7	-54.4	-25.4	-14.4	6.0	8.5	3.3
MFE (%)	33.4	18.9	19.2	25.2	42.1	43.7	56.8	32.5	34.6	15.2	23.0	31.1
A _p	0.3	-0.2	0.3	0.2	-0.6	-0.2	-0.1	0.2	-0.1	0.0	0.3	0.2
NMB (%)	34.2	-5.8	20.3	6.5	-38.6	-32.5	-40.2	-15.6	-4.3	6.2	15.6	7.7
NME (%)	37.3	17.3	22.5	27.3	38.6	32.5	42.8	25.3	25.1	15.2	23.4	29.9
MNB (%)	40.9	-3.7	20.5	6.3	-32.1	-33.2	-38.6	-18.5	-6.7	8.8	12.5	9.7
MNGE (%)	43.2	18.7	22.7	26.0	32.1	33.2	41.1	27.0	29.6	17.4	23.5	33.1
MB	3.3	-0.7	2.4	0.7	-7.1	-5.0	-6.2	-2.1	-0.7	0.9	1.8	0.8
MAGE	3.6	2.2	2.7	2.8	7.1	5.0	6.6	3.4	4.1	2.1	2.6	2.9
Geometric Mean Bias	0.3	-0.1	0.2	0.0	-0.4	-0.5	-0.6	-0.3	-0.2	0.1	0.1	0.0
Geometric Mean Error	0.3	0.2	0.2	0.3	0.4	0.5	0.6	0.3	0.4	0.2	0.2	0.3
RMSE	4.1	2.7	3.7	3.7	10.8	7.0	8.1	4.2	4.6	2.9	3.1	3.3
Max _{OBS}	14.7	23.8	15.8	14.9	43.2	27.5	23.6	18.3	36.8	20.4	15.5	15.7
Max _{PRE}	18.6	20.1	20.5	17.9	17.3	21.5	20.1	21.7	33.1	20.3	20.8	18.8
Mean Observations	9.7	12.6	11.9	10.3	18.5	15.3	15.3	13.4	16.5	14.1	11.3	9.8
Mean Predictions	13.0	11.9	14.3	11.0	11.4	10.3	9.2	11.3	15.8	14.9	13.0	10.6
Standard Deviation of Observations	3.2	6.5	3.6	2.8	10.2	7.6	5.0	3.4	9.3	4.5	2.8	3.4
Standard Deviation of Predictions	3.5	5.5	5.2	4.8	3.8	6.4	4.9	5.6	10.2	4.3	5.0	4.7
R ²	0.5	0.8	0.7	0.4	0.3	0.5	0.1	0.6	0.8	0.6	0.8	0.5
BF	1.4	1.0	1.2	1.1	0.7	0.7	0.6	0.8	0.9	1.1	1.1	1.1
Number of Samples	9	9	6	10	10	10	10	10	10	9	9	10

2.3.1.2 Model Performance Statistics for STN Sites

The model performance was evaluated for particulate matter components measured at the all STN sites in GA and separately at the STN site in the Macon nonattainment area. Since detailed graphical performance evaluation was conducted for all available PM_{2.5} species, we briefly present annual summary statistics for these species and total PM_{2.5} here.

Sulfate and total PM_{2.5} had negative bias and error at the GA STN monitors (Table 2.3.1.2-1). Nitrate was underestimated in GA as previously seen throughout the model performance evaluation for the entire VISTAS 12-km modeling domain. However, this is not a significant issue for the overall model performance because the contribution of NO₃ to the total PM_{2.5} is relatively small in GA. Also, we saw under predictions of OC concentrations in GA. This issue was closely examined in Section 2.3.2.4. From Table 2.3.1.2-2, similar tendencies can be seen at the STN monitor in the Macon nonattainment area. More detailed performance analyses with graphical measures can be found in the following sections.

Table 2.3.1.2-1. Annual model performance statistics for PM_{2.5} species and total PM_{2.5} at all STN monitors in the State of Georgia.

Statistics	SO ₄	NO ₃	NH ₄	OC	EC	PM _{2.5}
MFB (%)	-17.1	-68.2	12.0	-26.5	-2.4	-18.4
MFE (%)	34.3	110.6	42.1	42.7	46.6	34.2
A _p	-0.6	0.6	-0.5	0.1	0.0	-0.2
NMB (%)	-13.7	9.4	8.9	-13.4	3.6	-14.9
NME (%)	31.5	95.5	41.5	35.0	42.4	29.4
MNB (%)	-7.6	0.1	37.9	-11.3	28.2	-10.5
MNGE (%)	32.7	101.2	61.6	40.4	65.6	30.5
MB	-0.7	0.1	0.1	-0.7	0.0	-2.3
MAGE	1.6	0.7	0.6	1.9	0.3	4.6
Geometric Mean Bias	-0.2	-1.3	0.1	-0.3	0.0	-0.2
Geometric Mean Error	0.4	1.8	0.4	0.5	0.5	0.4
RMSE	2.6	1.1	0.8	2.4	0.4	5.9
Max _{OBS}	39.9	5.0	10.7	13.6	3.5	40.9
Max _{PRE}	15.9	7.8	5.2	14.7	3.4	32.5
Mean Observations	5.0	0.7	1.4	5.4	0.6	15.7
Mean Predictions	4.3	0.8	1.5	4.7	0.7	13.4
Standard Deviation of Observations	3.3	0.6	0.9	2.1	0.5	7.0
Standard Deviation of Predictions	2.8	1.3	0.8	3.1	0.6	6.6
R ²	0.5	0.3	0.4	0.4	0.6	0.5
BF	0.9	1.0	1.4	0.9	1.3	0.9
Number of Samples	400	400	400	316	316	395

Table 2.3.1.2-2. Annual model performance statistics for PM_{2.5} at 13-021-0007.

Statistics	SO ₄	NO ₃	NH ₄	OC	EC	PM _{2.5}
MFB (%)	-27.9	-114.1	-5.4	-39.6	-37.4	-34.1
MFE (%)	40.7	142.0	45.5	52.9	59.5	41.7
A _p	-0.7	0.8	-0.7	0.5	-0.4	0.1
NMB (%)	-30.8	-16.8	-18.9	-19.8	-36.9	-25.3
NME (%)	42.3	92.3	48.4	40.1	44.3	34.2
MNB (%)	-18.3	-44.8	8.5	-25.5	50.3	-24.1
MNGE (%)	33.9	92.4	45.8	41.0	121.1	33.1
MB	-1.8	-0.1	-0.3	-1.1	-0.2	-4.1
MAGE	2.5	0.6	0.7	2.3	0.2	5.5
Geometric Mean Bias	-0.3	-2.4	-0.1	-0.4	-0.4	-0.4
Geometric Mean Error	0.4	2.7	0.5	0.6	0.7	0.4
RMSE	5.7	0.8	1.5	2.6	0.3	7.0
Max _{OBS}	39.9	1.9	10.7	9.8	1.3	28.7
Max _{PRE}	10.6	3.4	3.2	14.7	0.8	32.0
Mean Observations	5.8	0.6	1.5	5.8	0.5	16.2
Mean Predictions	4.0	0.5	1.2	4.6	0.3	12.1
Standard Deviation of Observations	6.9	0.4	1.9	1.8	0.3	6.0
Standard Deviation of Predictions	2.5	1.0	0.7	3.6	0.2	6.4
R ²	0.5	0.5	0.5	0.7	0.4	0.3
BF	0.8	0.6	1.1	0.7	1.5	0.8
Number of Samples	30	30	30	28	28	29

2.3.2 Graphical performance evaluation

2.3.2.1 Fine PM (PM_{2.5}) Model Performance

Figure 2.3.2.1-1 shows all available prediction-observation pairs of FRM PM_{2.5} in GA for the base year. Most of pairs are around the 1:1 line and few outliers can be found. Figure 2.3.2.1-2 depicts the same type of data pairs but only for the two FRM monitors in the Macon nonattainment area. In general, the model's overall tendency was similar to that of GA. The model showed more bias in the Macon nonattainment area compared with its performance across GA.

Figure 2.3.2.1-3 and Figure 2.3.2.1-4 display time series of daily PM_{2.5} at each of two FRM monitors in the Macon nonattainment area, 13-021-0007 and 13-021-0012. Throughout the base year, the model showed reasonable performance except some days in summer including July 4th at 13-021-0007 and May 8th at 13-021-0012. One of the issues at 13-021-0007 is it does not have observational data for the second quarter of the base year. Overall, the model showed a bit of positive bias during winter and recognizable negative biases during summer when observations were available.

These general tendencies are confirmed with Figure 2.3.2.1-5. Exception is a bit negative bias detected in March and December at STN monitors in GA. The model showed less than 50% mean fractional errors across all monitors and all monitoring networks in GA throughout the base year. In Figure 2.3.2.1-6, similar model behavior can be found at all monitors in the Macon nonattainment area although the magnitude of errors became larger.

Figure 2.3.2.1-7 and Figure 2.3.2.1-8 show the monthly model performance met the performance goal level in most cases. Overall, the model showed reasonable performance for PM_{2.5} throughout the base year across all monitors in GA. Also, the model performance at the Macon nonattainment monitors was deemed adequate for the purpose of supporting the Macon annual PM_{2.5} SIP.

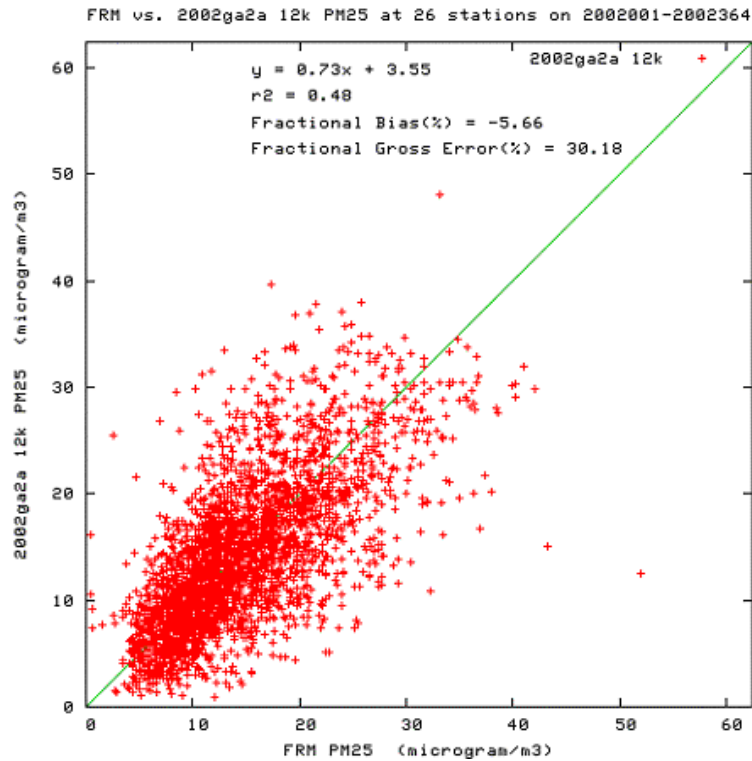


Figure 2.3.2.1-1. PM_{2.5} scatter plot for all FRM sites in the State of Georgia.

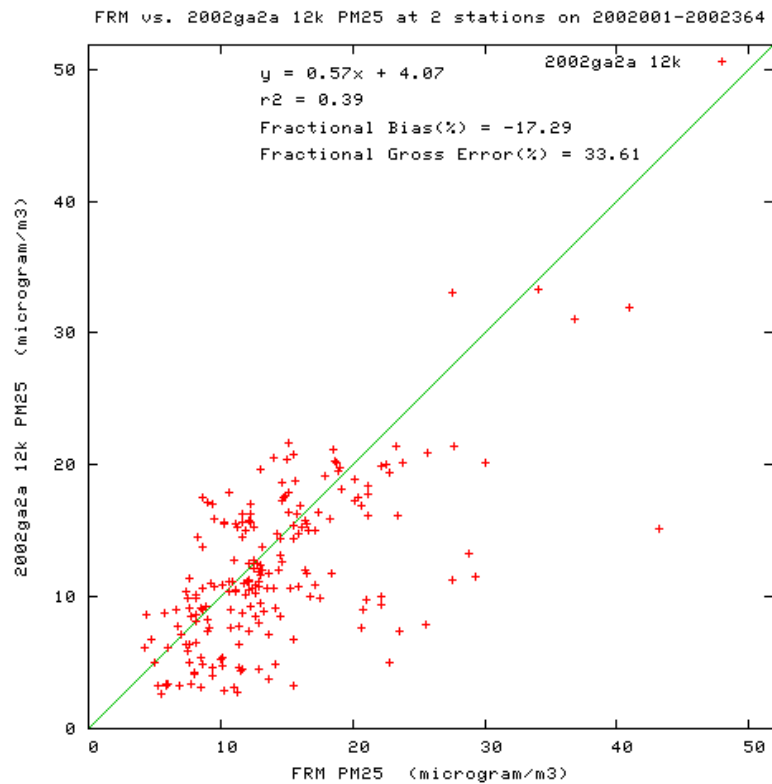


Figure 2.3.2.1-2. PM_{2.5} scatter plot for all FRM sites in the Macon nonattainment area.

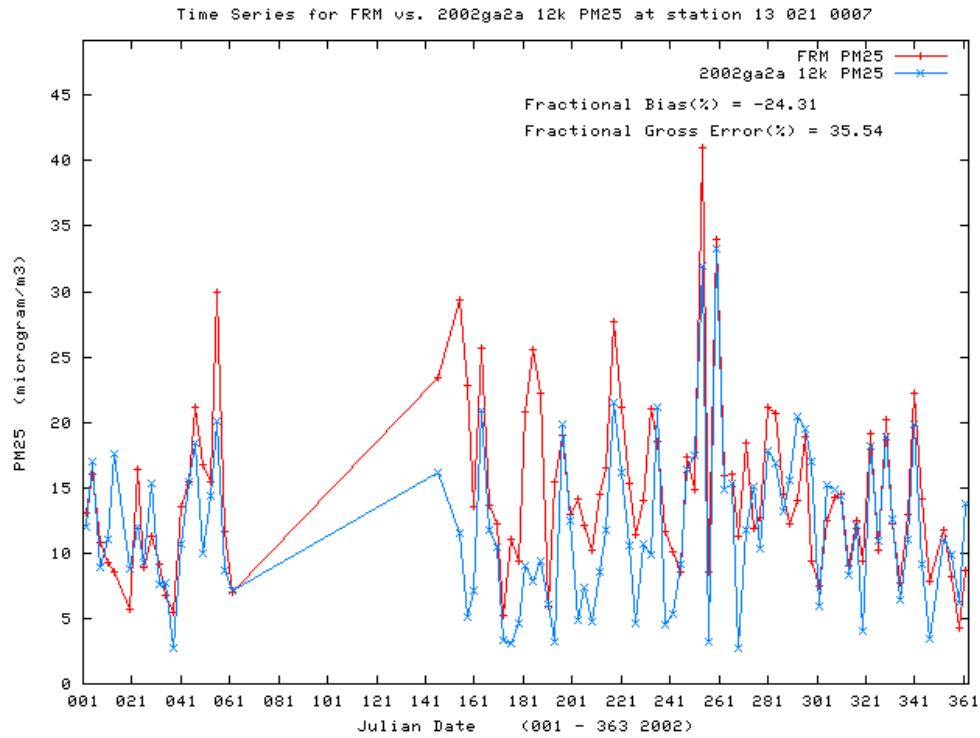


Figure 2.3.2.1-3. PM_{2.5} time series plot for 13-021-0007.

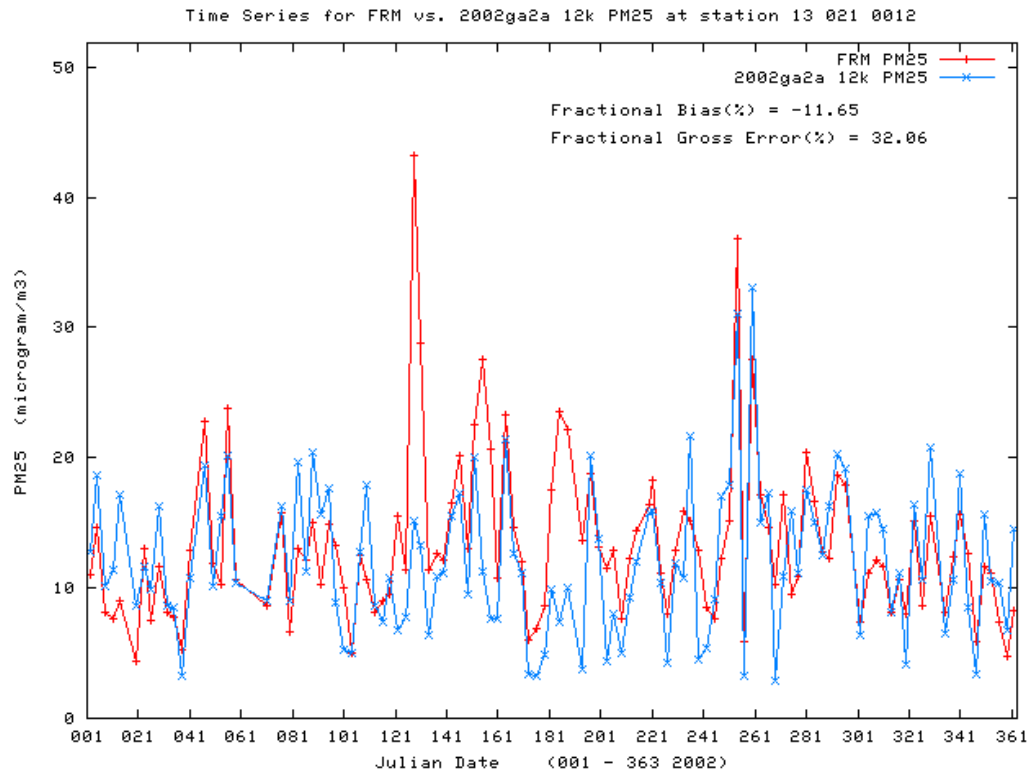


Figure 2.3.2.1-4. PM_{2.5} time series plot for 13-021-0012.

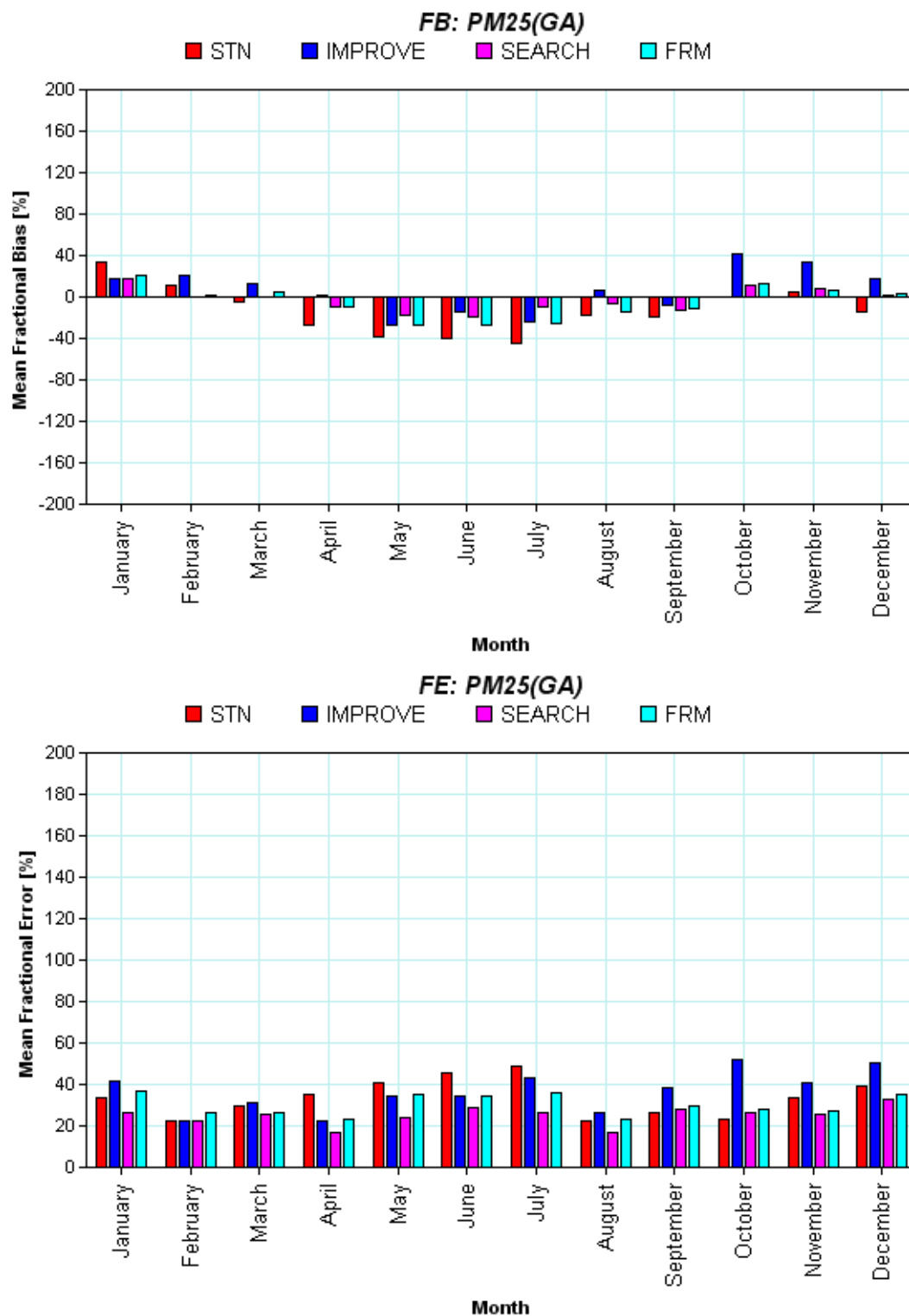


Figure 2.3.2.1-5. Monthly PM_{2.5} mean fractional bias (top) and mean fractional error (bottom) statistical measures for STN, IMPROVE, SEARCH, and FRM sites in the State of Georgia.

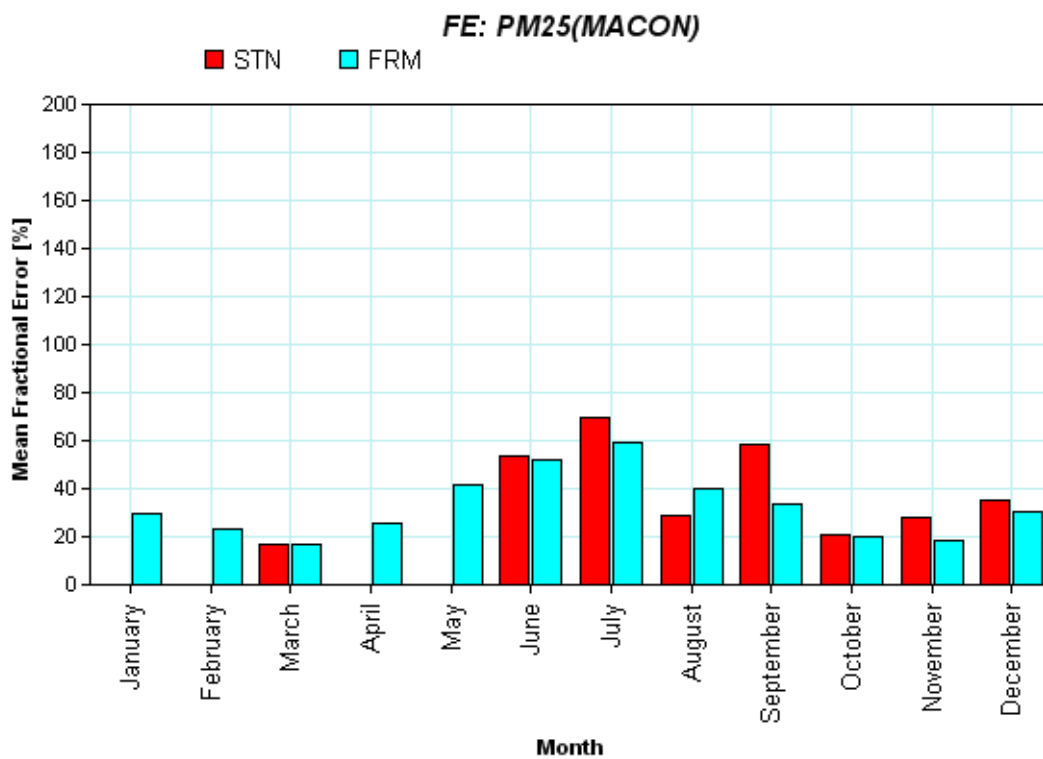
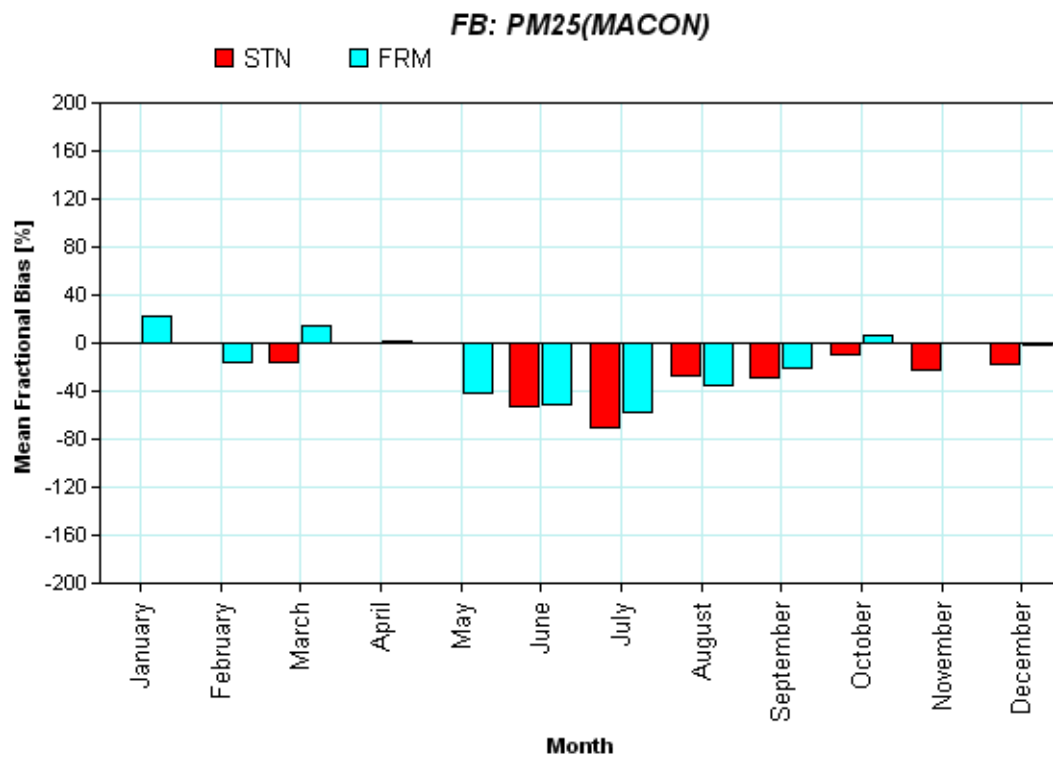


Figure 2.3.2.1-6. Monthly PM_{2.5} mean fractional bias (top) and mean fractional error (bottom) statistical measures for STN and FRM sites in the Macon nonattainment area.

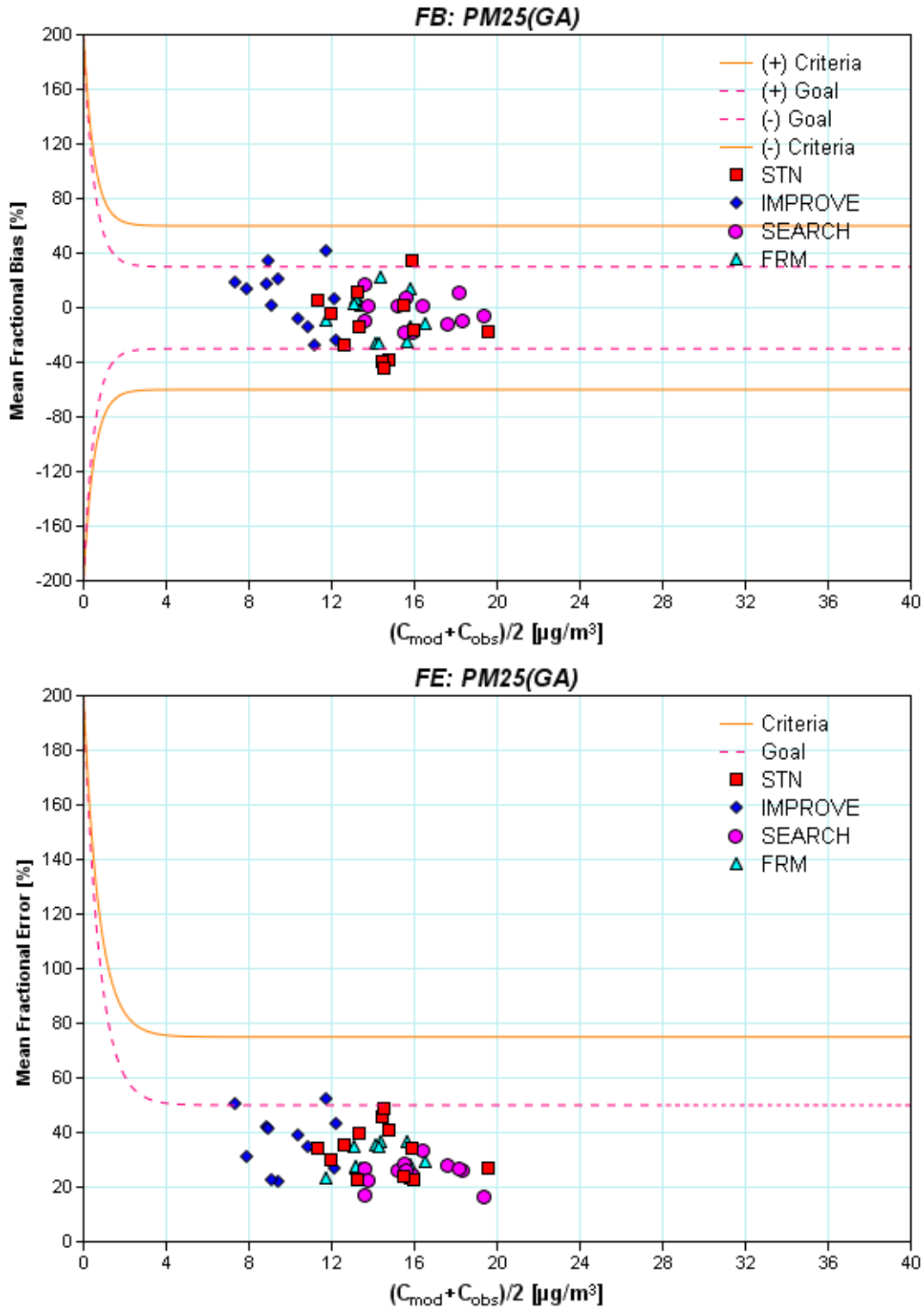


Figure 2.3.2.1-7. Bugle Plots of monthly mean fractional bias (top) and mean fractional error (bottom) for $\text{PM}_{2.5}$ in the State of Georgia and comparison to model performance goals (solid orange) and criteria (dotted pink).

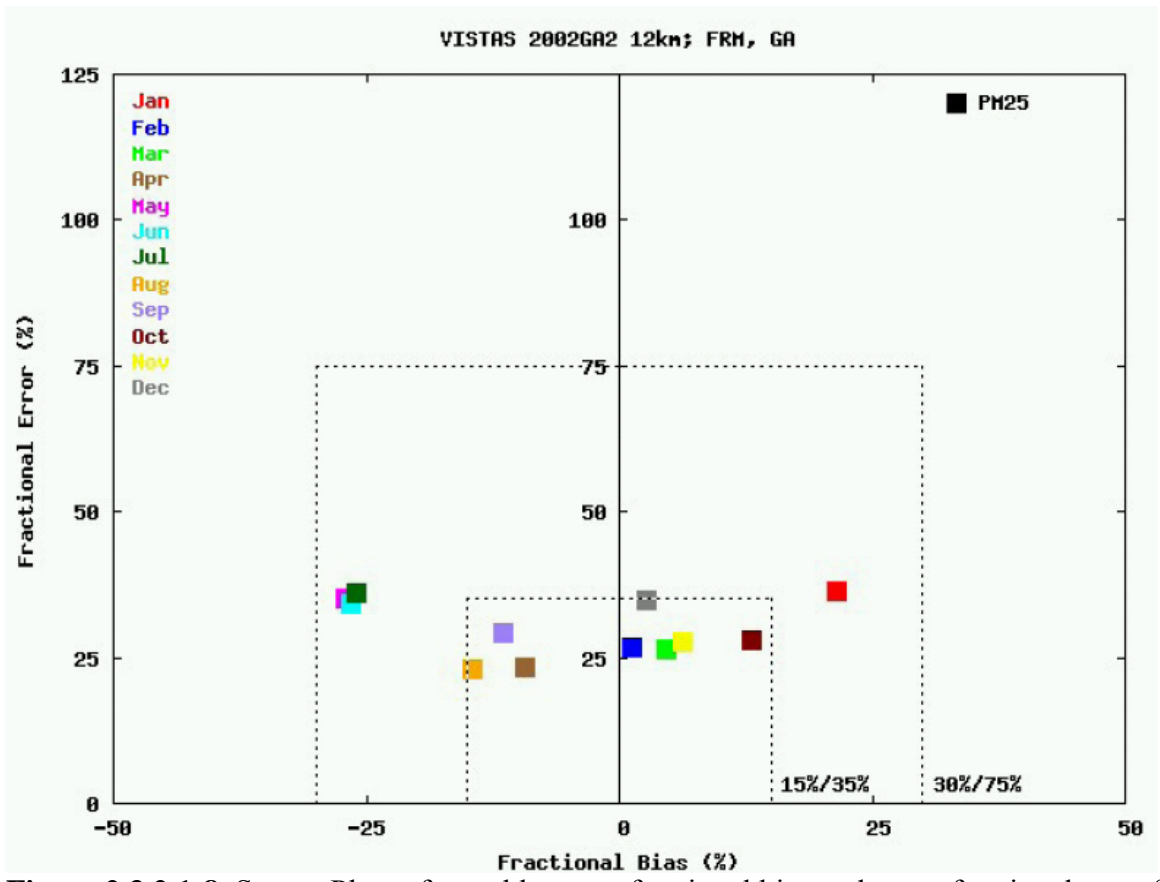


Figure 2.3.2.1-8. Soccer Plots of monthly mean fractional bias and mean fractional error for PM_{2.5} in the State of Georgia and comparison to model performance goal levels (outer dots) and “excellent performance” levels (inner dots).

2.3.2.2 Sulfate (SO₄) Model Performance

Figure 2.3.2.2-1 shows all available prediction-observation pairs of SO₄ from the STN monitors in GA for the base year. Most of pairs are around the 1:1 line with one exceptional outlier. Figure 2.3.2.2-2 is the scatter plot of SO₄ at 13-021-0007 and the outlier found in Figure 2.3.2.2-1 is actually at this monitor. The time series of SO₄ at 13-021-0007 (Figure 2.3.2.2-3) revealed that it indeed happened on September 11, 2002. The modeled SO₄ concentration was about 10.6 µg/m³ while the observation was about 39.9 µg/m³. Although this monitor failed to measure almost all of SO₄ concentrations for the first half of base year, the model's performance for the rest of the year seems to be reasonable.

Figure 2.3.2.2-4 displays the model's monthly SO₄ performance across all STN monitors in GA. In most of cases, the model showed negative biases except for a few cases. The magnitude of bias was not significant. Similar tendency can be found at 13-021-0007 as shown in Figure 2.3.2.2-5. Figure 2.3.2.2-6 and Figure 2.3.2.2-7 show the monthly model performance met the performance goal level in most cases except for a few months at the IMPROVE monitors and at the STN monitors where the model could achieve the performance criteria goal with ample margins.

To clarify the exceptional case found in September 11, GA EPD conducted more in-depth examination. It turned out that the measured PM_{2.5} at the same STN site was 20.3 µg/m³ while the co-located FRM monitor showed 41.0 µg/m³ of PM_{2.5}. The model predicted 32.0 µg/m³ of PM_{2.5} for the same day. Composition-wise comparison revealed that there was also a noticeable discrepancy in OC and NH₄. The model predicted 14.7 µg/m³ of OC and 3.2 µg/m³ of NH₄ while the observation was 9.8 µg/m³ of OC and 10.7 µg/m³ of NH₄. Therefore, the model's overall PM_{2.5} performance for this day was likely due to a compensating error of individual PM_{2.5} species performance. At the same time, the SO₄ measurement at this STN site on September 11, 2002 is highly uncertain due to the fact that the sum of five measured PM_{2.5} species was 63.0 µg/m³ that is well-above the PM_{2.5} concentrations at the same site and at the co-located FRM site. Therefore, GA EPD concluded that overall the model showed reasonable performance for the SO₄ throughout the base year across all monitors in GA.

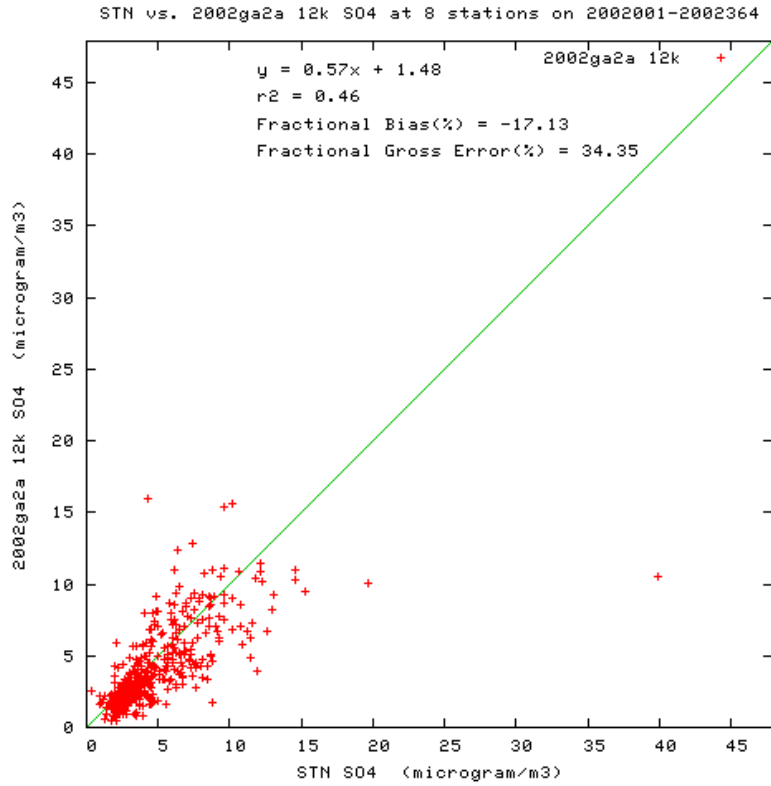


Figure 2.3.2.2-1. SO₄ scatter plot for all STN sites in the State of Georgia.

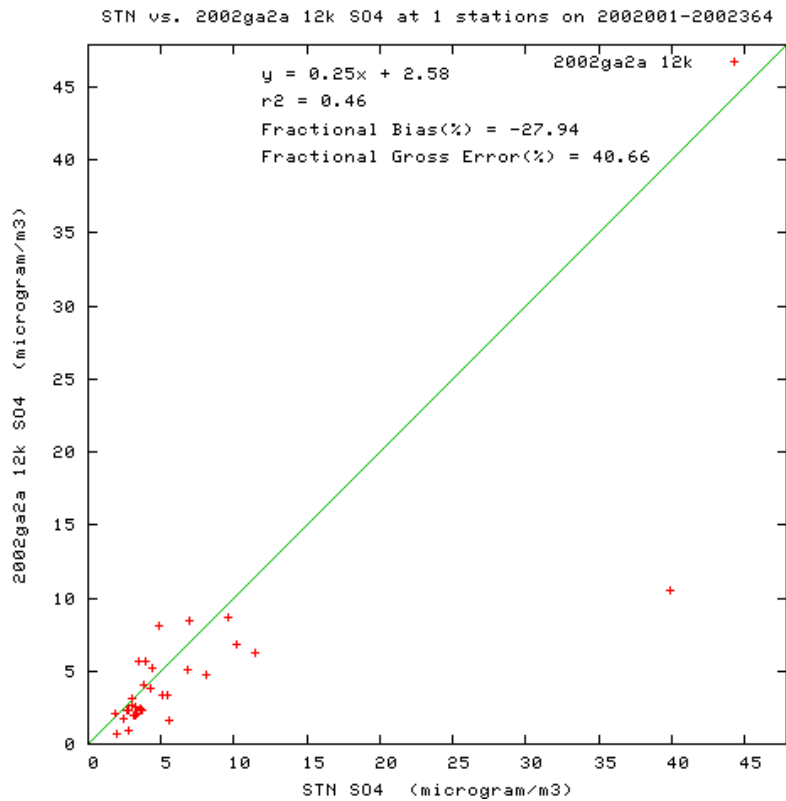


Figure 2.3.2.2-2. SO₄ scatter plot for all STN sites in the Macon nonattainment area.

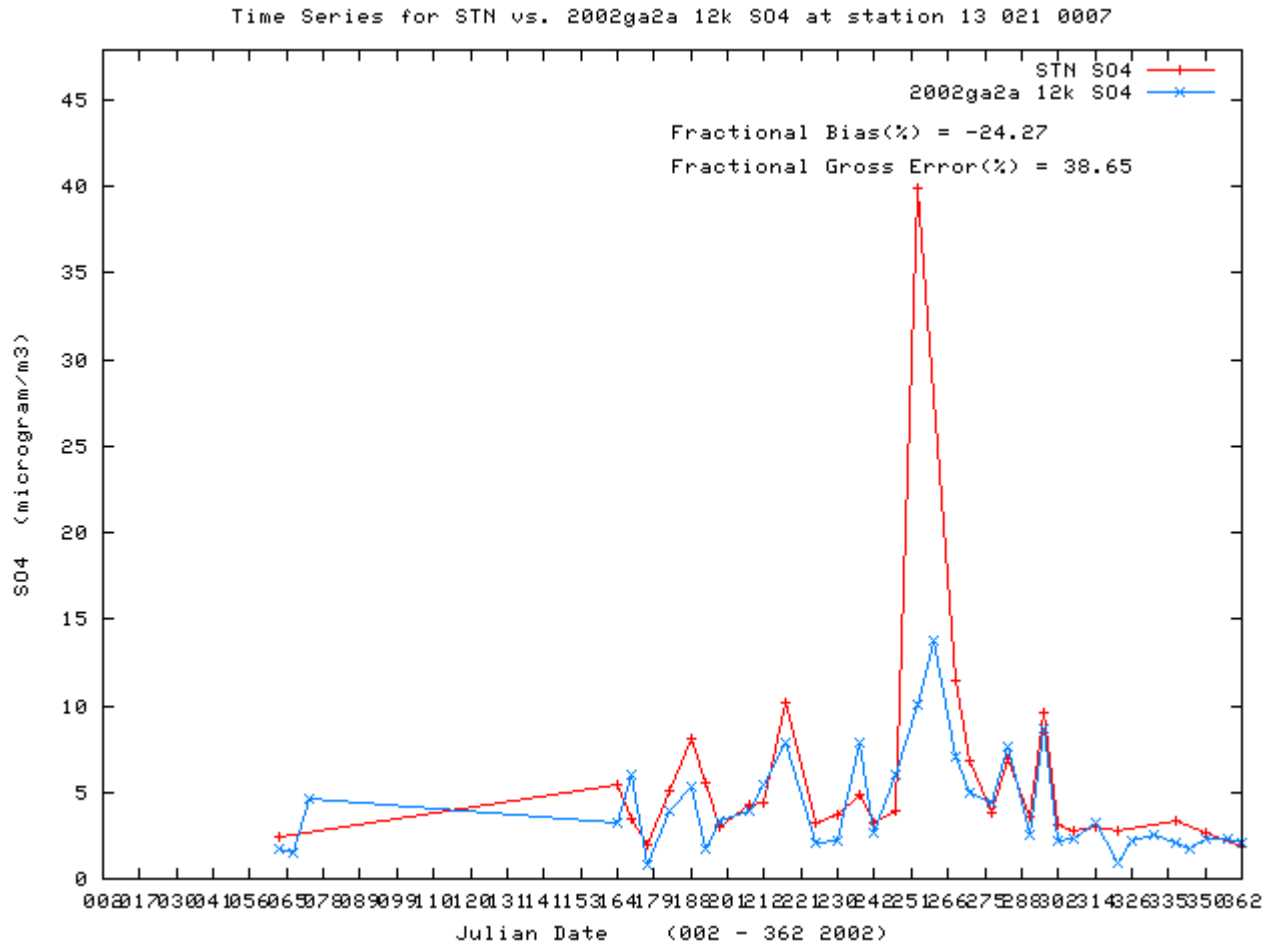


Figure 2.3.2.2-3. SO₄ time series plot for 13-021-0007.

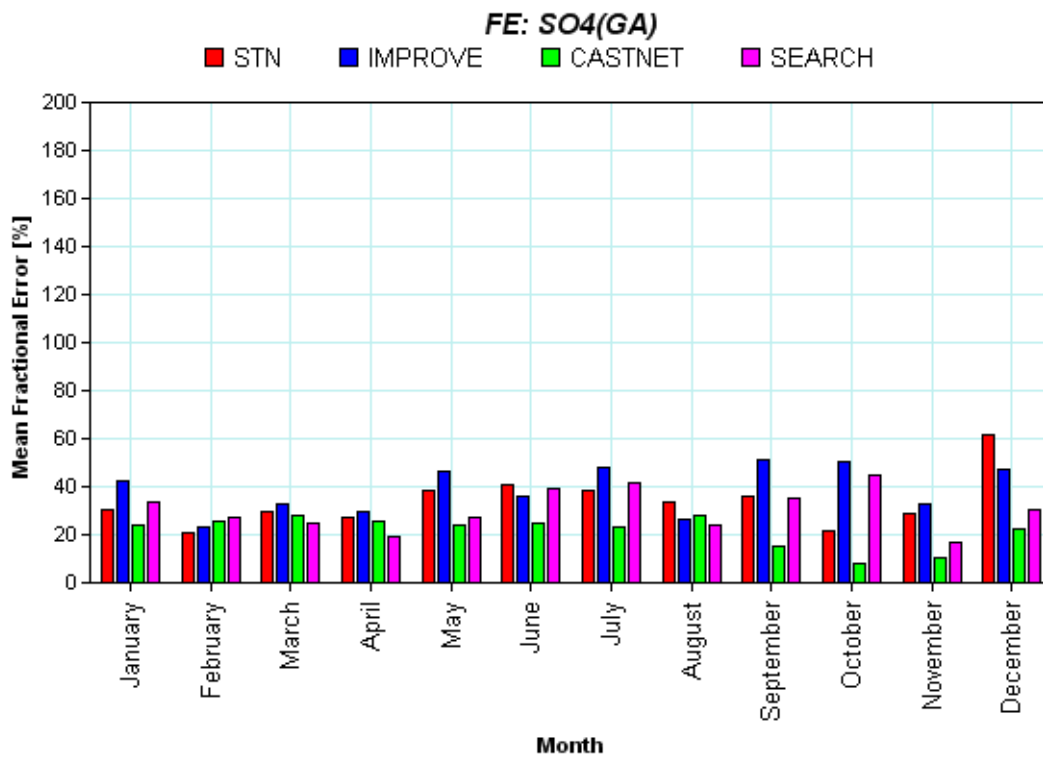
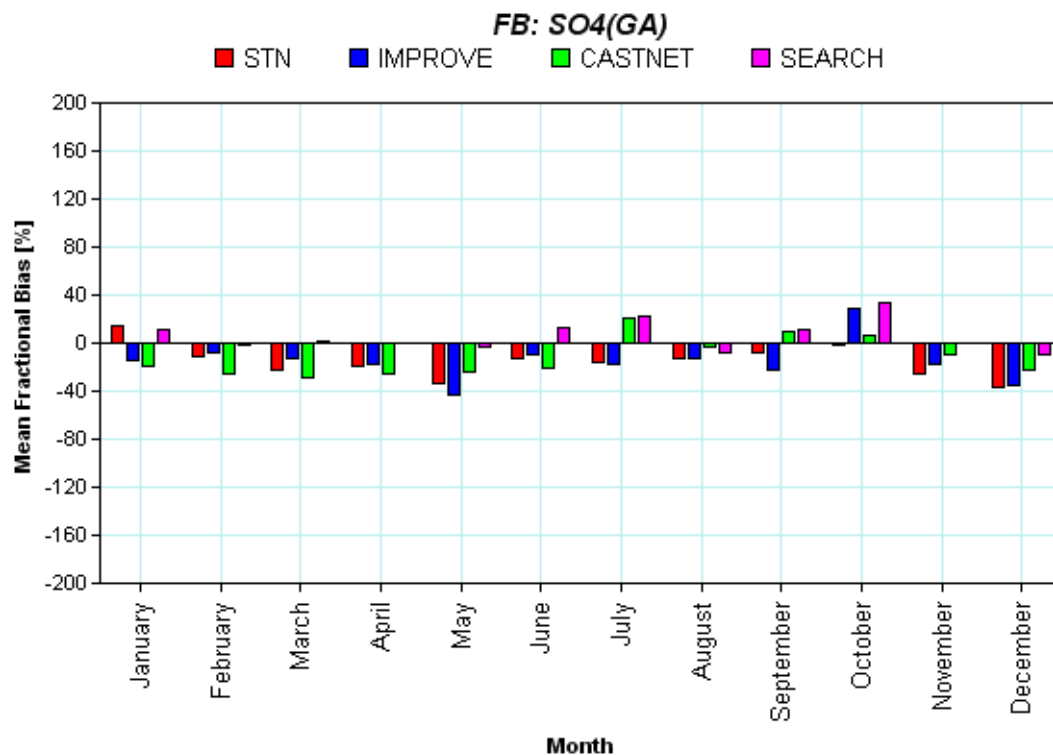


Figure 2.3.2.2-4. Monthly SO₄ mean fractional bias (top) and mean fractional error (bottom) statistical measures for STN, IMPROVE, CASTNET, and SEARCH monitoring sites in the State of Georgia.

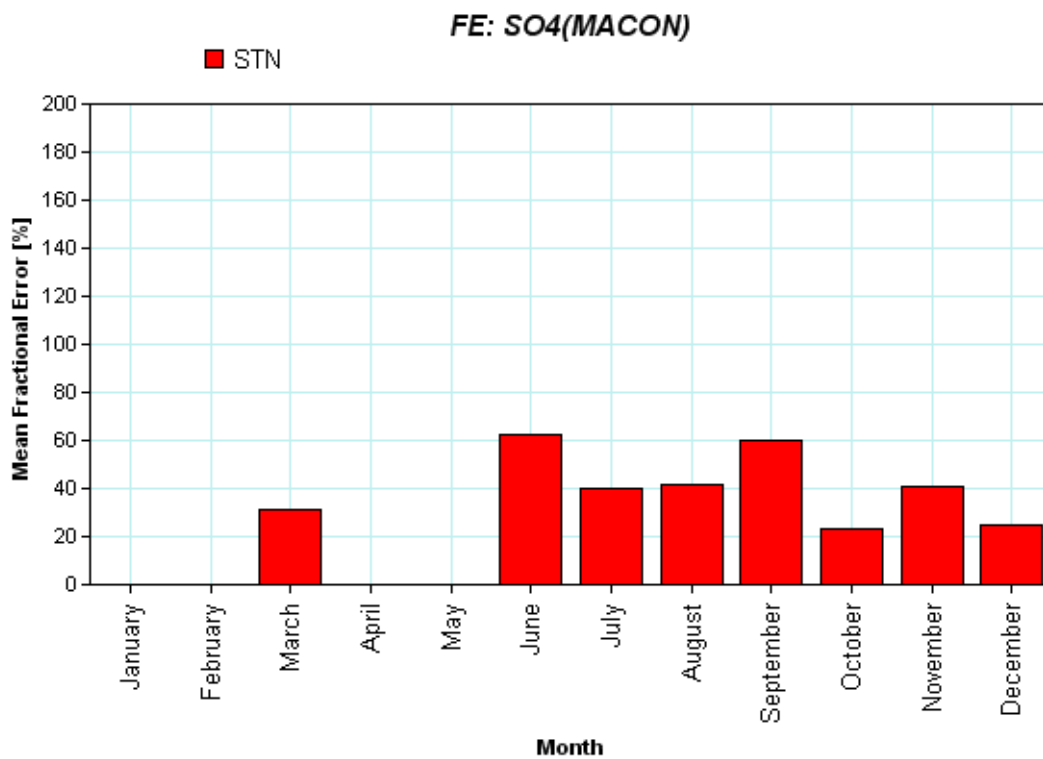
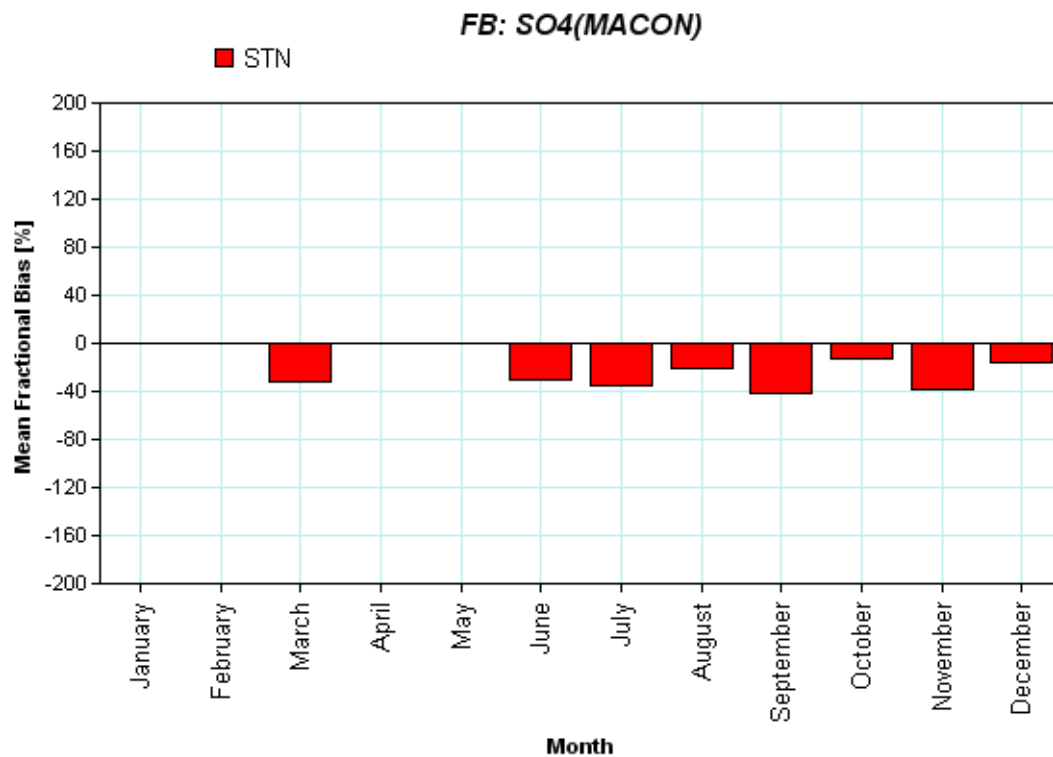


Figure 2.3.2.2-5. Monthly SO₄ mean fractional bias (top) and mean fractional error (bottom) statistical measures for the STN monitoring site in the Macon nonattainment area.

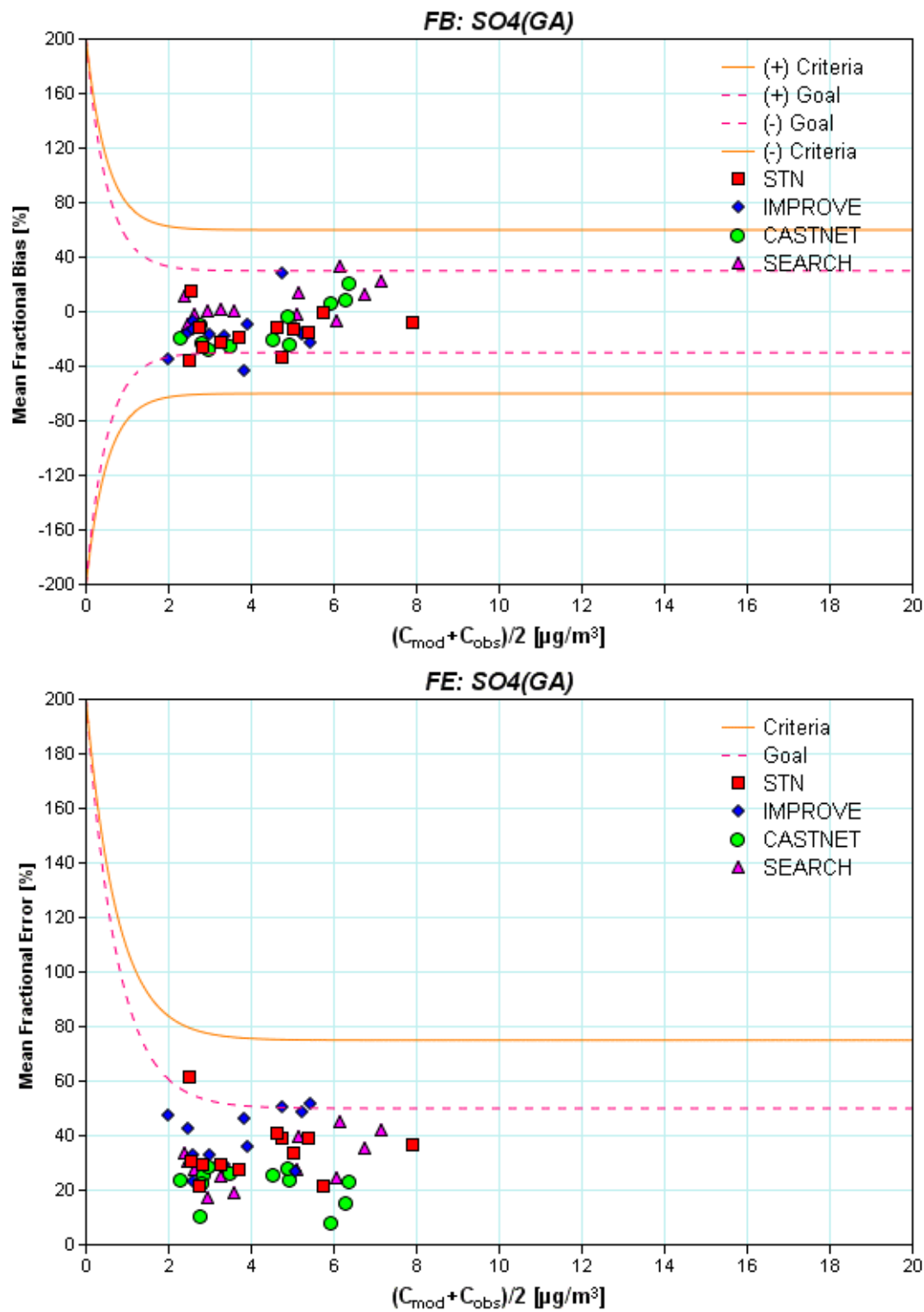


Figure 2.3.2.2-6. Bugle Plots of monthly mean fractional bias (top) and mean fractional error (bottom) for SO₄ in the State of Georgia and comparison to model performance goals (solid orange) and criteria (dotted pink).

VISTAS 2002GA2 12km; STN, GA, SO4

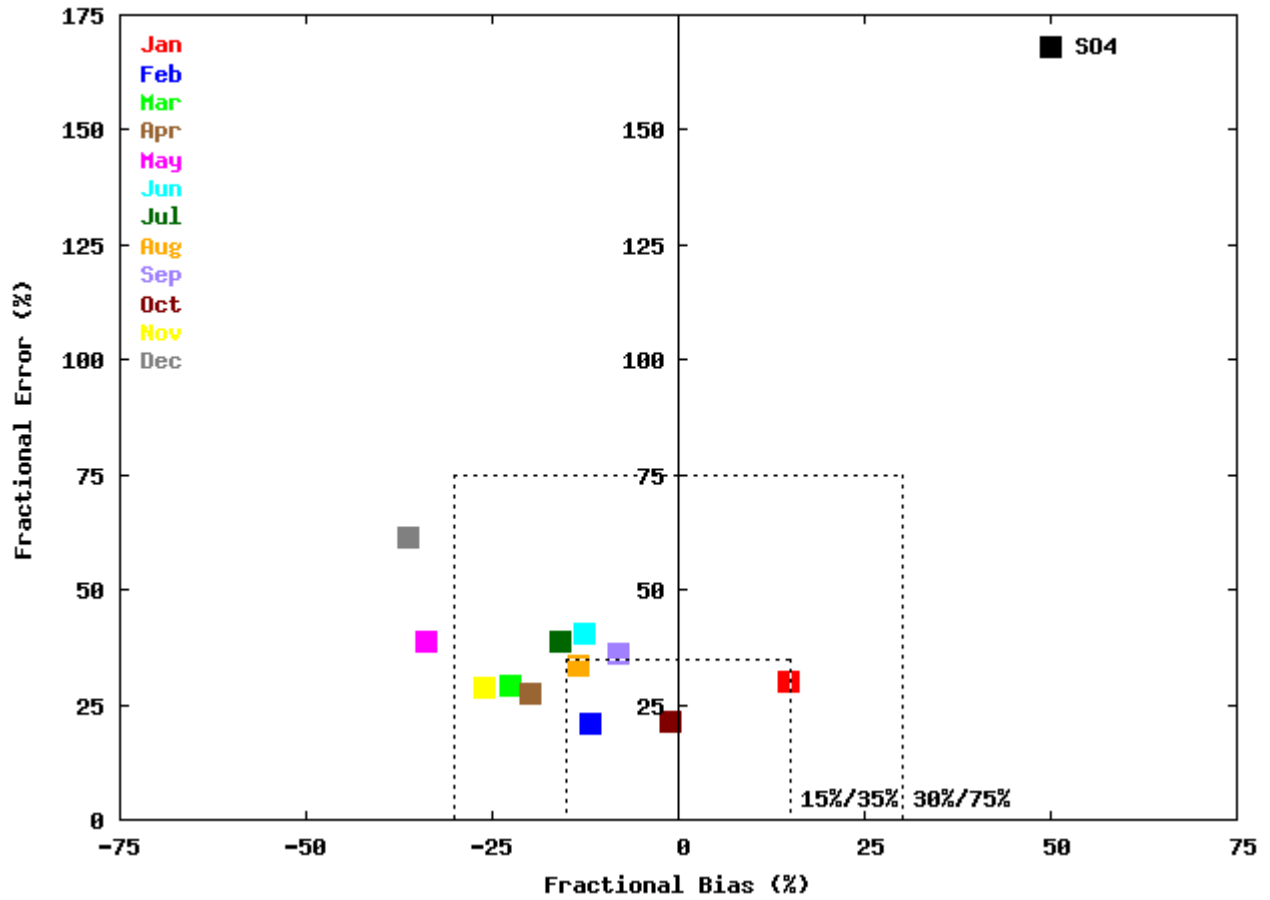


Figure 2.3.2.2-7. Soccer Plots of monthly mean fractional bias and mean fractional error for SO₄ in the State of Georgia and comparison to model performance goal levels (outer dots) and “excellent performance” levels (inner dots).

2.3.2.3 Nitrate (NO₃) Modeling Performance

Figure 2.3.2.3-1 shows all available prediction-observation pairs of NO₃ from the STN monitors in GA for the base year. The model's performance of NO₃ seemed to have a large amount of unsystematic errors as well as large under predictions for low NO₃ concentrations. The same tendency can be found at 13-021-0007 (Figure 2.3.2.3-2). Time series plot for 13-021-0007 showed that most of negative bias cases are accounted for summer days (Figure 2.3.2.3-3). In addition, there was large day-to-day fluctuation in the model during early winter while the observation did not show that fluctuation. Figure 2.3.2.3-4 reveals a seasonal variation of NO₃ performance with a severe under prediction larger than -100% during summer and moderate over prediction at monitors in GA during winter. Figure 2.3.2.3-5 shows the same type of issue can be found at 13-021-0007. Figure 2.3.2.3-6, however, shows that the amount of error and bias in monthly time series was most likely by low concentration (< 1.0 µg/m³) cases. In fact, magnitudes of these data points of STN monitors SEARCH monitors were barely over 2.0 µg/m³ as combined monthly average concentrations of mean observed and predicted NO₃ concentrations. In addition, the model performance became better when observed and predicted concentrations were higher.

GA EPD agrees with possible causes of poor NO₃ performance that the VISTAS modeling team proposed: the summer NO₃ under prediction bias is likely due in part to the overstated MM5 convective precipitation. The modeled NO₃ concentrations are highly sensitive to ammonia (NH₃) concentrations. Whether the oxidized nitrogen compounds are gaseous nitric acid (HNO₃) or particulate NO₃ depends on, in part, the availability of NH₃ or other basic compounds to buffer NO₃. Although VISTAS spent considerable effort updating and improving the ammonia emissions, they are still highly uncertain. Overall, GA EPD concluded that the NO₃ performance was considered adequate for the purpose of supporting the Macon annual PM_{2.5} SIP.

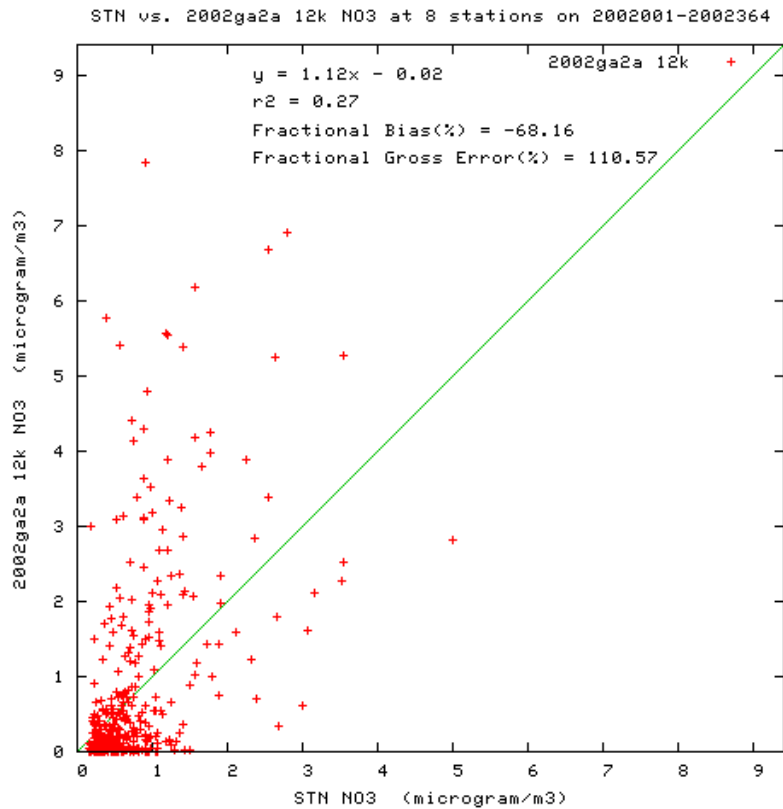


Figure 2.3.2.3-1. NO₃ scatter plot for all STN sites in the State of Georgia.

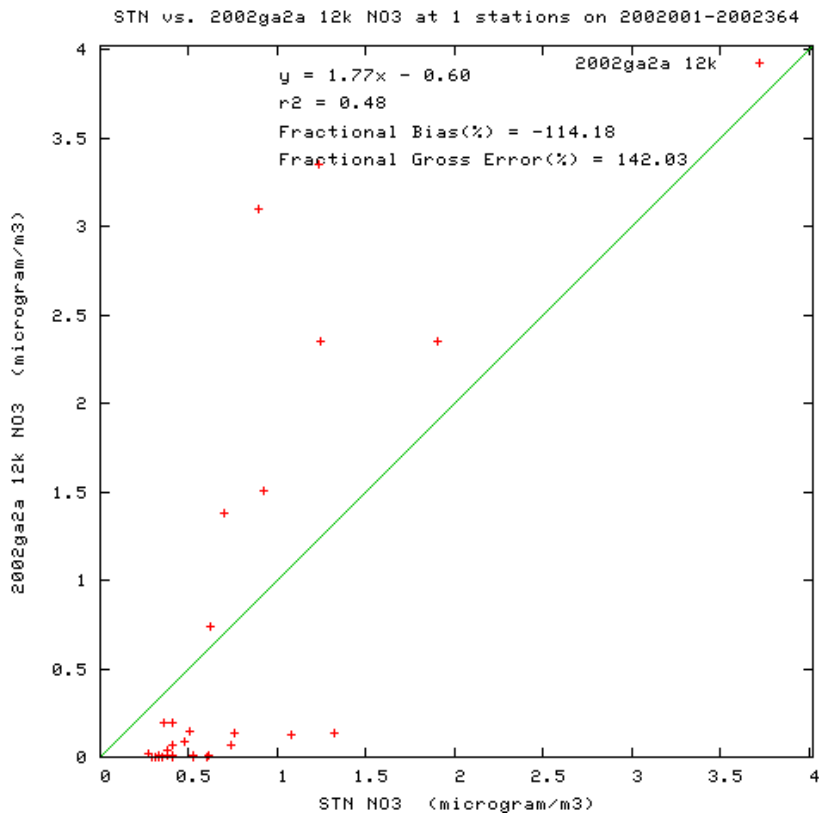


Figure 2.3.2.3-2. NO₃ scatter plot for the STN site in the Macon nonattainment area.

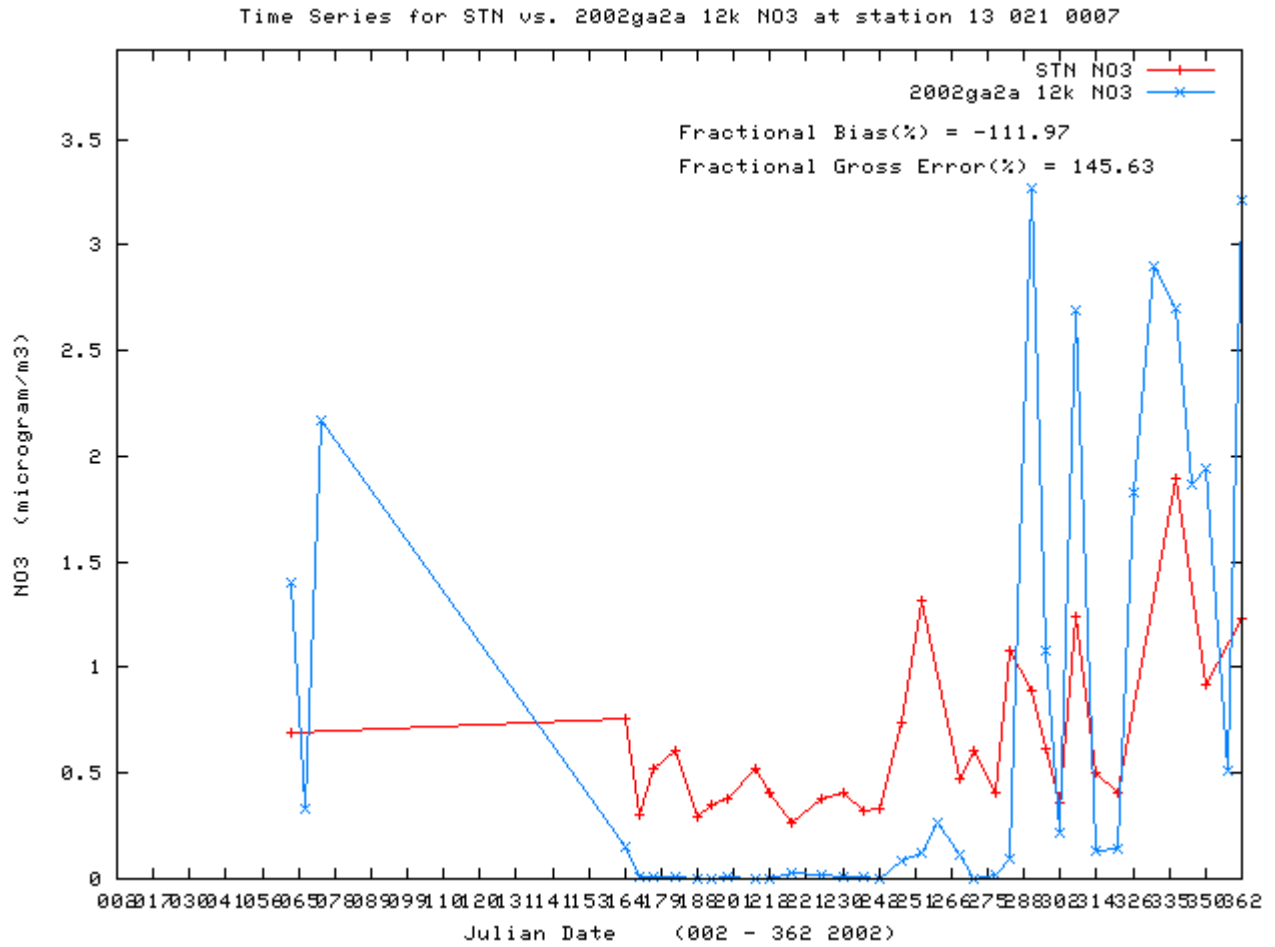


Figure 2.3.2.3-3. NO₃ time series plot for 13-021-0007.

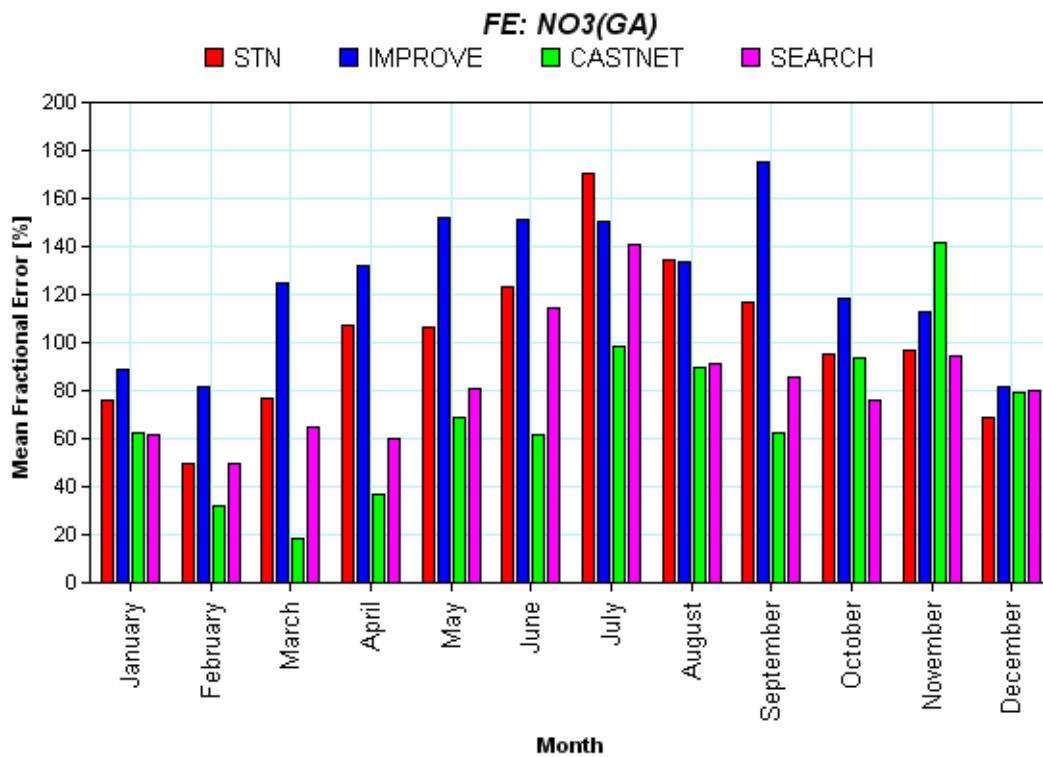
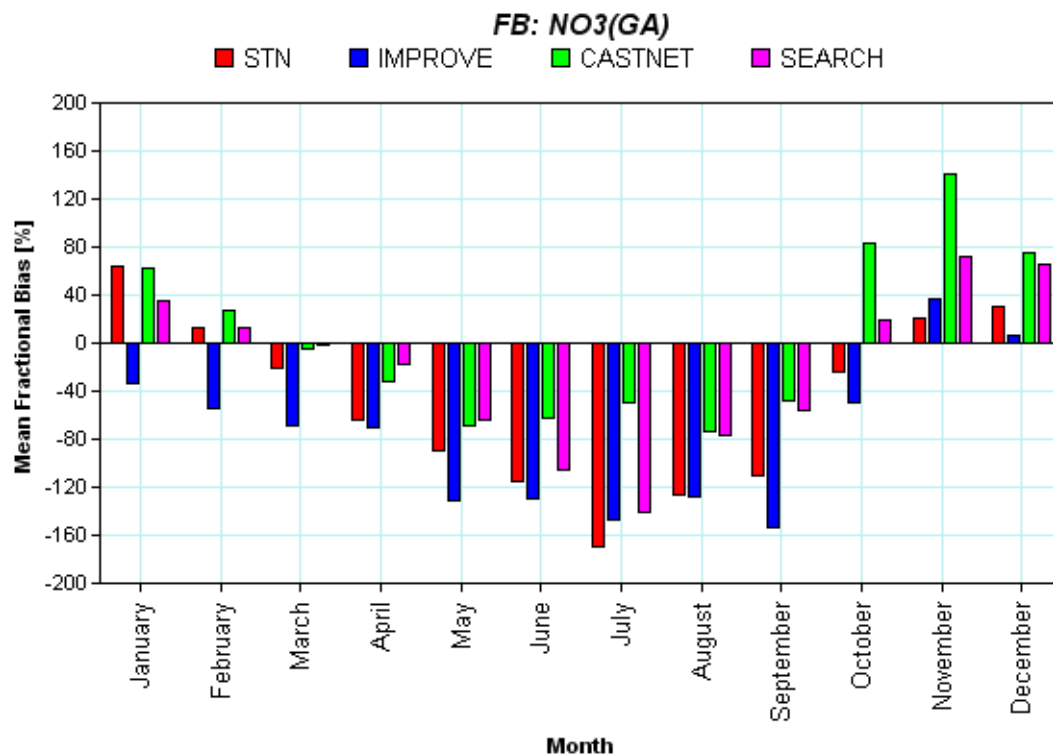


Figure 2.3.2.3-4. Monthly NO₃ fractional bias (top) and fractional gross error (bottom) statistical measures for STN, IMPROVE, CASTNET, and SEARCH monitoring sites in the State of Georgia.

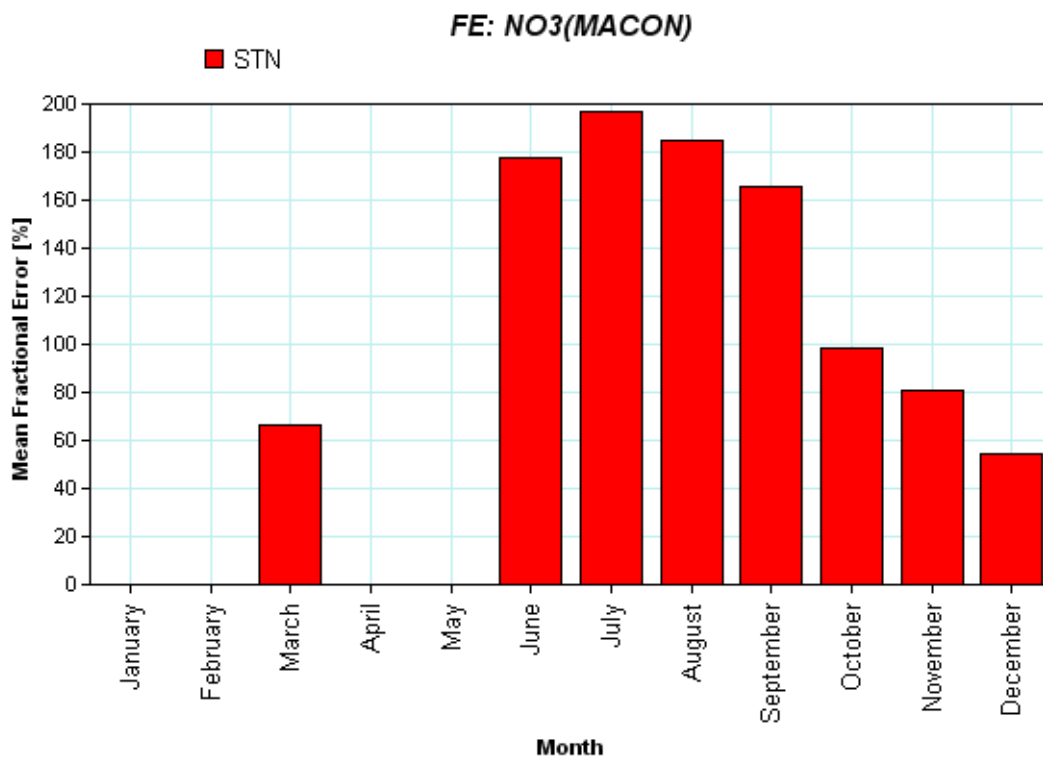
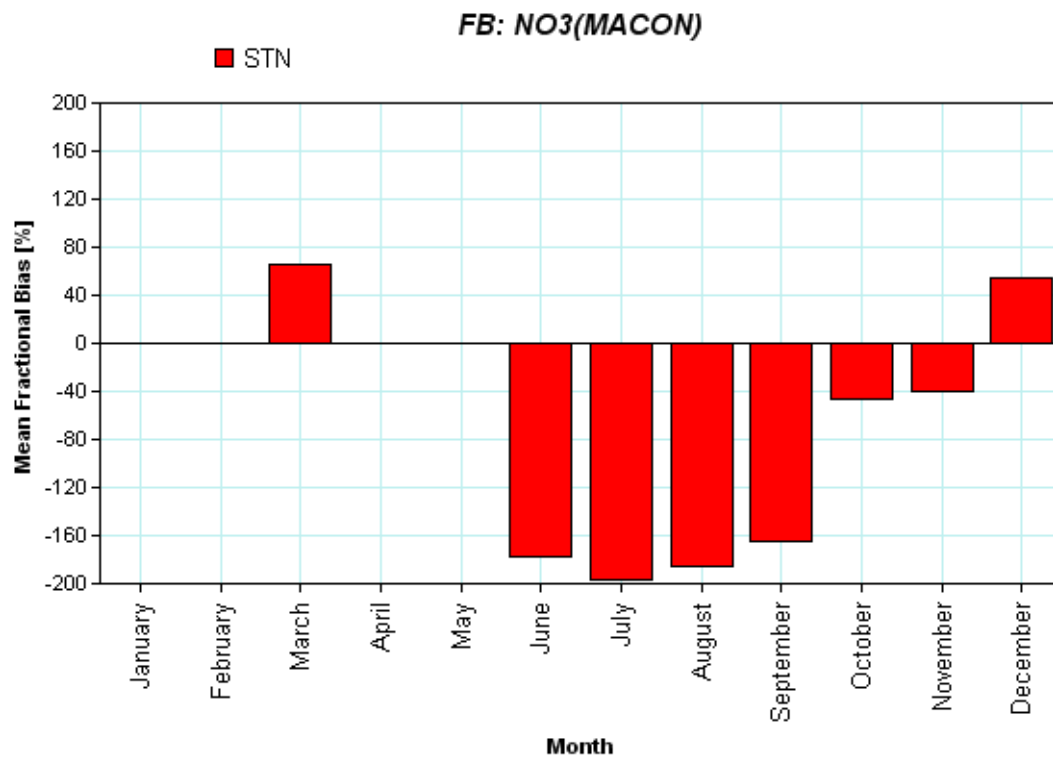


Figure 2.3.2.3-5. Monthly NO₃ mean fractional bias (top) and mean fractional error (bottom) statistical measures for the STN monitoring site in the Macon nonattainment area.

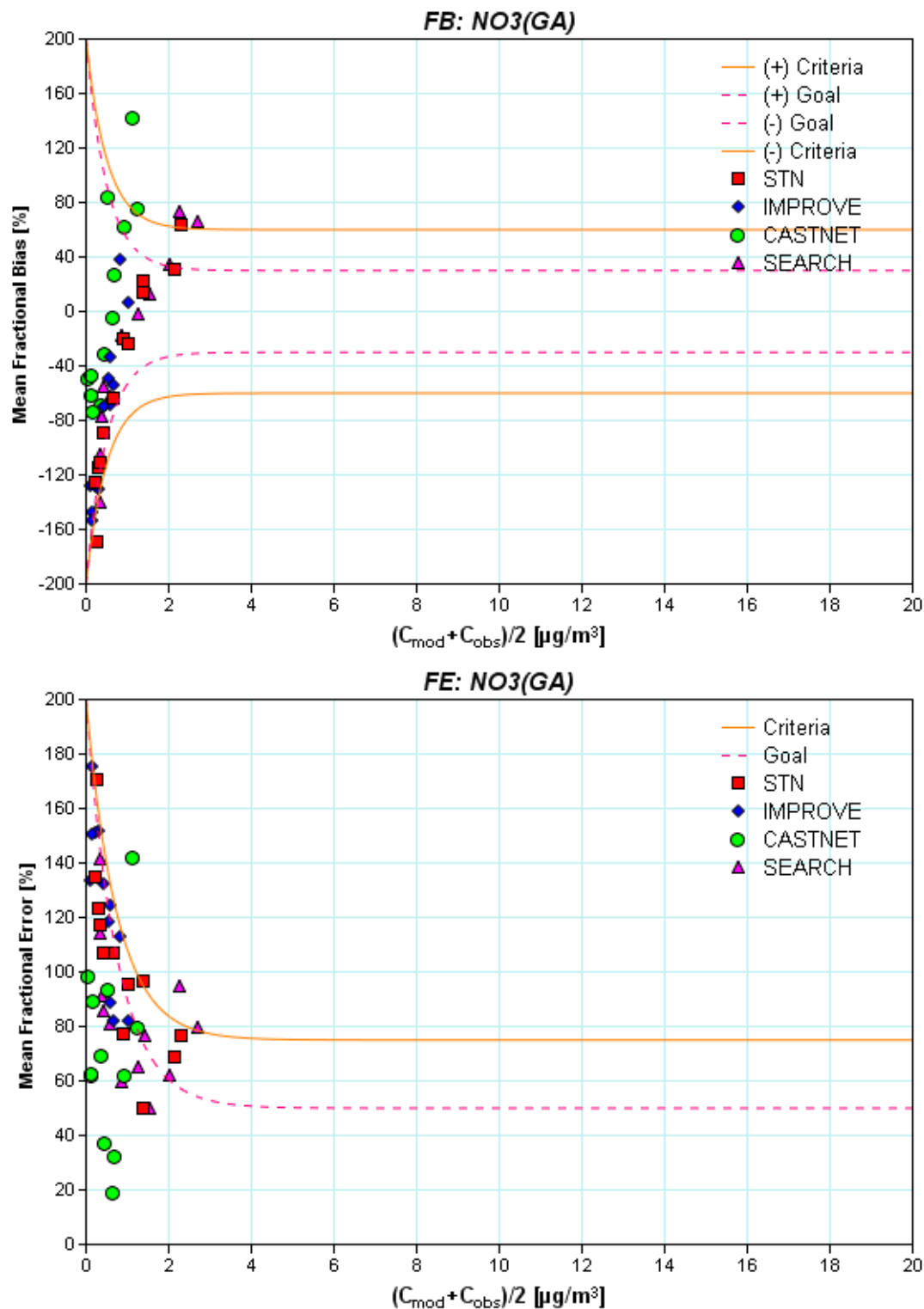


Figure 2.3.2.3-6. Monthly NO₃ fractional bias (top) and fractional gross error (bottom) statistical measures for STN, IMPROVE, CASTNET, and SEARCH monitoring sites in the State of Georgia.

VISTAS 2002GA2 12km; STN, GA, NO3

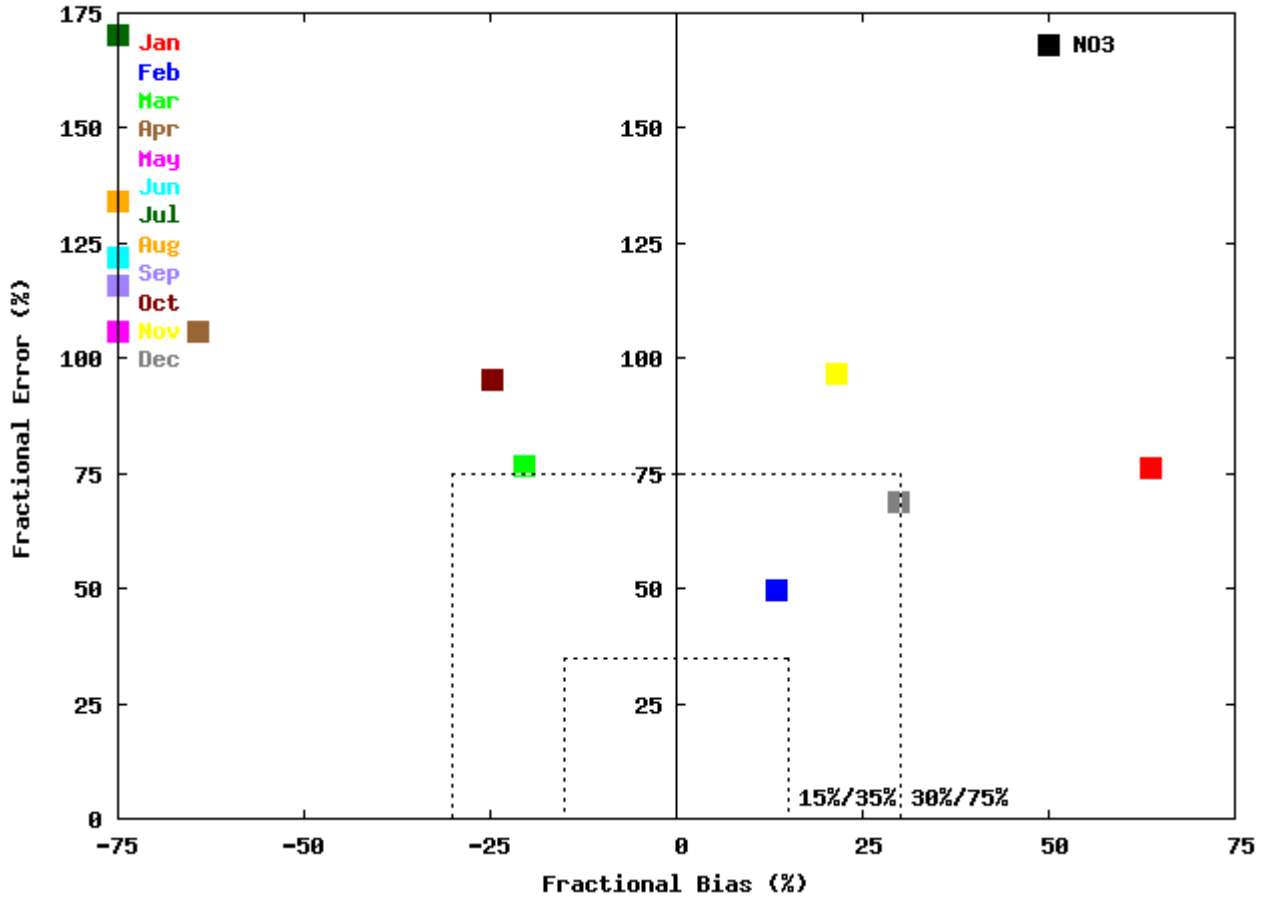


Figure 2.3.2.3-7. Soccer Plots of monthly mean fractional bias and mean fractional error for NO₃ in the State of Georgia and comparison to model performance goal levels (outer dots) and “excellent performance” levels (inner dots).

2.3.2.4 Organic Mass Carbon (OMC) Performance

Figure 2.3.2.4-1 shows all available prediction-observation pairs of OMC from the STN monitors in GA for the base year. Most pairs are around the 1:1 line with some degree of scattering and a few exceptional outliers. Figure 2.3.2.4-2 is the scatter plot of OMC at 13-021-0007 and the model's performance of OMC seemed to be better than that for the GA. The time series of OMC at 13-021-0007 (Figure 2.3.2.4-3) shows that the model's prediction matched observations reasonably with some marginal errors although the number of samples was small.

Figure 2.3.2.4-4 shows the monthly mean fractional bias and error of OMC across the State of Georgia at monitors of STN, IMPROVE, and SEARCH networks. It is clear that there were inter-network biases for OMC performance. That is, monthly OMC performance at IMPROVE monitors almost always showed over predictions while other two networks, STN and SEARCH, showed opposite trend. The model showed positive biases at STN in August and at SEARCH monitors in March and August. It over-predicted OMC concentrations at IMPROVE monitors except May. In most of cases, however, the model met the performance criteria level. Figure 2.3.2.4-5 displays the same monthly statistics for 13-021-0007. It is obvious that the model under predicted OMC at the STN monitor in the Macon nonattainment area. Figure 2.3.2.4-6 indicates the model met the performance criteria of mean fractional bias and error for all monitoring networks except for one month at SEARCH.

To investigate the model performance at this month, GA EPD conducted more in-depth analyses and found that the month that the model did not meet the performance criteria was December. Two SEARCH network monitors, Jefferson Street site (JST) and the Yorkville site (YRK), were included in this detailed analysis. At JST in December, the model predicted monthly average OMC concentrations of $4.7 \mu\text{g}/\text{m}^3$ and the observed concentration was $16.0 \mu\text{g}/\text{m}^3$. At YRK, the model predicted the monthly average OMC concentration ($2.9 \mu\text{g}/\text{m}^3$) that is very close to the observed concentrations ($3.1 \mu\text{g}/\text{m}^3$). A STN site (13-089-0002) near JST observed $5.9 \mu\text{g}/\text{m}^3$ of monthly average OMC and the model predicted $3.8 \mu\text{g}/\text{m}^3$ at that site. This implies a possible error in OMC observation at JST.

Figure 2.3.2.4-7 shows the observed OMC concentrations at JST and 13-089-0002 in December. From this figure, we speculated some potential issues related to emission inventory and observational uncertainties. First, atypically high OMC concentration observed at JST on December 9, 2002 might be caused by some events (such as fires) that might not be in the emission inventory. Second, JST had data for only three days in December 2002, which might indicate that the quality of sampling might be questionable. Last, JST showed about 80% higher OMC concentrations than what is observed at 13-089-0002 on December 8, 2002. Since 13-089-0002 had more samples and showed more typical winter urban OMC signals, we concluded the apparently poor OC performance at JST in December might not be significant for the future projection. Therefore, GA EPD concluded that the model's OMC performance is acceptable.

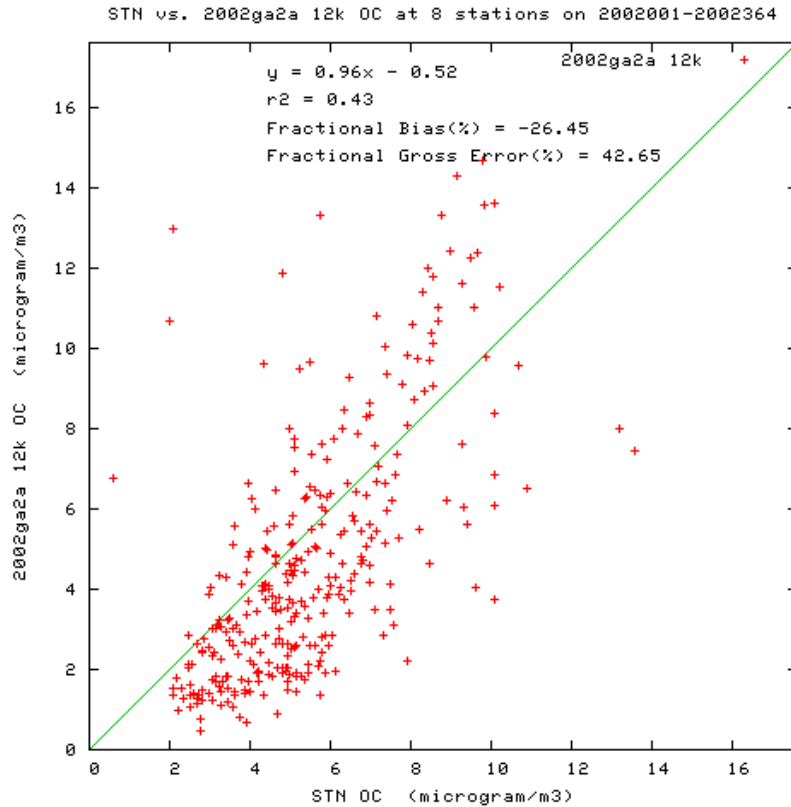


Figure 2.3.2.4-1. OMC scatter plot for all STN sites in the State of Georgia.

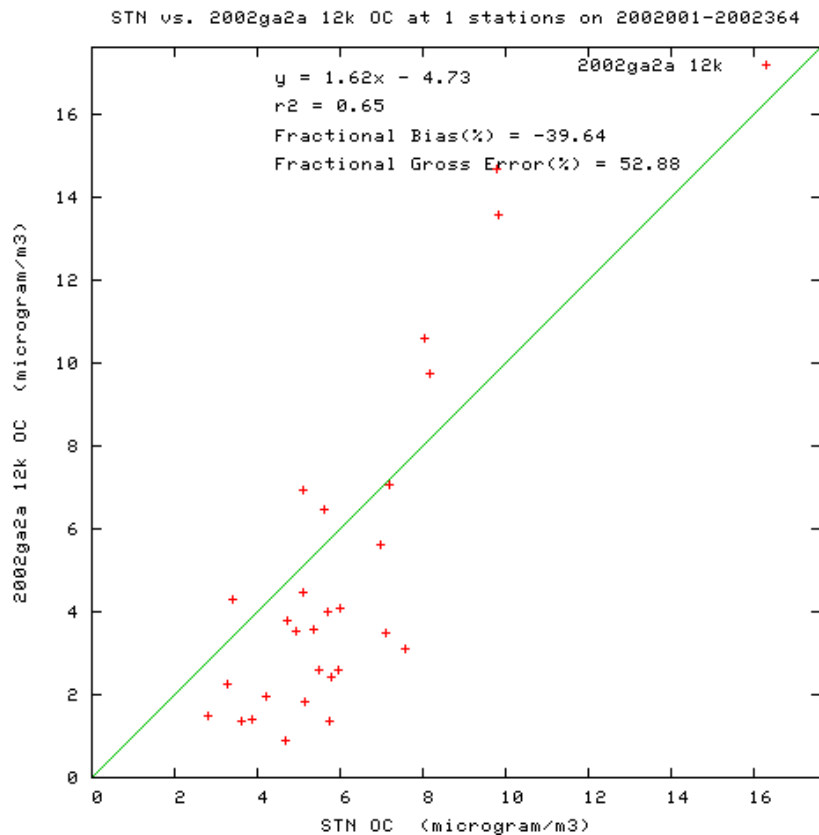


Figure 2.3.2.4-2. OMC scatter plot for the STN site in the Macon nonattainment area.

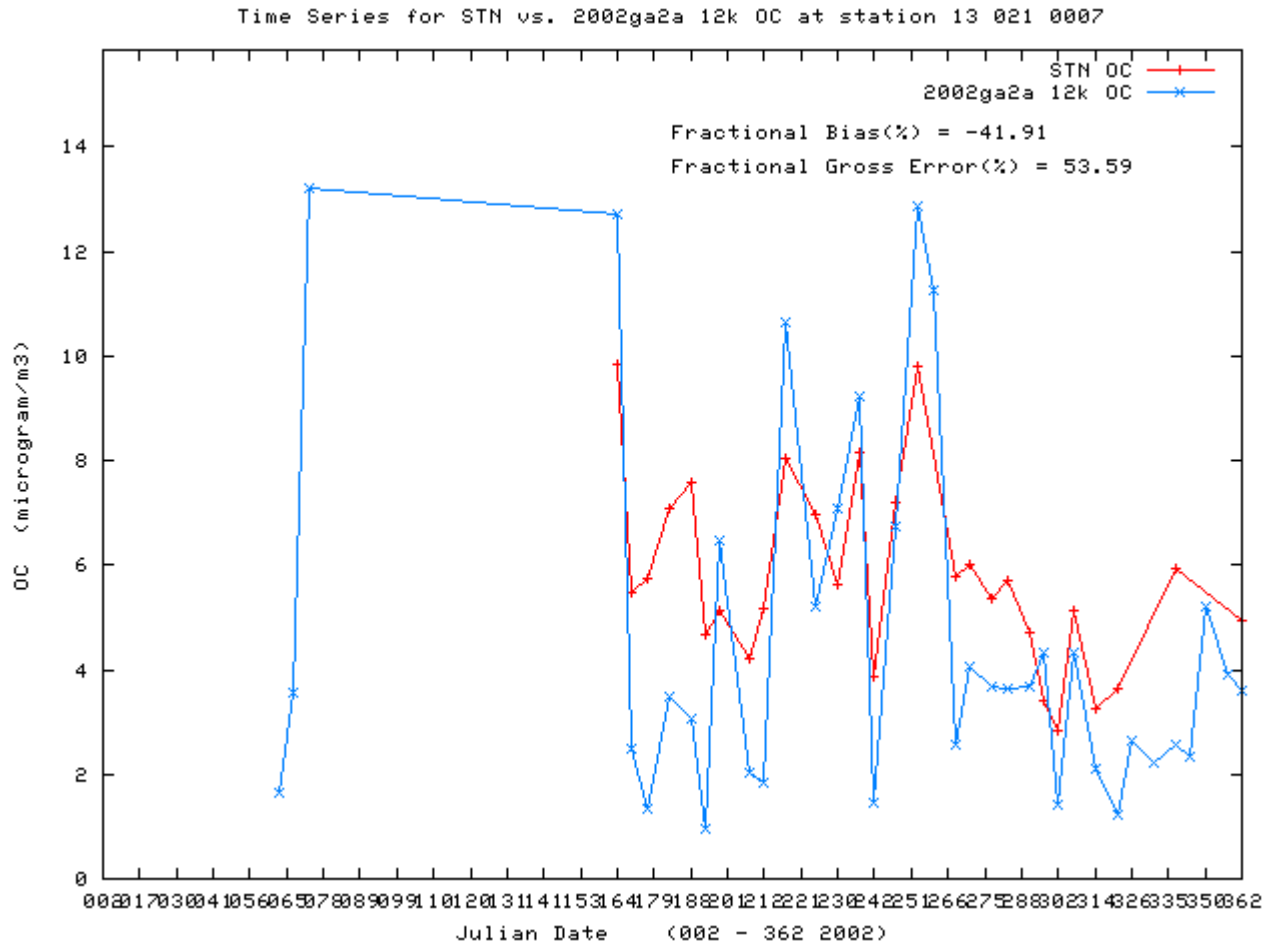


Figure 2.3.2.4-3. OMC time series plot for 13-021-0007.

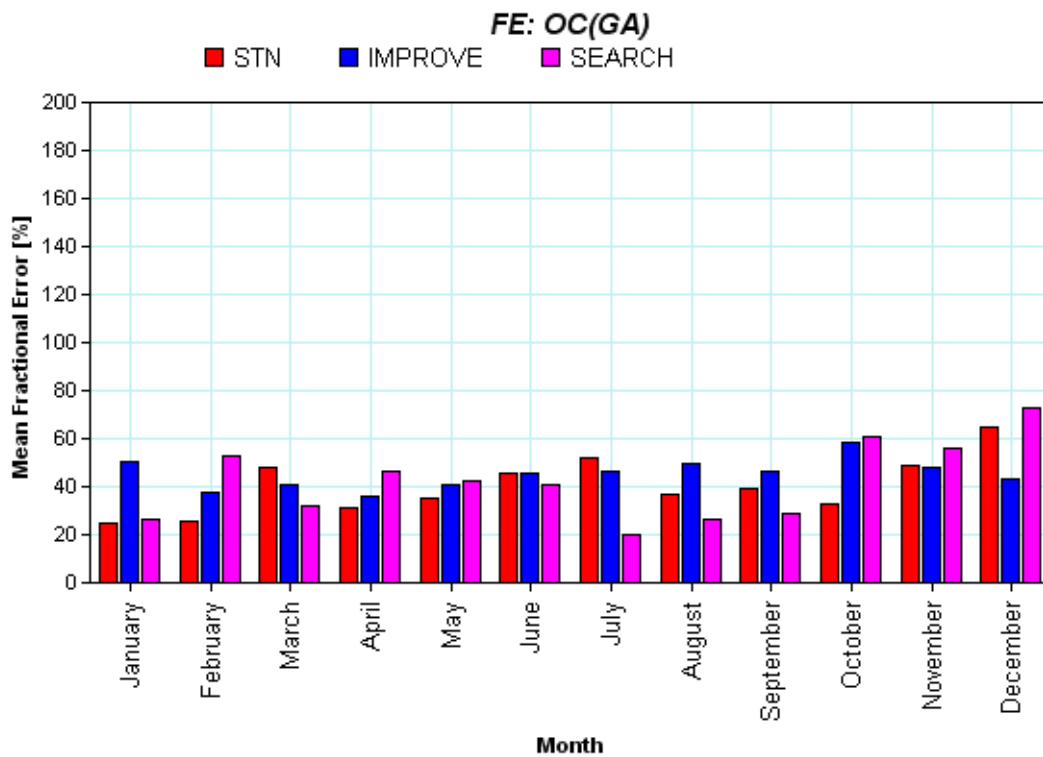
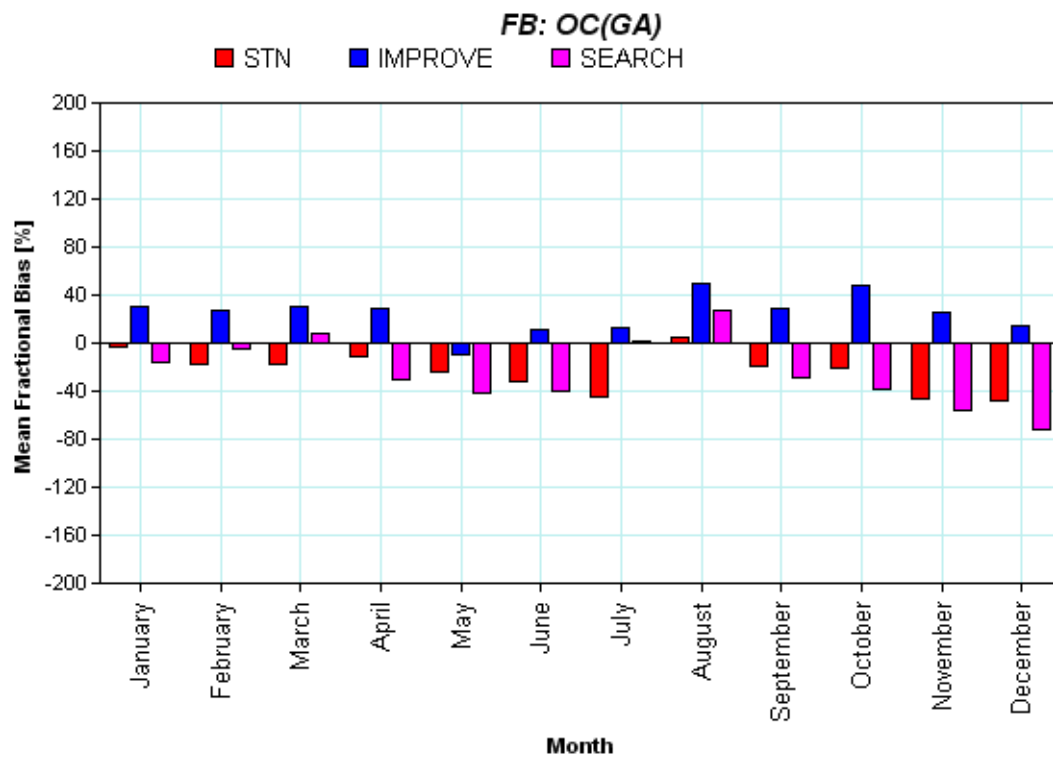


Figure 2.3.2.4-4. Monthly OMC fractional bias (top) and fractional gross error (bottom) statistical measures for STN, IMPROVE, and SEARCH monitoring sites in the State of Georgia.

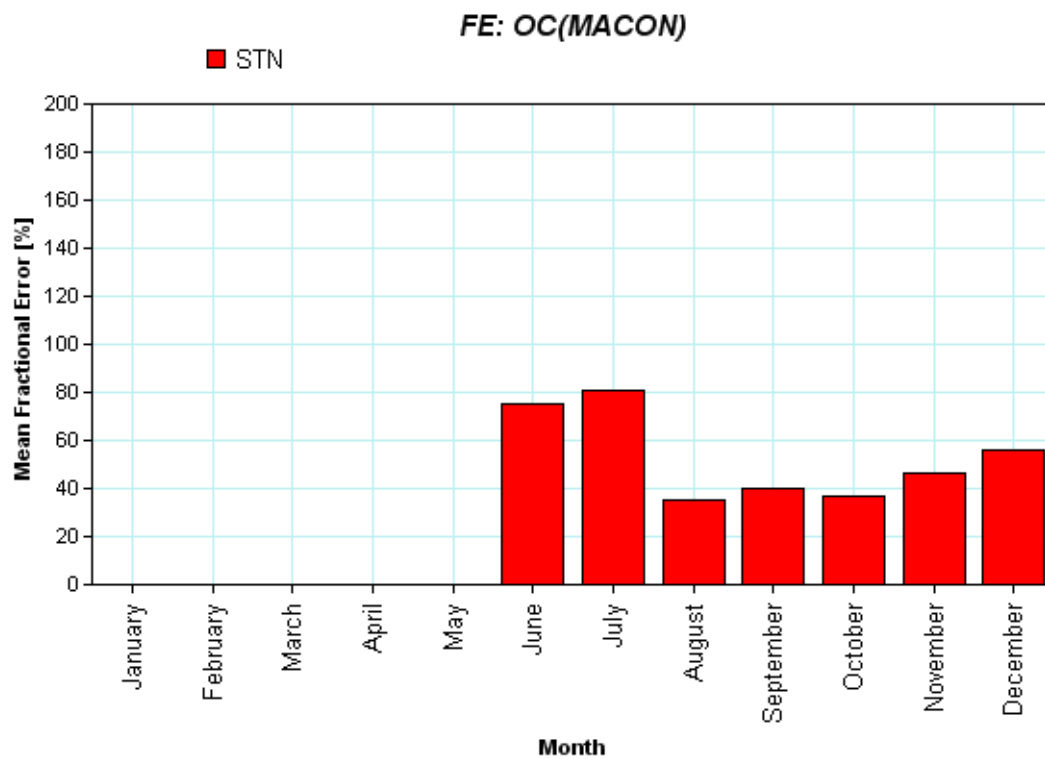
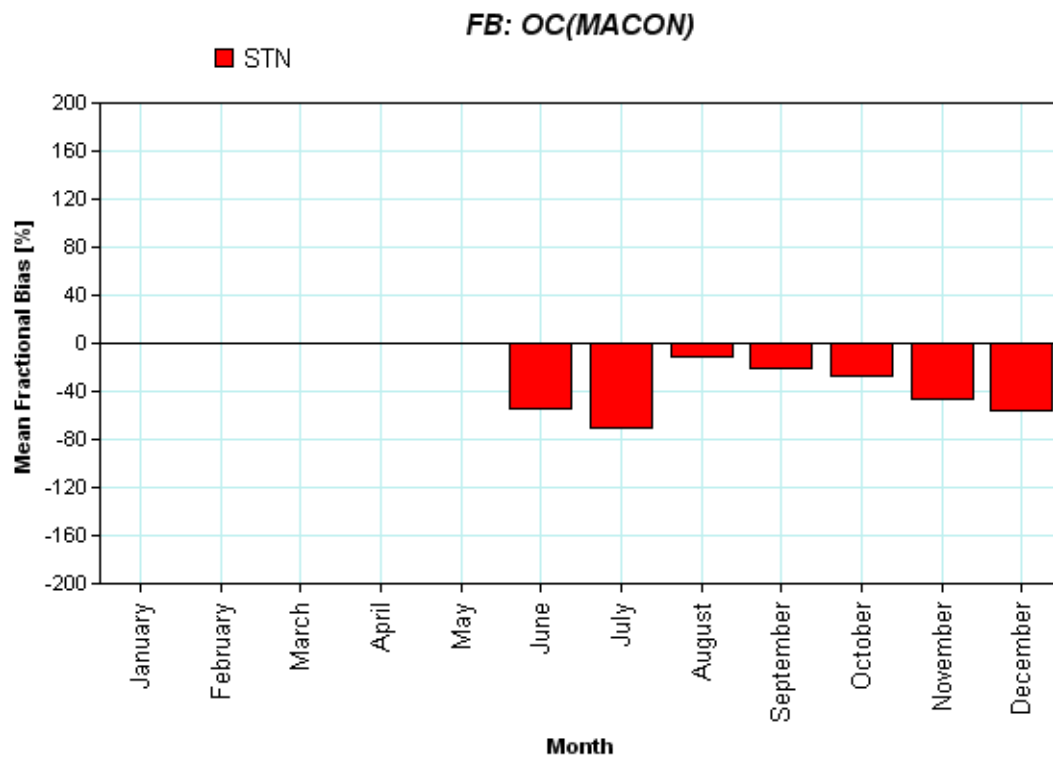


Figure 2.3.2.4-5. Monthly OC mean fractional bias (top) and mean fractional error (bottom) statistical measures for the STN monitoring site in the Macon nonattainment area.

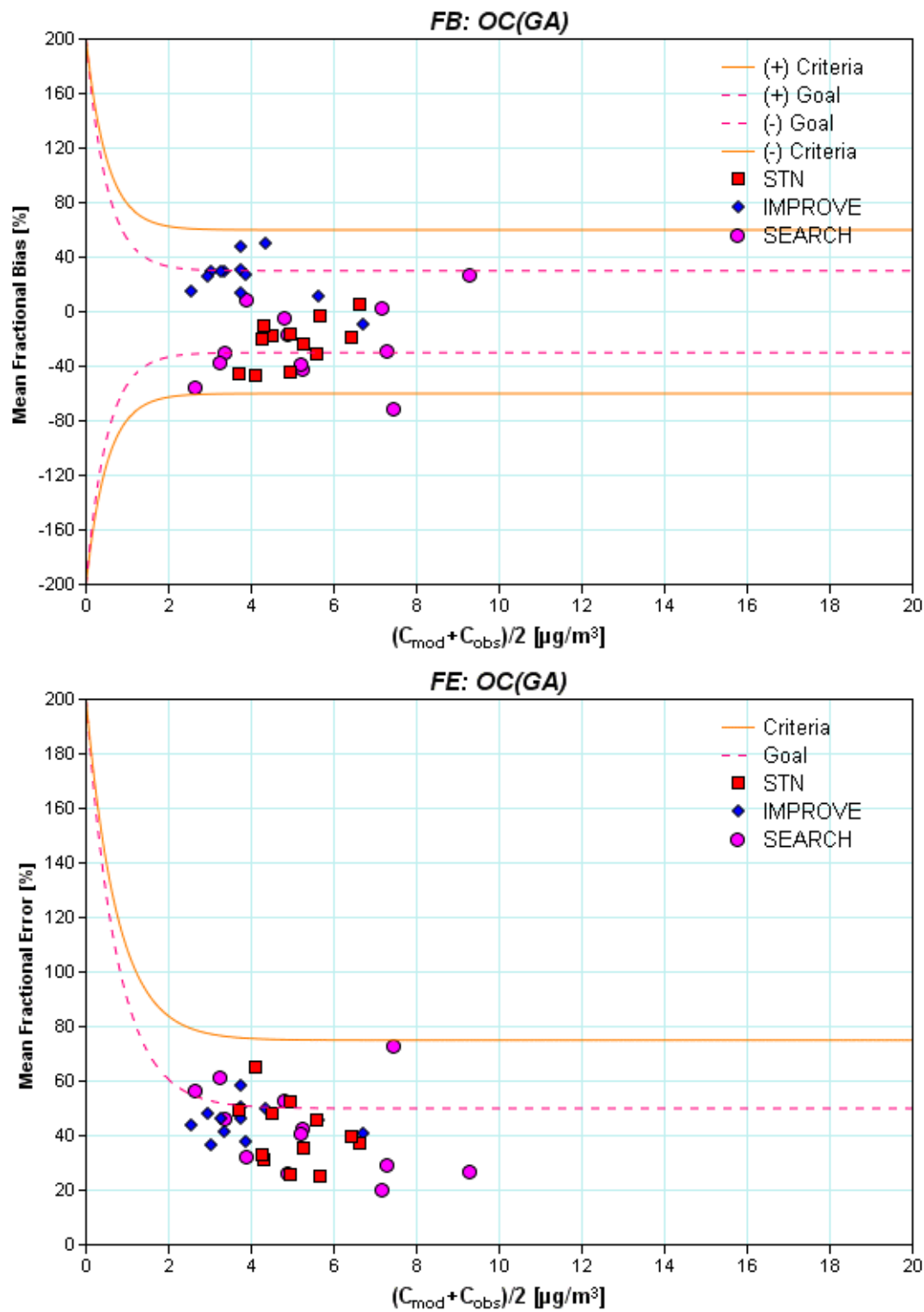


Figure 2.3.2.4-6. Bugle Plots of monthly mean fractional bias (top) and mean fractional error (bottom) for OMC in the State of Georgia and comparison to model performance goals (solid orange) and criteria (dotted pink).

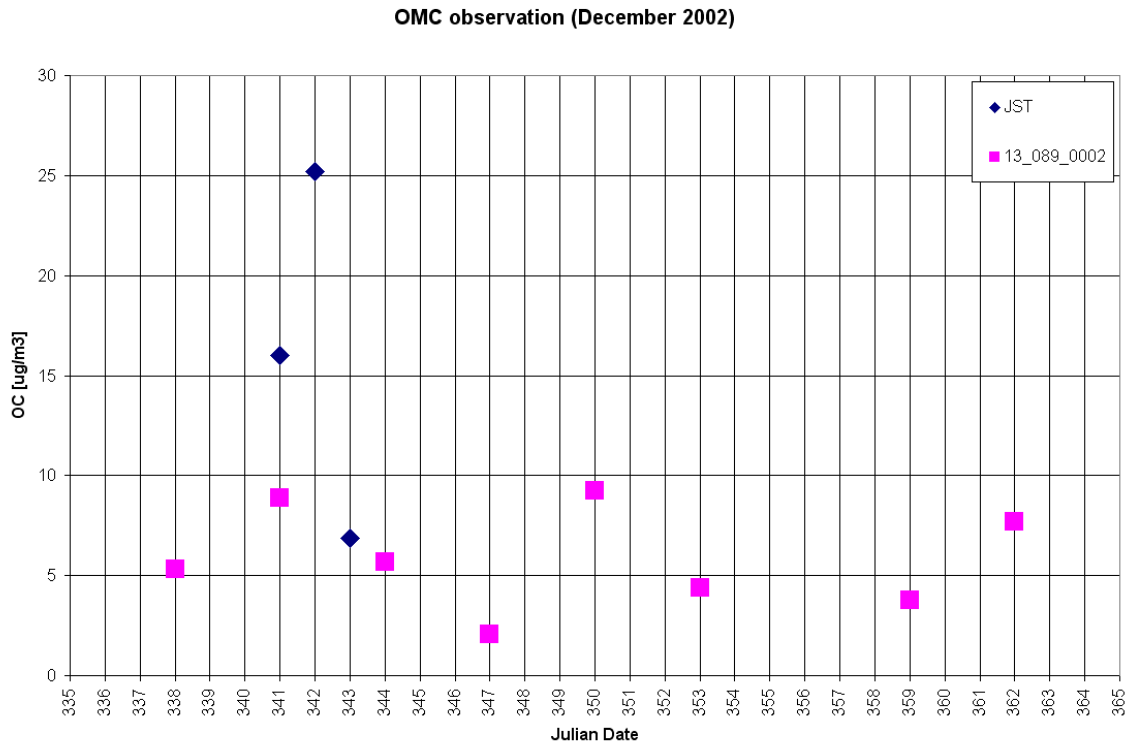


Figure 2.3.2.4-7. Observed OMC concentrations at JST of the SEARCH network and 13-089-0002 of the STN network in DeKalb county.

VISTAS 2002GA2 12km; STN, GA, OC

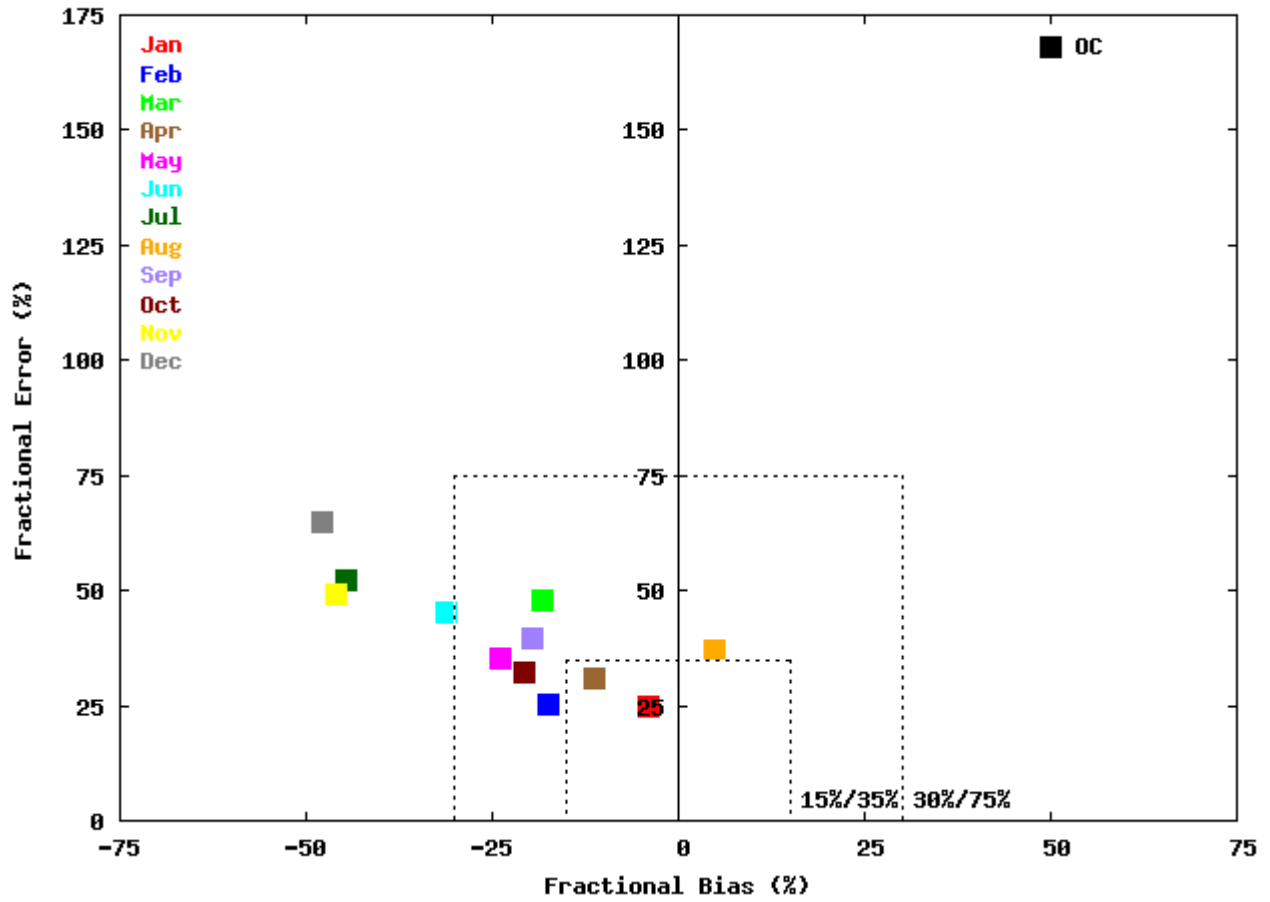


Figure 2.3.2.4-8. Soccer Plots of monthly mean fractional bias and mean fractional error for OMC in the State of Georgia and comparison to model performance goal levels (outer dots) and “excellent performance” levels (inner dots).

2.3.2.5 Elemental Carbon (EC) Performance

Figure 2.3.2.5-1 shows all available prediction-observation pairs of EC from the STN monitors in GA for the base year. Most pairs are around the 1:1 line with some outliers. While the model showed some degree of over-prediction in GA, Figure 2.3.2.5-2 displays that the model under-predicted EC at 13-021-0007. However, the time series of EC at 13-021-0007 (Figure 2.3.2.5-3) indicates that there was no performance issue to be concerned about.

Figure 2.3.2.5-4 shows the monthly bias and error performance statistics for EC across the State of Georgia. The model's performance at the IMPROVE sites show greater bias and error than other monitoring network sites. The model's performance showed high level of errors in June, July, and September. Similar tendency can be found in Figure 2.3.2.5-5 for the STN monitor in the Macon nonattainment area. However, Figure 2.3.2.5-6 indicates these performance issues were tied to low EC concentrations ($< 1 \mu\text{g}/\text{m}^3$) cases. In general, the contribution of EC to the overall model $\text{PM}_{2.5}$ prediction is small and GA EPD concluded the model's EC performance is acceptable for the SIP modeling purpose.

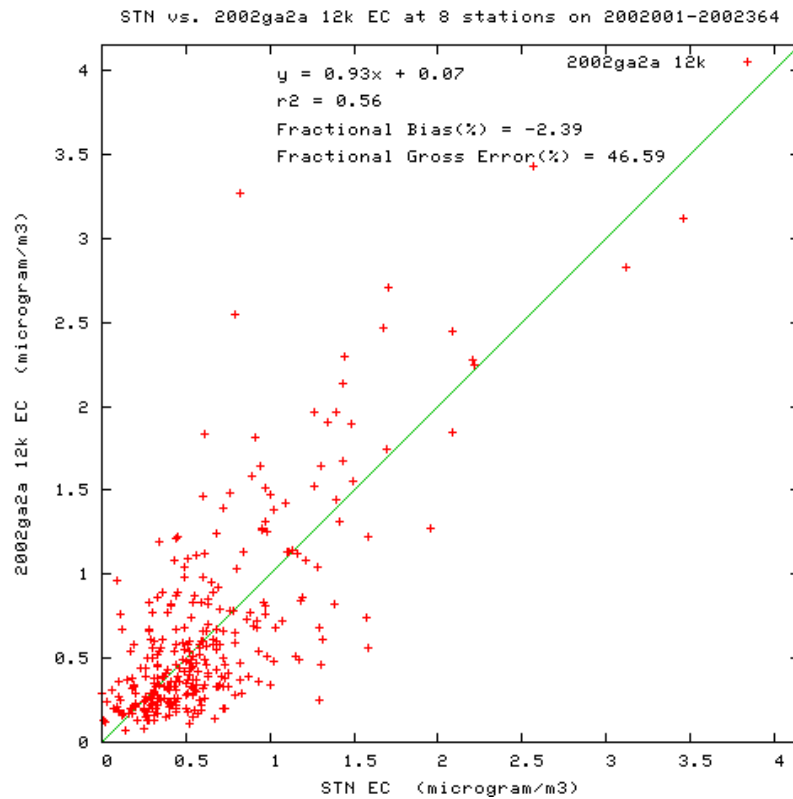


Figure 2.3.2.5-1. EC scatter plot for all STN sites in the State of Georgia.

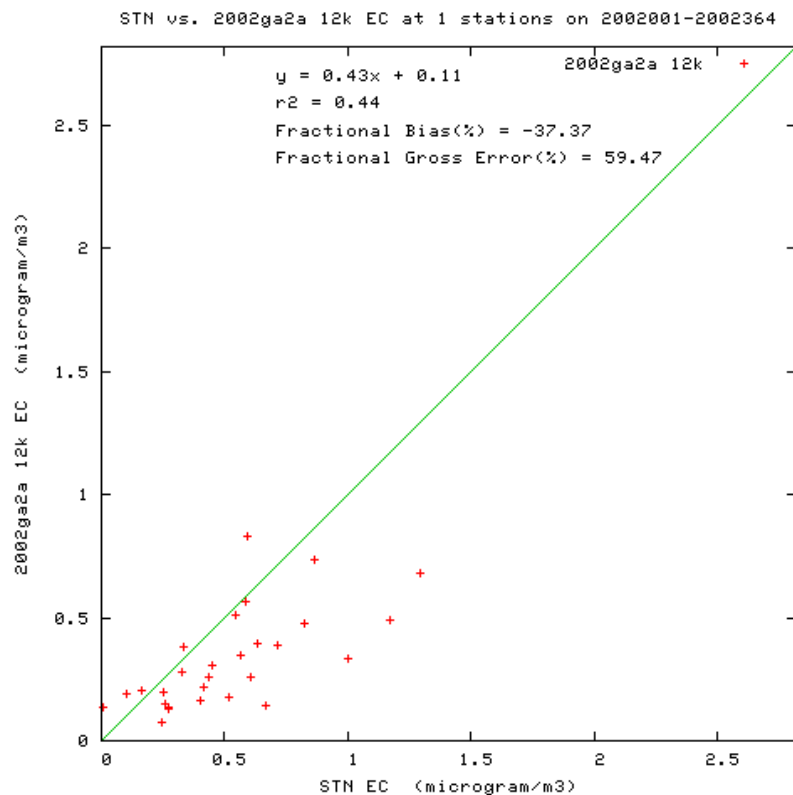


Figure 2.3.2.5-2. EC scatter plot for the STN site in the Macon nonattainment area.

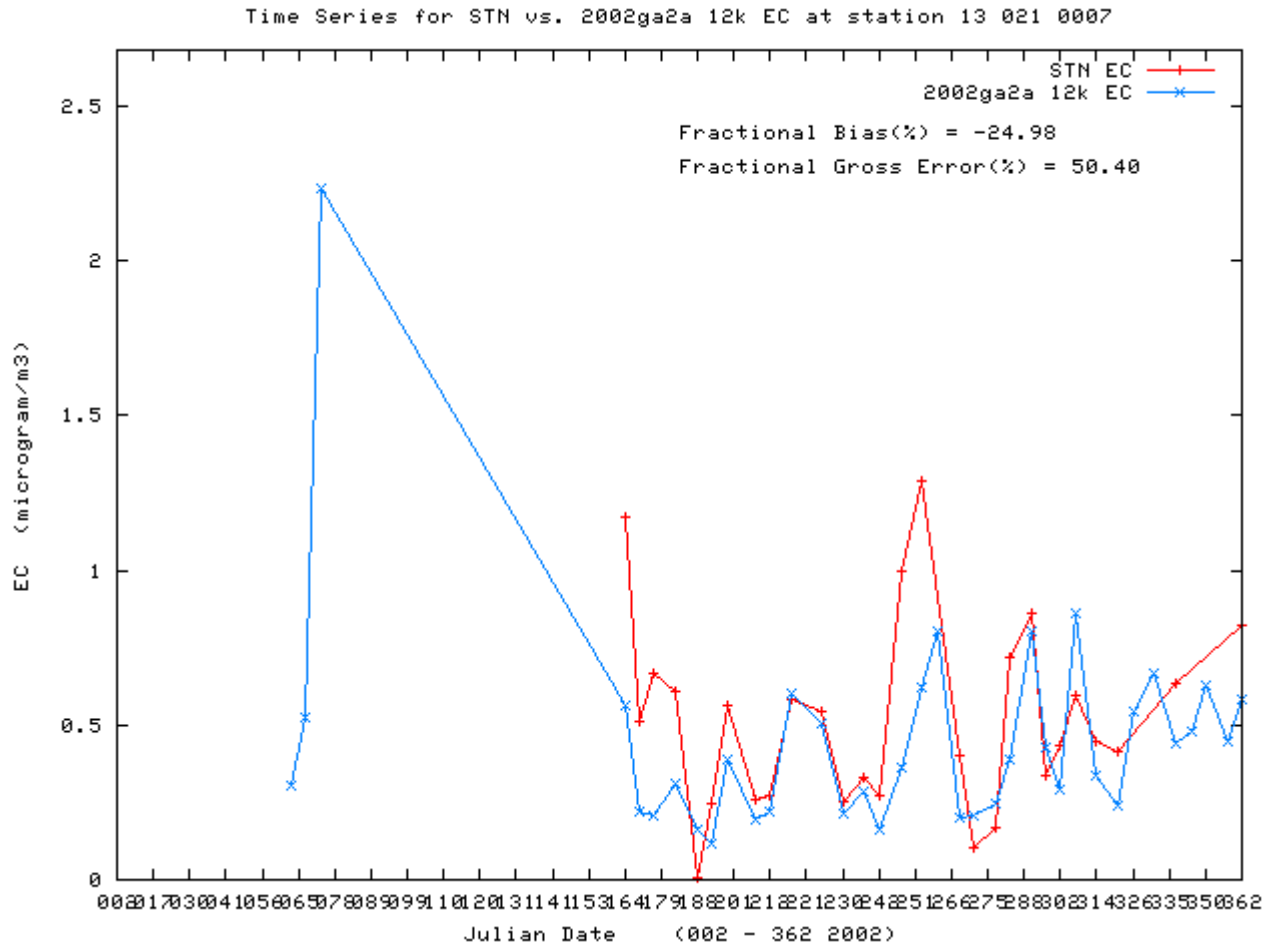


Figure 2.3.2.5-3. EC time series plot for 13-021-0007.

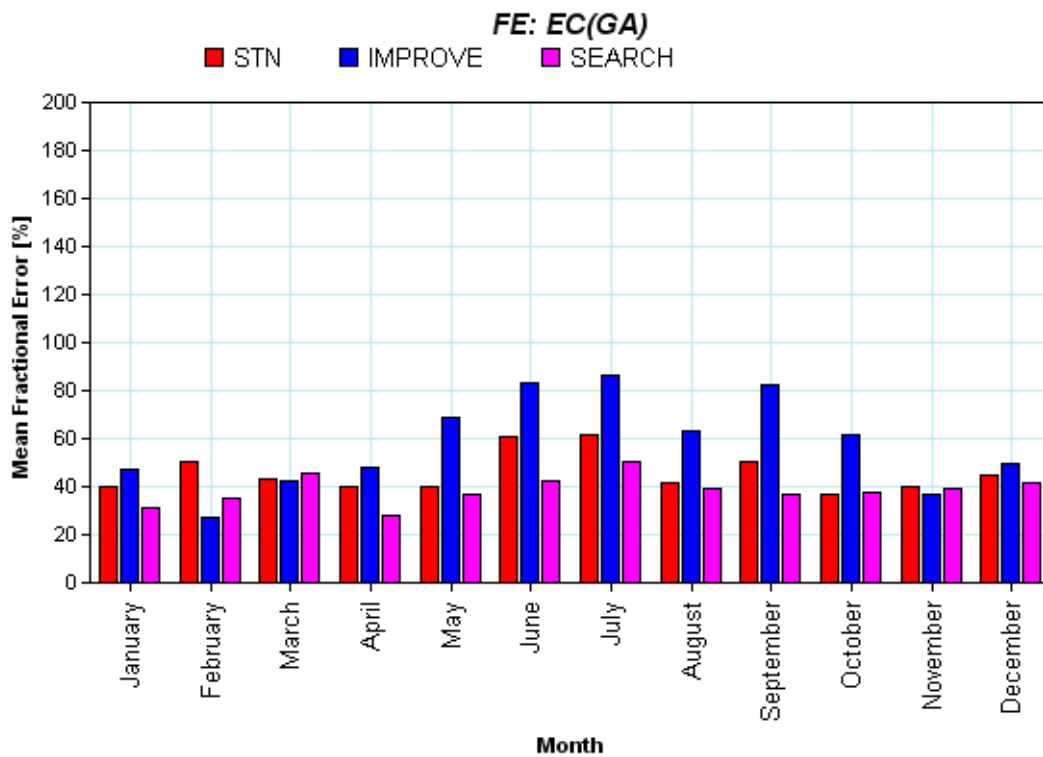
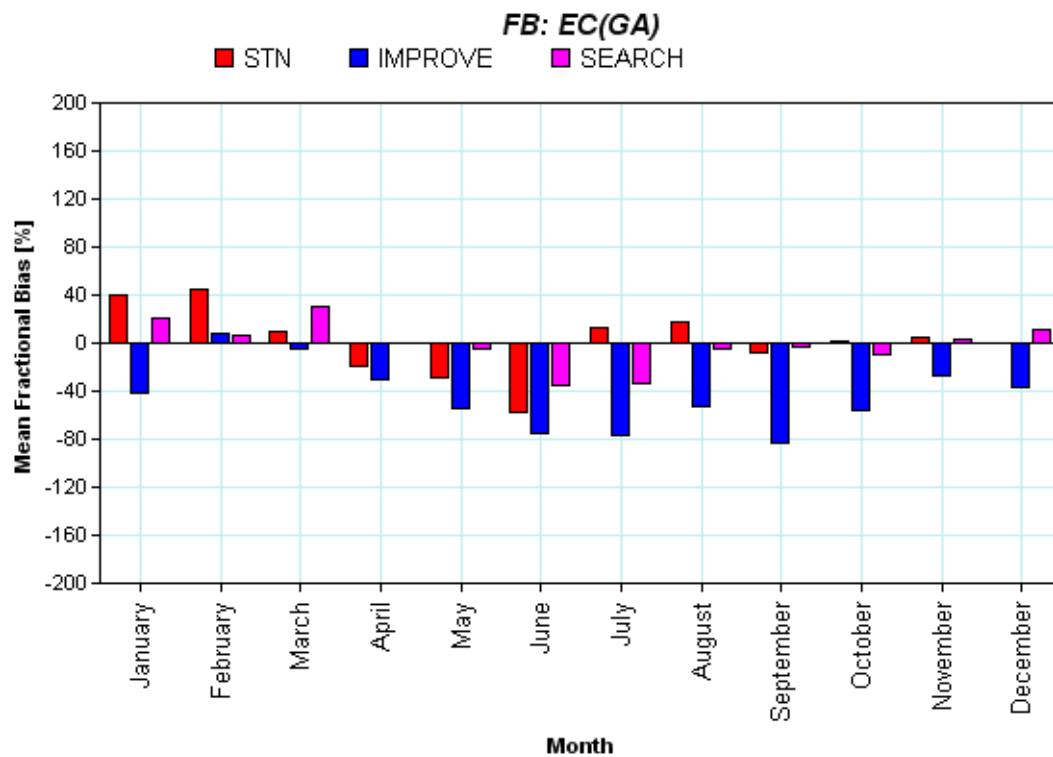


Figure 2.3.2.5-4. Monthly EC fractional bias (top) and fractional gross error (bottom) statistical measures for STN, IMPROVE, and SEARCH monitoring sites in the State of Georgia.

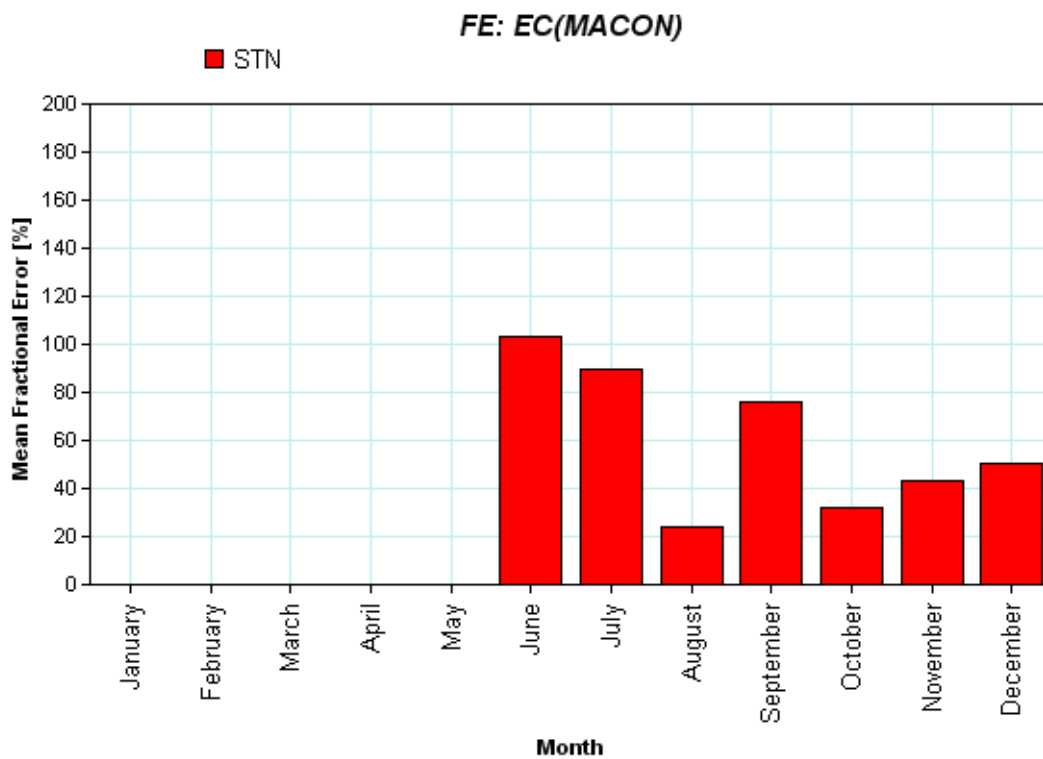
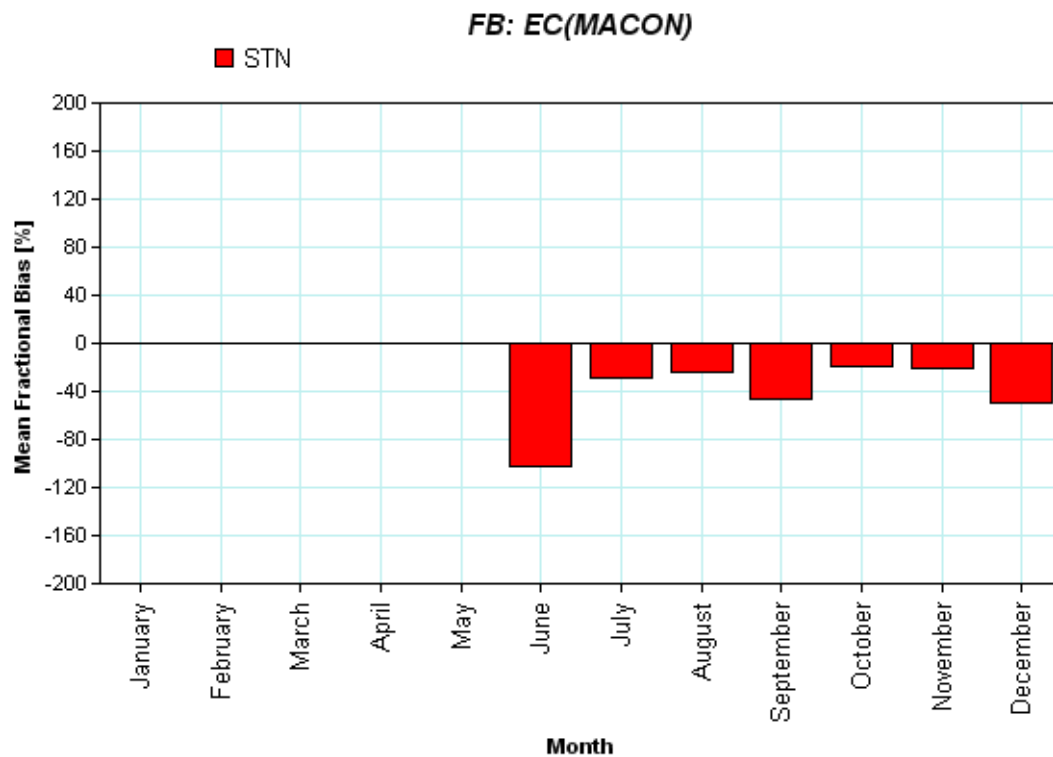


Figure 2.3.2.5-5. Monthly EC mean fractional bias (top) and mean fractional error (bottom) statistical measures for the STN monitoring site in the Macon nonattainment area.

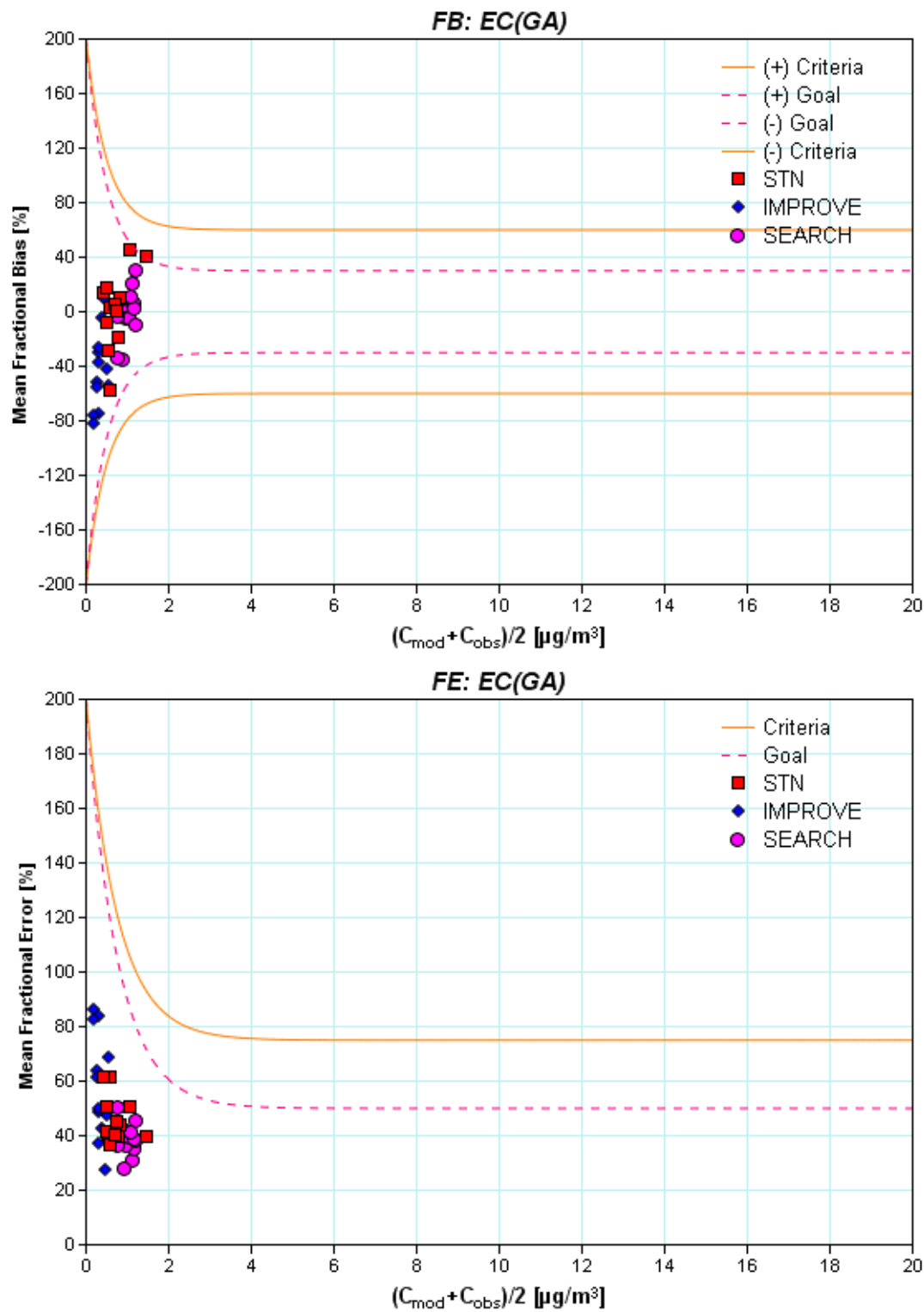


Figure 2.3.2.5-6. Bugle Plots of monthly mean fractional bias (top) and mean fractional error (bottom) for EC in the State of Georgia and comparison to model performance goals (solid orange) and criteria (dotted pink).

VISTAS 2002GA2 12km; STN, GA, EC

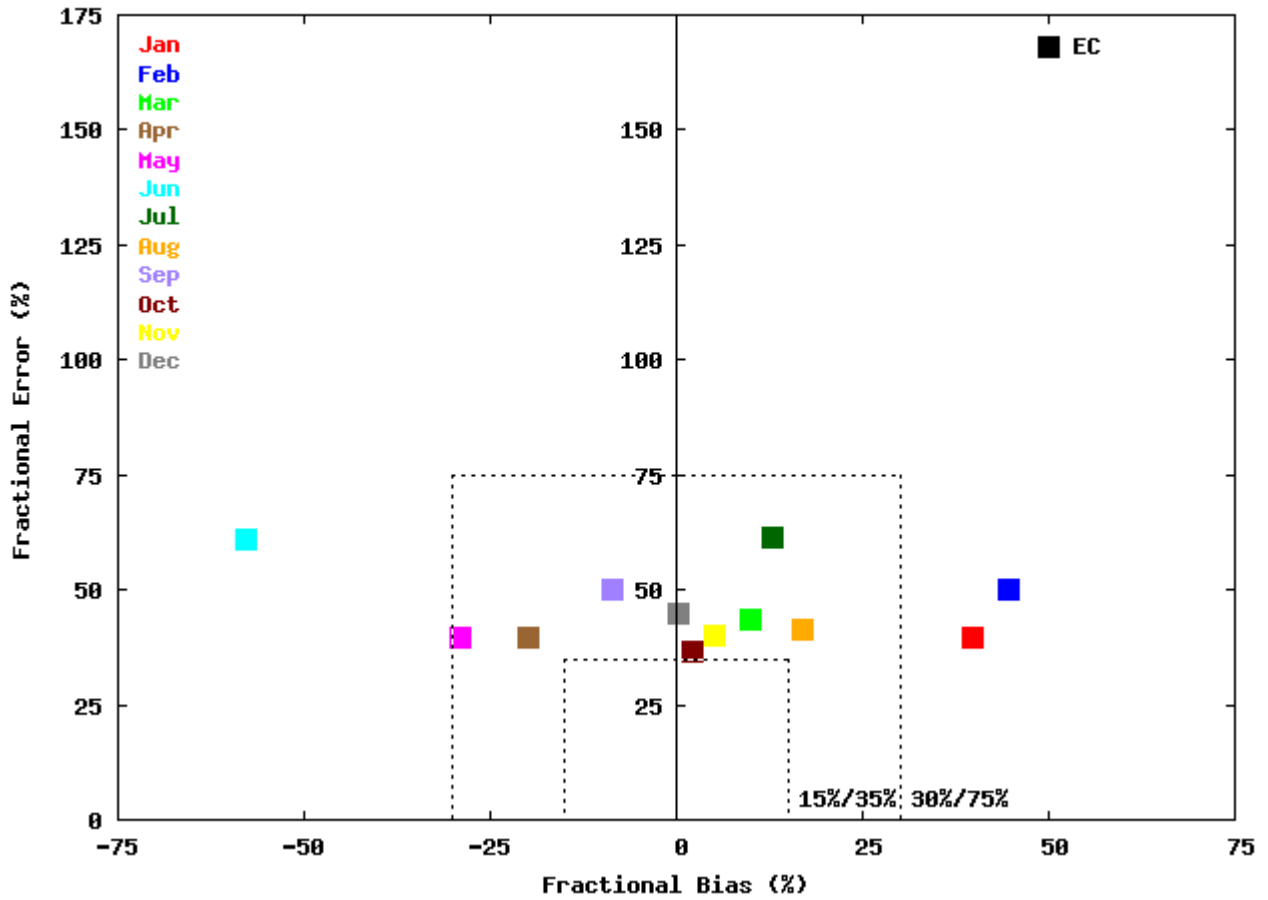


Figure 2.3.2.5-7. Soccer Plots of monthly mean fractional bias and mean fractional error for EC in the State of Georgia and comparison to model performance goal levels (outer dots) and “excellent performance” levels (inner dots).

2.3.2.6 NH₄ Performance

Figure 2.3.2.6-1 shows all available prediction-observation pairs of NH₄ from the STN monitors in GA for the base year. Most pairs are around the 1:1 line with one exceptional outlier. Figure 2.3.2.6-2 is the scatter plot of NH₄ at 13-021-0007 and the outlier found in Figure 2.3.2.2-1 is actually at this monitor. This outlier is the exact data pair that was examined more rigorously in the SO₄ performance analysis. The time series of NH₄ at 13-021-0007 (Figure 2.3.2.6-3) confirms that it happened in September 11, 2002 where the model predicted about 3.2 µg/m³ of NH₄ while the observation was about 10.7 µg/m³. This monitor failed to measure almost all of NH₄ observations for the first half of base year. However, performance for the rest of the year seems to be reasonable.

Figure 2.3.2.6-4 displays the model's monthly NH₄ performance across all available NH₄ monitors in GA. In most of cases, the model showed negative biases while there were positive biases during some winter months at STN, CASTNET, and SEARCH monitors as well as early spring and late fall at the STN monitors. The magnitude of bias was not significant except January at the STN monitor. Similar seasonal tendency can be found at 13-021-0007 as shown in Figure 2.3.2.6-5.

Figure 2.3.2.6-6 and Figure 2.3.2.6-7 show the monthly model performance met the performance goal level in many cases although the IMPROVE monitors did not perform as well as the others. As with the case of EC, Figure 2.3.2.6-6 indicates NH₄ performance issues were tied to relatively low concentrations (<2 µg/m³) and GA EPD concluded that the model's performance is acceptable.

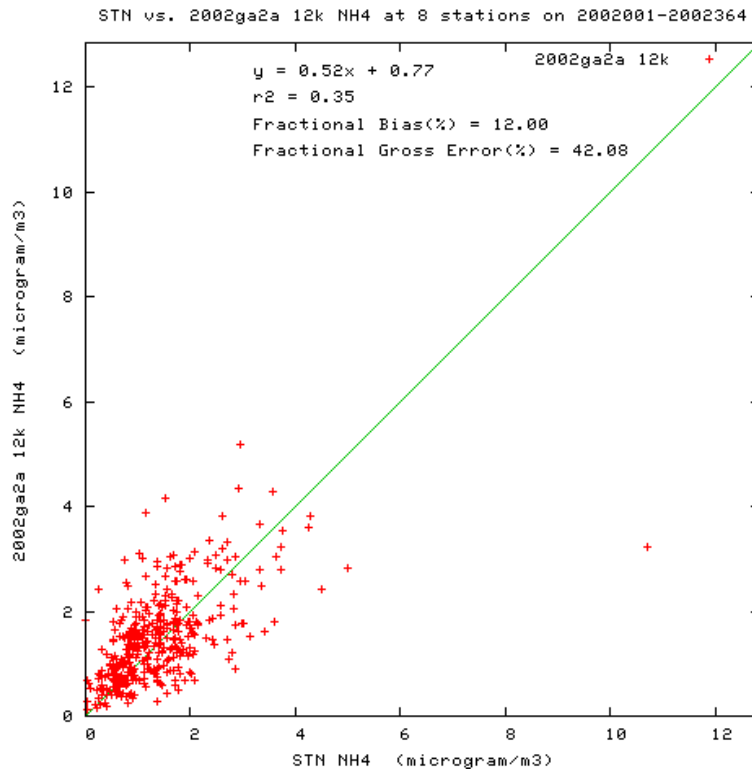


Figure 2.3.2.6-1. NH₄ scatter plot for all STN sites in the State of Georgia.

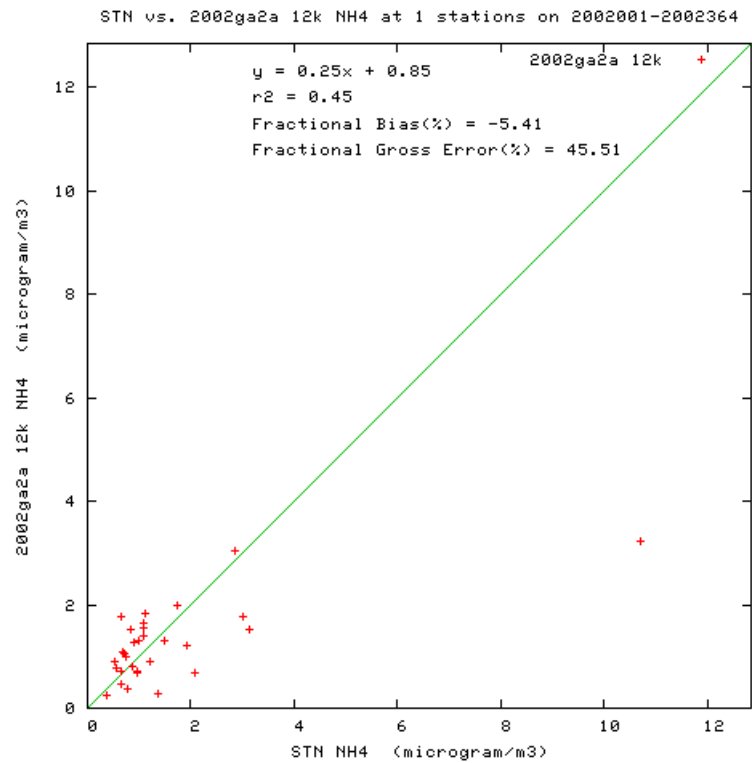


Figure 2.3.2.6-2. NH₄ scatter plot for the STN site in the Macon nonattainment area.

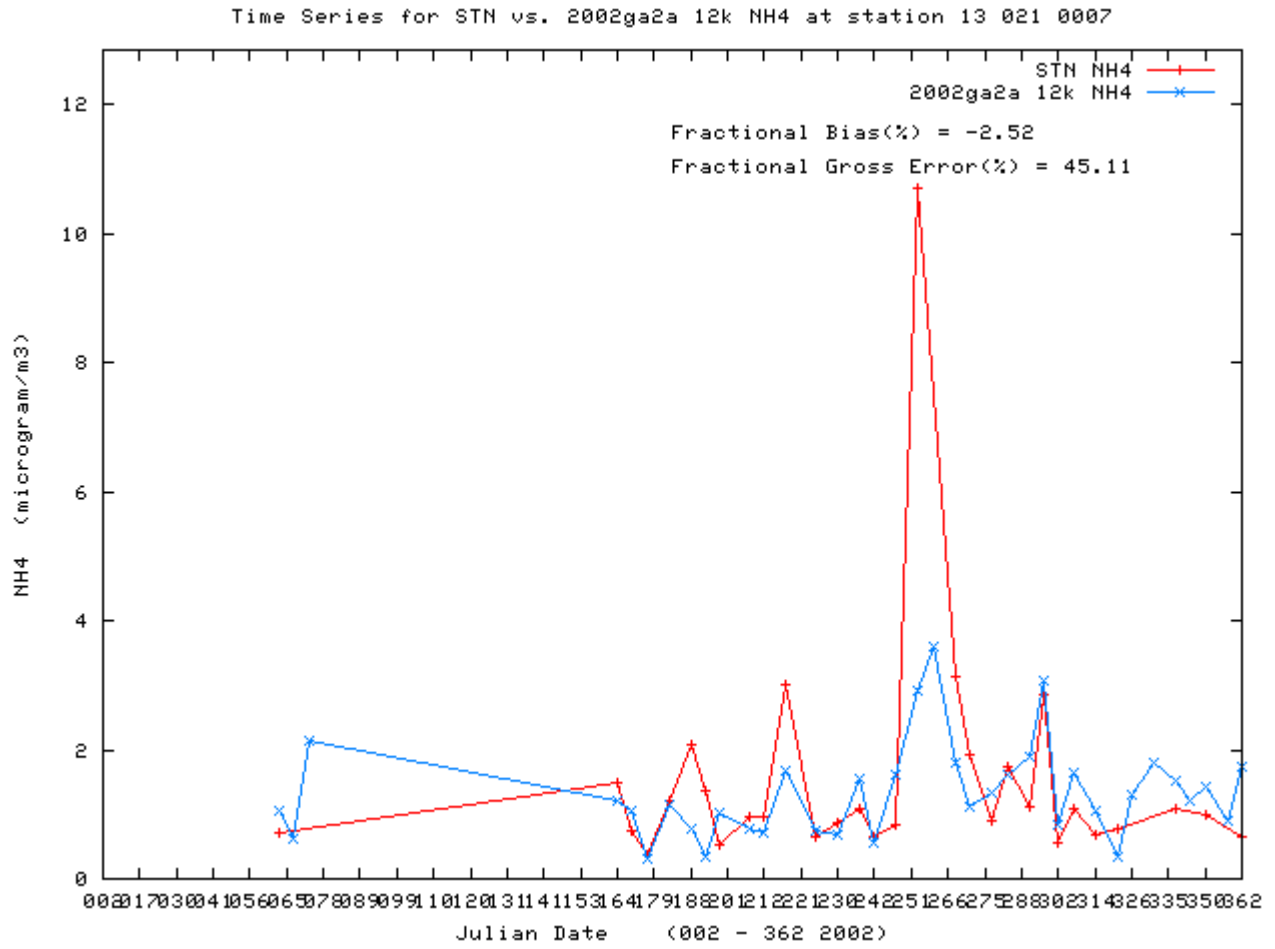


Figure 2.3.2.6-3. NH₄ time series plot for 13-021-0007.

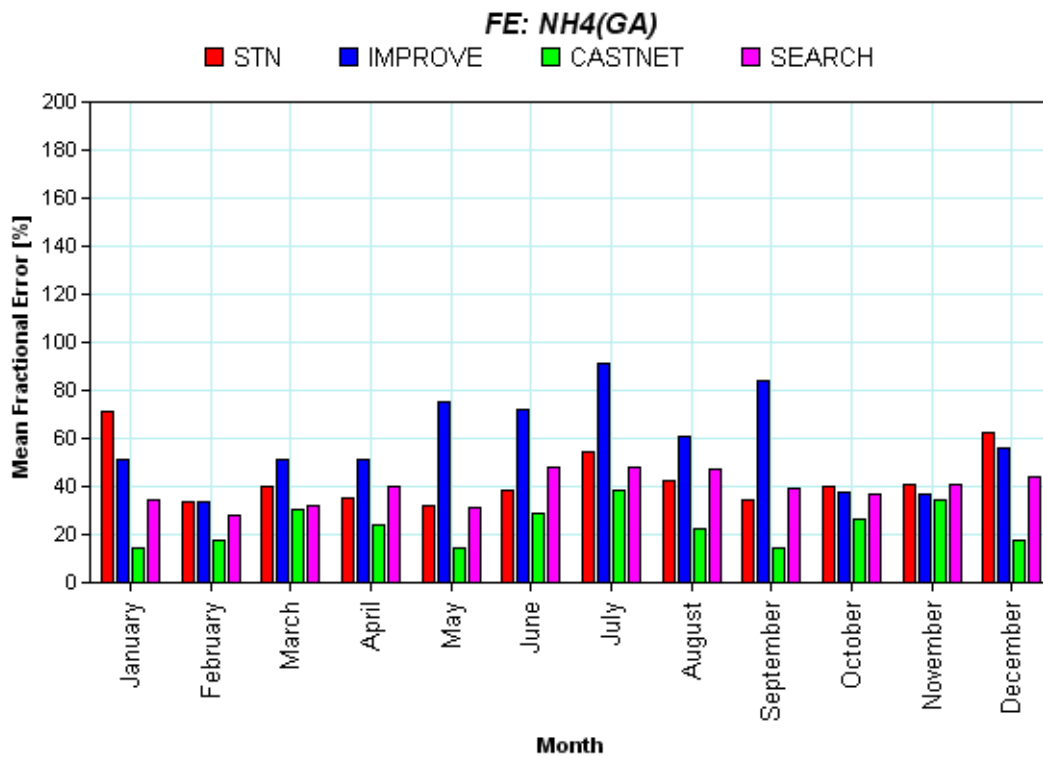
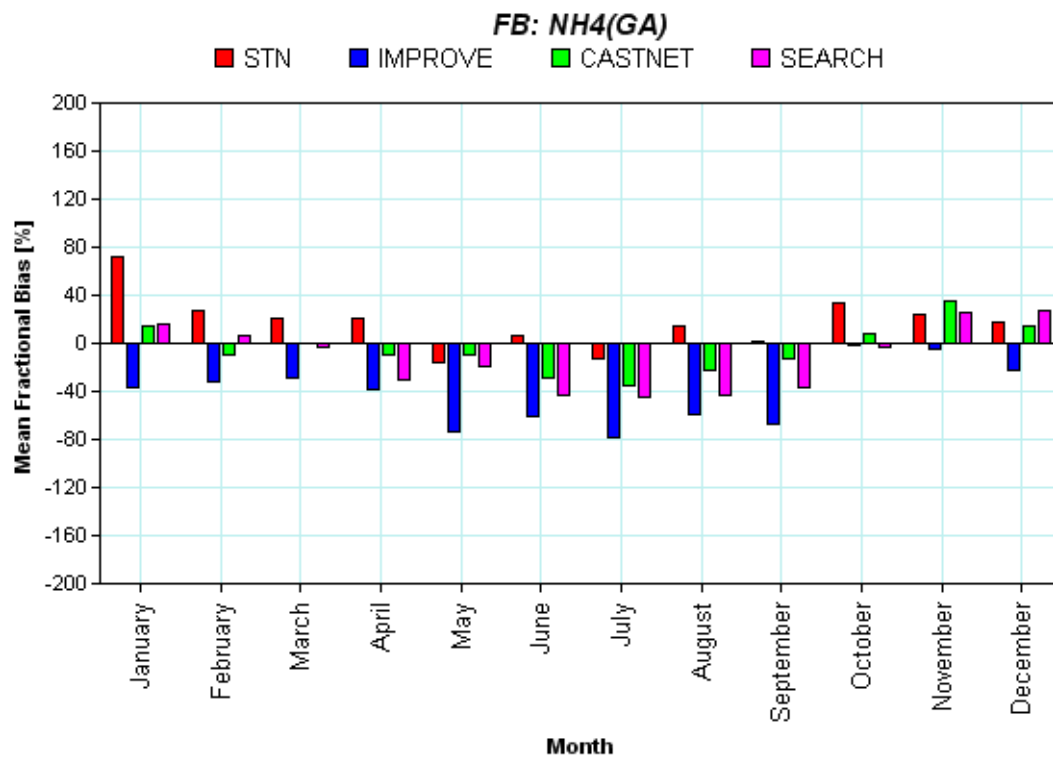


Figure 2.3.2.6-4. Monthly NH₄ fractional bias (top) and fractional gross error (bottom) statistical measures for STN, IMPROVE, CASTNET, and SEARCH monitoring sites in the State of Georgia.

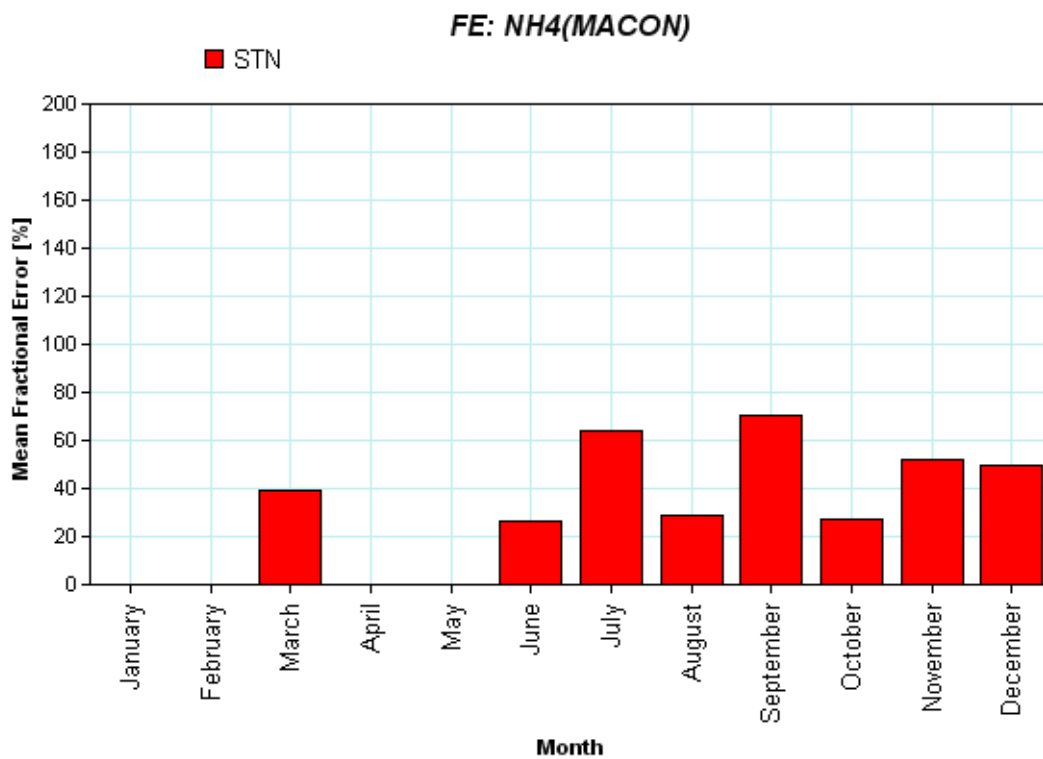
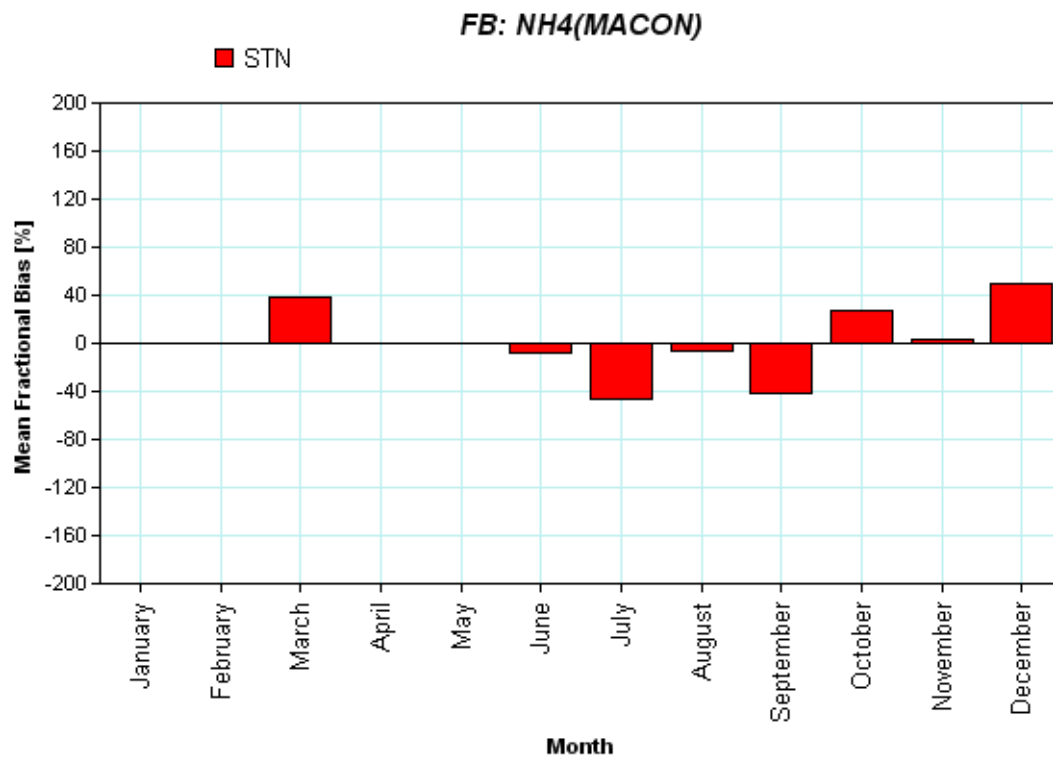


Figure 2.3.2.6-5. Monthly NH₄ mean fractional bias (top) and mean fractional error (bottom) statistical measures for the STN monitoring site in the Macon nonattainment area.

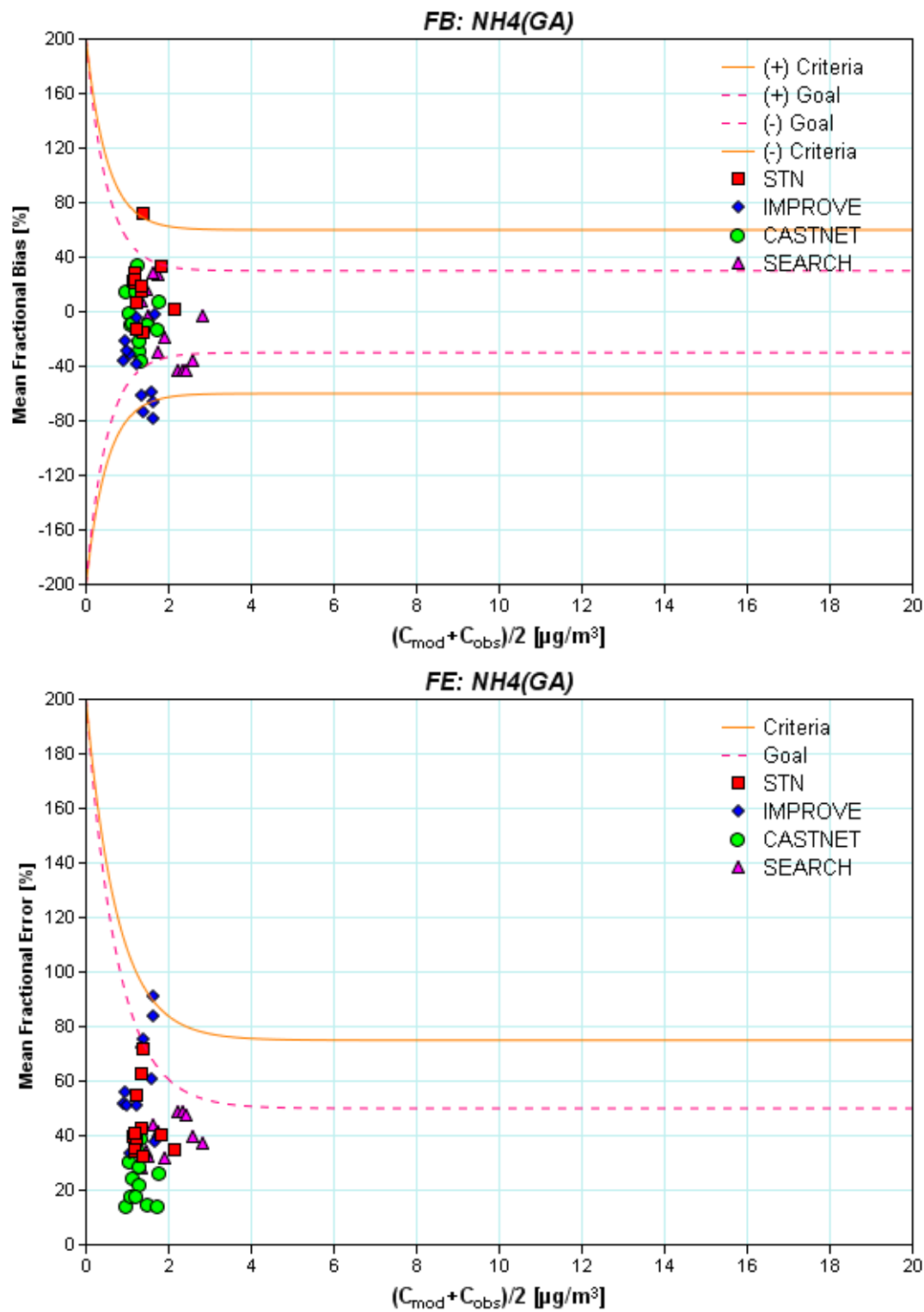


Figure 2.3.2.6-6. Bugle Plots of monthly mean fractional bias (top) and mean fractional error (bottom) for NH_4 in the State of Georgia and comparison to model performance goals (solid orange) and criteria (dotted pink).

VISTAS 2002GA2 12km; STN, GA, NH4

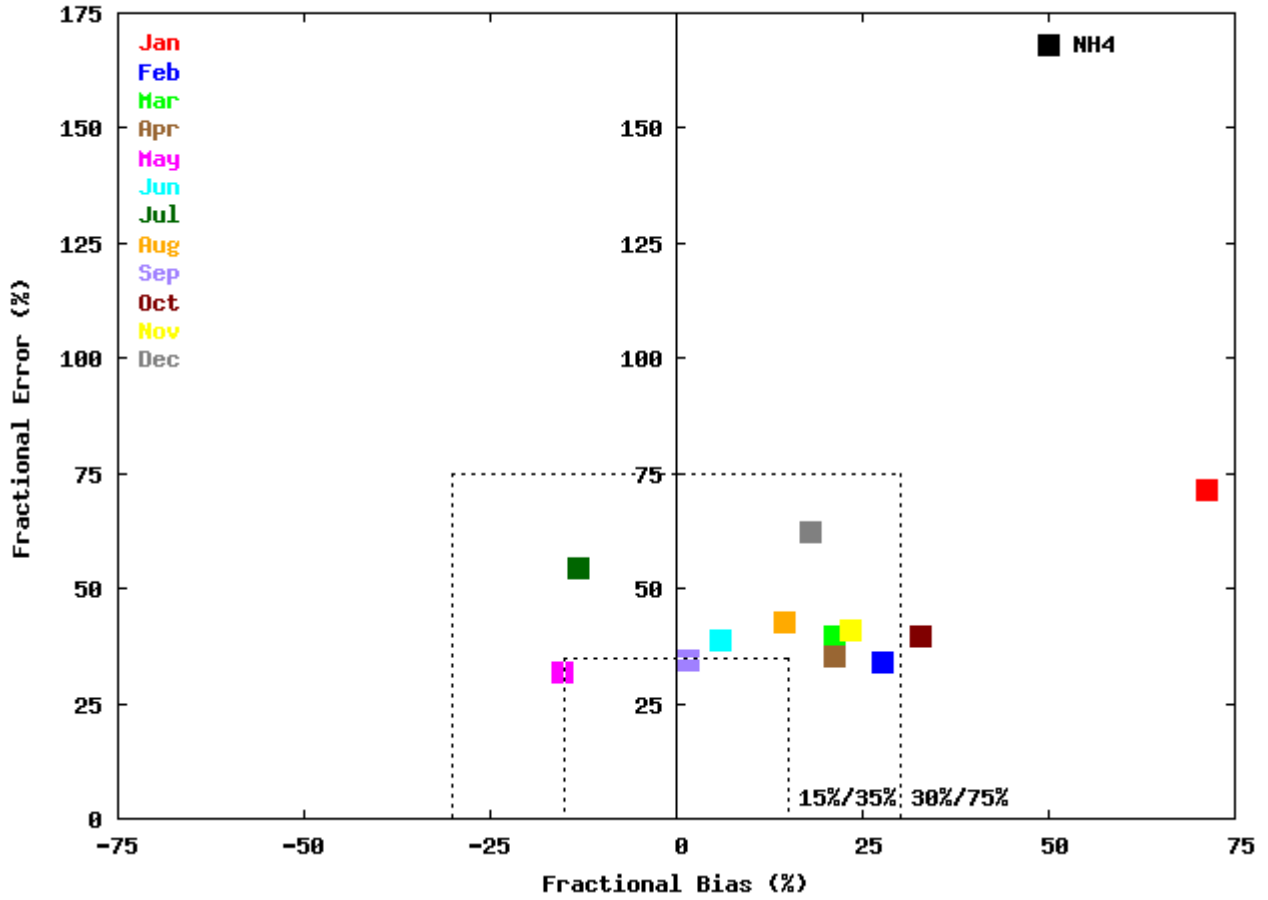


Figure 2.3.2.6-7. Soccer Plots of monthly mean fractional bias and mean fractional error for NH₄ in the State of Georgia and comparison to model performance goal levels (outer dots) and “excellent performance” levels (inner dots).

2.3.2.7 Soil Performance

Figure 2.3.2.7-1 indicates there seems to be a seasonal variation of the model performance and shows a possible systematic bias between IMPROVE and SEARCH. In general, the model showed better performance at IMPROVE sites than at SEARCH sites. As the case of EC performance issues, however, Figure 2.3.2.7-2 indicates SOIL performance issues are tied to relatively low concentrations ($<2 \mu\text{g}/\text{m}^3$). Therefore, GA EPD concluded that the model's performance is acceptable.

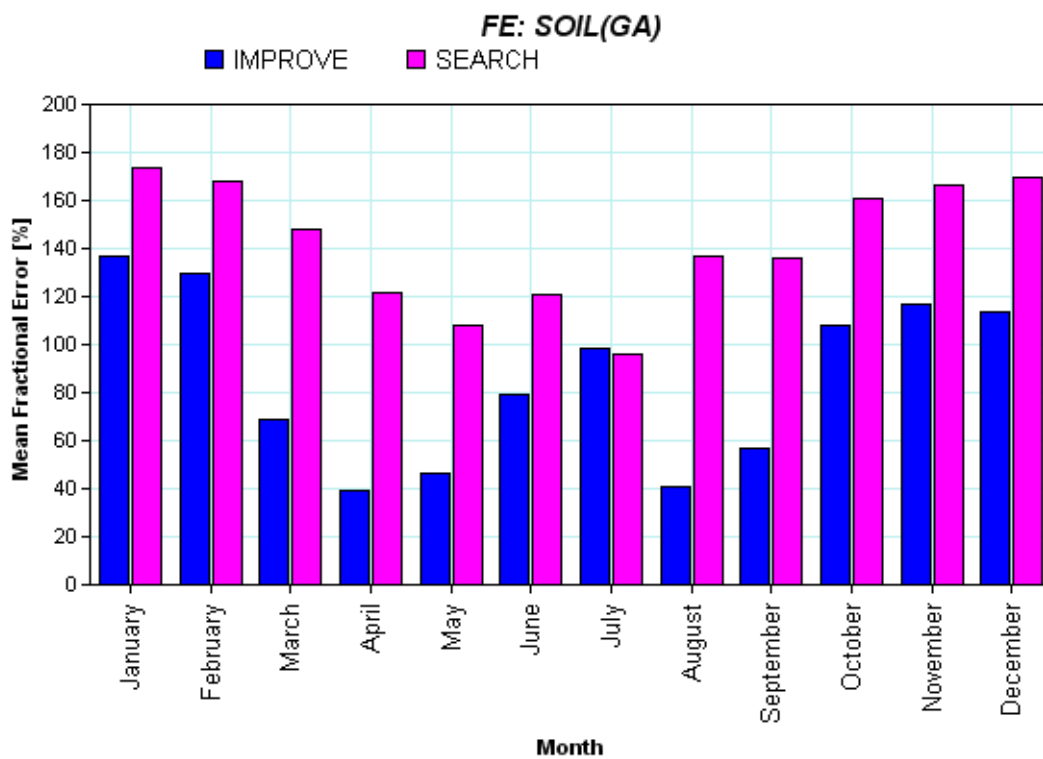
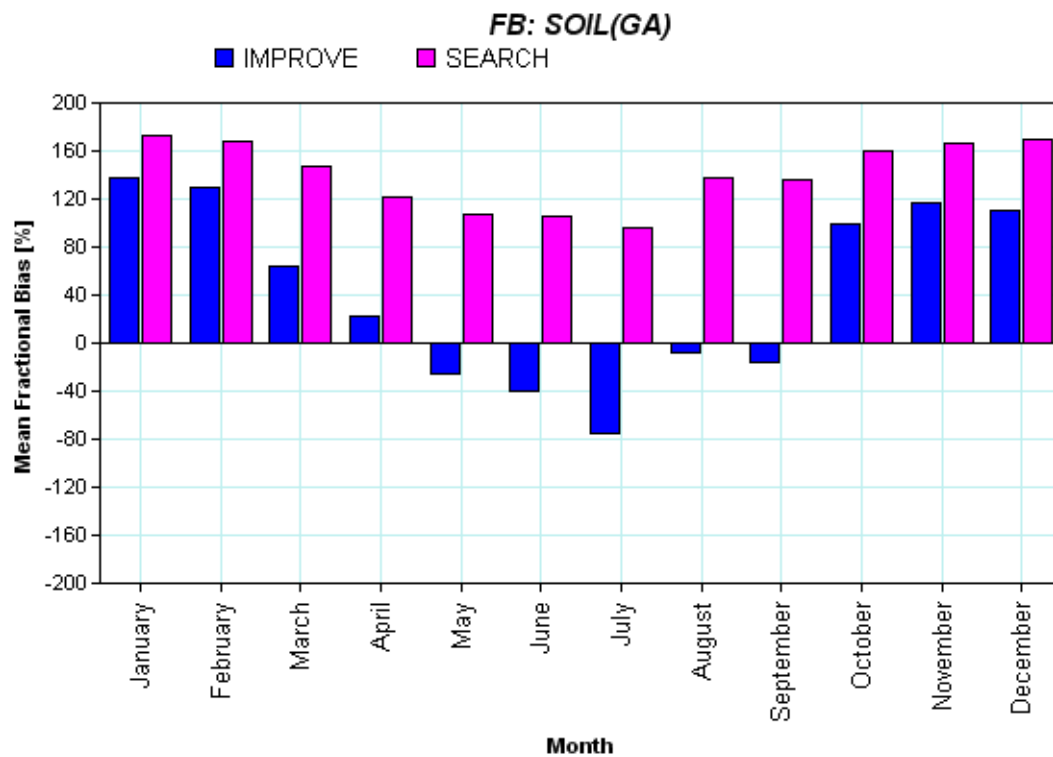


Figure 2.3.2.7-1. Monthly SOIL fractional bias (top) and fractional gross error (bottom) statistical measures for IMPROVE and SEARCH monitoring sites in the State of Georgia.

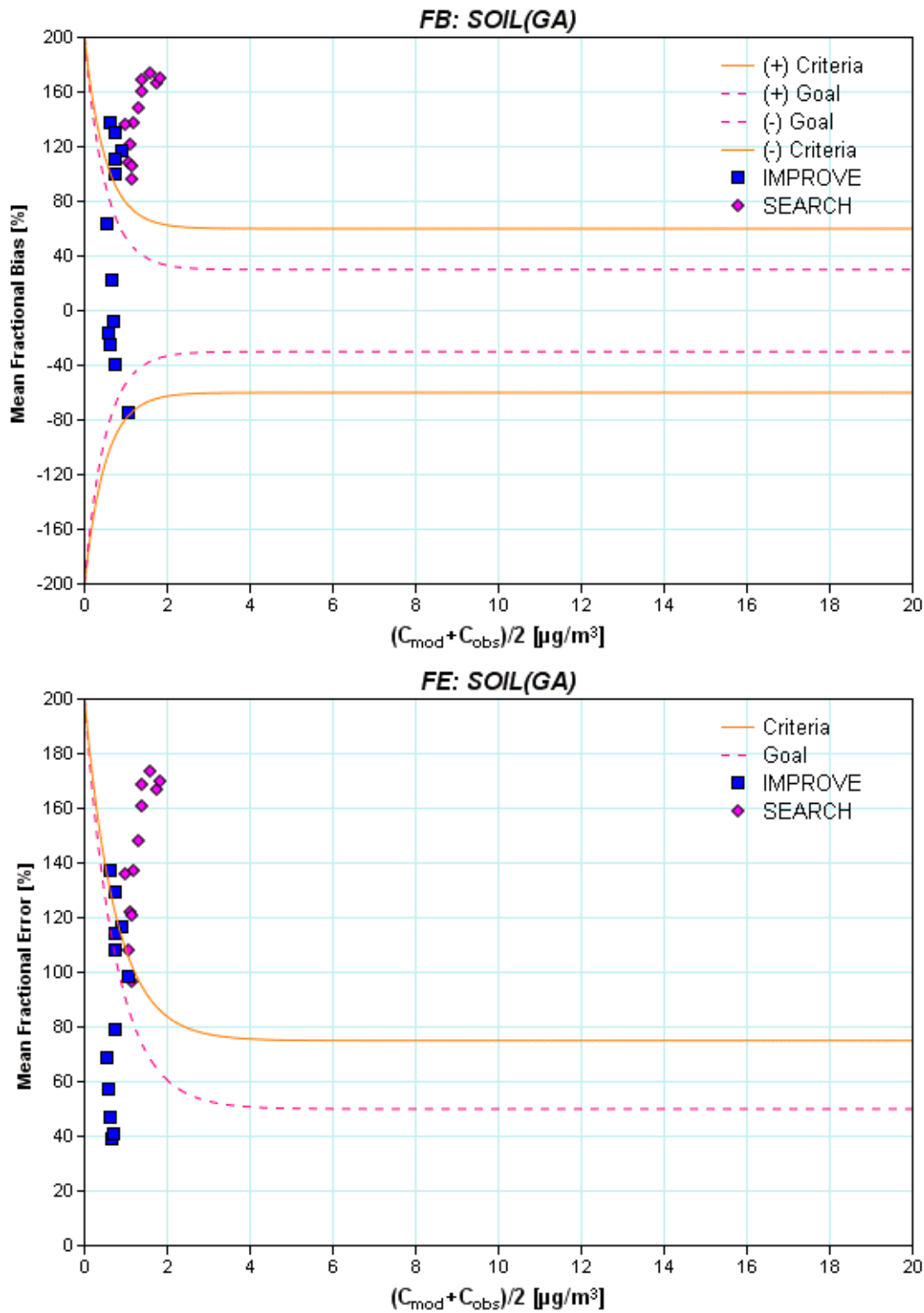


Figure 2.3.2.7-2. Bugle Plots of monthly mean fractional bias (top) and mean fractional error (bottom) for SOIL in the State of Georgia and comparison to model performance goals (solid orange) and criteria (dotted pink).

2.3.3 Summary of the performance evaluation of the CMAQ modeling

In general, the CMAQ modeling met the performance “criteria level” for all major PM_{2.5} constituents and the total PM_{2.5} across the State of Georgia throughout the base year. As the first step of model performance evaluation, GA EPD estimated several statistical measures for all FRM monitors and all STN monitors within GA and in the Macon nonattainment areas annually and monthly. Important findings from this statistical performance evaluation at the FRM monitors was the model’s performance at FRM monitors within GA was comparable to the performance at two FRM monitors collectively in the Macon nonattainment area although there were slight negative biases observed in the Macon nonattainment area. These under-predictions became more apparent during summer. Monthly performance analyses of mean concentrations and maximum concentrations revealed that these apparently negative biases were likely due to the model’s lack of ability to capture exceptionally high PM_{2.5} concentration cases. After examining the statistical performance measures, GA EPD found that the model’s performance is generally adequate across GA and acceptable for the Macon nonattainment area.

Similar analyses were conducted for the STN monitors on total PM_{2.5} and all of measured PM_{2.5} species. The most significant findings were that (1) the model’s sulfate and PM_{2.5} performance were quite good and (2) NO₃ and OMC were somewhat under predicted. In addition, the model’s performance at the STN monitor in the Macon nonattainment area was similar to that of the STN monitors within GA.

During the graphical performance analyses, GA EPD examined a set of various graphical measures as a “package”. Each PM_{2.5} species and total PM_{2.5} concentrations were examined with these packages. Whenever data were available, each package included scatter plots for monitors within GA and in the Macon nonattainment area, time series plots for monitors in the Macon nonattainment area, bar plots of fractional bias and fractional error for monitors within GA, bar plots of fractional bias and fractional error for monitors in the Macon nonattainment area, bugle plots for monitors within GA, and soccer plots for monitors within GA. In addition, more graphical measures were examined if necessary. These graphical packages helped GA EPD conduct the analysis in a systematic and consistent manner. The following is a brief summary of what was found by this graphical analysis. The evaluation included speciated data available from IMPROVE, CASTNET, SEARCH, and STN as well as total PM_{2.5} from FRM monitors.

Overall, the model showed reasonable performance for PM_{2.5}, SO₄, NH₄, and OC throughout the base year across all monitors in GA. During summer, the model showed a seasonal variation of NO₃ performance with under prediction bias greater than –100% and moderate winter over prediction at CASTNET sites. The amount of error and bias in monthly time series was most likely contributed by low concentration (< 1.0 µg/m³) cases. For EC, the model showed some over-prediction in GA while under-predicting at 13-021-0007. However, these performance issues are tied to low EC concentrations and the same tendency was found in the model’s SOIL performance. As shown in Figure 2.3.3-1, SO₄ and OMC were the major contributors to the Macon nonattainment areas. Therefore, GA EPD concluded that performance issues found in minor constituents of PM_{2.5} are not likely degrading the overall model performance.

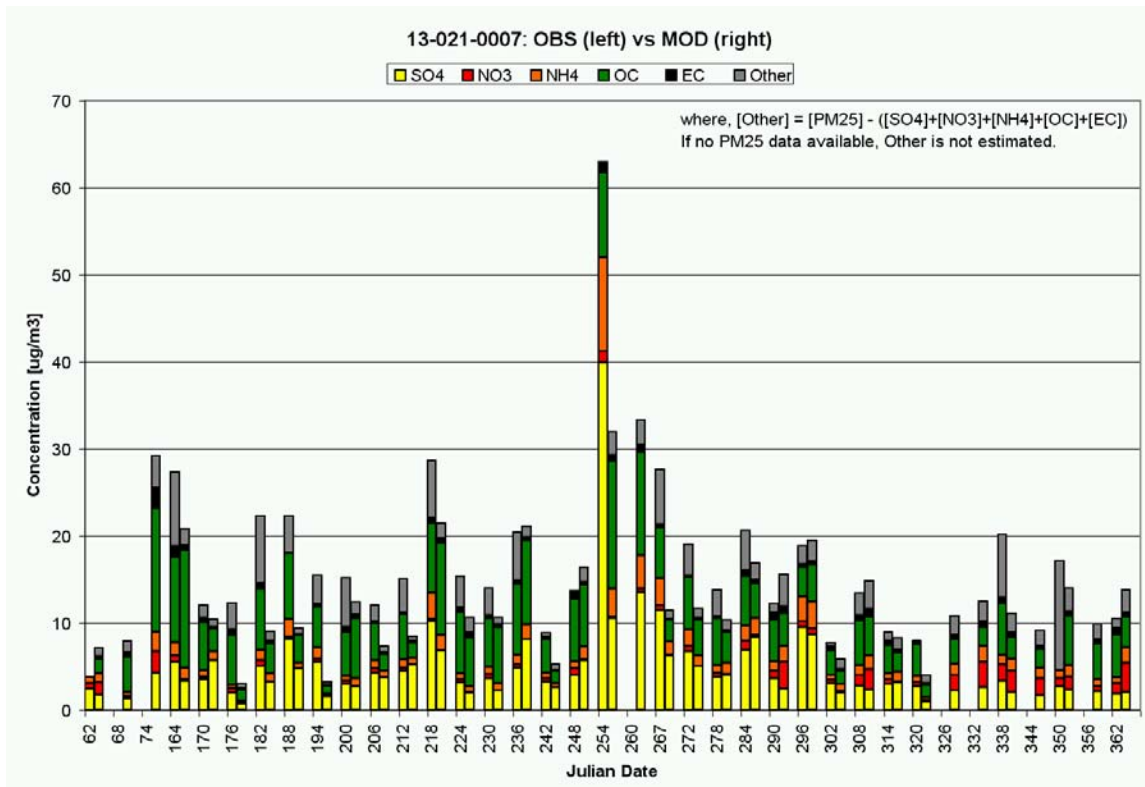


Figure 2.3.3-1. Stacked bar plots of daily PM_{2.5} species concentration at 13-021-0007.

Detailed graphical analyses led GA EPD to investigate a few exceptional performance issues for SO₄, OMC, and NH₄. These analyses helped GA EPD to narrow down the possible causes of the performance issues. After reviewing these exceptional cases more closely, GA EPD concluded that these issues do not preclude the use of the model for the purpose of supporting this SIP for the Macon nonattainment area.

When the performance is looked at as a function of concentration, as in the bugle plots, the performance metrics indicate acceptable model performance for all species. Overall, GA EPD believes that the model predictions can be used to form the scientific foundation for proposed control options because its performance is well within the limits of acceptable performance criteria established in the Attainment Modeling Guidance.

References:

Emery, C., E. Tai, and G. Yarwood, 2001: Enhanced meteorological modeling and performance evaluation for two Texas episodes, A report prepared for the Texas Natural Resources Conservation Commission (TNRCC), ENVIRON International Corporation, Novato, CA.

Mass, C. F., D. Ovens, K. Westrick, B. A. Colle, 2002, Does increasing horizontal resolution produce more skillful forecast. *Bulletin of American Meteorological Society*, 83, 407-430.

EPA, 2007. *Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, PM_{2.5} and Regional Haze*. U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-454/B-07-002. April.

Boylan, J.W. and Russell, A.G. (2006) PM and Light Extinction Model Performance Metrics, Goals, and Criteria for Three-Dimensional Air Quality Models; *Atmos. Environ.*, Volume 40, pp. 4946-4959.

Morris, R.E., B. Koo, B. Wang, G. Stella, D. McNally, C. Loomis, C-J. Chien, and G. Tonnesen. 2007. *Technical Support Document for VISTAS Emission and Air Quality Modeling to Support Regional Haze State Implementation Plans (Draft Final Report)*. ENVIRON International Corporation, Novato, California. November 14.