APPENDIX A

Model Performance Evaluation of the 2002 36 km MM5 Meteorological Model Simulation used in the CENRAP Modeling and Comparison to VISTAS Final 2002 36 km MM5 and WRAP Interim 2002 36 km MM5 Simulations

The CENRAP 2002 36 km MM5 simulation (Johnson, 2007) was evaluated against observed surface and upper-air meteorological observations and observed precipitation amounts and its performance was compared against the VISTAS final and the WRAP interim 2002 36 km MM5 simulations. The CENRAP, VISTAS and WRAP 2002 36 km MM5 simulations used several common science options:

- Lambert Conformal Projection with center at (97°, 40°) and standard parallels at (33°, 45°).
- 164 by 128 36 km by 36 km horizontal grids covering the continental U.S. and adjacent regions.
- 34 vertical layers up to 100 mb (~15 km AGL).
- Pleim-Xiu Land Surface Module (LSM).
- Asymmetric Convective Mixing (ACM) Planetary Boundary Layer (PBL) model.
- RRTM long-wave radiation.
- Dudhia short-wave radiation.
- No Shallow convection.

However, there were some differences in the choice of science options:

- VISTAS and CENRAP MM5 simulations used the Kain Fritsch 2 cumulus parameterization, whereas WRAP MM5 used Kain Fritsch 1.
- VISTAS and CENRAP MM5 simulations used the Reisner 1 moist physics while WRAP MM5 used Reisner 2.
- All three MM5 simulations used Four Dimensional Data Assimilation (FDDA analysis nudging at the surface for winds, but WRAP also used surface analysis nudging to temperature and moisture.
- All three MM5 simulations used analysis nudging FDDA above the PNL to winds, temperature and moisture.

Much of the difference in the model performance for the three MM5 simulations was related to the surface temperature and moisture analysis nudging used in the interim WRAP MM5 simulations that resulted in better surface temperature model performance, but caused instabilities resulting in degradation in meteorological model performance above the surface. The final WRAP 2002 36 km MM5 simulation did not use the surface temperature and moisture FDDA and used the Betts-Miller cumulus scheme instead of Kain Fritsch that resulted in much improved meteorological model performance in the western States (Kemball-Cook et al., 2005).

A.1 Surface Meteorological Model Performance

The performance of the three MM5 simulations at the surface was evaluated through comparisons against observed surface wind, temperature and humidity measurements from the ds472 observational database. The METSTAT program was used to evaluate the MM5 simulations for each month of 2002 and across the 11 subdomains shown in Figure A-1. These subdomains are as follows:

1 = Pacific NW
2 = SW
3 = North
4 = Desert SW
5 = CenrapN
6 = CenrapS
7 = Great Lakes
8 = Ohio Valley
9 = SE
10 = NE
11 = MidAtlantic

Emery and Tai (2001) have developed model performance benchmarks by analyzing over 30 MM5RAMS meteorological model simulations and tabulating the typical level of performance that a good meteorological model achieves. These performance benchmarks are not intended to be pass/fail grades; rather they provide a framework to evaluate the model performance against past applications. Since many of the past MM5/RAMS meteorological model simulations that the benchmarks were developed from were in support of urban ozone modeling that are typically fairly stagnant conditions with little or no precipitation and involved multiple iterations to achieve the final base case simulation. Thus, we may not expect the 2002 annual MM5 simulations to achieve a similar level of performance given the complicating factors of precipitation and complex terrain associate with many Class I areas in the west. Table A-1 lists the meteorological model performance benchmarks for wind speed, wind direction, temperature and humidity.

Table A-1. Meteorological model performance benchmarks (Source: Emery et al., 1999).

Statistic	Wind Speed	Wind Direction	Temperature	Humidity
RMSE	≤ 2 m/s			
Mean Bias	≤ ±0.5 m/s	≤ ±10°	≤ ±0.5 K	≤ ±1.0 g/kg
Index of Agreement	≤ 0.6		≤ 0.8	≤ 0.6
Gross Error		≤ 30°	≤ 2.0 K	≤ 2.0 g/kg

Below we present the evaluation of the CENRAP, VISTAS and interim WRAP 2002 36 km MM5 simulations against surface meteorological observations for the four seasonal months of January, March, July and October and the CENRAP North (CenrapN) and CENRAP South (CenrapS) subdomains (i.e., subdomains 5 and 6 in Figure A-1). The surface evaluation of the three MM5 2002 36 km simulations outside of the CENRAP subdomains can be found in Kemball-Cook et al., (2004).

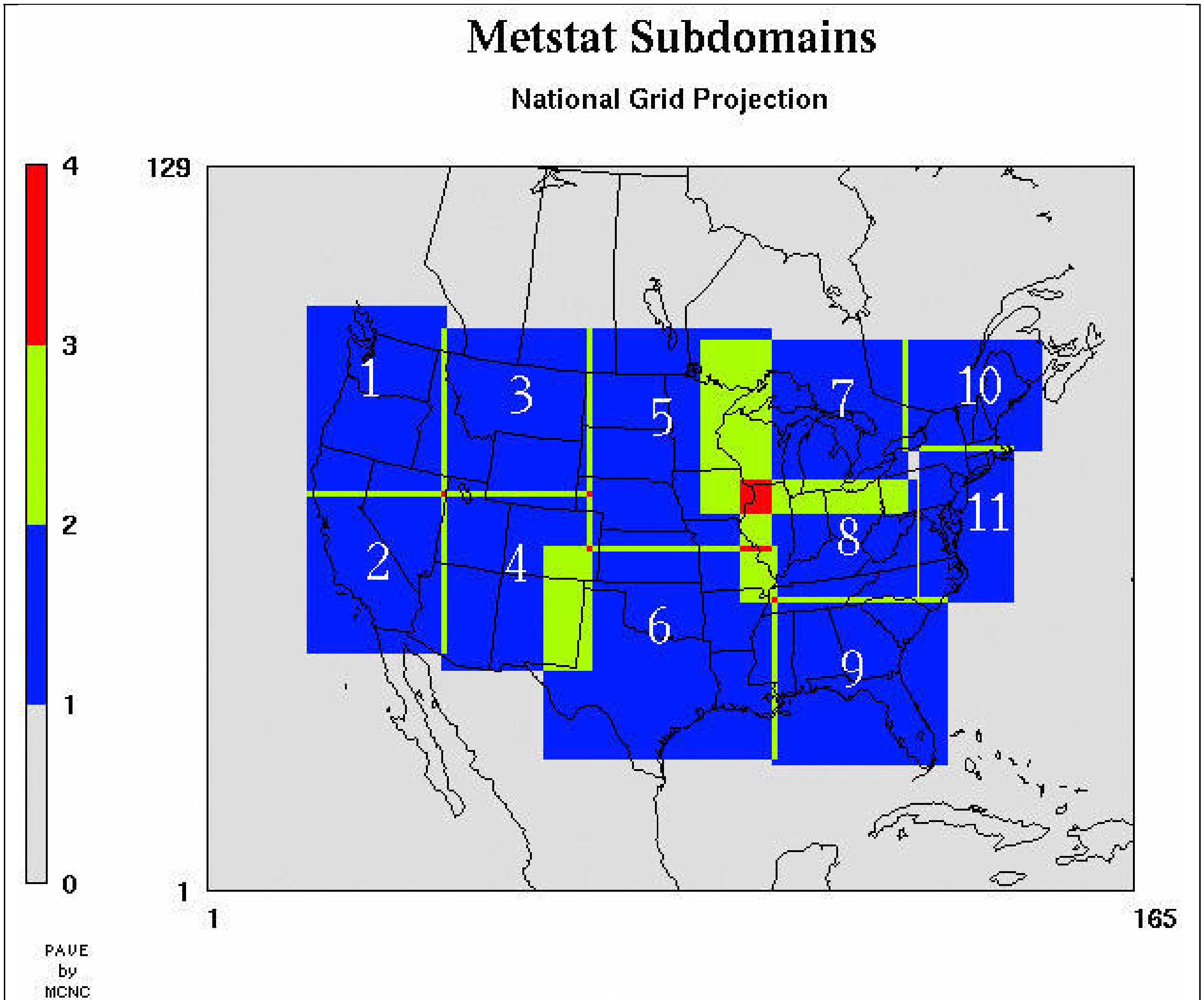


Figure A-1. Eleven subdomains where monthly evaluation of the MM5 simulations surface model performance was evaluated.

A.1.1 Temperature

Figure A-2 displays the surface temperature model performance for the CENRAP, VISTAS and WRAP 2002 36 km MM5 simulations in the CenrapN and CenrapS subdomains and the months of January, March, July and October. The WRAP MM5 simulations are performing best for January temperature in both CENRAP domains exhibiting low bias and the lowest error that are within the benchmark. The VISTAS MM5 rum is performing next best with bias well within the benchmark and error within but close to the error benchmark. The CENRAP MM5 simulation performs well for the CenrapS domain with zero bias and error within, but approaching the benchmark. However, the CENRAP performance for the CenrapN domain does not achieve the performance benchmarks due to a too cold bias.

The temperature performance in March is similar to January with both the VISTAS and WRAP MM5 simulations achieving the benchmark for both CENRAP subdomains. Again the CENRAP MM5 simulation has a near zero bias and achieves the error benchmark in the CenrapS subdomain, but is too cold in the CenrapN domain falling out of the bias benchmark range.

In July the three simulations achieve the temperature benchmark in both CENRAP subdomains, although the WRAP MM5 simulations is cooler with the CenrapS bias right at the -0.5 K lower bound benchmark. The CENRAP MM5 simulation is slightly warmer than the VISTAS MM5 simulation.

In October, all three MM5 simulations achieve the temperature performance benchmarks. The WRAP MM5 simulation performs best with near zero bias and lower error than either the VISTAS or CENRAP simulations. The VISTAS and CENRAP MM5 simulations exhibit nearly identical temperature performance in October with a near zero bias for the CenrapS subdomain and a cool bias for the CenrapN subdomain.

In conclusion, the WRAP MM5 simulation is always performing best for surface temperature with the lowest bias and usually the lowest error. The VISTAS MM5 simulations is performing next best as the CENRAP MM5 simulations exhibits a cool bias for the CenrapN subdomain in January and March that exceed the performance benchmarks.

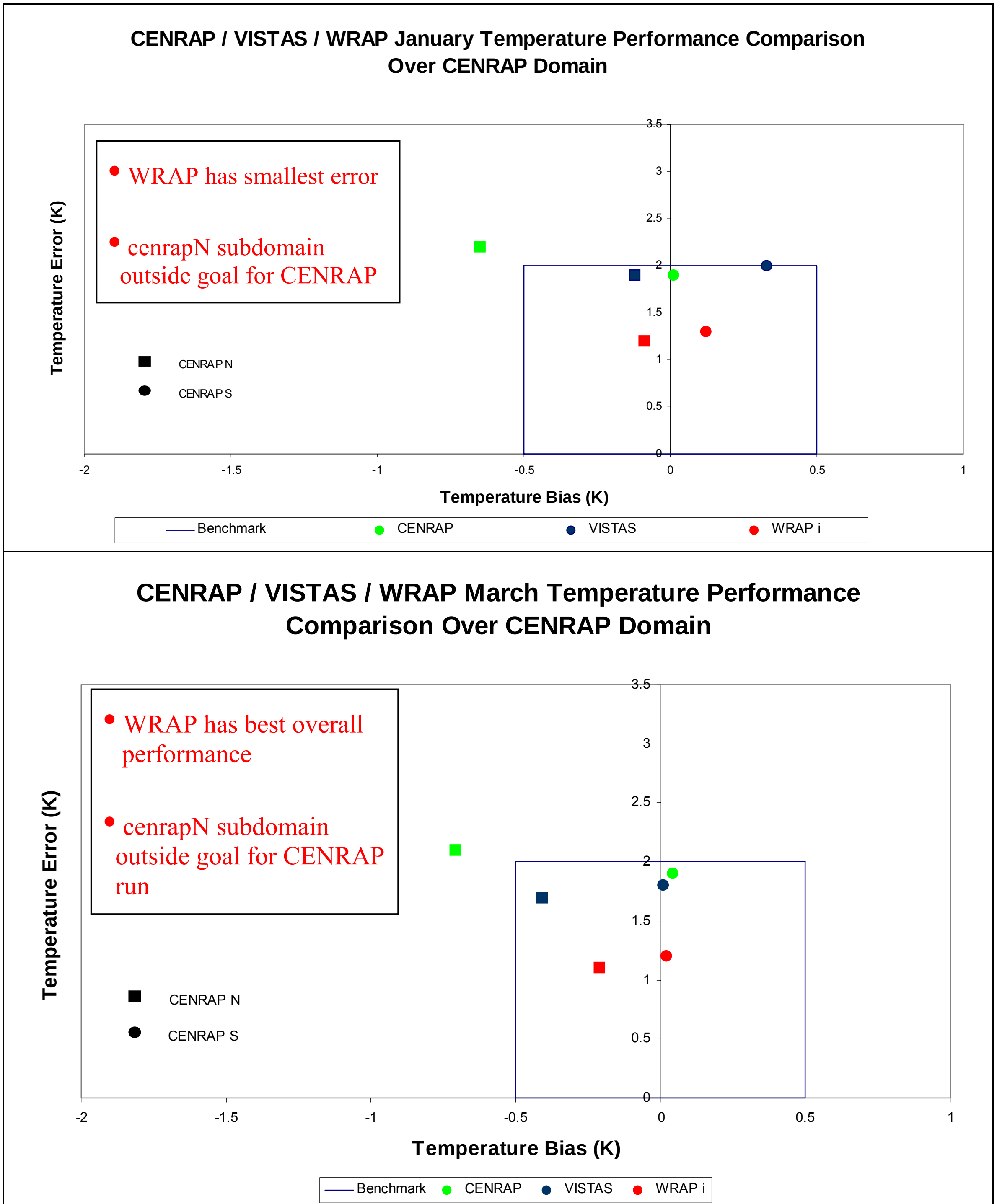
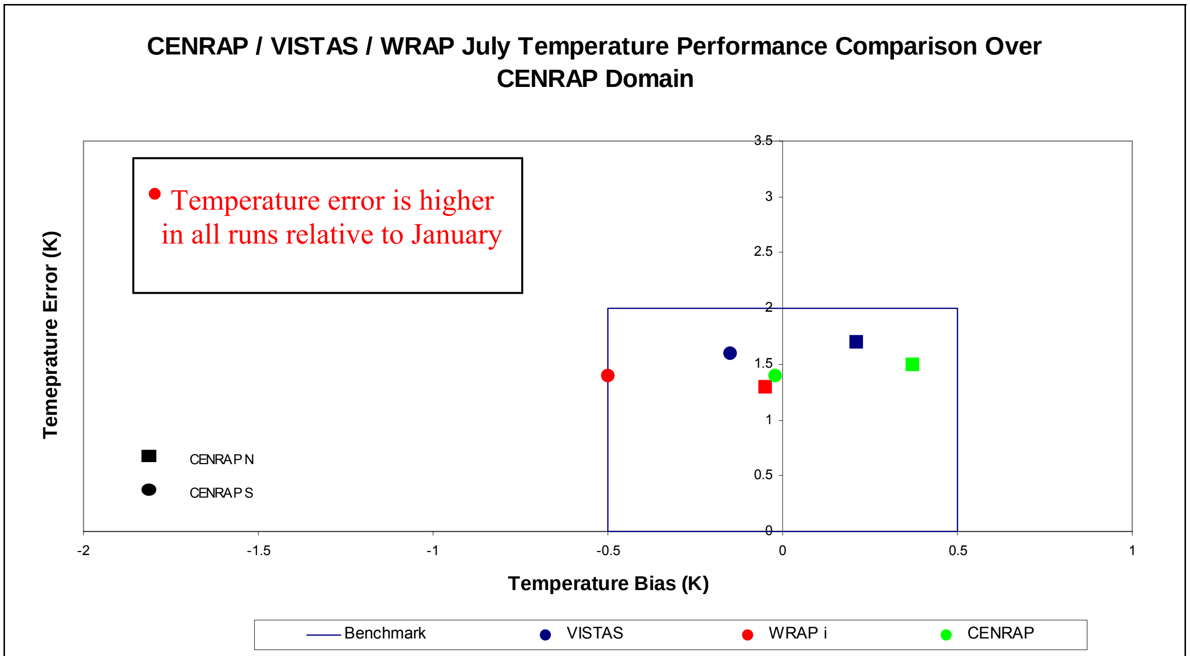


Figure A-2a. Temperature performance for the CENRAP, VISTAS and interim WRAP 2002 36 km MM5 simulations, the CenrapN and CenrapS subdomains and January (top) and March (bottom).



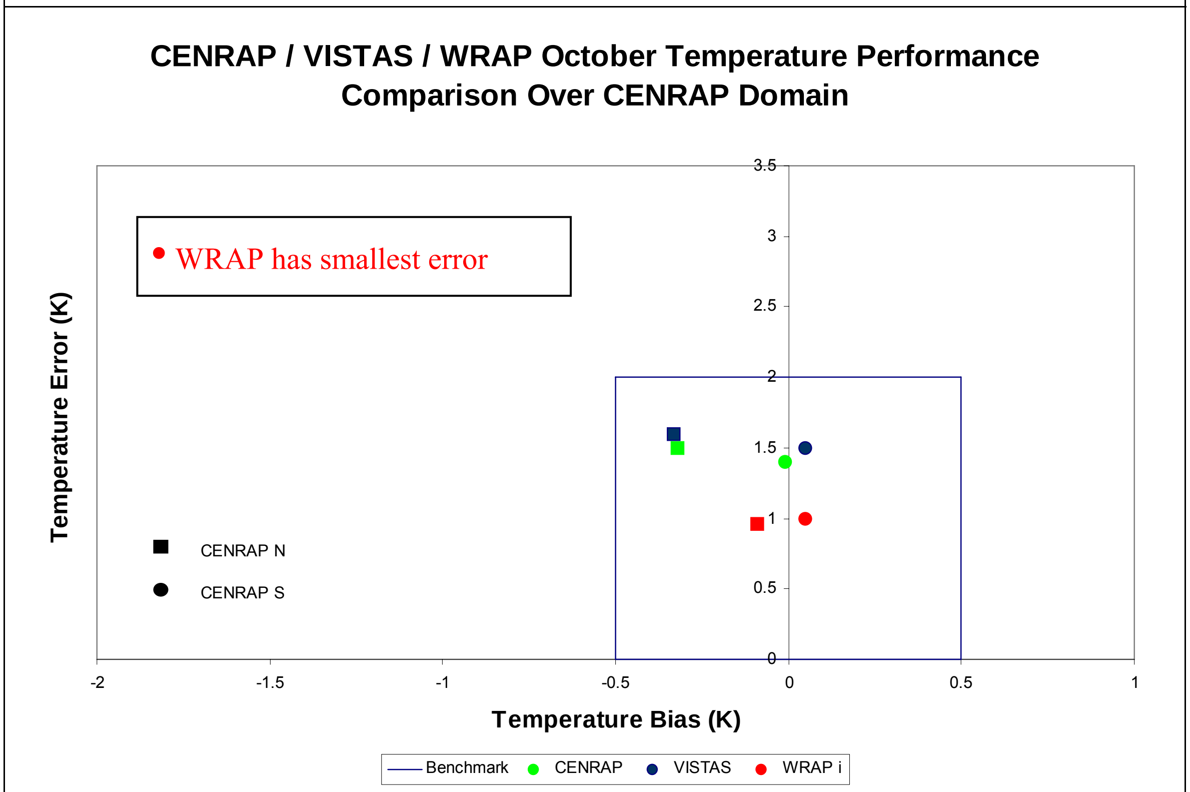
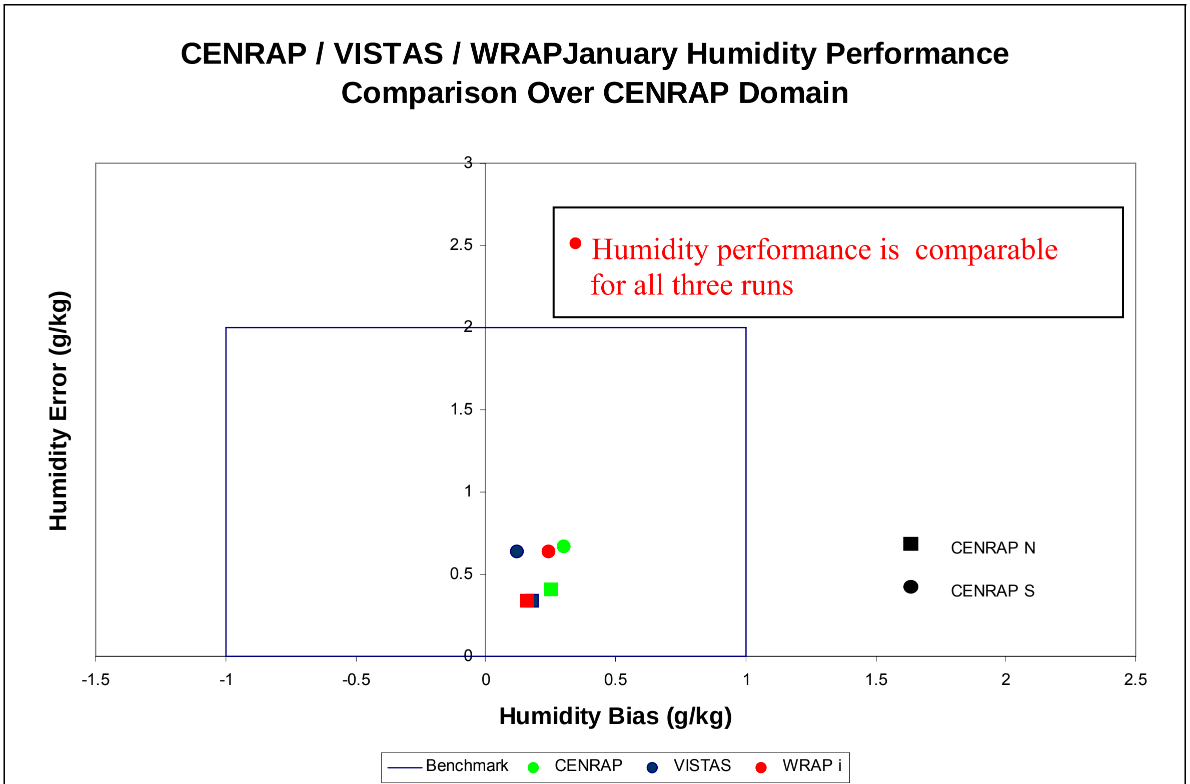


Figure A-2b. Temperature performance for the CENRAP, VISTAS and interim WRAP 2002 36 km MM5 simulations, the CenrapN and CenrapS subdomains and July (top) and October (bottom).

A.1.2 Humidity

The humidity performance for the three MM5 simulations is comparable and always achieves the performance benchmarks. The humidity bias is always near zero for all three runs and four months. In January, March and October the humidity error is at or less than half of the 2.0 g/kg benchmark. However, in July there is more error in the humidity with it within but approaching the benchmark value for all three models.

In conclusion, all three MM5 simulations achieved the humidity benchmark performance goals for all months studied. No model simulation exhibited superior performance over another.



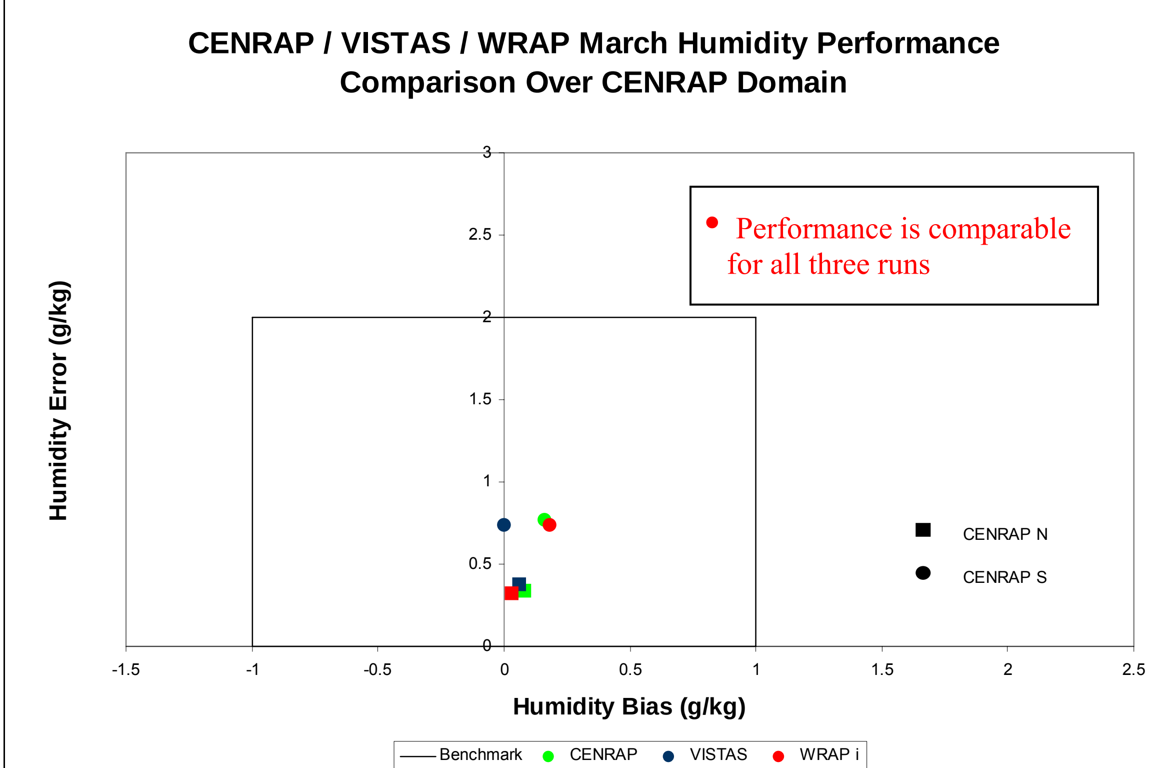
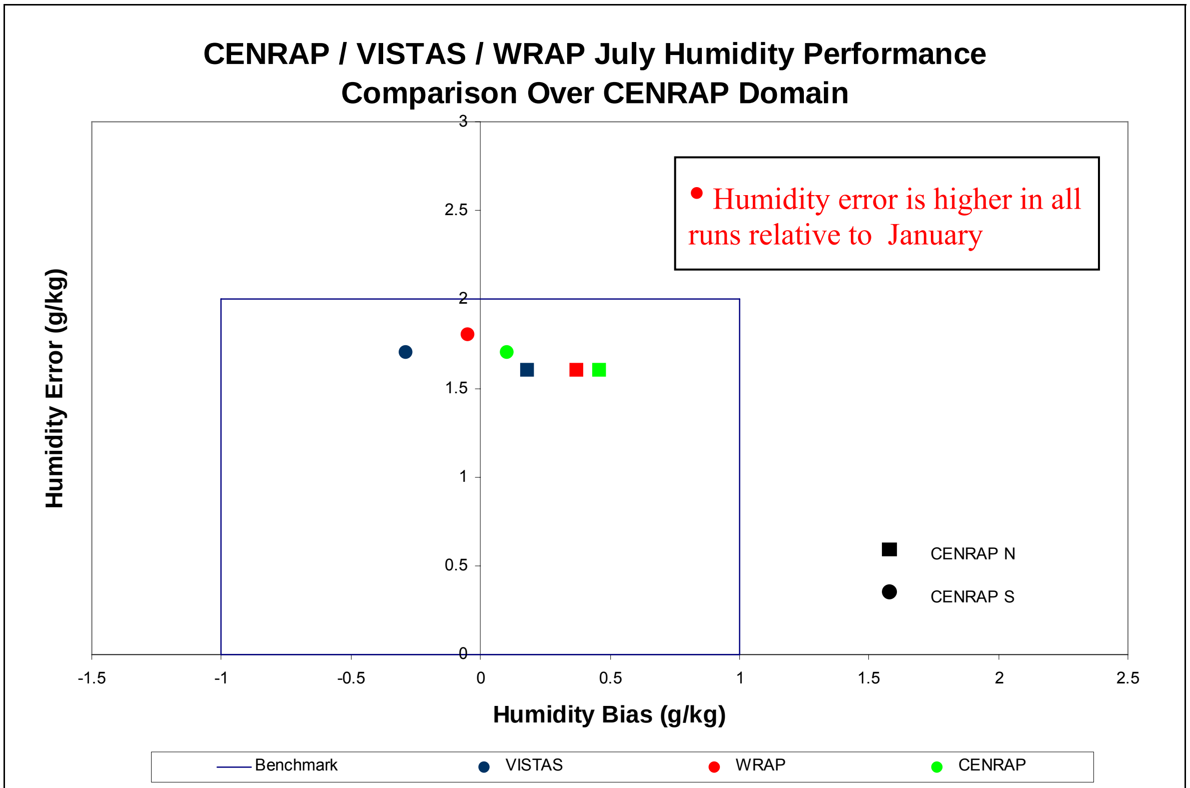


Figure A-3a. Humidity performance for the CENRAP, VISTAS and interim WRAP 2002 36 km MM5 simulations, the CenrapN and CenrapS subdomains and January (top) and March (bottom).



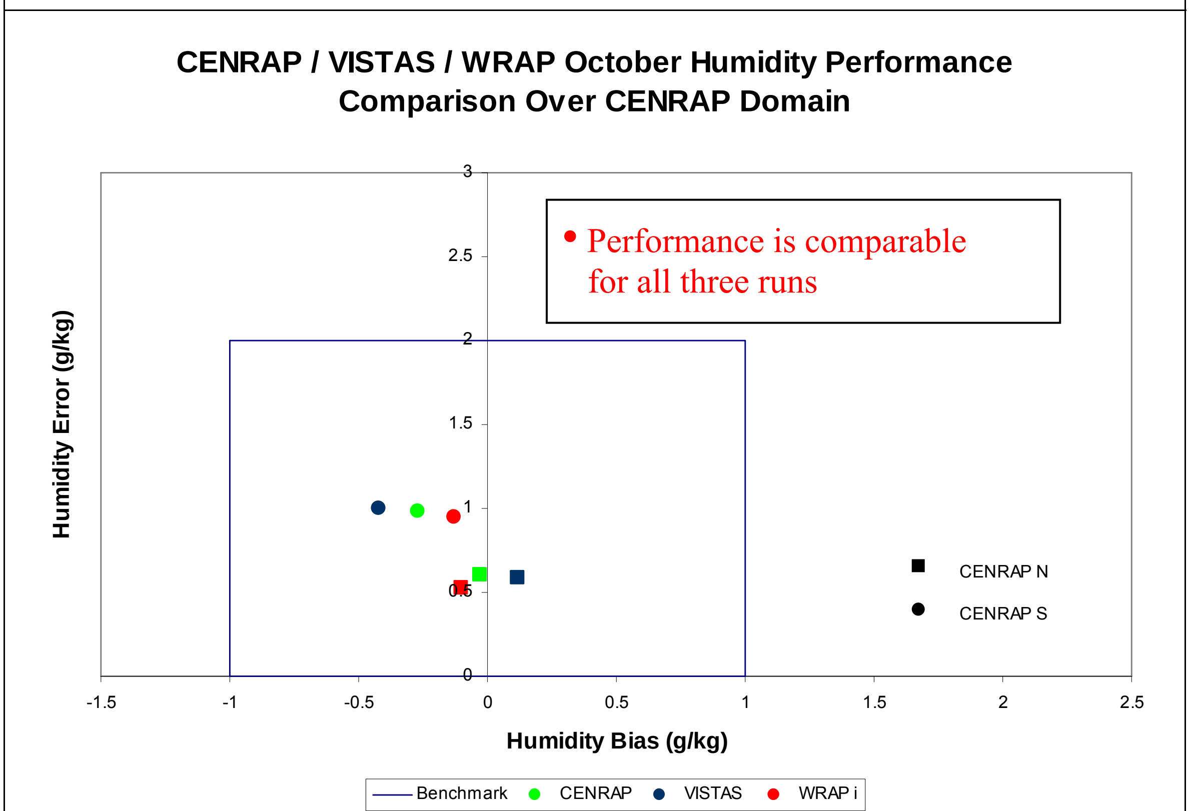


Figure A-3b. Humidity performance for the CENRAP, VISTAS and interim WRAP 2002 36 km MM5 simulations, the CenrapN and CenrapS subdomains and July (top) and October (bottom).

A.1.3 Winds

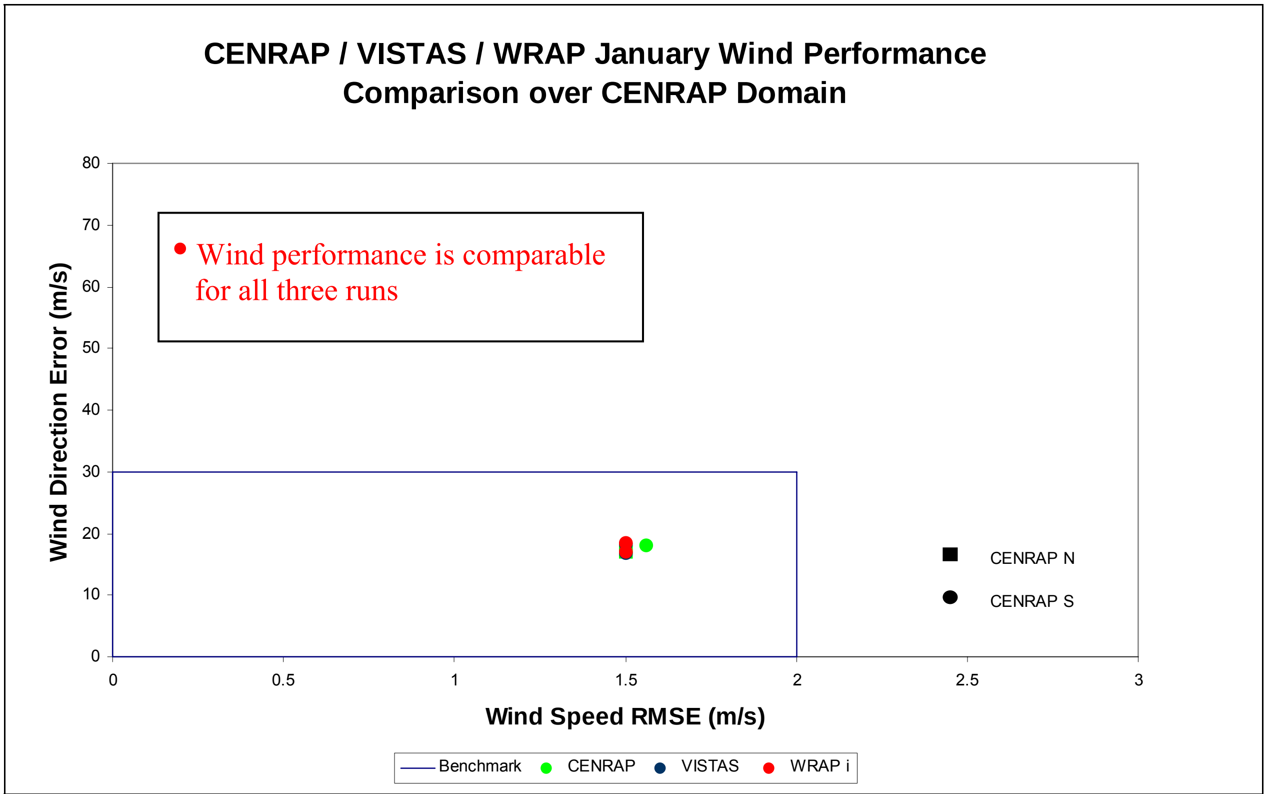
The model performance for wind speed and direction and January is almost identical and within the benchmarks for all three models and both CENRAP subdomains. In fact, the performance is so close the CenrapS symbols are plotted over and obliterate the CenrapN performance symbols.

In March, the wind performance is within the benchmark for all three MM5 simulations, which exhibit similar performance statistics. The wind performance in the CenrapS subdomain is slightly better than CenrapN with the CENRAP MM5 simulations showing the largest wind speed RMSE in the CenrapN subdomain, although still within the benchmarks.

Slight degraded wind direction performance is seen in July with the error increases to just below 20 degrees to just below the 30 degree benchmark value for all three models. Similar wind speed RMSE is seen for all three models.

The October wind performance is within the benchmarks for all three models with performance between that seen for January/March and July.

In summary, the models exhibited similar model performance for surface wind speed and direction.



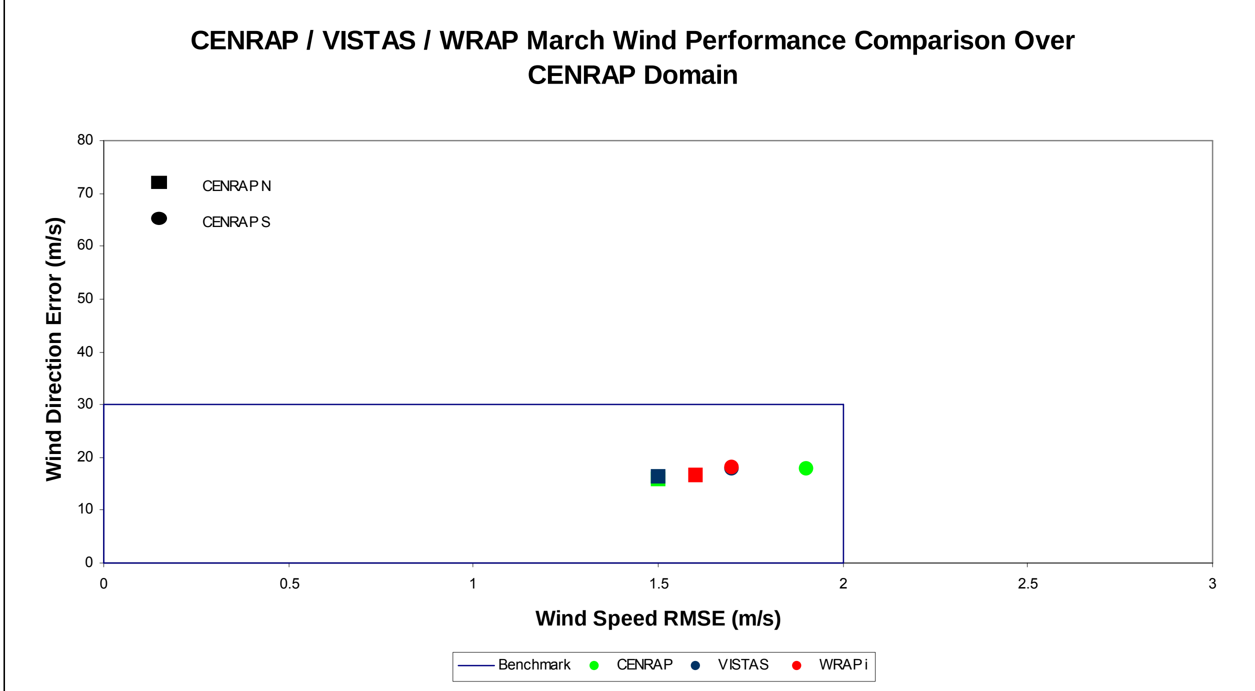
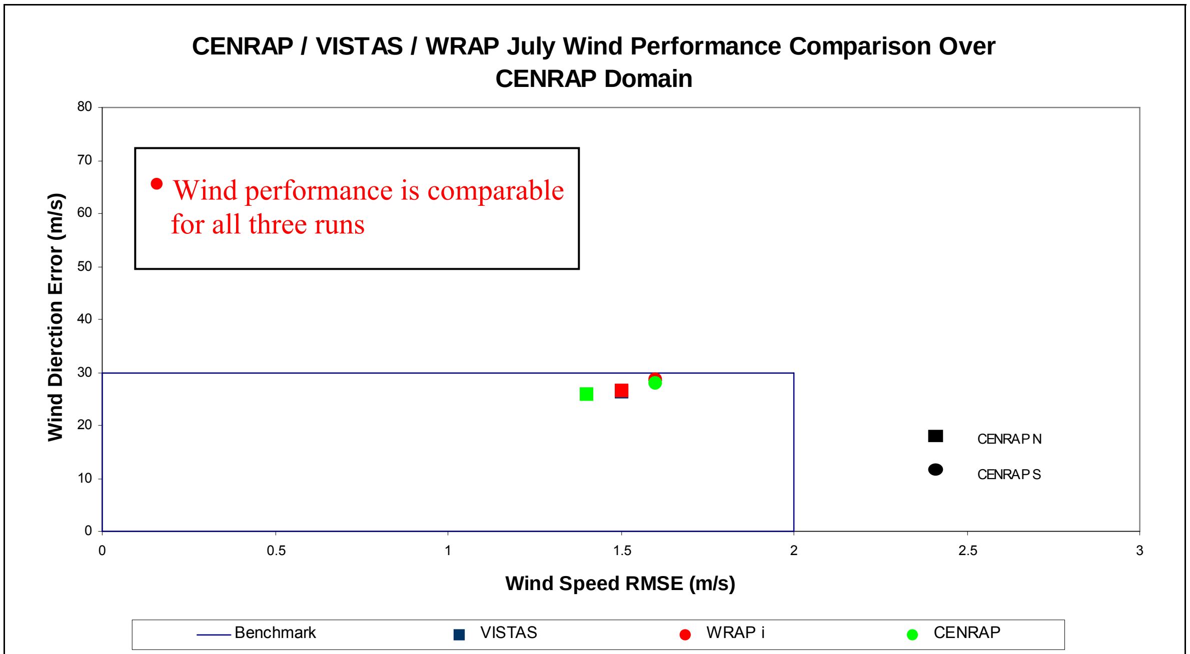


Figure A-4a. Wind Speed and Wind Direction performance for the CENRAP, VISTAS and interim WRAP 2002 36 km MM5 simulations, the CenrapN and CenrapS subdomains and January (top) and March (bottom).



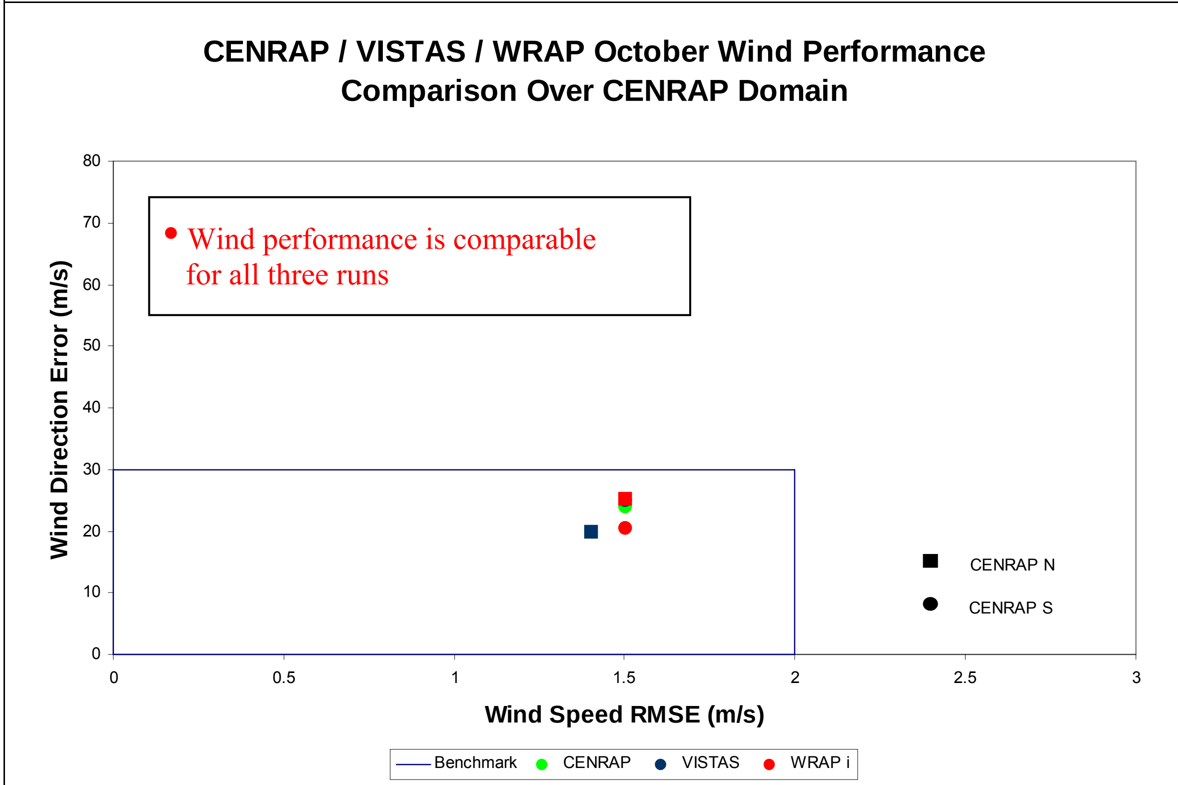


Figure A-4b. Wind Speed and Wind Direction performance for the CENRAP, VISTAS and interim WRAP 2002 36 km MM5 simulations, the CenrapN and CenrapS subdomains and July (top) and October (bottom).

A.2 Upper-Air Meteorological Evaluation

Figure A-5 displays an example comparison of the vertical profile of predicted and observed winds and temperature for Midland, Texas and January 7 2002 at 12 GMT (6am LST) and for July 16, 2002 at 00 GMT (6pm LST). Above the surface, all three models do a good job in replicating the observed temperature, dew point temperature and winds at 6a on January 7, 2002. Although the WRAP MM5 simulation predicts the surface temperature better than the other two simulations, the vertical structure of the temperature and the surface temperature inversion is not reproduced as well.

All three models understate the afternoon PBL depth on July 16, 2002 at Midland Texas. This phenomenon was seen at other sites as well.

The upper-air meteorological model evaluation found that all three models had difficulty reproducing the observed nocturnal inversion. The day time convective mixing depths were also typically underestimated.

Although the WRAP MM5 simulation reproduced the surface temperature the best of the three models, it was worst at reproducing the observed vertical temperature structure and resultant level of mixing. These results are likely due to the surface data assimilation of temperature employed by the WRAP interim MM5 simulation and resulted in WRAP eliminating the surface temperature and humidity FDDA in their final simulation.

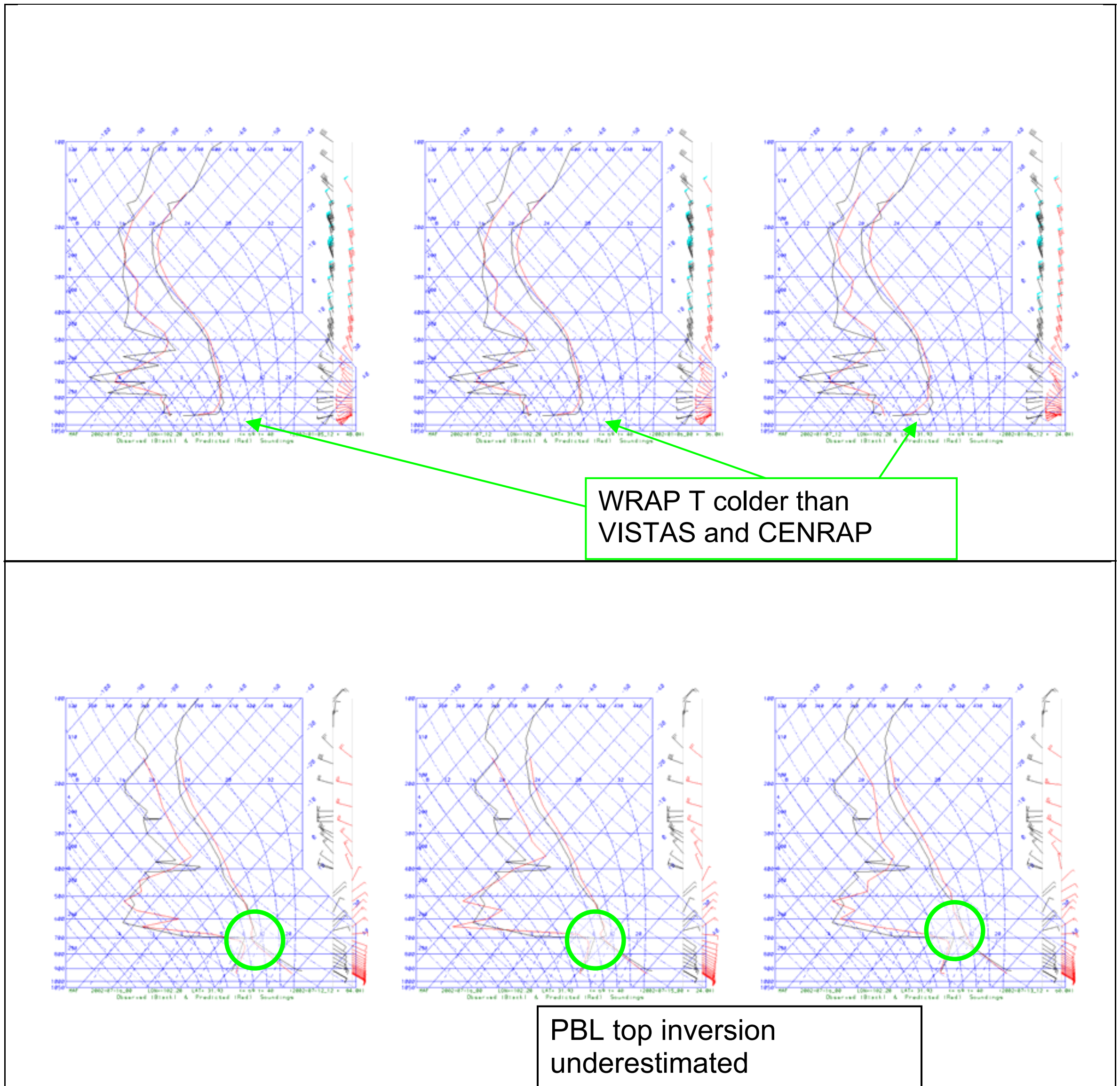


Figure A-5. Comparison of predicted and observed vertical temperature, dew point and winds profiles for the CENRAP (left), VISTAS (middle) and WRAP (right) at Midland Texas on January 7, 2002 at 12 GMT (top) and July 16, 2002 at 00 GMT (bottom).

A.4 Precipitation Model Performance Evaluation

The three MM5 model simulation precipitation estimates were evaluated by comparing the monthly average spatial distributions and amounts with observed values from the observed CPC 0.25 by 0.25 degree (approximately 28 km by 28 km) gridded analysis fields. The CPC analysis fields are gridded from on U.S. land-based observations, consequently the gridded observed fields are not available over the oceans and Canada and Mexico. The CPC observed monthly average precipitation fields were displayed using the MM5 modeling domain. The MM5 total precipitation estimates were accumulated for a month and plotted. Here total precipitation includes both explicit large scale synoptic precipitation as well as the subgrid-scale convective precipitation from the cumulus parameterization (Kain Fritsch 1 or 2).

Figures A-6 through A-9 display the monthly average precipitation fields for the months of January, March, July and October and the CPC observed and CENRAP, VISTAS and interim WRAP MM5 simulations. In January (Figure A-6), all three models reproduce the observed monthly average precipitation well with enhanced predicted and observed precipitation over the Pacific Northwest and the Appalachian Mountains. The MM5 simulations also estimated enhanced precipitation in off-shore areas north of Seattle, over the Atlantic Ocean and in the Gulf of Mexico that can not be either confirmed or refuted by the CPC observations. MM5 does overstate the amount of precipitation in January over the northern CENRAP region including over Minnesota, Iowa and Nebraska.

The three models also do a good job in reproducing the observed spatial distribution and amounts of the precipitation in March 2002 (Figure A-7). Elevated precipitation areas in the Pacific Northwest and across the lower Midwest from Arkansas and up into the Ohio River Valley and adjacent areas. The MM5 simulations do understate the highest observed precipitation amounts in Arkansas. The MM5 simulations also overstate the amount of precipitation in the desert southwest (Four Corners) area in March.

The MM5 monthly average precipitation performance is dramatically worse in July 2002 (Figure A-8). Precipitation is overstated by all three MM5 simulations throughout the U.S. and particularly in the southern states, from Arkansas across Texas to the southeastern U.S. particularly Florida South and North Carolina. This over-prediction bias is due to convective precipitation from the cumulus parameterization (either Kain Fritsch 1 or 2). This overactive precipitation is the result of the over-prediction bias I humidity seen in many subdomains (see Table A-3b and Kemball-Cook et al., 2004a).

In October 2002, the three MM5 simulations reproduced the observed monthly average rainfall fairly well across the U.S. (Figure A-9). The models predict the location of the maximum precipitation in southern Louisiana well, but under-predict the magnitude, which may be due to a slight spatial displacement offshore in the Gulf of Mexico. The MM5 simulations understate the precipitation over the CENRAP region, which explains the dry humidity bias in the CenrapS subdomain in October (Figure A-3b).

In conclusion, the three MM5 simulations do a good job in simulating the observed precipitation when it is due to synoptic weather systems. However, when precipitation is due to convective activity as seen in July that is simulated by the MM5 cumulus parameterization, MM5 greatly overstates the precipitation amounts. This is particularly pronounced in the southern states from the Four Corners area to Florida with the interim WRAP simulation exhibiting the largest over-prediction bias. In the final WRAP MM5 simulation the Betts-Miller cumulus parameterization was used that greatly reduced the convective precipitation amounts resulting in better model performance (Kemball-Cook et al., 2005). However, an overestimation bias under convective precipitation conditions still was present.

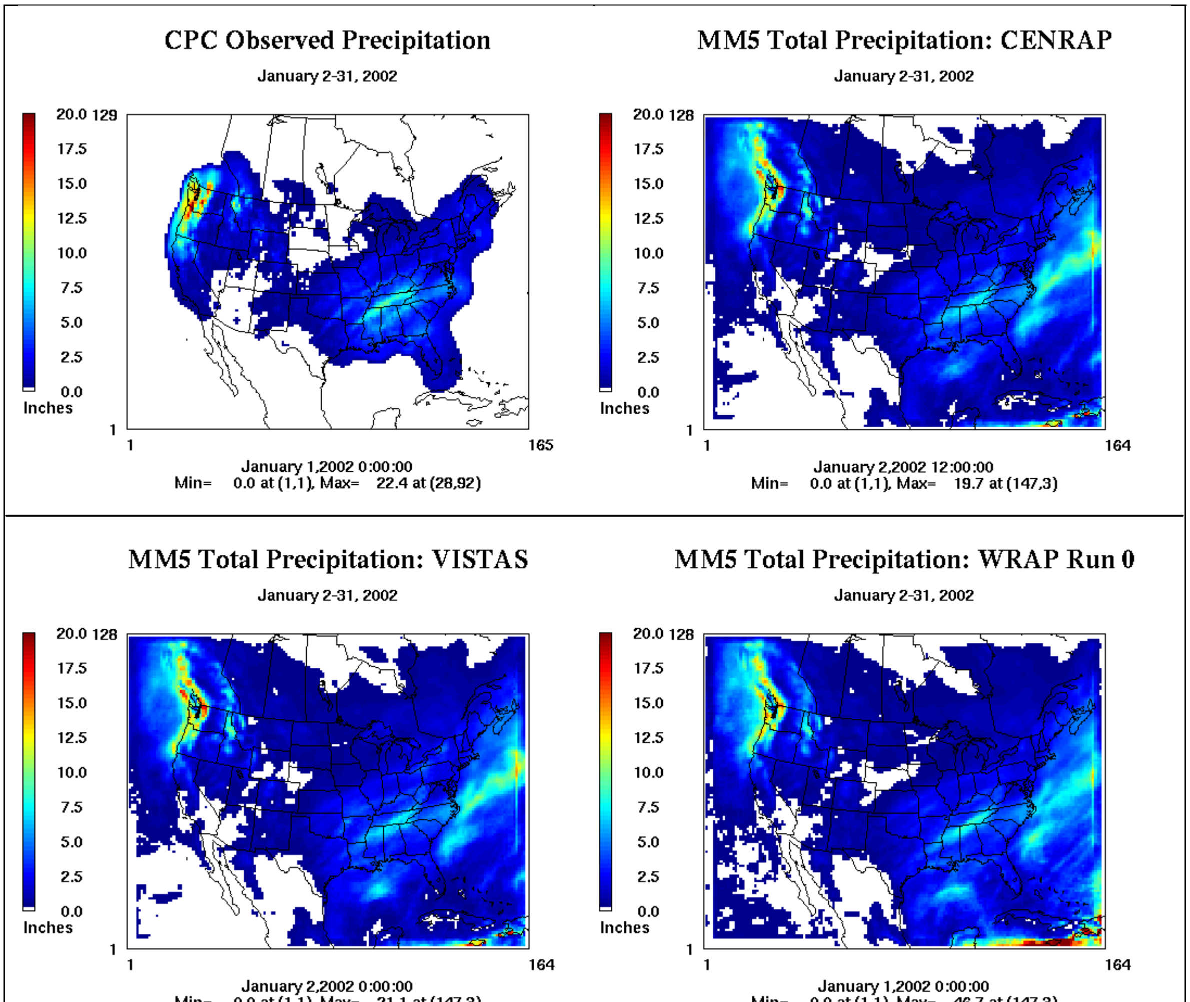


Figure A-6. Comparison of January 2002 observed monthly average precipitation (top left) with predicted values for the CENRAP (top right), VISTAS (bottom left) and WRAP (bottom right January 2002 simulation (note: observed precipitation not valid over water due to lack of measurements).

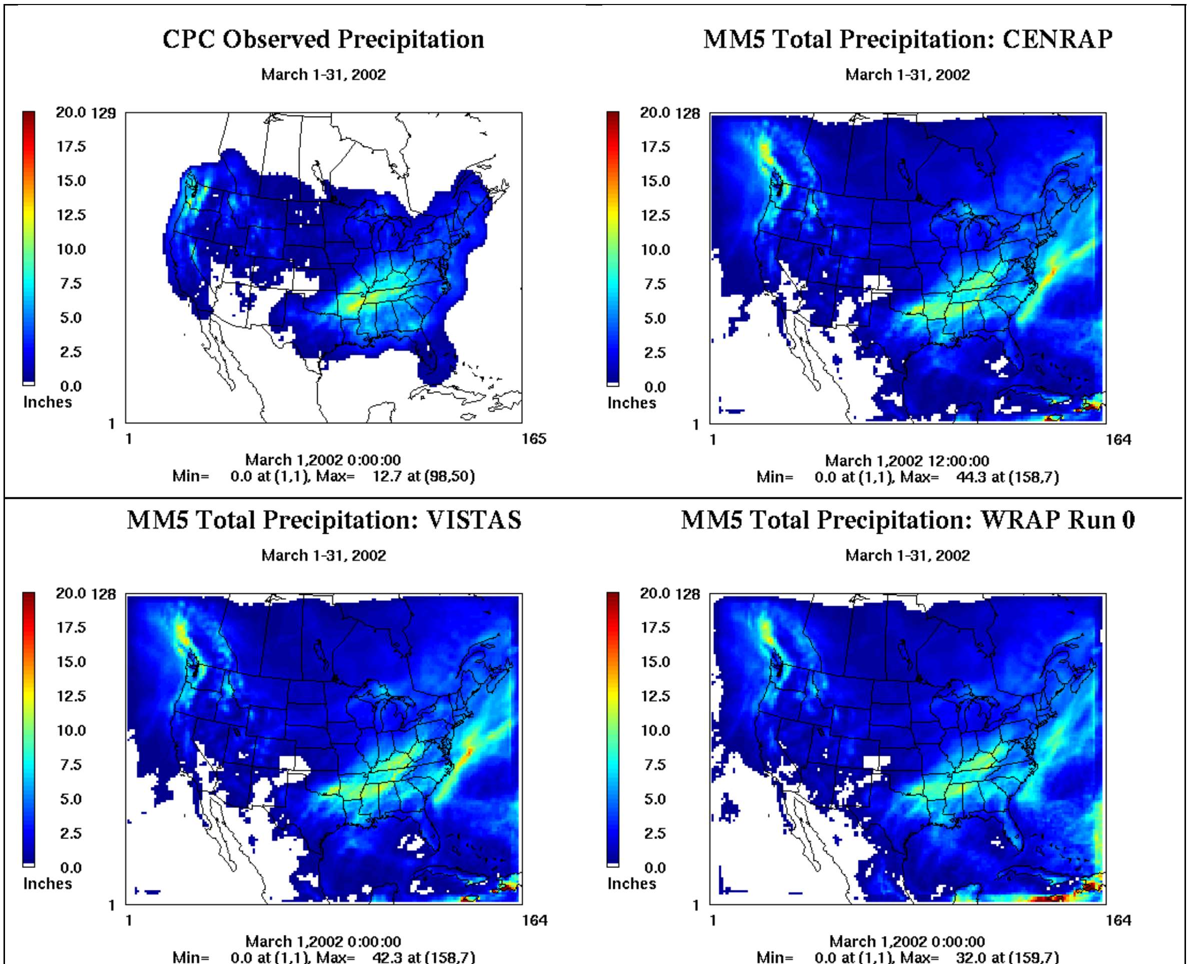


Figure A-7. Comparison of March 2002 observed monthly average precipitation (top left) with predicted values for the CENRAP (top right), VISTAS (bottom left) and WRAP (bottom right January 2002 simulation (note: observed precipitation not valid over water due to lack of measurements).

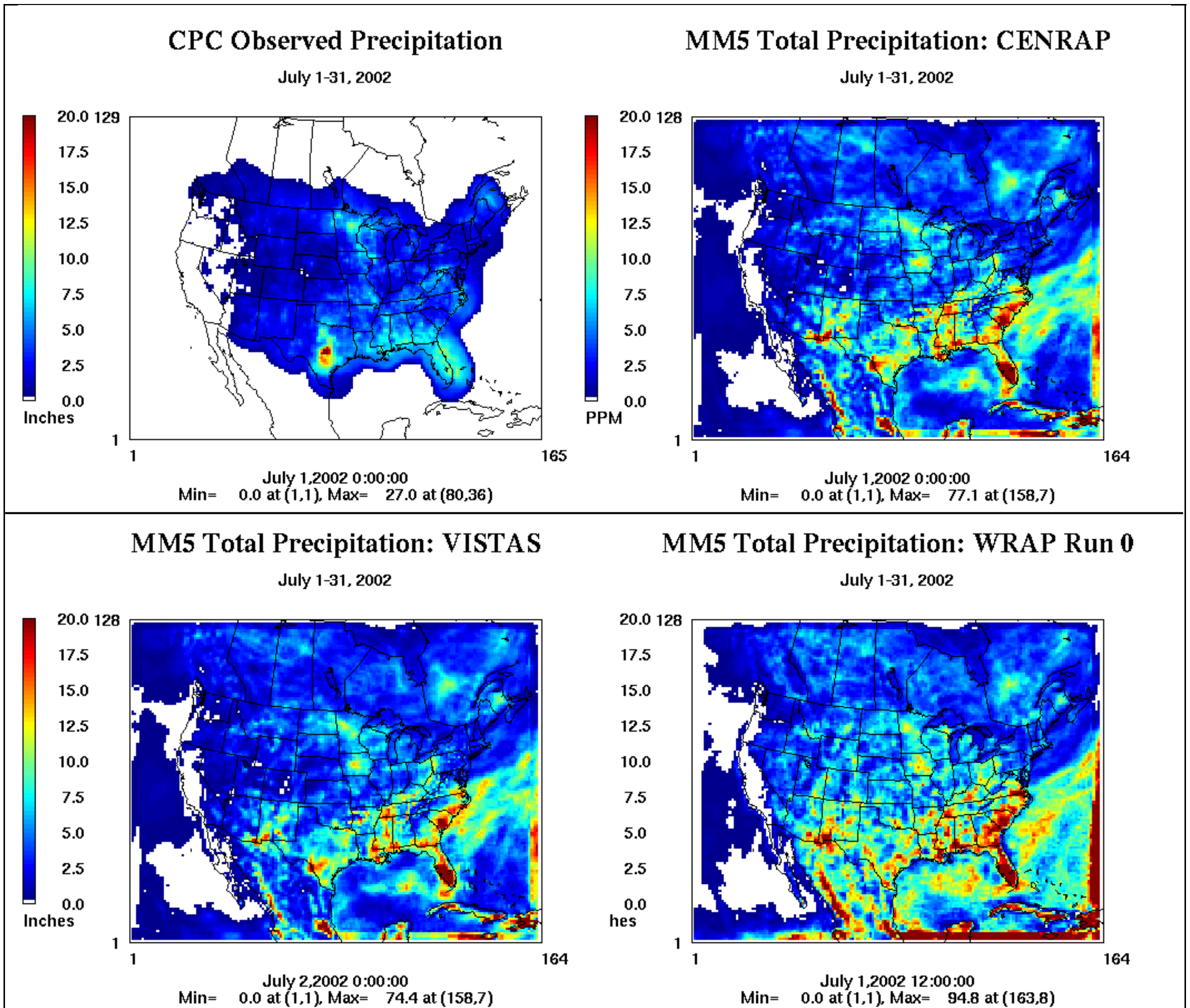


Figure A-8. Comparison of July 2002 observed monthly average precipitation (top left) with predicted values for the CENRAP (top right), VISTAS (bottom left) and WRAP (bottom right) (note: observed precipitation not valid over water due to lack of measurements).

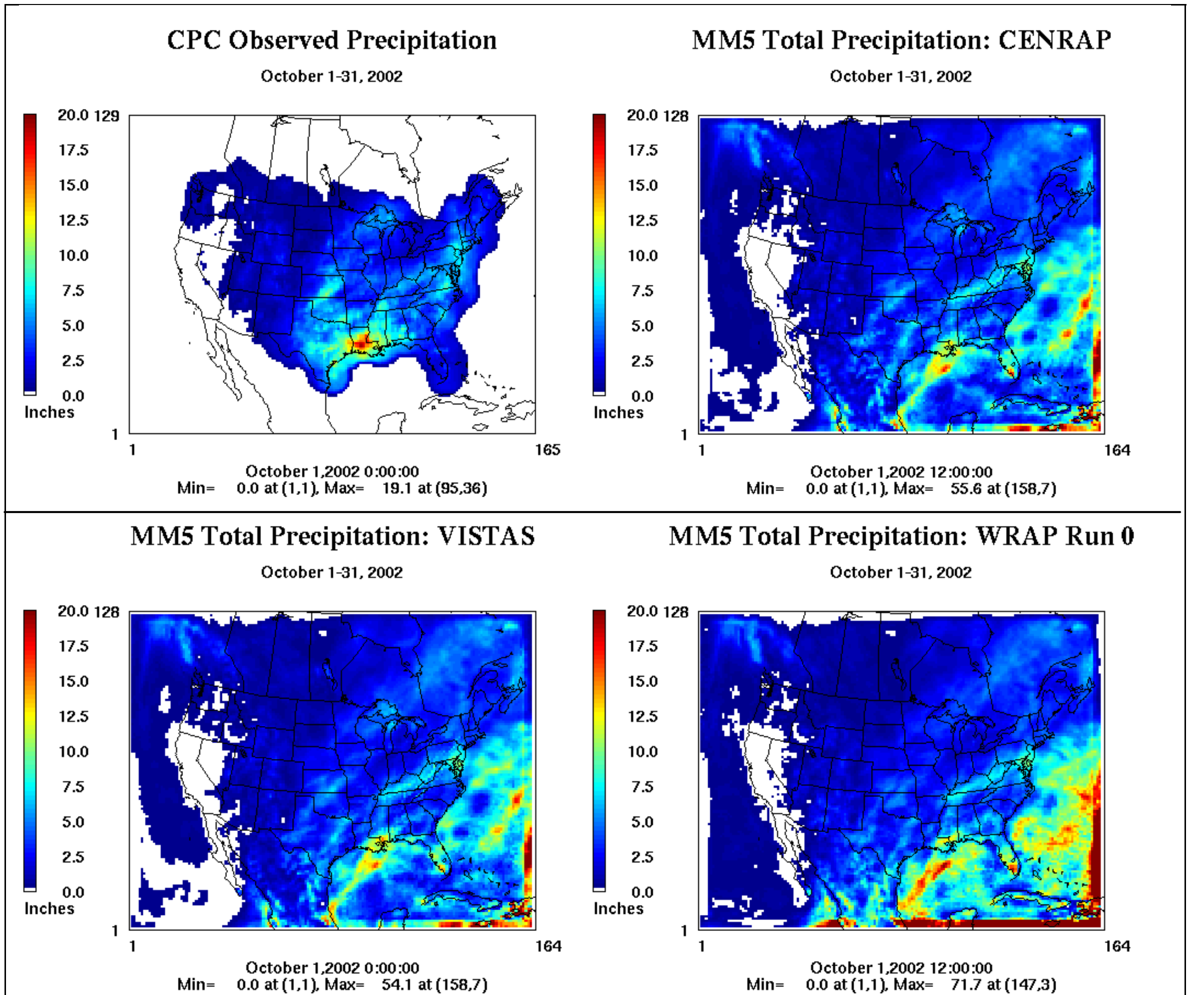


Figure A-9. Comparison of October 2002 observed monthly average precipitation (top left) with predicted values for the CENRAP (top right), VISTAS (bottom left) and WRAP (bottom right) (note: observed precipitation not valid over water due to lack of measurements).

APPENDIX B

File Names, Data Source and Type and Description of Emissions Used in the 2002 Typical and 2018 Base G Emissions Inventories

Table A-1. CENRAP 2002 Typical Base G (Typ02G) emissions inventory.

Filename	Source	Data type	Description
1 Stationary Area Sources			
arinv_Mexico99phase3_border_20051027v4_noDust_noFire.ida	**ERG**	**Text**	**1999 BRAVO Mexico inventory for the six Northern states; annual**
arinv_Mexico99phase3_interior_ERG_Oct06_noDust_noFire.ida	**ERG**	**Text**	**1999 BRAVO Mexico inventory for the Southern states; annual**
arinv_nodust_noOilGas_CA2002_111105.ida	**ERG**	**Test**	**California 2002 inventory; annual**
arinv_noDUST_noREF_vistas_2002g_2453908.ida	**Alpine Geophysics**	**Test**	**VISTAS 2002 inventory; annual**
arinv_nodust_wrap2002_v1_noCAWANDORUT_081205.ida	**ERG**	**Text**	**WRAP 2002 inventory for AZ, CO, ID, MT, NM, NV, SD, and WY ; annual**
arinv_nodust_wrap2002_v2_WANDORUT_102105.ida	**ERG**	**Text**	**WRAP 2002 inventory for ND, OR, UT, and WA; annual**
arinv_NoFire_CANADA2000_v2.ida	**Environment, Canada 011205**		**2000 Canada inventory; annual**
arinv_NoFire_noDUST_noREF_mrpok_2002_20jun2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 inventory; annual**
arinv_NoFire_nodust_ref_mane-vu2002_011705.ida	**MARAM web site**	**Text**	**MANE_VU 2002 inventory, annual**
arinv_NoFire_nodust_ref_nh3_cenrap2002_081705.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; annual**
arinv_vistas2002_TypicalFires2610000_112704.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 inventory for SCC 2610000500**
2 Fugitive Dust			
fdinv1_CA2002_v2_wfac_111105.ida	**ERG**	**Text**	**CA 2002 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_CANADA2000_v2_wfac.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_cenrap2002_wfac_081705.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_manevu2002_wfac_011705.ida	**MARMA web site**	**Text**	**MANE-VU2002 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_Mexico99phase3_border_20051027v4_wTfac.ida	**MARMA web site**	**Text**	**Mexico Northern states 1999 inventory; extracted from stationary area inventory using initial list of**

Filename	Source	Data type	Description
			SCCs; transport fractions applied; annual
fdinv1_Mexico99phase3_interior_ERG_Oct06_wo_pmfac.ida	**ERG**	**Text**	**Mexico Southern states 1999 inventory; extracted from stationary area inventory using initial list of SCCs; no transport fractions applied; annual**
fdinv1_mrpok_2002_20jun2006_w_tfrac.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_vistas_2002g_2453908_w_pmfac.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_wrap2002_wfac_noCAWANDORUT_081205.ida	**ERG**	**Text**	**WRAP 2002 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_wrap2002_wfac_WANDORUT_102105.ida	**ERG**	**Text**	**WRAP 2002 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv2_CA2002_111105.w_tfrac.ida	**ERG**	**Text**	**CA 2002 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2_CANADA_v2.w_tfrac.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2_cenrap2002_081705.w_tfrac.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2_mane-vu2002_011705.w_tfrac.ida	**MARAMA web site**	**Text**	**MANE-VU2002 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2_vistas_2002g_2453908_w_pmfac.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 inventory; extracted from stationary area inventory using extended list of SCCs; transport**

Filename	Source	Data type	Description
			fractions applied; annual
fdinv2_wrap2002_v1_noCAWANDORUT_081205.w_tfrac.ida	**ERG**	**Text**	**WRAP 2002 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2_wrap2002_v2_WANDORUT_102105.w_tfrac.ida	**ERG**	**Text**	**WRAP 2002 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
3 Road Dust			
rdinv_CA2002_v2_wfac_111105.ida	**Environ**	**Text**	**California 2002 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_CANADA2000_v2_wfac.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_cenrap2002_wfac_081705.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_manevu2002_wfac.ida	**Alpine Geophysics**	**Text**	**MANE-VU 2002 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_vistas_2002g_2453908_w_pmfac.txt	**Alpine Geophysics**	**Text**	**VISTAS 2002 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_wrap2002_wfac_${season}_082205.ida	**ENVIRON**	**Text**	**WRAP 2002 inventory; transport fractions applied; seasonal**
4 Ammonia			
arinv_nh3_2002_mrpok_${month}_3may2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 agricultural ammonia inventory; monthly**
arinv_nh3_cenrap02_082406__${month}.ida	**Pechan**	**Text**	**CENRAP 2002 xxxx inventory; monthly**
CENRAP_AREA_MISC_SMOKE_INPUT_NH3_MONTH_${month}_072805_NoBio.txt	**Pechan**	**Text**	**CENRAP 2002 xxxx inventory; monthly**
NH3_CENRAP_ANN.082506.txt	**Pechan**	**Text**	**CENRAP 2002 xxxx inventory; annual**
CENRAP_AREA_MISC_SMOKE_INPUT_ANN_STATE_071905.txt	**Pechan**	**Text**	**CENRAP 2002 xxxx inventory; annual**
5 WRAP Ammonia			
nh3gts_l.2002###.1.WRAP36.base02b_nosoil.ncf	**Environ**	**Binary, netCDF**	**Includes domestic, livestock, fertilizer, and wild life gridded inventory; daily**
6 Area Anthropogenic Fires			
arfinv_anthro_cenrap2002_081705.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted**

Filename	Source	Data type	Description
			from stationary area inventory; annual
AREA_BURNING_SMOKE_INPUT_ANN_TX_NELI_071905.txt	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_CANADA2000_v2.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_mane-vu2002_011705.ida	**MARAM web site**	**Text**	**MANE-VU2002 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_Mexico99phase3_border_20051027v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; extracted from stationary area inventory; annual**
arfinv_anthro_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states inventory; extracted from stationary area inventory; annual**
arfinv_anthro_mrpok_2002_20jun2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_vistas2002_TypicalFires_No2610000_112704.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 inventory; annual**
7 Area Wild Fires			
arfinv_wf_CANADA2000_v2.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; extracted from stationary area inventory; annual**
arfinv_wf_cenrap2002_081705.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted from stationary area inventory; annual**
arfinv_wf_mane-vu2002_011705.ida	**MARAM web site**	**Text**	**MANE-VU 2002 inventory; extracted from stationary area inventory; annual**
arfinv_wf_Mexico99phase3_border_20051027v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states inventory; extracted from stationary area inventory; annual**
arfinv_wf_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states inventory; extracted from stationary area inventory; annual**
arfinv_wf_mrpok_2002_20jun2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 inventory; extracted from stationary area inventory; annual**
arfinv_wf_vistas2002_TypicalFires_No2610000_112704.ida	**Alpine**	**Text**	**VISTAS 2002 inventory; annual**

Filename	Source	Data type	Description
	Geophysics		
8 Offshore Area Sources (Gulf of Mexico)			
CO_noCM.txt	**MMS**	**Text**	**Commercial marines records were removed; they are modeled in offshore shipping**
NOX_noCM.txt	**MMS**	**Text**	**Commercial marines records were removed; they are modeled in offshore shipping**
PM_noCM.txt	**MMS**	**Text**	**Commercial marines records were removed; they are modeled in offshore shipping**
SO2_noCM.txt	**MMS**	**Text**	**Commercial marines records were removed; they are modeled in offshore shipping**
VOC_noCM.txt	**MMS**	**Text**	**Commercial marines records were removed; they are modeled in offshore shipping**
9 Non Road (Annual Inventory)			
arinv_marine_mrpok_2002_27apr2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 Marine inventory; annual**
marinv_vistas_2002g_2453972.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 Marine inventory; annual**
nrinv_CANADA2000_v2_aircraft.ida	**Environment Canada**	**Text**	**Canada 2000 aircraft inventory; extracted from non-road inventory; annual**
nrinv_CANADA2000_v2.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; annual**
nrinv_CANADA2000_v2_locomotive.ida	**Environment Canada**	**Text**	**Canada 2000 locomotive inventory; extracted from non-road inventory; annual**
nrinv_CANADA2000_v2_marine.ida	**Environment Canada**	**Text**	**Canada 2000 marine inventory; extracted from non-road inventory; annual**
nrinv_cenrap2002_annual_071305.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; annual**
nrinv_mane-vu2002_052505.ida	**MARAM web site**	**Text**	**MANE_VU 2002 inventory; annual**
nrinv_mane-vu2002_aircraft_052505.ida	**MARAM web site**	**Text**	**MANE-VU 2002 aircraft inventory; extracted from non-road inventory; annual**
nrinv_mane-vu2002_locomotive_052505.ida	**MARAM web site**	**Text**	**MANE-VU 2002 locomotive inventory; extracted from non-road inventory; annual**
nrinv_mane-vu2002_shipping_052505.ida	**MARAM web site**	**Text**	**MANE-VU 2002 marine inventory;**

Filename	Source	Data type	Description
			extracted from non-road inventory; annual
nrinv_Mexico1999_ERG_Aircraft_Locomotive_Rec_102705.ida	**ERG**	**Text**	**Mexico 1999 aircraft and locomotive inventory; annual**
nrinv_Mexico99phase3_border_20061025v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; annual**
nrinv_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states; annual**
nrinv_vistas_2002g_2453908.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 inventory; annual**
nrinv_wrap2002_InshoreMarine_annual_tpd_080205.ida	**ENVIRON**	**Text**	**WRAP marine inventory; annual**
nrinv_wrap2002_v2_locomotive_annual_tpd_102705.ida	**ENVIRON**	**Text**	**WRAP locomotive inventory; annual**
11 Non Road (Monthly and Seasonal Inventory)			
nrinv_2002_mrpok_$month_3may2006.ida	**Missouri DNR**	**Text**	**MWRPO 2002 inventory; monthly**
nrinv_CA2002_v2_OffRoad_${season}_103105.ida	**EENVIRON**	**Text**	**California 2002 inventory, seasonal**
nrinv_cenrap2002_$month_082806.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; monthly**
nrinv_wrap2002_nonCA_${season}_060705.ida	**ENVIRON**	**Text**	**WRAP 2002 inventory, monthly**
nrinv_wrap2002_v2_Aircraft_${season}_103105.ida	**ENVIRON**	**Text**	**WRAP 2002 aircraft inventory; seasonal**
12 Stationary Point			
pthour_2002typ_baseg_${month}_28jun2006.ems	**Alpine Geophysics**	**Text**	**VISTAS 2002 hourly inventory for the EGUs; monthly**
egu_ptinv_vistas_2002typ_baseg_2453909.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 EGUs inventory; annual**
negu_ptinv_vistas_2002typ_baseg_2453909.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 non EGUs inventory, annual**
ptinv_CA2002_101405.ida	**ERG**	**Text**	**California 2002 inventory; annual**
ptinv_CA2002_CARBofs_v1.ida	**ARB**	**Text**	**California 2002 offshore inventory; annual**
Ptinv_CANADA2000_v2_032407.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; annual**
Ptinv_cenrap2002_033007.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; annual**
ptinv_egu_2002_mrpok_1may2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 EGUs inventory; annual**
ptinv_mane-vu2002_v2_${WINSUM}_041905.ida	**MARAM web site**	**Text**	**MANE-VU 2002 inventory, seasonal; winter summer**
ptinv_Mexico99phase3_border_20061025v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; annual**
ptinv_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states; annual**
ptinv_negu_2002_mrpok_1may2006.ida		**Text**	**MWRPO 2002 non EGUs inventory;**

Filename	Source	Data type	Description
			annual
ptinv_wrap2002_AKAZMTNMORUTWAWY_102405.ida	**ERG**	**Text**	**WRAP 2002 inventory for AK, AZ, MT, NM, OR, UT, WA, and WY; annual**
tinv_wrap2002_v2_NVIDSDNDCO_090805.ida	**ERG**	**Text**	**WRAP 2002 inventory for NV, ID, SD, ND, and CO; annual**
ptinv_WRAPTribes2002_102005.ida	**ERG**	**Text**	**WRAP/Tribes 2002 inventory; annual**
13 Offshore Point (Gulf)			
CO.afs.gwei2000.20000801.latlong.ida	**MMS**	**Text**	
PM10.afs.gwei2000.20000801.latlong.ida	**MMS**	**Text**	
SO2.afs.gwei2000.20000801.latlong.ida	**MMS**	**Text**	
NOX.afs.gwei2000.20000801.latlong.ida	**MMS**	**Text**	
PM2_5.afs.gwei2000.20000801.latlong.ida	**MMS**	**Text**	
VOC.afs.gwei2000.20000801.latlong.ida	**MMS**	**Text**	
14 On Road Mobile (Emissions)			
mbinv_wrap2002_v2_noCA_${season}_101305.ida	**ENVIRON**	**Text**	**WRAP 2002 inventory; seasonal**
mbinv_CA2002_v2_${season}_102705.ida	**ENVIRON**	**Text**	**California 2002 inventory; seasonal**
mbinv_CANADA2000.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; annual**
mbinv_Mexico99phase3_border_20051021v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; annual**
mbinv_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states; annual**
15 On Road Mobile (Activities, VMT)			
mbinv#_vmt_cenrap.ida	**STI**	**Text**	**CENRAP 2002 inventory; divided into three files; annual**
mbinv_2002_vmt_mane-vu.ida	**MARAM web site**	**Text**	**MANE-VU 2002 inventory; annual**
mbinv_mrpo_02f_vmt_02may06.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 inventory; annual**
mbinv_vistas_02g_vmt_12jun06.ida	**Alpine Geophysics**	**Text**	**VISTAS 2002 inventory; annual**
16 Point Fires			
ptday_2002CENRAP_ptfires_mon##.ida	**STI**	**Text**	**CENRAP 2002 prescribed fires; daily emissions; monthly**
ptday_agfires_##_vistas.ida	**Alpine Geophysics**	**Text**	**VISTA 2002 all fire sources; daily emissions; monthly**
PTDAY_200504051315_wrap2002_nfr.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 non federal rangeland fires; daily emissions; monthly**
PTDAY_200507011516_wrap2002_agf_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 Ag. Fires; daily emissions; monthly**
PTDAY_200510210936_wrap2002_wild_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fires; daily emissions; monthly**

Filename	Source	Data type	Description
PTDAY_200510211022_wrap2002_wfu_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fire use; daily emissions; monthly**
PTDAY_200510211029_wrap2002_rx_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 prescribed fires; daily emissions; monthly**
pthour_2002CENRAP_ptfires_mon##.ida	**STI**	**Text**	**CENRAP 2002 prescribed fires; hourly plume distribution; monthly**
pthour_agfires_##_vistas.ida	**Alpine Geophysics**	**Text**	**VISTA 2002 all fire sources; hourly plume distribution; monthly**
PTHOUR_200504051315_wrap2002_nfr.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 non federal rangeland; hourly plume distribution; monthly**
PTHOUR_200507011516_wrap2002_agf_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 Ag. Fires; hourly plume distribution; monthly**
PTHOUR_200510210936_wrap2002_wild_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fires; hourly plume distribution; monthly**
PTHOUR_200510211022_wrap2002_wfu_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fire use; hourly plume disributution; monthly**
PTHOUR_200510211029_wrap2002_rx_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 prescribed fires; hourly plume distribution; monthly**
ptinv_2002CENRAP_ptfires_mon##.ida	**STI**	**Text**	**CENRAP 2002 prescribed fires; fire location info.; monthly**
ptinv_agfires_##_vistas.ida	**Alpine Geophysics**	**Text**	**VISTA 2002 all fire sourcesfire location info; monthly**
PTINV_200504051315_wrap2002_nfr.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 non federal rangeland fires; fire location info; monthly**
PTINV_200507011516_wrap2002_agf_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 Ag. Fires; fire location info.; monthly**
PTINV_200510210936_wrap2002_wild_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fires; fire location info.; monthly**
PTINV_200510211022_wrap2002_wfu_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fire use; fire location info.; monthly**
PTINV_200510211029_wrap2002_rx_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 prescribed fires; fire location; monthly**
ptday.ontario_fires.2002.txt.ida	**Environment Canada**	**Text**	**Ontario/Canada wild fires; daily emissions and fire info.; monthly**
ptinv.ontario_fires.2002.txt.ida	**Environment Canada**	**Text**	**Ontario/Canada wild fires; fire location info.; monthly**
17 Biogenecs			
b3fac.beis3_efac_v0.98.txt	**EPA**	**Text**	**Version 0.98 biogenic emission factors**
b3_a.VISTAS36_148X112.beld3_v2.ncf	**Alpine Geophysics**	**Binary**	**Gridded land use**
b3_b.VISTAS36_148X112.beld3_v2.ncf	**Alpine**	**Binary**	**Gridded land use**

Filename	Source	Data type	Description
	Geophysics		
b3_t.VISTAS36_148X112.beld3_v2.ncf	**Alpine Geophysics**	**Binary**	**Gridded land use**
18 Windblown Dust			
wb_dust_ii_cenrap_cmaq_RPO36_2002###_agadj_tf_b.ncf	**ENVIRON/UCR**	**Binary; netCDF**	**Domain wide wind blown dust emissions from WRAP wind blown dust model; hourly**
19 WRAP Oil and Gas			
arinv_CA2002_v2_OilGas_111105.ida	**ENVIRON**	**Text**	**California 2002 oil and gas inventory; annual**
arinv_wrap2002_v2_OilGas_annual_082505.ida	**ENVIRON**	**Text**	**WRAP 2002 oil and gas inventory; annual**
20 Offshore Shipping			
ofsgts_l.2002###.1.vista36.baseg_2002.shipping.ncf	**ENVIRON/VISTAS**	**Binary; netCDF**	**Pacific, Gulf of Mex. and Atlantic 2002 Offshore shipping inventory; daily**

Table A-2. CENRAP 2018 Base G (Base18G) emissions inventory.

Filename	Source	Data type	Description
1 Stationary Area Sources			
arinv_Mexico99phase3_border_20051027v4_noDust_noFire.ida	**ERG**	**Text**	**1999 BRAVO Mexico inventory for the six Northern states; annual**
arinv_Mexico99phase3_interior_ERG_Oct06_noDust_noFire.ida	**ERG**	**Text**	**1999 BRAVO Mexico inventory for the Southern states; annual**
arinv_CA2018_112205.ida	**ERG**	**Text**	**California 2018 inventory; annual**
arinv_NoDust_NoREF_vistas_2018g_2453922.ida	**Alpine Geophysics**	**Test**	**VISTAS 2018 inventory; annual**
arinv_wrap2018.091205.ida	**ERG**	**Text**	**WRAP 2018 inventory; annual**
arinv_canada_2020_noDust_NoFire.ida	**Environment, Canada**		**Canada 2020 inventory; annual**
arinv_NoFire_NoDust_NoREF_mrpok_2018_22aug2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 inventory; annual**
arinv_mane_vu_2018v3_1_NoDust_NoFire.ida		**Text**	**MANE_VU 2018 inventory, annual**
arinv_NoFire_nodust_ref_nh3_cenrap2002-2018_101606.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 inventory; annual**
arinv_vistas_baseg_2018t_lofire_11feb2007_scc2610000500.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory for SCC 2610000500**
2 Fugitive Dust			
fdinv1.CA2018_wfac.ida	**ERG**	**Text**	**CA 2018 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1.canada_2020.wTfac.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1.cenrap2002_2018_wfac.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1.mane_vu2018_wfac.ida	**MARAM web site**	**Text**	**MANE-VU 2018 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions**

Filename	Source	Data type	Description
			applied; annual
fdinv1_Mexico99phase3_border_20051027v4_wTfac.ida	**ERG**	**Text**	**Mexico Northern states 1999 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_Mexico99phase3_interior_ERG_Oct06_wo_pmfac.ida	**ERG**	**Text**	**Mexico Southern states 1999 inventory; extracted from stationary area inventory using initial list of SCCs; no transport fractions applied; annual**
fdinv1_mrpok_2018_22aug2006_wfac.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1_vistas_2018g_2453922_w_pmfac.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv1.wrap2018_wfac.ida	**ERG**	**Text**	**WRAP 2018 inventory; extracted from stationary area inventory using initial list of SCCs; transport fractions applied; annual**
fdinv2.CA2018_wfac.ida	**ERG**	**Text**	**CA 2018 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2.canada_2020.wTfac.ida	**Environment Canada**	**Text**	**Canada 2020 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2.cenrap2002_2018_wfac.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2.mane-vu2018_wfac.ida	**MARAM web site**	**Text**	**MANE-VU 2018 inventory;**

Filename	Source	Data type	Description
			extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual
fdinv2_vistas_2018g_2453922_w_pmfac.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
fdinv2_wrap2018.091205_wfac.ida	**ERG**	**Text**	**WRAP 2018 inventory; extracted from stationary area inventory using extended list of SCCs; transport fractions applied; annual**
3 Road Dust			
rdinv.CA2018_wfac.ida	**Environ**	**Text**	**California 2018 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_canada_2020_wTfac.ida	**Environment Canada**	**Text**	**Canada 2020 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv.cnrap2002_2018.wfac.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_mane_vu_2018v3_1_wTfac.ida	**MARAM web site**	**Text**	**MANE-VU 2018 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv_vistas_vistas_2018g_2453922_w_pmfac.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory; extracted from stationary area inventory; transport fractions applied; annual**
rdinv.wrap2018_wfac_${season}.ida	**ENVIRON**	**Text**	**WRAP 2018 inventory; transport fractions applied; seasonal**
4 Ammonia			
arinv_nh3_2018_mrpok_${month}_22aug2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 agricultural ammonia inventory; monthly**
nh3minv.cenrap2018gr_18.apr.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 xxxx inventory; monthly**

Filename	Source	Data type	Description
nh3inv.misc.cnrap2002_2018.feb.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 xxxx inventory; monthly**
nh3yinv.annual.cnrap2002_2018.100406.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 xxxx inventory; annual**
nh3inv.misc_annual.cnrap2002_2018.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 xxxx inventory; annual**
5 WRAP Ammonia			
nh3gts_l.2002###.1.WRAP36.base02b_nosoil.ncf	**Environ**	**Binary, netCDF**	**Includes domestic, livestock, fertilizer, and wild life gridded inventory; daily**
6 Area Anthropogenic Fires			
arfinv_anthro_cenrap2002_081705.ida	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted from stationary area inventory; annual**
AREA_BURNING_SMOKE_INPUT_ANN_TX_NELI_071905.txt	**Pechan**	**Text**	**CENRAP 2002 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_canda2020.ida	**Environment Canada**	**Text**	**Canada 2000 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_mane_vu_2018v3_1.ida	**MARAM web site**	**Text**	**MANE-VU 2018 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_Mexico99phase3_border_20051027v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; extracted from stationary area inventory; annual**
arfinv_anthro_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states inventory; extracted from stationary area inventory; annual**
arfinv_anthro_mrpok_2018_22aug2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 inventory; extracted from stationary area inventory; annual**
arfinv_anthro_vistas_baseg_2018t_11feb2007_NOscc2610000500.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory; annual**
7 Area Wild Fires			
arfinv_wf_canada2020.ida	**Environment Canada**	**Text**	**Canada 2020 inventory; extracted from stationary area inventory; annual**
arfinv_wf_cenrap2002-2018_101606.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 inventory; extracted from stationary area inventory; annual**

Filename	Source	Data type	Description
arfinv_wf_mane_vu_2018v3_1.ida	**MARAM web site**	**Text**	**MANE-VU 2018 inventory; extracted from stationary area inventory; annual**
arfinv_wf_Mexico99phase3_border_20051027v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states inventory; extracted from stationary area inventory; annual**
arfinv_wf_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states inventory; extracted from stationary area inventory; annual**
arfinv_wf_mrpok_2018_22aug2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 inventory; extracted from stationary area inventory; annual**
arfinv_wf_vistas_baseg_2018t_11feb2007_NOscc2610000500.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory; annual**
8 Offshore Area Sources (Gulf of Mexico)			
ofsarinv.cnrap2002_2018_noCM.ida	**UCR; grown from 2002**	**Text**	**Commercial marines records were removed; they are modeled in offshore shipping; all pollutants; annual**
9 Non Road (Annual Inventory)			
arinv_mar_mrpok_2018_22aug2006.ida		**Text**	**MWRPO 2018 Marine inventory; annual**
marinv_vistas_2018g_2453972.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 Marine inventory; annual**
NONROAD2020_Canada.ida	**Environment Canada**	**Text**	**Canada 2020 aircraft inventory; extracted from non-road inventory; annual**
CENRAP_2018_Fnl_Nrd_Emissions091506.ida	**Pecahn**	**Text**	**CENRAP 2018 inventory; annual**
nrinv_mane_vu_2018v3_1.ida	**MARAM web site**	**Text**	**MANE_VU 2018 inventory; annual**
nrinv_Mexico1999_ERG_Aircraft_Locomotive_Rec_102705.ida	**ERG**	**Text**	**Mexico 1999 aircraft and locomotive inventory; annual**
nrinv_Mexico99phase3_border_20061025v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; annual**
nrinv_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states; annual**
nrinv_vistas_2018g_2453908.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory; annual**
nrinv_wrap2018_Locomotive_annual_tpd_111805.ida	**ENVIRON**	**Text**	**WRAP 2018 locomotive inventory; annual**

Filename	Source	Data type	Description
11 Non Road (Monthly and Seasonal Inventory)			
nrinv_2018_mrpok_apr_22aug2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 inventory; monthly**
nrinv_CA2018_win_111805.ida	**EENVIRON**	**Text**	**California 2018 inventory, seasonal**
2018NONROAD_AG_IA_${month}.ida	**Missouri DNR**	**Text**	**CENRAP/IA 2018 inventory; monthly**
nrinv.mrpok.minn.apr_2018.011306.ida	**Missouri DNR**	**Text**	**CENRAP/MN 2018 inventory; monthly**
nrinv_WRAP2018_${season}_102105.ida	**ENVIRON**	**Text**	**WRAP 2018 inventory, monthly**
nrinv_WRAP2018_Aircraft_${season}.111805.ida	**ENVIRON**	**Text**	**WRAP 2018 aircraft inventory; seasonal**
12 Stationary Point			
pthour_2018_baseg_sep_2453993.ems	**Alpine Geophysics**	**Text**	**VISTAS 2018 hourly inventory for the EGUs; monthly**
ptinv_egu_18_vistas_g_2453993.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 EGUs inventory; annual**
ptinv_nonEGU_vistas_2018_baseg_2453957.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 non EGUs inventory, annual**
pgts3d_l.2002###.1.cmaq.cb4p25.us36b.CANADA_20i01.19L.ncf	**EPA**	**Binary; netCDF**	**Canada 2020 inventory; daily**
Ptinv_cenrap2018_EGU_${WINSUM}_annual_050407.ida	**CENRAP**	**Text**	**CENRAP 2018 EGUs inventory, seasonal; winter summer**
ptinv_o.cenrap2002_2018_nonEGU050307.ida	**UCR; grown from 2002**	**Text**	**CENRAP 2018 non EGUs inventory; annual**
ptinv_cenrapNonegu_2018_050707_refin_new_sources.ida	**CENRAP**	**Text**	**CENRAP 2018 Additional sources; annual**
ptinv_egu_2018_mrpok_11sep006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2002 EGUs inventory; annual**
Ptinv_manevu2018_EGU_${WINSUM}_ANNUAL_080805.ida	**MARAM web site**	**Text**	**MANE-VU 2018 EGUs inventory, seasonal; winter summer**
ptinv_manevu2018_nonEGU_112105.ida		**Text**	**MANE-VU 2018 non EGUs inventory, annual**
ptinv_Mexico99phase3_border_20061025v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; annual**
ptinv_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states; annual**
ptinv_negu_2018_mrpok_23aug2006.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 non EGUs inventory; annual**
ptinv_wrap2018_NoOG_050406.ida	**ERG**	**Text**	**WRAP 2018 inventory; no oil and gas; annual**

Filename	Source	Data type	Description
ptinv_wrap2018_OG_091205.ida	**ERG**	**Text**	**WRAP 2018 inventory; oil and gas; annual**
ptinv_WRAPTribes2018_NoOG_091205.ida	**ERG**	**Text**	**WRAP/Tribes 2018 inventory; no oil and gas annual**
ptinv_WRAPTribes2018_OG_091205.ida	**ERG**		**WRAP/Tribes 2018 inventory; oil and gas annual**
13 Offshore Point (Gulf)			
ofsinv_o_CO.cnrap2002_2018.ida	**UCR; grown from 2002 emissions**	**Text**	
ofsinv_o_NOX.cnrap2002_2018.ida	**UCR; grown from 2002 emissions**	**Text**	
ofsinv_o_PM10.cnrap2002_2018.ida	**UCR; grown from 2002 emissions**	**Text**	
ofsinv_o_PM2_5.cnrap2002_2018.ida	**UCR; grown from 2002 emissions**	**Text**	
ofsinv_o_SO2.cnrap2002_2018.ida	**UCR; grown from 2002 emissions**	**Text**	
ofsinv_o_VOC.cnrap2002_2018.ida	**UCR; grown from 2002 emissions**	**Text**	
14 On Road Mobile (Emissions)			
mbinv_WRAP2018_aut_102105.ida	**ENVIRON**	**Text**	**WRAP 2018 inventory; seasonal**
mbinv_CA2018_win_111805.ida	**ENVIRON**	**Text**	**California 2018 inventory; seasonal**
mbinv_CANADA2020.ida	**Environment Canada**	**Text**	**Canada 2020 inventory; annual**
mbinv_Mexico99phase3_border_20051021v4.ida	**ERG**	**Text**	**Mexico 1999 inventory for Northern states; annual**
mbinv_Mexico99phase3_interior_ERG_Oct06.ida	**ERG**	**Text**	**Mexico 1999 inventory for Southern states; annual**
15 On Road Mobile (Activities, VMT)			
mbinv.mbv#_vmt_cenrap2018_072005.ida	**STI**	**Text**	**CENRAP 2018 inventory; divided into tow files; annual**
mbinv_vmt_manevu2018_update.ida	**MARAM web site**	**Text**	**MANE-VU 2018 inventory; annual**
mbinv_mrpo_18f_vmt_11aug06.ida	**Alpine Geophysics**	**Text**	**MWRPO 2018 inventory; annual**
mbinv_vistas_18g_vmt_12jun06.ida	**Alpine Geophysics**	**Text**	**VISTAS 2018 inventory; annual**
16 Point Fires			
ptday_2002CENRAP_ptfires_mon##.ida	**STI**	**Text**	**CENRAP 2002 prescribed fires; daily emissions; monthly**
ptday.plume.vistasG2_2018.##.ida	**Alpine**	**Text**	**VISTA 2018 all fire sources; daily**

Filename	Source	Data type	Description
	Geophysics		emissions; monthly
PTDAY_200504051315_wrap2002_nfr.mon##.ida	AirSciences	Text	WRAP 2002 non federal rangeland fires; daily emissions; monthly
PTDAY_200604272314_wrap02_04_agf.mon##.ida	AirSciences	Text	WRAP 2002-4 Ag. Fires; daily emissions; monthly
PTDAY_200510210936_wrap2002_wild_base.mon##.ida	AirSciences	Text	WRAP 2002 wild fires; daily emissions; monthly
PTDAY_200510211022_wrap2002_wfu_base.mon##.ida	AirSciences	Text	WRAP 2002 wild fire use; daily emissions; monthly
PTDAY_200604281056_wrap02_04_arx.mon##.ida	AirSciences	Text	WRAP 2002-4 prescribed fires; daily emissions; monthly
PTDAY_200604281056_wrap02_04_nrx.mon##.ida	AirSciences	Text	WRAP 2002-4 natural prescribed fires; daily emissions; monthly
pthour_2002CENRAP_ptfires_mon##.ida	STI	Text	CENRAP 2002 anthro. prescribed fires; hourly plume distribution; monthly
pthour.plume.vistasG2_2018.##.ida	Alpine Geophysics	Text	VISTA 2002 all fire sources; hourly plume distribution; monthly
PTHOUR_200504051315_wrap2002_nfr.mon##.ida	AirSciences	Text	WRAP 2002 non federal rangeland; hourly plume distribution; monthly
PTHOUR_200604272314_wrap02_04_agf.mon##.ida	AirSciences	Text	WRAP 2002 Ag. Fires; hourly plume distribution; monthly
PTHOUR_200510210936_wrap2002_wild_base.mon##.ida	AirSciences	Text	WRAP 2002 wild fires; hourly plume distribution; monthly
PTHOUR_200510211022_wrap2002_wfu_base.mon##.ida	AirSciences	Text	WRAP 2002 wild fire use; hourly plume disributution; monthly
PTHOUR_200604281056_wrap02_04_arx.mon##.ida	AirSciences	Text	WRAP 2002 natural prescribed fires; hourly plume distribution; monthly
PTHOUR_200604281056_wrap02_04_nrx.mon##.ida	AirSciences	Text	WRAP 2002 anthro. prescribed fires; hourly plume distribution; monthly
ptinv_2002CENRAP_ptfires_mon##.ida	STI	Text	CENRAP 2002 prescribed fires; fire location info.; monthly
ptinv.plume.vistasG2_2018.11.ida	Alpine Geophysics	Text	VISTA 2002 all fire sourcesfire location info; monthly
PTINV_200504051315_wrap2002_nfr.mon##.ida	AirSciences	Text	WRAP 2002 non federal rangeland fires; fire location info; monthly

Filename	Source	Data type	Description
PTINV_200507011516_wrap2002_agf_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 Ag. Fires; fire location info.; monthly**
PTINV_200510210936_wrap2002_wild_base.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fires; fire location info.; monthly**
PTINV_200604272314_wrap02_04_agf.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 wild fire use; fire location info.; monthly**
PTINV_200604281056_wrap02_04_arx.mon##.ida	**AirSciences**	**Text**	**WRAP 2002 anthro. prescribed fires; fire location; monthly**
PTINV_200604281056_wrap02_04_nrx.mon##.ida	**AirSciences**		**WRAP 2002 natural prescribed fires; fire location; monthly**
ptday.ontario_fires.2002.txt.ida	**Environment Canada**	**Text**	**Ontario/Canada wild fires; daily emissions and fire info.; monthly**
ptinv.ontario_fires.2002.txt.ida	**Environment Canada**	**Text**	**Ontario/Canada wild fires; fire location info.; monthly**
17 Biogenecs			
b3fac.beis3_efac_v0.98.txt	**EPA**	**Text**	**Version 0.98 biogenic emission factors**
b3_a.VISTAS36_148X112.beld3_v2.ncf	**Alpine Geophysics**	**Binary**	**Gridded land use**
b3_b.VISTAS36_148X112.beld3_v2.ncf	**Alpine Geophysics**	**Binary**	**Gridded land use**
b3_t.VISTAS36_148X112.beld3_v2.ncf	**Alpine Geophysics**	**Binary**	**Gridded land use**
18 Windblown Dust			
wb_dust_ii_cenrap_cmaq_RPO36_2002###_agadj_tf_b.ncf	**ENVIRON/UCR**	**Binary; netCDF**	**Domain wide wind blown dust emissions from WRAP wind blown dust model; hourly**
19 WRAP Oil and Gas			
arinv_CA2018_OilGas_112205.ida	**ENVIRON**	**Text**	**California 2018 oil and gas inventory; annual**
oginv_WRAP2018_annual_tpd_111605.ida	**ENVIRON**	**Text**	**WRAP 2018 oil and gas inventory; annual**
20 Offshore Shipping			
ofsgts_l.2002###.1.vista36.baseg_2002.shipping.ncf	**ENVIRON/VISTAS**	**Binary; netCDF**	**Pacific, Gulf of Mex. and Atlantic 2002 Offshore shipping inventory; daily**

APPENDIX C

Model Performance Evaluation for the CMAQ 2002 Base F Base Case Simulation in the CENRAP Region

C.1 2002 Typical Base F Model Performance Evaluation Scenario

This Appendix presents the operational evaluation of the CMAQ model for the 2002 36 km Typical Base F emissions scenario. The final CENRAP 2002 and 2018 emissions scenarios used in the 2018 visibility projections was Base G. The main differences between Base G and Base F emissions inventories were updated Mexican emissions in the northern states, addition of Mexican emissions in the southern states that were not included in CENRAP's emission inventories prior to Base G and correction of a few point source stack parameters and emissions in the CENRAP states and Canada (see: http://pah.cert.ucr.edu/aqm/cenrap/QA_typ02g36.plots/log_inv_categ_Typ02g.doc). Figure C-1 displays the differences in annual average $PM_{2.5}$ and ozone concentrations between the 2002 Typical Base G and Base F simulations. Most of the differences in the two simulations are concentrations within Mexico where no monitoring data were available for the model evaluation. Thus, given the very small differences between the 2002 Typical Base F and G base case simulations, the model performance evaluation is presented for just the 2002 Typical Base F simulation (for additional comparisons of Base G and F see: http://pah.cert.ucr.edu/aqm/cenrap/cmaq.shtml#typ02gvstyp02f_mpe).

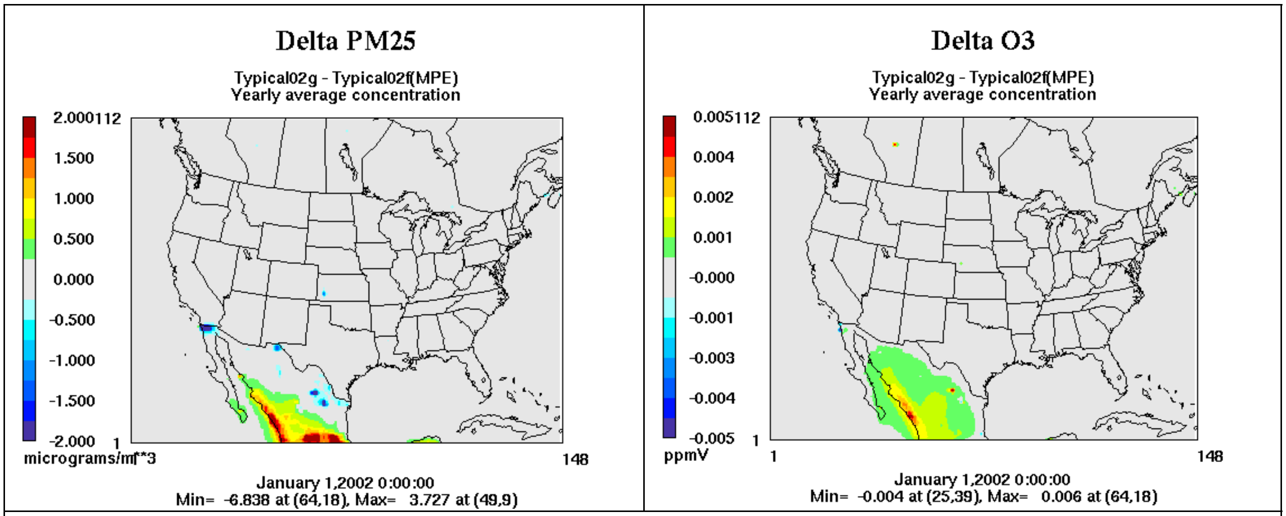


Figure C-1. Comparison of differences in annual average $PM_{2.5}$ (left) and ozone concentrations between 2002 Typical Base G and F (Base G – Base F).

The CENRAP emissions and air quality modeling initially conducted 2002 base case modeling for two 2002 base case emissions scenarios: a 2002 Actual emissions base case; and a 2002 Typical emissions base case. For the 2002 Actual base case, day-specific SO2 and NOx emissions for large stationary point sources were used based on measured continuous emissions monitoring (CEM) data along with actual 2002 fire emissions In the 2002 Typical base case, emissions for large stationary sources and fires were more representative of the 2000-2004 Baseline period. For large stationary sources' typical emissions, 5-years of CEM data were analyzed and typical seasonal and diurnally varying emissions were defined for when the sources where operating For the typical fire emissions, the locations of the 2002 Actual fire emissions were retained, but the intensity was reduced or increased to match the average conditions over the 5-year Baseline. The original intent of the CENRAP modeling of both a 2002 Actual and Typical base cases was to use the 2002 Actual base case for the model performance evaluation and the 2002 Typical base case with the 2018 emission scenario for the 2018 visibility projections.

The need to generate both the 2002 Typical and Actual base case inventories and perform CMAQ model simulations each time an emissions update or correction to the modeling occurred became burdensome and potentially could compromise the CENRAP schedule and available resources. For the Base F vintage emissions database, a model performance evaluation was conducted that compared the model performance of the 2002 Actual and Typical Base F CMAQ base case simulations to determine whether use of the Actual emissions substantially changed the interpretation of the model performance. The maximum change in model performance between the 2002 Actual and Typical base case was for sulfate and occurred during the summer months, when sulfate is the highest. Figure C-2 displays sulfate (SO4), nitrate (NO3), elemental carbon (EC) and organic matter carbon (OMC) performance for July 2002 across IMPROVE sites in the CENRAP region for the 2002 36 km Actual and Typical Base F CMAQ base case simulations. Although differences in predicted 24-hour SO4 concentrations are sometimes discernable in the scatter plot, the basic model performance conclusions remains the same and the difference in fractional bias (-48% vs. -49%) and fraction error (58% vs. 59%) are not significant. Similarly, the difference in NO3 model performance between the Actual and Typical Base F simulations are not significant. The performance of the CMAQ Actual and Typical simulation for EC and OMC is essentially identical. Given the similarity of the 2002 Base F Actual and Typical model performance evaluation, future CENRAP CMAQ model performance analysis were just performed on the Typical simulation.

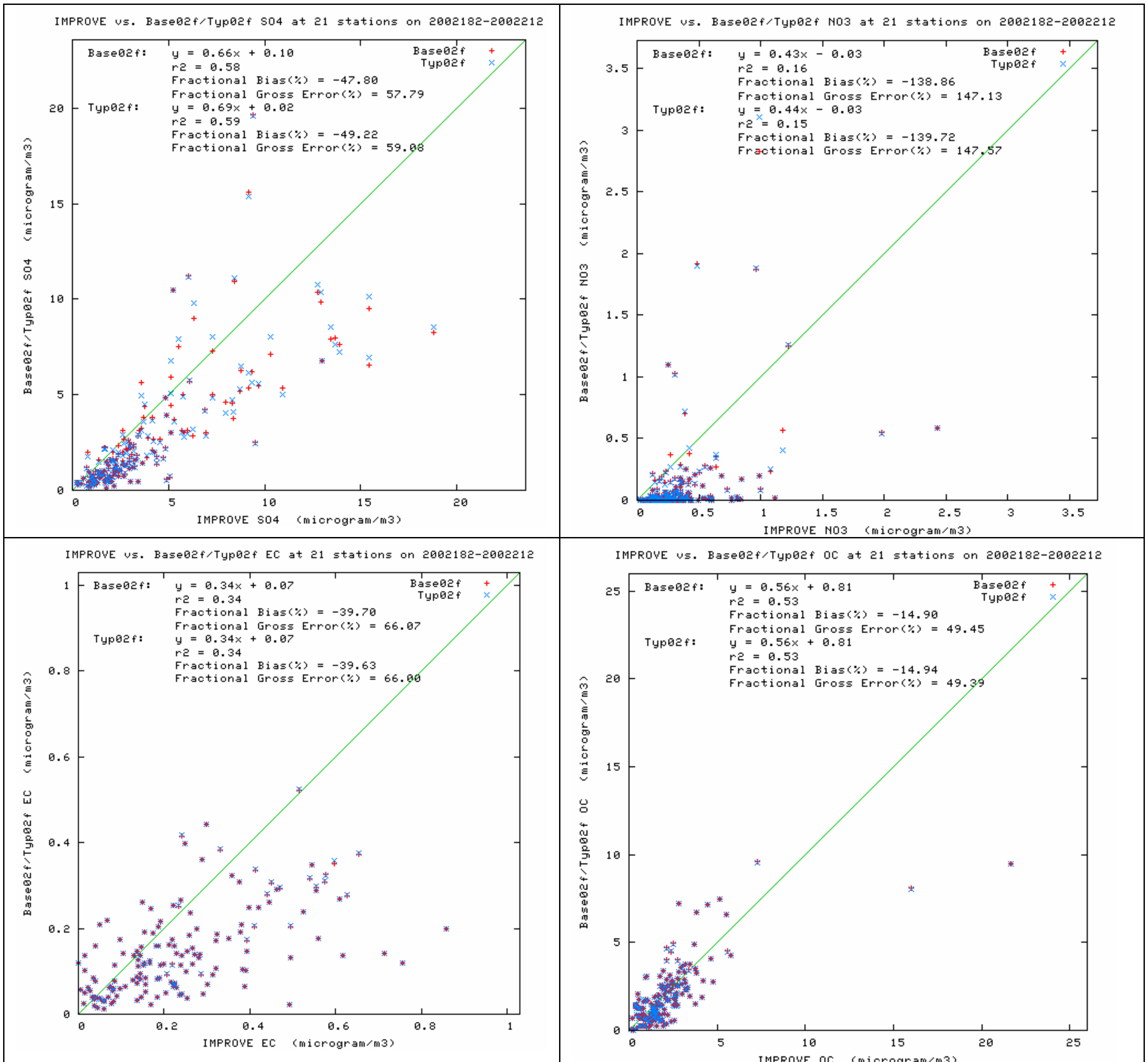


Figure C-2. Comparison of SO4 (top left), NO3 (top right), EC (bottom left) and OMC (bottom right) model performance for July 2002, the CENRAP region and the 2002 36 km Base F Actual (red) and Typical (blue) CMAQ base case simulation.

C.2 CMAQ Evaluation Methodology

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

- **<u>Operational Evaluation</u>**: Tests the ability of the model to estimate PM concentrations (both fine and coarse) and the components at PM_{10} and $PM_{2.5}$ including the quantities used to characterize visibility (i.e., sulfate, nitrate, ammonium, organic carbon, elemental carbon, other $PM_{2.5}$, and coarse matter ($PM_{2.5-10}$). This evaluation examines whether the measurements are properly represented by the model predictions but does not necessarily ensure that the model is getting "the right answer for the right reason"; and

- **<u>Diagnostic Evaluation:</u>** Tests the ability of the model to predict visibility and extinction, PM chemical composition including PM precursors (e.g., SOx, NOx, and NH_3) and associated oxidants (e.g., ozone and nitric acid); PM size distribution; temporal variation; spatial variation; mass fluxes; and components of light extinction (i.e., scattering and absorption).

The diagnostic evaluation also includes the performance of diagnostic tests to better understand model performance and identify potential flaws in the modeling system that can be corrected. The diagnostic evaluation may also includes the use of "probing tools" to understand why the model obtains a given prediction; probing tools include Process Analysis (PA), decoupled direct method (DDM) and source apportionment (SA).

In this final model performance evaluation for the 2002 Typical Base F CMAQ simulation, the operational evaluation has been given the greatest attention since this is the primarily thrust of EPA's modeling guidance. However, we have also examined certain diagnostic features dealing with the model's ability to simulate sub-regional and monthly/diurnal gas phase and aerosol concentration distributions. In the course of the CENRAP and other modeling process numerous diagnostic sensitivity tests were performed to investigate and improve model performance. Key diagnostic tests performed are discussed and the results for the rest are available on the CENRAP modeling website: http://pah.cert.ucr.edu/aqm/cenrap/index.shtml.

C.2.1 Ambient Air Quality Data for CENRAP Model Evaluation

The ground-level model evaluation database for 2002 was compiled by the modeling team using several routine and research-grade databases. The first is the routine gas-phase concentration measurements for ozone, NO, NO_2 and CO archived in EPA's Aerometric Information Retrieval System (AIRS) Air Quality System (AQS) database. Other sources of observed information come from the various PM monitoring networks in the U.S. These include the: (a) Interagency Monitoring of Protected Visual Environments (IMPROVE); (b) Clean Air Status and Trends Network (CASTNET); (c) Southeastern Aerosol Research and Characterization (SEARCH); (d) EPA Federal Reference Method $PM_{2.5}$ and PM_{10} Mass Networks (EPA-FRM); (e) EPA Speciation Trends Network (STN) of $PM_{2.5}$ species; and (f) National Acid Deposition Network (NADP). These PM monitoring networks may also provide ozone and other gas phase precursors and product species, and visibility measurements at some sites. During the course of the CENRAP modeling, the numerous base case simulations were evaluated across the continental U.S. In this section we focus our evaluation on model performance within the CENRAP region. Table C-1 summarizes the observations collected at each monitoring network within the CENRAP region and their sampling frequency with Figure C-3 displaying the locations of the monitors for the various monitoring networks operating in the CENRAP region during 2002.

Table C-1. Ambient monitoring data available in the CENRAP region during 2002.

Monitoring Network	Chemical Species Measured	Sampling Frequency; Duration
IMPROVE	Speciated $PM_{2.5}$ and PM_{10}	1 in 3 days; 24 hr
CASTNET	Speciated $PM_{2.5}$, Ozone	Hourly, Weekly; 1 hr, Week
SEARCH	24-hr PM_{25} (FRM Mass, OC, BC, SO_4, NO_3, NH_4, Elem.); 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;
NADP	WSO_4, WNO_3, WNH_4	Weekly
EPA-FRM	Only total fine mass ($PM_{2.5}$)	1 in 3 days; 24 hr
EPA-STN	Speciated $PM_{2.5}$	Varies; Varies
AIRS/AQS	CO, NO, NO_2, NO_x, O_3	Hourly; Hourly

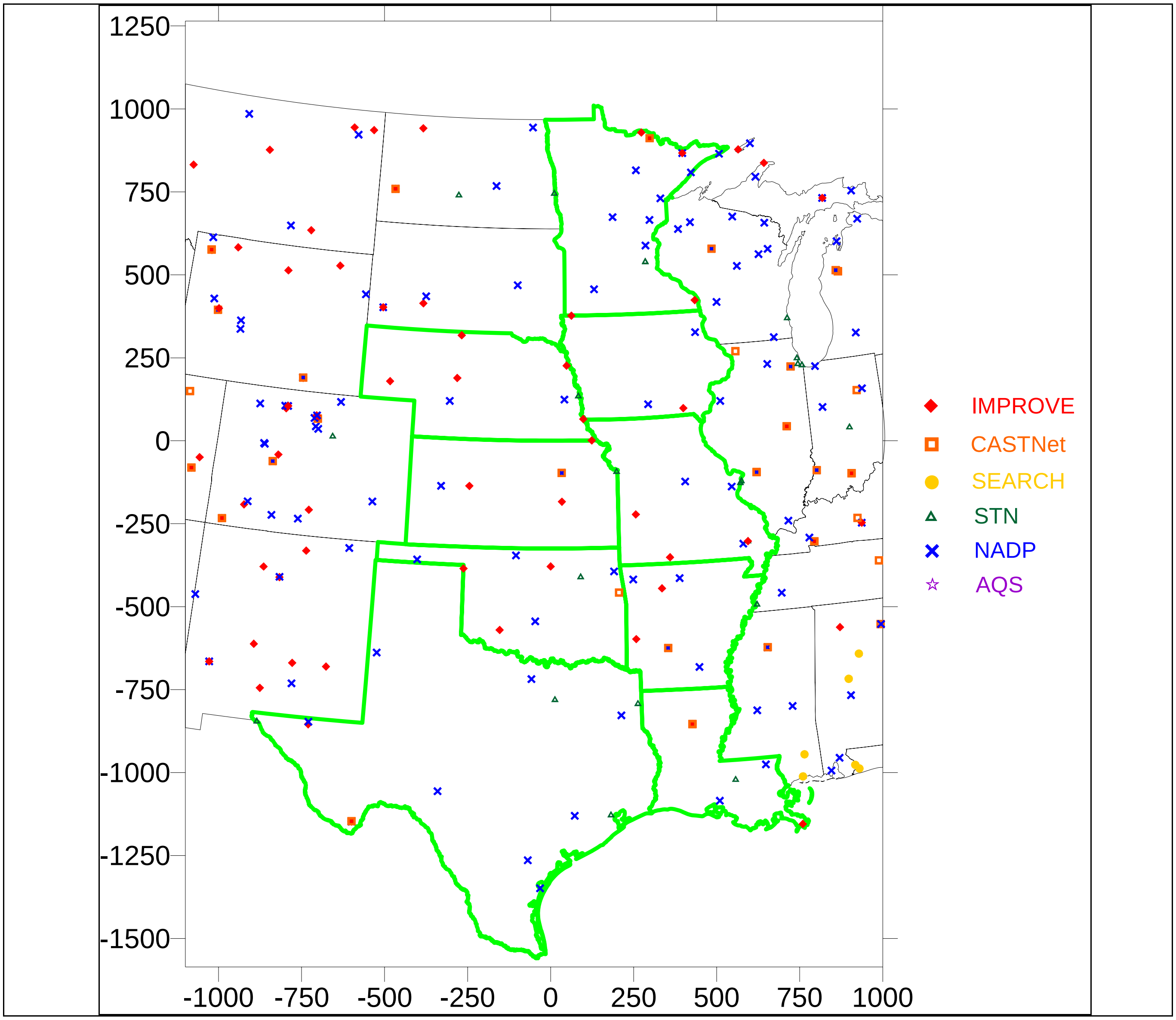


Figure C-3. Locations of surface monitors within the CENRAP states for sites operating during 2002.

C.2.2 Scope of CMAQ Model Performance Evaluation

The primary focus of the CMAQ Base F evaluation is on how well the model is able to replicate observed concentrations gas-phase pollutants and precursors, the various components of $PM_{2.5}$, total observed mass of $PM_{2.5}$, and wet deposition amounts. The CMAQ operational evaluation, model outputs are compared statistically and graphically with observational data obtained from the IMPROVE, CASTNet, STN, NADP and AQS monitoring networks. Because the SEARCH network is located in the southeastern U.S. (VISTAS region) outside of the CENRAP region, it is not a major component of our evaluation. Also, since the EPA-FRM network focuses on just $PM_{2.5}$ mass measurements primarily in $PM_{2.5}$ nonattainment or near nonattainment areas it is not very relevant for simulating regional haze at mainly remote Class I areas so is also not used in our model performance evaluation. The primary focus of the operational evaluation of the CMAQ 2002 Base F simulation is the performance of PM components in the CENRAP region for predicting regional haze at Class I areas.

Many statistical performance measures have been calculated using the different monitoring networks and across the different model performance subdomains (e.g., RPO regions). Table C-2 lists the definitions of the model performance evaluation statistical metrics. These performance metrics are routinely generate by the UCR Analysis Tool and are available on the project website. Many of them are measures of bias and error that are somewhat redundant.

Table C-2. Statistical Measures Used in the CENRAP CMAQ Model Evaluation.

Statistical Measure	Shorthand Notation	Mathematical Expression	Notes
Accuracy of paired peak (***A_p***)	**Paired_Peak**	$\frac{P - O_{peak}}{O_{peak}}$	P_{peak} = paired (in both time and space) peak prediction
Coefficient of determination (***r^2***)	**Coef_Determ**	$\frac{\left[\sum_{i=1}^{N}(P_i - \overline{P})(O_i - \overline{O})\right]^2}{\sum_{i=1}^{N}(P_i - \overline{P})^2 \sum_{i=1}^{N}(O_i - \overline{O})^2}$	P_i = prediction at time and location *i*; O_i = observation at time and location *i*; $\overline{P}$ = arithmetic average of P_i, i=1,2,…, N; $\overline{O}$ = arithmetic average of O_i, i=1,2,…,N
Normalized Mean Error (***NME***)	**Norm_Mean_Err**	$\frac{\sum_{i=1}^{N}\lvert P_i - O_i\rvert}{\sum_{i=1}^{N} O_i}$	Reported as %
Root Mean Square Error (***RMSE***)	**Rt_Mean_Sqr_Err**	$\left[\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2\right]^{1/2}$	Reported as %
Fractional Gross Error (***F_E***)	**Frac_Gross_Err**	$\frac{2}{N}\sum_{i=1}^{N}\left\lvert\frac{P_i - O_i}{P_i + O_i}\right\rvert$	Reported as %
Mean Absolute Gross Error (***MAGE***)	**Mean_Abs_G_Err**	$\frac{1}{N}\sum_{i=1}^{N}\lvert P_i - O_i\rvert$	
Mean Normalized Gross Error (***MNGE***)	**Mean_Norm_G_Err**	$\frac{1}{N}\sum_{i=1}^{N}\frac{\lvert P_i - O_i\rvert}{O_i}$	Reported as %
Mean Bias (***MB***)	**Mean_Bias**	$\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)$	Reported as concentration (e.g., $\mu g/m^3$)

Statistical Measure	Shorthand Notation	Mathematical Expression	Notes
Mean Normalized Bias (***MNB***)	**Mean_Norm_Bias**	$\frac{1}{N}\sum_{i=1}^{N}\frac{(P_i - O_i)}{O_i}$	Reported as %
Mean Fractionalized Bias (Fractional Bias, ***MFB***)	**Mean_Fract_Bias**	$\frac{2}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{P_i + O_i}\right)$	Reported as %
Normalized Mean Bias **(*NMB*)**	**Norm_Mean_Bias**	$\frac{\sum_{i=1}^{N}(P_i - O_i)}{\sum_{i=1}^{N}O_i}$	Reported as %
Bias Factor (***BF***)	**Bias Factor**	$\frac{1}{N}\sum_{i=1}^{N}\left(\frac{P_i}{O_i}\right)$	Reported as BF:1 or 1: BF or in fractional notation (BF/1 or 1/BF).

C.2.3 Operational Model Evaluation Approach

The CENRAP modeling databases will be used to develop the visibility State Implementation Plan (SIP) due in December 2007 as required by the Regional Haze Rule (RHR). Accordingly, the primary focus of the operational evaluation is on the six components of fine particulate ($PM_{2.5}$) and Coarse Matter ($PM_{2.5\text{-}10}$) within the CENRAP region that are used to characterize visibility at Class I areas:

- Sulfate (SO4);
- Particulate Nitrate (NO3);
- Elemental Carbon (EC);
- Organic Mass Carbon (OMC);
- Other inorganic fine particulate (IP or Soil); and
- Coarse Matter (CM).

The model performance for ozone and precursor and product species (e.g., SO_2 and HNO_3) is also evaluated to build confidence that the modeling system is sufficiently reliable to project future-year visibility.

C.2.5 Performance Evaluation Tools

One of the many challenges in evaluating an annual PM/ozone model simulation is how to synthesize model performance given the shear volume of output from an annual simulation. The model is run on a 148 x 112 x 19 grid with approximately 30 species producing hourly outputs for each day of the year. This results in approximately 90 trillion concentration estimates that are produced for an annual simulation. Thus, the synthesis and interpretation of numerous graphical and tabular displays of model performance into a few concise and descriptive displays that identify the most salient features of model performance is necessary. As part of the CENRAP modeling, as well as work performed by WRAP, VISTAS, MRPO and MANE-VU, several analysis tools and summary displays have been developed and are used:

> UCR Analysis Tools: The University of California at Riverside (UCR) Analysis Tools have been used extensively to evaluate the CMAQ and CAMx models for CENRAP (e.g., Morris et al., 2005), WRAP (Tonnesen et al., 2004), VISTAS (Morris et al., 2004) as well as other studies and are run on a Linux platform separately for each network. Numerous graphical displays of model performance are automatically generated using gnuplot. The software generates the following summary and graphical displays of model performance:
>
> - Tabular statistical measures (see Table C-2);
> - Time Series Plots for each site and species; and
> - Scatter Plots for each species by allsite_allday, allday_onesite and allsite_oneday.
>
> The UCR Analysis Tool is run for a specific subregion (e.g., by RPO region) and for selected monitoring networks. Because each monitoring network has its own measurement artifacts, the model is evaluated separately for each monitoring network.
>
> Summary Bias/Error Plots: The modeling team has developed additional displays of model performance statistics that elucidate model performance in a concise manner: (1) monthly time series plots of average bias and error; (2) soccer plots that display bias versus error and compares them to model performance goals and criteria; and (3) tools to analyze visibility model performance for the worst and best 20 percent visibility days that are used in visibility projections.
>
> GA DNR Analysis Plots: Dr. James Boylan of the Georgia Department of Natural Resources has extended the concept in EPA's draft PM fine particulate and regional haze modeling guidance that model performance for species that make up a major contribution to visibility impairment be subjected to more stringent goals than species that are minor contributors by developing concentration-dependent performance goals and "Bugle Plots" to display them (Boylan, 2004).

The evaluation of the CENRAP 2002 36 km Base F CMAQ simulation used each of the analysis tools listed above taking advantage of their different descriptive and complimentary nature. The use of these analysis tools generated thousands of statistical measures and graphical displays of model performance that cannot all be displayed in this report. The modeling team has gone through the plots and measures using slide shows to identify those displays that are most descriptive in conveying model performance so should be included in this TSD. The complete set of model performance statistics and graphical performance displays can be found on the CENRAP modeling Website at:

> http://pah.cert.ucr.edu/aqm/cenrap/cmaq.shtml#cmaq_typ02f_mpe

Note that model performance statistics are calculated separately for each of the monitoring networks. Different PM measurement technology can produce different measurement values even when measuring the same air parcel. Thus, when calculating model performance metrics, measurements in different networks are not mixed.

C.2.4 Subdomains Analyzed

CENRAP has been analyzing model performance in five subdomains corresponding to the states contained in the five RPOs (see Figure 1-1):

- CENRAP
- MRPO
- VISTAS
- MANE-VU
- WRAP

As CENRAP has refined its emissions inventory, the changes in model performance from one 2002 base case to another has diminished to the point where little has changed in the last few iterations. Thus, the CMAQ 2002 36 km Base F evaluation presented in this section was just performed for the CENRAP region and the reader is referred to the modeling Website (http://pah.cert.ucr.edu/aqm/cenrap/cmaq.shtml) and Morris and co-workers (2005) for the evaluation outside of the CENRAP region and the diagnostic model evaluation.

C.2.5 Model Performance Goals and Criteria

The issue of model performance goals for PM species is an area of ongoing research and debate. For ozone modeling, EPA has established performance goals for 1-hour ozone normalized mean bias and gross error of #±15% and #35%, respectively (EPA, 1991). EPA's draft fine particulate modeling guidance notes that performance goals for ozone should be viewed as upper bounds of model performance that PM models may not be able to always achieve and we should demand better model performance for PM components that make up a larger fraction of the PM mass than those that are minor contributors (EPA, 2001). EPA's final modeling guidance does not list any specific model performance goals for PM and visibility modeling and instead provides a summary of PM model performance across several historical applications that can be used for comparisons if desired. Measuring PM species is not as precise as ozone monitoring. In fact, the differences in measurement techniques for some species likely exceed the more stringent performance goals, such as those for ozone. For example, recent comparisons of the PM species measurements using the IMPROVE and STN measurement technologies found differences of approximately ∀20% (SO4) to ∀50% (EC) (Solomon et al., 2004).

For the CENRAP, VISTAS and WRAP modeling we have adopted three levels of model performance goals and criteria for bias and gross error as listed in Table C-3. Note that we are not suggesting that these performance goals be adopted as guidance or that they are the most appropriate goals to use. Rather, we are just using them to frame and put the PM model performance into context and to facilitate model performance intercomparison across episodes, species, models and sensitivity tests.

Table C-3. Model performance goals and criteria used to assist in interpreting modeling results.

Fractional Bias	Fractional Error	Comment
#∀15%	#35%	Ozone model performance goal for which PM model performance would be considered good – note that for many PM species measurement uncertainties may exceed this goal.
#∀30%	#50%	Proposed PM model performance goal that we would hope each PM species could meet
#∀60%	#75%	Proposed PM criteria above which indicates potential fundamental problems with the modeling system.

As noted in EPA's PM modeling guidance, less abundant PM species should have less stringent performance goals (EPA, 2001; 2007). Accordingly, we are also using performance goals that are a continuous function of average concentrations, as proposed by Dr. James Boylan at the Georgia Department of Natural Resources (GA DNR), that have the following features (Boylan, 2004):

- Asymptotically approaching proposed performance goals or criteria (i.e., the ∀30%/50% and ∀60%/75% bias/error levels listed in Table C-1) when the mean of the observed concentrations are greater than 2.5 ug/m^3.
- Approaching 200% error and ∀200% bias when the mean of the observed concentrations are extremely small.

Bias and error are plotted as a function of average concentrations. As the mean concentration approach zero, the bias performance goal and criteria flare out to ∀200% creating a horn shape, hence the name "Bugle Plots". Dr. Boylan has defined three Zones of model performance: Zone 1 meets the ∀30%/50% bias/error performance goal and is considered "good" model performance; Zone 2 lies between the ∀30%/50% performance goal and ∀60%/75% performance criteria and is an area where concern for model performance is raised; and Zone 3 lies above the ∀60%/75% performance criteria and is an area of questionable model performance.

C.2.6 Performance Time Periods

The CMAQ 2002 36 km Base F evaluation, model performance statistics and graphical displays are generated monthly using the native averaging times of each monitoring network (i.e., 24-hour for IMPROVE and STN; weekly for CASTNet and NADP; and hourly for AQS). As the focus of the RHR is on daily average visibility that is calculated from daily average PM species concentrations then the evaluation of the model for 24-hour concentrations is particularly relevant. The RHR places particular emphasis on the Worst 20% (W20%) and Best 20% (B20%) days at Class I areas. Thus, we also place particular emphasis on the model performance for PM species on the W20% and B20% days during 2002 at Class I areas.

C.2.7 Key Measures of Model Performance

Although we have generated numerous statistical performance measures (see Table C-2) that are available on the CENRAP modeling website, when comparing model performance across months, subdomains, networks, grid resolution, models, studies, etc. it is useful to have a few key measurement statistics to be used to facilitate the comparisons. It is also useful to have a subset of the 2002 year that can represent the entire year so that a more focused evaluation can be conducted. We have found that the Mean Fractional Bias and Mean Fractional Gross Error appear to be the most consistent descriptive measure of model performance (Morris et al., 2004b; 2005). The Fractional Bias and Error normalize by the average of the observed and predicted value (see Table C-2) because it provides descriptive power across different magnitudes of the model and observed concentrations and is bounded by -200% to +200%. This is in contrast to the normalized bias and error (as recommended for ozone performance goals, EPA, 1991) that is normalized by just the observed value so can "blow up" to infinity as the observed value approaches zero. Below we perform a focused evaluation of model performance for four months of the 2002 year that are used to represent the seasonal variation in performance:

- January
- April
- July
- October

We also present fractional bias and error for all months of 2002 using time series and bugle plots.

C.3 Operational Model Performance Evaluation in the CENRAP Region

In the following discussions we use selected monthly scatter plots, time series plots and model performance statistical measures from the UCR Analysis Tools application to the 2002 CMAQ Base F base case simulation in an operational evaluation of the model for PM species. We focus on the six main components of PM that are used to project visibility.

C.3.1 Sulfate (SO4) Monthly Model Performance

C.3.1.1 SO4 in January 2002

Figure C-4a displays scatter plots of predicted and observed SO4 concentrations or wet depositions for sites in the CENRAP regions using observations from the IMPROVE, STN, CASTNet and NADP monitoring networks; the IMPROVE and STN SO4 concentrations are 24-hour averages whereas the CASTNet SO4 concentrations and NADP SO4 wet deposition are weekly averages. The January SO4 performance at the IMPROVE and STN networks in the CENRAP region is quite good with low fractional bias (-12% to -13%) and some scatter (fractional error of 42% and 34%) but centered in the 1:1 line of perfect agreement. There is a net SO4 underestimation bias in January across the CASTNet network (fractional bias of -34%) with wet SO4 deposition overstated on average across the NADP sites in the CENRAP region (+40% fractional bias). Whether the overstated SO4 wet deposition is a contributor to the SO4 concentration underestimation bias is unclear, but it is in the correct direction to account for it.

The time series comparisons of predicted and observed 24-hour SO4 concentrations at CENRAP Class I area IMPROVE sites during January 2002 shown in Figure C-4b are quite encouraging. Although there are some days and sites with mismatches (e.g., January 26 at BOWA and VOYA) and sites with systematic performance problems (SO4 underestimated at BIBE), the time series in generally are quite good with the model tracking the observed temp[oral variation in daily sulfate in January and some sites exhibiting remarkable agreement (e.g., MING).

Figure C-4c displays the spatial variations in the predicted and IMPROVE observed SO4 concentrations for January 20, 23, 26 and 29, 2002, which are four consecutive days of IMPROVE monitoring using its 1:3 day monitoring frequency. On January 20 both the model and observations agree on that an elevated sulfate clouds is entering the CENRAP region across southern Illinois and Missouri. There is a sharp SO4 concentration gradient going east to west with both the model and observations estimating relatively clean SO4 values over Colorado. By January 23 the model and observations agree that elevated SO4 exists along a diagonal orientation from Chicago to East Texas. Although there are some SO4 model/observed spatial mismatches on this day (e.g., northern Louisiana and western Arkansas) the model generally reproduces the areas of elevated and low observed SO4. By January 29 the model and observations agree that SO4 has cleaned out of the CENRAP region. Although there are elevated SO4 observations in western North Dakota and northern Minnesota not reflected in the model. On January 29 there is an elevated tongue of SO3 entering the CENRAP region through southern Illinois stretching to the southwest almost to Big Bend in western Texas. Observed SO4 is measured at Big Bend but the modeled high SO4 is slightly east of there. There is very good agreement on this day between the predicted and observed spatial distribution of SO4.

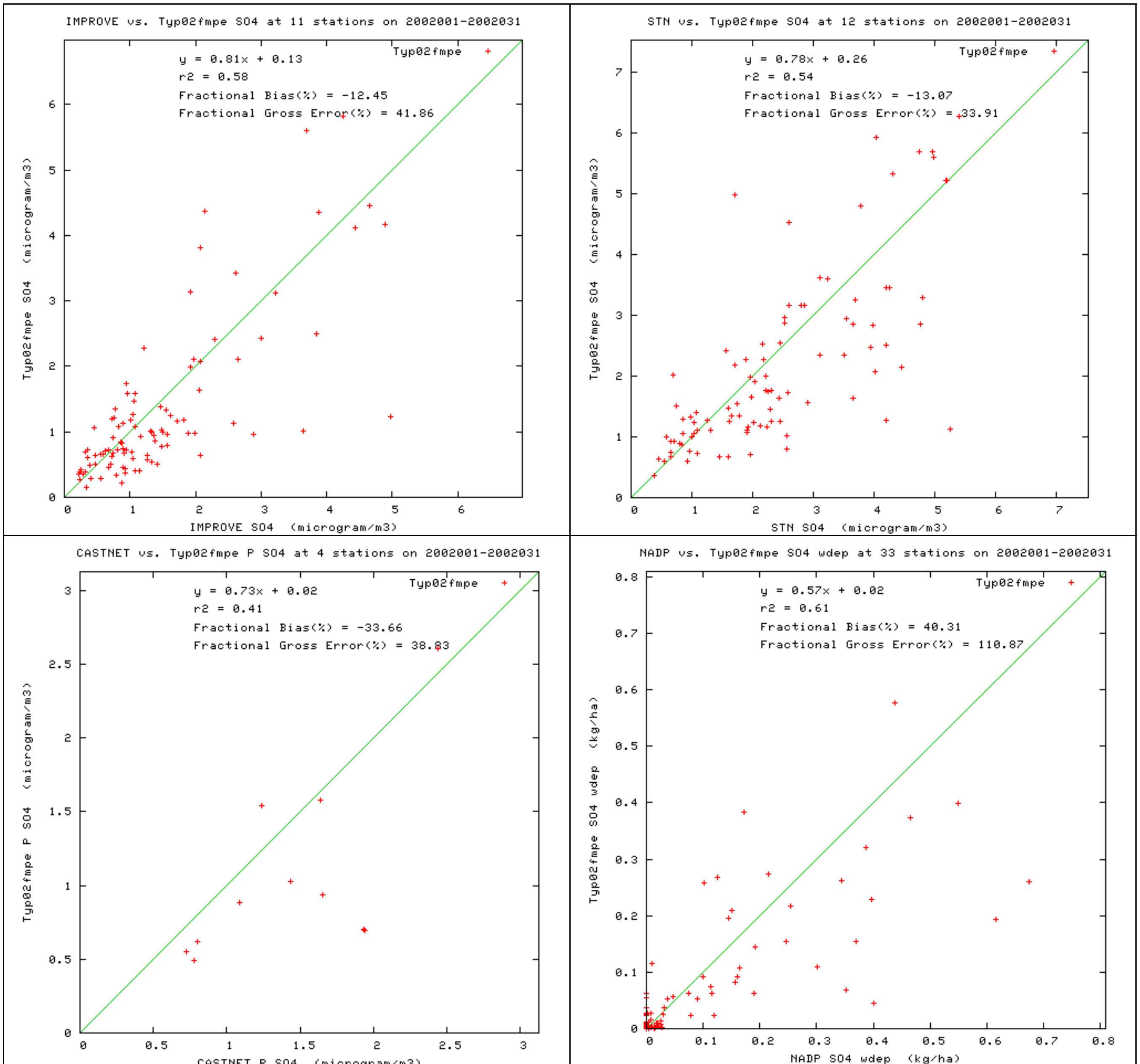
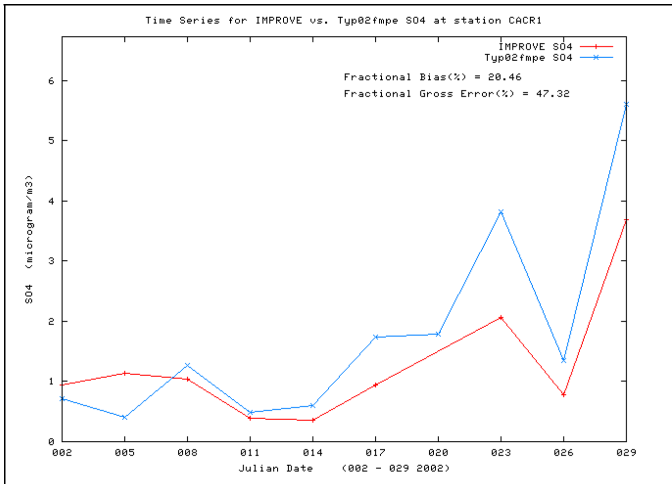
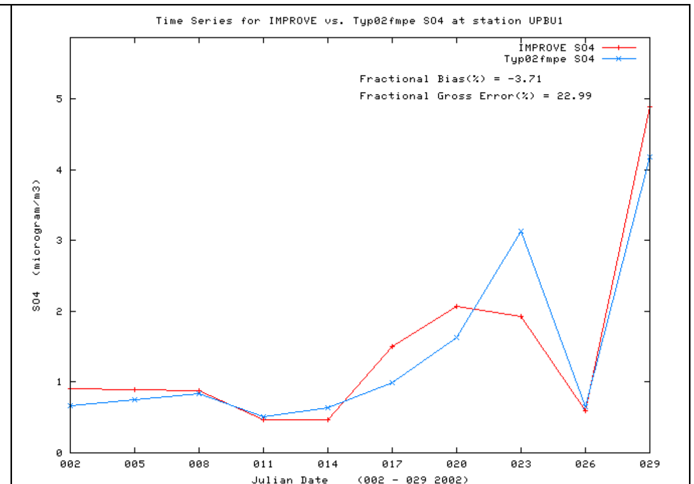
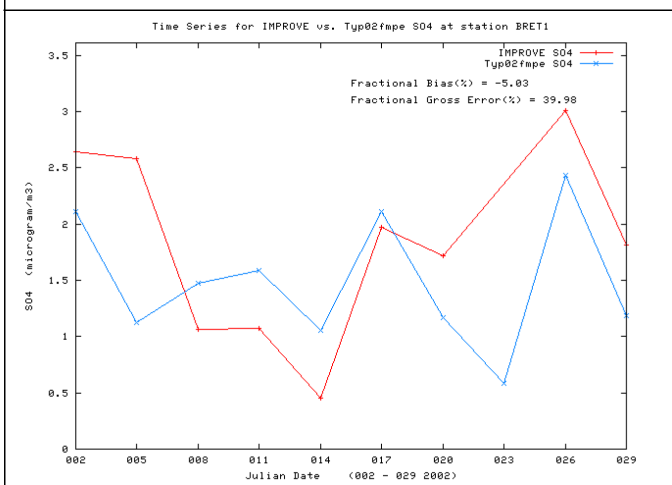
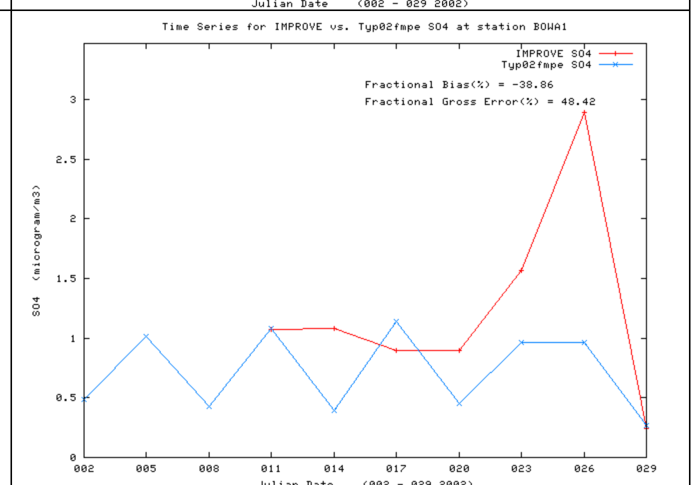


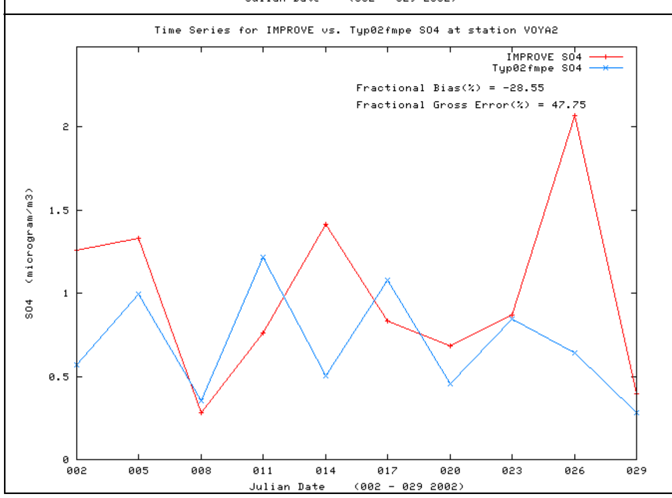
Figure C-4a. Scatter plots of predicted and observed sulfate (SO4) concentrations for January 2002 and sites in the CENRAP region using IMPROVE (top left), STN (top right), CASTNet (bottom left) and NADP monitoring networks using the CMAQ 2002 36 km Base F base case simulation.

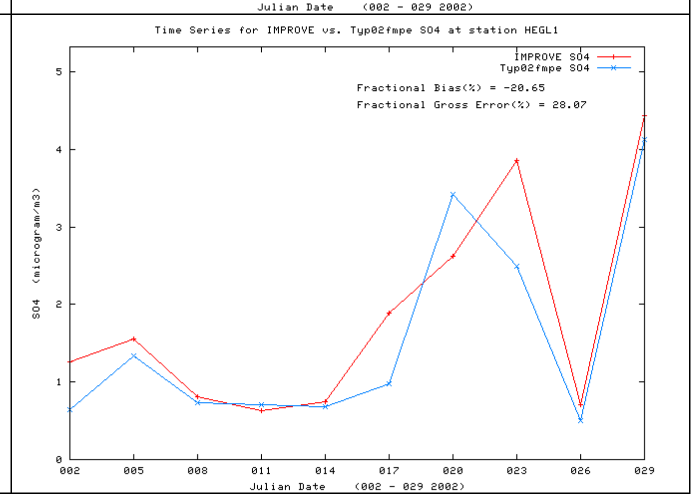

Time Series for IMPROVE vs. Typ02fmpe SO4 at station CACR1
IMPROVE SO4
Typ02fmpe SO4
Fractional Bias(%) = 20.46
Fractional Gross Error(%) = 47.32
SO4 (microgram/m3)
Julian Date (002 - 029 2002)


Time Series for IMPROVE vs. Typ02fmpe SO4 at station UPBU1
IMPROVE SO4
Typ02fmpe SO4
Fractional Bias(%) = -3.71
Fractional Gross Error(%) = 22.99
SO4 (microgram/m3)
Julian Date (002 - 029 2002)


Time Series for IMPROVE vs. Typ02fmpe SO4 at station BRET1
IMPROVE SO4
Typ02fmpe SO4
Fractional Bias(%) = -5.03
Fractional Gross Error(%) = 39.98
SO4 (microgram/m3)
Julian Date (002 - 029 2002)


Time Series for IMPROVE vs. Typ02fmpe SO4 at station BOWA1
IMPROVE SO4
Typ02fmpe SO4
Fractional Bias(%) = -38.86
Fractional Gross Error(%) = 48.42
SO4 (microgram/m3)
Julian Date (002 - 029 2002)


Time Series for IMPROVE vs. Typ02fmpe SO4 at station VOYA2
IMPROVE SO4
Typ02fmpe SO4
Fractional Bias(%) = -28.55
Fractional Gross Error(%) = 47.75
SO4 (microgram/m3)
Julian Date (002 - 029 2002)


Time Series for IMPROVE vs. Typ02fmpe SO4 at station HEGL1
IMPROVE SO4
Typ02fmpe SO4
Fractional Bias(%) = -20.65
Fractional Gross Error(%) = 28.07
SO4 (microgram/m3)
Julian Date (002 - 029 2002)

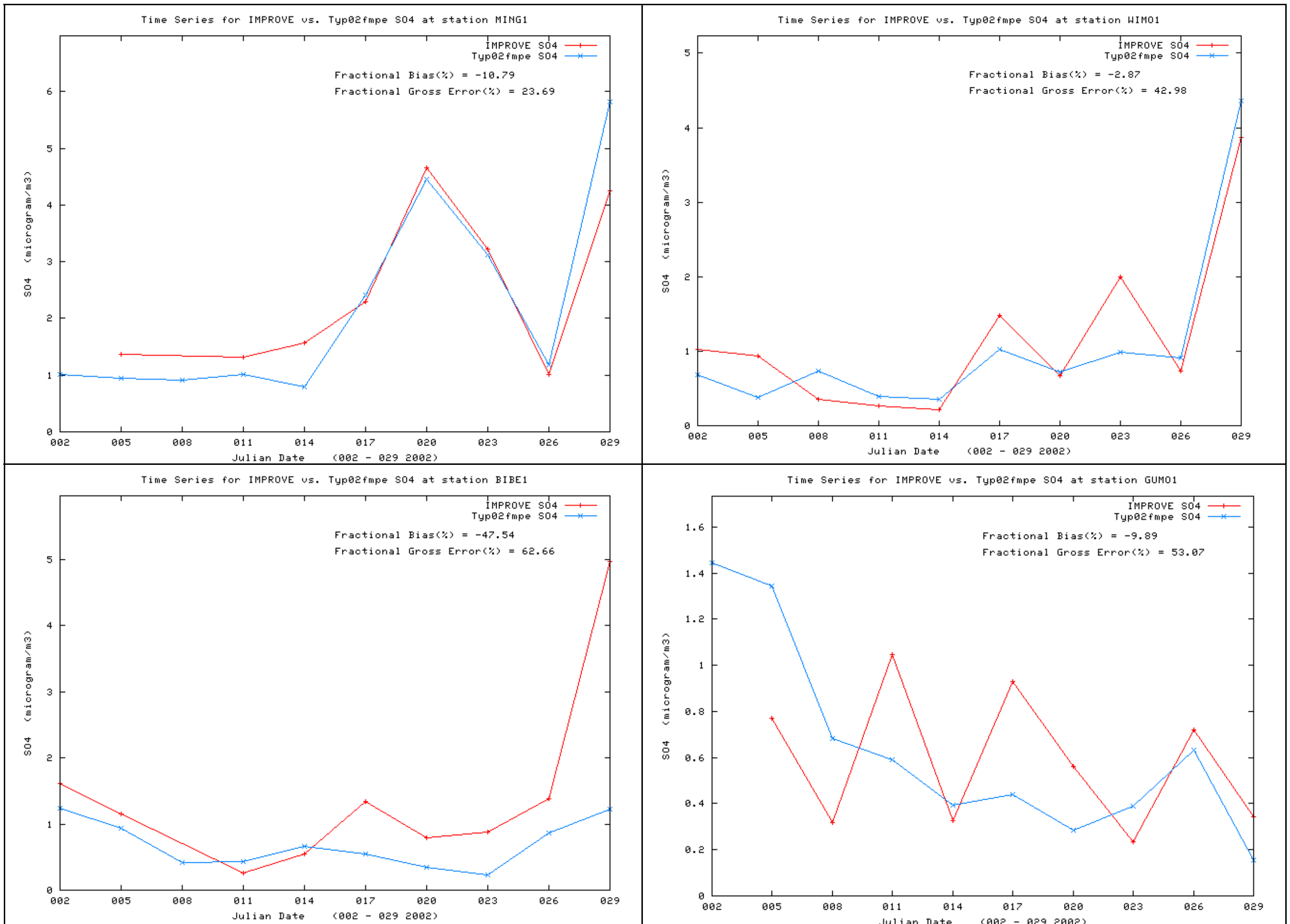


Figure C-4b. Time series of predicted and observed 24-hour sulfate (SO4) concentrations at CENRAP IMPROVE CLASS I AREA sites in January 2002 for CMAQ 2002 36 km Base F base case simulation.

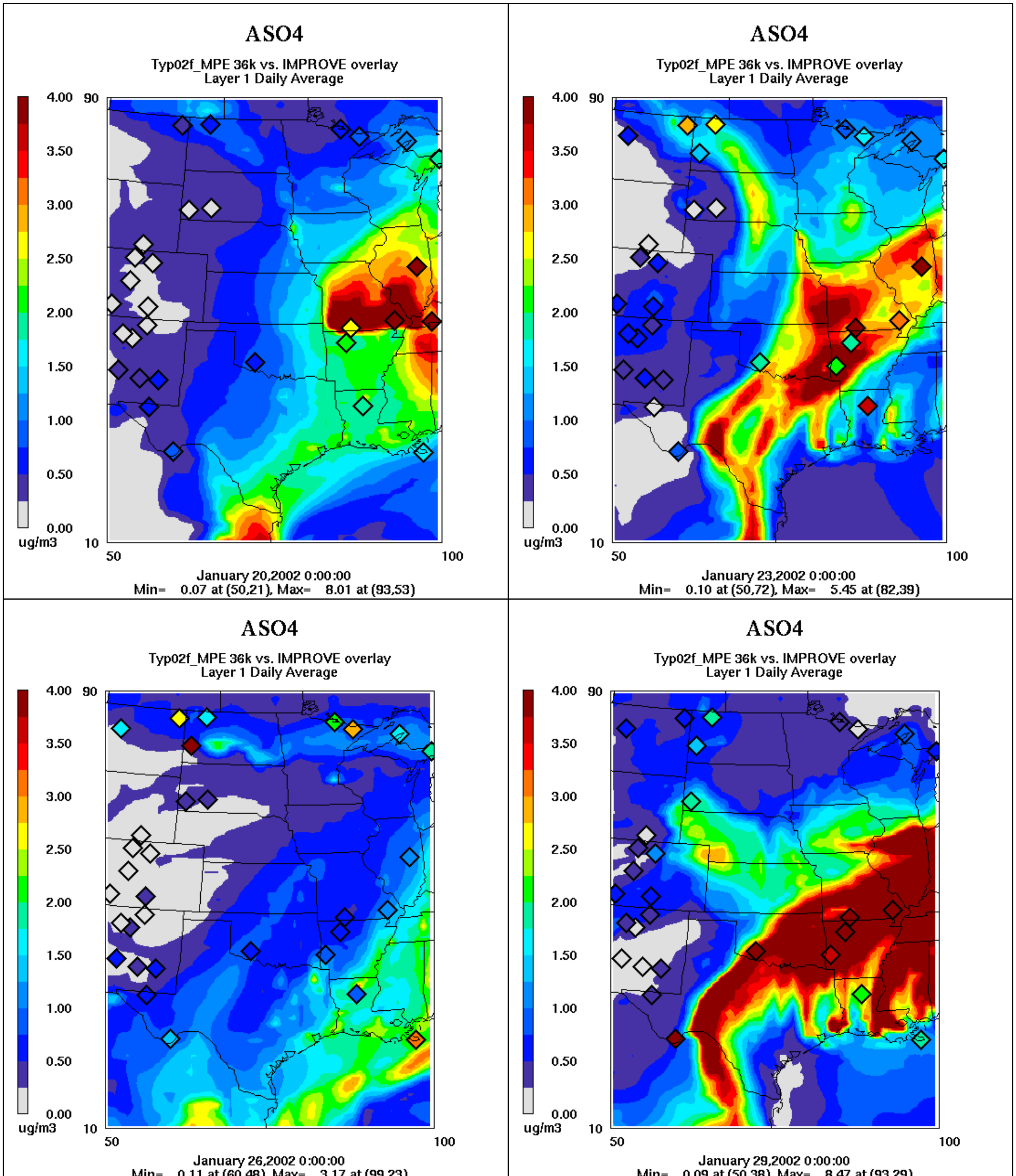


Figure C-4c. Spatial plot comparisons of the predicted and IMPROVE observed 24-hour SO4 concentrations for January 20, 23, 26 and 29, 2002.

C.3.1.2 SO4 in April 2002

In April CMAQ underestimates the observed SO4 in the CENRAP region with fractional bias values of -52%, -30% and -58% across the IMPROVE, STN and CASTNet networks (Figure C-5a). The fractional bias for wet SO4 deposition is quite low (3%) albeit with a lot of scatter which is reflected in high fractional error (78%). The ability of the model to reproduce the temporal variability of the April observed SO4 concentrations at the IMPROVE sites is quite variable. The SO4 underprediction bias is clearly present at several sites (e.g., HEGL, BIBE and GUMO), whereas there is quite good agreement at others (UPBU, BRET and VOYA). Comparisons of the spatial distributions of the predicted and observed SO4 concentrations on April 5, 8, 11 and 14 are shown in Figure C-5c. On April 5 the model reproduces the half circle of elevated SO4 across Texas-Louisiana, but appears to not be as large an area as observed coming up short from some of the sites (e.g., BIBE and GUMO). Model and observations agree that April 8 is a relatively low SO4 day in the CENRAP region with just a small intrusion of elevated values across Mississippi. On April 14 the model has two separate clouds of elevated SO4, one over East Texas-Louisiana and one over northeastern Illinois and eastward with a clean area in between in southern Missouri. The observations agree except that it has these two elevated SO4 areas connected with the southern Missouri area not as clean as in the model.

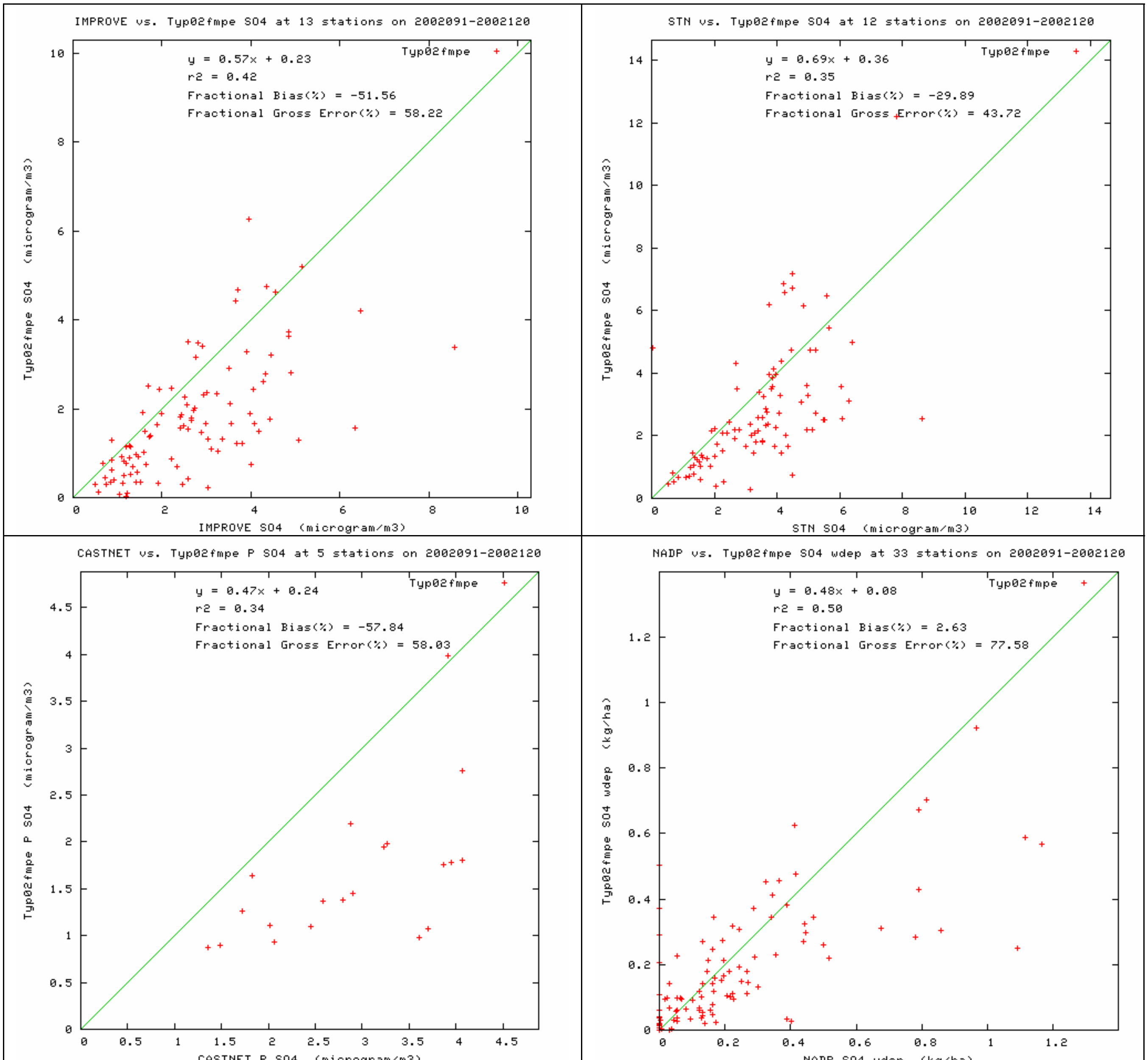


Figure C-5a. Scatter plots of predicted and observed sulfate (SO4) concentrations for April 2002 and sites in the CENRAP region using IMPROVE (top left), STN (top right), CASTNet (bottom left) and NADP monitoring networks using the CMAQ 2002 36 km Base F base case simulation.