Final Report

MODELING AN AUGUST 13-22, 1999 OZONE EPISODE IN THE DALLAS/FORT WORTH AREA

Work Order No. 582-04-65563-01

Prepared for

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EXECUTIVE SUMMARY

In 1997, the EPA established a new ozone standard, set at 0.08 parts per million ozone averaged over an 8-hour time frame. New implementation guidance for the 8-hour standard was issued on April 15, 2004. The new guidance classifies nine counties in the DFW area (Collin, Dallas, Denton, Tarrant, Ellis, Johnson, Kaufman, Parker and Rockwall) as a moderate 8-hour nonattainment area with an attainment date of 2010.

This TCEQ Work Order supports the photochemical modeling and SIP development required for the Dallas-Fort Worth (DFW) area. Specifically, it addresses the enhancement of the existing MM5 meteorological modeling in order to improve the accuracy of the meteorological modeling for the August 13-22, 1999 ozone episode. Further, the TCEQ developed updates to the DFW base year on-road mobile emission estimates, and under a separate Work Order, ENVIRON has included those changes to the input-modeling inventory. Both the meteorological and base year emission updates are documented in this report.

The focus of this work effort was an attempt to improve DFW CAMx ozone base-case performance for the August 1999 episode, particularly on August 17 when the model is under predicting peak ozone (ENVIRON, 2003) and showing the least sensitivity to emission controls. One hypothesis going into this work was that a general over prediction bias in MM5 surface wind speeds was leading to the development of high ozone too far downwind of the DFW core. This causes an ozone under prediction bias nearly every day of the episode, but acceptable unpaired peak performance when comparing the peak observation to the peak ozone in the downwind plume. By removing or reducing the over prediction bias in wind speed, perhaps the ozone performance would come more in line with acceptance criteria, and the impacts from emission controls may be magnified.

The work described here specifically attempts to improve the meteorological performance within and around the DFW over the entire simulation episode, with the goal of further improving the ozone air quality simulation as well. The original and alternative meteorological fields are evaluated in CAMx, and include tests using the original model configuration (original emissions in conjunction with CAMx v4.02), as well as an updated model configuration (updated on-road emissions in conjunction with CAMx v4.03).

Meteorological Improvements

The sensitivity tests designed and carried out in this project did not involve artificial tuning to obtain the answers we desired. The meteorological rework was based upon the problems that had been identified in the first round of modeling. All of the changes were justifiable since they were based upon operational experience, good science and new data.

Three MM5 sensitivity tests were conducted to evaluate impacts to wind performance. By increasing the surface roughness (Run1), the wind speed decreased noticeably, especially on the 12-km domain. The temperature and humidity performance also showed slight improvement in this simulation. A test without any analysis and observation FDDA (Run2) damaged wind and temperature performance, especially in terms of wind direction. The nudging was found to have positive impacts on the model performance. Nudging toward alternative large-scale analyses developed from the NNRP (Run3) indicated that there may be some improvements to the temperature and humidity performance. But the impact on the wind performance was negative with relatively higher overestimation of wind speed. Given that Run3 was made without the increased surface roughness, we feel that the NNRP data could be employed as an alternative analysis for this MM5 application. Neither sensitivity tests Run2 nor Run3 significantly improved MM5 model performance.

In Run4, additional data (DFW radar profiler data, Oklahoma Mesonet data, and SODAR data) were incorporated into the observation FDDA data file to improve the wind performance. Run 5 repeated this simulation, except that the EDAS analyses were replaced with NNRP analyses as input for initial/boundary conditions and analysis FDDA. The increased surface roughness used in Run1 was adopted in both of these last two MM5 runs. The addition of profiler and mesonet data to the observational FDDA inputs did not have any significant impact on MM5 performance in the DFW area, which remained quite similar to Run1. The same general results were true in Run5 as well.

Ozone Response

CAMx simulations were undertaken with the Run1, Run4, and Run5 meteorological fields to evaluate impacts on air quality model performance for ozone in the DFW area (referred to as CAMx Runs 13, 15, and 16, respectively). Note that the emission and other non-meteorological inputs were not altered for these simulations, and CAMx version 4.02 was used following the original work documented by ENVIRON (2003).

The largest improvements in MM5 wind performance resulting in Run1 did not lead to any dramatic improvement in CAMx ozone performance (on the basis of both 1- and 8-hour statistics). In fact, ozone performance was slightly degraded in general using both Run1 and Run4 meteorology. Evaluation of the spatial patterns of daily maximum ozone on the key day of interest (August 17) indicated no major differences among the different simulations. However, the MM5 Run5 (CAMx Run 16) scenario (which included increased surface roughness, additional profiler data into the observation FDDA file, and the use of NNRP in lieu of EDAS for analysis FDDA) generally led to better 1-hour and 8-hour bias/error performance statistics over the entire episode. On August 17, this model configuration led to lower 1-hour ozone levels, but conversely improved the under prediction bias for 8-hour ozone. Furthermore, quantile-quantile plots for peak 8-hour ozone were generally worse than the original TCEQ base case (CAMx Run 7c from ENVIRON, 2003).

The impacts of revised base-year on-road emission inputs on DFW ozone predictions were also explored in this study. Using the new emissions and upgrading to CAMx v4.03, daily maximum 8-hour ozone performance was evaluated using both the original meteorology (Run 17a) and best performing new meteorology (Run 17b). Results indicated only minor differences in ozone between the two different meteorological inputs. Subjective analyses of the daily maximum ozone fields in the DFW 4-km grid suggested that the new meteorological fields usually lead to slightly better model performance. Objective evaluation of quantile-quantile plots following EPA model performance guidance (EPA, 1999) similarly indicated minor differences in performance, with possibly the old meteorology resulting in somewhat better performance.

Conclusions

Although attempts to reduce the wind speed over prediction bias in the DFW area through a defensible modification to surface roughness were successful (and led to much improved wind speed performance over the region), the hypothesis that this should bring the urban ozone plume closer to the DFW core and therefore improve daily peak ozone performance was not substantiated in the tests we conducted. In fact, 1-hour peak ozone results were mixed. Run 16, which included all of the meteorological enhancements (increased roughness, additional observational nudging, and NNRP analyses), increased peak 1-hour ozone on August 16, but decreased peak ozone on the key day of interest (August 17). Overall, the under prediction bias exhibited in the original TCEQ base case simulation was improved in Run 16.

There are two possible reasons for this behavior. First, even though increasing surface roughness reduced surface wind speeds, it is likely that this effect was not translated through the bulk of the well-mixed planetary boundary layer, which is the region of urban plume transport. With effectively the same transport winds aloft, the overall spatial pattern of surface peak ozone was not significantly different from the original case, and so very similar bias and gross error was achieved. Apparently the simulated winds aloft were not impacted to any large degree by the inclusion of profiler data into the observational FDDA inputs. Second, subtle differences in meteorological fields arising from the roughness change and use of alternative NNRP input analyses led to modifications in temperature and mixing rates, which were likely the keys to impacting the values of the unpaired peak ozone statistics on certain days by slightly altering ozone formation efficiency and dilution.

The subtle differences in ozone performance arising from the different meteorological realizations modeled in this study confound the choice of the "best" MM5 simulation to use to establish a base case ozone model for DFW. The key to this choice is to emphasize objective metrics that remain consistent with the context within which this model will be used for potential regulatory analyses in the future. In this case, the emphasis should be on 8-hour ozone performance. The new Run 16 shows the greatest tendency toward improvement of overall 8-hour bias and error (over all observation/prediction pairings above 60 ppb) relative to the original TCEQ base case. However, the peak 8-hour performance as shown in the quantile-quantile (Q-Q) plots indicates worse performance for the highest peaks, consistent performance for mid-range values (50-80 ppb), and a larger degree of scatter. Although the Run 16 Q-Q plot showed poorer performance at the top end, the middle of the distribution (70-90 ppb) is most important because the majority of the data which will drive the RRF are included in those quantiles. The middle of the Run 16 quantile plot is very comparable to the middle of the Run 7c plot.

Given the "equivalence" between photochemical modeling results using the new (MM5 Run 5) and the original meteorology, our decision essentially reduces to which set of meteorology is the best performer against wind, temperature, and humidity observations in the area of focus. For this reason, we believe that the new MM5 Run 5 meteorology should be used for all future photochemical simulations. TCEQ has concurred with this decision, and has added additional weight by considering the overall improvements to the photochemical model's 1- and 8-hour bias and gross error with the new Run5 meteorology. Therefore, all future year DFW simulations for 2010 and Ozone Source Apportionment modeling in related projects (work orders 582-04-65563-4 and 58881-04-02) will utilize the MM5 Run 5 meteorology.

Also, past modeling of August 1999 in East Texas has shown the limitations of the large-scale analyses in properly characterizing the synoptic scale forcings in MM5 through FDDA. While this was dramatically improved in the latest East Texas MM5 applications (upon which the DFW modeling was based) it is possible that EDAS analyses are not properly specifying the location and intensity of the surface high pressure system that establishes itself in the south-central U.S. during August 16-19. We have looked into the use of an alternative source of analyses, and have undertaken MM5 sensitivity runs with these. We have also conducted one run in which MM5 was allowed to simulate August 17 freely without any analysis nudging to gauge the impact that analysis FDDA has on the results for that day.

Regional NOAA profiler data were incorporated into the original MM5 observation FDDA files, and these were used to nudge the model on the 12- and 4-km grids. However, the profiler data did not include local profilers operating in the DFW area during the August 1999 episode. TCEQ identified two additional sources of wind profile data, one that was compiled from several different sensors at the DFW airport by the Massachusetts Institute of Technology (MIT) Lincoln Laboratories as part of an ambient turbulence study (Dasey et al., 1998), and the other a SODAR operated by TCEQ at the Hinton air quality monitoring site. Review of documentation that discusses the FDDA data preparation performed by the University of Texas/CEER in 2001 verified that these additional DFW sites were not part of the profiler network that was originally prepared for MM5 nudging algorithm. TCEQ supplied both MIT and Hinton profiler data to ENVIRON so that they could be incorporate into the MM5 inputs.

Section 2 of this report details the MM5 applications and provides a summary of model performance for each additional simulation. Section 3 documents the resulting CAMx performance for replicating 1-hour and 8-hour ozone when input meteorology was developed from three of the MM5 runs; these CAMx runs were otherwise identical to the original CAMx simulations reported by ENVIRON (2003), and used v4.02 of the model for consistency. Section 4 presents CAMx results from two runs using the original and best new meteorology, but using v4.03 of the model and incorporating the latest TCEQ mobile source emission updates for the DFW area incorporated by ENVIRON under TCEQ Work Order #4. Section 5 provides our conclusions and recommendations.

The updated 1999 base-year emission inventory is detailed in the Appendices to this report. Appendix A provides tables of daily criteria emission rates by day, by county, and by source category. Appendix B provides daily criteria emission density plots by source category and by day.

1. INTRODUCTION

The 1990 Clean Air Act Amendments authorized the Environmental Protection Agency (EPA) to designate areas failing to meet the National Ambient Air Quality Standard (NAAQS) for ozone as nonattainment and to classify them according to severity. Once an area is declared nonattainment, the state must develop a State Implementation Plan (SIP) to improve the air quality by the attainment deadline. The SIP must contain an attainment demonstration, usually based upon photochemical modeling to show attainment by the deadline.

The TCEQ plans to submit to EPA an "Early Increment of Progress" plan not later than June of 2005 showing a 5% reduction in emissions from a 2002 baseline, effective by June of 2007. Then, a State Implementation Plan (SIP) including an attainment demonstration based on ozone modeling must be developed and submitted to EPA not later than June of 2007 showing attainment of the 8-hour ozone standard by 2010.

This TCEQ Work Order supports the photochemical modeling and SIP development required for the Dallas-Fort Worth (DFW) area. Specifically, it addresses the enhancement of the existing MM5 meteorological modeling in order to improve the accuracy of the meteorological modeling for the August 13-22, 1999 ozone episode. Further, the TCEQ developed updates to the DFW base year on-road mobile emission estimates, and under a separate Work Order, ENVIRON has included those changes to the input modeling inventory. Both the meteorological and base year emission updates are documented in this report.

This Work Order consisted of three tasks. The first task was to develop a work plan; this was completed and submitted to the TCEQ on May 18, 2004. Upon review, the TCEQ authorized ENVIRON to proceed with the remaining two technical work tasks. The objective of Task 2 was to undertake various sensitivity tests with MM5 to investigate potential reasons for poor wind performance in and around the DFW area on August 17, 1999. The objective of Task 3 was to incorporate additional DFW meteorological data sources into the MM5 nudging algorithm to improve wind performance overall and specifically on August 17th, and to expand the 36-km MM5 domain for future expansion of the CAMx 36-km air quality modeling domain. The work described here specifically attempts to improve the meteorological performance within and around the DFW over the entire simulation episode, with the goal of further improving the ozone air quality simulation as well. The original and alternative meteorological fields are evaluated in CAMx, and include tests using the original model configuration (original emissions in conjunction with CAMx v4.02), as well as an updated model configuration (updated on-road emissions in conjunction with CAMx v4.03).

BACKGROUND

While MM5 performance is generally acceptable for most days of the current August 1999 DFW 1-hour ozone modeling episode, a key under performing day (August 17) in the CAMx air quality model is linked to possible wind speed/direction errors in MM5. In the current MM5 results, the wind speed around DFW is slightly over-estimated. It is now clear from other MM5 applications around the country that default surface roughness is too low for the urban land use category. We have looked into increasing the surface roughness of the urban area, which slows near-surface winds, and possibly improves air quality model performance.

2. REVISED MM5 APPLICATIONS

APPROACH

The initial series of revised MM5 simulations included 3 investigative runs to gauge the impacts from various changes to the model and its inputs on surface wind performance in the DFW area. The first of these MM5 run involved testing the use of the latest Pleim-Xiu LSM/PBL module in MM5 (version 3.6) during the entire episode (August 12 – 22, 1999) with revised surface roughness to reduce wind speeds. The second run involved running a short MM5 simulation for August 16-17 without any analysis nudging to determine if the model performs better on the key days of interest without nudging. The third involved running an MM5 simulation for the same two-day period with nudging from a different data set, the NCEP/NCAR Reanalysis Project (NNRP), to determine if errors in the original nudging field lead to errors in the final output. Model performance for all three runs were developed using the METSTAT post-processor. Furthermore, surface wind fields and PBL depths were plotted to gauge any impacts to these parameters with these changes on the key days of interest.

After these initial simulations were completed and evaluated, an additional set of two MM5 simulations were carried out for the entire episode. The first included the updated observational FDDA input file that included new DFW wind profile data from the airport and the TCEQ Hinton site. The second was a re-run of the first, but using the NNRP dataset as input for analysis FDDA and initial/boundary conditions, rather than the EDAS dataset used in the original runs. Both of these simulations included the increased surface roughness specifications developed in the first investigative run described above.

Model Configuration

ENVIRON has previously suggested that CAMx air quality simulation results in Texas are influenced by the choice of boundary condition values set on the eastern and northern boundaries of the CAMx 36-km grid. To solve this issue, the TCEQ has agreed to expand the CAMx 36-km modeling grid eastward and northward to include all of the emissions in the Great Lakes, Ohio Valley, and East Coast areas. Therefore, the MM5 36-km domain must also be similarly extended; this new domain structure was developed under Task 2. The 36-km domain now has 76 by 88 points, which covers the East Coast and the Great Lakes areas. The 108, 12 and 4-km domains remain the same as the original modeling reported by ENVIRON (2003). Figure 2-1 shows the new and original domain configuration. Processing of all terrain and large-scale meteorological analysis datasets for the enlarged 36-km grid was conducted as previously reported.

The configuration of the MM5 physical treatments was taken from the original Run3, as described by ENVIRON (2003). Run3 was the case that provided meteorological inputs for the DFW CAMx modeling completed in 2003 (herein we refer to this run as Run3_old). It is summarized as follows:

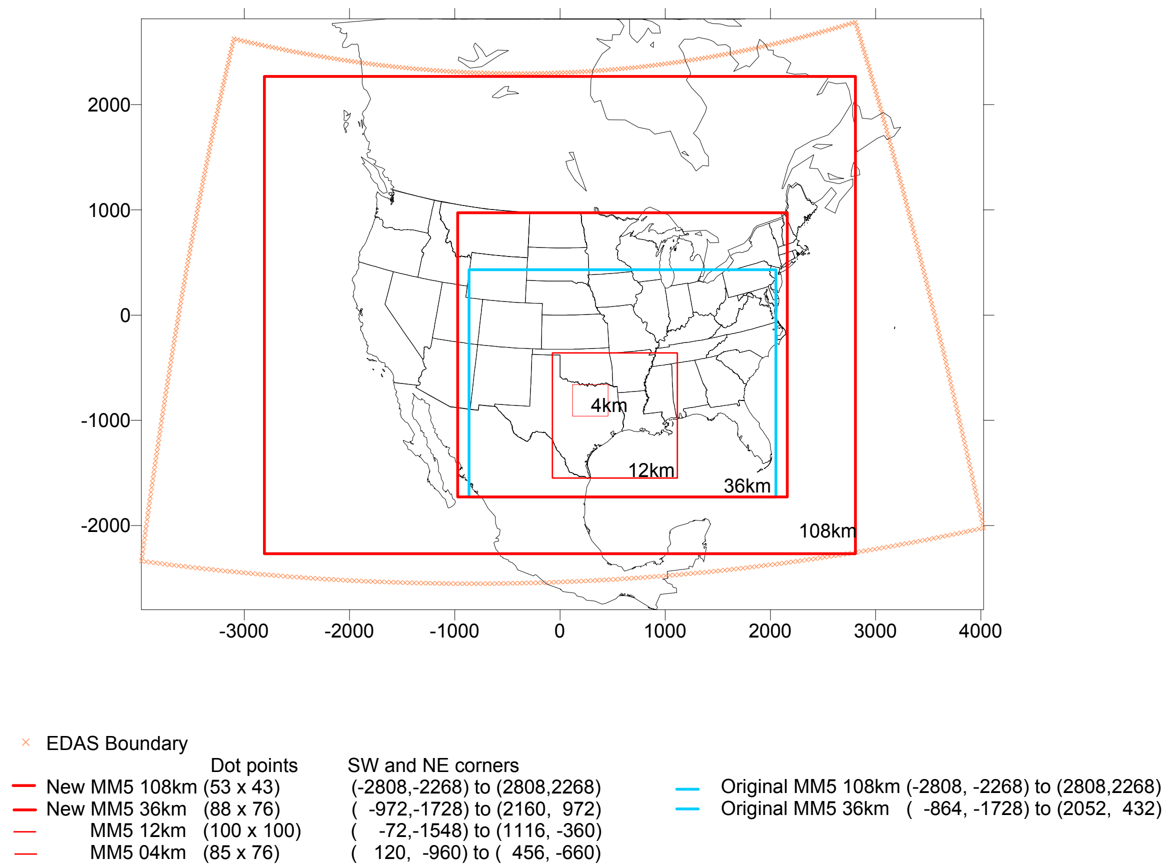


Figure 2-1. Alignment of the MM5 grids relative to the EDAS domain. Blue line shows the original extent of the 36-km grid.

- Simple Ice Microphysics
- Kain-Fritsch Cumulus Parameterization
- RRTM Radiation Scheme
- Pleim-Xiu Land Surface Model (LSM) and its coupled PBL Scheme
- Surface and 3D analysis nudging to wind, temperature and humidity fields in the 108, 36 and 12-km domains (nudging in the boundary layer is excluded);
- Observation nudging to wind in the 4 and 12-km domains.

However, an updated MM5 version (v3.6.2) was used in the current model simulations. The current MM5 release has two bugs fixed on the Pleim-Xiu Land Surface Model. These were related to daily and seasonal adjustments to vegetation fraction that mainly impacted deposition in the CMAQ air quality model. It is not clear at this point how much these changes affect MM5 results.

SENSITIVITY TEST ONE

In the first sensitivity test (Run1), the surface roughness was modified in order to lower the surface wind speed and possibly improve upon the general over prediction bias for surface winds. Studies (e.g., Boucouvala, et al., 2003) show that the current default surface roughness in

MM5 is too low for urban areas. Thus, the default summer season surface roughness table was modified to triple roughness for the urban classification (from 50 to 150 cm), and to double roughness for all other land use classifications. Note that this change applies to all grids and for the entire modeling episode.

Statistics on the 4-km Domain

The Run1 hourly statistics for surface wind, temperature, and humidity on the 4-km domain are compared to Run3_old in Figure 2-2. The overestimation of wind speed is lowered noticeably compared to Run3_old, especially during the starting and ending days of the episode. The simulation of wind direction is comparable to that of Run3_old. The performance for temperature and humidity in Run1 are also slightly improved during most of the episode days.

The daily statistics of surface wind, temperature, and humidity on the 4-km domain for Run1 and Run3_old are displayed in Figure 2-3. The wind speed bias from Run1 is much lower than that of Run3_old during the whole episode. But the wind direction biases are relatively higher during the first two episode days and August 18-19. This is possibly due to the weaker speeds that may lead to more variable directions. The temperature performance of Run1 and Run3_old are comparable while the humidity performance of Run1 is slightly better.

Statistics on the 12-km Domain

The hourly time series and statistics of surface wind, temperature, and humidity on the 12-km domain are shown in Figure 2-4. Compared to the results on the 4-km domain, the improvements for wind speed and humidity are significantly larger in Run1. The overestimation of wind speed (Figure 2-4a) is decreased consistently during the whole episode. The underestimation of humidity (Figure 2-4c) is largely improved in Run1 compared to Run3_old. The overall temperature performance for Run1 is similar to that of Run3_old, though the temperature bias from Run1 is relatively higher on August 14.

The same trend is evident in the daily statistics (Figure 2-5). The wind speed bias (Figure 2-5a) is much lower in Run1, as is the humidity bias. However, the temperature performance (Figure 2-5c) in Run1 is worse to a certain degree. Though the temperature IOA from Run1 and Run3_old are comparable, the temperature bias, gross error and RMSE from Run1 are all higher to some extent.

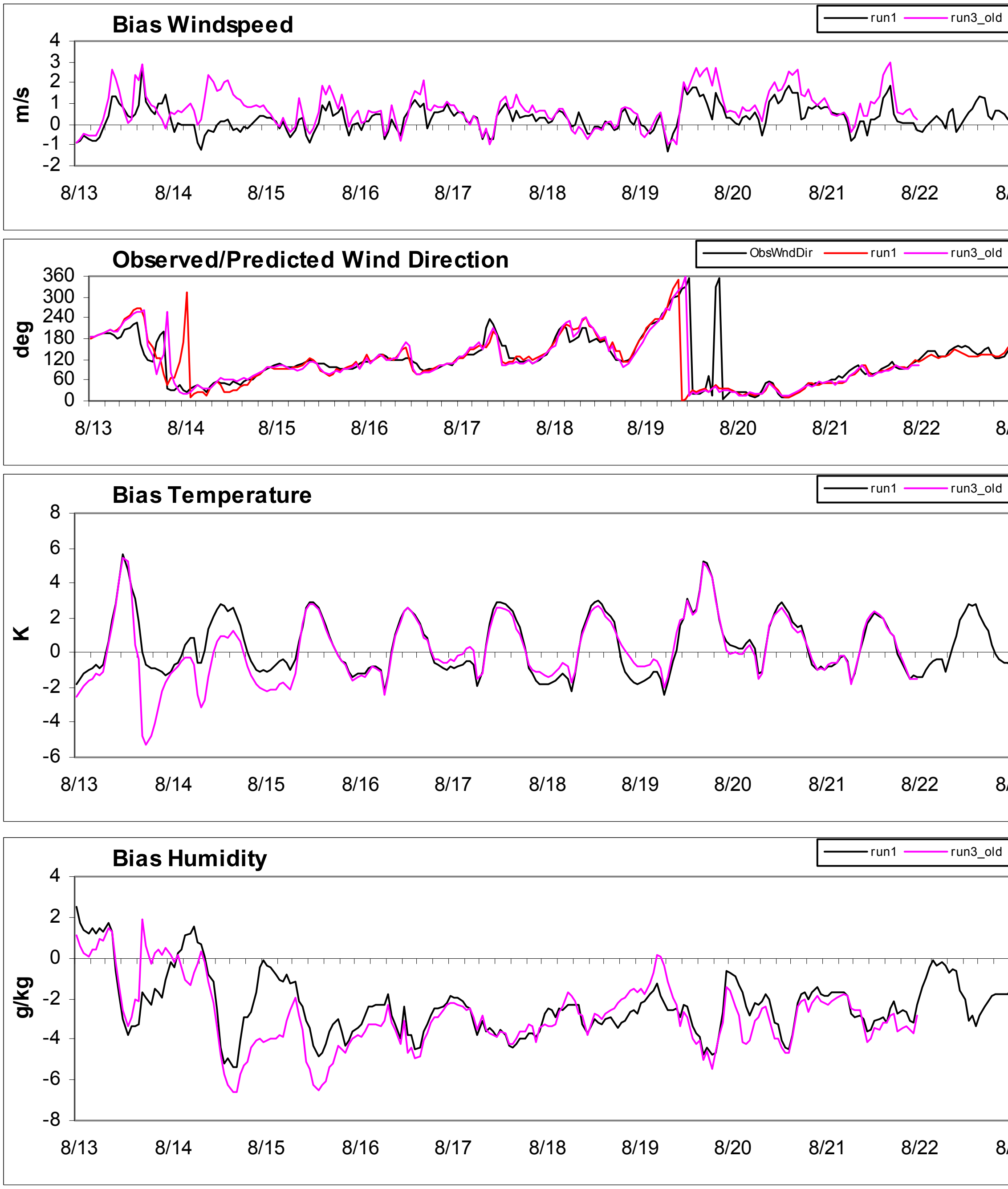


Figure 2-2. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run1 and Run3_old in the MM5 4-km domain.

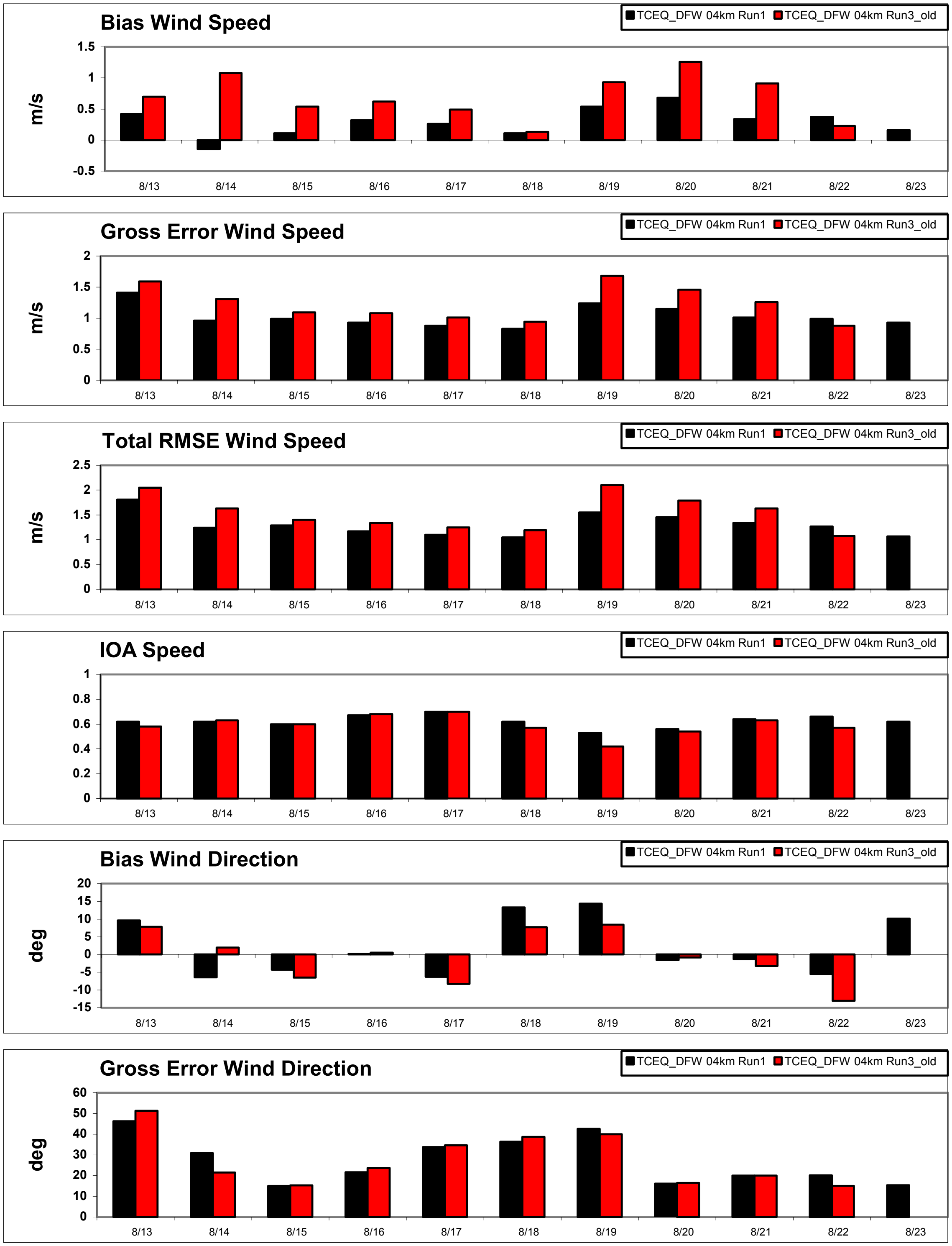


Figure 2-3a. Daily performance statistics for winds for Run1 and Run3_old in the MM5 4-km domain.

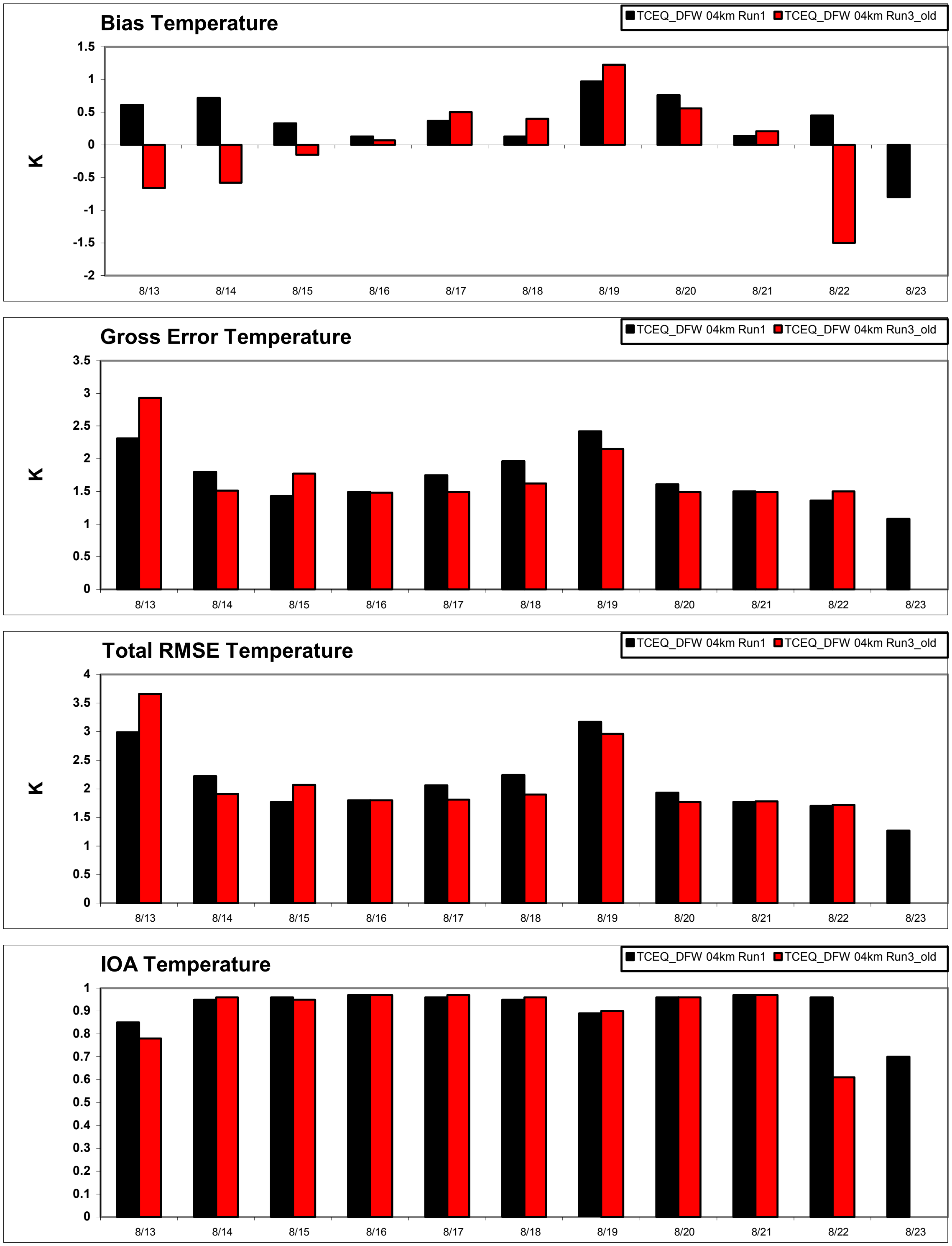


Figure 2-3b. Daily performance statistics for temperature for Run1 and Run3_old in the MM5 4-km domain.

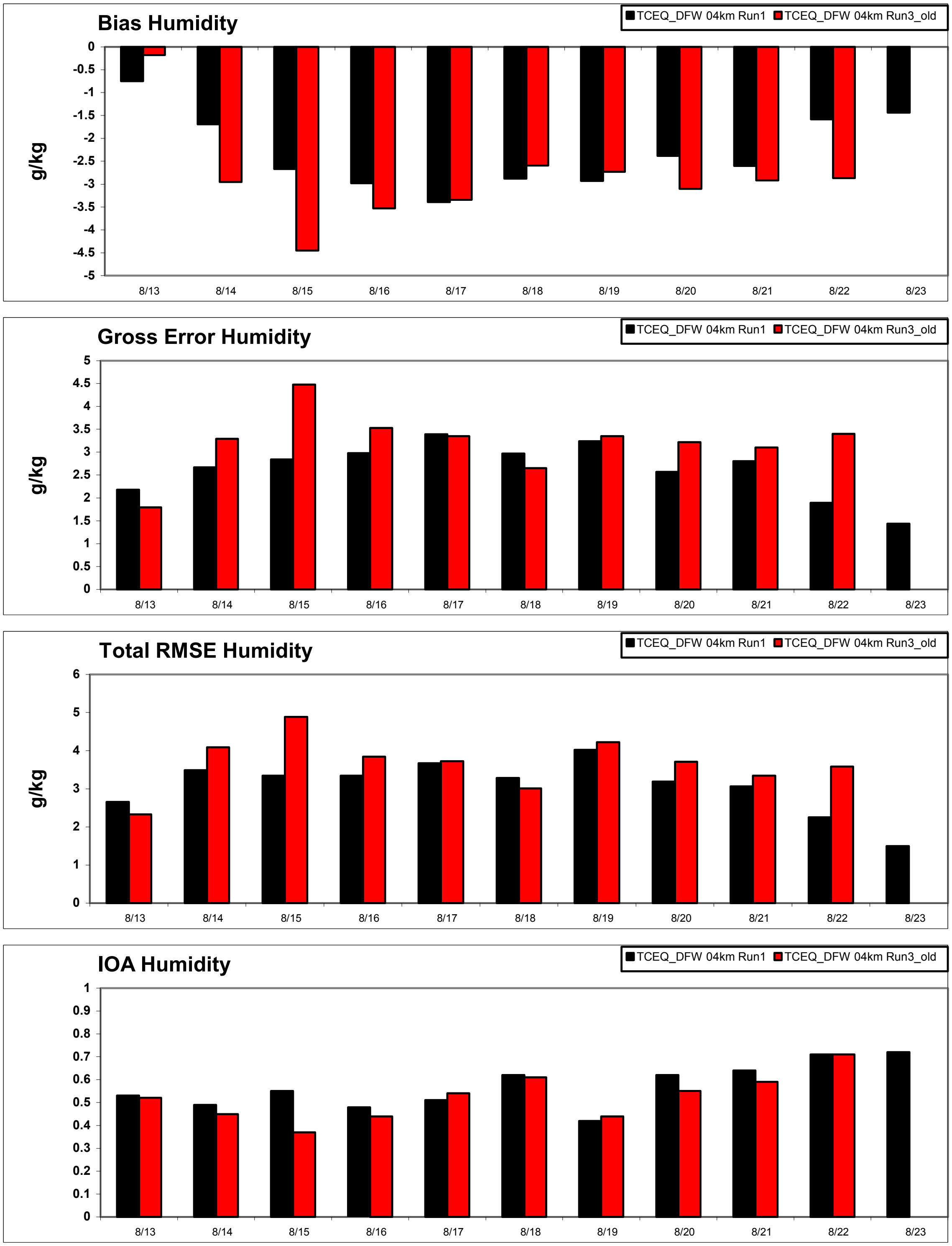


Figure 2-3c. Daily performance statistics for humidity for Run1 and Run3_old in the MM5 4-km domain.

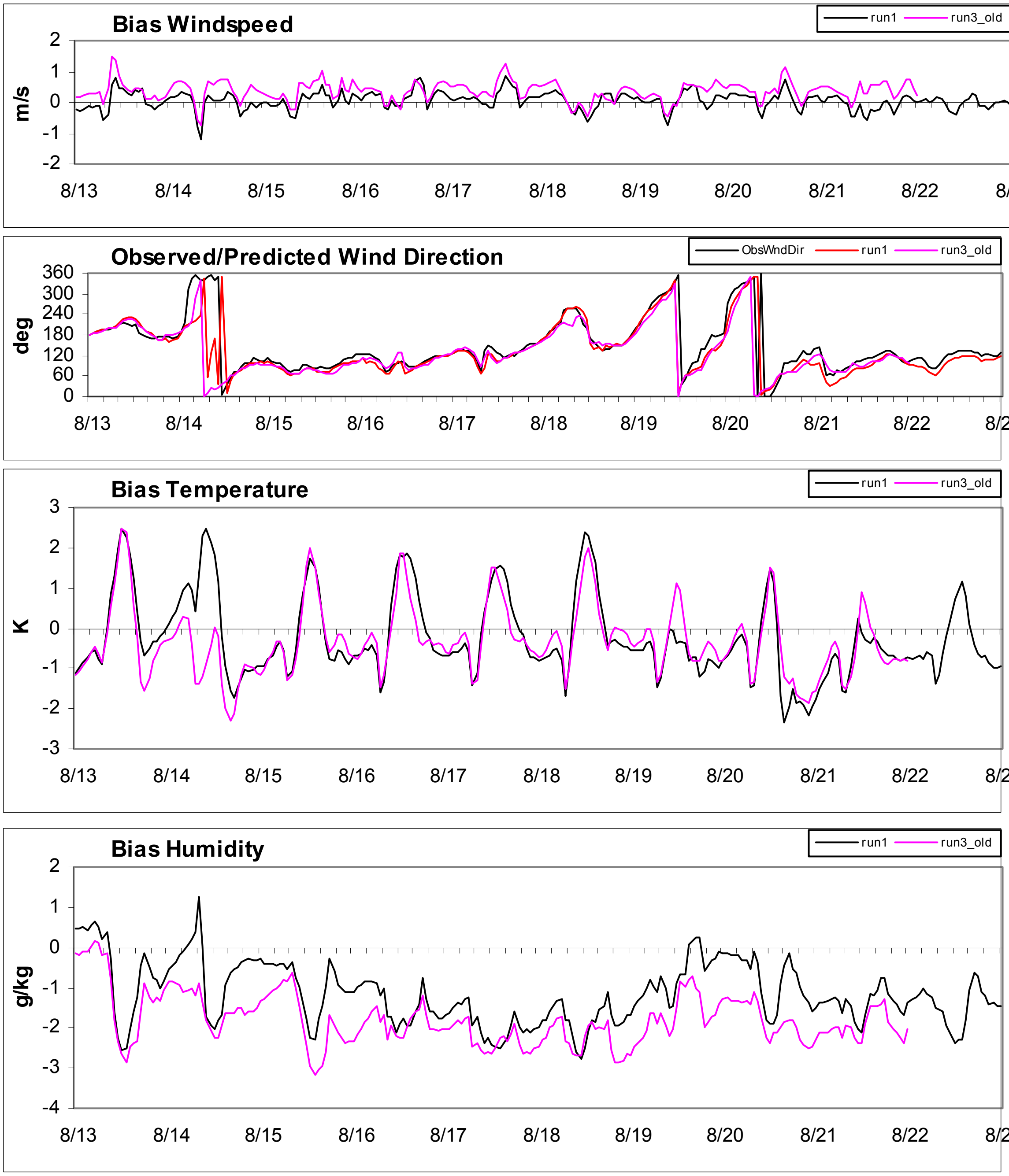


Figure 2-4. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run1 and Run3_old in the MM5 12-km domain.

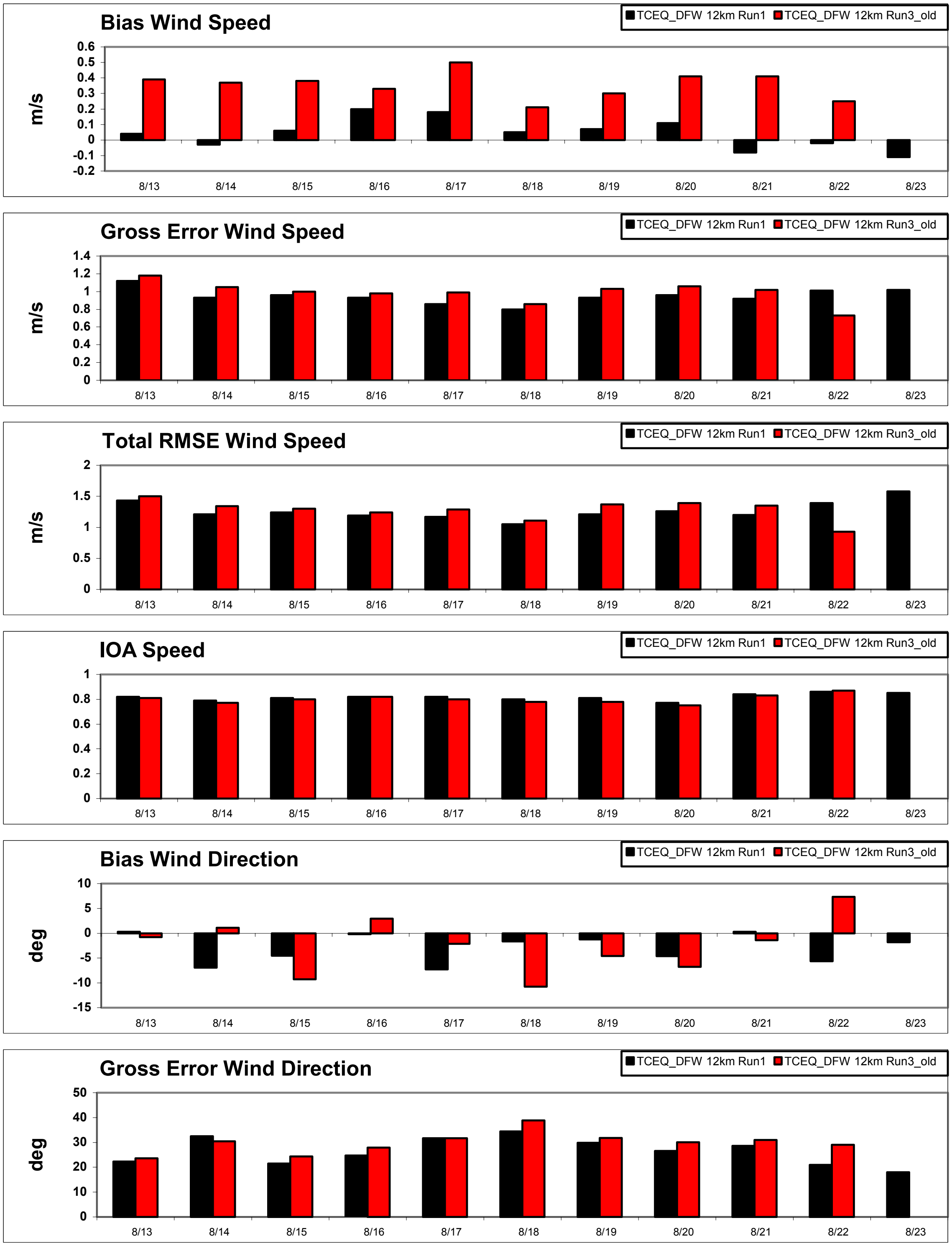


Figure 2-5a. Daily performance statistics for winds for Run1 and Run3_old in the MM5 12-km domain.

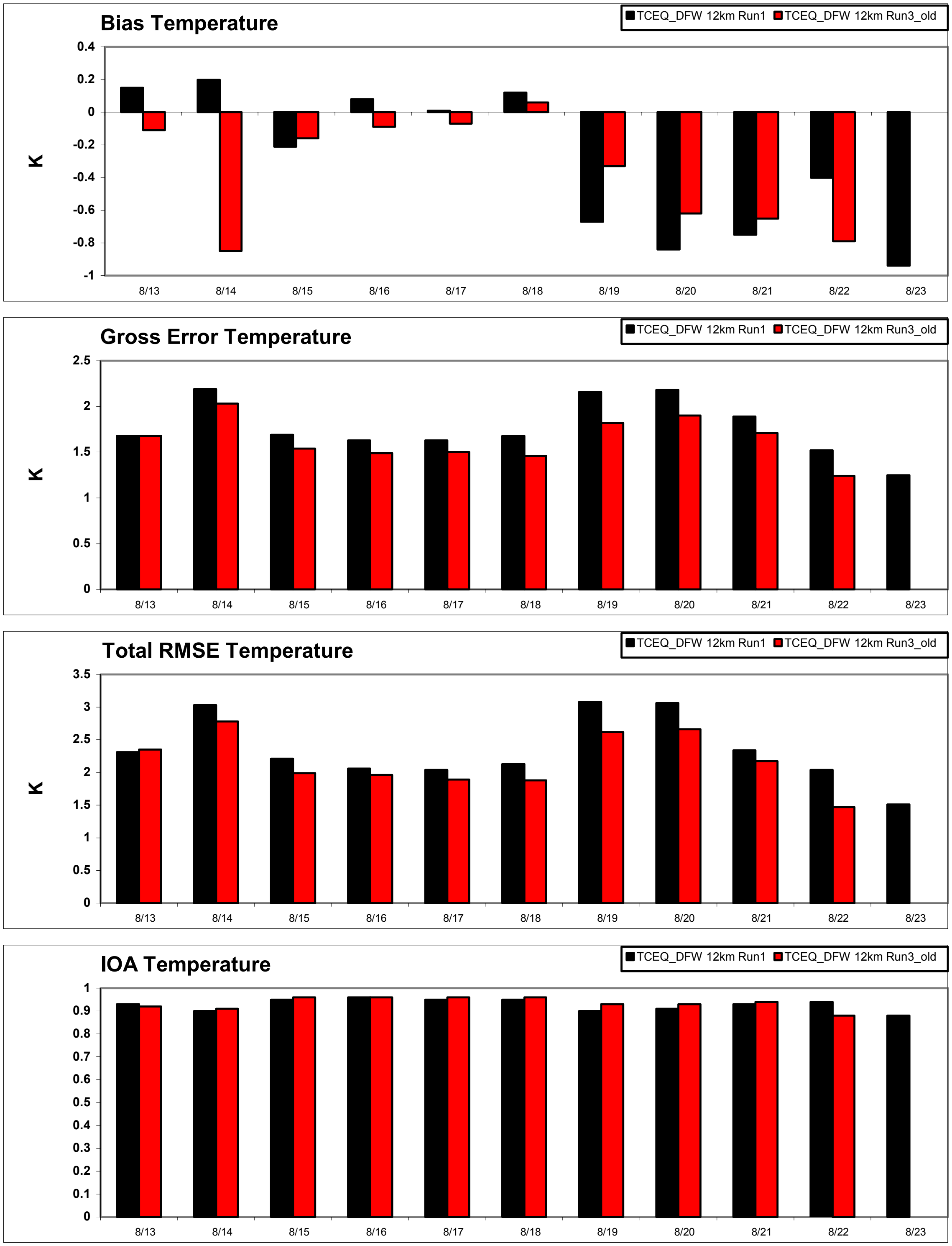


Figure 2-5b. Daily performance statistics for temperature for Run1 and Run3_old in the MM5 12-km domain.

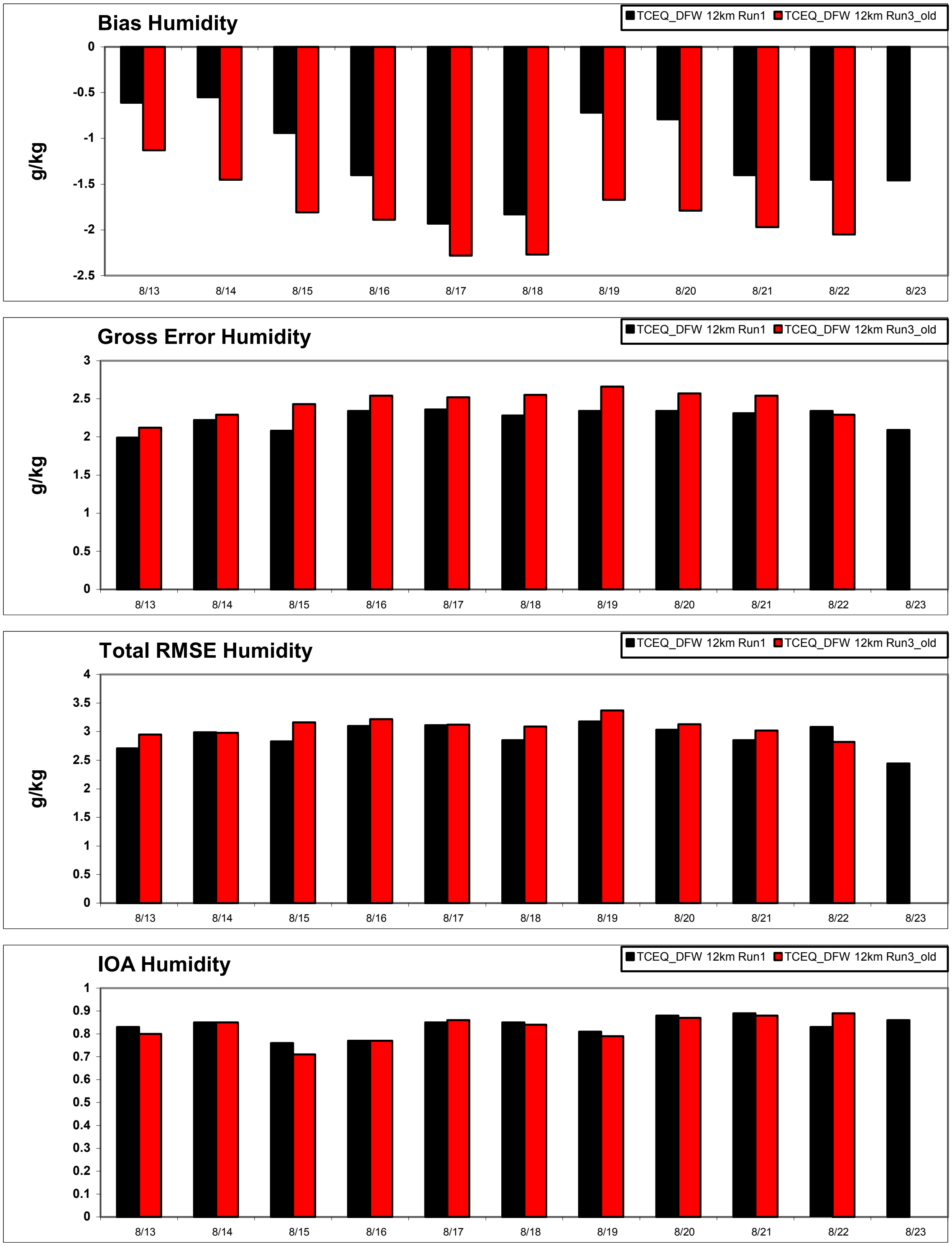


Figure 2-5c. Daily performance statistics for humidity for Run1 and Run3_old in the MM5 12-km domain.

Evaluation of Surface Wind Fields and PBL Depths

The 4-km surface wind fields from Run1 and Run3_old at 3 PM local time on August 16-18 are displayed in Figures 2-6 through 2-8. The major circulation patterns from these two runs are similar. However, the wind speed from Run1 is lower over most of the domain. On August 16 (Figure 2-6), winds were mainly from the east and slightly southeast (Run1) instead of northeast (Run3_old) in the northeast and central portions of the domain. On August 17 (Figure 2-7), the stagnant conditions are stronger, and more southerly wind occurred in the eastern areas in Run1. On August 18, much weaker winds occurred in the southern area, but winds were relatively stronger in the western area in Run1 (Figure 2-8).

The 4-km PBL depths from Run1 and Run3_old at 3 PM local time on August 16 – 18 are shown in Figures 2-9 through 2-11. There were no significant changes between these two runs except that the PBL "holes" were relatively deeper in Run1. These "holes" have consistent locations each day of the episode, and are associated with lakes in the area. On August 18 (Figure 2-11), the extremely high PBL depth areas from Run1 were mainly constricted to the central and northwest corner of the domain, unlike those of Run3_old, which spread all over the domain.

SENSITIVITY TESTS TWO AND THREE

To further investigate the performance for wind speed on August 17, two sensitivity tests were designed to simulate 60 hours containing August 17, starting at 00 UTC August 16:

- Run2 involved running MM5 without any nudging for the 60 hour period to determine if the model performs better without nudging.

- Run3 involved running MM5 with analysis nudging to a different data set, the NCEP/NCAR Reanalysis Project (NNRP) data, to determine if errors in the original nudging field lead to errors in the final output. The NNRP data were also used to provide boundary conditions.

Note that no modifications to surface roughness were applied for the above two runs.

The NNRP dataset differs substantially in terms of data sources, content and resolution from the EDAS dataset used in all MM5 simulations for DFW up to this point. The EDAS system provides a set of surface and multiple pressure level meteorological analyses at 3-hour intervals over the North American continent with a spatial resolution of ~40 km (a Lambert projection is employed, referred to by NCEP as the "212" grid). EDAS also provides deep soil temperature and moisture fields, which are accessed for MM5's land surface models. EDAS ingests a variety of data sources, from standard surface and rawinsonde observations, ships, aircraft, radar, and satellites. The products of these analyses are used to initialize the NCEP's operational 48-hour Eta model forecasting cycles.

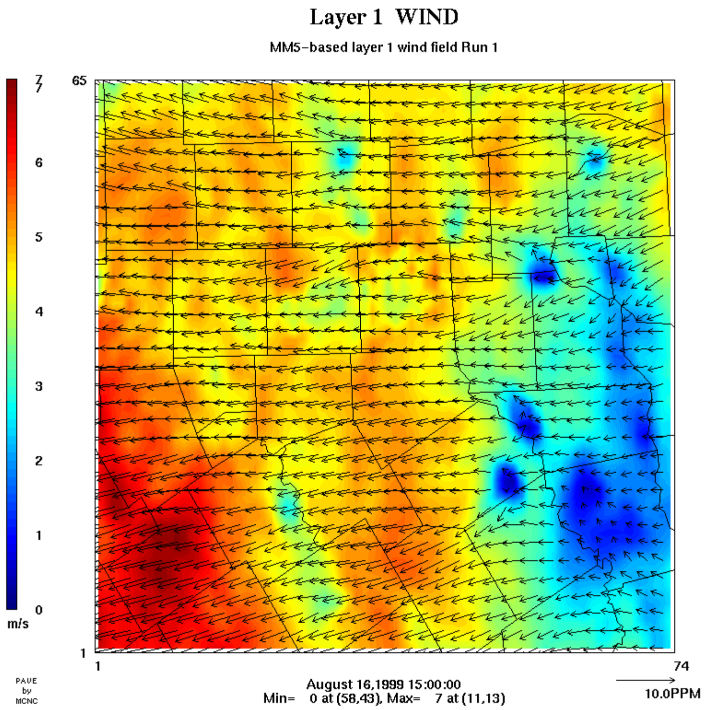


Figure 2-6a. Surface wind speed (colors) and vectors from Run1 on the 4-km domain at 3 PM LST August 16, 1999.

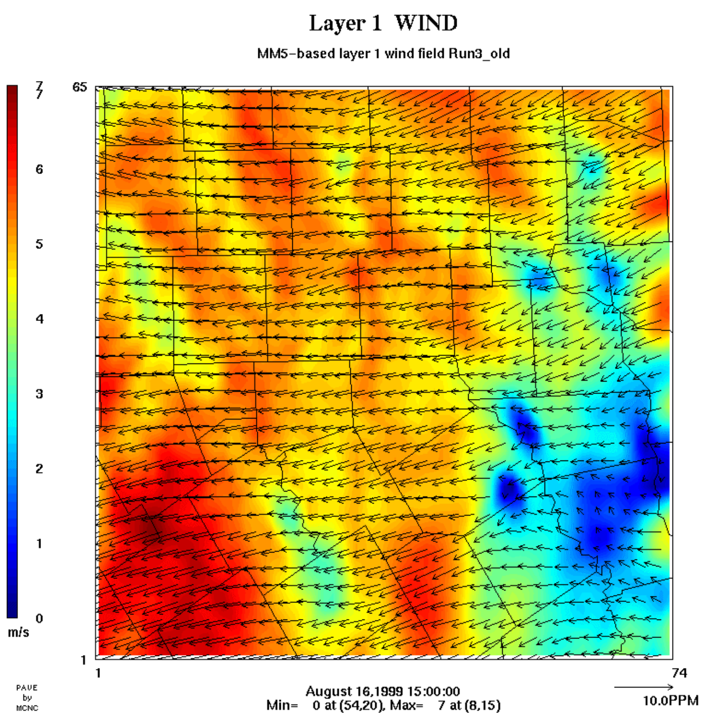


Figure 2-6b. Surface wind speed (colors) and vectors from Run3_old on the 4-km domain at 3 PM LST August 16, 1999.

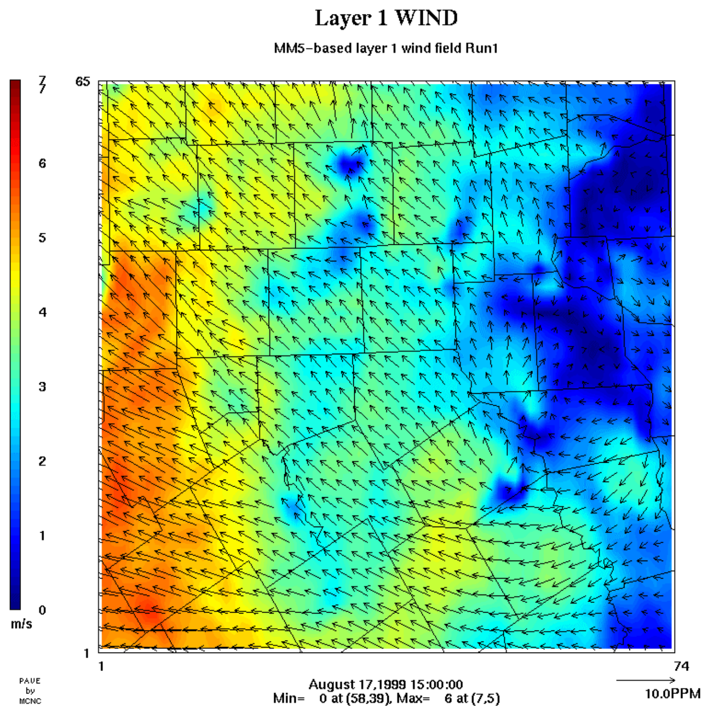


Figure 2-7a. Surface wind speed (colors) and vectors from Run1 on the 4-km domain at 3 PM LST August 17, 1999.

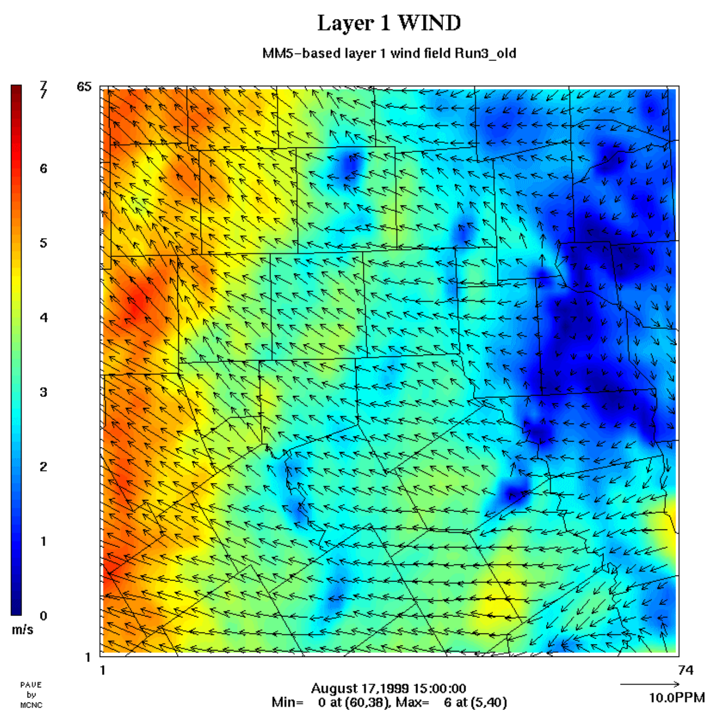


Figure 2-7b. Surface wind speed (colors) and vectors from Run3_old on the 4-km domain at 3 PM LST August 17, 1999.

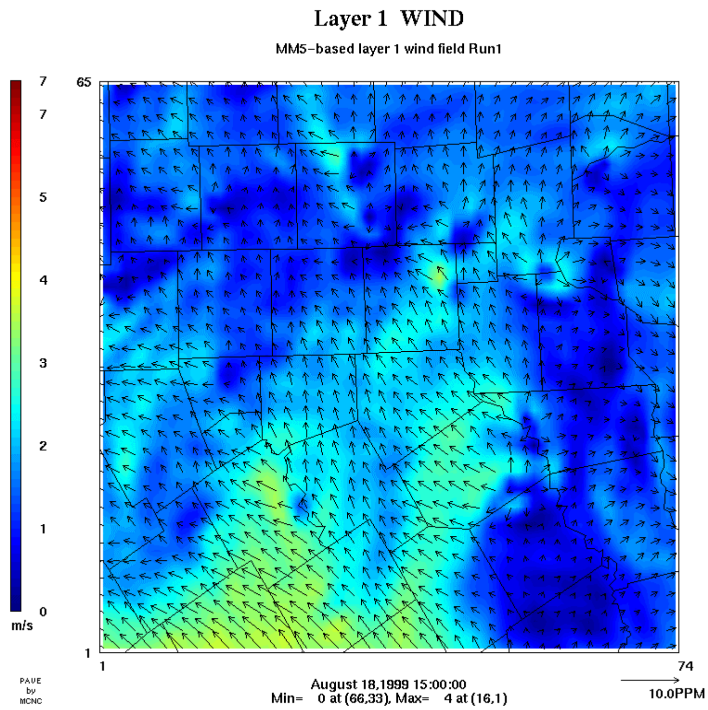


Figure 2-8a. Surface wind speed (colors) and vectors from Run1 on the 4-km domain at 3 PM LST August 18, 1999.

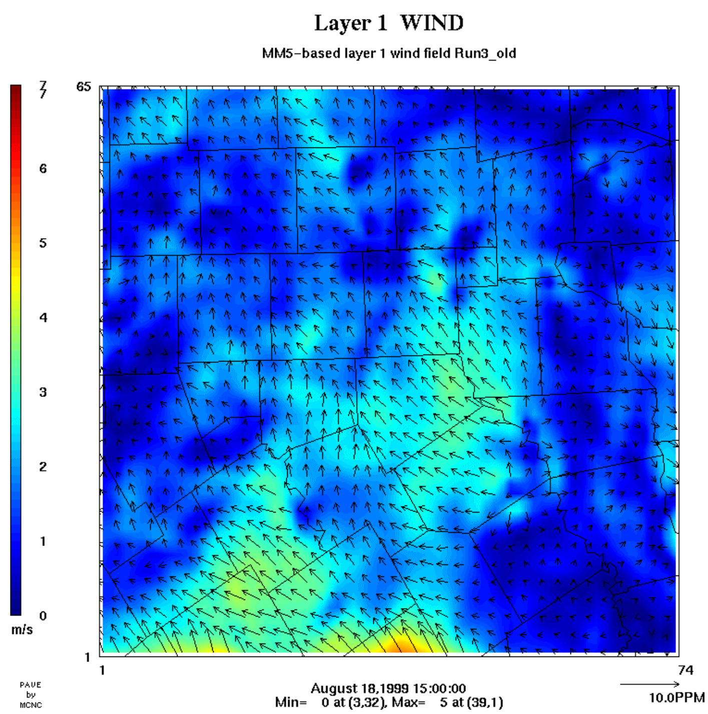


Figure 2-8b. Surface wind speed (colors) and vectors from Run3_old on the 4-km domain at 3 PM LST August 18, 1999.

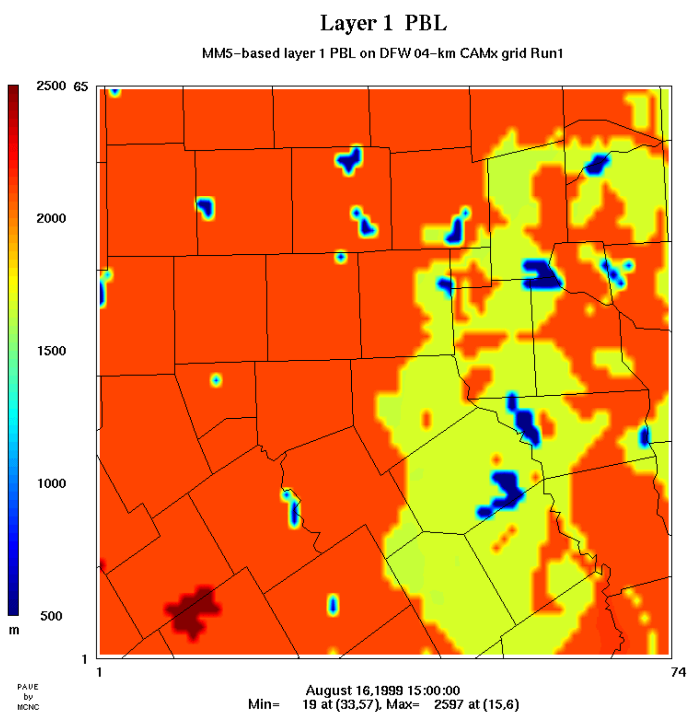


Figure 2-9a. Effective PBL depth (based on CAMx layer structure and input Kv field) from Run1 on the 4-km domain at 3 PM LST August 16, 1999.

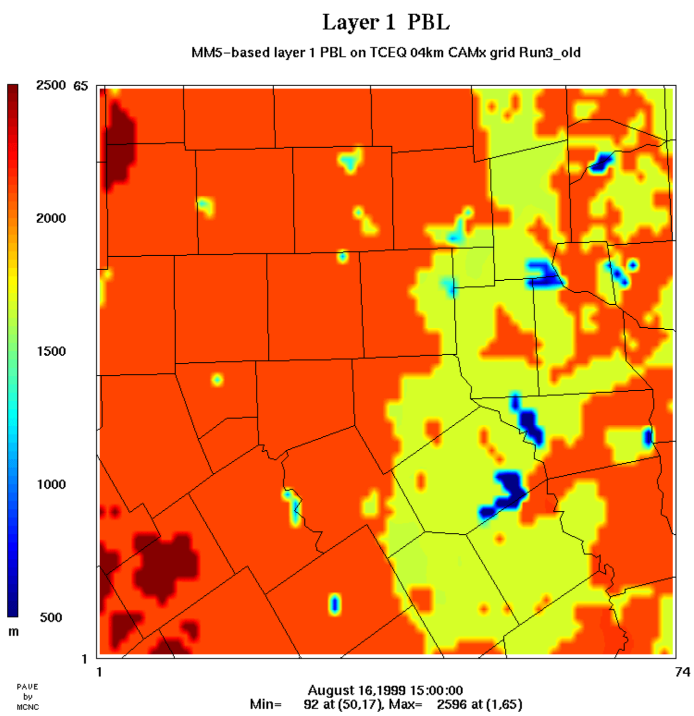


Figure 2-9b. Effective PBL depth (based on CAMx layer structure and input Kv field) from Run3_old on the 4-km domain at 3 PM LST August 16, 1999.

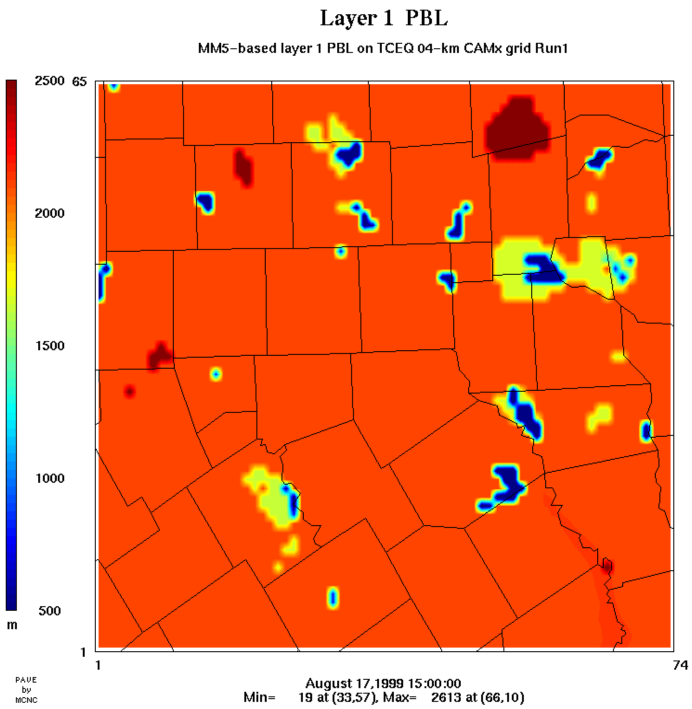


Figure 2-10a. Effective PBL depth (based on CAMx layer structure and input Kv field) from Run1 on the 4-km domain at 3 PM LST August 17, 1999.

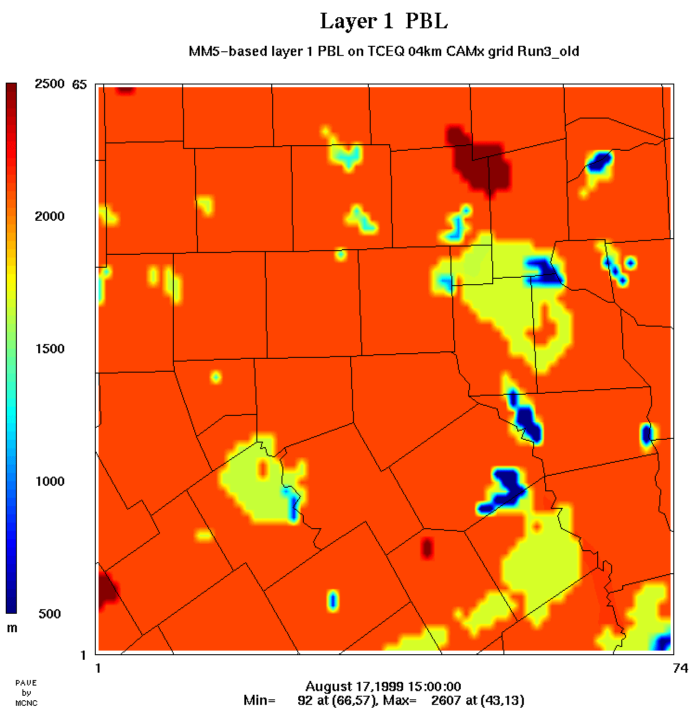


Figure 2-10b. Effective PBL depth (based on CAMx layer structure and input Kv field) from Run3_old on the 4-km domain at 3 PM LST August 17, 1999.

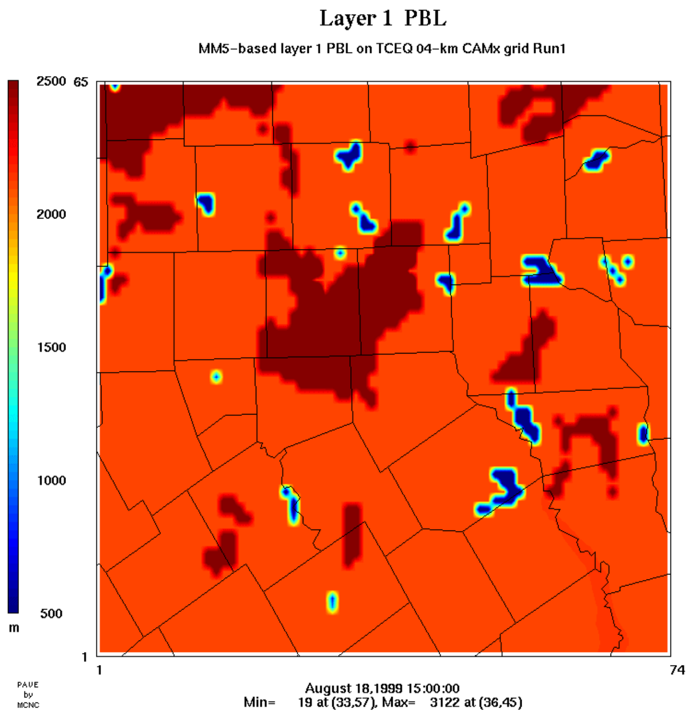


Figure 2-11a. Effective PBL depth (based on CAMx layer structure and input Kv field) from Run1 on the 4-km domain at 3 PM LST August 18, 1999.

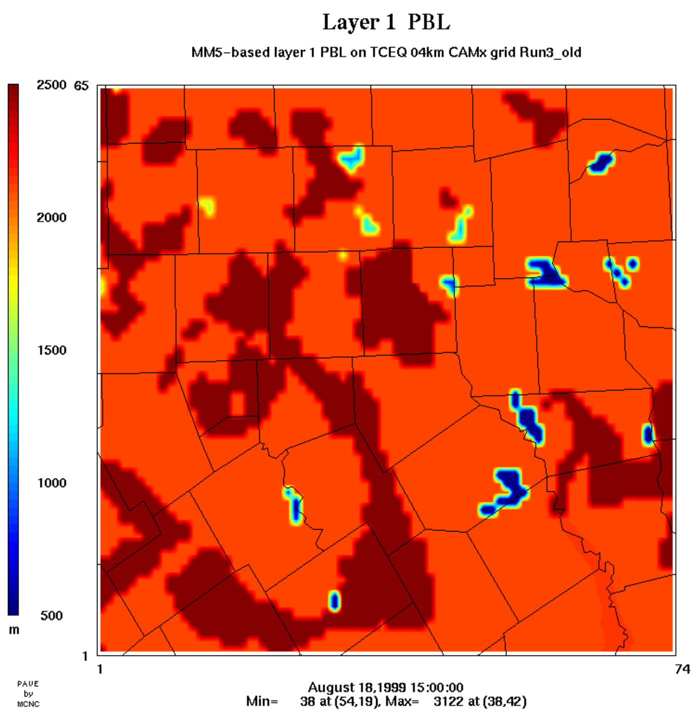


Figure 2-11b. Effective PBL depth (based on CAMx layer structure and input Kv field) from Run3_old on the 4-km domain at 3 PM LST August 18, 1999.

The NNRP is a joint project between NCAR and NCEP to re-analyze global analyses dating back to the 1950's using model numerical techniques and additional data source where available. NNRP provides a set of surface and multiple pressure level meteorological analyses at 6-hour intervals over the entire globe with a spatial resolution of 2.5 degrees. NNRP also provides deep soil temperature and moisture fields. Given the lower spatial and time resolution of this dataset, we used the MM5 preprocessing system to interpolate the 6-hourly analyses to 3-hour intervals (via REGRID), and developed MM5 grid-specific meteorological analyses by blending in 3-hourly surface and upper air data into the NNRP analyses (via LITTLE_R).

Statistics on the 4-km Domain

The Run2 hourly statistics of surface wind, temperature, and humidity on the 4-km domain are compared to Run3_old in Figure 2-12. The wind speed bias from Run2 shows the same pattern as that of Run3_old with often higher overestimation for wind speed. The wind direction from Run2 agrees with Run3_old at the beginning of the simulation. But a relatively large deviation from the observed wind direction occurs in the morning of August 17 (around 6 AM) and persists until early afternoon.

The temperature bias from Run2 also has the same trend as that of Run3_old, but the whole pattern shifts downward. That is, the cold bias during the nighttime becomes even stronger and the daytime warm bias is weaker. The humidity performance from Run2 and Run3_old are comparable except at the very beginning of the simulation.

The hourly statistics for Run3 are compared to Run3_old in Figure 2-13. The overestimation of wind speed is slightly higher in Run3 on August 17. The wind direction performance between the two runs are very similar. The temperature performance is quite similar as well. The humidity bias is much lower in the early hours of simulation but it grows larger in the last 12 hours of the simulation.

In terms of the daily statistics (not shown), the wind speed bias and gross error are slightly higher for Run2 compared to Run3_old. They are even higher for Run3. Though the bias of wind direction in Run2 is relatively lower, the gross error for Run2 is the highest among the all three runs. Overall the wind performance of Run3_old is the best among these three runs. For temperature performance, Run2 gives the worst results with the highest bias and larger gross error. Temperature from Run3 performs better with slightly higher IOA. The humidity results are mixed, with the best performance for Run3 on August 16, but the worst on August 17. The humidity performance for Run2 and Run3_old are quite similar.

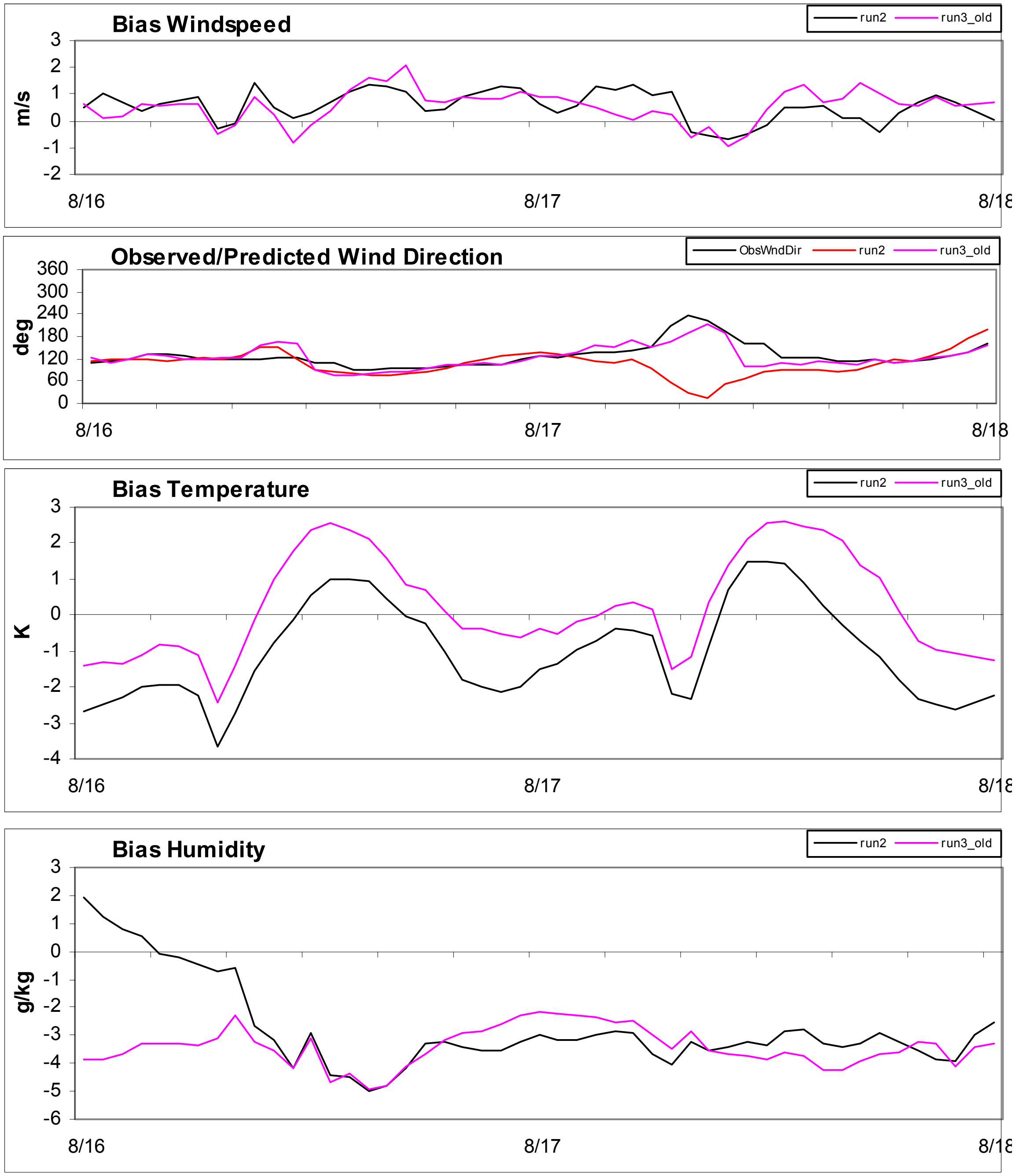


Figure 2-12. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run2 and Run3_old in the MM5 4-km domain.

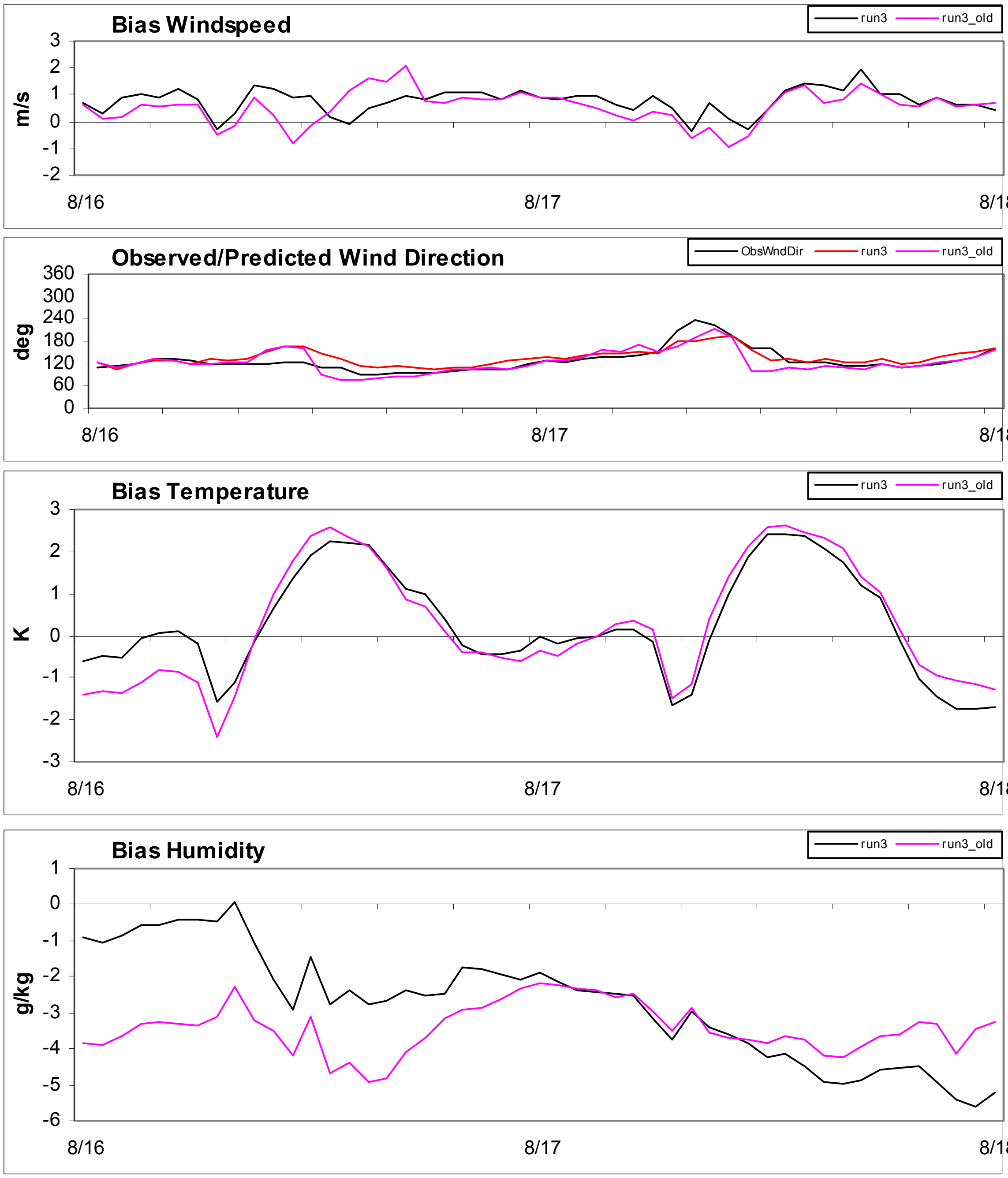


Figure 2-13. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run3 and Run3_old in the MM5 4-km domain.

Statistics on the 12-km Domain

The time series of hourly statistics on the 12-km domain for both Run2 and Run3 (not shown) are very similar to the 4-km results, except that the Run2 overestimation of wind speed and poorer directional agreement are particularly evident. Run 3 wind performance is very similar to Run3_old. No obvious improvement is seen in the temperature and humidity results, except possibly for Run3 humidity bias.

Without the analysis and observation nudging, Run2 obviously leads to worse daily wind performance (not shown) with the highest wind speed and direction bias and gross error of the three runs. FDDA on the 12-km domain certainly plays an important role in the wind performance. However, the nudging effects are not that obvious in the temperature and humidity. Daily performance for Run3 agrees closely with Run3_old for most parameters.

SENSITIVITY TEST FOUR

Data Preparation

To further improve MM5 model performance for wind, additional observational data from several different sources were obtained and incorporated into the MM5 observational nudging input file.

In the original modeling reported by ENVIRON (2003), NOAA profiler data were incorporated into the MM5 observation FDDA files on the 12 and 4 km domains. However, detailed review of documentation that discusses the FDDA data preparation performed by the University of Texas/CEER in 2001 suggests that the DFW site was not part of the NOAA network. Thus no high-resolution profiler information from the DFW area was included in the observation nudging file in the original DFW MM5 modeling. In this application, the DFW profiler data from MIT's Lincoln Laboratory were processed into the observation nudging file. The raw DFW profiler data were provided to ENVIRON in terms of 5 minute averages over 35 layers reaching 1400 meters altitude (AGL). These raw data were averaged to hourly averages.

Another set of SODAR data were provided by TCEQ from Hinton monitoring site. The raw data were provided to ENVIRON in terms of 15 minute averages with 27 layers reaching 700 meters altitude. Again the data were processed into hourly averages. The processed profiler data were checked using the METSTAT sounding program to assure that the formatting procedure was correctly applied and the data were correctly incorporated into the observation nudging file.

The hourly surface observations from the Oklahoma Mesonet Network were also incorporated into the MM5 nudging data file to improve the overall performance for synoptic-scale weather patterns and regional surface-level circulations.

After all of the new data were processed and incorporated into the MM5 observation nudging file, the model run with the same configuration as Run1 for the whole episode (which included increased surface roughness). The results from this new run (Run4) are discussed in the following sections.

Review of Profiler Data

Before the DFW profiler data were blended into the existing observational FDDA file, we conducted a quality-assurance step to review the data against the original simulation. This served two purposes: (1) to ensure that the process by which the data were hourly averaged and reformatted for the FDDA file was performed correctly, and (2) to review the sounding data against a pre-existing MM5 simulation in order to identify the degree of differences between the observations and simulation results, thereby establishing our expected outcome once those data were used in the nudging scheme. The observed and predicted soundings for wind speed and direction at DFW site from Run3_old and Run4 were displayed and compared for the entire episode using the sounding plotter feature of METSTAT. Examples are provided in Figure 2-14(a-d) for August 16 and 17 at 2 PM and 8 PM. The predictions in both runs show general agreement with the observed profiler patterns. The predicted sounding with the additional profiler data nudging (Run4) shows just slight improvement for wind speed aloft. Zero or trivial effects are seen for wind direction. Based on the similarities between observed and predicted soundings from Run3_old, this was not an unexpected outcome.

Statistics on the 4-km Domain

The Run4 hourly statistics for surface wind, temperature, and humidity on the 4-km domain are compared to Run1 and Run3_old in Figure 2-15. The wind, temperature and humidity performance are almost identical to those of Run1. Only trivial differences are apparent in temperature and humidity: the simulation from Run4 is little bit drier and warmer during the daytime of August 14.

The daily statistics of Run4 for surface wind, temperature, and humidity on the 4-km domain are compared to Run1 and Run3_old in Figure 2-16. The daily statistics show the same trend as the hourly statistics. Run4 shows slightly better results for wind speed and temperature IOA and humidity gross error.

Statistics on the 12-km Domain

The Run4 hourly statistics for surface wind, temperature, and humidity on the 12-km domain are compared to Run1 and Run3_old in Figure 2-17. The same similarity for wind, temperature and humidity between Run4 and Run1 is also shown in these results. There is almost no difference between these two runs.

The daily statistics for Run4 for surface wind, temperature, and humidity on the 12-km domain are compared to Run1 and Run3_old in Figure 2-18. The Run4 simulation leads to slightly lower bias in wind speed and humidity, but a little bit higher error in wind direction and temperature.

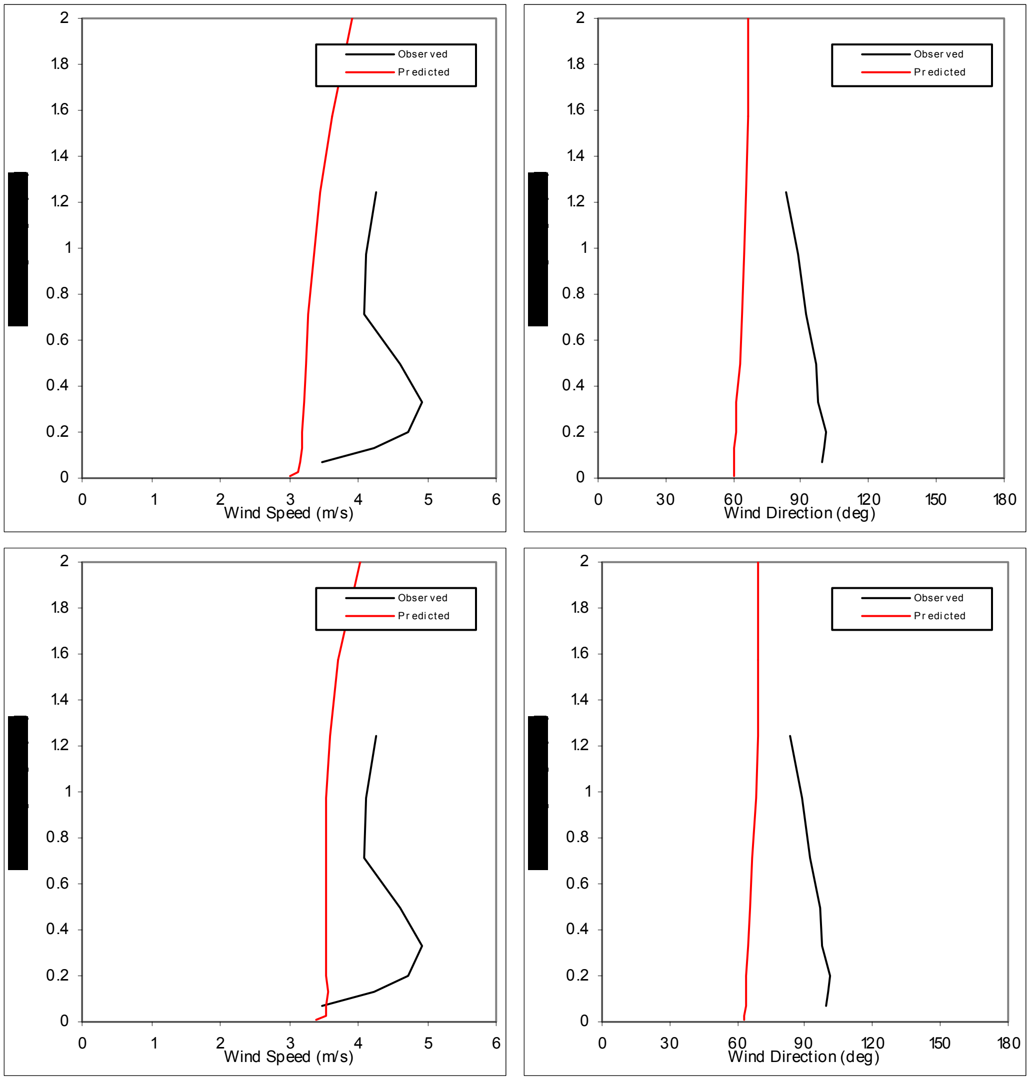


Figure 2-14a. Vertical profiles of observed and predicted wind speed and direction on August 16, 1999 at 1400 CST. Observations are taken from the composite DFW profiler. Plots show predictions for Run3_old (bottom row), and Run4 (top row).

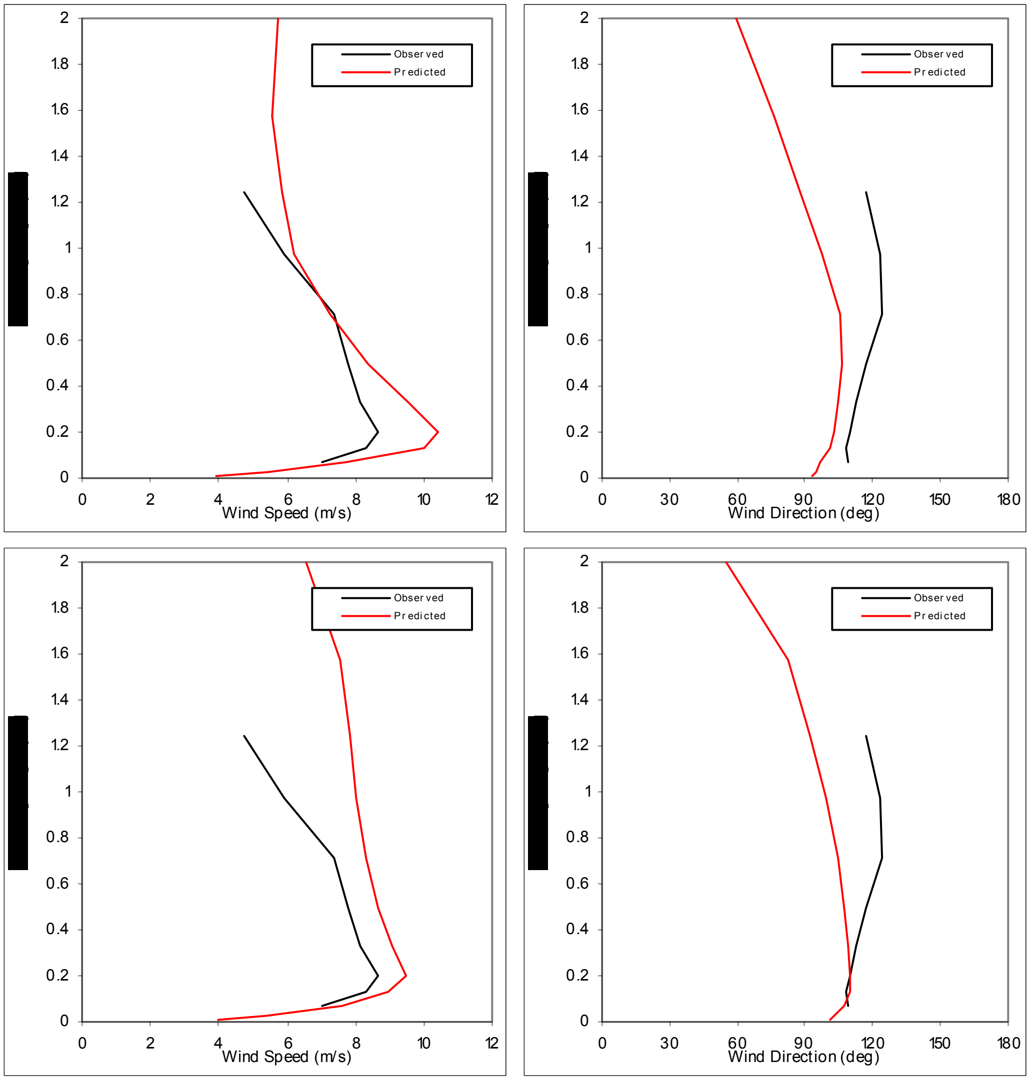


Figure 2-14b. Vertical profiles of observed and predicted wind speed and direction on August 16, 1999 at 2000 CST. Observations are taken from the composite DFW profiler. Plots show predictions for Run3_old (bottom row), and Run4 (top row).

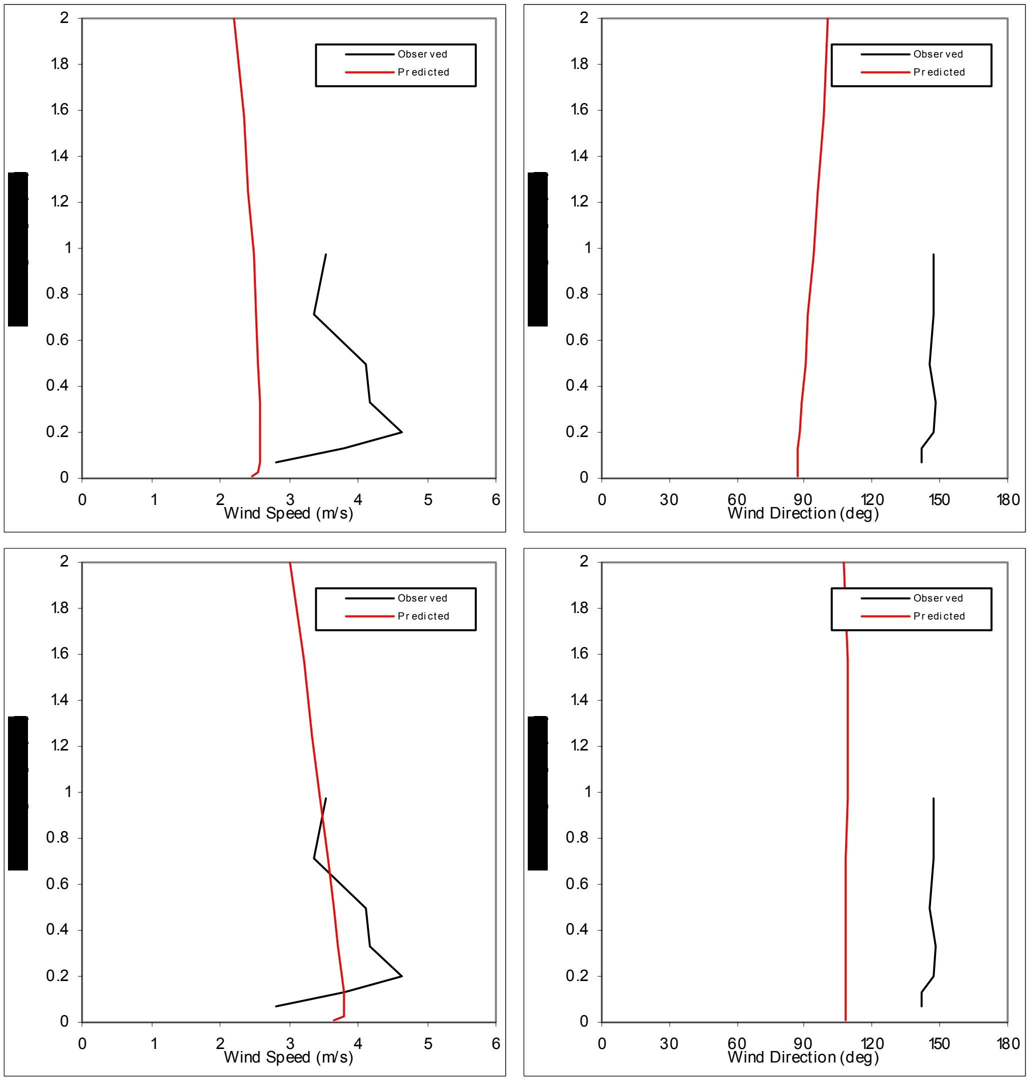


Figure 2-14c. Vertical profiles of observed and predicted wind speed and direction on August 17, 1999 at 1400 CST. Observations are taken from the composite DFW profiler. Plots show predictions for Run3_old (bottom row), and Run4 (top row).

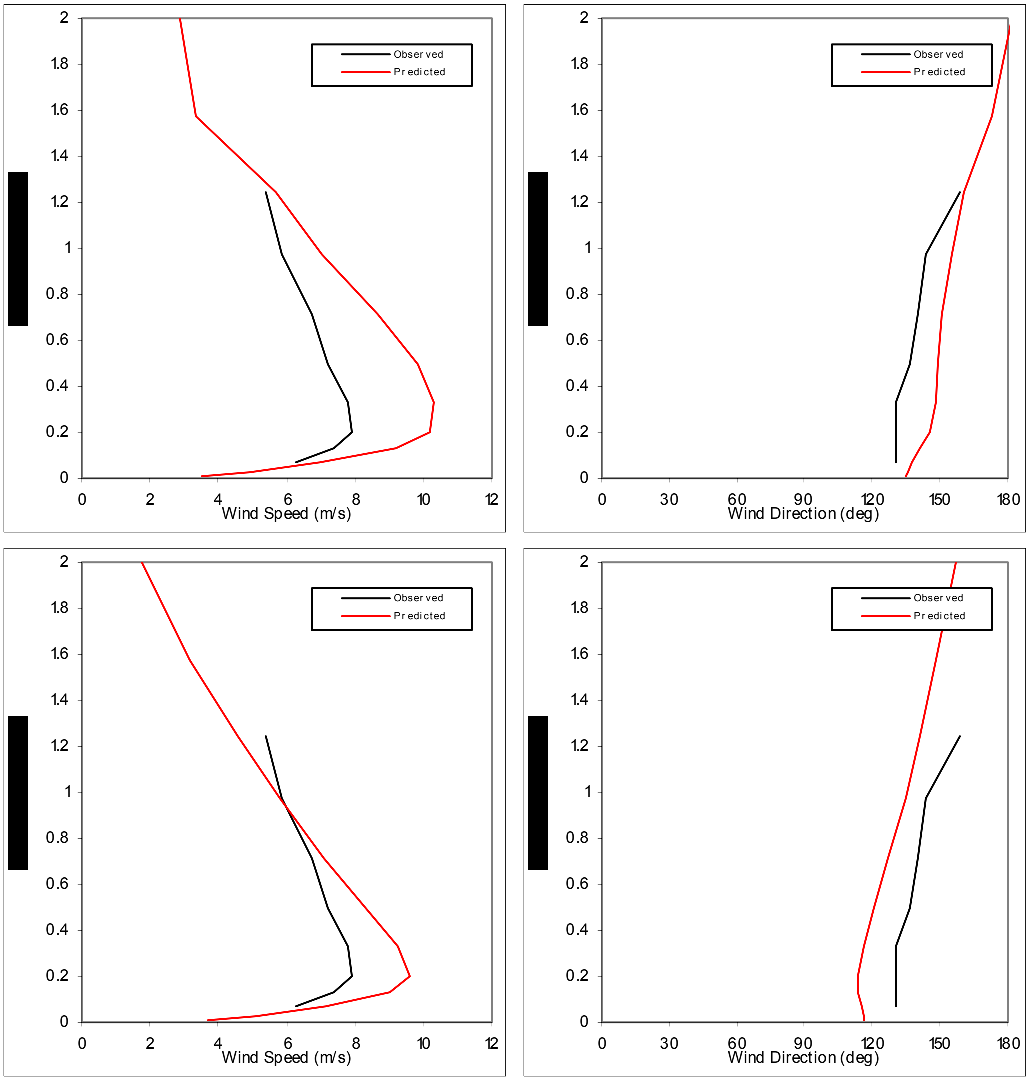


Figure 2-14d. Vertical profiles of observed and predicted wind speed and direction on August 17, 1999 at 2000 CST. Observations are taken from the composite DFW profiler. Plots show predictions for Run3_old (bottom row), and Run4 (top row).

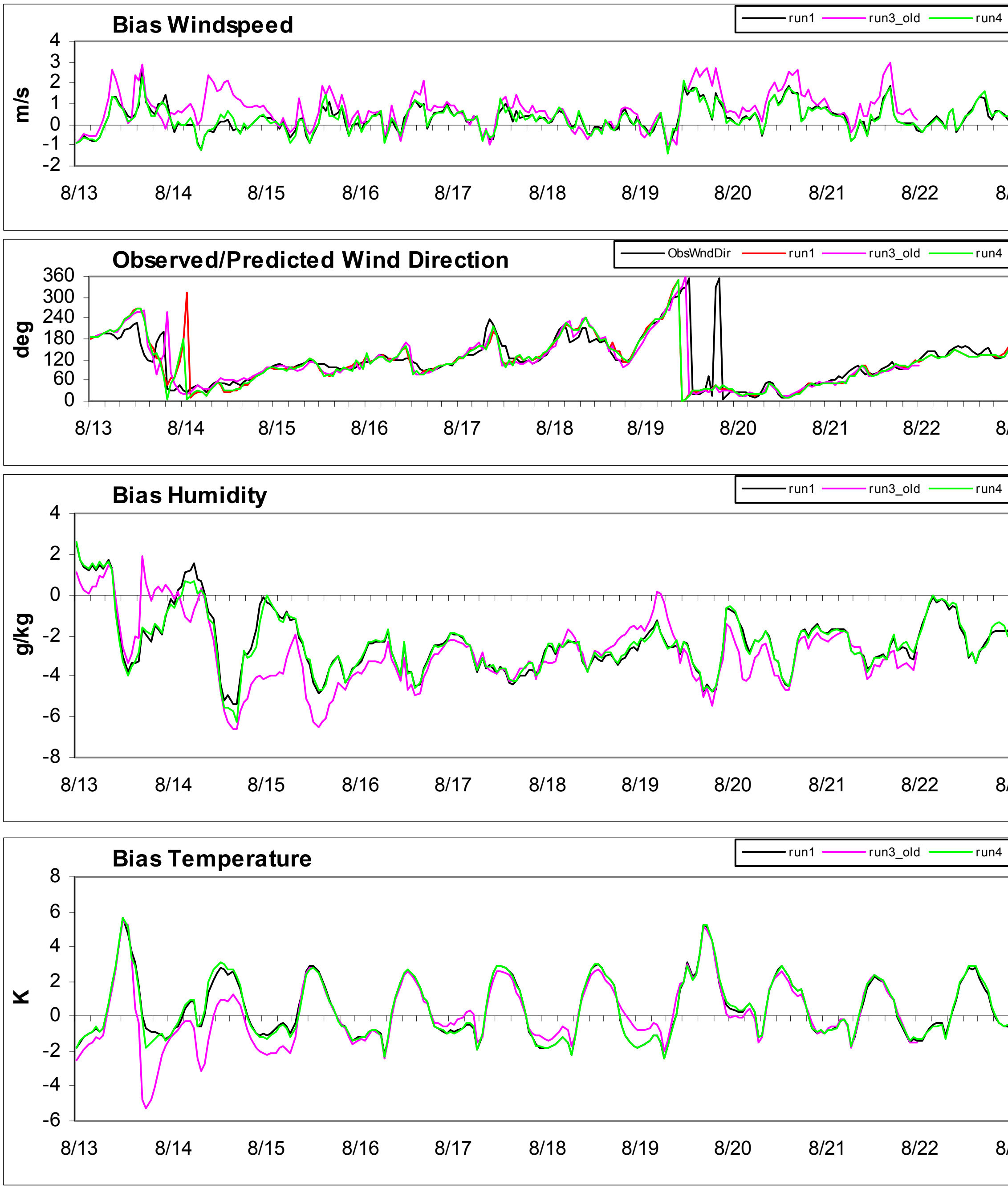


Figure 2-15. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run1, Run4, and Run3_old in the MM5 4-km domain.

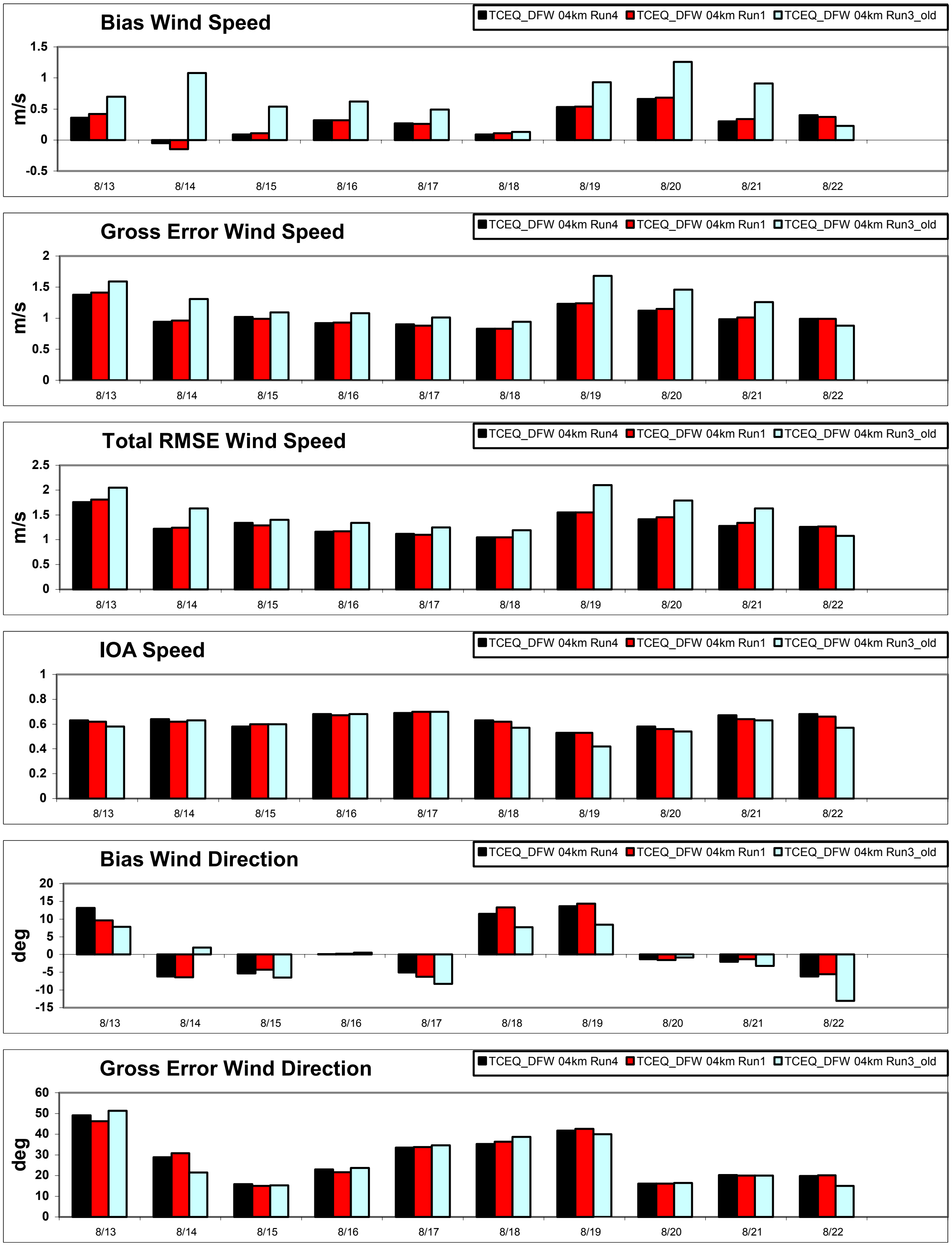


Figure 2-16a. Daily performance statistics for winds for Run1, Run4, and Run3_old in the MM5 4-km domain.

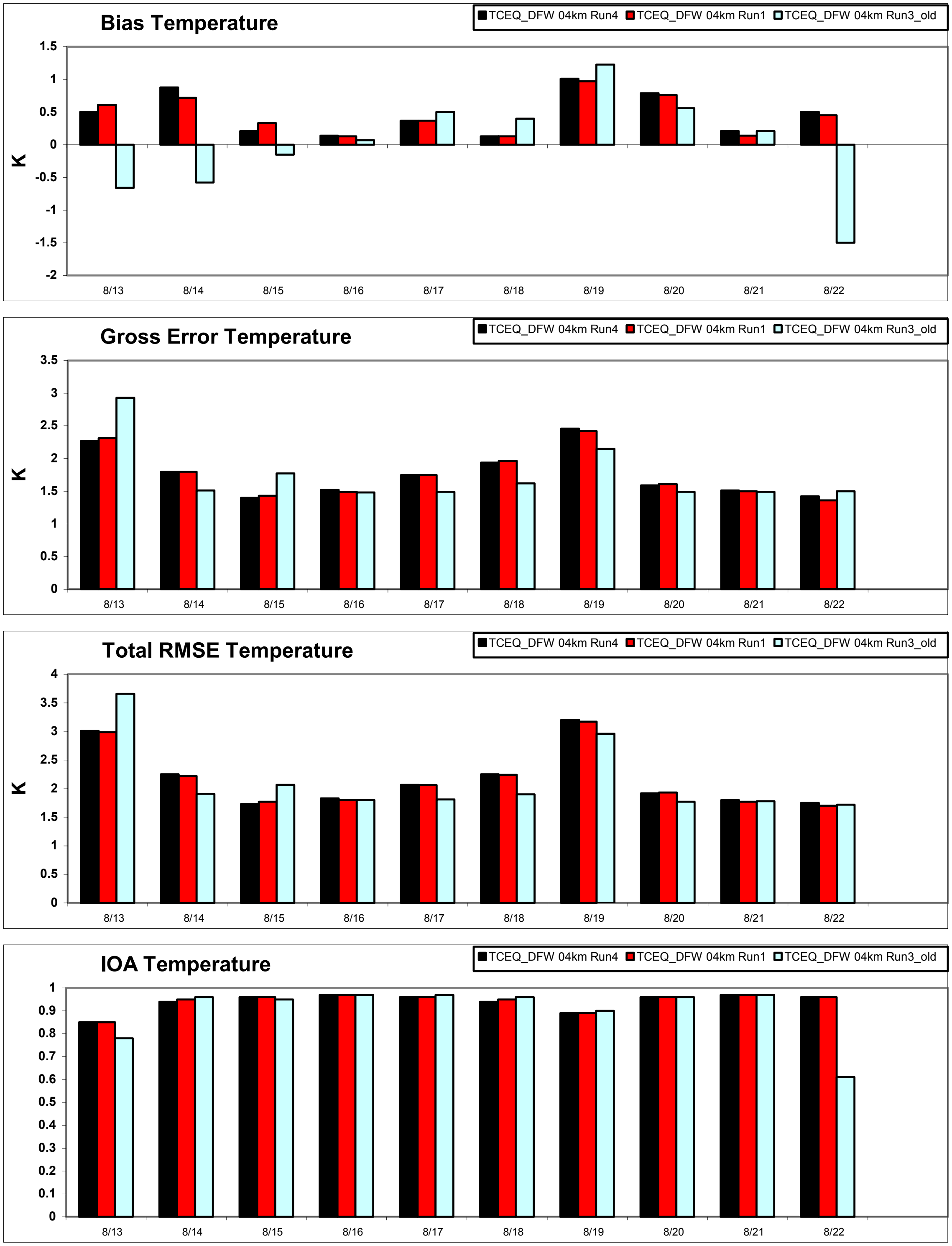


Figure 2-16b. Daily performance statistics for temperature for Run1, Run4, and Run3_old in the MM5 4-km domain.

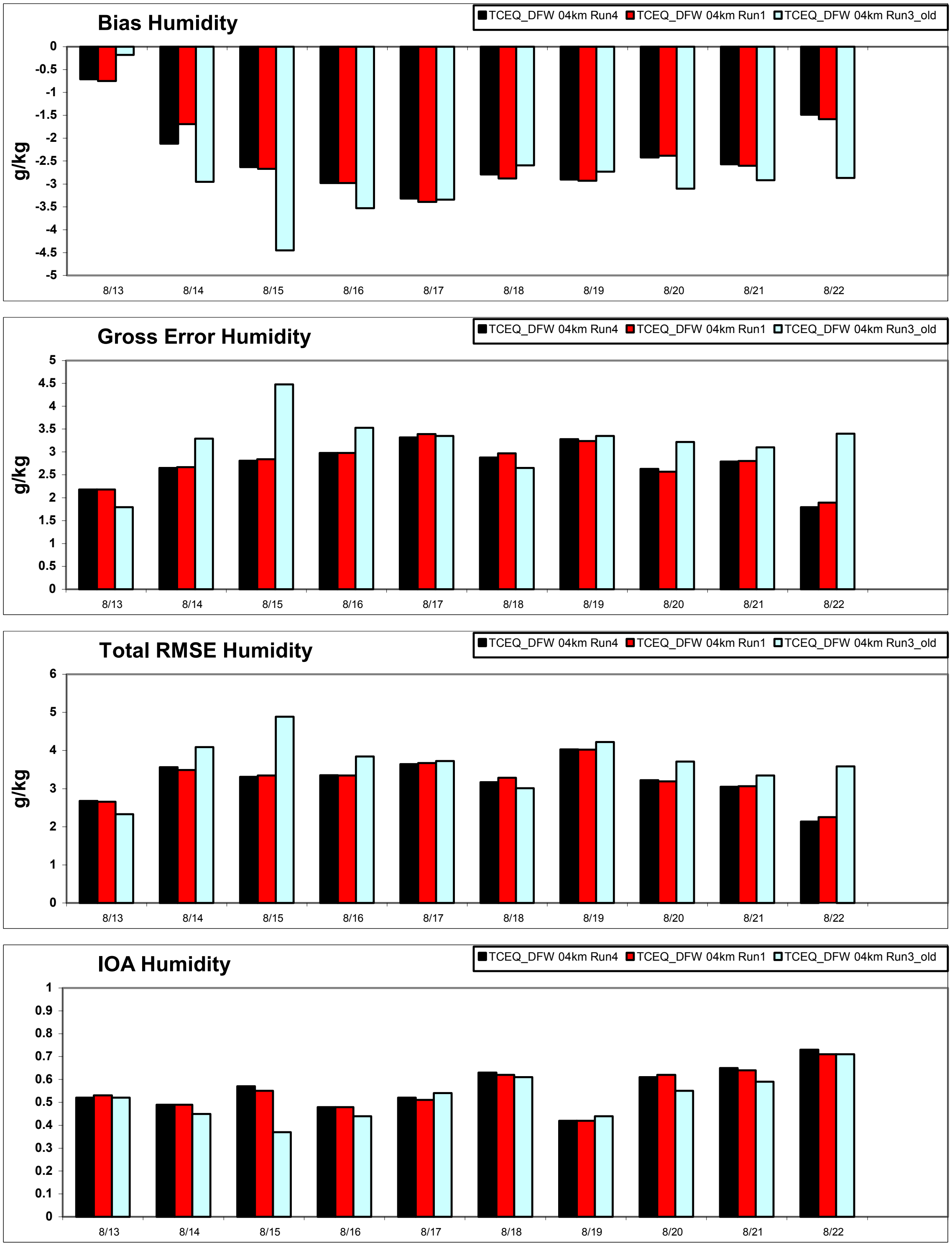


Figure 2-16c. Daily performance statistics for humidity for Run1, Run4, and Run3_old in the MM5 4-km domain.

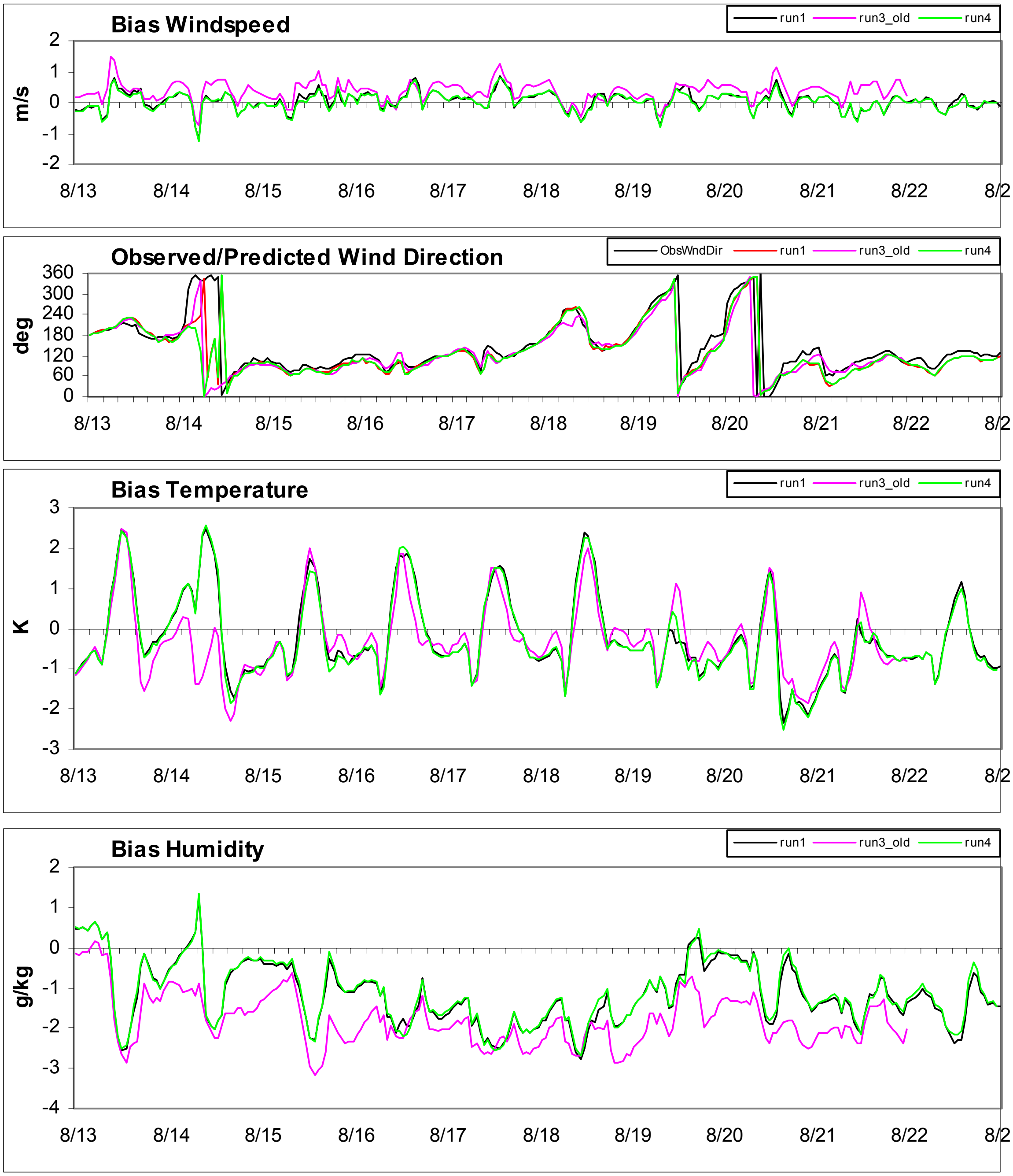


Figure 2-17. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run1, Run4, and Run3_old in the MM5 12-km domain.

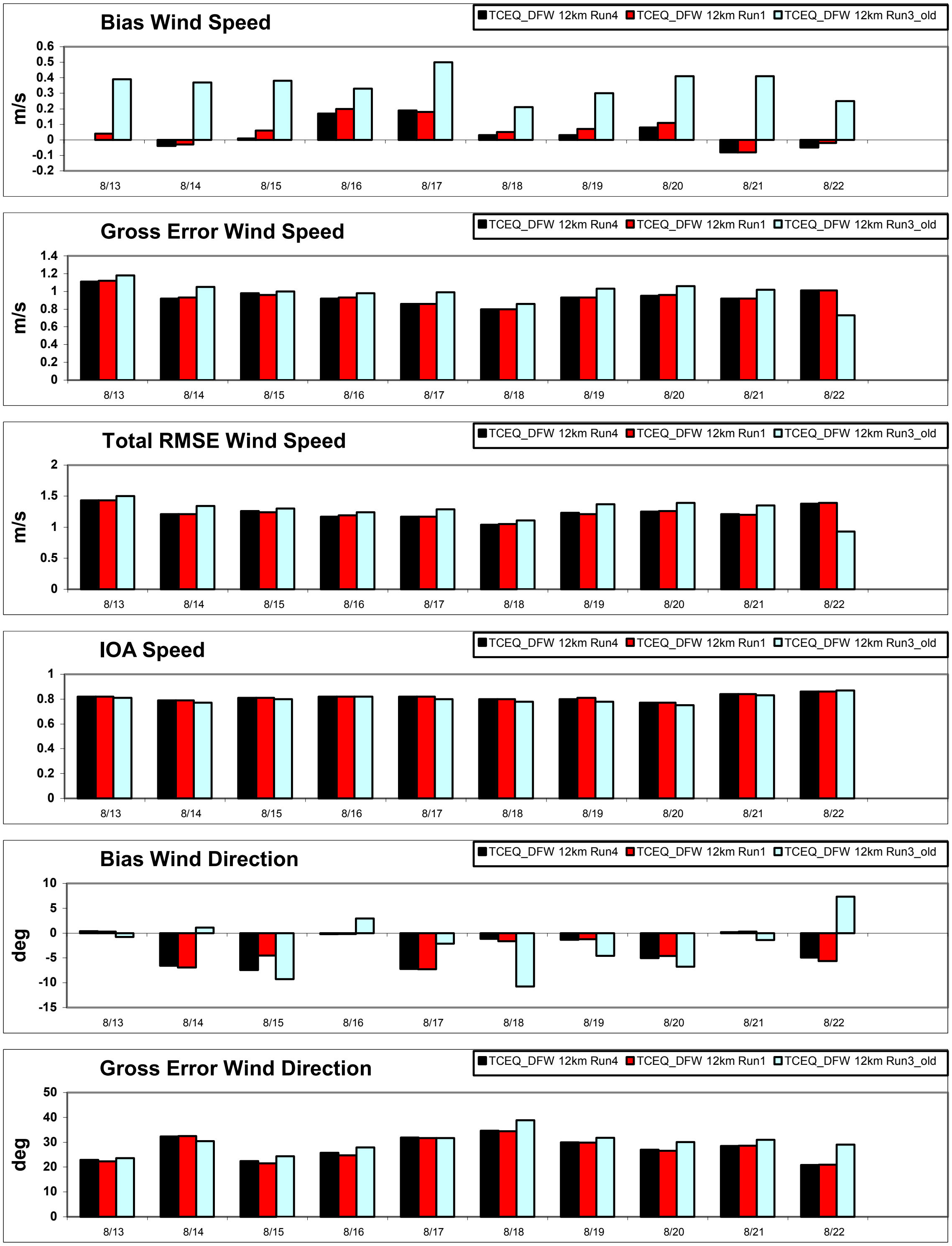


Figure 2-18a. Daily performance statistics for winds for Run1, Run4, and Run3_old in the MM5 12-km domain.

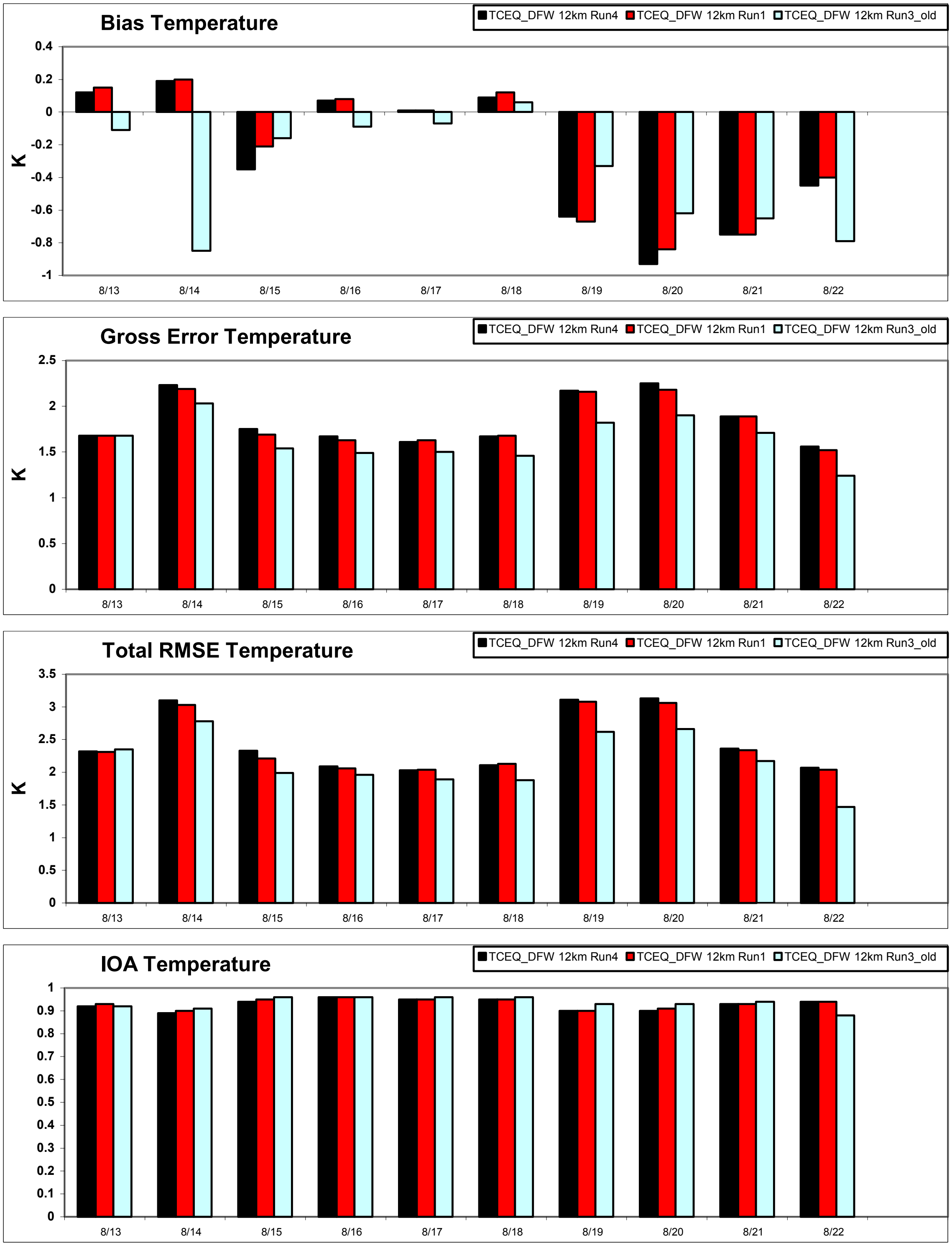


Figure 2-18b. Daily performance statistics for temperature for Run1, Run4, and Run3_old in the MM5 12-km domain.

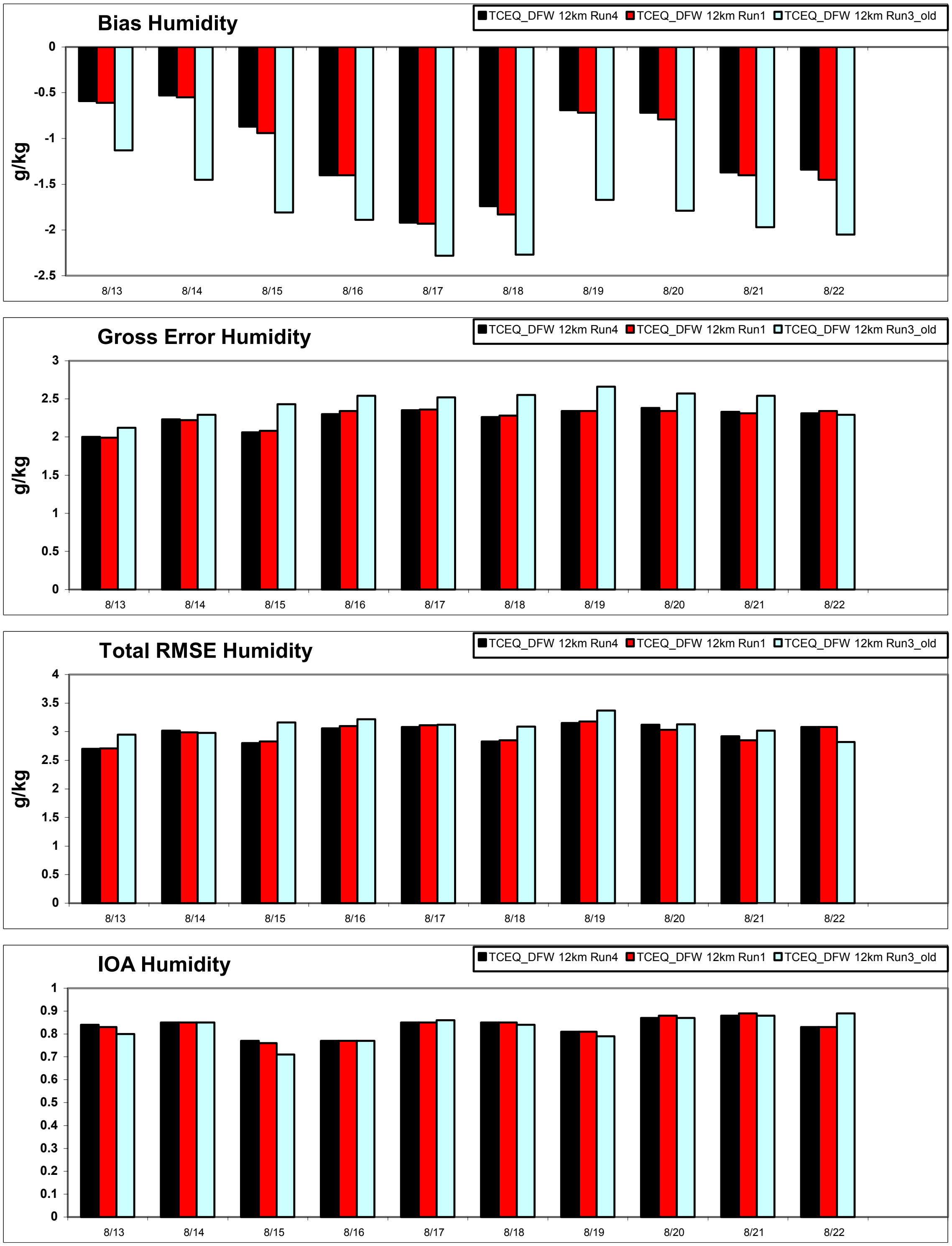


Figure 2-18c. Daily performance statistics for humidity for Run1, Run4, and Run3_old in the MM5 12-km domain.

SENSITIVITY TEST FIVE

In Run3 described above, the NNRP analyses were used to provide the initial/boundary conditions and analysis nudging inputs to MM5 in order to investigate whether alternative large-scale input analyses might provide improved model performance. When the meteorological output from this run were fed into the CAMx model, the ozone concentration distribution exhibited very different patterns and responses (some positive, some negative). Therefore, we decided to run MM5 for the whole August 1999 episode (Run5) using NNRP-based analysis inputs along with the new observation FDDA nudging file and the increased surface roughness specifications. The results are discussed below.

Statistics on the 4-km Domain

The hourly statistics from Run5 for surface wind, temperature, and humidity on the 4-km domain are compared to Run4 in Figure 2-19. Compared to the results of Run4, the wind performance (Figure 2-19a) from Run5 is mixed with better results on some days but worse results on other days. However, the overall wind performance from these two runs is similar. The hourly temperature statistics (Figure 2-19b) show that the diurnal pattern shifts to the warm side. That is, the nighttime cold bias is reduced but the daytime warm bias becomes larger. The hourly humidity statistics display a relatively dryer trend during most of the episode days.

The daily statistics for surface wind, temperature, and humidity on the 4-km domain are compared to Run4 in Figure 2-20. While bias is relative worse for winds and temperature, their respective gross errors are slightly better in Run4 than in Run4. However, humidity performs worse. Though both Run4 and Run5 do not meet the humidity benchmarks for bias and error, Run5 shows even worse performance.

Statistics on the 12-km Domain

The hourly statistics from Run5 for surface wind, temperature, and humidity on the 12-km domain are compared to Run4 in Figure 2-21. The same performance patterns for winds, temperature and humidity are exhibited in the 12-km domain as well. However, the temperature warm shift is even stronger and the drying trend is more obvious.

The daily statistics from Run5 for surface wind, temperature, and humidity on the 12-km domain are compared to Run4 in Figure 2-22. Only temperature bias and gross errors are slightly lower in Run5. The wind and humidity both show poorer performance in Run5 than in Run4.

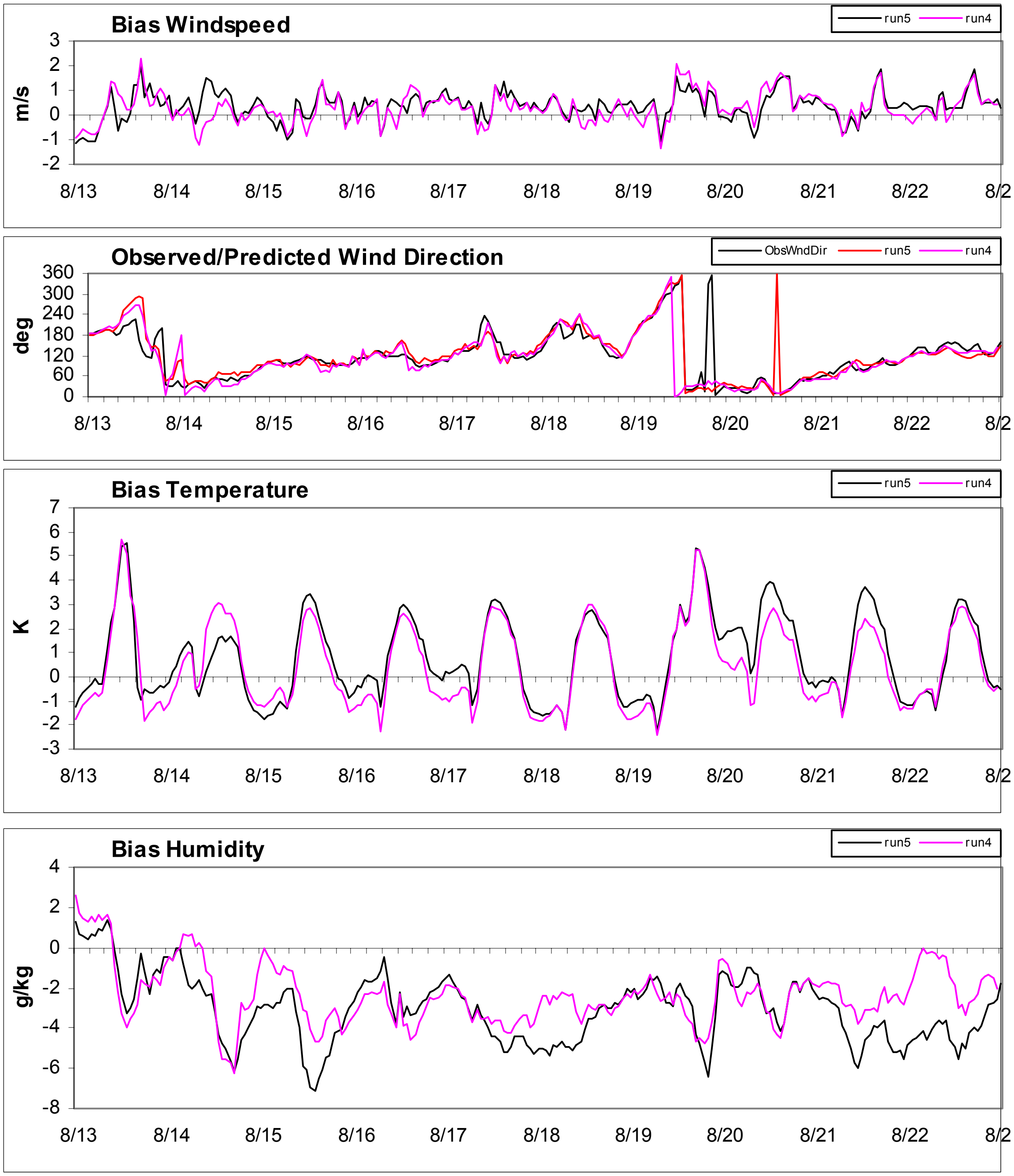


Figure 2-19. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run4 and Run5 in the MM5 4-km domain.

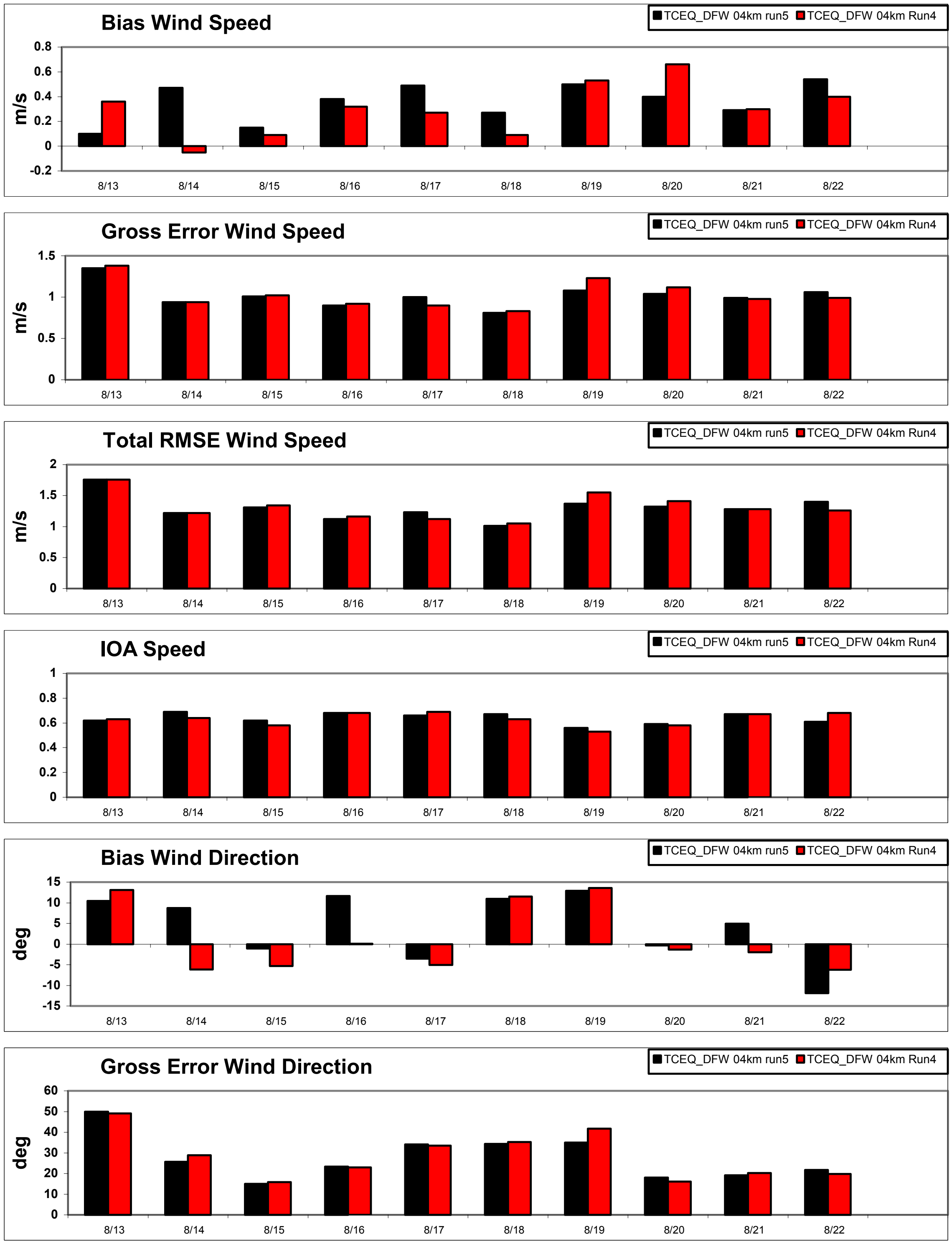


Figure 2-20a. Daily performance statistics for winds for Run4 and Run5 in the MM5 4-km domain.

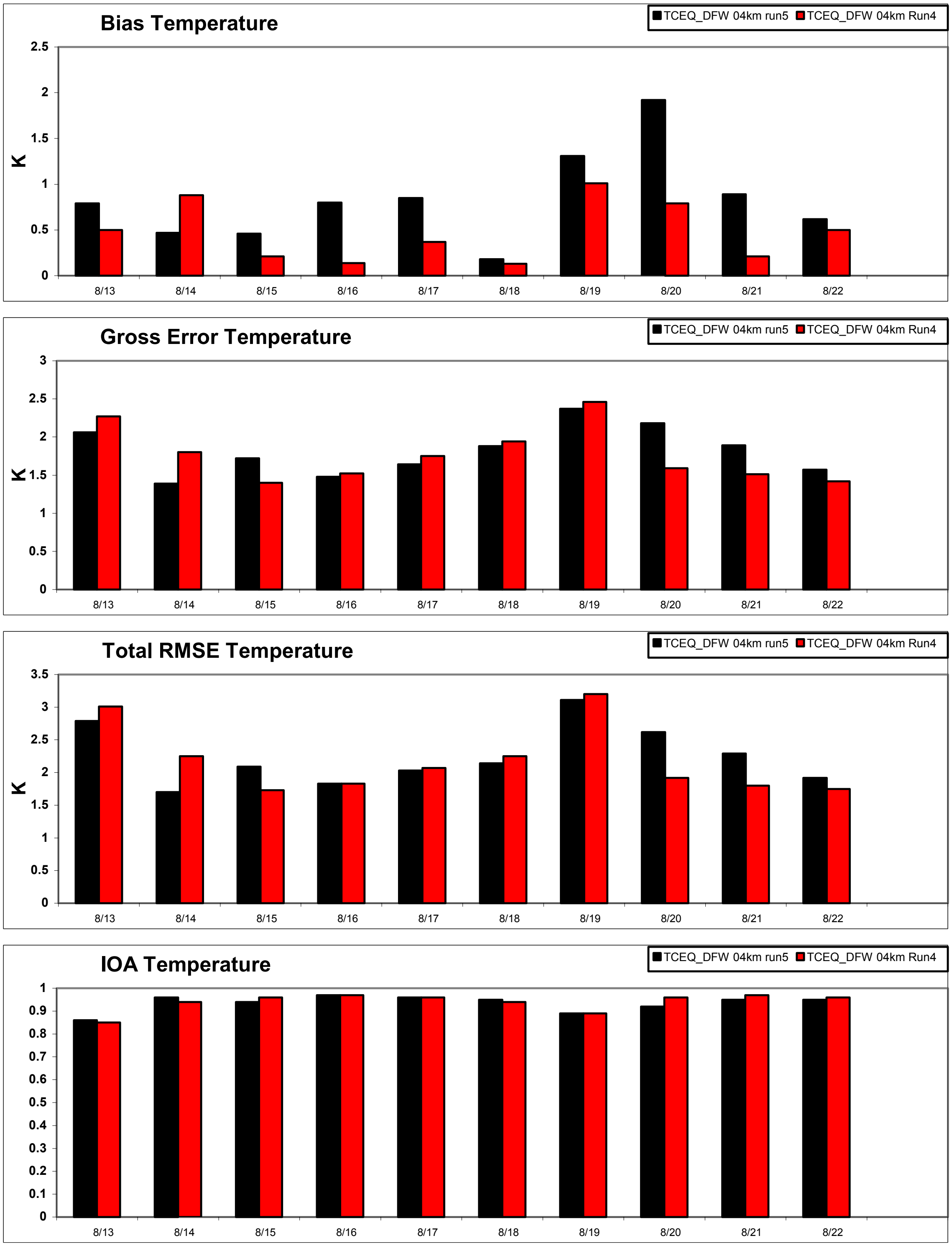


Figure 2-20b. Daily performance statistics for temperature for Run4 and Run5 in the MM5 4-km domain.

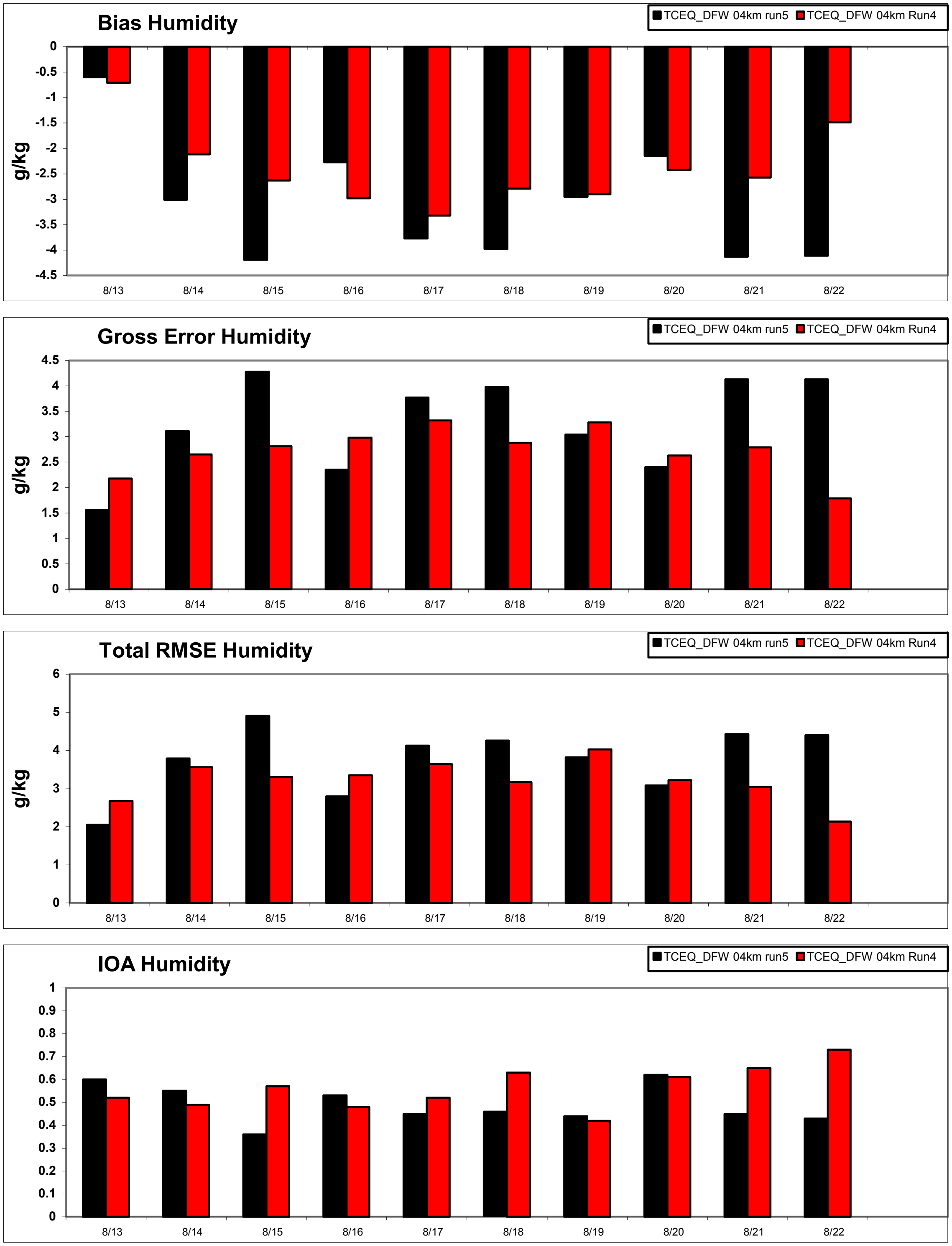


Figure 2-20c. Daily performance statistics for humidity for Run4 and Run5 in the MM5 4-km domain.

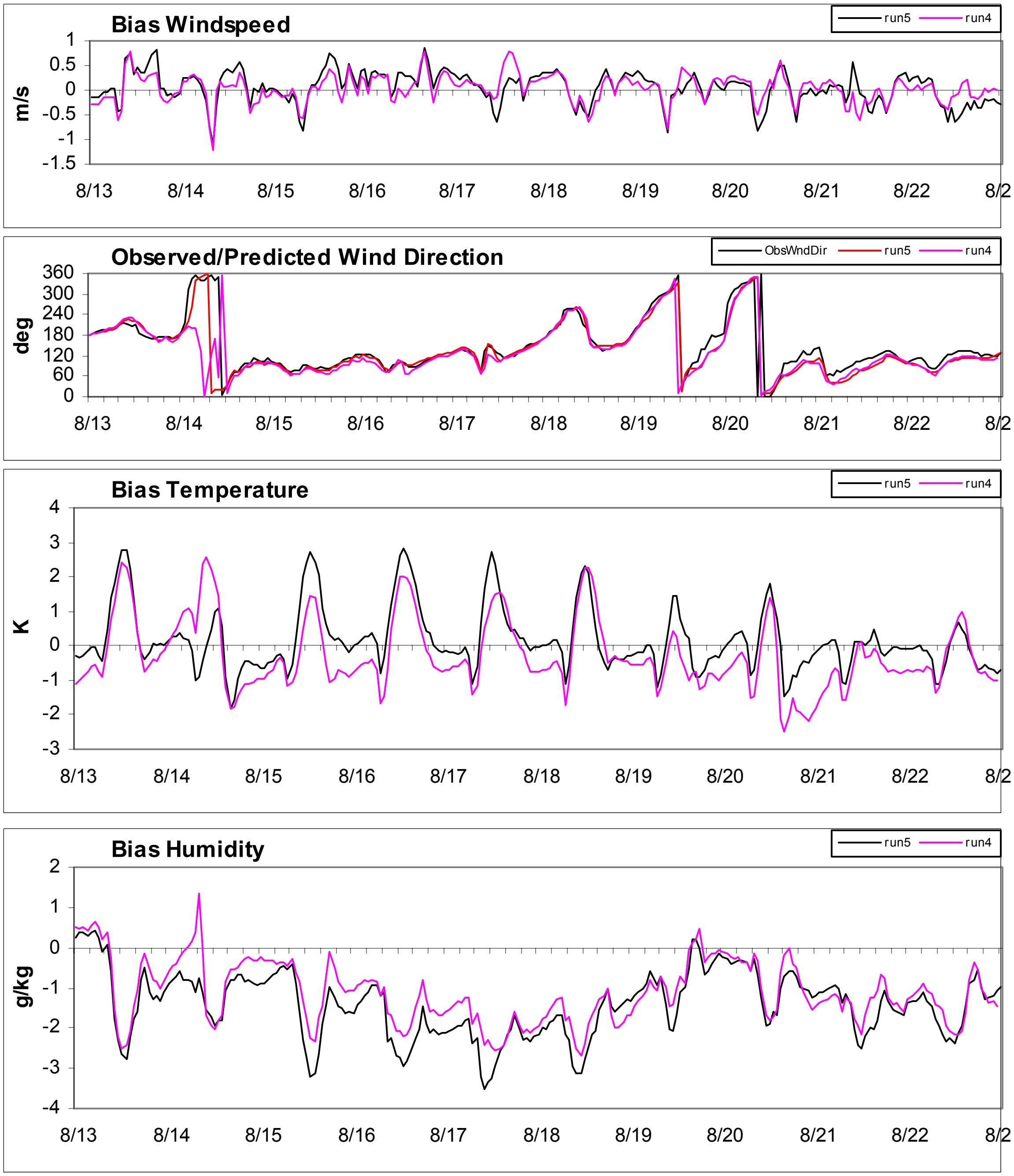


Figure 2-21. Hourly time series of wind speed bias, wind direction, temperature bias, and humidity bias for Run4 and Run5 in the MM5 12-km domain.

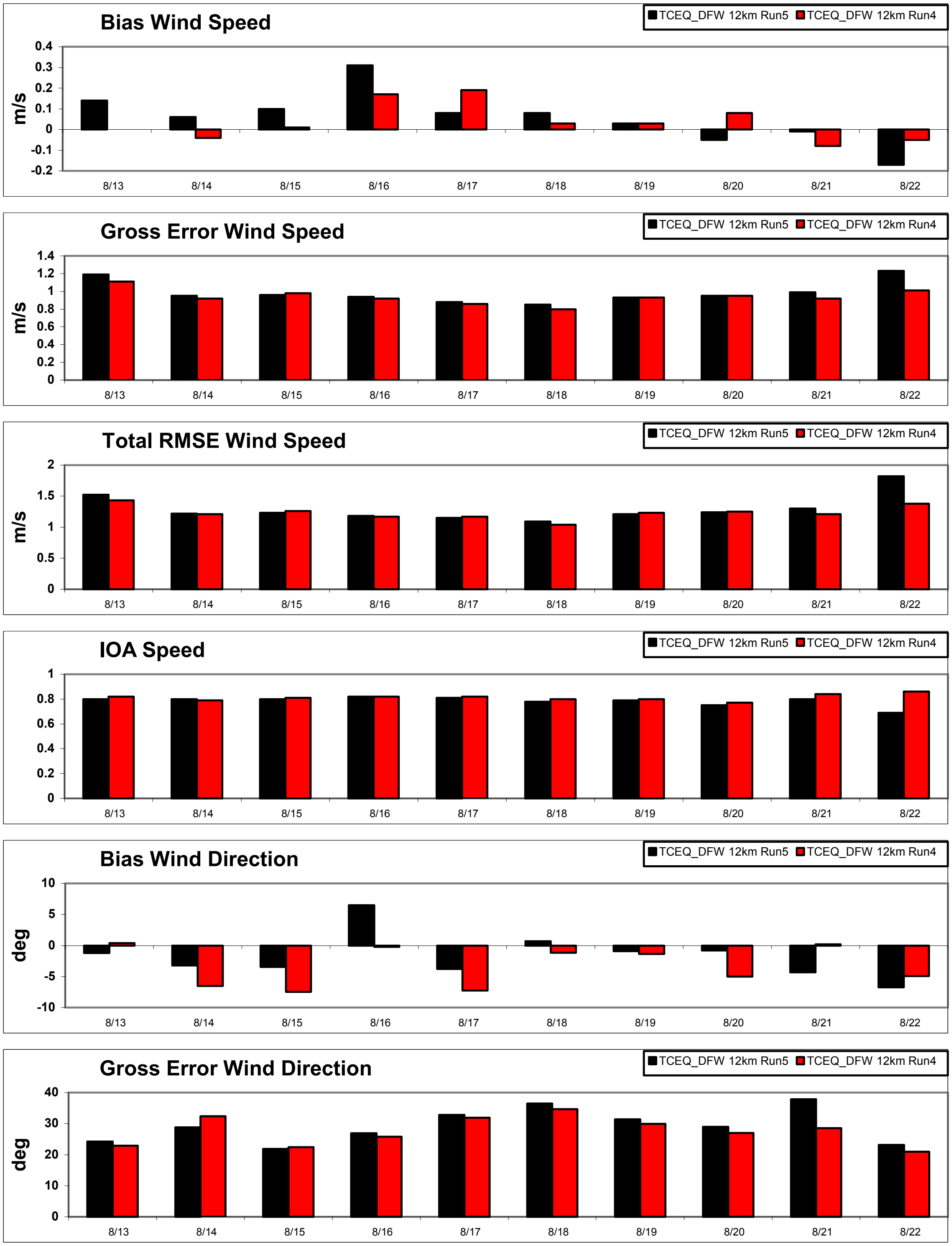


Figure 2-22a. Daily performance statistics for winds for Run4 and Run5 in the MM5 12-km domain.

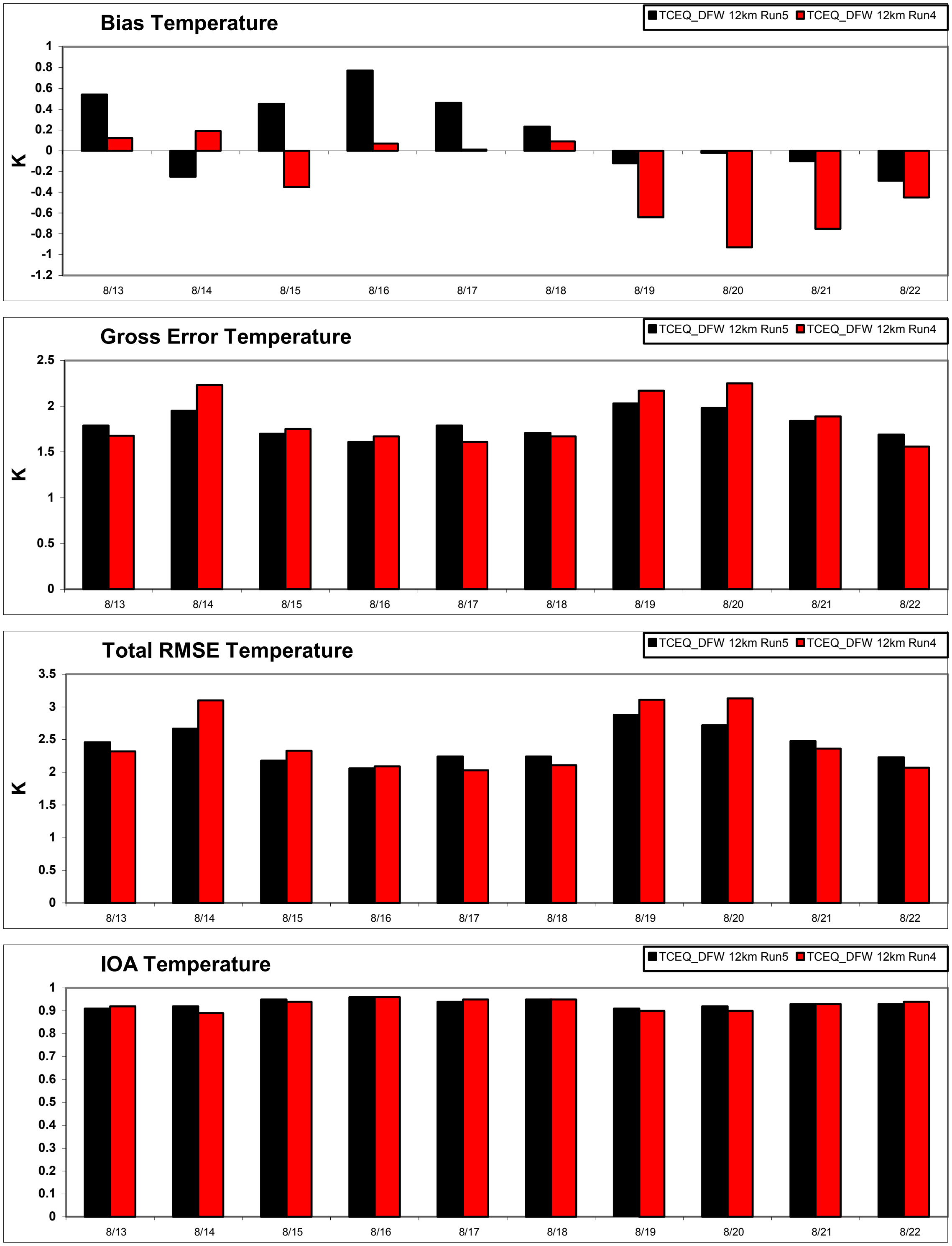


Figure 2-22b. Daily performance statistics for temperature for Run4 and Run5 in the MM5 12-km domain.

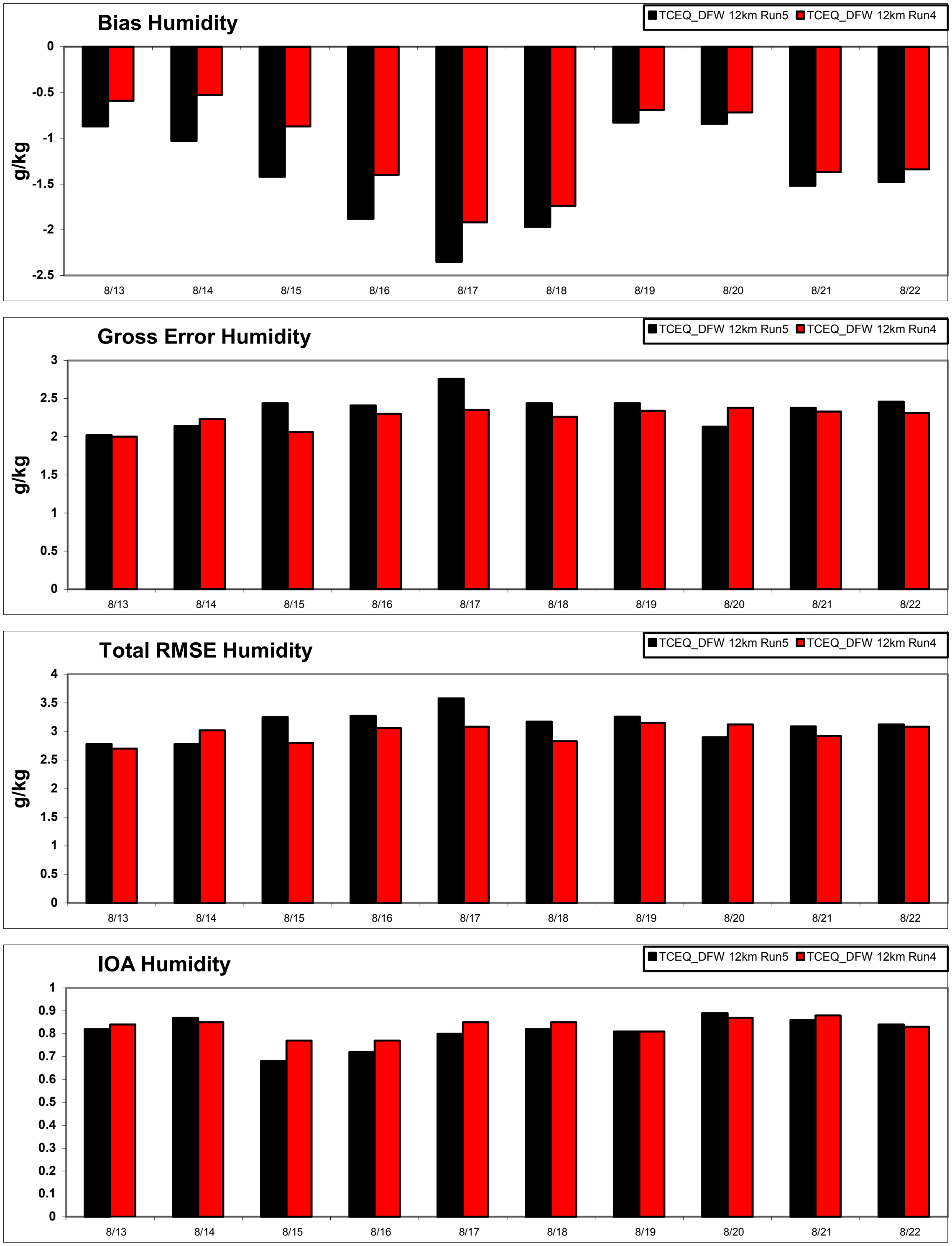


Figure 2-22c. Daily performance statistics for humidity for Run4 and Run5 in the MM5 12-km domain.

SUMMARY

We conclude that the hourly wind speeds in Run1 (increased surface roughness) are significantly reduced relative to the previous MM5 simulation used for DFW base case modeling, as reported by ENVIRON (2003). The wind speed gross error and RMSE error are reduced compared to the observations, and this moved model performance in the anticipated direction.

The MM5 rerun that extended the observation nudging to include additional surface Oklahoma Mesonet observations and profiler data from the DFW and Hinton sites, indicates no noticeable improvement for winds and other fields. The MM5 performance results using NNRP analyses similarly do not show any consistent promising impacts on winds or temperature, and appear to result in a consistently worse humidity simulation.

3. REVISED CAMx APPLICATIONS

The three full-length MM5 simulations described in Section 2 were used to drive three revised CAMx photochemical simulations for the August 13-22, 1999 episode. Statistical and graphical results from each of these new runs are compared in this Section to the original CAMx "Run 7c", which was the official DFW CAMx base case used up to this point by TCEQ and described by ENVIRON (2003).

The three revised CAMx simulations described here are listed below:

- Run 13: uses MM5 "Run1" (increased surface roughness);
- Run 15: uses MM5 "Run4" (increased surface roughness + additional wind profiler FDDA); and
- Run 16: uses MM5 "Run5" (increased surface roughness + additional wind profiler FDDA + NNRP for analysis FDDA and initial/boundary conditions).

Note that only the meteorological inputs were altered for each of these runs, and that all other inputs (emissions, ancillary inputs, configuration switches) were identical to those used in the original CAMx "Run 7c". All CAMx runs reported here used v4.02 to remain consistent with Run 7c reported by ENVIRON (2003).

EVALUATION OF DAILY MAXIMUM OZONE

The simulated daily maximum ozone on August 16 and 17 from Run 7c and each of the new runs are compared in Figure 3-1. The different input meteorological fields in Runs 13 and 15 do not lead to any significant spatial shifts or magnitude differences in the daily maximum ozone patterns. Rather, only some minor differences can be seen. However, more substantial differences are exhibited in Run 16, which uses meteorology developed from a fundamentally different set of large-scale analyses (NNRP vs. EDAS). These differences include a change in the peak ozone cloud exiting DFW to the northwest on both days (+21 ppb on August 16, -12 ppb on August 17), as well as rather different spatial patterns. Note that the domain-wide peak ozone on August 17 in Run 7c is actually lower for Run 16.

It is also interesting to note that the fundamental result that we expected to achieve, namely the slowing of winds and the shifting of peak ozone closer to DFW on August 17, is not clearly evident with the introduction of higher surface roughness in the fields that drive these CAMx simulations. Differences in daily peak 1-hour ozone between Runs 7c and 13 for each day of the episode are shown in Figure 3-2. Similar difference plots are shown for Runs 7c and 16 in Figure 3-3 (results for Run 15 are quite similar to Run 13 and are not shown). Difference patterns in both cases do not show a consistent day-to-day pattern or obvious impact to the DFW plume per se, but rather show domain-wide patterns of both increased and decreased daily peak ozone. Run 16 generally causes larger peak ozone differences on each day of the episode, whereas Run 13 leads to minor differences on 5 of the 10 days.

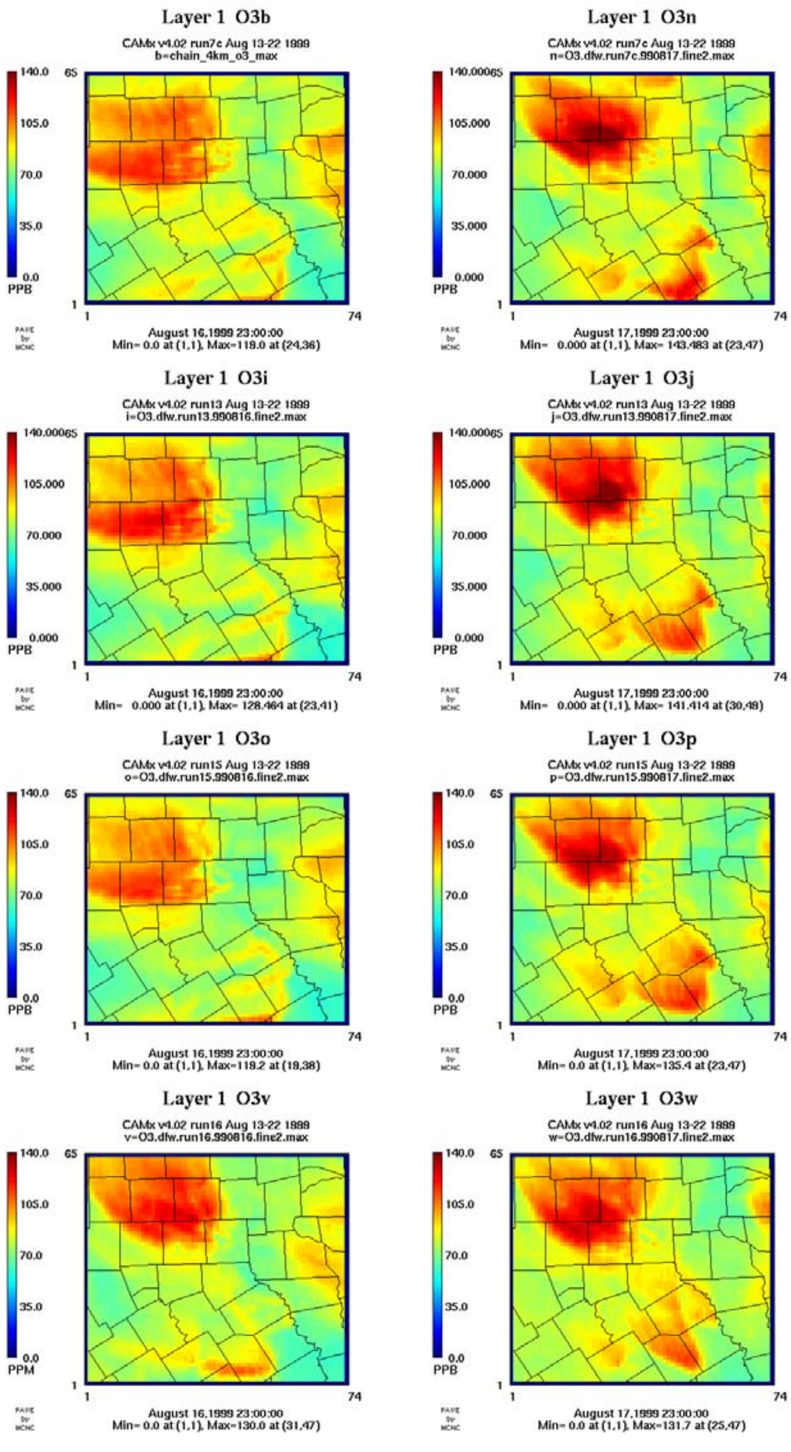


Figure 3-1. Comparison of daily maximum 1-hour ozone in the DFW 4-km CAMx grid. Results are shown for August 16 and 17 (columns) for Runs 7c, 13, 15, and 16 (rows).

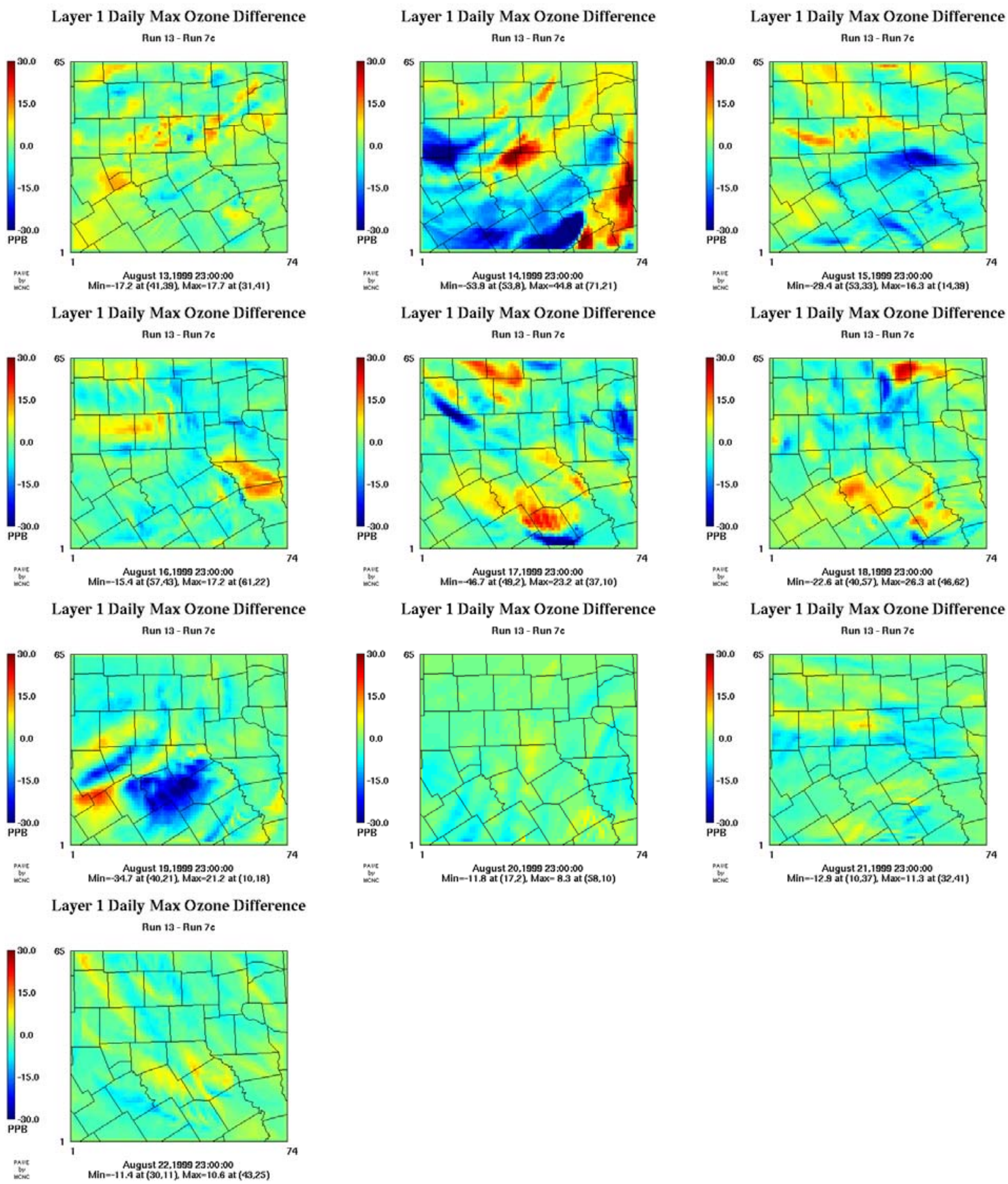


Figure 3-2. Difference in daily maximum 1-hour ozone between Run 7c and Run 13 for the entire August 1999 DFW modeling episode.

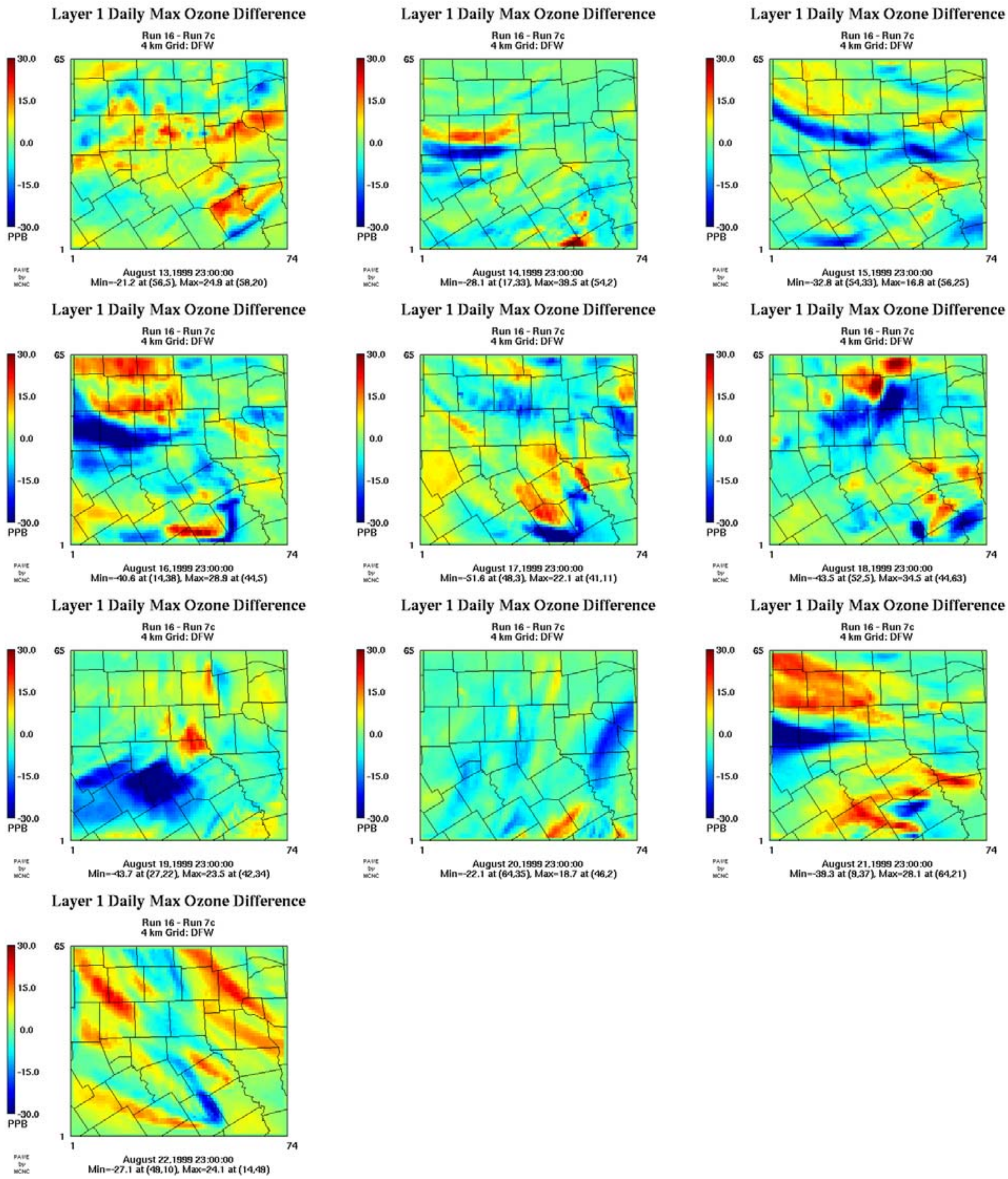


Figure 3-3. Difference in daily maximum 1-hour ozone between Run 7c and Run 16 for the entire August 1999 DFW modeling episode.

STATISTICAL RESULTS

1-Hour Ozone

Standard daily statistical performance metrics were calculated for 1-hour prediction/observation pairings (for observations greater than 60 ppb) for all CAMx simulations described above. Figure 3-4 displays these statistics for each day and for all runs as a series of bar graphs. The EPA acceptance criteria for unpaired peak accuracy, normalized bias, and normalized gross error are also noted on the charts. Note that the first two days of the simulation (August 13 and 14) are "spin-up" days, and do not need to be considered in the performance evaluation since they did not exhibit any ozone exceedances. Nevertheless they are included in the plots below to show how the model responds to initial conditions and whether the model is stabilized by the third day.

Generally, the performance for Runs 13 and 15 are consistent with each other and slightly worse on most days relative to the original Run 7c. Performance for Run 16 is more in agreement with Run 7c, with four days showing improved statistical performance, two days showing worse performance, and four days with roughly similar performance. Overall, the improvements made in the MM5 meteorological fields do not translate to any substantial improvements in the CAMx simulations over the episode. Regarding August 17, a key focus day for expected improvements, unpaired and average paired peak accuracy are all slightly worse in the new simulations, while the broader metrics of bias and gross error are nearly constant across all runs.

"Soccer goal" plots provide another way to graphically present these statistics to more clearly indicate performance relative to EPA acceptance criteria and relative to the different runs. This is shown in Figure 3-5 for 1-hour ozone bias (x-axis) and gross error (y-axis). The EPA criteria levels are shown as the rectangular "goal" at the center of the plot, and the combined bias/error values for each CAMx run for each day are plotted as individual points in the bias-error space. The 1:1 bias/error lines are also shown, and represent the extreme conditions when significant bias constitutes 100% of the gross error.

Figure 3-5 shows that five of the ten simulation days are within the EPA "goal" for Run 7c, with several days extending out to about 25% bias/error and the most extreme day (August 13, the first spinup day) approaching 40%. Runs 13 and 15 show generally worse performance, with only four days within the "goal". Run 16 brings performance back into the goals, with a tighter cluster of performance than any of the other CAMx simulations. Note that all of the new simulations improve performance dramatically on August 13 (the first spin-up day).

8-Hour Ozone

As the new national 8-hour ozone standard is replacing the older 1-hour standard, areas such as DFW are required to develop SIPs to meet the more stringent regulations. The EPA has developed new modeling guidance for 8-hour ozone modeling, which will also supercede the older guidance. Coupled with that fact that TCEQ will begin modeling the 2010 8-hour ozone attainment year based upon the findings of this study, it is important to investigate the impact of the revised meteorological fields on CAMx results in terms of 8-hour performance metrics.

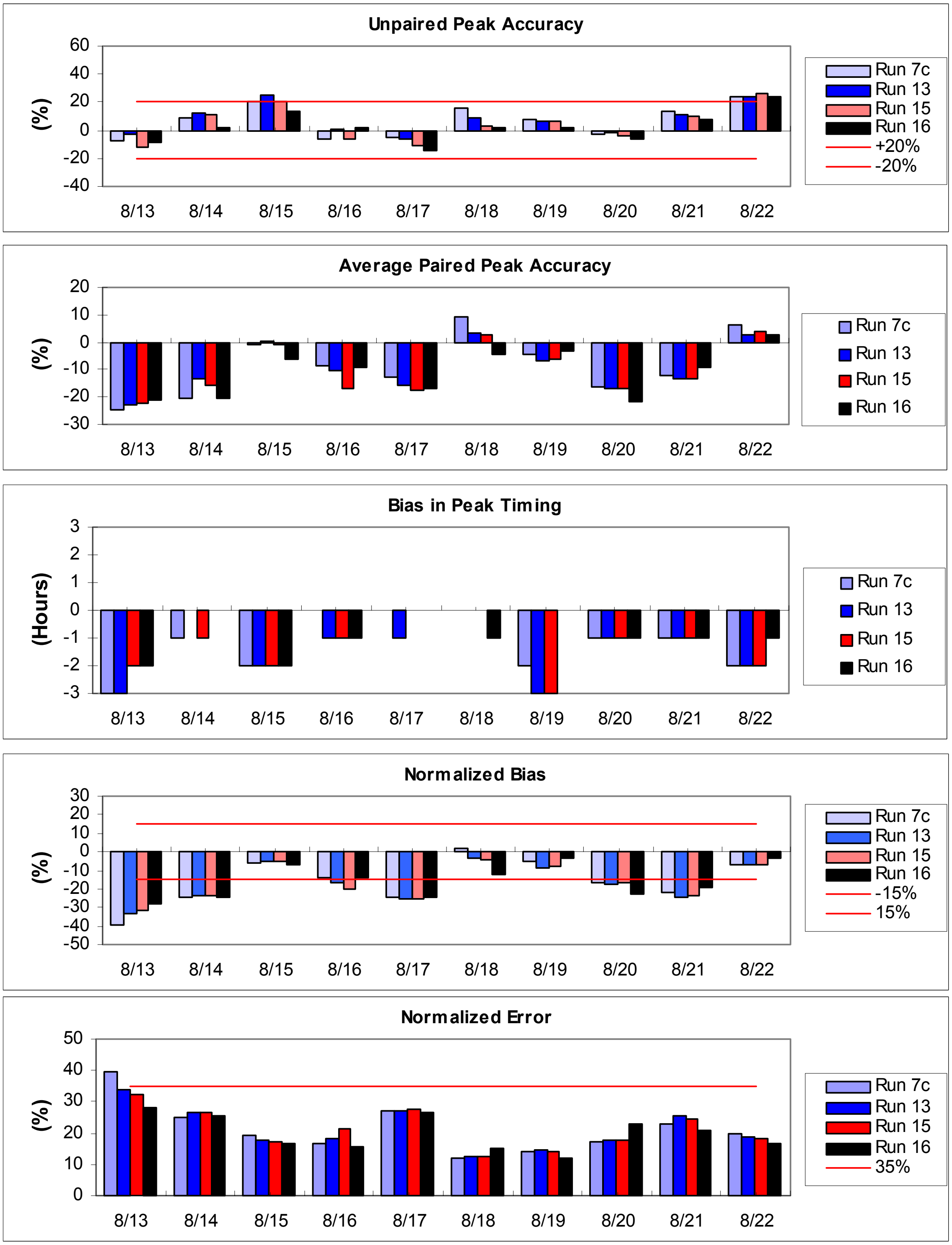


Figure 3-4. Daily performance statistics for 1-hour ozone for four CAMx simulations over the August 1999 modeling episode. EPA performance criteria are shown as red lines. See text for the definition of each run.

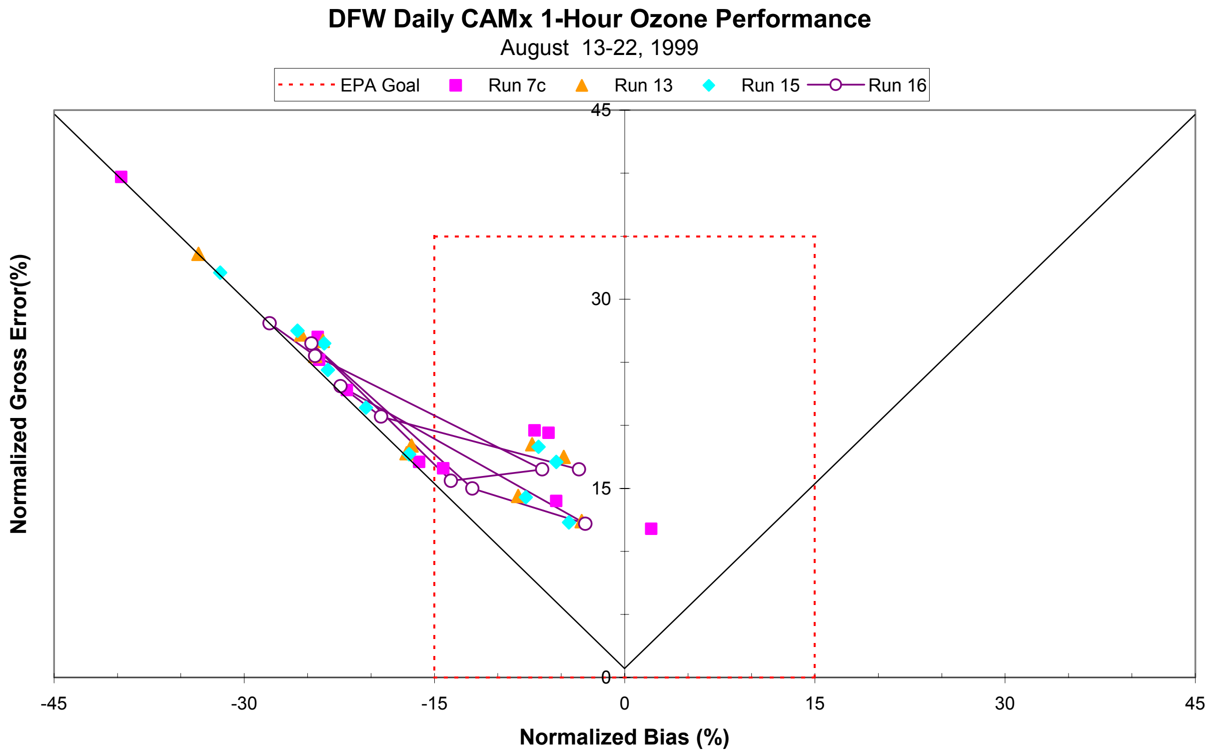


Figure 3-5. Daily performance statistics for 1-hour ozone for four CAMx simulations over the August 1999 modeling episode. Bias and gross error data are the same as plotted in Figure 3-4, but shown in bias/error space. EPA performance criteria are shown as red dashed lines.

Draft 8-Hour Ozone Performance Metrics and Goals

Table 3-1 summarizes several of EPA's new ozone model performance tests from their draft 8-hour ozone modeling guidance (EPA, 1999). The updated EPA guidance suggests a variety of analysis tools to validate 8-hour performance. Distinct from the original 1-hour guidance, there are no set pass/fail criteria as EPA now promotes more of a 'weight of evidence' approach. One of the new ozone performance metrics listed in EPA's draft 8-hour modeling guideline is as follows:

> "bias pred/obs mean 8-hr (& 1-hr) daily maxima near each monitor"

EPA's performance goal for this ozone metric is as follows:

> "~20% most monitors (8-hr comparisons only)"

Note the "~20%" performance goal for *most* monitors. Also, the draft guidance does not define "near each monitor", nor which estimated 8-hour ozone concentration to select "near" the monitor to compare with the observed 8-hour ozone concentration at the monitor. Elsewhere in the EPA draft 8-hour ozone modeling guidance, under the attainment demonstration test using relative reduction factors (RRF), EPA defines "near" as a block of NX by NY cells centered over the monitor that encompasses the circle with a radius of 15 km. When EPA was contacted they confirmed that this definition of "near" appeared to be a consistent and reasonable interpretation of the guidance when also calculating the performance tests.

The next step in defining this 8-hour ozone performance metric was to determine which estimated daily maximum 8-hour ozone concentration should be selected from the array of NX by NY cells that defines "near" the monitor. We have developed three interpretations of the EPA guidance as follows:

1. Selection of the maximum estimated daily peak 8-hour ozone concentration "near" the monitor for comparison with the observed value. This interpretation is totally consistent with EPA's draft 8-hour ozone guidance attainment test. However, it is an unbalanced approach that would tend toward an overestimation bias. Thus, care must be taken in the interpretation when comparing against EPA's performance goal of ±20% because an overestimation tendency may not necessarily indicate a poorly performing model. Thus, when using the maximum estimated daily maximum 8-hour ozone concentration "near" a monitor, only the less than –20% EPA performance goal should be used.

2. Selection of the best fit estimated daily peak 8-hour ozone concentrations "near" the monitor. In this test the estimated 8-hour ozone concentrations within the NX by NY array of cells that matches the observed value most closely is selected for comparison. This test asks whether there is an estimated 8-hour ozone value near the monitor that matches the observed value. In this case, the ±20% EPA performance goal is applicable.

3. The third approach uses the spatially paired value at the monitor. This is the most stringent definition of "near" the monitor as it spatially matches the prediction to the point location of the observation. Thus, the ±20% performance goal is not truly applicable.

When making the comparisons of predicted and observed daily maximum 8-hour ozone concentrations, a 60 ppb observed ozone cut off is used, similarly to the 1-hour ozone performance comparisons.

Table 3-1. EPA's draft 8-hour ozone modeling guidance ozone performance tests and goals.

Test(s)	Goals/Objectives	Comment
"bias pred/obs mean 8-hr (& 1-hr) daily maxima near each monitor"	"~20% most monitors (8-hr comparisons only)"	EPA's draft modeling guidance does not define "near each monitor". After discussing this issue with EPA "near" was defined to mean the same block of grid cells near the monitor used in EPA's attachment test (e.g., 7 x 7 for 5 km grid). There are three ways we defined "near" for this metric: (1) Select the maximum predicted daily peak 8-hr ozone concentrations "near" the monitor; (2) Select the predicted values closest in value to the observed value "near" the monitor; and (3) Select the predicted value at the monitor.
"Fraction bias pred/obs mean 8-hr (& 1-hr) daily maxima near each monitor"	"~20% most monitors (8-hr comparisons only)"	Define "near" the three ways described above.
"Correlation coefficients, all data, temporally paired means, spatially paired means"	"Moderate to large positive correlations"	Apply to three data sets described above.
"bias (8-hr daily max and 1-hr obs/pred), all monitors"	"~5-15%"	
"gross error (8-hr daily max and 1-hr obs/pred), all monitors"	"~30-35%"	
Partition data base into upwind, center city and downwind sites and repeat analysis		Get better ideas of level of model agreement based on upwind/downwind stratification and whether there is any obvious pattern of the model performance.
"Scatter plots & Q-Q plots of 8-hr and 1-hr metrics"		Applied to three sets of databases listed above.

Figures 3-6a,b show similar "soccer goal" plots as in Figure 3-5, but calculated for 8-hour bias and gross error for paired observation/prediction pairings greater than 60 ppb. While all three new CAMx simulations appear to tighten up the bias/error cluster, it is fairly obvious that Run 16 shows the best overall performance gains of the three. It is clearly performing better than the original Run 7c, with seven days indicating improved performance to only 2 with worse performance (Figure 3-7b). On August 17 specifically, bias and error improved from –28/30% in Run 7c to –23/25% in Run 16. On August 16, bias and error improved from –16/18% to –12/14%.

As a way to present the entire distribution of performance for 8-hour peak ozone on all days and at all sites, Figure 3-7(a-d) presents quantile plots for CAMx Runs 7c, 13, 15, and 16. The EPA draft guidance suggests that "most" pairings should meet the ±20% criteria, and this envelope is also shown on the plot. We have chosen to show the quantile-quantile (Q-Q) plots based on space-paired peak observation/predictions (approach #3 listed above) for two reasons: (1) it is the most technically stringent and robust way to show model performance at observation sites; and (2) it is the approach that is most likely to show differences among the various runs (i.e., less stringent prediction-observation comparisons tend to mask subtle differences in the model).

The Q-Q plots provide several levels of information. First, the paired peaks are plotted as a scatter diagram, where each point represents performance in replicating the peak 8-hour ozone at a given site on a given day. The coefficient of determination (r^2) provides a single metric relating the "spread" of the data scatter, and measures the fraction of variation that is explained (or captured) by the model. The Q-Q circles are shown as 20 points, defining the 5^{th}-percentiles over the range of paired values. The purpose of the quantile data is to evaluate whether the model forecasts high or low over different portions of the range of data. EPA has established +/-20% boundaries for this metric.

The Q-Q plot for Run 7c (Figure 3-7a) indicates a consistent under prediction bias with the quantile values remaining parallel to the 1:1 line to within –5 to -10 ppb throughout the distribution. The data pairings spread well beyond the 20% envelope on the under prediction side, and this spread contributes to a "moderate" coefficient of determination (0.46). In Run 13 (Figure 3-7b), generally worse performance is indicated, which follows from the 1-hour results. The spread is slightly larger, and the quantile values show worse performance for the highest value. However, the quantile values remain within the 20% envelope throughout the entire distribution. A very similar pattern is seen for Run 15 (Figure 3-7c), but the quantile values are shifted even lower. Run 16 shows the widest data spread of all runs (Figure 3-7d), with a coefficient of determination of just 0.41. However, the mid-range of the quantile values move upward toward the 1:1 line suggesting much less negative bias than Runs 13 and 15 (consistent with the 1-hour results); the highest quantiles and data pairings show the lowest ozone predictions.

As seen in the "soccer-goal" plots, bias and gross error statistics for all 8-hour data pairings above 60 ppb suggest that Run 16 is generally the best performing run as it consistently reduced negative bias, especially on August 16 and 17, our key days of interest. Nevertheless, these improvements were not sufficient to rescue the episode from its performance problems. Based upon analysis of the Q-Q plots for peak 8-hour ozone performance, Run 7c appears to be the best overall simulation. Run 16 is similar to Run 7c for the mid-range of the peak 8-hour pairings;

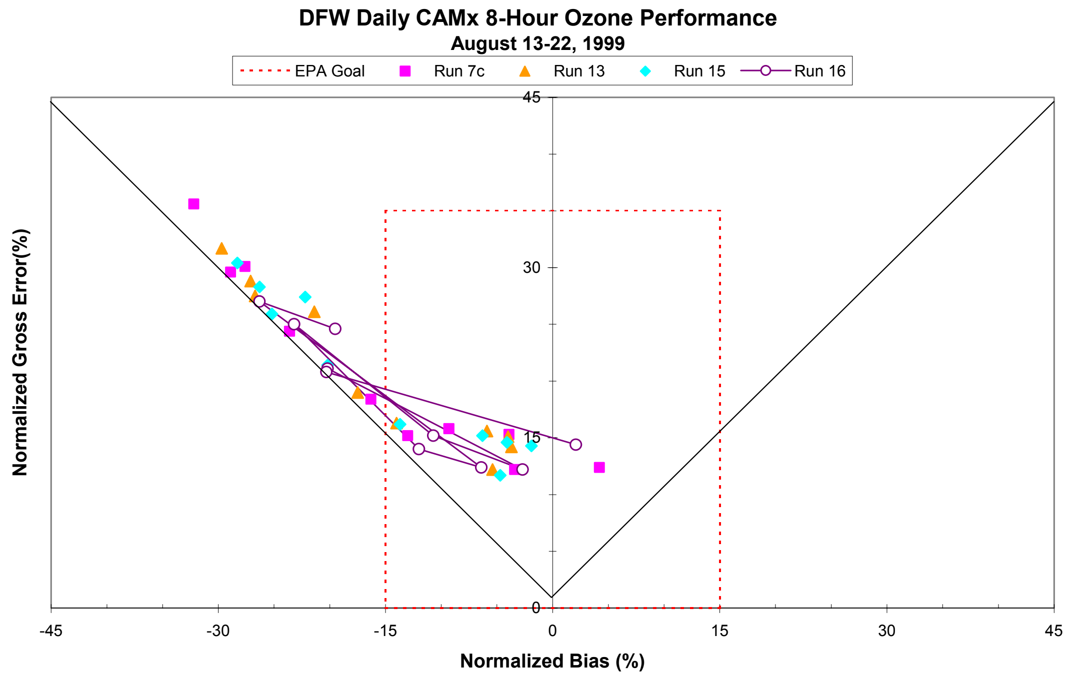


Figure 3-6a. Daily performance statistics for 8-hour ozone for four CAMx simulations over the August 1999 modeling episode. EPA performance criteria are shown as red dashed lines.

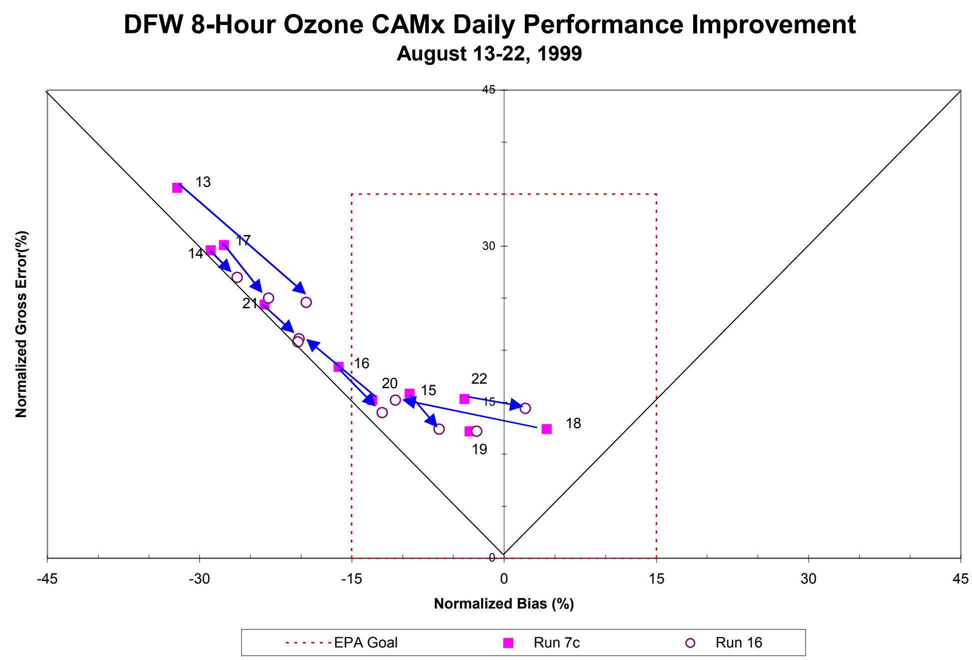


Figure 3-6b. As in Figure 3-6a, but showing only Runs 7c and 16, with arrows indicating the direction of change. Numbers indicate the date of August for each statistical point.

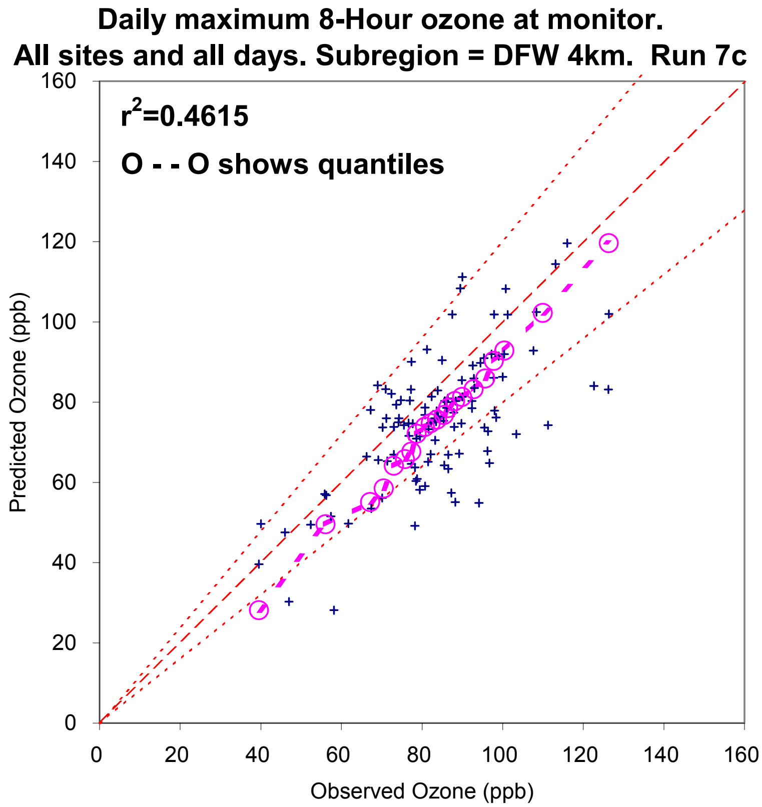


Figure 3-7a. Quantile-quantile plot of observed/predicted paired peak 8-hour ozone at each site and for each day of the August 1999 episode for CAMx Run 7c (original CAMx simulation from ENVIRON [2003] – original meteorology and emissions, CAMx v4.02). EPA recommended ±20% envelope is shown as red dotted lines surrounding the 1:1 line (middle red dashed line).

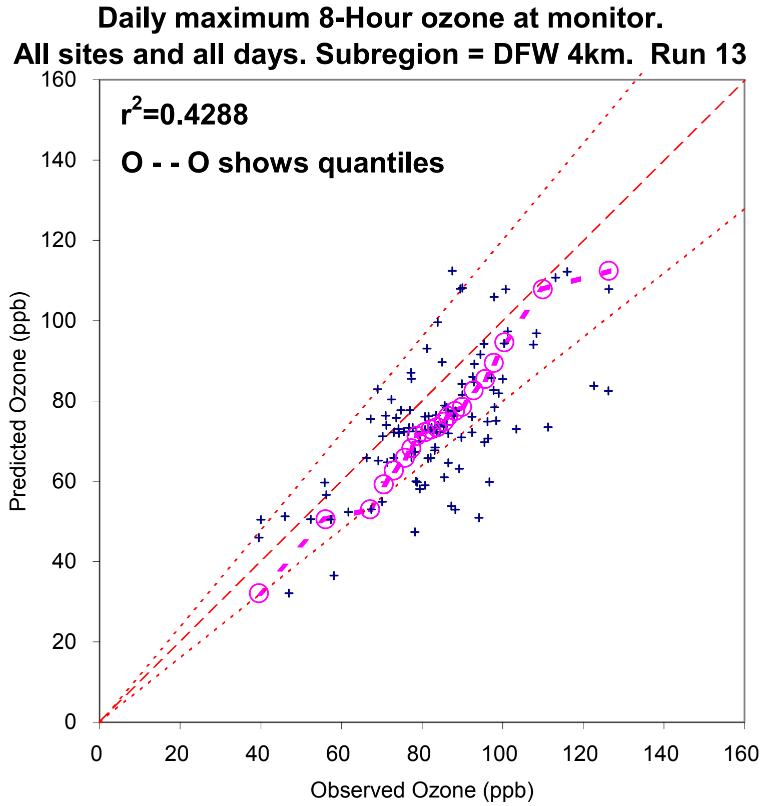


Figure 3-7b. Quantile-quantile plot of observed/predicted paired peak 8-hour ozone at each site and for each day of the August 1999 episode for CAMx Run 13 (new CAMx simulation – new MM5 meteorology ["run1"] and original emissions, CAMx v4.02). EPA recommended ±20% envelope is shown as red dotted lines surrounding the 1:1 line (middle red dashed line).

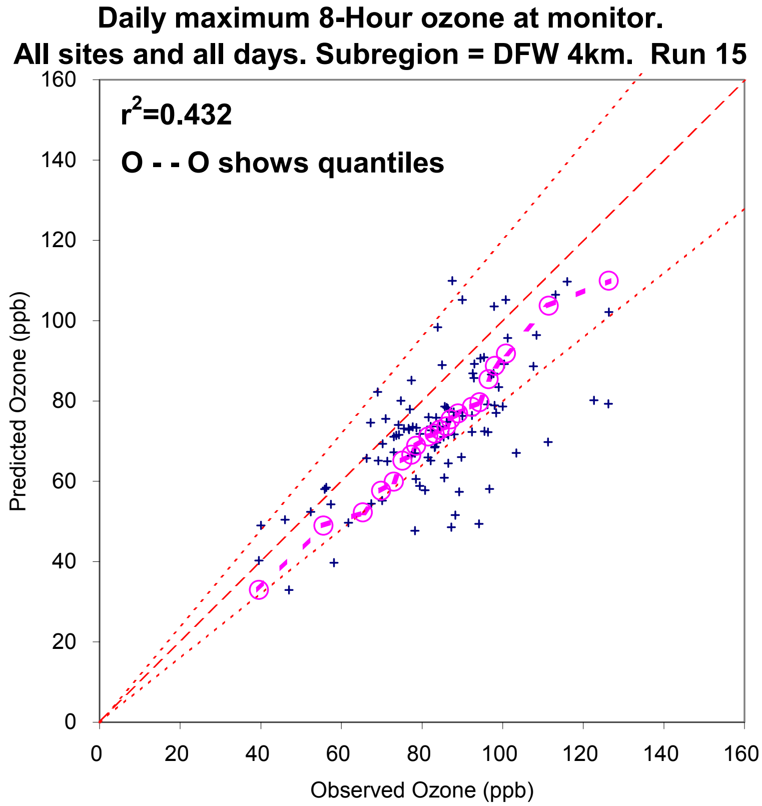


Figure 3-7c. Quantile-quantile plot of observed/predicted paired peak 8-hour ozone at each site and for each day of the August 1999 episode for CAMx Run 15 (new CAMx simulation – new MM5 meteorology ["run4"] and original emissions, CAMx v4.02). EPA recommended ±20% envelope is shown as red dotted lines surrounding the 1:1 line (middle red dashed line).

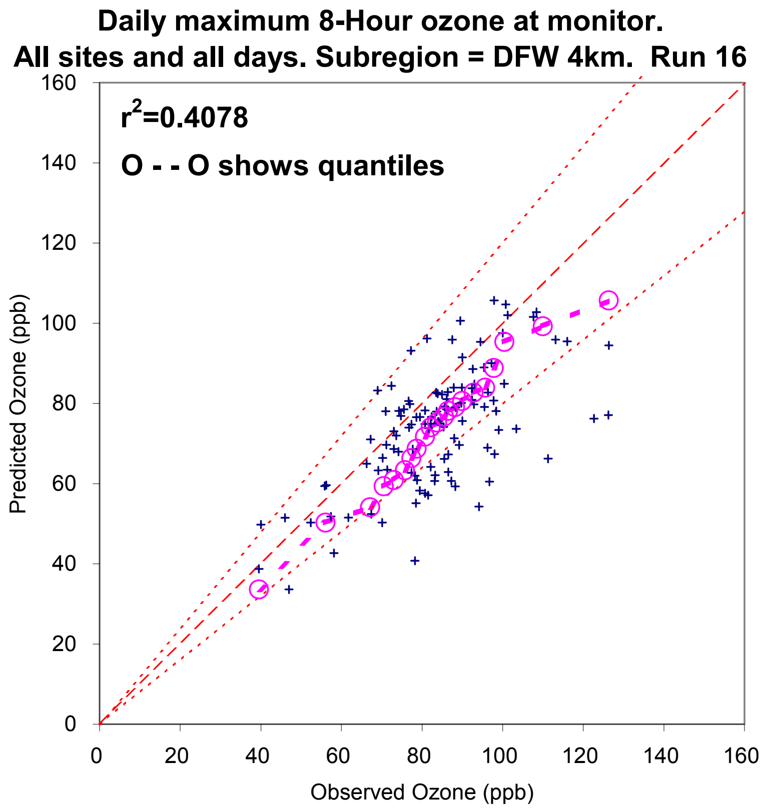


Figure 3-7d. Quantile-quantile plot of observed/predicted paired peak 8-hour ozone at each site and for each day of the August 1999 episode for CAMx Run 16 (new CAMx simulation – new MM5 meteorology ["run5"] and original emissions, CAMx v4.02). EPA recommended ±20% envelope is shown as red dotted lines surrounding the 1:1 line (middle red dashed line).

and even though Run 16 performance is deteriorated at the high end of the distribution, the top 5-10% quantile increments are based upon very few data points (perhaps just one pairing defines the top quartile value). Since the Relative Reduction Factor computation is specifically designed to average multiple measurements at each monitor, the 'middle' quantiles (70-90 ppb) are the most representative and robust segment of the distribution. Also, although the low end of the quantiles informs how the model is performing at the low range, it is not relevant to the RRF computation since any modeled values less than 70 are dropped from the computation.

8-HOUR DAILY MAXIMUM OZONE FIELDS

Figure 3-8 compares the daily maximum ozone fields in the 4-km domain generated by Run 7c and Run 16 for each (non-spin up) day of the August 1999 DFW episode. Daily peak 8-hour observations are overlaid at the locations of the monitoring sites.

As suggested by the analyses and discussions of time series and statistics presented earlier in this section, the two runs are similar but vary day-to-day in terms of the highest simulated peaks, and in details of the ozone patterns. No obvious performance improvements are noted for Run 16.

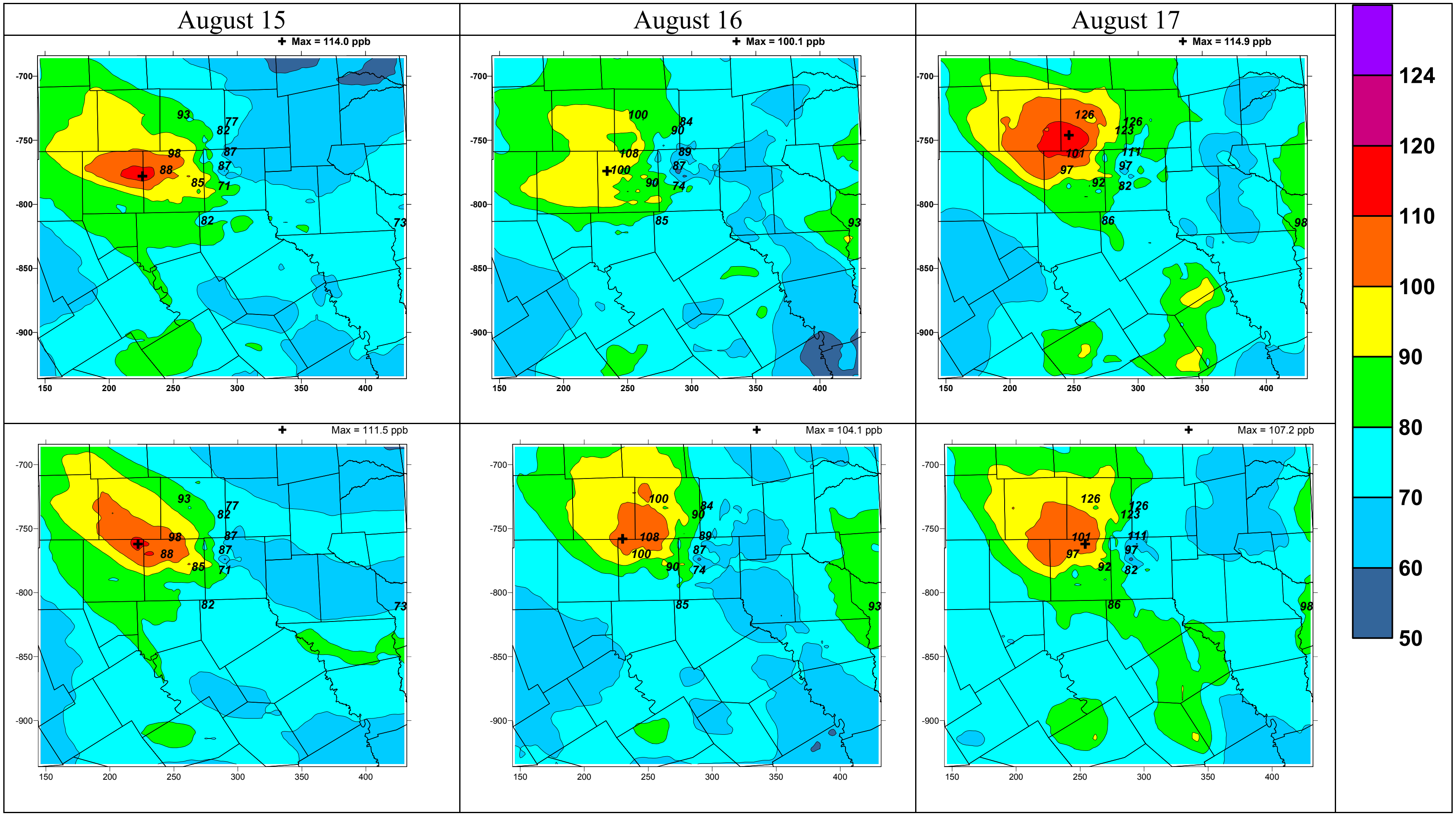


Figure 3-8. Comparison of daily maximum 8-hour ozone in the DFW 4-km grid between CAMx Run 7c (top row – original CAMx simulation with original meteorology and emissions) and Run 16 (bottom row – new CAMx simulation with best new MM5 simulation and original emissions) over the August 1999 modeling episode.

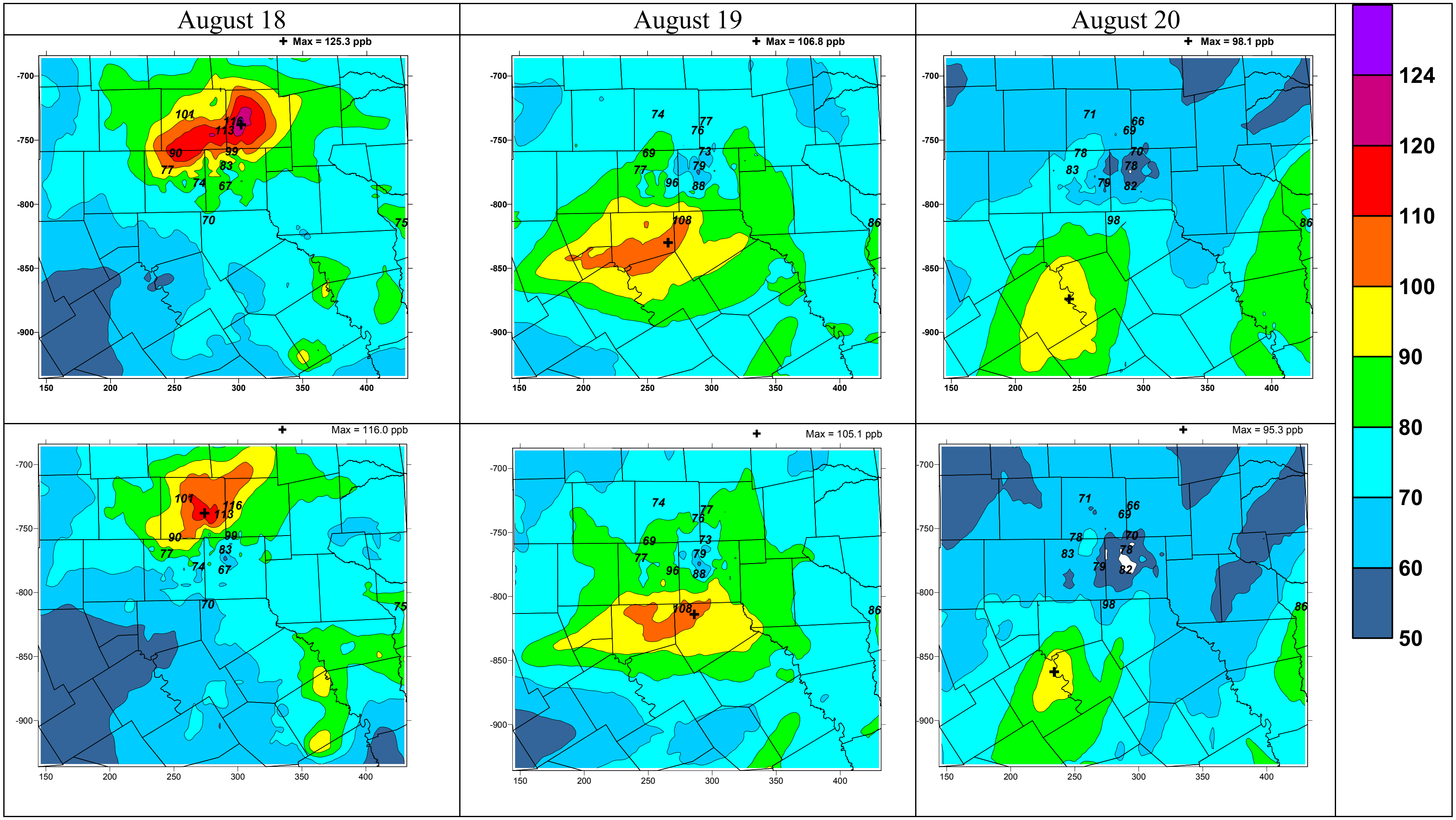


Figure 3-8. (continued).

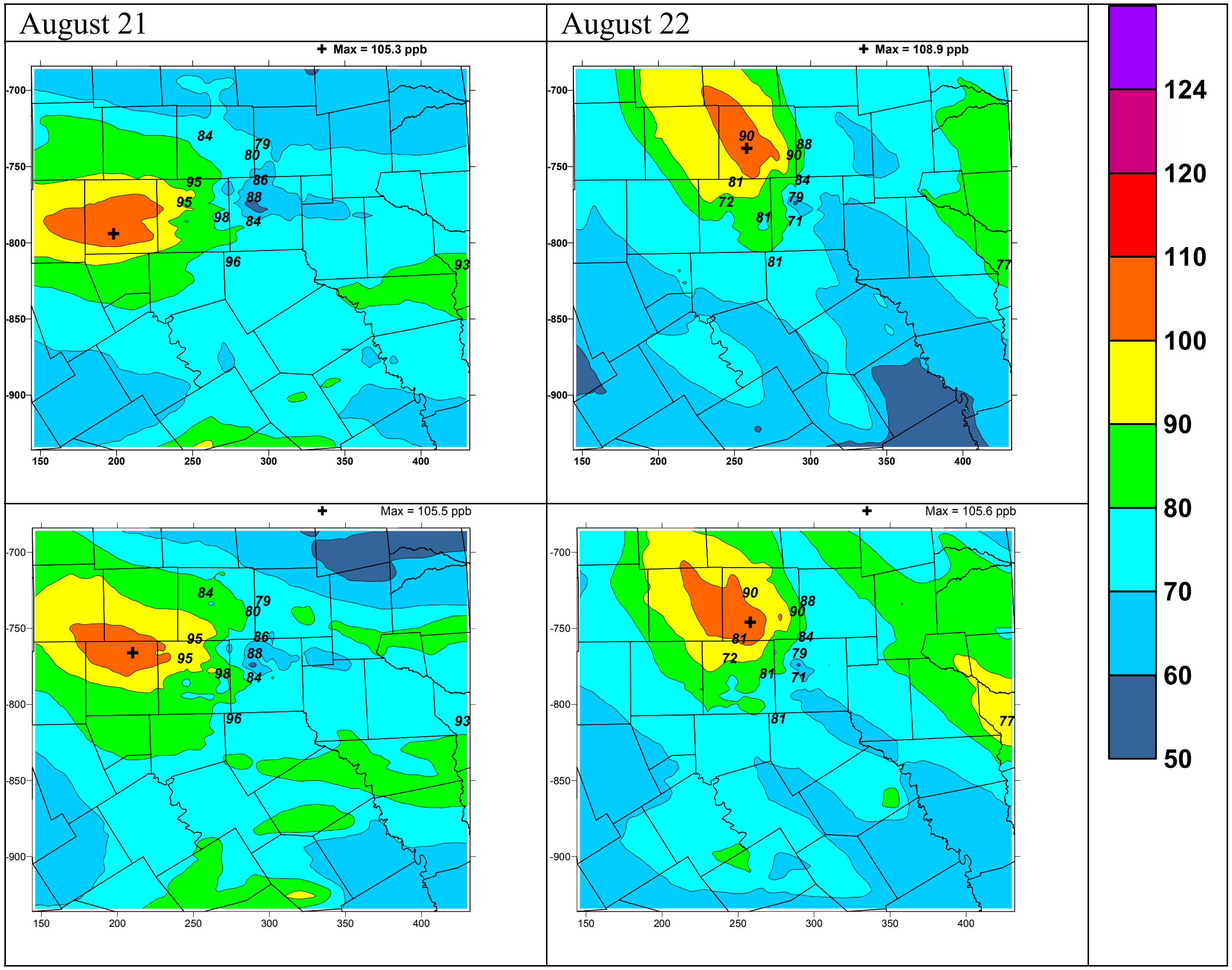


Figure 3-8. (concluded).

4. CAMx APPLICATIONS USING UPDATED EMISSIONS

Upon completion of the CAMx simulations described in Section 3, the original DFW base year on-road mobile source emission estimates were updated as part of a separate Work Order through the TCEQ.[1] CAMx performance was reevaluated using these new emissions in combination with the original meteorology and the best performing of the new meteorology. Additionally, the version of CAMx was upgraded to v4.03.[2] These two runs are listed below:

1) Run 17a: 1999 base case using revised emissions, but with the original meteorology documented in ENVIRON (2003); and
2) Run 17b: 1999 base case using revised emissions and the best of the revised meteorology (MM5 Run5, as in CAMx Run 16).

UPDATES TO DFW 1999 EMISSIONS INVENTORY

The updates to the 1999 emission inventory for the Dallas/Ft Worth air quality modeling include primarily an updated on-road mobile source inventory for the entire modeling domain. A correction to the Louisiana point source inventory was also included. All other components of the inventory were unchanged from the 1999 base year inventory as documented by ENVIRON (2003).

On-road emissions processing for the 12-County DFW CMSA were developed under contract by NCTCOG and included the following updates and corrections:

- Use of updated weekend "VMT mix", resulting in considerably less "18 Wheeler" NOx for the Saturday and Sunday episode days.
- 3.4% of the "18 Wheeler" emissions were extracted as "extended idling" and processed as low-level points located at known locations of truck-stop locations.
- On-road mobile emissions for the 12-County DFW CMSA were processed as day-specific inventories for each day of the episode. On-road mobile source emissions in the remaining Texas portions of the modeling were processed as Weekday, Friday, Saturday, Sunday "day types".
- All Texas on-road mobile source emissions have been processed using temperature/ humidity NOx corrections.
- The non-Texas emissions are based on the latest "final" NEI Version 3 posted on 1-20-04 at the following EPA FTP site:
  ftp://ftp.epa.gov/EmisInventory/finalnei99ver3/criteria/datafiles/onroad/
  The non-Texas on-road mobile source emissions were processed for the Weekday, Friday, Saturday and Sunday "day types".

[1] DFW on-road mobile emissions were updated as part of TCEQ Work Order 582-04-65563-04. These updates, along with revised 2010 future base case inventories and CAMx Ozone Source Apportionment applications, are described in the final report for Work Order #4.
[2] CAMx v4.03 fixes a bug in the dry deposition routine; small reductions (1-3 ppb) in peak ozone are typically seen when comparing results of v4.03 with results of v4.02.

The Louisiana point source emissions were corrected to remove a double counting of the non-EGU point source inventory.

Tables summarizing the updated 1999 base year DFW emissions inventory are provided in Appendix A. Emission density plots of the same inventory are provided in Appendix B.

CAMx SIMULATION RESULTS

Figure 4-1 presents plots of daily maximum 8-hour ozone in the DFW 4-km grid for Run 17a and 17b over August 15-22. From a qualitative perspective, it is unclear which model simulation performs best. Certain days indicate some significant differences in the details of the peak 8-hour ozone field, while on many days the differences are more minor. Subjective evaluation of the predicted fields against the posted observations in Figure 4-1 suggests to us that Run 17b out performs Run 17a on 6 of 8 days. Again, differences are mostly minor, not dramatic.

Evaluation of Figures 4-2 and 4-3 provide a more objective/quantitative means of assessing model performance for Runs 17a and b. The "soccer goal" plot (Figure 4-2) shows daily 8-hour bias and gross error for all sites in the 4-km grid and for data pairings in which the observations are greater than 60 ppb. Six of the eight days show at least some improvement in the overall statistics, similarly to comparisons of the original Run 7c and new Run 16. However, statistical differences are small on most days.

Figure 4-3 specifically follows current EPA guidance for 8-hour ozone modeling (EPA, 1999). As described in Section 3, the plots show quantile-quantile (Q-Q) distributions of peak 8-hour observed and predicted ozone in the 4-km domain. Note that there are two sets of plots for the two simulations: the first set is similar to those shown in Section 3, where the daily 8-hour peak predictions are "paired" with observations at each site location (the most scientifically stringent test); the second set compares quantiles for a more lenient test described by EPA (1999), where the prediction "nearest" in magnitude to each observation among the nine surrounding cells is used. Hence, the Q-Q plots in the second set tend to look much better than the first. The differences between Runs 17a and 17b are fairly minor. Note that in both the "paired" and "nearest" cases, the coefficient of determination (r^2) is slightly worse using new meteorology in Run 17b. Also, the scatter in peak 8-hour prediction-observation pairings is shifted a bit more to under predictions with the new meteorology.

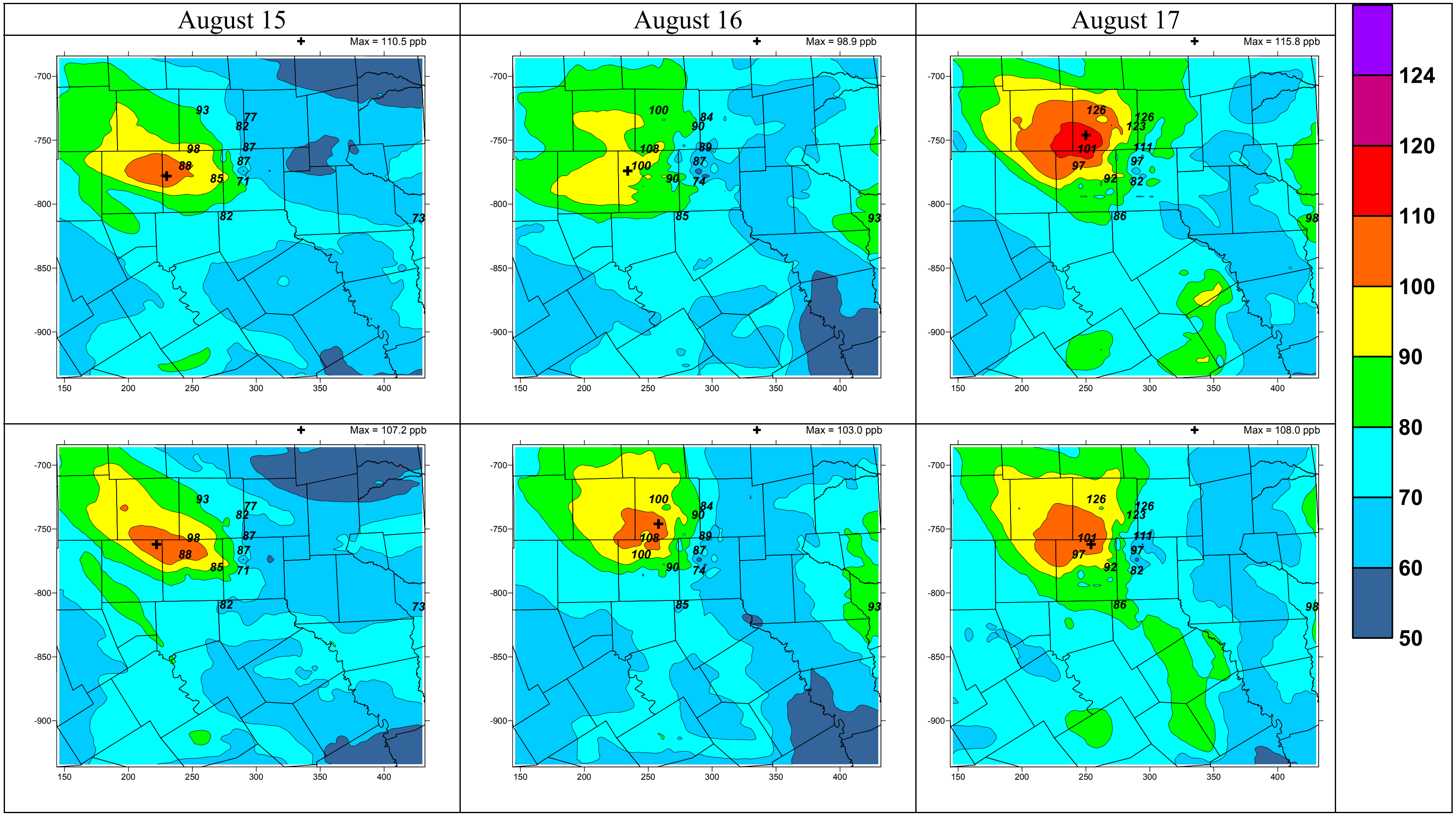


Figure 4-1. Comparison of daily maximum 8-hour ozone in the DFW 4-km grid between CAMx Run 17a (top row – new CAMx v4.03 simulation with original meteorology and revised on-road mobile emissions) and Run 17b (bottom row – new CAMx v4.03 simulation with best new meteorology and revised on-road mobile emissions) over the August 1999 modeling episode.

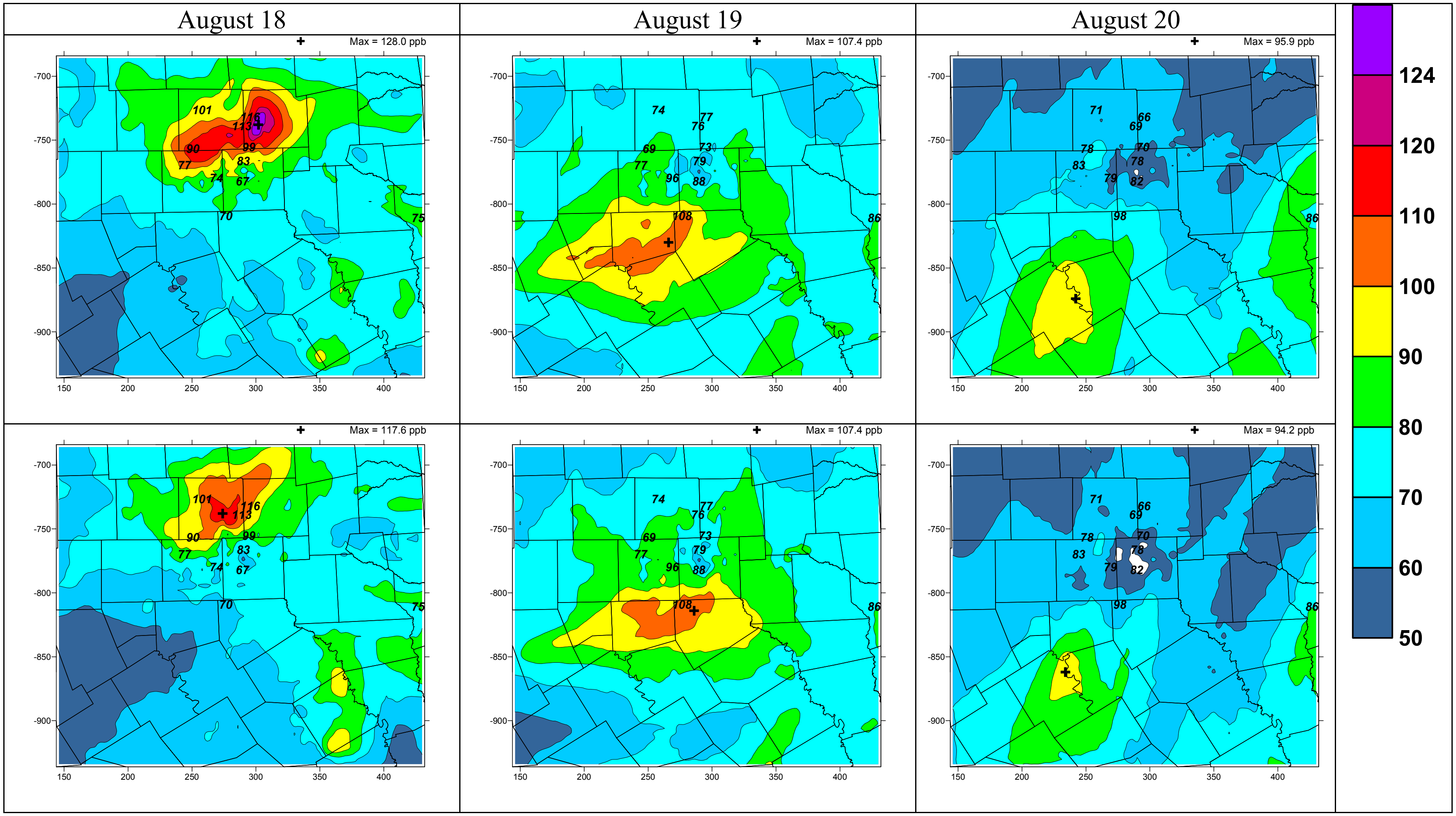


Figure 4-1. Continued.

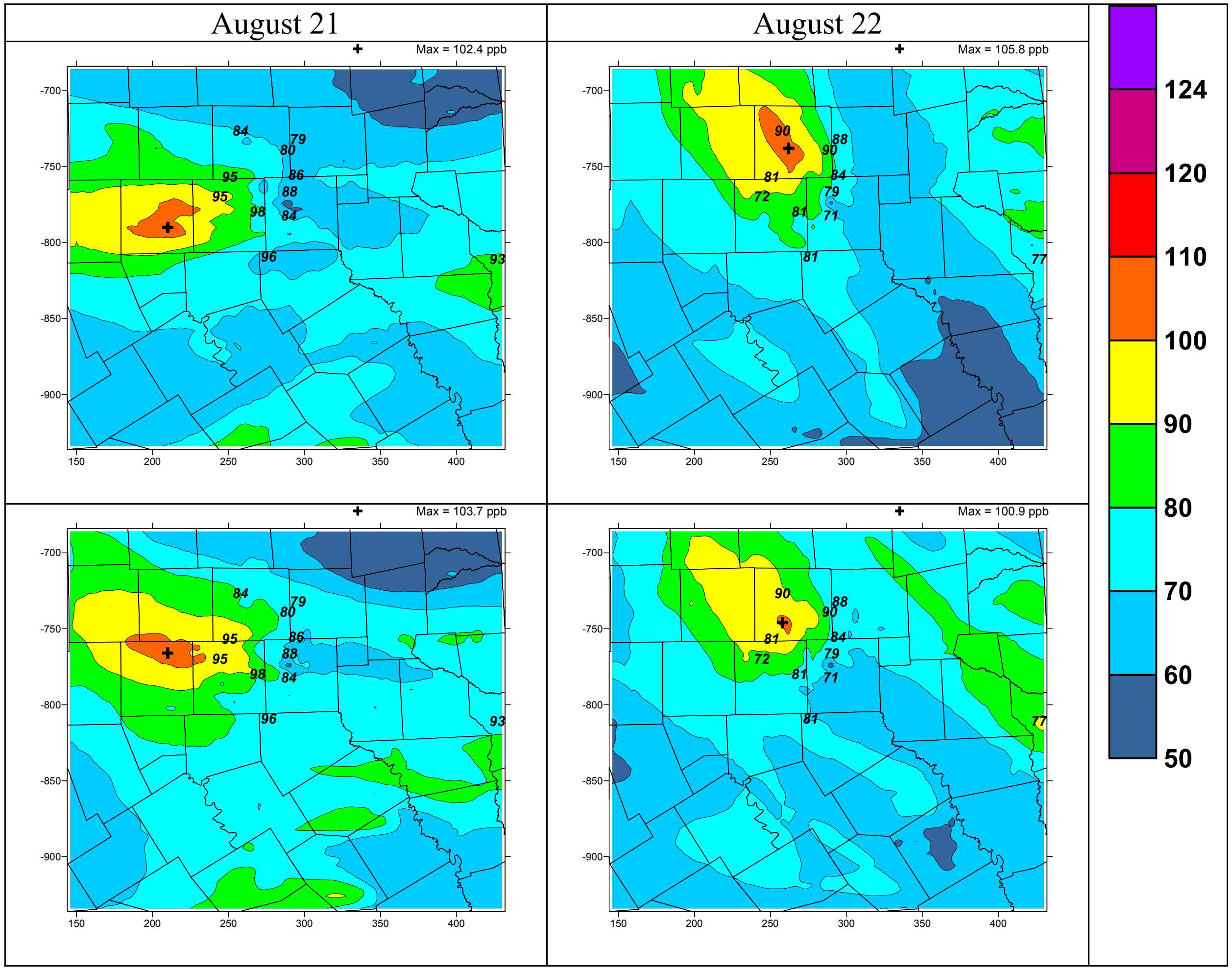


Figure 4-1. Concluded.

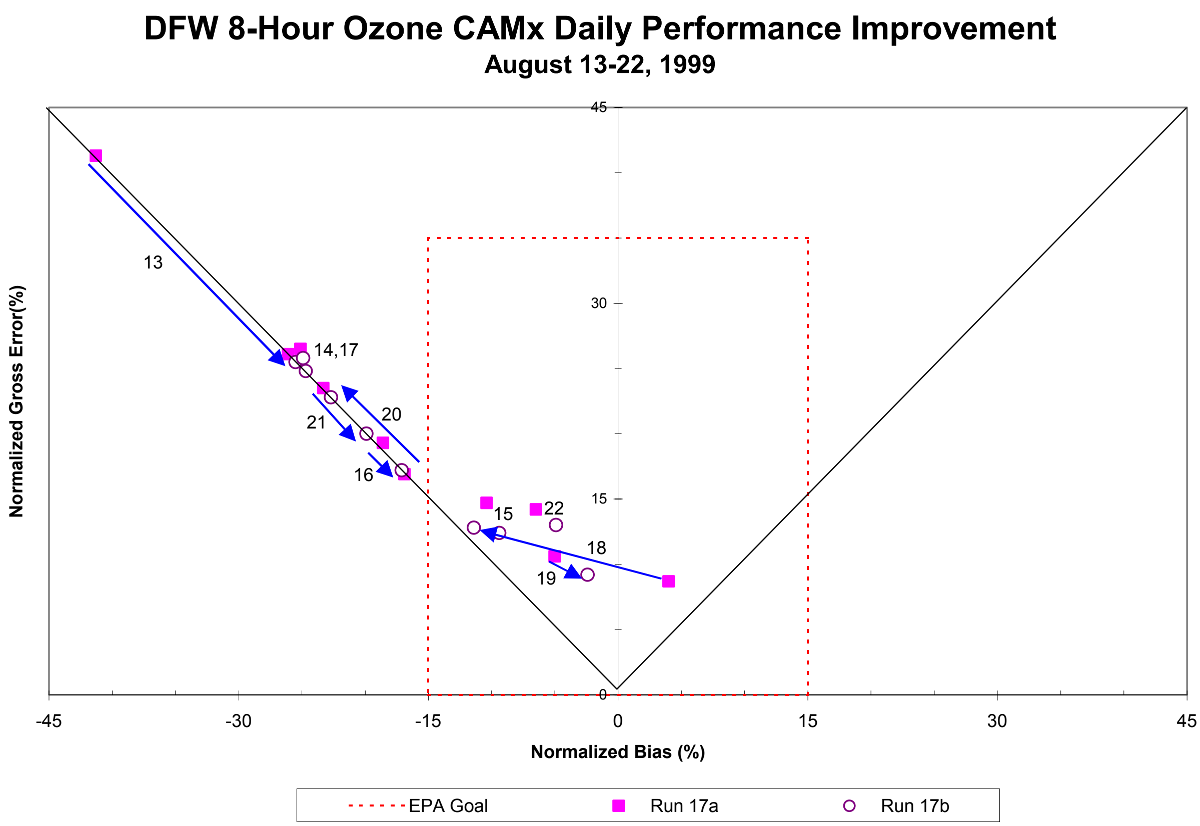
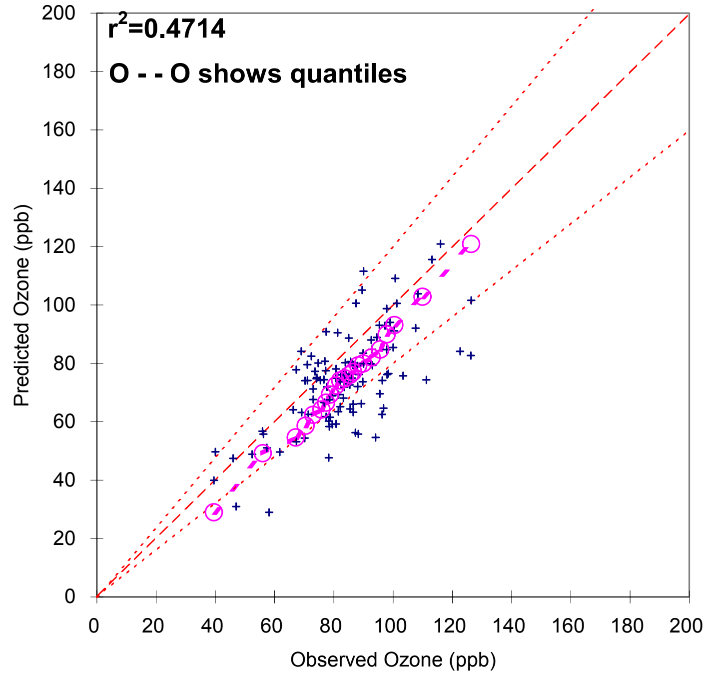


Figure 4-2. Daily performance statistics for 8-hour ozone from CAMx simulations Run 17a and 17b over the August 1999 modeling episode. EPA performance criteria are shown as red dashed lines. Arrows indicate the direction of change. Numbers indicate the date of August for each statistical point.

Daily maximum 8-Hour ozone at monitor.
All sites and all days. Subregion = DFW 4 km Run 17a



Daily maximum 8-Hour ozone at monitor.
All sites and all days. Subregion = DFW 4 km RUN17b

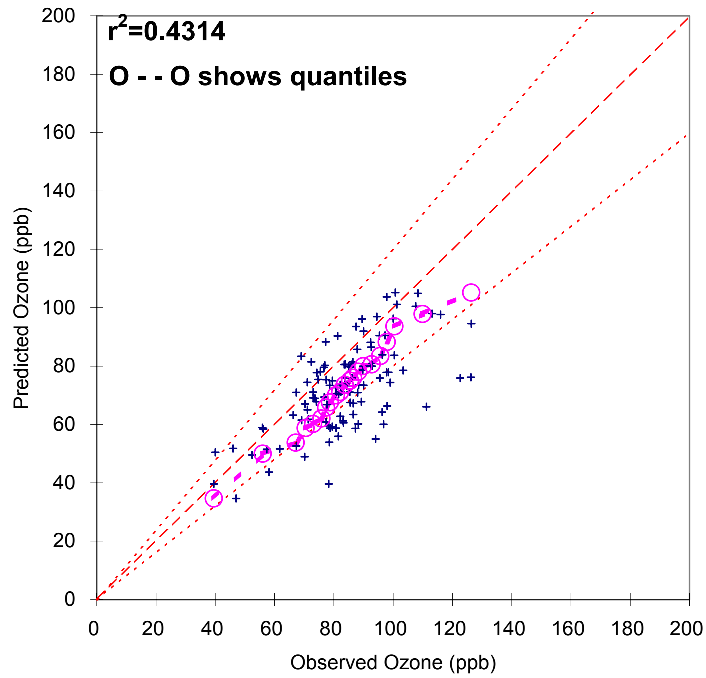
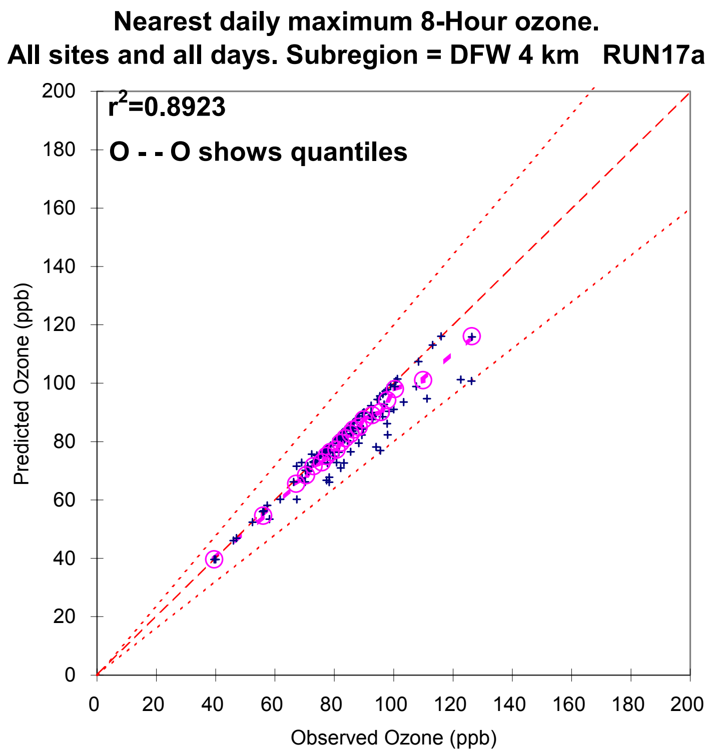


Figure 4-3a. Quantile-quantile plots of observed/predicted paired peak 8-hour ozone at each site and for each day of the August 1999 episode for CAMx Runs 17a (top) and 17b (bottom). EPA recommended ±20% envelope is shown as red dotted lines surrounding the 1:1 line (middle red dashed line).



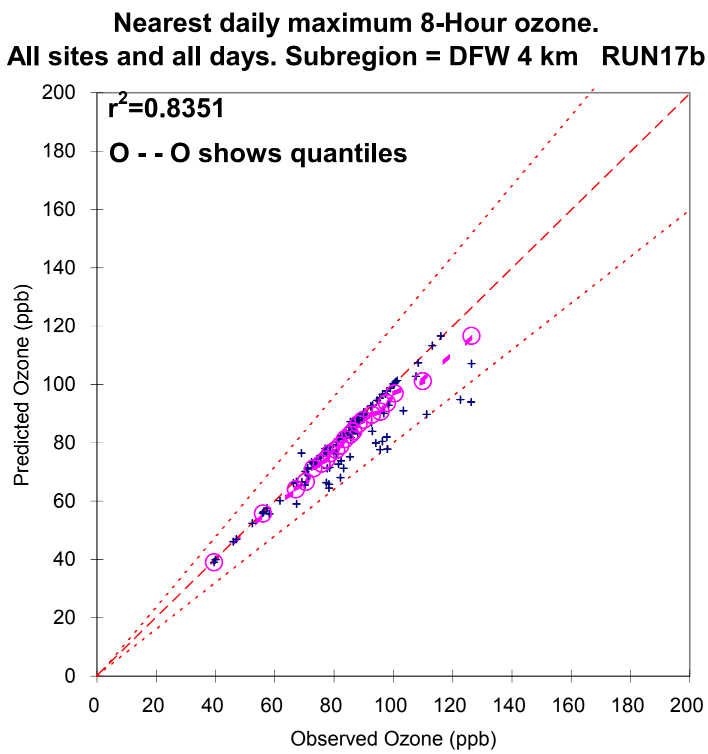


Figure 4-3b. Quantile-quantile plot of predicted peak 8-hour ozone nearest in magnitude to observations at each site and for each day of the August 1999 episode for CAMx Runs 17a (top) and 17b (bottom).

5. CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

The focus of this work effort was an attempt to improve DFW CAMx ozone base-case performance for the August 1999 episode, particularly on August 17 when the model is under predicting peak ozone (ENVIRON, 2003) and showing the least sensitivity to emission controls. One hypothesis going into this work was that a general over prediction bias in MM5 surface wind speeds was leading to the development of high ozone too far downwind of the DFW core. This causes an ozone under prediction bias nearly every day of the episode, but acceptable unpaired peak performance when comparing the peak observation to the peak ozone in the downwind plume. By removing or reducing the over prediction bias in wind speed, perhaps the ozone performance would come more in line with acceptance criteria, and the impacts from emission controls may be magnified.

Meteorological Improvements

The sensitivity tests designed and carried out in this project did not involve artificial tuning to obtain the answers we desired. The meteorological rework was based upon the problems that had been identified in the first round of modeling. All of the changes were justifiable since they were based upon operational experience, good science and new data.

Three MM5 sensitivity tests were conducted to evaluate impacts to wind performance. By increasing the surface roughness (Run1), the wind speed decreased noticeably, especially on the 12-km domain. The temperature and humidity performance also showed slight improvement in this simulation. Without any analysis and observation FDDA (Run2), the wind and temperature performance were damaged, especially in terms of wind direction. The nudging has positive impacts on the model performance. Nudging toward the NNRP analyses (Run3) indicated that there may be some improvements to the temperature and humidity performance. But the impact on the wind performance was negative with relatively higher overestimation of wind speed. Given that Run3 was made without the increased surface roughness, we feel that the NNRP data could be employed as an alternative analysis for this MM5 application. Neither sensitivity tests Run2 nor Run3 significantly improved MM5 model performance.

In Run4, additional data (DFW radar profiler data, Oklahoma Mesonet data, and SODAR data) were incorporated into the observation FDDA data file to improve the wind performance. Run 5 repeated this simulation, except that the EDAS analyses were replaced with NNRP analyses as input for initial/boundary conditions and analysis FDDA. The increased surface roughness used in Run1 was adopted in both of these last two MM5 runs. The addition of profiler and mesonet data to the observational FDDA inputs did not have any significant impact on MM5 performance in the DFW area, which remained quite similar to Run1. The same general results were true in Run5 as well.

Ozone Response

CAMx simulations were undertaken with the Run1, Run4, and Run5 meteorological fields to evaluate impacts on air quality model performance for ozone in the DFW area (referred to as CAMx Runs 13, 15, and 16, respectively). Note that the emission and other non-meteorological inputs were not altered for these simulations, and CAMx version 4.02 was used following the original work documented by ENVIRON (2003).

The largest improvements in MM5 wind performance resulting in Run1 did not lead to any dramatic improvement in CAMx ozone performance (on the basis of both 1- and 8-hour statistics). In fact, ozone performance was slightly degraded in general using both Run1 and Run4 meteorology. Evaluation of the spatial patterns of daily maximum ozone on the key day of interest (August 17) indicated no major differences among the different simulations. However, the MM5 Run5 (CAMx Run 16) scenario (which included increased surface roughness, additional profiler data into the observation FDDA file, and the use of NNRP in lieu of EDAS for analysis FDDA) generally led to better 1-hour and 8-hour bias/error performance statistics over the entire episode. On August 17, this model configuration led to lower 1-hour ozone levels, but conversely improved the under prediction bias for 8-hour ozone. Furthermore, quantile-quantile plots for peak 8-hour ozone were generally worse than the original TCEQ base case (CAMx Run 7c from ENVIRON, 2003).

The impacts of revised base-year on-road emission inputs on DFW ozone predictions were also explored in this study. Using the new emissions and upgrading to CAMx v4.03, daily maximum 8-hour ozone performance was evaluated using both the original meteorology (Run 17a) and best performing new meteorology (Run 17b). Results indicated only minor differences in ozone between the two different meteorological inputs. Subjective analyses of the daily maximum ozone fields in the DFW 4-km grid suggested that the new meteorological fields usually lead to slightly better model performance. Objective evaluation of quantile-quantile plots following EPA model performance guidance (EPA, 1999) similarly indicated minor differences in performance, with possibly the old meteorology resulting in somewhat better performance.

DISCUSSION

Although attempts to reduce the wind speed over prediction bias in the DFW area through a defensible modification to surface roughness were successful (and led to much improved wind speed performance over the region), the hypothesis that this should bring the urban ozone plume closer to the DFW core and therefore improve daily peak ozone performance was not substantiated in the tests we conducted. In fact, 1-hour peak ozone results were mixed. Run 16, which included all of the meteorological enhancements (increased roughness, additional observational nudging, and NNRP analyses), increased peak 1-hour ozone on August 16, but decreased peak ozone on the key day of interest (August 17). Overall, the under prediction bias exhibited in the original TCEQ base case simulation was improved in Run 16.

There are two possible reasons for this behavior. First, even though increasing surface roughness reduced surface wind speeds, it is likely that this effect was not translated through the bulk of the well-mixed planetary boundary layer, which is the region of urban plume transport. With effectively the same transport winds aloft, the overall spatial pattern of surface peak ozone was not significantly different from the original case, and so very similar bias and gross error was achieved. Apparently the simulated winds aloft were not impacted to any large degree by the inclusion of profiler data into the observational FDDA inputs. Second, subtle differences in meteorological fields arising from the roughness change and use of alternative NNRP input analyses led to modifications in temperature and mixing rates, which were likely the keys to impacting the values of the unpaired peak ozone statistics on certain days by slightly altering ozone formation efficiency and dilution.

The subtle differences in ozone performance arising from the different meteorological realizations modeled in this study confound the choice of the "best" MM5 simulation to use to establish a base case ozone model for DFW. The key to this choice is to emphasize objective metrics that remain consistent with the context within which this model will be used for potential regulatory analyses in the future. In this case, the emphasis should be on 8-hour ozone performance. The new Run 16 shows the greatest tendency toward improvement of overall 8-hour bias and error (over all observation/prediction pairings above 60 ppb) relative to the original TCEQ base case. However, the peak 8-hour performance as shown in the quantile-quantile (Q-Q) plots indicates worse performance for the highest peaks, consistent performance for mid-range values (50-80 ppb), and a larger degree of scatter. Although the Run 16 Q-Q plot showed poorer performance at the top end, the middle of the distribution (70-90 ppb) is most important because the majority of the data which will drive the RRF are included in those quantiles. The middle of the Run 16 quantile plot is very comparable to the middle of the Run 7c plot.

RECOMMENDATIONS

Given the "equivalence" between photochemical modeling results using the new (MM5 Run 5) and the original meteorology, our decision essentially reduces to which set of meteorology is the best performer against wind, temperature, and humidity observations in the area of focus. For this reason, we believe that the new MM5 Run 5 meteorology should be used for all future photochemical simulations. TCEQ has concurred with this decision, and has added additional weight by considering the overall improvements to the photochemical model's 1- and 8-hour bias and gross error with the new Run5 meteorology. Therefore, all future year DFW simulations for 2010 and Ozone Source Apportionment modeling in related projects (work orders 582-04-65563-4 and 58881-04-02) will utilize the MM5 Run 5 meteorology.

REFERENCES

Boucouvala, D., R. Bornstein, J. Wilkinson, and D. Miller. 2003. MM5 Simulations of a SCOS97-NARSTO episode. *Atmos. Environ*. 37, No. 2, ps95-s117.

Dasey, T.J., R.E. Cole, R.M. Heinrichs, M.P. Matthews, and G.H. Perras. 1998. "Aircraft Vortex Spacing System (AVOSS), Initial 1997 System Deployment at Dallas/Ft. Worth (DFW) Airport." Project Report NASA/L-3, Prepared by the Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, MA.

ENVIRON. 2003. "Development of Base Case Photochemical Modeling to Address 1-Hour and 8-Hour Ozone Attainment in the Dallas/Fort Worth Area." Prepared for Texas Commission on Environmental Quality by ENVIRON International Corporation, 101 Rowland Way, Novato, CA 94945. October 3, 2003.

EPA. 1999. "Draft Guidance on the Use of Models and Other Analysis in Attainment Demonstrations for the 8-Hour Ozone NAAQS." U.S. Environmental Protection Agency, Research Triangle Park, NC (EPA-454/R-99-004).

Appendix A

Emission Summary Tables
August 13-22, 1999

Table A-1. Episode day NOx emission summaries by major source type for the DFW non-attainment counties and the surrounding 8 perimeter counties.

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
Friday, August 13	Area	1.54	13.25	1.24	0.24	2.65	2.87	0.21	0.23	0.14	10.88	0.09	6.72
	Non-road	24.35	71.85	17.53	7.69	5.94	0.44	3.04	7.66	4.36	5.81	0.85	54.26
	On-road	32.77	179.42	35.38	22.87	5.23	2.39	12.13	12.08	16.13	15.75	5.52	111.70
	Points	6.61	61.09	5.10	29.81	9.42	31.56	0.50	6.03	0.86	3.18	0.00	41.91
	Subtotal	65.27	325.60	59.25	60.60	23.23	37.26	15.88	26.00	21.49	35.62	6.45	214.59
	Biogenic	12.16	4.48	8.59	15.61	0.69	0.22	7.45	5.25	5.45	0.71	1.81	3.09
	Total	77.43	330.08	67.83	76.20	23.93	37.48	23.33	31.25	26.94	36.32	8.26	217.68
Saturday,August 14	Area	1.20	9.78	0.99	0.20	2.62	2.85	0.18	0.18	0.11	10.85	0.07	4.93
	Non-road	20.41	64.85	16.27	7.48	6.08	0.47	2.93	7.47	4.31	5.74	0.80	48.48
	On-road	20.25	109.30	21.46	13.31	3.73	1.70	7.69	7.77	9.92	9.69	3.10	70.74
	Points	6.33	51.87	5.12	29.80	9.63	28.89	0.65	6.00	0.86	3.56	0.00	32.66
	Subtotal	48.19	235.80	43.84	50.79	22.06	33.92	11.45	21.42	15.21	29.83	3.97	156.80
	Biogenic	11.78	4.50	8.46	15.74	0.67	0.23	7.09	5.38	5.37	0.72	1.77	3.16
	Total	59.97	240.30	52.30	66.53	22.73	34.15	18.54	26.80	20.58	30.55	5.74	159.96
Sunday, August 15	Area	0.85	6.32	0.74	0.16	2.59	2.84	0.15	0.13	0.08	10.82	0.06	3.13
	Non-road	16.10	55.98	14.57	7.19	5.86	0.43	2.61	7.24	4.14	5.61	0.65	41.88
	On-road	15.12	82.11	15.58	11.02	3.41	1.48	6.65	6.62	8.61	7.82	2.29	50.30
	Points	5.57	50.38	3.88	29.80	9.50	25.85	0.24	6.00	0.86	3.24	0.00	37.13
	Subtotal	37.65	194.79	34.78	48.17	21.36	30.59	9.66	20.00	13.70	27.48	2.99	132.44
	Biogenic	11.13	4.20	8.14	14.81	0.62	0.22	6.61	5.14	4.98	0.71	1.65	3.02
	Total	48.78	198.99	42.92	62.98	21.98	30.82	16.27	25.14	18.67	28.19	4.64	135.46
Monday, August 16	Area	1.54	13.25	1.24	0.24	2.65	2.87	0.21	0.23	0.14	10.88	0.09	6.72
	Non-road	24.35	71.85	17.53	7.69	5.94	0.44	3.04	7.66	4.36	5.81	0.85	54.26
	On-road	33.22	180.65	35.82	20.10	4.72	2.10	11.01	10.74	14.62	14.23	5.59	112.15
	Points	6.45	63.24	5.37	29.81	9.11	30.26	0.80	6.03	0.86	4.24	0.00	40.96
	Subtotal	65.56	328.99	59.95	57.83	22.42	35.67	15.06	24.66	19.98	35.15	6.52	214.09
	Biogenic	10.85	4.08	7.96	14.30	0.59	0.22	6.42	4.97	4.80	0.69	1.60	2.93
	Total	76.41	333.07	67.91	72.13	23.01	35.88	21.48	29.63	24.79	35.84	8.12	217.03
Tuesday, August 17	Area	1.54	13.25	1.24	0.24	2.65	2.87	0.21	0.23	0.14	10.88	0.09	6.72
	Non-road	24.35	71.85	17.53	7.69	5.94	0.44	3.04	7.66	4.36	5.81	0.85	54.26
	On-road	33.25	179.00	36.24	19.86	4.61	2.05	10.82	10.43	14.26	14.26	5.50	112.52
	Points	5.76	60.41	5.30	29.81	7.95	30.10	0.61	6.02	0.86	4.06	0.00	39.90

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
	Subtotal	64.90	324.51	60.31	57.59	21.15	35.46	14.68	24.34	19.62	35.01	6.43	213.40
	Biogenic	11.18	4.18	7.99	14.51	0.63	0.21	6.78	4.94	5.02	0.67	1.67	2.92
	Total	76.08	328.69	68.30	72.10	21.78	35.67	21.46	29.28	24.65	35.67	8.10	216.31
Wed, August 18	Area	1.54	13.25	1.24	0.24	2.65	2.87	0.21	0.23	0.14	10.88	0.09	6.72
	Non-road	24.35	71.85	17.53	7.69	5.94	0.44	3.04	7.66	4.36	5.81	0.85	54.26
	On-road	31.75	172.43	34.43	19.52	4.37	1.92	10.32	9.86	13.58	13.59	5.24	106.51
	Points	7.01	65.70	5.42	29.81	9.76	35.57	0.92	6.03	0.86	2.39	0.00	42.64
	Subtotal	64.65	323.23	58.61	57.25	22.72	40.80	14.48	23.78	18.94	32.66	6.18	210.13
	Biogenic	12.11	4.57	8.63	15.84	0.69	0.22	7.35	5.34	5.50	0.71	1.82	3.17
	Total	76.77	327.80	67.24	73.10	23.41	41.03	21.83	29.12	24.44	33.37	7.99	213.31
Thursday, August 19	Area	1.54	13.25	1.24	0.24	2.65	2.87	0.21	0.23	0.14	10.88	0.09	6.72
	Non-road	24.35	71.85	17.53	7.69	5.94	0.44	3.04	7.66	4.36	5.81	0.85	54.26
	On-road	32.60	174.26	34.24	19.47	4.41	1.97	10.52	9.92	13.70	13.49	5.34	106.38
	Points	7.81	65.88	5.35	29.81	9.04	34.55	0.52	6.03	0.86	2.39	0.00	40.63
	Subtotal	66.31	325.24	58.35	57.19	22.05	39.83	14.29	23.84	19.06	32.57	6.27	207.99
	Biogenic	12.47	4.73	8.76	16.44	0.73	0.22	7.61	5.41	5.74	0.70	1.89	3.18
	Total	78.78	329.97	67.12	73.63	22.78	40.06	21.90	29.25	24.80	33.27	8.16	211.17
Friday, August 20	Area	1.54	13.25	1.24	0.24	2.65	2.87	0.21	0.23	0.14	10.88	0.09	6.72
	Non-road	24.35	71.85	17.53	7.69	5.94	0.44	3.04	7.66	4.36	5.81	0.85	54.26
	On-road	37.97	198.79	40.54	24.54	5.95	2.74	14.00	13.80	18.21	18.39	6.33	128.24
	Points	7.07	63.63	6.18	29.81	9.27	23.15	0.82	6.03	0.86	3.31	0.00	37.34
	Subtotal	70.93	347.52	65.50	62.27	23.80	29.20	18.06	27.72	23.57	38.39	7.26	226.56
	Biogenic	10.80	4.17	7.59	14.84	0.68	0.20	6.62	4.88	5.12	0.62	1.66	2.81
	Total	81.73	351.69	73.09	77.11	24.48	29.40	24.69	32.60	28.69	39.01	8.92	229.37
Sat, August 21	Area	1.20	9.78	0.99	0.20	2.62	2.85	0.18	0.18	0.11	10.85	0.07	4.93
	Non-road	20.41	64.85	16.27	7.48	6.08	0.47	2.93	7.47	4.31	5.74	0.80	48.48
	On-road	21.00	113.73	21.84	13.65	3.92	1.81	8.00	8.24	10.34	10.05	3.22	70.60
	Points	7.06	63.40	4.72	29.80	8.28	2.16	0.12	5.98	0.86	3.26	0.00	31.75
	Subtotal	49.67	251.77	43.81	51.14	20.89	7.30	11.23	21.88	15.63	29.90	4.09	155.75
	Biogenic	10.71	4.06	7.67	14.23	0.63	0.20	6.46	4.77	4.90	0.63	1.61	2.81
	Total	60.38	255.83	51.49	65.36	21.52	7.50	17.69	26.64	20.53	30.53	5.70	158.56
Sunday, August 22	Area	0.85	6.32	0.74	0.16	2.59	2.84	0.15	0.13	0.08	10.82	0.06	3.13
	Non-road	16.10	55.98	14.57	7.19	5.86	0.43	2.61	7.24	4.14	5.61	0.65	41.88
	On-road	14.45	81.70	15.32	10.88	3.24	1.48	6.31	6.61	8.17	7.78	2.19	49.83

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
	Points	6.93	53.65	5.19	29.80	8.80	23.40	0.01	6.00	0.86	2.69	0.00	26.39
	Subtotal	38.33	197.66	35.82	48.03	20.49	28.15	9.08	19.98	13.25	26.90	2.89	121.23
	Biogenic	11.87	4.44	8.42	15.32	0.66	0.22	7.17	5.15	5.34	0.69	1.77	3.04
	Total	50.21	202.10	44.24	63.35	21.15	28.37	16.25	25.12	18.59	27.59	4.66	124.28

Table A-2. Episode day VOC emission summaries by major source type for the DFW non-attainment counties and the surrounding 8 perimeter counties.

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	Source	48085	48113	48121	48139	48213	48221	48231	48251	48257	48367	48397	48439
Friday, August 13	Area	11.72	63.98	12.72	8.56	8.43	3.64	8.69	8.20	9.58	10.48	2.28	48.02
	Non-road	12.81	53.52	7.98	1.48	2.08	0.54	1.68	1.73	1.12	1.10	0.86	28.73
	On-road	18.26	92.34	17.96	6.64	4.20	1.68	5.60	5.96	6.67	5.49	2.34	54.23
	Points	0.99	12.63	2.68	6.46	0.73	0.38	0.09	0.42	0.88	0.98	0.00	12.80
	Subtotal	43.78	222.47	41.34	23.14	15.44	6.25	16.05	16.30	18.25	18.05	5.48	143.78
	Biogenic	24.94	47.78	52.42	87.80	270.77	29.24	66.90	89.97	102.23	108.72	3.28	48.72
	Total	68.72	270.26	93.75	110.94	286.21	35.48	82.95	106.27	120.48	126.76	8.77	192.50
Saturday,August 14	Area	8.73	38.71	8.09	6.91	6.88	2.92	4.63	5.02	4.96	8.45	1.56	25.88
	Non-road	15.14	63.44	12.39	2.34	6.40	1.41	4.17	2.03	2.36	1.61	2.00	33.20
	On-road	12.99	65.89	12.96	6.11	3.86	1.58	5.26	5.61	6.07	5.20	1.68	39.13
	Points	0.65	8.36	1.49	6.36	0.74	0.38	0.04	0.41	0.86	0.98	0.00	6.58
	Subtotal	37.51	176.41	34.92	21.73	17.88	6.29	14.11	13.07	14.25	16.24	5.24	104.79
	Biogenic	27.84	55.51	63.41	94.23	274.45	36.68	74.66	113.29	109.44	134.33	3.69	64.04
	Total	65.35	231.92	98.34	115.96	292.33	42.97	88.76	126.36	123.69	150.58	8.93	168.84
Sunday, August 15	Area	6.86	30.12	6.61	4.96	6.01	2.51	2.85	3.49	3.58	7.38	1.12	20.17
	Non-road	14.33	61.66	12.07	2.28	6.36	1.41	4.10	1.98	2.33	1.59	1.97	31.91
	On-road	10.28	52.04	10.23	5.52	3.43	1.44	4.69	5.05	5.42	4.73	1.32	31.16
	Points	0.65	8.46	1.49	6.36	0.74	0.38	0.04	0.41	0.86	0.98	0.00	6.58
	Subtotal	32.12	152.28	30.40	19.12	16.54	5.74	11.69	10.93	12.18	14.68	4.41	89.83
	Biogenic	25.42	48.95	60.56	82.51	230.43	35.33	66.00	104.71	93.77	131.95	3.24	59.68
	Total	57.54	201.23	90.95	101.63	246.97	41.07	77.68	115.65	105.95	146.63	7.65	149.51
Monday, August 16	Area	11.72	63.98	12.72	8.56	8.43	3.64	8.69	8.20	9.58	10.48	2.28	48.02
	Non-road	12.81	53.52	7.98	1.48	2.08	0.54	1.68	1.73	1.12	1.10	0.86	28.73
	On-road	16.33	81.78	16.23	5.20	3.29	1.34	4.38	4.66	5.21	4.38	2.04	48.95
	Points	0.99	12.63	2.68	6.46	0.73	0.38	0.09	0.42	0.88	0.98	0.00	12.80
	Subtotal	41.84	211.92	39.61	21.70	14.53	5.90	14.83	15.01	16.80	16.93	5.19	138.50
	Biogenic	25.72	49.59	61.60	82.66	231.67	34.72	67.06	104.12	94.89	131.12	3.26	60.22
	Total	67.56	261.51	101.20	104.36	246.19	40.62	81.89	119.12	111.69	148.05	8.45	198.72
Tuesday, August 17	Area	11.72	63.98	12.72	8.56	8.43	3.64	8.69	8.20	9.58	10.48	2.28	48.02
	Non-road	12.81	53.52	7.98	1.48	2.08	0.54	1.68	1.73	1.12	1.10	0.86	28.73
	On-road	16.86	84.12	16.69	5.22	3.33	1.35	4.43	4.69	5.27	4.41	2.09	49.85
	Points	0.99	12.63	2.68	6.46	0.73	0.38	0.09	0.42	0.88	0.98	0.00	12.80

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
	Subtotal	42.38	214.25	40.07	21.72	14.56	5.91	14.88	15.03	16.86	16.97	5.23	139.41
	Biogenic	27.37	51.14	62.39	84.35	248.62	32.99	74.21	100.61	101.34	126.55	3.51	59.67
	Total	69.75	265.39	102.46	106.07	263.18	38.91	89.08	115.64	118.20	143.52	8.74	199.08
Wed, August 18	Area	11.72	63.98	12.72	8.56	8.43	3.64	8.69	8.20	9.58	10.48	2.28	48.02
	Non-road	12.81	53.52	7.98	1.48	2.08	0.54	1.68	1.73	1.12	1.10	0.86	28.73
	On-road	17.08	85.56	16.83	5.30	3.36	1.38	4.47	4.77	5.33	4.48	2.12	50.48
	Points	0.99	12.63	2.68	6.46	0.73	0.38	0.08	0.42	0.88	0.97	0.00	12.80
	Subtotal	42.60	215.70	40.20	21.80	14.59	5.94	14.92	15.11	16.91	17.03	5.26	140.03
	Biogenic	29.50	55.34	66.21	91.30	269.69	34.85	79.64	107.25	109.25	132.32	3.81	63.65
	Total	72.10	271.04	106.41	113.10	284.28	40.78	94.56	122.36	126.16	149.35	9.08	203.68
Thursday, August 19	Area	11.72	63.98	12.72	8.56	8.43	3.64	8.69	8.20	9.58	10.48	2.28	48.02
	Non-road	12.81	53.52	7.98	1.48	2.08	0.54	1.68	1.73	1.12	1.10	0.86	28.73
	On-road	17.44	85.73	17.05	5.45	3.39	1.38	4.52	4.90	5.38	4.49	2.14	50.60
	Points	0.99	12.63	2.68	6.46	0.73	0.38	0.09	0.42	0.88	0.97	0.00	12.79
	Subtotal	42.96	215.86	40.42	21.95	14.63	5.94	14.97	15.24	16.96	17.04	5.29	140.15
	Biogenic	30.90	58.87	68.30	98.82	297.09	36.42	83.84	114.86	117.00	133.77	4.00	66.11
	Total	73.86	274.73	108.73	120.77	311.72	42.35	98.81	130.10	133.96	150.81	9.29	206.26
Friday, August 20	Area	11.72	63.98	12.72	8.56	8.43	3.64	8.69	8.20	9.58	10.48	2.28	48.02
	Non-road	12.81	53.52	7.98	1.48	2.08	0.54	1.68	1.73	1.12	1.10	0.86	28.73
	On-road	18.11	90.70	17.94	6.54	4.08	1.67	5.43	5.85	6.46	5.45	2.29	53.75
	Points	0.99	12.63	2.68	6.46	0.73	0.38	0.09	0.42	0.88	0.98	0.00	12.79
	Subtotal	43.63	220.84	41.31	23.04	15.31	6.23	15.88	16.20	18.05	18.00	5.44	143.29
	Biogenic	25.12	49.93	56.28	87.45	268.22	31.89	69.06	100.81	101.82	114.81	3.38	56.14
	Total	68.75	270.76	97.59	110.48	283.53	38.13	84.94	117.01	119.87	132.82	8.81	199.44
Sat, August 21	Area	8.73	38.71	8.09	6.91	6.88	2.92	4.63	5.02	4.96	8.45	1.56	25.88
	Non-road	15.14	63.44	12.39	2.34	6.40	1.41	4.17	2.03	2.36	1.61	2.00	33.20
	On-road	12.72	63.93	12.65	5.83	3.69	1.51	5.04	5.33	5.82	4.98	1.62	38.13
	Points	0.65	8.46	1.49	6.36	0.74	0.05	0.04	0.41	0.86	0.98	0.00	6.54
	Subtotal	37.25	174.55	34.61	21.45	17.71	5.89	13.88	12.79	14.00	16.03	5.18	103.75
	Biogenic	24.38	47.95	56.24	82.07	241.99	31.79	65.47	97.77	95.11	116.78	3.21	55.63
	Total	61.63	222.50	90.86	103.52	259.70	37.68	79.35	110.56	109.11	132.81	8.39	159.38
Sunday, August 22	Area	6.86	30.12	6.61	4.96	6.01	2.51	2.85	3.49	3.58	7.38	1.12	20.17
	Non-road	14.33	61.66	12.07	2.28	6.36	1.41	4.10	1.98	2.33	1.59	1.97	31.91
	On-road	10.45	52.61	10.38	5.54	3.48	1.45	4.76	5.07	5.50	4.75	1.34	31.30

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
	Points	0.65	8.46	1.49	6.36	0.74	0.38	0.04	0.41	0.86	0.98	0.00	6.54
	Subtotal	32.29	152.85	30.55	19.14	16.59	5.74	11.76	10.95	12.26	14.69	4.43	89.93
	Biogenic	26.10	49.01	58.86	82.15	240.53	33.03	69.19	98.26	96.24	124.47	3.37	56.80
	Total	58.39	201.86	89.41	101.29	257.12	38.77	80.95	109.21	108.50	139.17	7.80	146.72

Table A-3. Episode day CO emission summaries by major source type for the DFW non-attainment counties and the surrounding 8 perimeter counties.

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
Friday, August 13	Area	10.36	26.59	6.32	2.42	2.75	2.08	1.67	1.76	1.73	7.53	0.63	12.99
	Non-road	186.28	817.42	103.69	16.13	14.19	6.18	14.34	23.65	13.36	13.62	10.31	400.89
	On-road	240.93	1203.81	244.18	104.07	55.91	23.48	79.83	83.64	98.61	80.75	37.21	737.30
	Points	2.75	16.53	1.30	17.06	5.10	5.10	0.15	1.23	0.07	1.43	0.00	12.98
	Subtotal	440.32	2064.35	355.49	139.67	77.95	36.84	95.99	110.28	113.78	103.34	48.14	1164.16
	Biogenic	2.19	4.01	3.18	6.91	17.32	5.93	5.00	6.84	5.95	10.88	0.30	3.95
	Total	442.51	2068.36	358.66	146.57	95.28	42.77	100.99	117.12	119.73	114.21	48.45	1168.11
Saturday,August 14	Area	7.23	14.98	5.16	1.78	2.44	1.98	1.42	1.25	1.12	7.33	0.41	7.46
	Non-road	219.43	1122.47	131.65	23.05	27.00	10.12	22.57	27.71	21.63	19.11	15.40	511.26
	On-road	178.09	919.81	185.33	94.49	48.23	20.44	69.84	74.12	86.51	72.14	27.56	559.12
	Points	2.60	14.33	1.27	17.04	5.17	5.10	0.15	1.22	0.07	1.43	0.00	12.69
	Subtotal	407.36	2071.58	323.40	136.36	82.84	37.65	93.98	104.30	109.33	100.01	43.37	1090.53
	Biogenic	2.12	4.09	3.19	6.96	16.51	6.18	4.70	7.16	5.84	11.35	0.30	4.18
	Total	409.48	2075.68	326.59	143.32	99.35	43.83	98.68	111.45	115.17	111.35	43.66	1094.71
Sunday, August 15	Area	4.17	3.60	4.00	1.15	2.14	1.89	1.18	0.75	0.52	7.14	0.19	2.03
	Non-road	211.97	1103.46	128.61	22.27	26.61	10.04	21.87	27.18	21.24	18.84	15.13	497.98
	On-road	140.98	720.27	147.74	85.55	42.85	18.94	62.30	66.92	77.00	67.08	21.41	453.15
	Points	2.60	15.84	1.27	17.04	5.17	5.10	0.15	1.22	0.07	1.43	0.00	12.69
	Subtotal	359.72	1843.16	281.61	126.01	76.77	35.97	85.50	96.07	98.82	94.48	36.74	965.85
	Biogenic	1.93	3.65	2.98	6.26	14.47	5.95	4.19	6.69	5.16	11.05	0.26	3.86
	Total	361.65	1846.81	284.59	132.27	91.24	41.92	89.69	102.75	103.99	105.53	37.00	969.71
Monday, August 16	Area	10.36	26.59	6.32	2.42	2.75	2.08	1.67	1.76	1.73	7.53	0.63	12.99
	Non-road	186.28	817.42	103.69	16.13	14.19	6.18	14.34	23.65	13.36	13.62	10.31	400.89
	On-road	203.05	1003.16	207.73	77.94	41.67	17.85	59.03	62.90	72.82	61.43	30.58	628.71
	Points	2.75	16.53	1.30	17.06	5.10	5.10	0.15	1.23	0.07	1.43	0.00	12.98
	Subtotal	402.44	1863.70	319.04	113.54	63.72	31.21	75.19	89.53	87.99	84.01	41.52	1055.57
	Biogenic	1.87	3.53	2.91	5.98	13.63	5.73	4.04	6.42	4.94	10.69	0.26	3.72
	Total	404.31	1867.23	321.95	119.52	77.35	36.94	79.24	95.95	92.93	94.71	41.77	1059.29
Tuesday, August 17	Area	10.36	26.59	6.32	2.42	2.75	2.08	1.67	1.76	1.73	7.53	0.63	12.99
	Non-road	186.28	817.42	103.69	16.13	14.19	6.18	14.34	23.65	13.36	13.62	10.31	400.89
	On-road	210.16	1042.44	213.66	79.37	42.72	18.10	60.57	64.10	74.85	61.77	31.67	641.57
	Points	2.75	16.53	1.30	17.06	5.10	5.10	0.15	1.23	0.07	1.43	0.00	12.98

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
	Subtotal	409.55	1902.98	324.97	114.96	64.76	31.46	76.73	90.73	90.02	84.35	42.61	1068.43
	Biogenic	1.97	3.68	2.92	6.22	15.17	5.44	4.44	6.28	5.33	10.17	0.27	3.70
	Total	411.52	1906.66	327.88	121.19	79.94	36.90	81.17	97.01	95.35	94.52	42.88	1072.13
	Area	10.36	26.59	6.32	2.42	2.75	2.08	1.67	1.76	1.73	7.53	0.63	12.99
	Non-road	186.28	817.42	103.69	16.13	14.19	6.18	14.34	23.65	13.36	13.62	10.31	400.89
	On-road	216.61	1093.61	219.95	81.80	43.71	18.93	62.03	66.76	76.80	64.38	32.89	670.89
Wed, August 18	Points	2.75	16.53	1.30	17.06	5.10	5.10	0.04	1.23	0.07	1.36	0.00	12.98
	Subtotal	416.00	1954.15	331.26	117.40	65.75	32.29	78.09	93.40	91.97	86.90	43.82	1097.75
	Biogenic	2.22	4.19	3.27	7.08	17.31	5.92	5.00	6.98	6.07	11.03	0.31	4.17
	Total	418.22	1958.33	334.52	124.48	83.06	38.21	83.09	100.37	98.04	97.93	44.13	1101.91
	Area	10.36	26.59	6.32	2.42	2.75	2.08	1.67	1.76	1.73	7.53	0.63	12.99
	Non-road	186.28	817.42	103.69	16.13	14.19	6.18	14.34	23.65	13.36	13.62	10.31	400.89
	On-road	222.27	1094.16	224.69	84.14	43.91	18.81	62.08	68.51	77.02	64.42	33.15	668.80
Thursday, August 19	Points	2.75	16.53	1.30	17.06	5.10	5.10	0.15	1.23	0.07	1.36	0.00	12.87
	Subtotal	421.66	1954.70	335.99	119.74	65.95	32.17	78.24	95.14	92.19	86.93	44.09	1095.55
	Biogenic	2.31	4.42	3.33	7.60	18.98	5.97	5.27	7.16	6.53	10.84	0.33	4.19
	Total	423.97	1959.12	339.32	127.34	84.93	38.14	83.51	102.31	98.72	97.77	44.42	1099.74
	Area	10.36	26.59	6.32	2.42	2.75	2.08	1.67	1.76	1.73	7.53	0.63	12.99
	Non-road	186.28	817.42	103.69	16.13	14.19	6.18	14.34	23.65	13.36	13.62	10.31	400.89
	On-road	222.66	1119.02	227.02	100.44	52.00	22.12	73.63	79.58	91.08	75.87	33.93	678.65
Friday, August 20	Points	2.75	16.53	1.30	17.06	5.10	5.10	0.15	1.23	0.07	1.43	0.00	12.87
	Subtotal	422.05	1979.56	338.32	136.04	74.04	35.48	89.80	106.22	106.24	98.45	44.87	1105.40
	Biogenic	1.85	3.63	2.68	6.51	16.97	5.20	4.27	6.20	5.51	9.21	0.27	3.49
	Total	423.90	1983.19	341.00	142.55	91.01	40.68	94.07	112.42	111.76	107.66	45.14	1108.89
	Area	7.23	14.98	5.16	1.78	2.44	1.98	1.42	1.25	1.12	7.33	0.41	7.46
	Non-road	219.43	1122.47	131.65	23.05	27.00	10.12	22.57	27.71	21.63	19.11	15.40	511.26
	On-road	171.16	866.81	177.29	88.92	45.64	19.13	66.05	69.10	81.85	67.96	26.18	534.79
Sat, August 21	Points	2.60	15.84	1.27	17.04	5.17	0.06	0.15	1.22	0.07	1.43	0.00	12.04
	Subtotal	400.43	2020.10	315.36	130.79	80.24	31.29	90.20	99.27	104.67	95.83	41.98	1065.54
	Biogenic	1.83	3.51	2.74	6.07	15.00	5.19	4.10	6.02	5.12	9.48	0.26	3.49
	Total	402.26	2023.61	318.10	136.85	95.24	36.48	94.30	105.29	109.79	105.31	42.24	1069.03
Sunday, August 22	Area	4.17	3.60	4.00	1.15	2.14	1.89	1.18	0.75	0.52	7.14	0.19	2.03
	Non-road	211.97	1103.46	128.61	22.27	26.61	10.04	21.87	27.18	21.24	18.84	15.13	497.98
	On-road	146.48	734.39	151.61	86.77	44.13	19.01	64.31	67.52	79.58	67.31	22.27	455.57

		Collin	Dallas	Denton	Ellis	Henderson	Hood	Hunt	Johnson	Kaufman	Parker	Rockwall	Tarrant
Date	**Source**	**48085**	**48113**	**48121**	**48139**	**48213**	**48221**	**48231**	**48251**	**48257**	**48367**	**48397**	**48439**
	Points	2.60	15.84	1.27	17.04	5.17	5.10	0.15	1.22	0.07	1.43	0.00	12.09
	Subtotal	365.23	1857.28	285.48	127.23	78.04	36.04	87.51	96.66	101.40	94.71	37.59	967.66
	Biogenic	2.13	3.98	3.11	6.71	16.21	5.64	4.75	6.58	5.75	10.61	0.30	3.89
	Total	367.36	1861.26	288.59	133.94	94.25	41.69	92.27	103.24	107.16	105.32	37.89	971.55

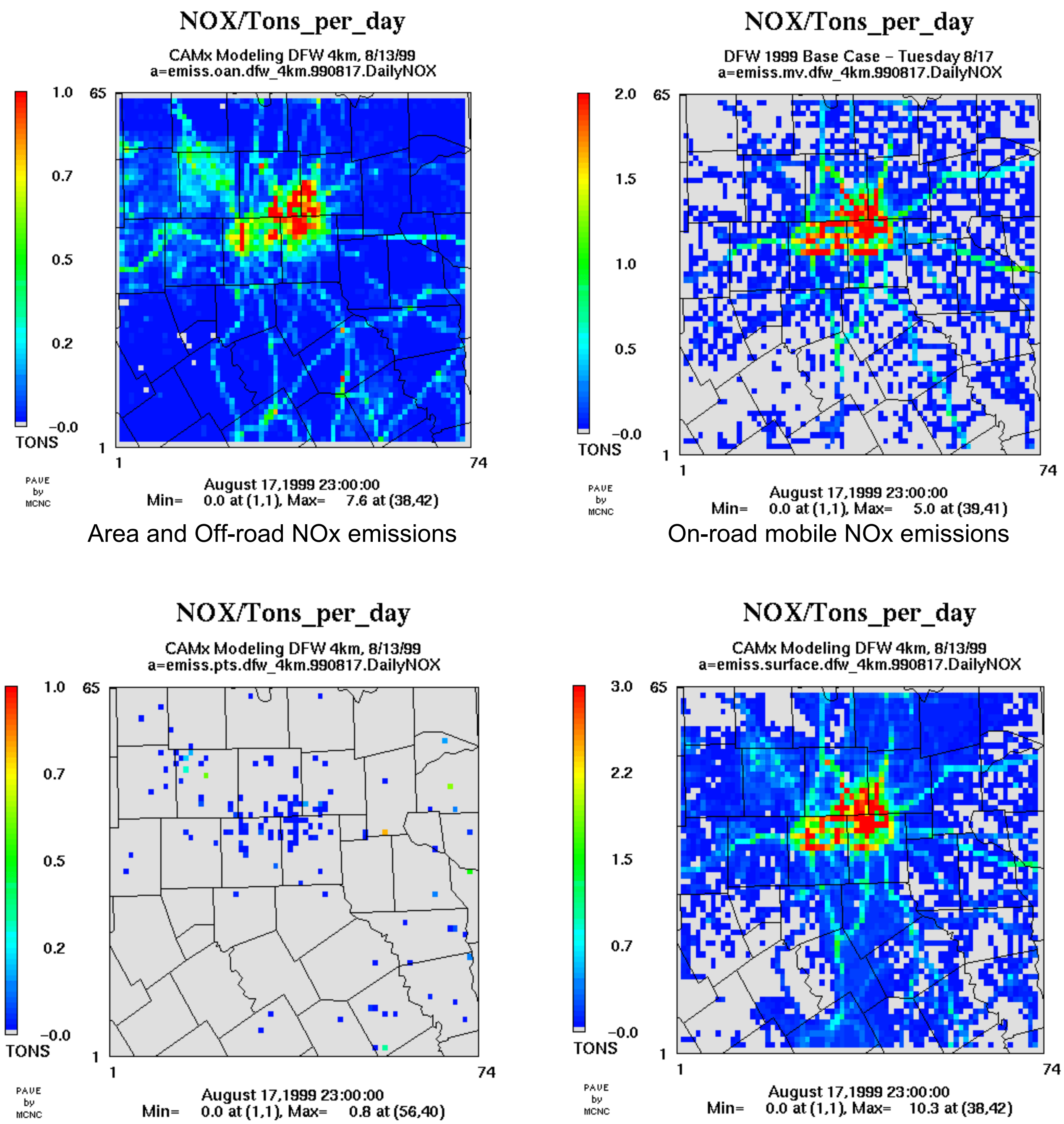
Table A-4. Summary of gridded emissions by major source type for states other than Texas.

State	Area			On-Road			Off-Road			Points			Anthropogenic		
	Weekay	Sat	Sun	Weekay	Sat	Sun	Weekday	Sat	Sun	Weekay	Sat	Sun	Weekay	Sat	Sun
NOx															
Alabama	35.06	34.06	33.56	441.77	287.15	212.05	517.92	513.83	497.69	849.39	834.40	834.40	1043.51	920.37	903.73
Arkansa	116.02	106.95	102.41	226.64	147.32	108.79	209.16	204.02	192.57	404.13	403.07	403.07	639.49	554.50	538.51
Florida	6.97	60.42	126.94	109.00	70.85	52.32	35.33	39.36	34.64	509.46	508.16	508.16	163.98	192.34	254.15
Georgia	72.21	67.95	65.82	559.88	363.92	268.74	192.44	173.27	149.81	1055.25	1047.92	1047.92	921.62	737.07	711.48
Illinois	12.87	208.38	11.89	237.09	154.11	113.80	257.17	252.56	245.26	554.35	836.99	836.99	552.14	686.12	482.33
Indiana	32.51	30.22	29.07	271.54	176.50	130.34	153.07	144.29	133.28	1558.88	1565.45	1565.45	513.83	449.43	437.27
Kansas	33.19	30.77	29.56	197.46	128.35	94.78	314.04	302.05	287.67	987.98	843.41	843.41	772.91	597.03	581.44
Kentucky	246.12	226.71	217.01	409.63	266.26	196.62	273.26	267.35	253.91	1684.48	1669.39	1669.39	1490.18	1339.03	1315.88
Louisiana	327.48	301.31	288.22	373.54	242.80	179.30	684.76	682.90	665.08	869.52	866.21	865.05	1475.86	1351.98	1319.91
Mississippi	6.35	6.18	6.10	310.99	202.14	149.27	220.21	216.80	206.08	540.00	539.48	539.48	854.15	761.49	750.69
Missouri	177.23	372.18	159.20	546.93	355.50	262.53	447.49	444.10	421.70	1408.42	1762.97	1762.97	1262.81	1309.27	1073.90
Nebraska	3.94	3.64	3.49	32.47	21.11	15.59	60.08	59.58	58.94	32.05	14.91	14.91	94.97	89.63	88.83
North Carolina	0.64	0.64	0.64	19.92	12.95	9.56	2.85	2.33	1.80	18.91	18.89	18.89	34.83	29.03	28.49
Ohio	23.83	22.13	21.28	136.04	88.42	65.30	98.95	91.67	83.54	1302.89	1300.46	1300.46	314.69	270.47	261.50
Oklahoma	71.14	65.63	62.87	361.50	234.97	173.52	327.93	324.61	314.34	266.73	284.27	284.27	841.95	841.85	826.17
South Caronlina	0.28	0.27	0.27	5.59	3.63	2.68	0.39	0.36	0.30	0.00	0.00	0.00	3.74	2.93	2.87
Tennessee	62.79	59.11	57.27	530.72	344.97	254.75	274.51	264.03	242.29	1303.99	1322.81	1322.81	902.41	748.17	724.59
Virginia	1.02	0.96	0.93	7.29	4.74	3.50	4.50	4.04	3.59	2.50	0.47	0.47	15.34	11.89	11.41
West Virginia	3.10	2.92	2.83	20.39	13.25	9.79	37.50	36.72	35.49	227.22	227.26	227.26	58.18	53.46	52.13
Grand Total	**1232.76**	**1600.42**	**1219.36**	**4798.38**	**3118.95**	**2303.22**	**4111.55**	**4023.87**	**3827.97**	**13576.15**	**14046.54**	**14045.38**	**11956.58**	**10946.06**	**10365.29**
VOC															
Alabama	490.84	490.82	490.81	328.42	295.57	256.16	139.80	344.79	342.15	208.29	166.54	166.54	1112.22	1197.21	1194.56
Arkansa	381.25	381.14	381.09	146.89	132.20	114.57	81.51	200.52	198.73	102.75	87.89	87.89	690.93	752.49	750.65
Florida	126.95	6.57	60.32	79.72	71.74	62.18	52.12	188.80	188.03	282.66	276.40	276.40	303.14	292.20	345.18
Georgia	421.23	421.13	421.09	365.20	328.68	284.85	135.60	212.34	208.18	94.23	69.92	69.92	1013.50	975.14	970.94
Illinois	208.39	37.51	208.37	142.15	127.93	110.88	62.65	114.50	113.39	92.24	78.85	78.85	471.22	309.46	479.21
Indiana	278.62	278.59	278.57	183.95	165.55	143.48	53.92	94.54	92.70	127.95	75.22	75.22	611.23	559.00	557.15
Kansas	317.57	317.31	317.18	138.15	124.34	107.76	83.65	127.85	125.53	508.24	233.02	233.02	1049.30	779.49	777.05
Kentucky	409.57	409.29	409.15	262.38	236.15	204.66	92.96	224.81	222.76	417.99	319.87	319.87	1148.15	1136.57	1134.38
Louisiana	419.79	419.43	419.26	232.84	209.55	181.61	149.90	420.97	418.12	256.73	271.08	271.08	997.89	1218.71	1215.69
Mississippi	427.40	427.39	427.39	179.64	161.68	140.12	79.77	219.48	218.03	191.04	188.20	188.20	904.03	989.13	987.67
Missouri	921.66	165.21	921.29	352.74	317.47	275.14	205.21	490.87	486.96	155.49	120.76	120.76	1614.67	1019.73	1771.90

Nebraska	44.27	44.26	44.26	22.21	19.99	17.32	8.78	13.02	12.98	5.64	5.52	5.52	69.72	71.16	71.11
North Carolina	16.93	16.93	16.93	10.70	9.63	8.35	4.96	10.24	10.18	9.15	6.74	6.74	42.70	42.66	42.60
Ohio	151.86	151.84	151.82	98.18	88.36	76.58	49.85	58.36	56.77	28.81	23.11	23.11	323.02	301.66	300.06
Oklahoma	310.53	310.45	310.41	259.46	233.51	202.38	96.96	219.02	217.43	103.41	95.06	95.06	903.49	997.56	1008.07
South Caronlina	1.98	1.98	1.98	3.34	3.01	2.61	0.53	1.31	1.30	0.00	0.00	0.00	4.35	4.66	4.66
Tennessee	708.69	708.55	708.48	349.76	314.78	272.81	133.77	316.09	312.30	338.55	180.97	180.97	1376.15	1356.44	1352.58
Virginia	7.77	7.77	7.77	5.38	4.84	4.20	0.82	1.03	0.95	5.41	1.76	1.76	18.36	14.53	14.45
West Virginia	23.30	23.29	23.28	14.85	13.36	11.58	5.63	12.48	12.27	16.24	15.37	15.37	54.12	57.47	57.25
Grand Total	**5668.58**	**4619.45**	**5599.44**	**3175.95**	**2858.35**	**2477.23**	**1438.39**	**3271.01**	**3238.77**	**2944.81**	**2216.28**	**2216.27**	**12708.22**	**12075.27**	**13035.17**
VOC															
Alabama	245.23	244.93	244.78	3563.64	3385.46	2928.24	1195.26	1963.75	1928.51	482.12	438.38	438.38	5181.33	5049.87	5014.49
Arkansas	121.23	119.87	119.18	1699.67	1614.69	1396.62	702.22	1154.07	1128.38	309.98	306.21	306.21	2994.88	2938.59	2912.21
Florida	60.42	126.94	0.00	828.71	787.28	680.95	358.14	743.90	735.71	1492.32	1491.48	1491.48	1416.62	1653.98	1518.85
Georgia	501.86	500.54	499.88	4198.96	3989.01	3450.29	1850.89	2574.27	2523.58	285.67	262.25	262.25	6998.46	6560.03	6508.68
Illinois	37.63	11.89	37.45	1648.64	1566.21	1354.69	680.38	928.75	912.32	110.92	114.74	114.74	2224.93	2077.80	2086.92
Indiana	92.77	92.02	91.64	2004.53	1904.31	1647.12	685.19	903.16	879.02	228.11	199.08	199.08	2604.13	2375.51	2351.00
Kansas	86.62	83.94	82.61	1550.50	1472.98	1274.05	1016.82	1345.99	1316.77	366.19	307.15	307.15	3065.22	2886.50	2855.93
Kentucky	200.33	197.00	195.33	2915.84	2770.05	2395.94	896.63	1442.42	1412.86	514.70	498.21	498.21	4634.03	4392.15	4360.92
Louisiana	182.28	178.46	176.56	2727.01	2590.66	2240.78	1180.51	2097.15	2064.07	839.27	856.55	856.55	4456.99	4684.25	4649.26
Mississippi	124.89	124.86	124.84	1890.48	1795.96	1553.41	647.41	1125.98	1103.11	196.26	195.44	195.44	3038.16	2992.97	2970.09
Missouri	372.18	921.42	367.60	3794.48	3604.76	3117.92	2087.06	3230.89	3179.69	374.64	374.59	374.59	6534.28	7224.42	6619.42
Nebraska	3.39	3.34	3.31	246.71	234.38	202.72	94.16	125.56	124.03	4.23	3.36	3.36	222.51	223.43	221.88
North Carolina	17.30	17.30	17.30	132.96	126.32	109.26	43.82	62.00	60.90	10.46	10.46	10.46	205.32	190.04	188.94
Ohio	63.20	62.93	62.79	1033.96	982.26	849.60	754.60	901.28	883.39	143.59	134.42	134.42	1905.90	1798.03	1780.00
Oklahoma	84.02	83.20	82.79	2750.69	2613.15	2260.23	964.35	1487.97	1466.44	158.61	157.45	157.45	3999.66	4420.99	4436.76
South Caronlina	3.15	3.15	3.15	38.77	36.83	31.86	4.35	6.67	6.58	0.00	0.00	0.00	27.98	25.18	25.09
Tennessee	267.00	265.46	264.68	3852.00	3659.41	3165.18	1374.46	2160.54	2111.82	323.47	319.36	319.36	5551.75	5360.09	5310.59
Virginia	4.72	4.65	4.62	65.55	62.27	53.86	10.88	14.44	13.89	1.42	0.86	0.86	76.32	64.52	63.94
West Virginia	12.13	11.89	11.77	166.29	157.98	136.64	48.61	76.51	74.35	49.11	48.40	48.40	208.41	206.99	204.71
Grand Total	**2480.36**	**3053.78**	**2390.29**	**35109.40**	**33353.95**	**28849.37**	**14595.74**	**22345.30**	**21925.43**	**5891.07**	**5718.38**	**5718.38**	**55346.89**	**55125.35**	**54079.68**

Appendix B

Emission Density Plots
August 13-22, 1999



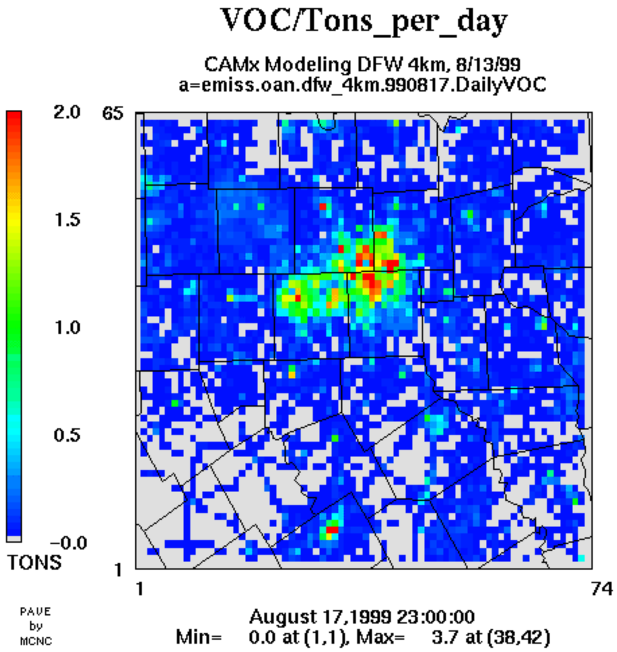
Area and Off-road NOx emissions

On-road mobile NOx emissions

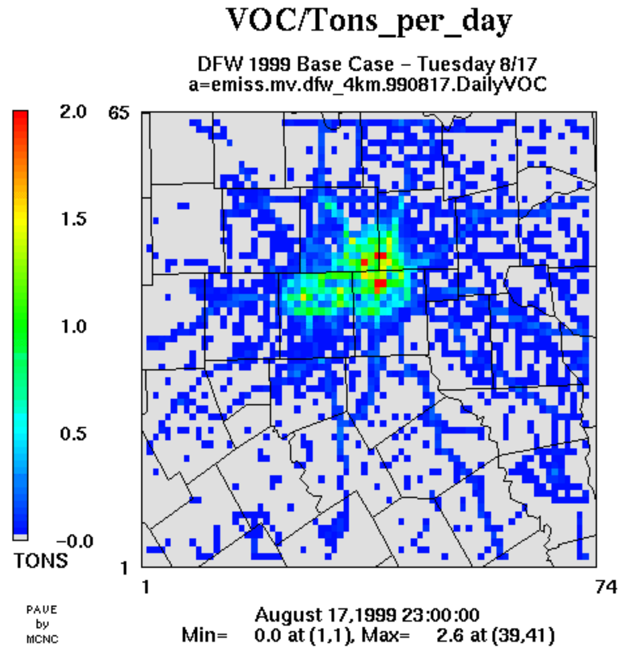
Low-level point source NOx emissions

Total merged surface NOx emissions

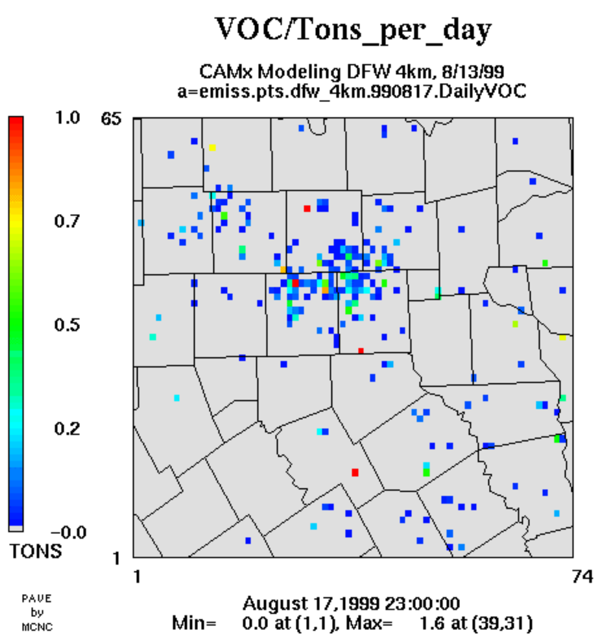
Figure B-1. 1999 NOx emissions for Tuesday August 17th on the 4-km grid.



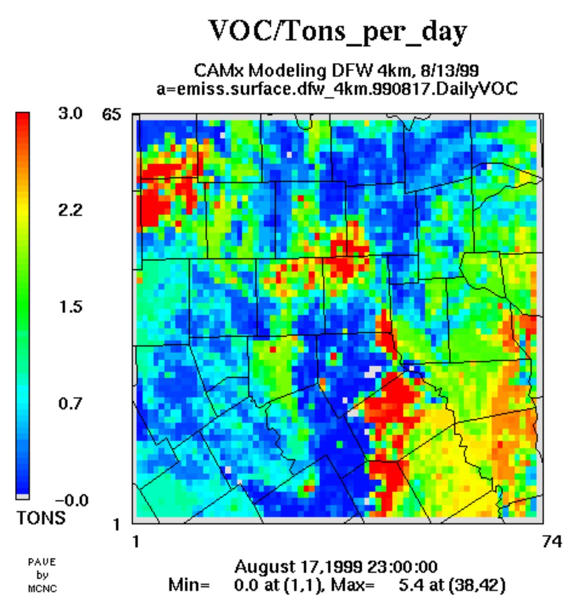
Area and Off-road VOC emissions



On-road mobile VOC emissions

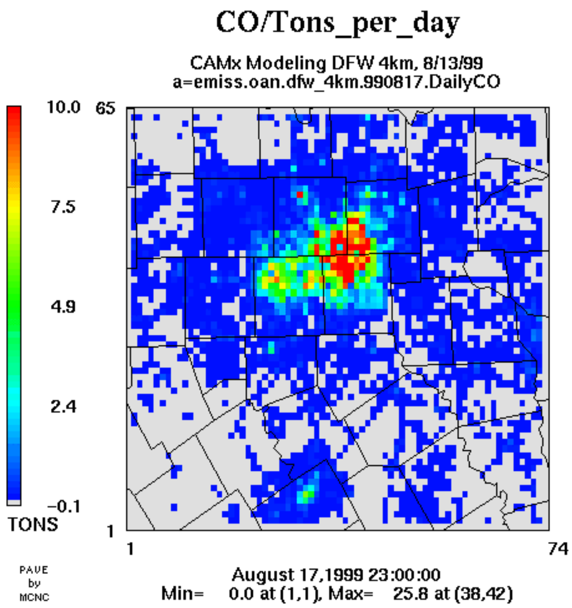


Low-level point source VOC emissions

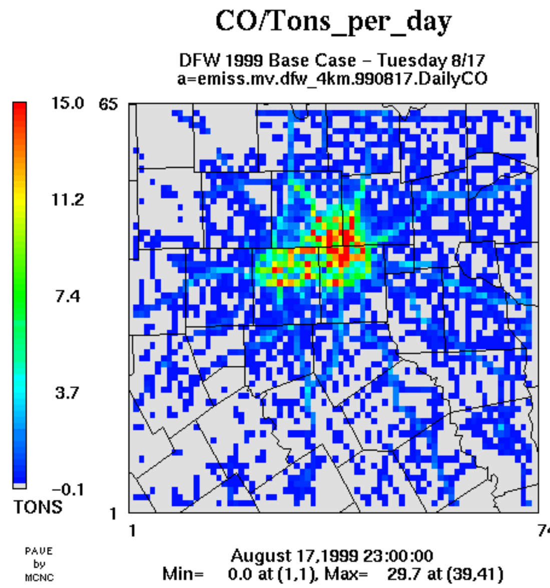


Total merged surface VOC emissions

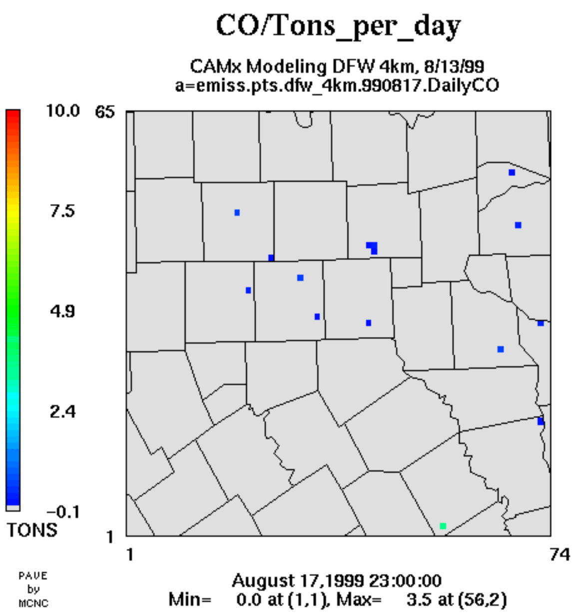
Figure B-2. 1999 VOC emissions for Tuesday August 17th on the 4-km grid.



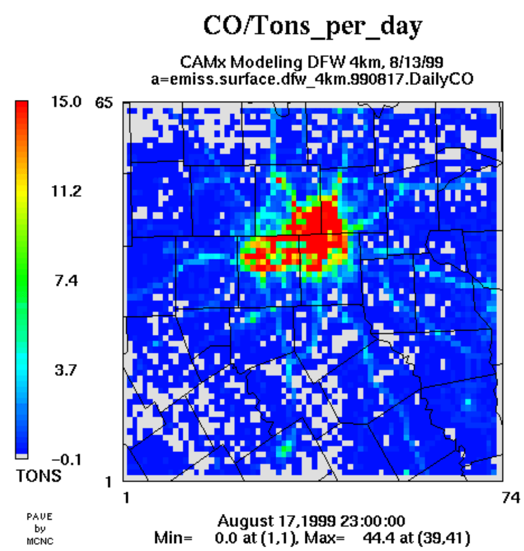
Area and Off-road CO emissions



On-road mobile CO emissions

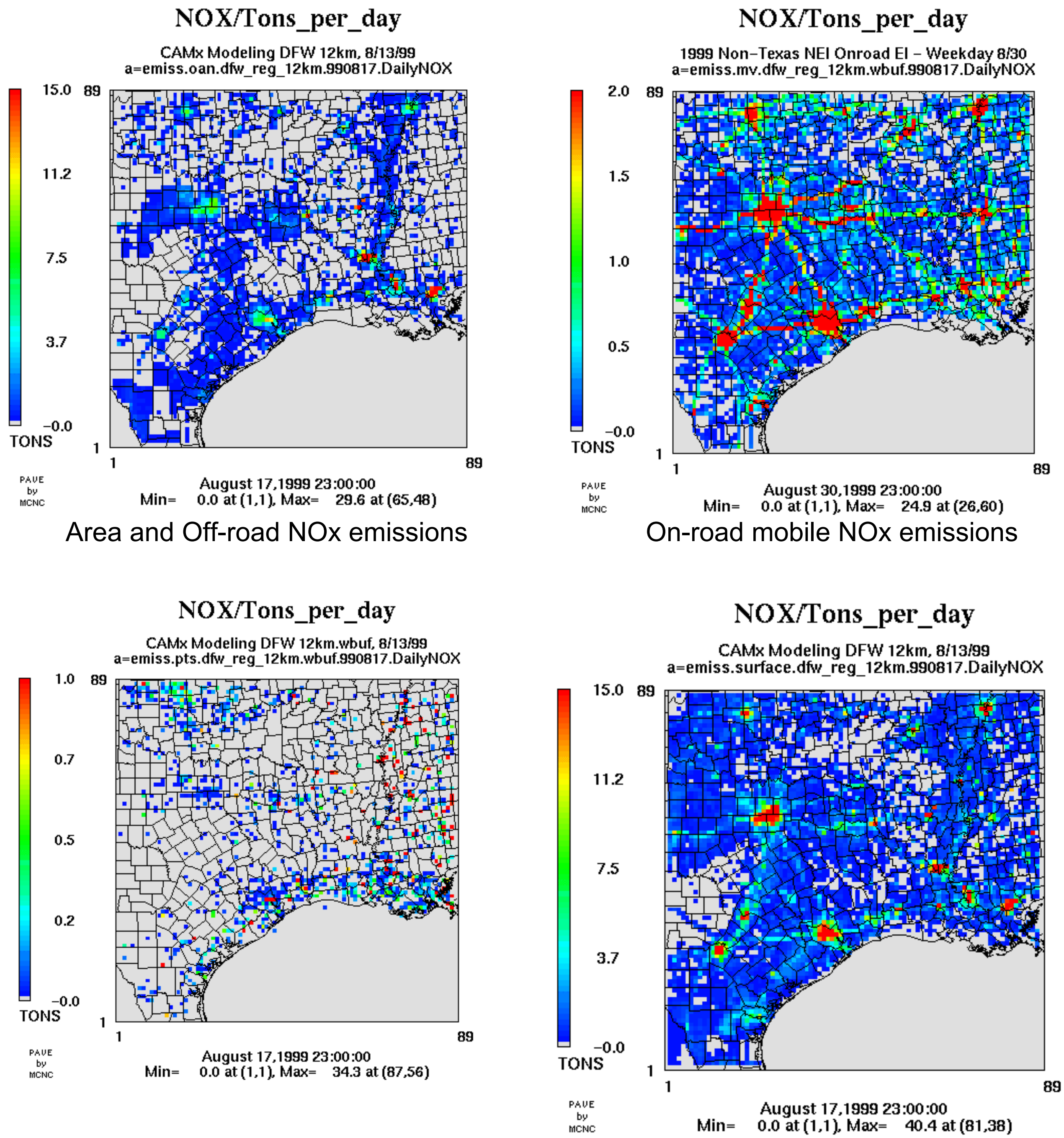


Low-level point source CO emissions



Total merged surface CO emissions

Figure B-3. 1999 CO emissions for Tuesday August 17th on the 4-km grid.



Low-level point source NOx emissions

Total merged surface NOx emissions

Figure B-4. 1999 NOx emissions for Tuesday August 17th on the 12-km emissions grid.

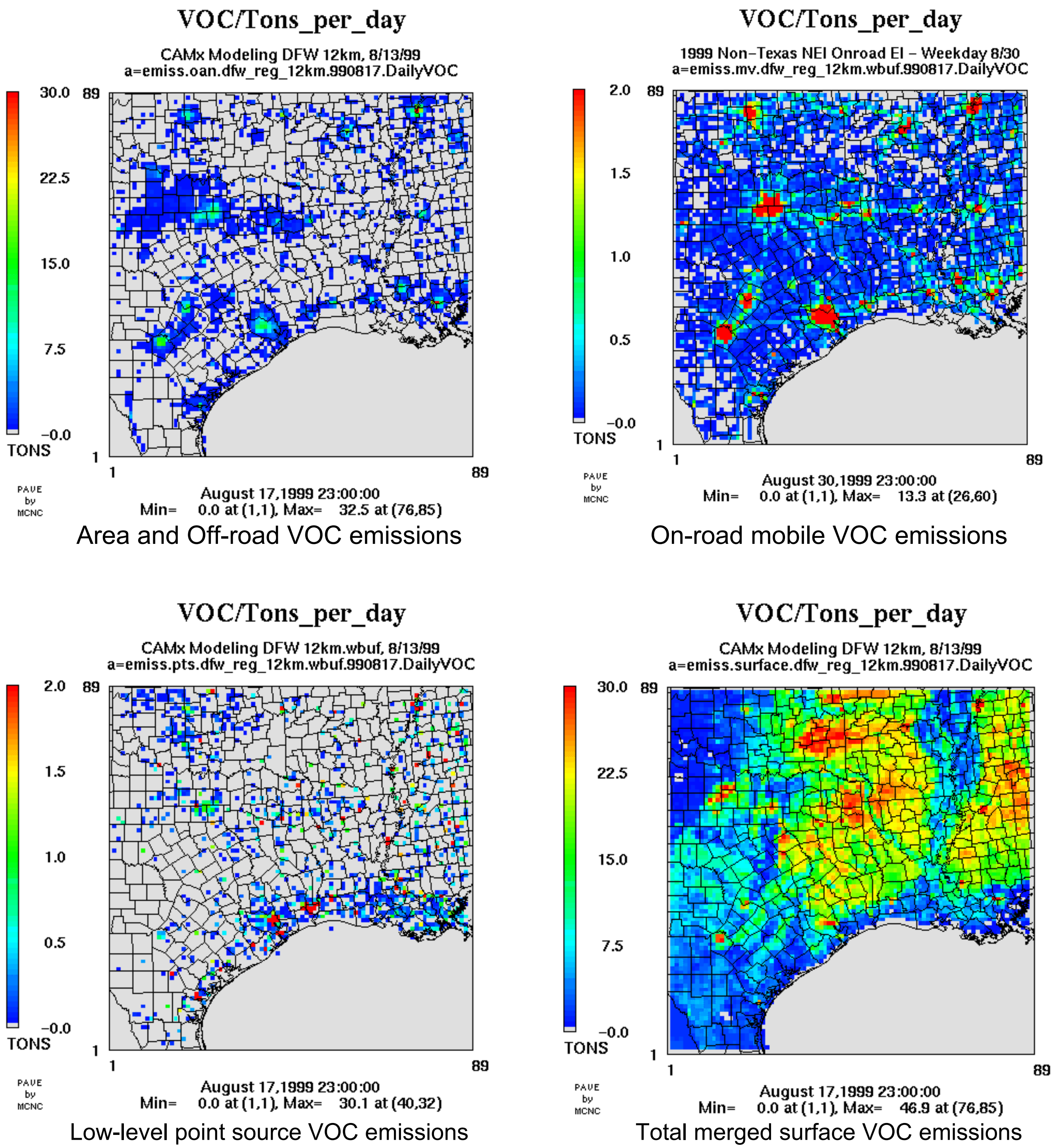
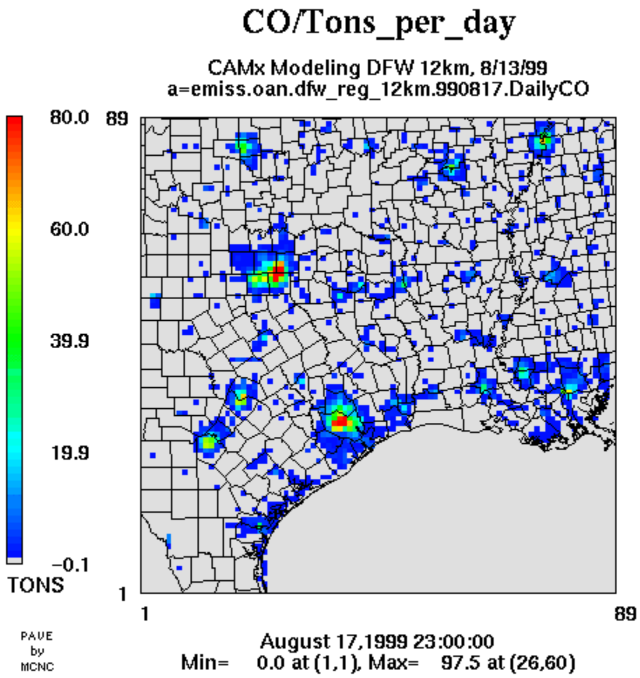
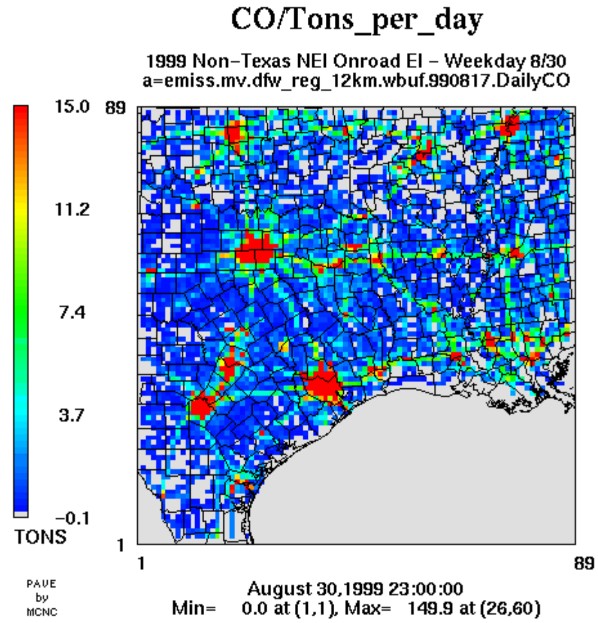


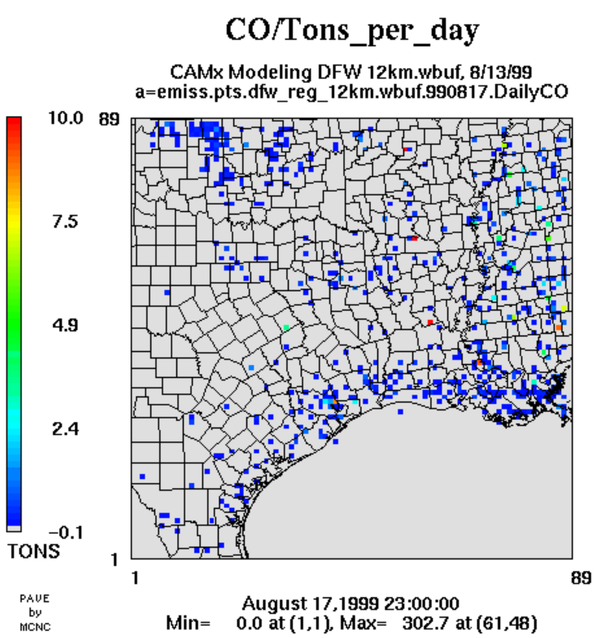
Figure B-5. 1999 VOC emissions for Tuesday August 17th on the 12-km emissions grid.



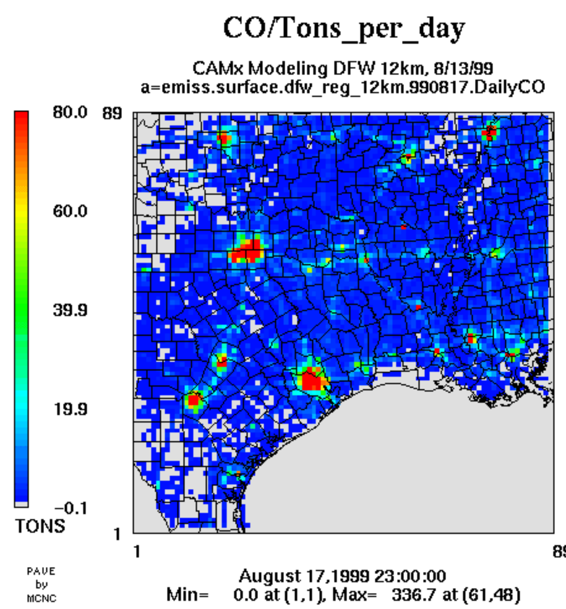
Area and Off-road CO emissions



On-road mobile CO emissions



Low-level point source CO emissions



Total merged surface CO emissions

Figure B-6. 1999 CO emissions for Tuesday August 17th on the 12-km emissions grid.