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SESARM

Early Action Compact Ozone Modeling Analysis for the State of Tennessee and Adjacent Areas of Arkansas and Mississippi

Technical Support Document

March 30, 2004

04-012

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Prepared for:
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Executive Summary

This report summarizes the methods and results of a photochemical modeling analysis designed and conducted to support the attainment and maintenance of the 8-hour ozone standard for five areas in Tennessee (and several adjacent counties in Arkansas, Mississippi, and Georgia) as part of an Early Action Compact (EAC). The Early Action Compact agreements (effective December 31, 2002) provide for planning and implementation of voluntary measures to ensure future attainment/maintenance of the 8-hour ozone standard. Under these compacts, local, state, and EPA officials agreed to work cooperatively to ensure clean air and a designation of attainment.

The five areas with active EAC agreements include:

- **Memphis EAC area:** Shelby, Tipton, and Fayette Counties (Tennessee), Crittenden County (Arkansas), and DeSoto County (Mississippi).
- **Nashville EAC area:** Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson Counties.
- **Knoxville EAC area:** Anderson, Blount, Knox, Loudon, Sevier, Union, and Jefferson Counties.
- **Chattanooga EAC area:** Hamilton, Marion, and Meigs Counties (Tennessee), and Walker and Catoosa Counties (Georgia).
- **Tri-Cities EAC area:** Carter, Hawkins, Sullivan, Unicoi, and Washington Counties.

The National Ambient Air Quality Standard (NAAQS) for 8-hour ozone requires the three-year average of each year's fourth highest 8-hour ozone concentration (the 8-hour design value) for each monitoring site in a given area to be less than or equal to 84 parts per billion (ppb). Ozone concentrations and calculated 8-hour design values for monitors within each of the EAC areas have in recent years approached or exceeded the 8-hour standard. Specifically, the 2000–2002 and 2001–2003 design values are listed in Table ES-1.

Table ES-1.
Observation-Based 8-Hour Ozone Design Values (ppb) for the EAC Areas: 2000–2002 and 2001–2003

EAC Area	2000–2002	2001–2003
Memphis	94	92
Nashville	88	86
Knoxville	98	92
Chattanooga	93	86
Tri-Cities	92	75

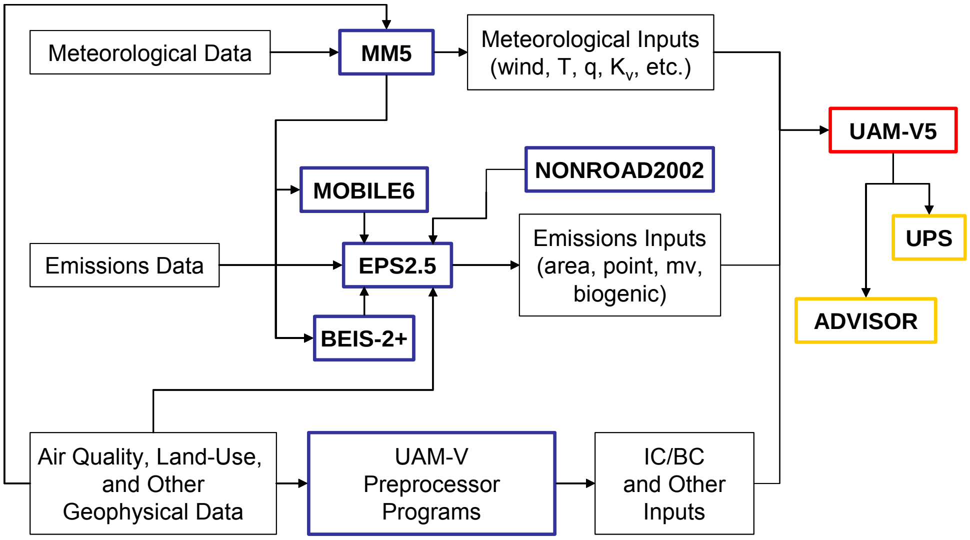
The EAC agreements require that photochemical modeling be used to demonstrate attainment of the 8-hour ozone NAAQS by 2007 and maintenance of the NAAQS through 2012. Consequently, a comprehensive modeling analysis and attainment and maintenance demonstration was conducted to support the EAC modeling effort. The primary objectives of the modeling analysis are to provide (1) an improved understanding of the ozone formation/transport mechanisms that influence ozone levels within each EAC region, (2) a reliable projection of future-ozone concentrations, and (3) a platform for assessing the effectiveness of emission-reduction measures on future ozone air quality in the EAC areas. The modeling study was designed in accordance with draft EPA guidance (EPA, 1999) for using modeling and other analyses for 8-hour ozone attainment demonstration purposes.

The EAC modeling study utilized the databases and modeling tools developed for the Arkansas-Mississippi-Tennessee Ozone Study (ATMOS). Numerous enhancements were made to the overall ATMOS modeling analysis and detailed model input databases to ensure a comprehensive and technically up-to-date analysis of 8-hour ozone issues for the areas of interest. These included the addition of two multi-day modeling episodes to complement the ATMOS modeling episode period and to ensure a sufficient number and range of days for application of the modeled attainment test procedures, as well as full update of the modeling emission inventories to include the latest National Emission Inventory (NEI) data (for 1999), updated state-specific emissions data, and the use of the latest EPA tools for estimating on-road mobile and non-road emissions.

Overview of the Photochemical Modeling System

The primary modeling tools selected used for this study include: the variable-grid Urban Airshed Model, Version 1.5 (UAM-V5), a regional- and urban-scale, nested-grid photochemical model; the Emission Preprocessor System (EPS2.5), for preparation of model ready emission inventories; the Biogenic Emission Inventory System with high-resolution land-use and crop data (BEIS-2+), for estimating biogenic emissions; the MOBILE6.2 model, for estimating motor-vehicle emissions; and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5), for preparation of the meteorological inputs. The UAM-V5 modeling system outputs were summarized and displayed using the UAM-V Postprocessing System (UPS) and the ATMOS ACCESS Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR). Figure ES-1 provides an overview of the ATMOS EAC modeling system, including key input data requirements, UAM-V5 input files, and interactions among the modeling system components.

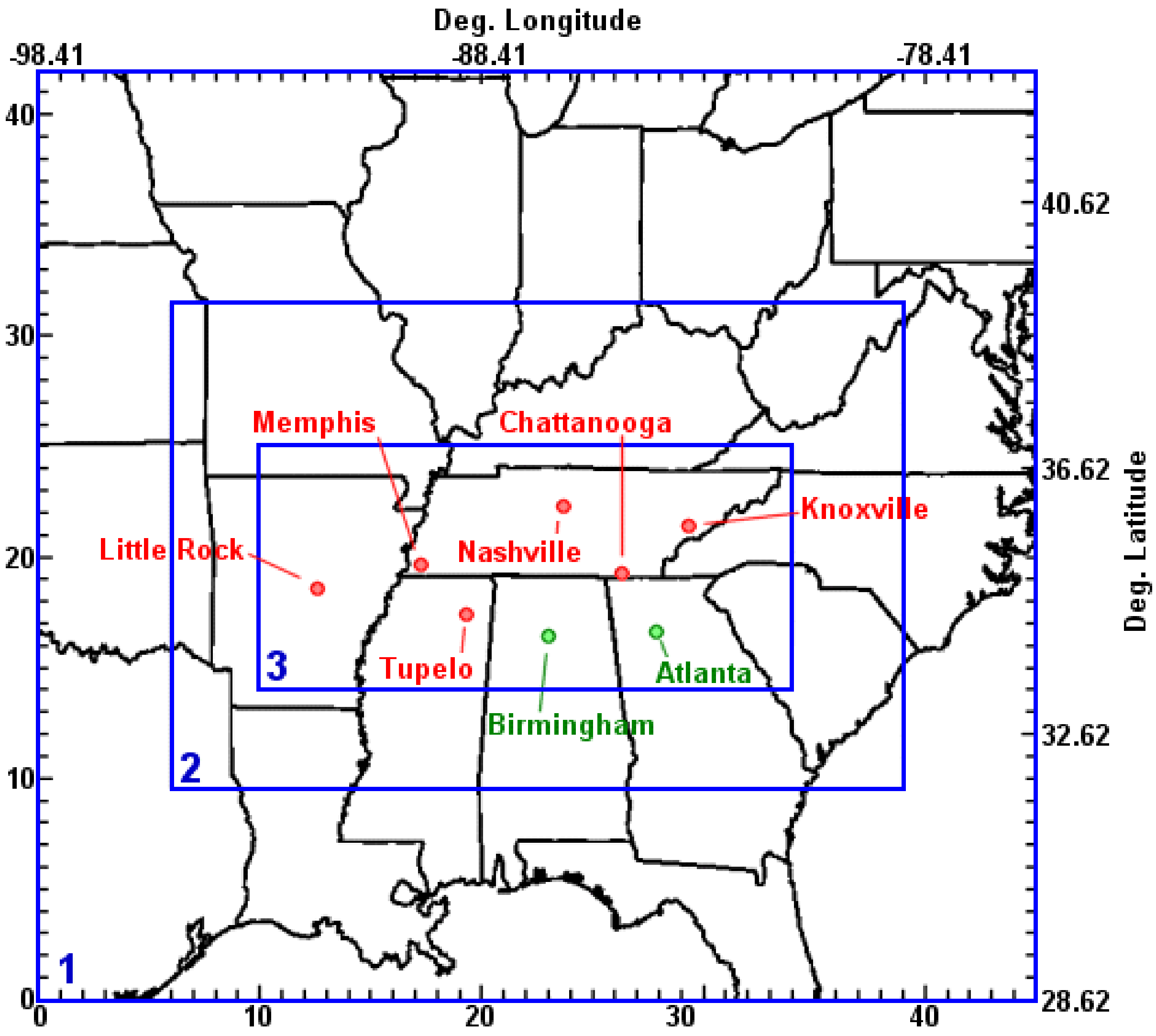
Figure ES-1.
Schematic Diagram of the ATMOS EAC Photochemical Modeling System



Modeling Domain

The modeling domain for application of the UAM-V5 modeling system for the ATMOS EAC modeling analysis is the same as the original ATMOS domain and was designed to accommodate both regional and subregional influences as well as to provide a detailed representation of the emissions, meteorological fields, and ozone (and precursor) concentration patterns over the areas of interest. It consists of an outer grid with 36-km horizontal resolution that encompasses the southeastern U.S., an intermediate grid with 12-km resolution over the mid-south, and a 4-km inner grid over Tennessee and portions of Arkansas, Mississippi, and other neighboring states. The domain is further defined by eleven vertical layers with interfaces at 50, 100, 200, 350, 500, 750, 1000, 1250, 1750, 2500, and 3500 meters above ground level. The domain is illustrated in Figure ES-2.

Figure ES-2.
UAM-V Modeling Domain for the ATMOS Study



Conceptual Model

Developing a conceptual model for 8-hour ozone is an important component of any 8-hour ozone modeling analysis. The conceptual model sets the stage for understanding the physical and chemical factors that influence ozone concentrations within the area of interest and that potentially result in exceedances of the 8-hour ozone standard. The conceptual model also provides the basis for identifying the type and frequency of occurrence of different types of 8-hour ozone episodes and thus for the selection of modeling episode periods or key days for analysis of the modeling results. Finally, the conceptual model serves to provide focus to the interpretation of the modeling results and the development of effective attainment strategies.

Examination of 8-hour ozone data for the EAC areas for the 1996-2002 analysis period shows that

- All areas had some exceedance days, and the Memphis, Nashville, and Knoxville area had 90th percentile values greater than 84 ppb.
- The Knoxville area experienced the greatest number of exceedance days (nearly as many as Atlanta).
- July and August are the peak ozone months for most areas, although Nashville and the Tri-Cities areas had more exceedance in June than in July.
- The years 1997, 1998 and 1999 were high ozone years for most of the areas; in contrast, ozone concentrations tended to be lowest for 2001.
- Same-day correlations among the areas of interest suggest that 8-hour ozone concentrations are subregionally correlated, presumably as the neighboring areas experience similar meteorological conditions.

Ozone episodes within each of the EAC areas occur under a variety of regional-scale meteorological conditions and prevailing wind directions. The regional-scale patterns, in turn, influence the development of local ozone-conducive meteorological conditions.

A more detailed analysis of the observed ozone data and meteorological conditions for each EAC area allowed us to tailor the conceptual description to each area. Some general key findings include:

- Yesterday’s maximum 8-hour ozone value is an important indicator of the 8-hour ozone concentration. This implies the buildup or recirculation of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures, stable lapse rates, and lower wind speeds (compared to lower ozone concentration days).
- The differences in wind speed and wind direction, in particular, highlight that differences in exceedance meteorological and recirculation conditions can lead to different source-receptor and transport relationships.
- Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions and that there are multiple pathways to high ozone for each of the areas.

Episode Selection

Episode selection for the ATMOS EAC modeling/analysis was based on a review of historical meteorological and air quality data with emphasis on representing typical ozone exceedance events in the areas of interest. The episode selection was conducted in stages. First, in 2000, a primary multi-day simulation period was selected for the ATMOS modeling. This period was selected to optimize the representation of typical 8-hour ozone exceedance conditions and concentration levels for all of the areas of interest (which, for ATMOS, included all of the EAC areas with the exception of the Tri-Cities EAC area). A second multi-day simulation period was added in 2003, to enhance the robustness of the EAC modeling by including additional days and types of exceedance conditions. This episode was specifically selected to complement the first ATMOS simulation period in terms of representing different key meteorological conditions and providing additional exceedance days for certain areas. Finally, a third multi-day simulation period was added in 2004, as modeling databases from the State of Arkansas became available for use in the ATMOS study. This third simulation period includes additional exceedance days for all of the areas of interest and some variation on the exceedance meteorological conditions for certain of the areas. It provides important additional exceedance days for the Tri-Cities area.

Overall, the primary objective of the episode selection was to identify and assemble suitable periods for analysis and modeling related to the 8-hour ozone NAAQS for the ATMOS EAC areas of interest. Important considerations in selecting (and adding to) the episodes include (1) representing the range of meteorological conditions that accompany ozone exceedances, (2) representing the ozone concentration levels that characterize the nonattainment problem, and (3) accounting for the frequency of occurrence of the exceedance meteorological regimes.

The three ATMOS EAC episodes are 29 August–9 September 1999, 16–22 June 2001, and 4–10 July 2002. The three episodes selected for this study each include two start-up days and one clean out day. The length of each episode was designed to capture the entire high ozone cycle for each area of interest as influenced by the synoptic and mesoscale meteorological conditions. The episodes also include both weekdays and weekend days. Area-specific observations are summarized below. The three modeling episodes include:

- Ten exceedance days that represent two of the three key exceedance meteorological regimes as well as several other high ozone regimes for Memphis, with a range of 8-hour ozone exceedance concentrations from 86 to 106 ppb and an average 8-hour ozone exceedance concentration of 94 ppb.
- Twelve exceedance days that represent four of the five key exceedance meteorological regimes for Nashville, with a range of 8-hour ozone exceedance concentrations from 85 to 110 ppb and an average 8-hour ozone exceedance concentration of 98 ppb.
- Eighteen exceedance days that represent four of the five key exceedance meteorological regimes as well as several other high ozone regimes for Knoxville, with a range of 8-hour ozone exceedance concentrations from 86 to 104 ppb and an average 8-hour ozone exceedance concentration of 95 ppb.
- Eleven exceedance days that represent two of the three key exceedance meteorological regimes for Chattanooga, with a range of 8-hour ozone exceedance concentrations from 85 to 107 ppb and an average 8-hour ozone exceedance concentration of 93 ppb.
- Five exceedance days for the Tri-Cities area with range of 8-hour ozone exceedance concentrations from 87 to 101 ppb and an average 8-hour ozone exceedance concentration of 92 ppb.

Meteorological Modeling

Meteorological inputs were prepared for the ATMOS UAM-V5 application using the Fifth Generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (MM5). Key features of the MM5 modeling system that are relevant to its use in this study include multiple nested-grid capabilities, incorporation of observed meteorological data using a four-dimensional data-assimilation technique, and a detailed treatment of the planetary boundary layer.

MM5 was applied for each simulation period and the results were evaluated using graphical and statistical analysis. Comparison with the observed data was used to examine the model’s ability to represent key meteorological features such as the wind speeds as directions and site-specific temperatures. In summary, the MM5 results for the three modeling episode periods represent the regional-scale airflow patterns and the temperature and moisture characteristics of the episodes. Wind speeds (especially under light wind conditions) to tend to be overestimated, and the MM5-derived vertical mixing profiles, while realistic, do not always agree with observation-based mixing height estimates.

Emission Inventory Preparation

Base-year, current-year (2001), and future-year (2007 and 2012) emissions were prepared using the final version of the EPA NEI 1999 emission inventory, state-specific emissions data and vehicle miles traveled (VMT) estimates, and Bureau of Economic Analysis (BEA) emissions projection factors. The data were processed using the latest version of the modeling tools discussed above and listed/outlined in Figure ES-1. Total emissions of oxides of nitrogen (NO_x) and volatile organic compounds (VOC) for each EAC area are displayed and compared for the current and future years in Figure ES-3.

Figure ES-3a.
Anthropogenic Emissions (tpd) for the Memphis EAC Area

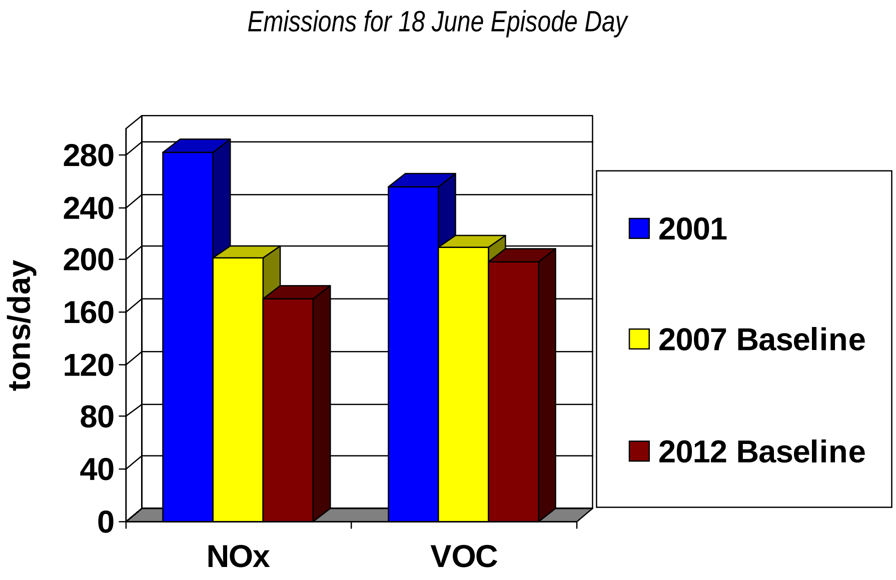


Figure ES-3b.
Anthropogenic Emissions (tpd) for the Nashville EAC Area

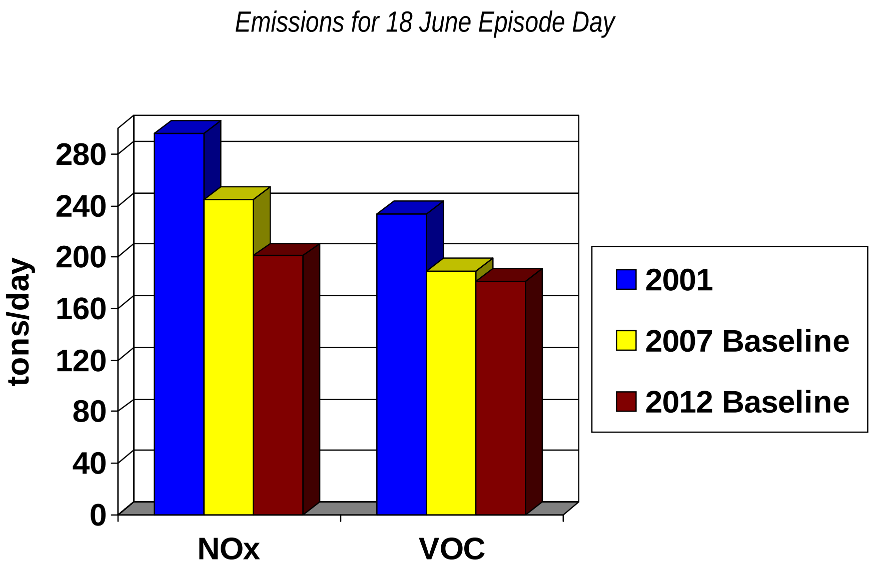


Figure ES-3c.
Anthropogenic Emissions (tpd) for the Knoxville EAC Area

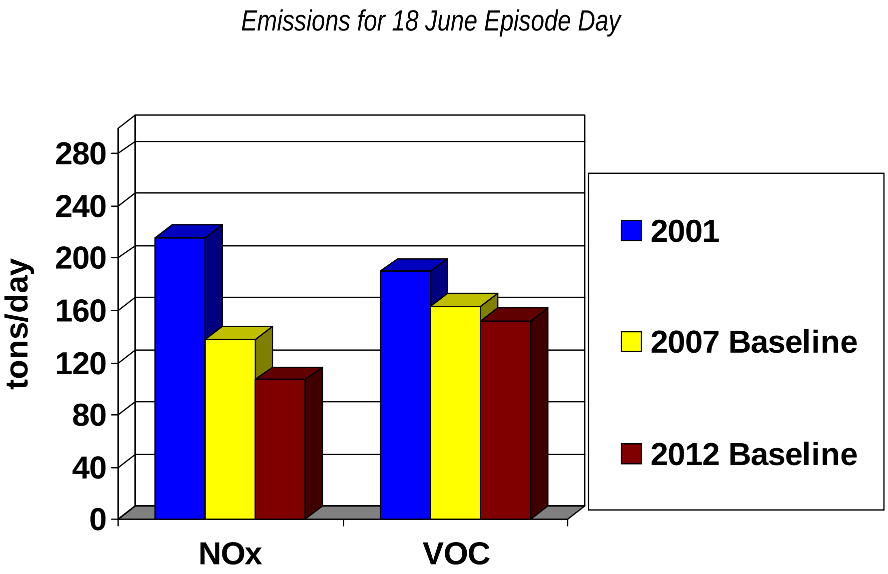


Figure ES-3d.
Anthropogenic Emissions (tpd) for the Chattanooga EAC Area

Emissions for 18 June Episode Day

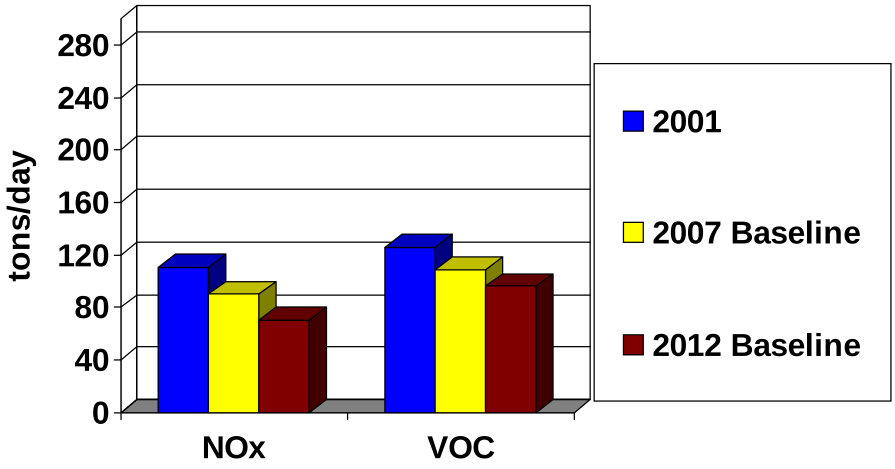
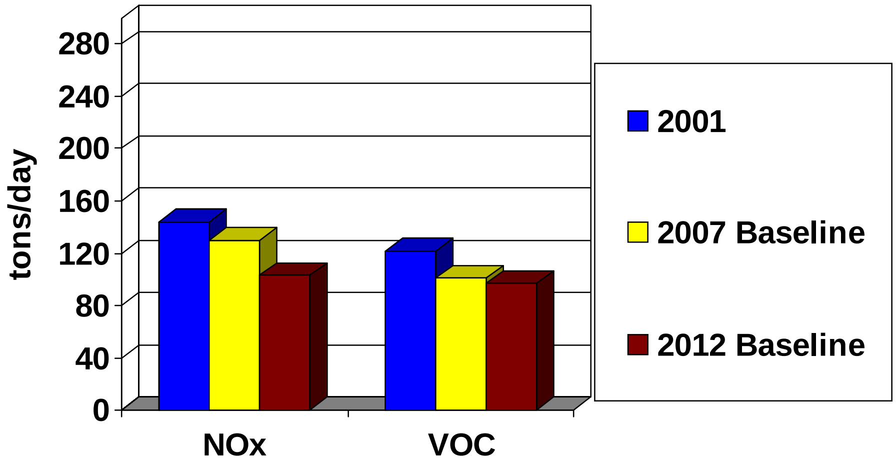


Figure ES-3e.
Anthropogenic Emissions (tpd) for the Tri-Cities EAC Area

Emissions for 18 June Episode Day



Model Performance Evaluation

The base-case modeling analysis for each simulation period consisted of an initial simulation, a series of diagnostic and sensitivity simulations, a final base-case simulation, and graphical and statistical analysis of each set of modeling results, including comparison with observed air quality data. We first focused on 1-hour ozone concentration patterns and statistical measures for the full modeling domain and each subdomain. This provided perspective on regional-scale model performance and whether the model is able to capture day-to-day variability in the concentration patterns and values. We then examined the hourly concentrations for each area and site of interest. It is important that the model capture the hourly variations and 1-hour peaks in order to reliably represent the 8-hour average values. We then examined the performance of the model in representing 8-hour ozone concentrations throughout the domain and for each area and site of interest.

Based on the graphical and statistical analysis, acceptable model performance is achieved for all three episode periods. Modeling results for all three episode combined are used in the attainment test to calculate the relative reduction factors and estimated future-year design values. Table ES-2 summarizes model performance for each site using all three of the simulations periods and the site-specific unpaired accuracy metric. For the most part, the metrics fall squarely within the EPA suggested bounds (of ± 20 percent) for acceptable performance. Overall the simulations tend to underestimate ozone within the Knoxville area, especially for the higher elevation sites located in the Great Smoky Mountains National Park. For the other areas, there is both some over- and underestimation of the 8-hour ozone values. These results indicate that the combined use of days provides an excellent basis for application of the attainment test procedures.

Table ES-2.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; All Episodes Combined, Excluding Startup Days

Site	Site-specific Average Accuracy Of The 8-Hour Ozone Peak (%)	Site-specific Average Accuracy of the 8-Hour Ozone Peak in the Vicinity of the Monitoring Site (%)
Memphis EAC		
DeSoto County, MS	-1.0	4.0
Edmond Orgill Park, TN	-7.9	-4.2
Frayser, TN	-6.1	2.1
Marion, AR	-4.6	2.9
Nashville EAC		
Cedars of Lebanon State Park	6.6	10.4
Cottontown Wright's Farm, TN	-8.8	-3.0
Dickson County, TN	-9.3	-5.3
East Nashville Health Center, TN	4.1	21.4
Fairview, TN	0.4	4.9
Percy Priest Dam, TN	2.8	16.2
Rockland Road, TN	7.0	11.8
Rutherford County, TN	-8.4	-5.8
Knoxville EAC		
Anderson County, TN	-2.3	3.0
Cades Cove, TN	8.9	11.9
Clingman's Dome, TN	-14.5	-11.8
Cove Mountain, TN	-16.4	-13.2
East Knox, TN	-4.6	0.1
Jefferson County, TN	-2.6	2.9
Look Rock (1), TN	-10.6	-5.8
Look Rock (2), TN	-21.1	-16.6
Spring Hill, TN	-17.7	-4.7
Chattanooga EAC		
Chattanooga VAAP, TN	-2.5	6.5
Meigs County, TN	-11.0	-3.9
Sequoyah, TN	-2.1	4.9
Tri-Cities EAC		
Kingsport, TN	-3.1	13.6
Sullivan County, TN	-3.9	4.3

Future-Year Modeling

The ATMOS EAC future-year modeling exercises include the application of the modeling system for a current-year (2001) and two future years (2007 and 2012). The use of a "current" year allowed us to combine the results from the three different episode period in applying the EPA modeled attainment test procedures, despite the different base years. In addition to the current- and future-year baseline simulations, several emissions sensitivity and control-strategy simulations were conducted for the 2007 future year. The UAM-V Oxidant and Precursor Tagging Methodology (OPTM) was used to assess the contribution to simulated ozone in the EAC areas from various source categories and source regions. Several control strategy simulations were conducted to quantify the effects of specific emission-reduction measures and packages of measures on the simulated future-year ozone concentrations. The final control-strategy simulation (AS-4) includes the final EAC attainment strategy measures for each area.

Attainment Demonstration

The procedures outlined in the draft guidance document on using models and other analyses to demonstrate future attainment of the proposed 8-hour ozone standard (EPA, 1999) were adapted for the ATMOS modeling domain and simulation periods and applied using the results from the 2007 attainment strategy simulation.

The attainment demonstration for each EAC area consisted of the modeled attainment test, the screening test, and additional corroborative analyses. For ATMOS, we offer a variety of weight-of-evidence analyses that are designed to improve our understanding and interpretation of the modeled attainment test results, and to explore the effects of the various assumptions that are employed in the application of the photochemical model and the attainment test procedures. Our goal here is to make the best possible use of the modeling results and the observed data to assign a level of confidence to the outcome of the modeled attainment test.

As part of the weight of evidence analysis, we explore the use of a meteorologically adjusted design value in the application of the attainment test. The design value is an important part of the modeled attainment test, in which future design values are estimated. For ATMOS, the modeled attainment test primarily uses, as its basis, the observation-based design value for the three-year period spanning the current model year. This value is expected to represent the current period in the same way the modeled simulation periods are expected to represent typical or frequently occurring meteorological conditions. Thus it is important that the base or current design value is representative of typical meteorological conditions. Given the form of the design value metric, however, year-to-year variations in meteorology and especially unusually persistent meteorological conditions during one or more of the years comprising a design value cycle can lead to a design value that is not representative of typical conditions.

While the 8-hour ozone design value is formulated in part to accommodate year-to-year variations in meteorological conditions, recent variations in the design values for the several of the ATMOS EAC areas have indicated that the metric may not be stable when weather conditions (either ozone conducive or not) persist over the region for large portions of the ozone season. In developing “meteorologically adjusted” design values for each area, our objective was to create a metric similar to the 8-hour design value but less sensitive to yearly meteorological variation.

Summary Attainment Demonstration for Memphis

The attainment and screening tests and additional corroborative analyses indicate that the Memphis EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests.

Three of the four monitoring sites in the Memphis area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. One site, the Marion site in Crittenden County, AR, has a future-year estimated design value (EDV) that is greater than the 84 ppb standard. The 2007 EDV for this site is 88 ppb if the 2000-2002 design value is used, 86 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. The 2000-2002 design value is the highest recorded in recent years. Based on the values for the other years as well as the indications from the meteorological adjustment, use of the 2000-2002 design value likely represents a worst case for Memphis for 2007. Thus, the modeling results together with the corroborative analysis indicate that Memphis will be in attainment of the 8-hour ozone standard by 2007.

Summary Attainment Demonstration for Nashville

The attainment and screening tests and additional corroborative analyses indicate that the Nashville EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests.

All of the monitoring sites in the Nashville area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. The areawide 2007 EDV for this site is 82 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. Use of a meteorologically adjusted DV that is higher than observed supports a finding of modeled attainment. Thus, the modeling results together with the corroborative analysis indicate that Nashville will be solidly in attainment of the 8-hour ozone standard by 2007.

Summary Attainment Demonstration for Knoxville

The modeled attainment test indicates that the Knoxville EAC area will likely not achieve attainment of the 8-hour ozone standard by 2007, unless additional controls to those included in the AS-4 control measure package are implemented. The modeling and attainment test results suggest a range in future-year estimated design values from 86 to 91 ppb. The higher value corresponds to the use of the 2000-2002 design value in the calculations, and the lower value corresponds to the use of the 2001-2003 DV. Use of a meteorologically adjusted DV is gives an EDV or 87 ppb. Although the EDV values are relatively high, the values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for 2007.

Oxidant tagging results indicate that 8-hour ozone concentrations in the Knoxville area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, other areas in northern Georgia, North Carolina, and South Carolina) will help to lower ozone in the Knoxville region.

Summary Attainment Demonstration for Chattanooga

The attainment and screening tests and additional corroborative analyses indicate that the Chattanooga EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests.

Oxidant tagging results indicate that 8-hour ozone concentrations in the Chattanooga area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, and other areas in northern Georgia, North Carolina, and South Carolina) will contribute positively to lower ozone in the Chattanooga region.

All three of the monitoring sites in the Chattanooga area have future-year estimated design values for 8-hour ozone that are less than or equal to 85 ppb if the 2000-2002 design value is used and less than or equal to 81 ppb if the 2001-2003 design value is used. Analysis of the effects of meteorology on the design value provides an estimate of a meteorologically adjusted design value for both 2000-2002 and 2001-2003 that is equal to 86 ppb. Use of a meteorologically adjusted DV of 86 ppb is consistent with the outcome of the attainment test based on the use of the 2001-2003 DV and gives an EDV of 79 ppb. Meteorologically adjusted trends indicate a value of 83 ppb, assuming that the emissions changes between 2003 and 2007 will be, on average, the same as that for 1996-2003.

Summary Attainment Demonstration for the Tri-Cities Area

The attainment and screening tests and additional corroborative analyses indicate that the Tri-Cities EAC area will be in attainment of the 8-hour ozone standard by 2007. Both of the monitoring sites in the Tri-Cities area have future-year estimated design values for 8-hour ozone that are less than or equal to 84 ppb. The areawide 2007 EDV is 84 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 82 ppb if a meteorologically adjusted design value is used.

Maintenance Demonstration

One of the requirements of the EAC is to evaluation maintenance of the 8-hour NAAQS for 2012, five years beyond the attainment date of 2007. As part of this modeling study, a 2012 baseline emission inventory was prepared and 2012 baseline simulations were conducted. The results for 2012 show substantial additional reductions in all of the ozone metrics considered, compared to 2007. The modeling results indicate that, despite the expected growth in population between 2007 and 2012, the expected emission reductions (reflecting local EAC and national measures) provide for further improvement in ozone air quality and maintenance of the 8-hour standard in all of these areas.

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1. Introduction

This document summarizes the results of an Early Action Compact (EAC) 8-hour ozone attainment demonstration modeling analysis conducted for the States of Arkansas, Tennessee, and Mississippi. The EAC modeling exercise leveraged off the accomplishments of the ongoing Arkansas-Tennessee-Mississippi Ozone Study (ATMOS) modeling analysis, which began in April 1999 and was originally designed to provide technical information relevant to attainment of an 8-hour National Ambient Air Quality Standard (NAAQS) for ozone primarily in the Memphis, Nashville, and Knoxville areas. In addition, the ATMOS analysis was also to provide information for addressing emerging 8-hour ozone issues in the Hamilton County (Chattanooga), Tennessee; Lee County (Tupelo), Mississippi; and Little Rock, Arkansas areas. This report summarizes the methods, approaches, and results of base-case and future-year modeling conducted to support the evaluation of emission-reduction measures that have been identified by each of the states as being effective in demonstrating attainment of the 8-hour standard in 2007.

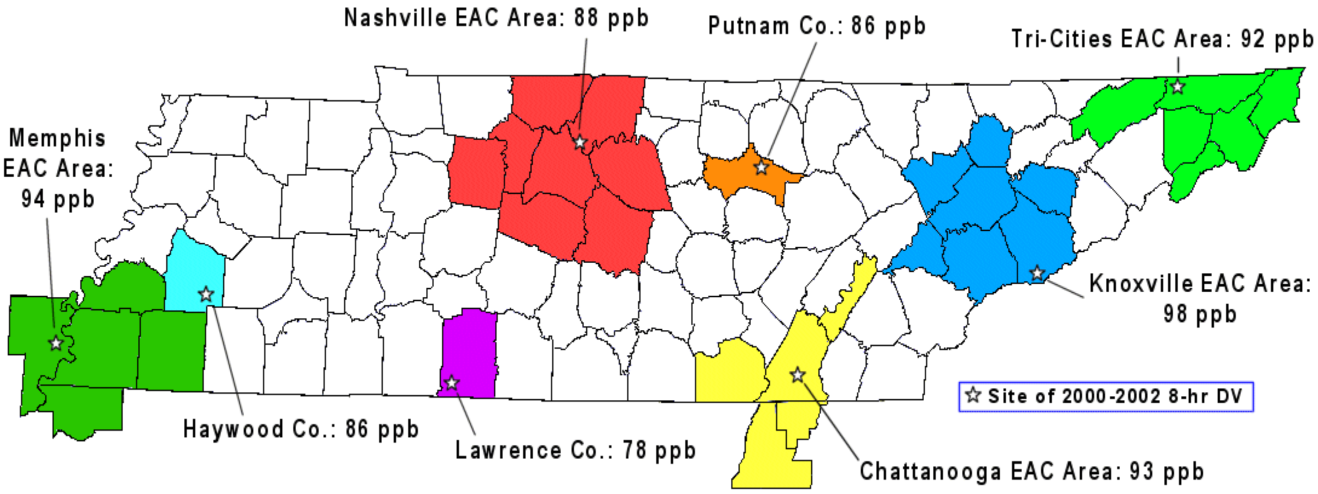
Background and Objectives

On December 31, 2002, the State of Tennessee entered into Early Action Compact agreements with EPA for eight areas within the state. The EAC areas include 30 counties within Tennessee, 2 adjacent counties in Georgia, and 1 adjacent county each in Arkansas and Mississippi, as well as 7 municipalities. The States of Arkansas and Mississippi also entered into an EAC agreement for the two counties adjacent to the Memphis area. Representatives from each of these jurisdictions signed the EAC. The EAC areas originally included the following counties:

- **Nashville EAC Area:** Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson Counties.
- **Knoxville EAC Area:** Anderson, Blount, Knox, Loudon, Sevier, Union, and Jefferson Counties.
- **Chattanooga EAC Area:** Hamilton, Marion and Meigs, counties (Tennessee), and Walker and Catoosa Counties, (Georgia).
- **Memphis EAC Area:** Shelby, Tipton, and Fayette Counties (Tennessee); Crittenden County (Arkansas); De Soto County (Mississippi).
- **Tri-Cities EAC Area:** Carter, Hawkins, Johnson, Sullivan, Unicoi, and Washington Counties.
- **Haywood County.**
- **Lawrence County (Florence, AL MSA).**
- **Putnam County.**

A map of the EAC areas, including the 2000-2002 design values for each area, is provided in Figure 1-1. The 8-hour ozone design value for a given monitoring site is defined as the three-year average of the fourth highest 8-hour ozone concentration at that site. The design value for a given area is the maximum of the site-specific design values over all sites in the area. The 8-hour National Ambient Air Quality Standard (NAAQS) for ozone requires the design value for an area to be less than or equal to 84 parts per billion (ppb).

Figure 1-1.
Tennessee EAC Areas with 2000–2002 Maximum 8-Hour Design Values



The ATMOS EAC modeling analysis was designed to provide technical information related to 8-hour ozone issues in the EAC areas. The EAC process provided an opportunity for these areas to conduct photochemical modeling to support decisions regarding control measures that could be adopted earlier than would be required by EPA, once the areas are formally designated nonattainment in 2004 under the new 8-hour NAAQS for ozone. Based on data for 1996-2003, the calculated design values for the areas listed above are given in Table 1-1. Based on the most recent design values as well as other considerations, Haywood, Lawrence, Johnson, and Putnam Counties opted out of the EAC process.

Table 1-1.
Maximum 8-Hour Ozone "Design Values"
for the ATMOS EAC Areas for the Period 1996-2003.

	Maximum 8-hour Ozone Design Values (ppb)					
	1996–1998	1997–1999	1998–2000	1999–2001	2000–2002	2001–2003
Memphis EAC Area	93	95	97	93	94	92
Nashville EAC Area	101	102	100	93	88	86
Knoxville EAC Area	100	104	104	98	98	92
Chattanooga EAC Area	93	94	97	92	93	87
Tri-Cities EAC Area	90	91	94	90	92	86
Haywood County	85	98	93	89	86	81
Lawrence County	84	88	89	83	78	77
Putnam County	87	88	91	87	86	82

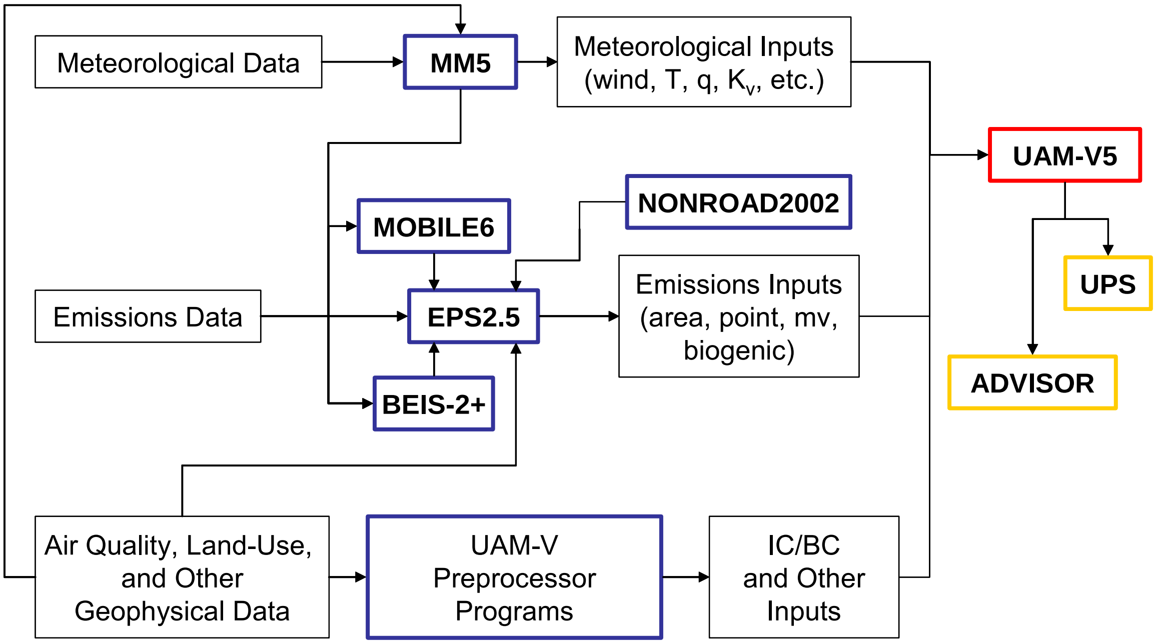
The primary objective of this study was to provide the modeling/analysis results needed to support an attainment demonstration for each of the remaining EAC areas. As such, the study was designed in accordance with draft EPA guidance (EPA, 1999a) for using modeling and other analyses for 8-hour ozone attainment demonstration purposes. Note that while the guidance is currently in draft form, the final version is not expected to be substantively different from the draft.

The ATMOS EAC modeling analysis components included a comprehensive episode selection analysis (identifying suitable periods for modeling), application and evaluation of a photochemical modeling system for three simulation periods, projection of emissions and ozone concentrations for two future years, and evaluation of ozone attainment strategies. The existing ATMOS committee structure (Technical, Operations, and Policy) was used throughout this study to support the technical work and as a means of communicating with all participants. All technical tasks were conducted in accordance with the draft EPA guidance and interim results of the analysis were presented in multiple meetings of the ATMOS Technical Committee and disseminated through the ATMOS web site (http://www.atmos.saintl.com).

Overview of the Modeling System Used for This Study

The ATMOS EAC modeling analysis utilized much of what was established for the original ATMOS analysis in terms of modeling tools and modeling domain specifications. The primary modeling tools selected for use in this study include: the variable-grid Urban Airshed Model (UAM-V) Version 1.5, a regional- and urban-scale, nested-grid photochemical model; the Emission Preprocessor System (EPS2.5), for preparation of model-ready emission inventories; the Biogenic Emission Inventory System with high-resolution land-use and crop data (BEIS-2+), for estimating biogenic emissions; the MOBILE6 model, for estimating motor-vehicle emissions; EPA’s NONROAD2002a model, which calculates non-road emissions; and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5), for preparation of the meteorological inputs. The UAM-V modeling system outputs were summarized and displayed using the UAM-V Postprocessing System (UPS) and the ATMOS ACCESS Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR). Figure 1-2 provides an overview of the ATMOS EAC modeling system, including key input data requirements, UAM-V input files, and interactions among the modeling system components.

Figure 1-2.
Schematic Diagram of the ATMOS EAC Photochemical Modeling System



Overview of the UAM-V Modeling System

The variable-grid Urban Airshed Model (UAM-V) is a three-dimensional photochemical grid model that calculates concentrations of pollutants by simulating the physical and chemical processes in the atmosphere. The basis for the UAM-V is the atmospheric diffusion or species continuity equation. This equation represents a mass balance that includes all of the relevant emissions, transport, diffusion, chemical reactions, and removal processes in mathematical terms.

The major factors that affect photochemical air quality include:

- The pattern of emissions of oxides of nitrogen (NO_x) and volatile organic compounds (VOC), both natural and anthropogenic.
- Composition of the emitted VOC and NO_x.
- Spatial and temporal variations in the wind fields.
- Dynamics of the boundary layer, including stability and the level of mixing.
- Chemical reactions involving VOC, NO_x, and other important species.
- Diurnal variations of solar insolation and temperature.
- Loss of ozone and ozone precursors by dry and wet deposition.
- Ambient background of VOC, NO_x, and other species in, immediately upwind of, and above the study region.

The UAM-V simulates all of these processes. The species continuity equation is solved using the following fractional steps: emissions are injected; horizontal advection/diffusion are solved; vertical advection/diffusion and deposition are solved; and chemical transformations are performed for reactive pollutants. The UAM-V performs these four calculations during each time step. The maximum time step is a function of the grid size, maximum wind velocity, and diffusion coefficient. The typical time step is 10–15 minutes for coarse (10–20 km) grids and a few minutes for fine (1–2 km) grids.

Because it accounts for spatial and temporal variations as well as differences in the reactivity of emissions, the UAM-V is ideal for evaluating the air-quality effects of emission control scenarios. This is achieved by first replicating a historical ozone episode to establish a base-case simulation. Model inputs are prepared from observed meteorological, emissions, and air quality data for the episode days using dynamic meteorological modeling and/or diagnostic and interpolative techniques. The model is then applied with these inputs, and the results are evaluated to assess model performance. Once the model results have been evaluated and determined to perform within prescribed levels, the same base-case meteorological inputs are combined with *modified* or *projected* emission inventories to simulate possible alternative/future emission scenarios.

The UAM-V modeling system (Version 1.5) incorporates the latest version of the Carbon-Bond chemical mechanism, known as Carbon Bond 5 (CB-V), with enhanced isoprene chemistry (SAI, 2002). Features of the UAM-V modeling system include:

- **Variable vertical grid structure:** The structure of vertical layers can be arbitrarily defined. This allows for higher resolution near the surface and facilitates matching with output from prognostic meteorological models.
- **Three-dimensional meteorological inputs:** The meteorological inputs for UAM-V vary spatially and temporally. These are usually calculated using a prognostic meteorological model.
- **Variable grid resolution for chemical kinetic calculations:** A chemical aggregation scheme can be employed, allowing chemistry calculations to be performed on a variable grid while advection/diffusion and emissions injections are performed on a fixed grid.
- **Two-way nested grid:** Finer grids can be imbedded in coarser grids for more detailed representation of advection/diffusion, chemistry, and emissions. Several levels of nesting can be accommodated.
- **Updated chemical mechanism:** The original Carbon Bond IV chemical mechanism has been updated to include many additional reactions. The updated chemical mechanism (CB-V) also supports the enhanced treatment of isoprene and hydrocarbon species.
- **Dry deposition algorithm:** The dry deposition algorithm is similar to that used by the Regional Acid Deposition Model (RADM).
- **True mass balance:** Concentrations are advected and diffused in the model using units of mass per unit volume rather than parts per million. This maintains true mass balance in the advection and diffusion calculations.
- **Plume-in-grid treatment:** Emissions from point sources can be treated by a subgrid-scale Lagrangian photochemical plume model. Pollutant mass is released from the subgrid-scale model to the grid model when the plume size is commensurate with grid cell size.

- **Plume rise algorithm:** The plume rise algorithm is based on the plume rise treatment for a Gaussian dispersion model.
- **OPTM method for ozone apportionment estimates:** The Ozone and Precursor Tagging Methodology (OPTM) approach allows the user to estimate contributions to ozone formation from various source categories or regions. The method tags oxidant formed during the chemistry step and attributes it to the NO_x and VOC participating in the chemistry during that step. At the end of a run the user can analyze the results based on the accumulated effects to help determine the most effective control strategies for ozone reduction.

Modeling Grid Specification

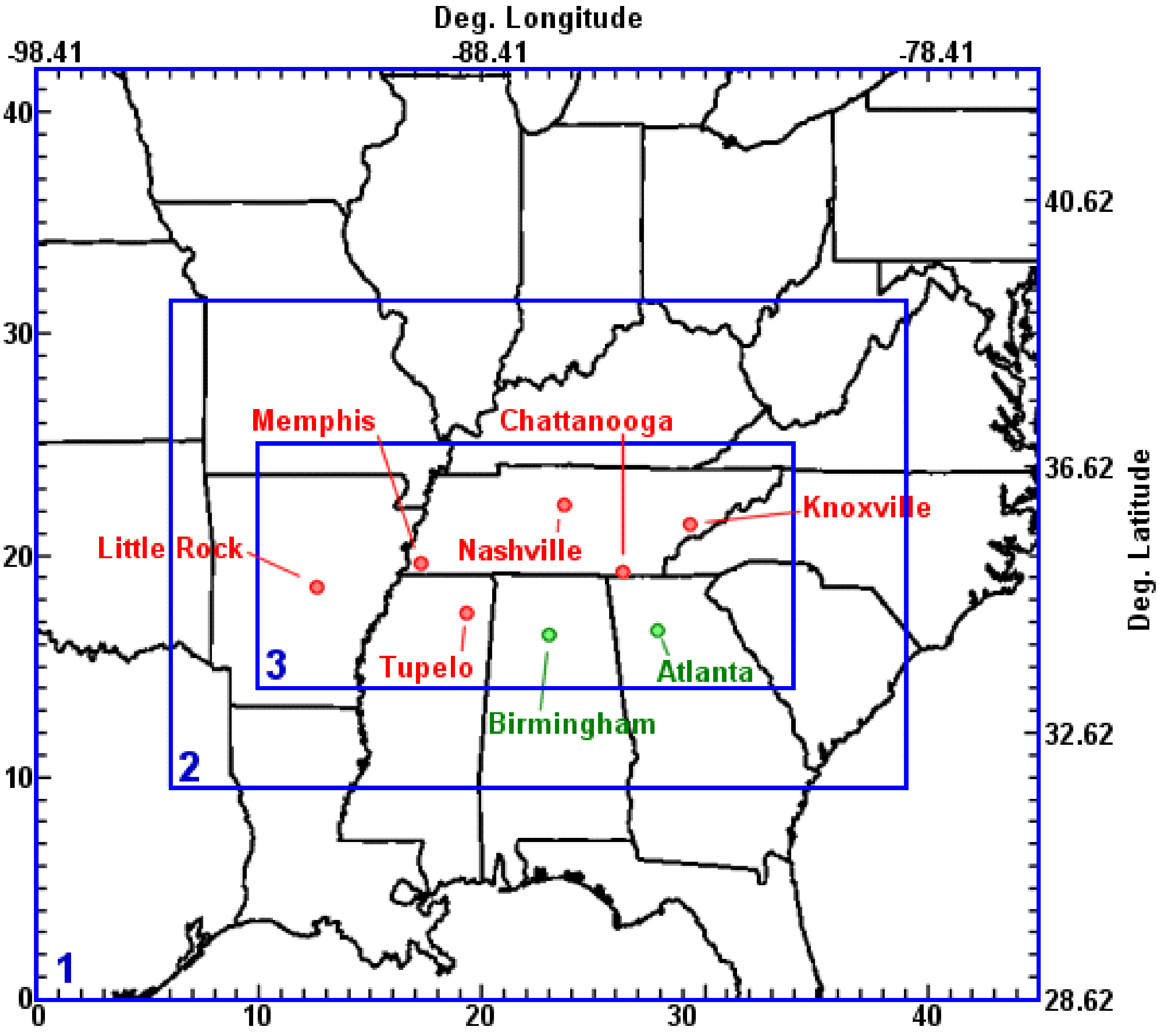
The modeling domain for application of the UAM-V for the ATMOS EAC analysis was designed to accommodate both regional and subregional influences as well as to provide a detailed representation of the emissions, meteorological fields, and ozone (and precursor) concentration patterns over the area of interest. The modeling domain used in the EAC modeling analysis is the same as what has been used for the original ATMOS modeling. The UAM-V modeling domain is presented in Figure 1-3 and includes a 36-km resolution outer grid encompassing the southeastern U.S; a 12-km resolution intermediate grid; and a 4-km resolution inner grid encompassing Tennessee and portions of Mississippi, Arkansas, and other neighboring states.

The regional extent of the modeling domain is intended to provide realistic boundary conditions for the primary areas of interest and thus avoid some of the uncertainty introduced in the modeling results through the incomplete and sometimes arbitrary specification of boundary conditions. The use of 4-km grid resolution over the primary area of interest is consistent with an urban-scale analysis of each of the areas of interest.

The UAM-V domain is further defined by eleven vertical layers with layer interfaces at 50, 100, 200, 350, 500, 750, 1000, 1250, 1750, 2500, and 3500 meters (m) above ground level (agl).

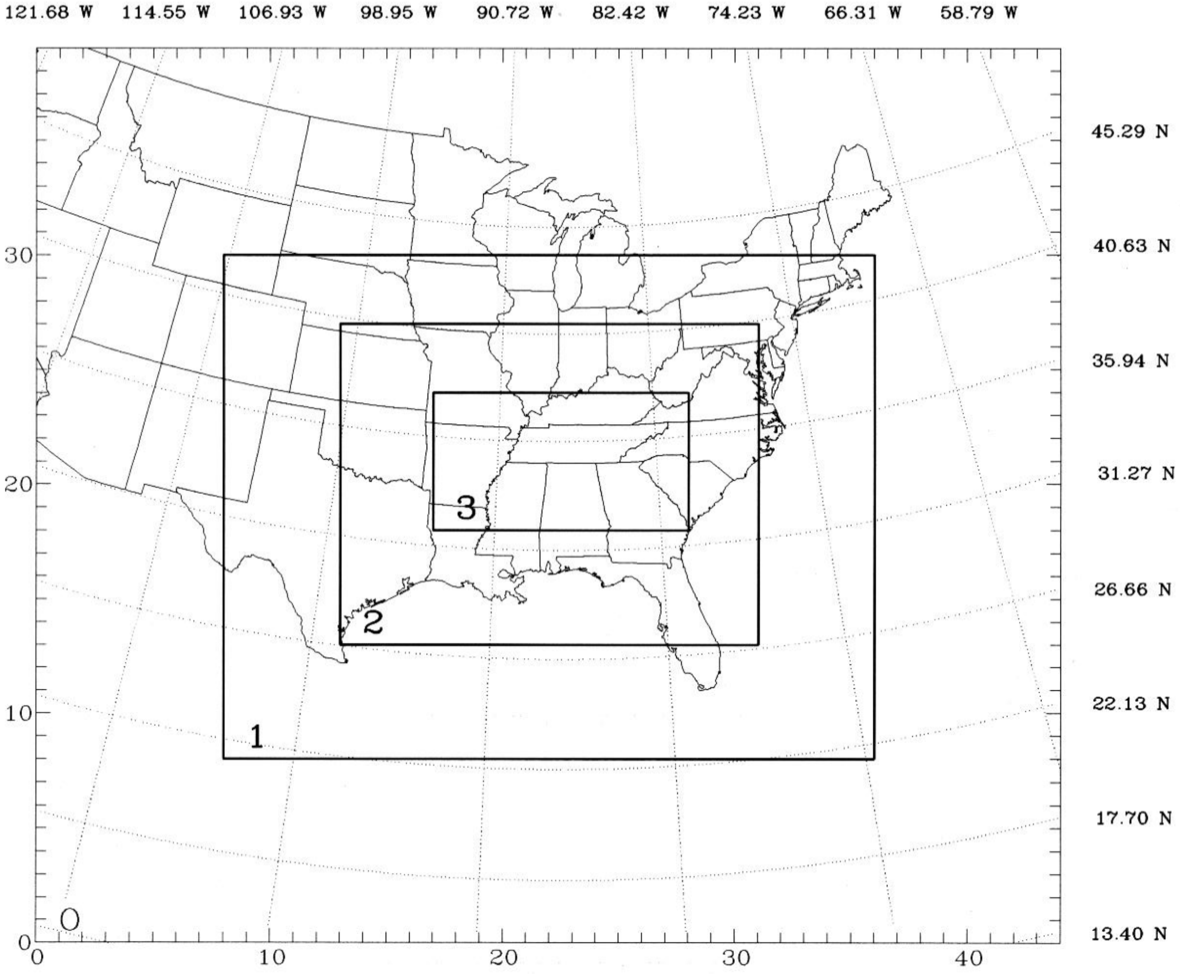
The modeling domain for application of MM5 is shown in Figure 1-4. This domain is much larger than that for UAM-V, in order to enable the simulation of any important synoptic scale features and their influence on the regional meteorology. The modeling domain consists of an extended outer grid with approximately 108-km horizontal resolution and three inner (nested) grids with approximately 36, 12, and 4-km resolution. The horizontal resolution was specified to match that for UAM-V. A one-way nesting procedure and 22 vertical levels were employed. The vertical grid is defined using the MM5 sigma-based vertical coordinate system. The layer thickness increases with height such that high resolution is achieved within the planetary boundary layer. The vertical layer heights for application of MM5 are listed in Table 1-2.

Figure 1-3.
UAM-V Modeling Domain for the ATMOS Study



Grid 1: (-98.41,28.62)—45x42—36-km Cells
Grid 2: (-95.41,31.79)—99X66—12-Km Cells
Grid 3: (-93.41,33.96)—215x81—4-km Cells

Figure 1-4.
MM5 Modeling Domain for the ATMOS Application



MM5 Grid Configuration for ATMOS. Central lat & lon (34.10, −87.40)

O: (0, 0) 44 x 39 – 108km Cells
1: (8, 8) 85 x 67 – 36km Cells
2: (13,13) 163 x 127 – 12km Cells
3: (17,18) 163 x 298 – 4km Cells

Table 1-2. MM5 Vertical Levels for the ATMOS Application

Level	Sigma	Average Height (m)
1	0.996	30
2	0.988	80
3	0.982	125
4	0.972	215
5	0.960	305
6	0.944	430
7	0.928	560
8	0.910	700
9	0.890	865
10	0.860	1115
11	0.830	1370
12	0.790	1720
13	0.745	2130
14	0.690	2660
15	0.620	3375
16	0.540	4260
17	0.460	5240
18	0.380	6225
19	0.300	7585
20	0.220	9035
21	0.140	10790
22	0.050	13355

Conceptual Description for 8-Hour Ozone for the ATMOS EAC Areas

Developing a conceptual model for 8-hour ozone is an important component of any 8-hour ozone modeling analysis. The conceptual model sets the stage for understanding the physical and chemical factors that influence ozone concentrations within the area of interest and that potentially result in exceedances of the 8-hour ozone standard, and for subsequently determining the extent to which secondary (upwind or downwind) areas need to be encompassed within the modeling domain and included in the assessment of the results with respect to ozone and precursor transport. The conceptual model also provides the basis for identifying the type and frequency of occurrence of different types of 8-hour ozone episodes and thus for the selection of modeling episode periods or key days for analysis of the modeling results. Finally, the conceptual model serves to provide focus to the interpretation of the modeling results and the development of effective attainment strategies.

In this section of the technical support document, we rely on observed air quality and emissions data to describe and characterize 8-hour ozone issues in the ATMOS EAC areas. We begin with a brief overview of the basics of ozone formation.

Overview of Ozone Chemistry

Ozone is a secondary pollutant that is not directly emitted into the atmosphere but instead is formed in the lower atmosphere by a series of reactions involving ultra violet (UV) radiation and precursor emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOC). NO_x consists of nitric oxide (NO) and nitrogen dioxide (NO_2), which are primarily emitted from anthropogenic sources. VOC consist of thousands of individual hydrocarbon and oxygenated hydrocarbon species emitted from both man-made and biogenic sources. Ozone formation near the earth's surface is affected by local weather conditions: winds, temperature, solar radiation, and horizontal and vertical dispersion characteristics, which influence precursor concentrations, reaction rates, formation, transport, and deposition.

On a typical summer day in the troposphere, UV radiation breaks the NO_2 molecule into NO and O (the oxygen atom). The oxygen atom then reacts with atmospheric oxygen (O_2) to form ozone (O_3). In another reaction, NO also reacts with ozone, destroying it and regenerating NO_2 and O_2. The role of VOC is a bit more complicated. Reactions involving VOC permit ozone to accumulate to higher concentrations by regenerating NO_2 from NO through free-radical reactions that do not destroy ozone, thus suppressing the destruction of ozone by NO. In the absence of VOC, ozone reaches a low steady-state concentration. Because the primary ozone-forming reaction is photochemically driven (i.e., by the sun), ozone concentrations typically peak during the daylight hours and then decrease after sunset.

In photochemical modeling, we are most interested in how changes in the emissions of NO_x and VOC affect the resultant ozone concentrations. In this case, it is NO_x that is more complicated. The chemical reactions tell us that reducing VOC emissions will always lead to slower rates of ozone formation and lower ambient ozone concentrations. Since NO_x emissions are needed to initiate ozone formation, reducing NO_x emissions will also tend to slow the rate of ozone formation. In some circumstances, however, reducing NO_x emissions will accelerate ozone formation (increase ozone concentrations) by limiting the rate of ozone destruction. When NO_x

emissions are reduced such that the VOC to NO_x ratio exceeds about 5.5:1, free radicals react primarily with VOC, breaking them down in a combustion-like process that accelerates ozone formation. This is most likely to occur during the nighttime hours and in areas where the ratio of VOC to NO_x concentrations is relatively low.

Regional-Scale Ozone Concentrations and Patterns

To aid our understanding of the regional-scale ozone concentration patterns for the ATMOS EAC areas and surrounding areas, we examined 8-hour ozone concentrations throughout the region, and specifically for the key areas of interest and other major metropolitan areas within the high-resolution ATMOS modeling subdomain (Grid 3). Please note that the Great Smoky Mountains National Park is a part of the Knoxville EAC area and is considered as such in this analysis. In keeping with the episode selection analysis, we specifically examined the period 1996-2002. This seven-year period was selected to optimize data availability for a consistent set of monitoring sites, to capture the range of meteorological conditions associated with ozone exceedances in the areas, and to limit the influence of emissions changes on the analysis and interpretation of results.

Table 1-3 presents some basic metrics calculated from the daily maximum 8-hour ozone value over all sites for each area. Eight-hour NAAQS exceedance days are fairly common for all sites, comprising at least 10 percent of the days for Memphis, Nashville, Knoxville, and Atlanta, with the worst 8-hour ozone—in terms of frequency and severity—at Knoxville and Atlanta. Chattanooga and the Tri-Cities area have lower 8-hour ozone but still see a significant number of exceedance days.

Table 1-3.
8-Hour Ozone Metrics for Areas of Interest, from 1996 to 2002, April to October Inclusive[1]

Average annual maximum values and percentiles are in ppb.

1996-2002	Memphis	Nashville	Knoxville	Chattanooga	Tri-Cities	Atlanta	Birmingham
Data availability	100%	100%	100%	98%	98%	86%	85%
Avg. annual max.	112.99	109.87	113.94	106.36	101.54	128.04	114.27
Exceedance days	150	162	278	94	65	281	113
90th percentile	85.0	85.9	92.3	80.3	78.4	98.8	83.3
50th percentile	60.1	61.5	69.9	56.6	55.9	65.5	56.6
10th percentile	37.1	38.5	52.0	33.0	35.6	40.5	35.1

Figure 1-5 shows the frequency of exceedances for each month, averaged over available years. For all areas, the peak ozone season occurs in the mid summer, with a peak in the number of exceedance days around August.

Individual years can be compared in Figure 1-6, which shows the changing value for the 90th percentile of each year’s daily maximum 8-hour ozone values. Here again the pattern is fairly

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[1] Although March is now considered an ozone-season month, it was not included in our analysis.

consistent for all sites, with high ozone occurring in 1998 and 1999, and relatively low levels in 2001.

Figure 1-5.
Number of 8-Hour Exceedance Days per Month, Averaged over Years 1996 to 2002

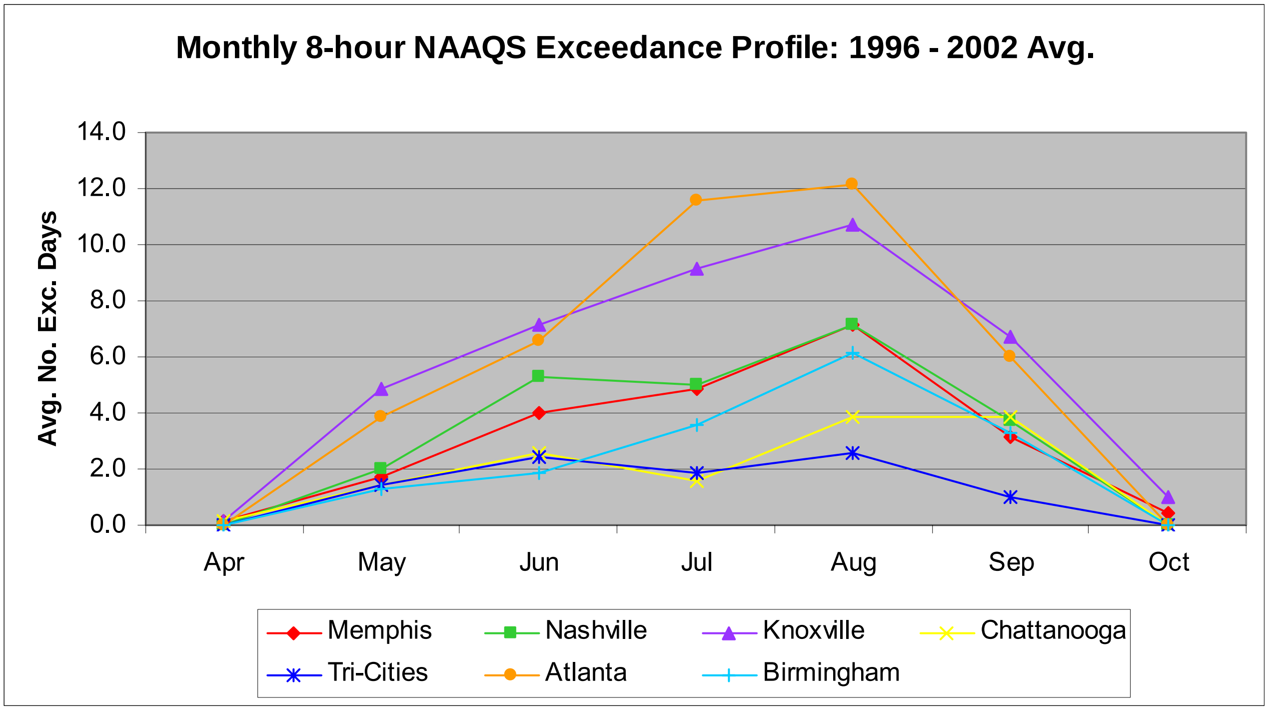
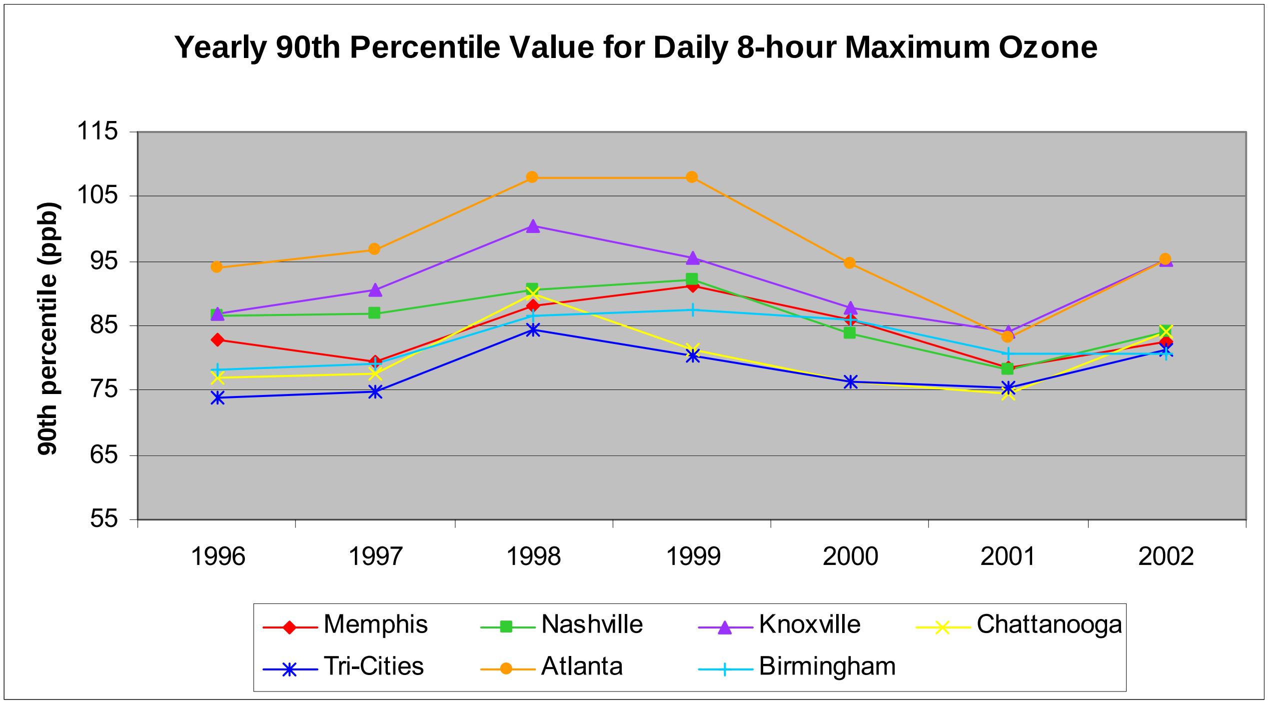


Figure 1-6.
Each Year's Ninetieth Percentile Value for Daily Maximum 8-Hour Ozone Values



To examine the regional-scale nature of high ozone, we also looked for correlations between the observed values for each area listed in Table 1-3 above. For this analysis, the correlation (R) is defined as the sample covariance between two datasets divided by the product of the standard deviations for each dataset, which is equivalent to:

$$R = \left(n\left(\sum XY\right) - \left(\sum X\right)\left(\sum Y\right)\right) \Big/ \sqrt{\left(n\sum X^2 - \left(\sum X\right)^2\right)\left(n\sum Y^2 - \left(\sum Y\right)^2\right)}$$

where the two datasets X and Y each have n data points.

R-squared is simply the square of the correlation; a value over 0.70 may be considered significant. Table 1-4 shows R-squared values for same-day 8-hour maximum ozone values, for every area combination, using all days with data for each area in the pair. It is apparent from the table that the R-squared values reflect and quantify the neighbor-to-neighbor correlations one might expect. For these correlations, between 1250 and 1500 data points are available for each pairing.

Table 1-4.
R-Squared Values for 8-Hour Ozone Daily Maximums for Areas of Interest, 1996-2002.

Shaded values are between different sites with their squared correlation greater than 0.50.

R-squared value	Memphis	Nashville	Knoxville	Chattanooga	Tri-Cities	Atlanta	Birmingham
Memphis	1.00	0.63	0.39	0.43	0.25	0.30	0.42
Nashville		1.00	0.64	0.66	0.47	0.47	0.49
Knoxville			1.00	0.68	0.67	0.59	0.44
Chattanooga				1.00	0.61	0.59	0.53
Tri-Cities					1.00	0.40	0.27
Atlanta						1.00	0.64
Birmingham							1.00

Moderate correlation appears between nearby areas, perhaps reflecting similar meteorological conditions. We also examined correlations with a one-day lag between the areas; only one of these gave R-squared values greater than 0.50: Knoxville and yesterday's Nashville have an R-squared value of 0.54. For Chattanooga, the correlation between the area 8-hour maximum and Chattanooga's own previous-day value was similar to the correlation between that area and previous-day Memphis or Nashville (all R-squared values between 0.42 and 0.44); the same is true for Tri-Cities related to its own previous-day value, Nashville, and Knoxville (R-squared values between 0.40 to 0.42). Nashville 8-hour ozone is correlated to its own previous-day ozone slightly more than to the previous-day ozone in Memphis (R-squared values of 0.48 and 0.45, respectively). For Memphis, the correlation to its own previous-day value is significantly greater than to any other site's previous day value. However, none of these correlations are very dramatic, the highest being between Knoxville and its own previous-day value, with R-squared of 0.57.

These results suggest that same-day 8-hour ozone concentrations are somewhat subregionally correlated, presumably as the neighboring areas experience similar meteorological conditions. Within the context of the correlations, there is also the possibility that ozone from one area affects ozone concentrations in one or more neighboring areas, in particular, transport from west Tennessee to Chattanooga and the Tri-Cities area, or between Atlanta and Birmingham and Tennessee.

ATMOS EAC Area Ozone Concentrations and Patterns

We also examine the 8-hour ozone characteristics of the individual AIRS sites of each EAC area. This provides some insight into the site-specific concentration characteristics and allows us to highlight the key high ozone sites as well as the extent of high ozone across each area.

Site-Specific 8-Hour Ozone Concentration Characteristics

Table 1-5a through 1-5e give the same overview as Table 1-3, except here the daily 8-hour ozone maximums are for individual sites instead of for areas.

Table 1-5a.
8-Hour Ozone Metrics for Sites in the Memphis EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	Edmond Orgill Park	Frayser Blvd.	Marion, AR	DeSoto County, MS
Data availability	99%	99%	97%	95%
Avg. annual max.	100.2	108.3	101.2	102.7
Exceedance days	80	53	55	43
90th percentile	78.9	75.4	76.4	74.4
50th percentile	57.8	51.9	54.6	53.6
10th percentile	36.1	30.5	33.8	32.6

Table 1-5b.
8-Hour Ozone Metrics for Sites in the Nashville EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	E. Nashville Health Center	Percy Priest Dam	Rutherford Co.	Rockland Rd.	Cottontown Wright's Farm	Fairview	Cedars of Lebanon State Park
Data availability	99%	98%	94%	96%	96%	96%	96%
Avg. annual max.	90.6	98.7	95.1	106.3	98.27	98.46	100.14
Exceedance days	23	40	37	106	39	65	44
90th percentile	67.4	72.9	74.1	81.0	72.8	77.9	76.6
50th percentile	44.4	51.4	53.9	56.5	52.8	57.4	54.5
10th percentile	24.1	29.4	34.7	33.4	32.1	36.9	33.0

Table 1-5c.
8-Hour Ozone Metrics for Sites in the Knoxville EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	East Knoxville	Spring Hill	Jefferson Co.	Anderson Co.	Cove Mountain	Clingman's Dome	Cades Cove	Look Rock
Data availability	99%	100%	95%	94%	94%	81%	94%	80%
Avg. annual max.	110.39	110.13	107.7	96.7	103.21	104.24	89.6	88.6
Exceedance days	120	124	122	65	158	135	16	108
90th percentile	82.5	83.4	83.1	79.1	86.3	86.3	72.2	83.7
50th percentile	58.1	56.9	58.6	56.3	65.8	67.6	53.1	62.0
10th percentile	35.1	32.4	37.3	34.4	48.4	51.8	34.1	43.6

Table 1-5d.
8-Hour Ozone Metrics for Sites in the Chattanooga EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	Chattanooga - VAAP	Sequoyah
Data availability	90%	97%
Avg. annual max.	103.4	105.3
Exceedance days	70	72
90th percentile	79.0	77.5
50th percentile	55.8	53.9
10th percentile	31.6	31.9

Table 1-5e.
8-Hour Ozone Metrics for Sites in the Tri-Cities EAC area, from April to October, 1996 to 2002

Average annual maximum values and percentiles are in ppb.

1996-2002	Kingsport	Blountville
Data availability	97%	96%
Avg. annual max.	100.3	97.9
Exceedance days	63	43
90th percentile	77.4	75.5
50th percentile	54.9	54.1
10th percentile	34.3	32.6

The indicators of high ozone don’t favor one site in the Memphis area during the entire period. The Edmund Orgill Park site has the most number of exceedances during the analysis period, while the Frayser site has the highest average of the annual maximum values. In recent years, however, the Marion site has experienced a greater number of exceedance days than either site in Shelby Co. and the higher values have also shifted to this site. Consequently, the Marion site currently has the highest design value for the Memphis area.

For the most part, a single site (Rockland Rd.) drives 8-hour ozone exceedances in the Nashville area. Several Knoxville sites see 10 percent of days at exceedance or near-exceedance 8-hour ozone levels: East Knoxville, Spring Hill, Jefferson County, Cove Mountain, Clingman’s Dome, and Look Rock. For Chattanooga, both sites experience high ozone about equally; in the Tri-Cities area the Kingsport site tends to slightly higher 8-hour ozone and more exceedances than Blountville.

Diurnal Patterns

The diurnal ozone concentration patterns vary among the sites within each region, depending upon the site location relative to the emissions sources and various meteorological influences. Composite diurnal profiles for selected key sites for each area for exceedance days only are presented in Figures 1-7a through 1-7e.

Because the Memphis area incorporates portions of three states, we show the average diurnal profiles for three sites—one from each state—in Figure 1-7a. The Frayser site located in Shelby Co., TN is characterized by a classic or typical diurnal profile with the peak ozone concentration in the early to mid afternoon. Concentrations during the nighttime hours are low, as ozone is titrated by NO emissions with the area. Ozone concentrations at the Marion and DeSoto County sites tend to peak later in the day, late afternoon to early evening. This indicates that ozone formed elsewhere in the domain (during the time of peak solar insolation) is transported to these sites and contributes to the maximum 1-hour and 8-hour ozone concentrations.

For the Nashville area (Figure 1-7b), the Rockland Road monitor consistently reports the highest values. It is characterized by a typical diurnal profile with a peak value during the middle of the day. This suggests that most of the ozone observed at this site is formed locally.

The Knoxville EAC area incorporates two distinct regions – the greater Knoxville area and the Great Smoky Mountains (GSM) National Park. In Figure 1-7c, average diurnal profiles for the Spring Hill monitor characterize the more urbanized area while those for Clingman's Dome are representative of the GSM area. The average exceedance-day diurnal profile for Spring Hill shows a mid-day peak. The elevated GSM sites (with elevations on the order of 600 to 1000 m) show very flat diurnal profiles, as illustrated by the profile for the Clingman's Dome site. The lack of variation throughout the day and specifically the lack of a distinct daytime peak indicate that ozone is transported into this area throughout the day (and not specifically formed during the daytime hours). Without local emission sources, titration of ozone during the nighttime hours also does not occur. The high 8-hour average ozone concentrations are due to the sustained relatively high ozone values rather than a combination of high and moderate values (as is the case for most urban sites).

For the Chattanooga and Tri-Cities areas (Figures 1-7d and 1-7e, respectively), the monitors are characterized by a typical diurnal profile with a peak value during the middle of the day.

Figure 1-7a.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Memphis EAC Area.

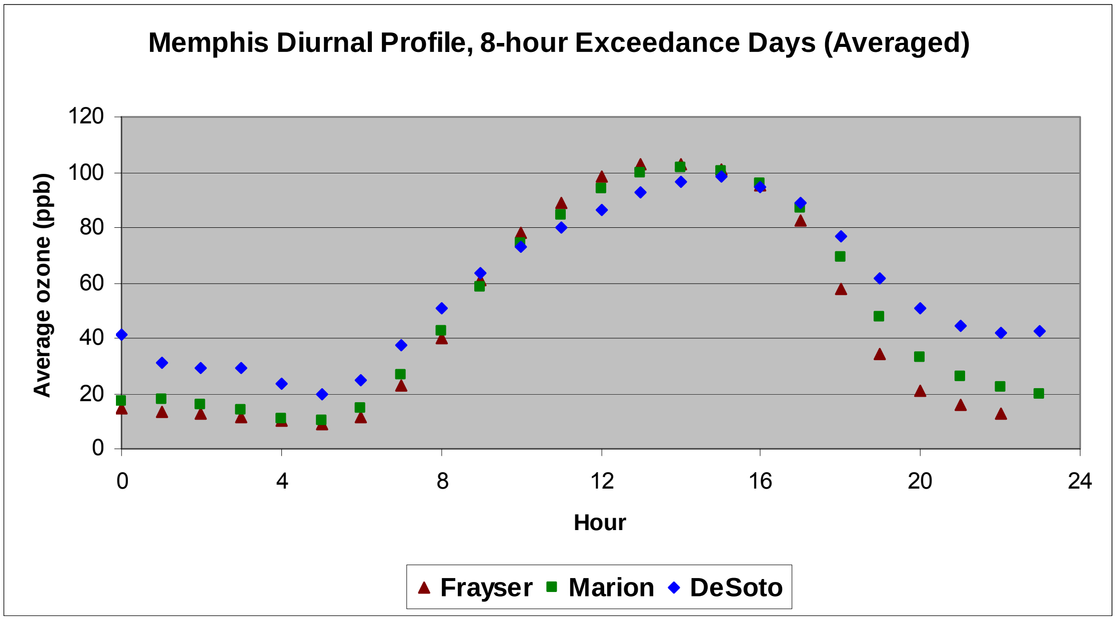


Figure 1-7b.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Nashville EAC Area.

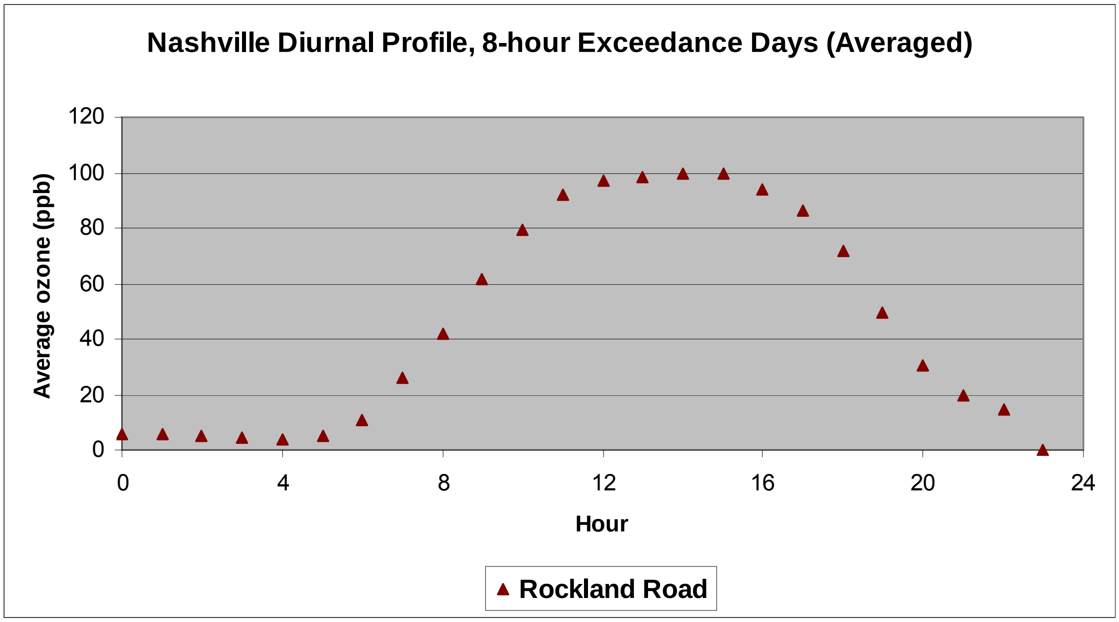


Figure 1-7c.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Knoxville EAC Area.

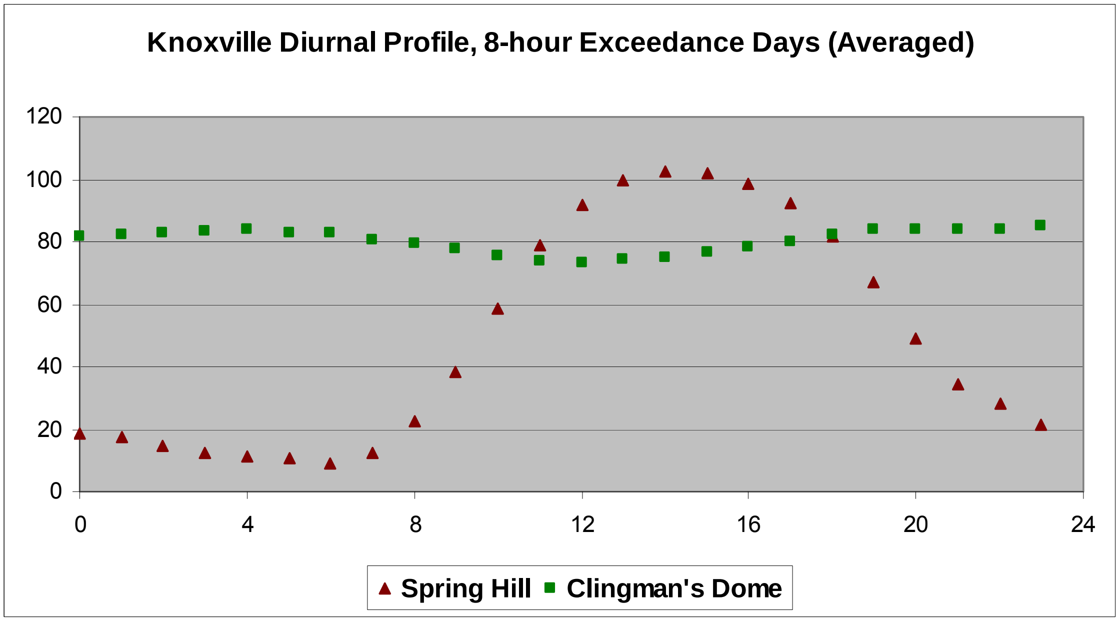


Figure 1-7d.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Chattanooga EAC Area.

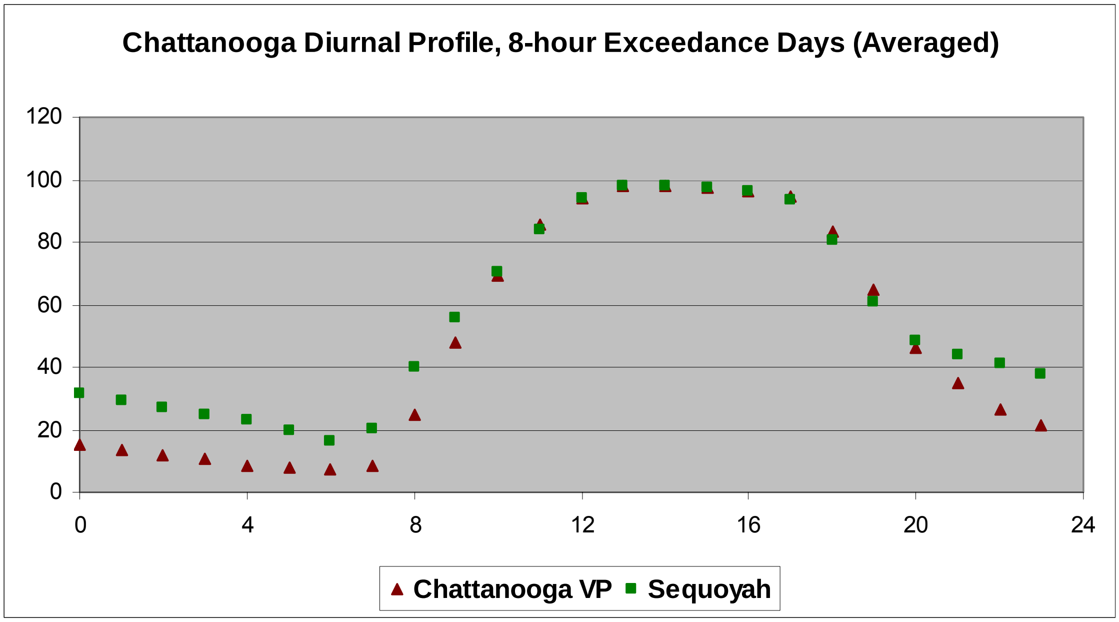
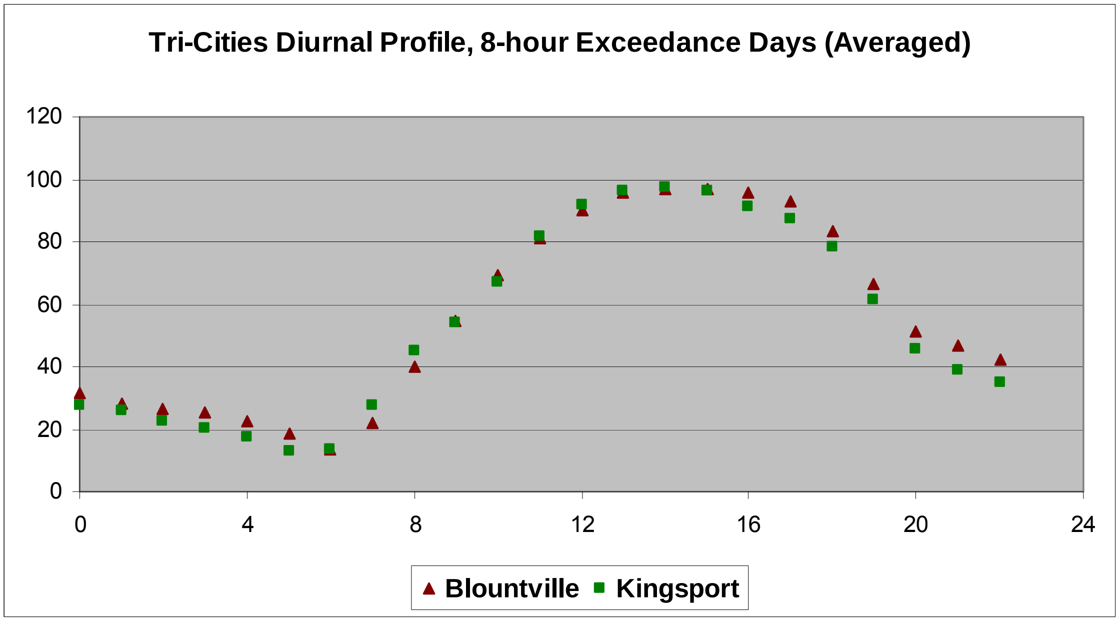


Figure 1-7e.
Diurnal Ozone Profile Averaged Over All Exceedance Days: Tri-Cities EAC Area.



Meteorological Characteristics of Ozone Episodes

Overview of Meteorological Factors Influencing Ozone

Ozone episodes for many areas in the U.S. are often characterized relative to regional-scale meteorological high- and low-pressure patterns and specifically to the presence of a surface-based high-pressure system (an area over which the atmospheric pressure is relatively higher than the surrounding areas). The location of the high-pressure system relative to the area of interest determines the prevailing wind and dispersion conditions and thus the source-receptor relationships that characterize an ozone episode, whereas the persistence and strength of the system influence/determine episode severity. A textbook depiction of an ozone episode places the high-pressure system over an urban area. This results in suppressed vertical mixing of emissions/pollutants, low wind speeds or stagnation, low humidity, high temperatures, clear skies, and strong solar insolation. These are the typical ingredients of an ozone episode.

The “recipe” for high ozone concentrations varies throughout the U.S. according to geographical characteristics, local and regional emissions characteristics, and the location of each area relative to other areas in combination with pollutant-transport-conducive meteorological conditions. The complexity of any conceptual model for ozone formation increases with each of these factors.

Ozone episodes within each of the EAC areas occur under a variety of regional-scale meteorological conditions and prevailing wind directions. The regional-scale patterns, in turn, influence the development of local ozone-conducive meteorological conditions. We explore both of these, in turn, in the remainder of this section.

Analysis of Exceedance and Non-Exceedance Regional Wind Patterns

Plots comparing the frequency of wind directions and speeds for all ozone season days (April through October) and 8-hour ozone exceedance days in each of the EAC areas of interest for the period 1996-2002 are presented in Figures 1-8 through 1-12. The wind information in these plots is for the Nashville upper-air monitoring site. Because Nashville is centrally located within the region of interest, these data are used here to represent the regional-scale winds. In these diagrams, wind direction is defined as the direction from which the wind is blowing. The length of the bar within that wind-direction sector indicates the frequency of occurrence of a particular wind direction. The shading indicates the distribution of wind speeds.

Upper-air winds for the 850 mb level (approximately 1500 m above ground) are available twice per day, at approximately 0600 and 1800 LST. Distinguishing features in the wind plots (also called wind rose diagrams) for the ozone exceedance days, when contrasted to those for all ozone-season days, may help to define the wind and/or transport patterns leading to high ozone. The wind distributions for the ozone season are presented in Figure 1-8. Those for the 8-hour exceedance days for each area follow.

Based on the Nashville sounding data (Figure 1-8a-b), upper-level winds during the ozone season tend to be southwesterly through northwesterly for both the morning and evening soundings.

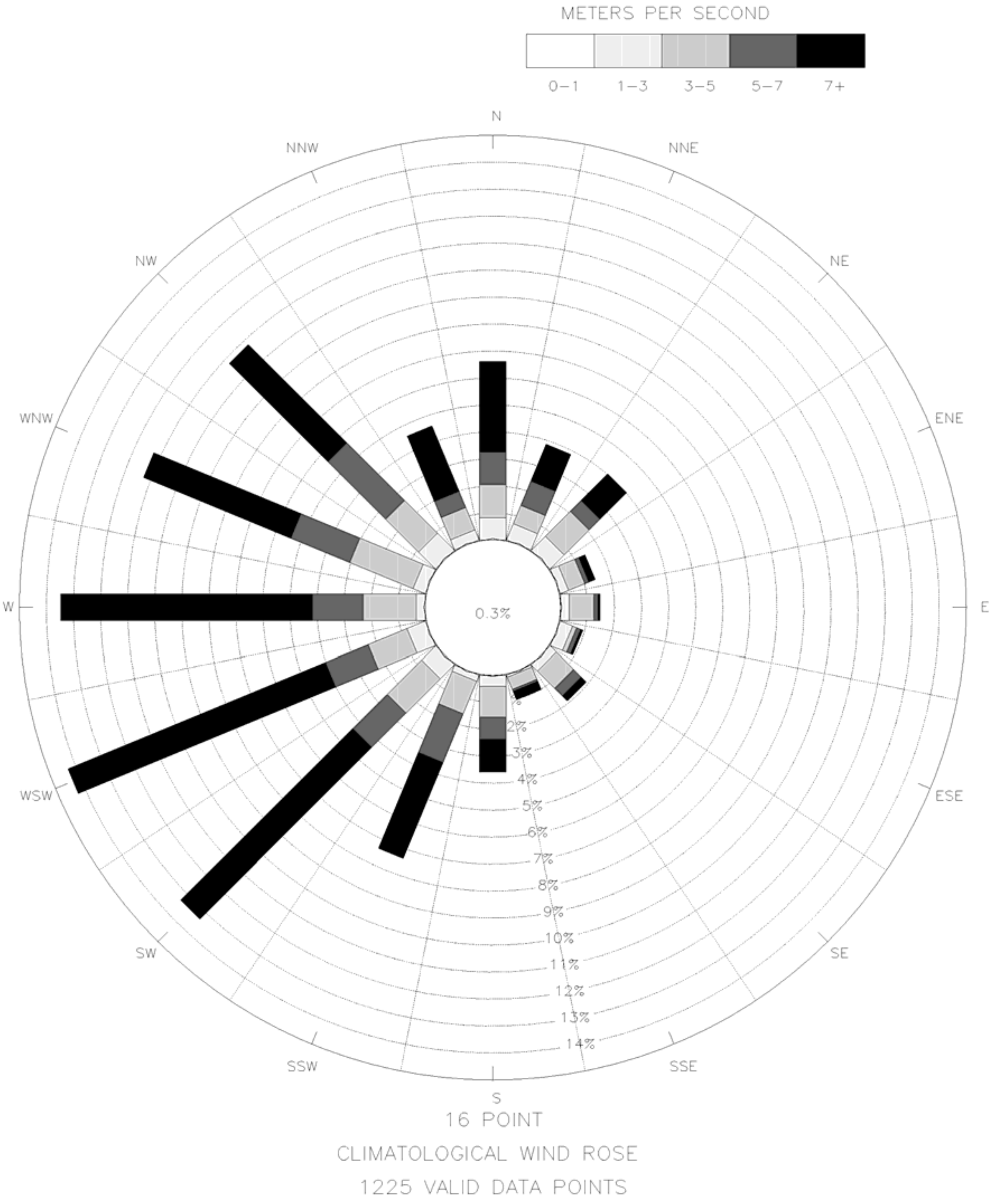
When only high ozone days in the Memphis area are considered (Figure 1-9), there is a discernable shift to more northerly and easterly components during the time of the morning sounding, and really no favored wind direction at the time of the evening sounding. The percentage of time that the winds are from the north, northeast, south, and southeast is greater for ozone exceedance days than for all ozone season days. The range of wind directions indicates that there is no one upper-air wind pattern associated with exceedances in the Memphis area. We also examined this same series of plots using upper-air wind data for Little Rock (not shown) and found a greater occurrence of easterly winds at the time of the morning sounding and a slight tendency for a shift from southwesterly to southeasterly winds at the time of the afternoon sounding for exceedance days in Memphis.

For the Nashville area (Figure 1-10), the upper-level winds suggest a greater tendency for winds aloft to have a westerly component during the time of the morning sounding, but easterly wind components also appear on certain of the exceedance days. Similar to Memphis, the evening winds exhibit a range of wind directions on ozone exceedance days for Nashville, with a tendency for more southerly and easterly wind components on the exceedance days.

For exceedance days in the Knoxville area (Figure 1-11), the upper-level winds suggest a greater tendency for winds aloft to have a southerly component during high ozone days, especially at the time of the evening soundings. Westerly to southwesterly winds dominate the wind roses for the Knoxville area ozone exceedance days.

Westerly to southerly winds also dominate the wind roses for exceedances days in the Chattanooga area (Figure 1-12). Compared to the full ozone season, there is a greater tendency for winds from south.

Figure 1-8a.
Winds at the 850 mb Level for the Nashville Sounding for the Ozone Season (April–October, 1996–2002): 0600 CST



850 mb (am) Winds in the Nashville Area (1996 – 2002)
for the Ozone Season (April – September)

Figure 1-8b.
Winds at the 850 mb Level for the Nashville Sounding for the Ozone Season (April–October, 1996–2002): 1800 CST

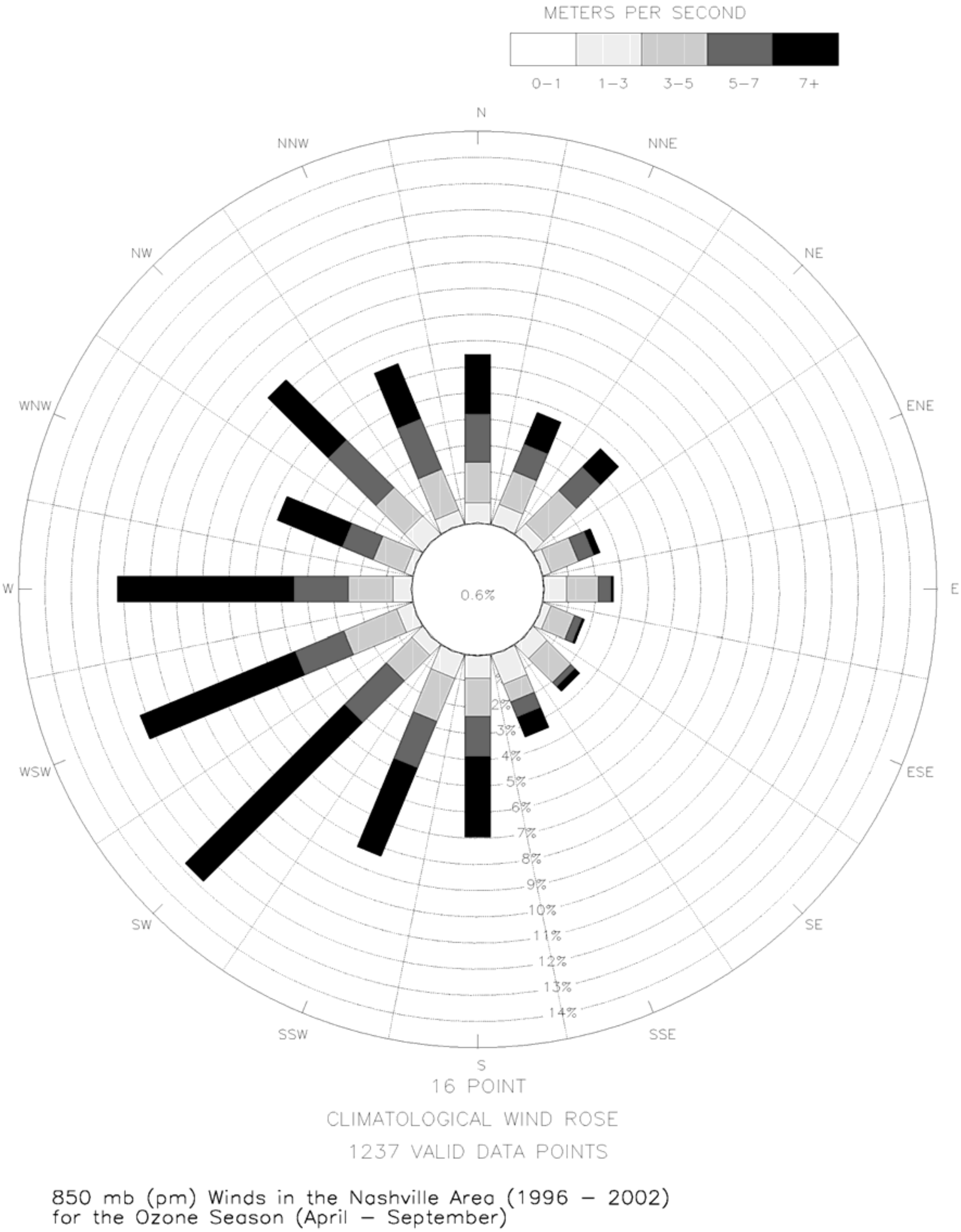


Figure 1-9a.
Winds at the 850 mb Level for the Nashville Sounding for 8-Hour Ozone Exceedance Days for Memphis (1996–2002): 0600 CST

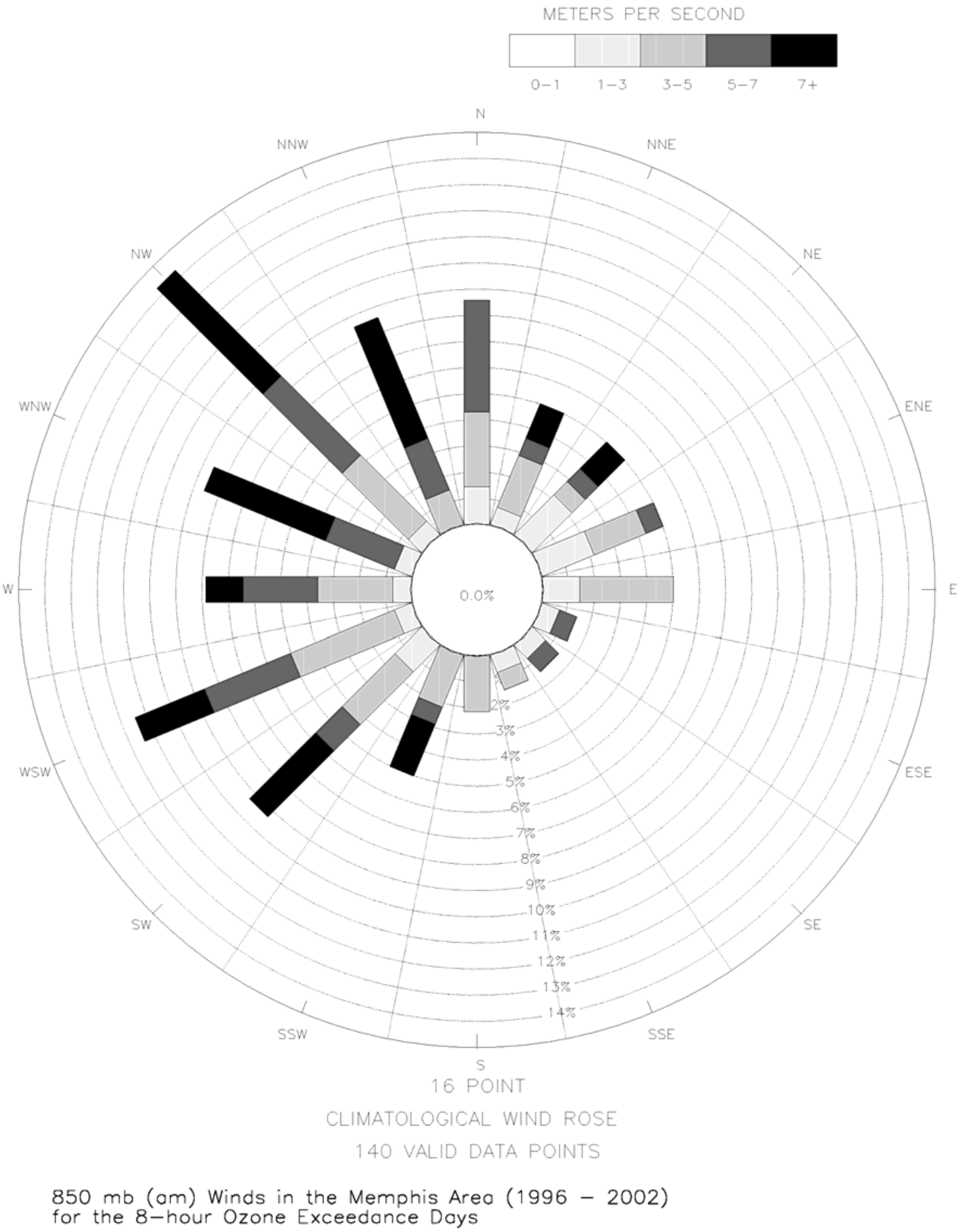


Figure 1-9b.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Memphis (1996–2002): 1800 CST

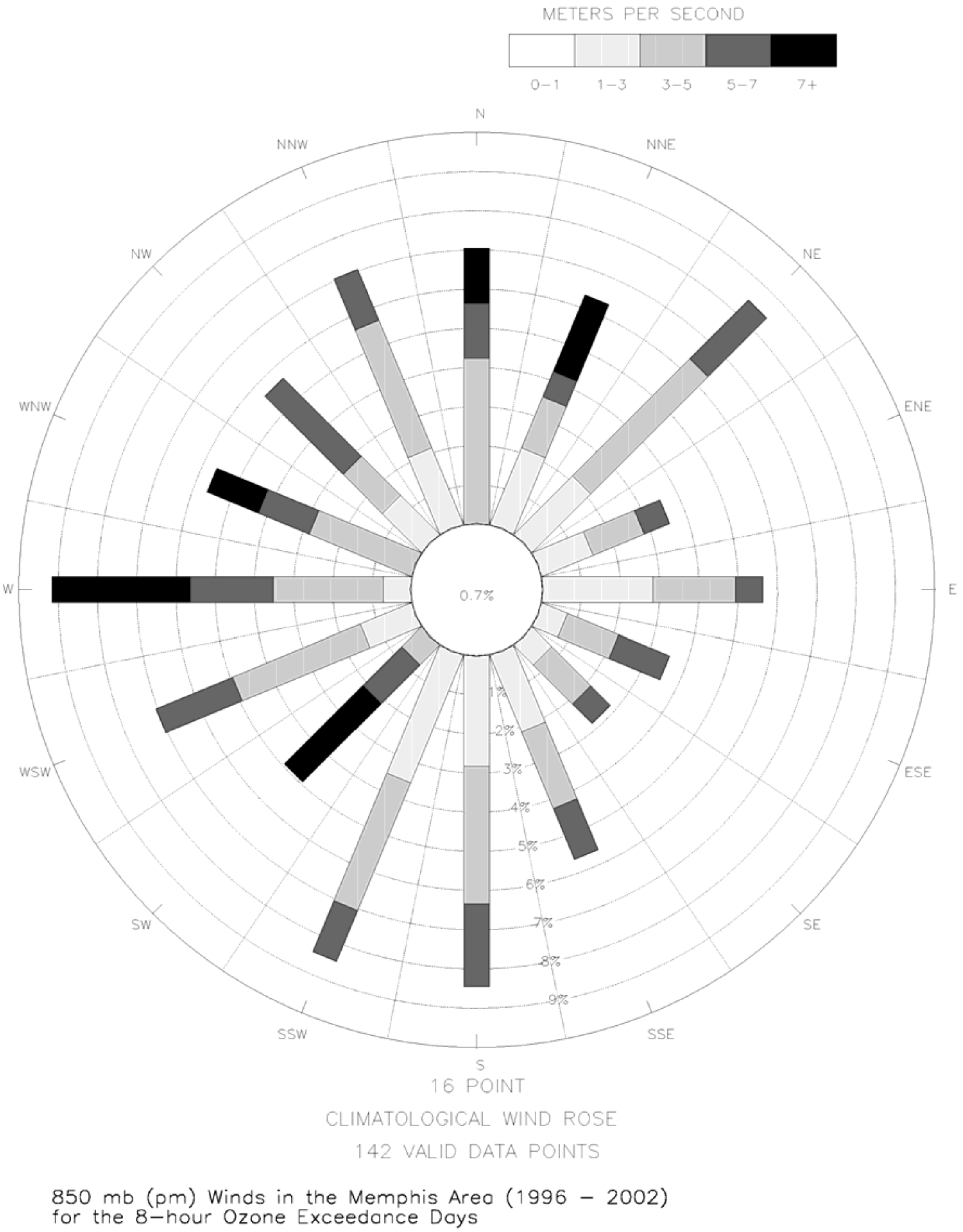


Figure 1-10a.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Nashville (1996–2002): 0600 CST

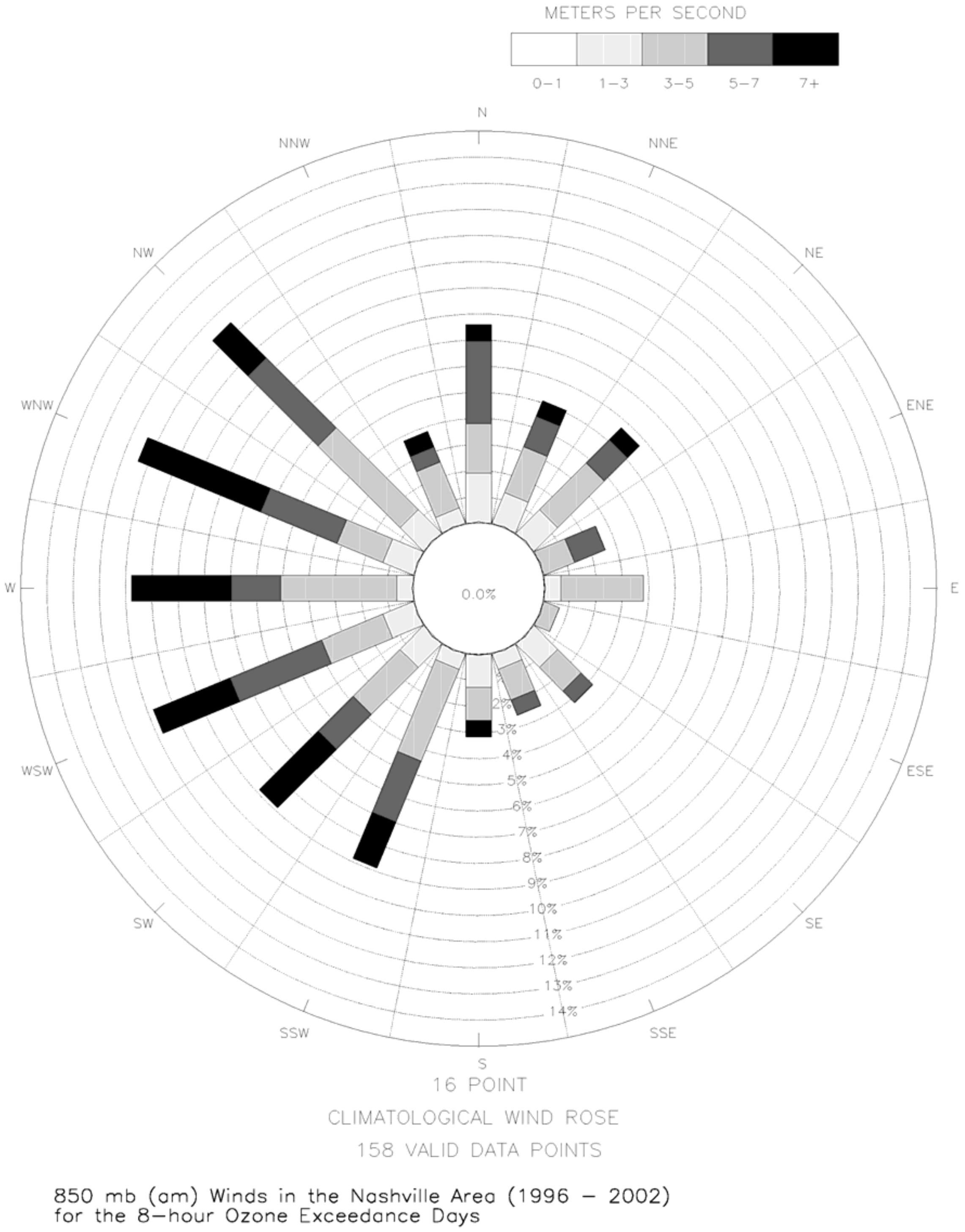


Figure 1-10b.
Winds at the 850 mb Level for the Nashville Sounding for 8-Hour Ozone Exceedance Days for Nashville (1996–2002): 1800 CST

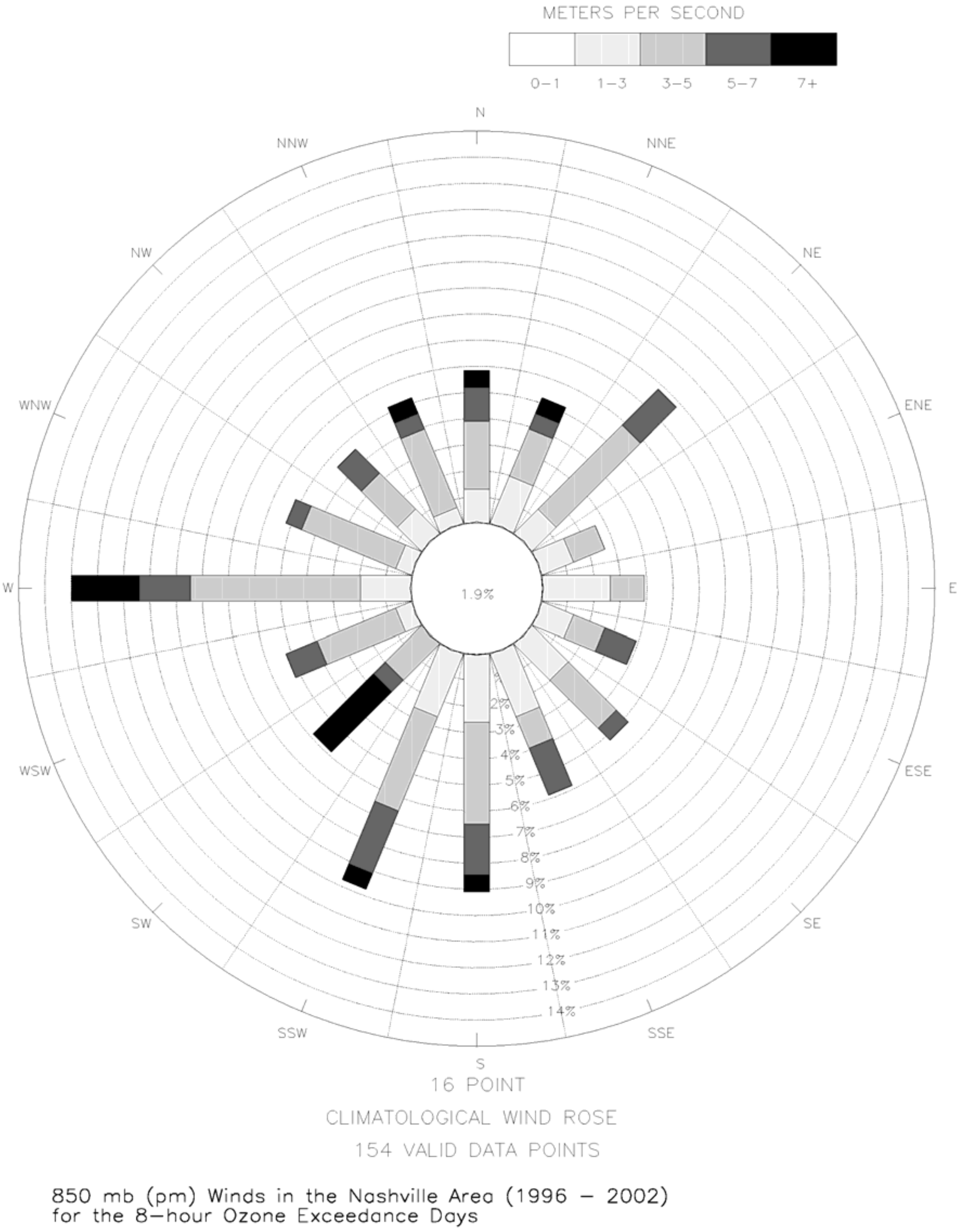


Figure 1-11a.
Winds at the 850 mb Level for the Nashville Sounding for 8-Hour Ozone Exceedance Days for Knoxville (1996–2002): 0600 CST

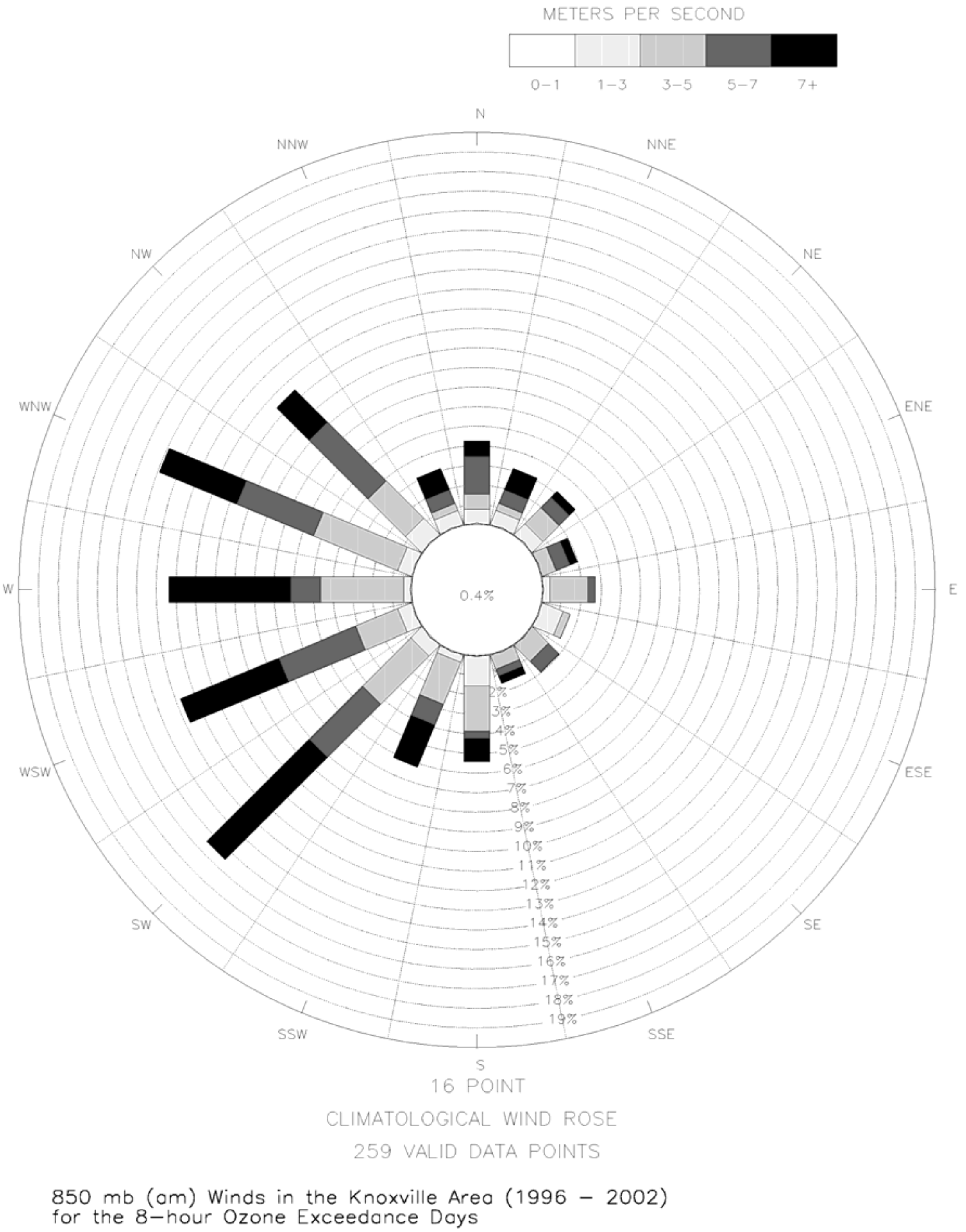


Figure 1-11b.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Knoxville (1996–2002): 1800 CST

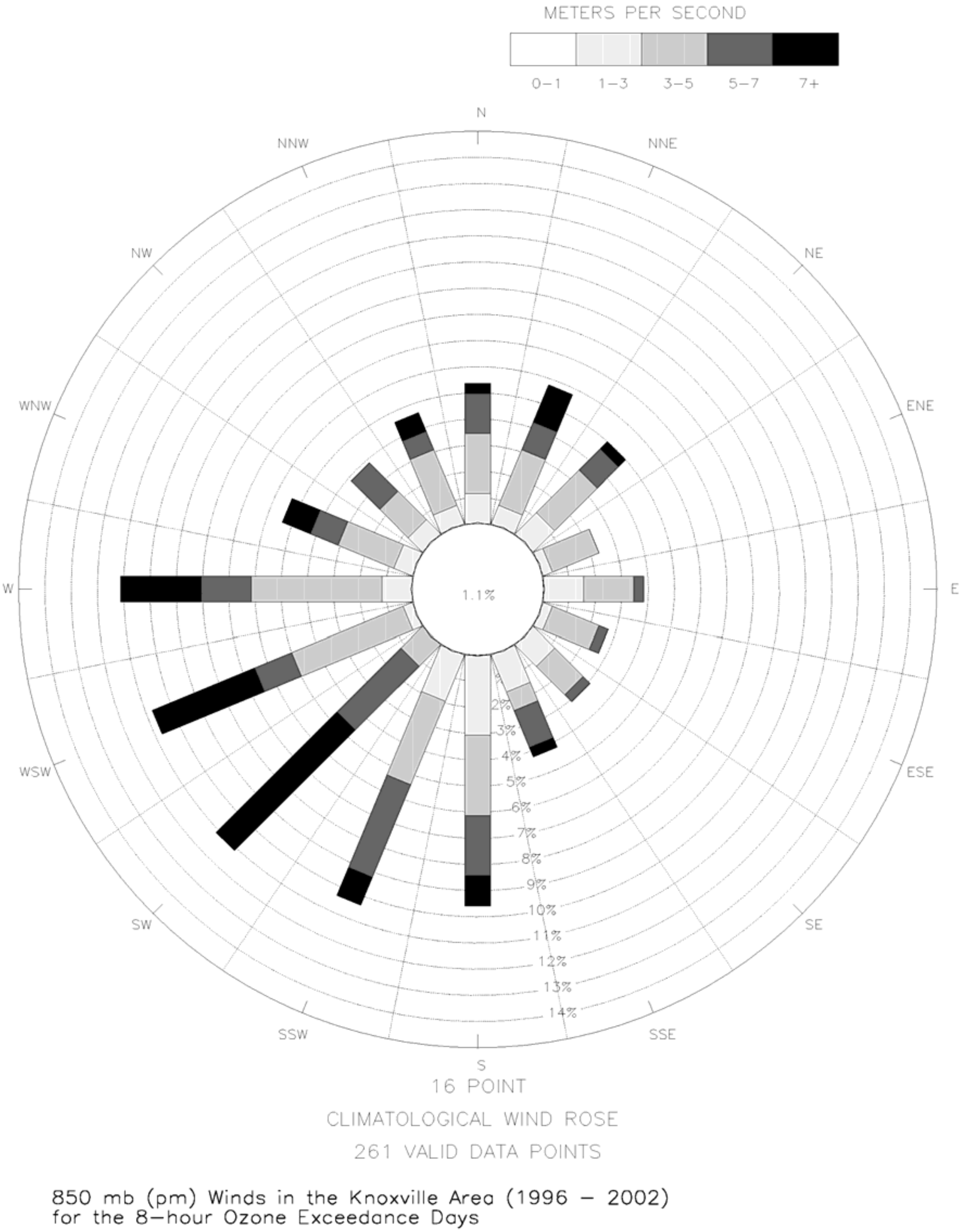
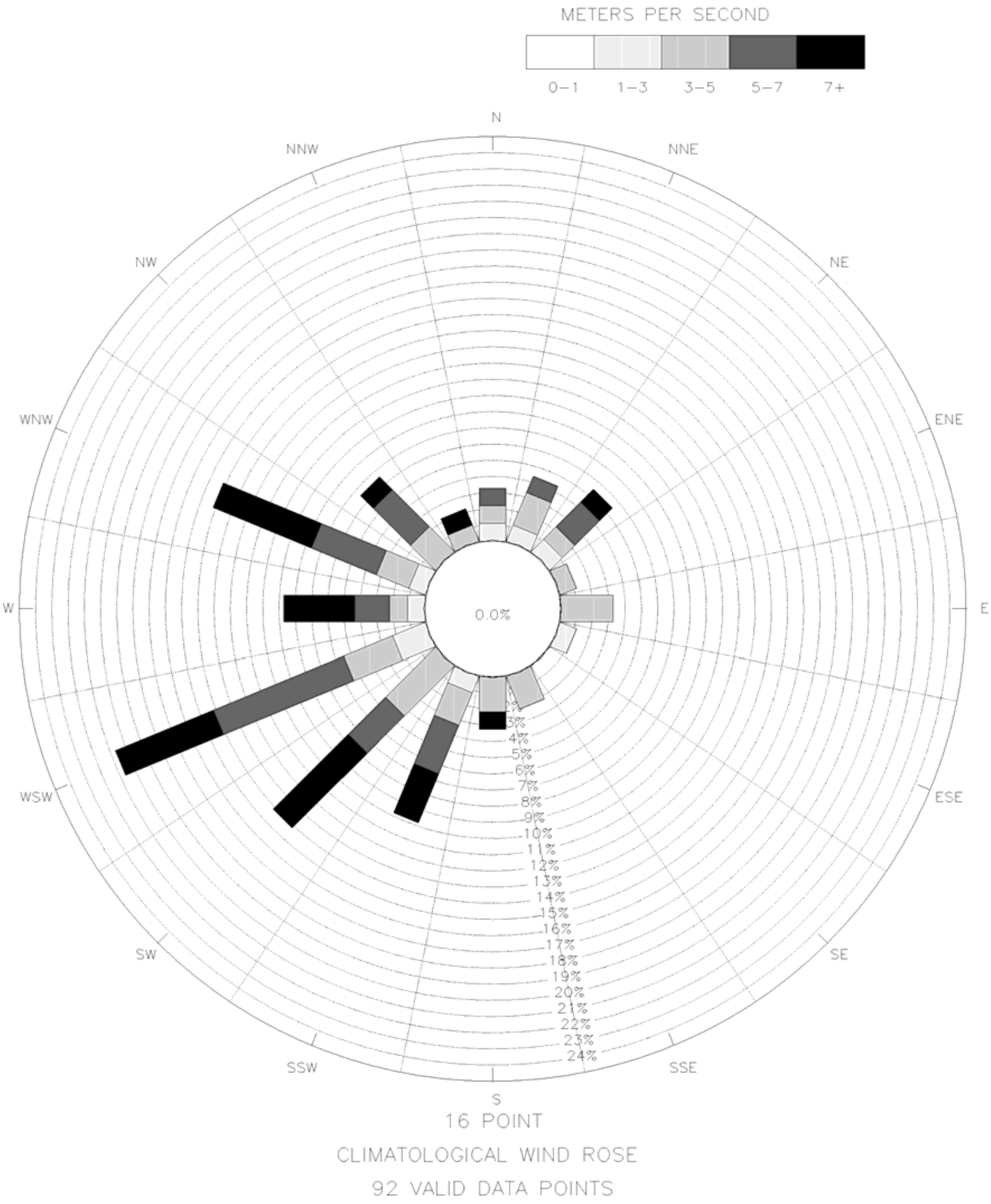
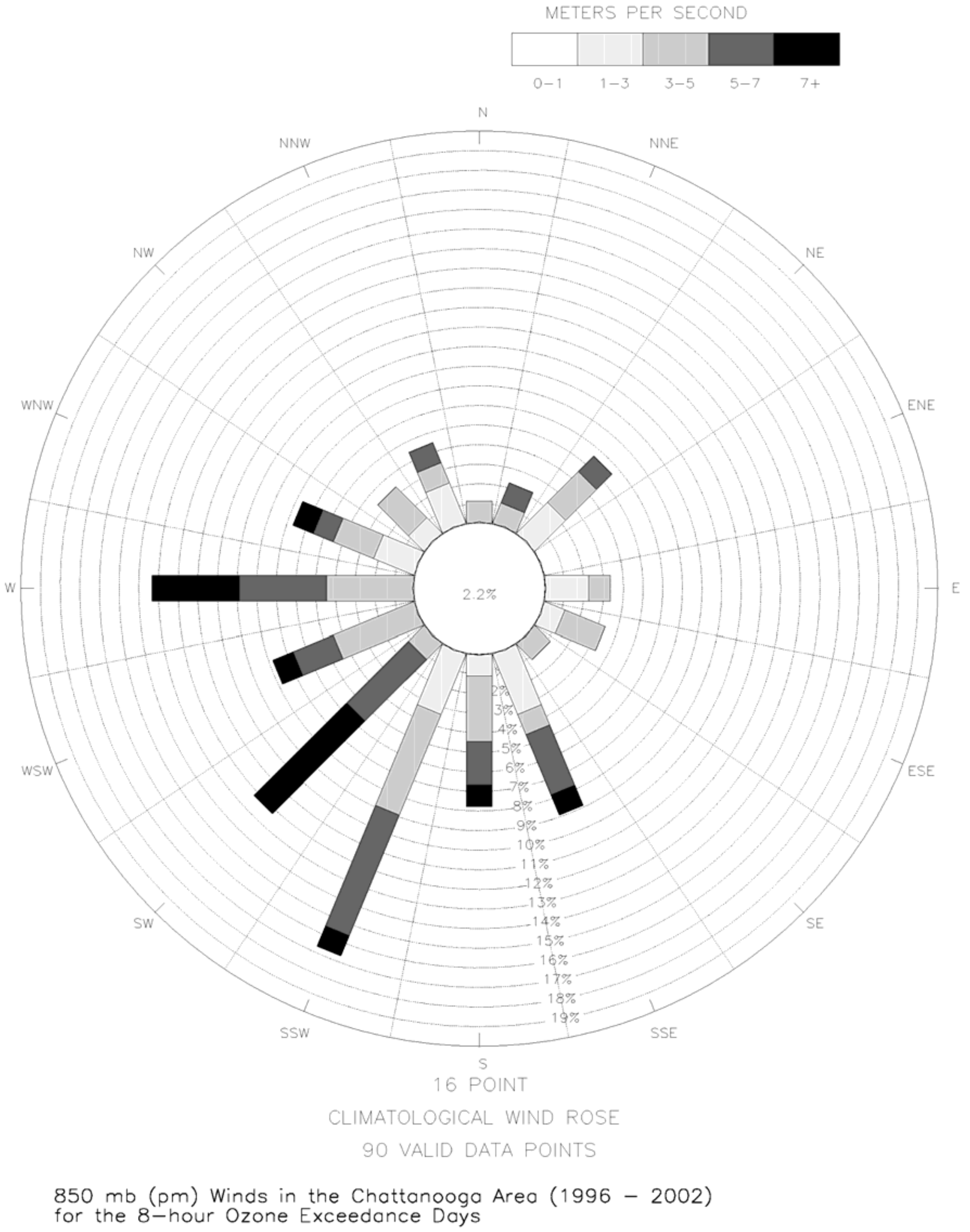


Figure 1-12a.
Winds at the 850 mb Level for the Nashville Sounding
for 8-Hour Ozone Exceedance Days for Chattanooga (1996–2002): 0600 CST



850 mb (am) Winds in the Chattanooga Area (1996 – 2002)
for the 8-hour Ozone Exceedance Days

Figure 1-12b.
Winds at the 850 mb Level for the Nashville Sounding for 8-Hour Ozone Exceedance Days for Chattanooga (1996–2002): 1800 CST



CART-Based Analysis of Meteorological Factors

The factors that influence 8-hour ozone concentrations in the EAC areas were further examined using the results from an application of the Classification and Regression Tree (CART) analysis technique. CART (Brieman et al., 1984; Steinberg and Colla, 1997) is a statistical analysis tool that was used in the ATMOS episode selection analysis to classify all ozone season days for the years 1996-2002 according to meteorological and air quality parameters. The CART analysis software was used to separate the days into different groups (classification "bins"), such that days placed within the same bin exhibit similar meteorological features and ozone concentrations. For example, one bin may include high ozone days associated with low wind speeds, while another may include days with higher wind speeds, with transport indicated. The classification variable (for separating the days into bins) is maximum 8-hour ozone concentration. For ATMOS, CART was applied for the Memphis, Nashville, Knoxville, and Chattanooga areas, but not for the Tri-Cities area.

The results of the CART analysis take the form of an upside-down "tree," with branches representing different values of the input variables, leading to bins representing different values of the classification variable (in this case, 8-hour ozone concentration). Each bin corresponds to a particular set of meteorological and ozone air quality conditions. By examining the parameters associated with each classification category, and specifically the parameters and parameter values used to segregate the days into the various classification bins, the analyst can gain insight into the key differences between exceedance days and non-exceedance days, and the mechanisms contributing to high ozone events. This information on the relationships between air quality and meteorology was used in developing the conceptual description of 8-hour ozone for each of the four areas.

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For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-6a. Table 1-6b considers the input parameter values for the Memphis key (most populated) ozone exceedance bins.

Table 1-6a
Summary of Input Parameters for Each CART Classification Category: Memphis

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Memphis (ppb)	55.3	70.5	80.5	82.8
Yesterday's maximum 8-hour ozone for Little Rock (ppb)	47.5	60.5	68.2	71.2
Surface Meteorological Parameters				
Maximum surface temperature (°F)	80.7	88.6	92.4	93.3
Surface relative humidity at noon (%)	60.9	49.8	45.3	45.2
Surface wind speed from 7-10 LST (ms^{-1})	3.9	2.9	2.3	2.0
Surface wind speed from 10-13 LST (ms^{-1})	4.5	3.7	2.7	1.7
Surface wind speed from 13-16 LST (ms^{-1})	4.6	3.9	3.0	2.1
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	4
Maximum surface pressure (mb)	1018	1018	1018	1017
Upper-Air Meteorological Parameters (Little Rock)				
Yesterday's 850 mb temperature (PM) (°C)	14.9	17.4	18.7	18.9
850 mb temperature (AM) (°C)	14.4	16.7	18.3	18.1
850 mb temperature (PM) (°C)	14.7	17.7	19.4	19.1
Temperature gradient (900 mb to surface; AM) (°C)	-1.39	-0.92	-0.90	-0.74
850 mb relative humidity (AM) (%)	64.1	61.5	57.1	62.1
850 mb relative humidity (PM) (%)	66.8	63.6	60.3	61.7
850 mb geopotential height gradient between Nashville and Little Rock (m)	8.8	6.3	9.6	11.1
Yesterday's 850 mb wind speed (PM) (ms^{-1})	8.2	5.5	4.9	4.1
850 mb wind speed (AM) (ms^{-1})	9.5	6.1	4.8	4.9
850 mb wind speed (PM) (ms^{-1})	8.1	5.7	4.8	4.2
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	1	2
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	3
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	3

A column-by-column comparison of the values in Table 1-6a reveals some clear tendencies in several of the air quality and meteorological parameters.

High ozone in the Memphis area is associated with relatively high ozone on the prior day—in Memphis as well as in Little Rock. Thus, a regional day-to-day build up of ozone is indicated for high ozone days.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Surface wind speeds for all three periods considered (0700 – 1000 LST, 1000 – 1300 LST, and 1300 – 1600 LST) tend to be lower for days with higher ozone concentrations. Surface wind directions do not show a clear tendency across the categories, and tend, on average, to be southerly to westerly during the ozone season days included in the analysis. Surface pressure does not vary much across the classification categories.

The upper-air meteorological parameters (based here on Little Rock) indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is also a tendency for more stable (positive) lapse rates to be associated with higher ozone days. The difference in geopotential height (defined such that a positive number indicates higher heights (pressures) over Nashville) is somewhat correlated with higher ozone concentrations. The average difference is positive (in the range of 9 - 11 m) for the ozone exceedance days indicating higher pressure over Nashville.

Lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations. The biggest jump in the wind speeds occurs between low and moderate ozone concentrations (Categories 1 and 2).

The information in table 1-6a provides a general overview of how average conditions vary across (and potentially lead to) different 8-hour ozone concentration levels for the Memphis area. Within the high ozone categories, there are other key differences among the parameters that result in different types of high ozone events. We have used the CART results to examine these differences.

Only certain of the CART bins are frequently associated with 8-hour ozone exceedances. Of these, we identified those bins with seven or more days (the equivalent of one day per year for the analysis period) as key bins. Table 1-6b considers the input parameter values for the Memphis key exceedance bins.

Table 1-6b.
Summary of Exceedance Bin Characteristics for the Memphis CART Analysis.

Bins 17, 25 and 30 are Category 3 CART bins

	Bin 17	Bin 25	Bin 30
Ozone Parameters			
Yesterday's maximum 8-hour ozone for Memphis (ppb)	80.2	72.7	68.4
Yesterday's maximum 8-hour ozone for Little Rock (ppb)	66.3	62.8	58.4
Surface Meteorological Parameters			
Maximum surface temperature (°F)	92.6	88.7	93.0
Surface relative humidity at noon (%)	43.6	44.2	46.0
Surface wind speed from 7-10 LST (ms^{-1})	2.0	2.1	2.7
Surface wind speed from 10-13 LST (ms^{-1})	2.2	2.6	1.9
Surface wind speed from 13-16 LST (ms^{-1})	2.7	4.6	3.7
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	2	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	3	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	2	3	4
Maximum surface pressure (mb)	1019	1019	1026
Upper-Air Meteorological Parameters (Little Rock)			
Yesterday's 850 mb temperature (PM) (°C)	18.4	18.0	18.2
850 mb temperature (AM) (°C)	17.8	16.7	16.0
850 mb temperature (PM) (°C)	18.9	17.5	16.8
Temperature gradient (900 mb to surface; AM) (°C)	-1.49	-1.34	-1.60
850 mb relative humidity (AM) (%)	62.3	63.3	89.6
850 mb relative humidity (PM) (%)	63.9	64.8	72.8
850 mb geopotential height gradient between Nashville and Little Rock (m)	12.0	4.4	13.5
Yesterday's 850 mb wind speed (PM) (ms^{-1})	4.4	5.3	4.6
850 mb wind speed (AM) (ms^{-1})	4.4	4.6	5.7
850 mb wind speed (PM) (ms^{-1})	3.7	5.4	5.7
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	2	2	4
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	3	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	3	4	4

Bins 17, 25 and 30 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin.

For Bin 17, a distinguishing characteristic is the relatively higher ozone concentrations on the previous day. Thus, for days within this bin, ozone builds up over multiple days. Surface winds tend to be lower than for the other exceedance bins, especially during the morning and late afternoon hours and surface winds tend to exhibit an easterly component. This same pattern is found in the winds aloft. The wind speeds tend to be lower than for the other exceedance bins and the directions are easterly to southerly.

For Bin 25, there is some regional-scale buildup of ozone and conditions are more stable than for the other bins. Surface winds are from the south, and moderate wind speeds characterize the afternoon hours. Weak pressure (height) gradients aloft and greater stability (compared to the other exceedance bins) also characterize the days within this bin. Winds aloft have a westerly component.

Days within Bin 30 are characterized by relatively low ozone on the prior day). Surface winds are from the south during the morning and then from the west during the afternoon hours. The wind speeds are in between those for the other two exceedance bins. High relative humidity aloft (indicative of some cloud cover) also characterizes this bin.

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For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-7a.

Table 1-7b considers the input parameter values for the Nashville key bins.

Table 1-7a.
Summary of Input Parameters for Each CART Classification Category: Nashville

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Nashville (ppb)	56.0	70.1	83.4	92.6
Surface Meteorological Parameters				
Maximum surface temperature (°F)	77.4	85.4	90.6	91.4
Surface relative humidity at noon (%)	62.4	49.7	46.6	41.6
Surface wind speed from 7-10 LST (ms^{-1})	3.2	2.2	1.6	1.0
Surface wind speed from 10-13 LST (ms^{-1})	3.9	3.4	2.4	2.3
Surface wind speed from 13-16 LST (ms^{-1})	4.2	3.7	2.9	2.3
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	1	3
Maximum surface pressure (mb)	1018	1018	1019	1019
Upper-Air Meteorological Parameters (Nashville)				
Yesterday's 850 mb temperature (PM) (°C)	13.5	15.3	17.7	18.0
850 mb temperature (AM) (°C)	12.5	14.8	17.1	17.7
850 mb temperature (PM) (°C)	13.0	15.9	18.6	19.3
Temperature gradient (900 mb to surface; AM) (°C)	-1.06	0.36	1.3	3.3
850 mb relative humidity (AM) (%)	73.3	65.6	62.5	52.2
850 mb relative humidity (PM) (%)	73.2	68.7	65.3	58.4
Change in the 850 mb geopotential height (today – yesterday) (m)	-2.1	1.6	2.3	-1.2
Yesterday's 850 mb wind speed (PM) (ms^{-1})	8.6	5.8	4.2	3.4
850 mb wind speed (AM) (ms^{-1})	9.8	7.1	5.1	4.7
850 mb wind speed (PM) (ms^{-1})	8.4	6.0	4.1	3.6
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	1	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4

High ozone days in the Nashville area are associated with relatively high ozone on the prior day. Thus, a day-to-day build up or carryover of ozone is indicated for high ozone days.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Surface wind speeds for all three periods considered (0700 – 1000 LST, 1000 – 1300 LST, and 1300 – 1600 LST) tend to be lower for days with higher ozone concentrations. Surface wind directions do not show a clear tendency across the categories, and tend, on average, to be southerly to westerly during the ozone season days included in the analysis. Surface pressure does not vary much across the classification categories.

The upper-air meteorological parameters for Nashville indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is a strong positive correlation between the 900 mb to surface temperature difference (an indicator of stability) and ozone category, with very stable conditions indicated for the highest category. Relative humidity aloft, an indicator of cloud cover, decreases with increasing ozone. Lower wind speeds aloft are also aligned with higher 8-hour ozone concentrations. There is no clear tendency in average wind direction aloft (note that this finding is consistent with the wind rose diagrams presented earlier in this section).

Table 1-7b examines the differences among the key exceedance bins and the parameters that result in different types of high ozone events.

Table 1-7b.
Summary of Exceedance Bin Characteristics for the Nashville CART Analysis.

Bins 7, 18, 20, and 34 are Category 3 CART bins and Bin 26 is a Category 4 CART bin.

	Bin 7	Bin 18	Bin 20	Bin 34	Bin 26
Ozone Parameters					
Yesterday's maximum 8-hour ozone for Nashville (ppb)	67.4	65.9	67.1	62.4	91.6
Surface Meteorological Parameters					
Maximum surface temperature (°F)	89.4	89.5	90.0	77.3	92.1
Surface relative humidity at noon (%)	47.1	50.4	51.4	34.3	38.4
Surface wind speed from 7-10 LST (ms^{-1})	1.2	2.0	1.7	3.4	1.0
Surface wind speed from 10-13 LST (ms^{-1})	2.3	4.0	2.8	5.1	2.3
Surface wind speed from 13-16 LST (ms^{-1})	2.9	3.6	3.3	5.3	2.7
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	2	3	3	3	3
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	2	1	4	3	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	2	1	3	2	4
Maximum surface pressure (mb)	1020	1017	1018	1019	1019
Upper-Air Meteorological Parameters (Nashville)					
Yesterday's 850 mb temperature (PM) (°C)	16.7	17.1	17.6	10.3	18.2
850 mb temperature (AM) (°C)	16.7	16.7	16.4	9.6	17.7
850 mb temperature (PM) (°C)	17.9	18.0	18.1	11.5	19.1
Temperature gradient (900 mb to surface; AM) (°C)	0.93	0.71	-0.02	0.63	3.8
850 mb relative humidity (AM) (%)	52.2	56.4	84.4	46.8	55.5
850 mb relative humidity (PM) (%)	68.1	69.2	74.4	51.6	60.8
Change in the 850 mb geopotential height (today – yesterday) (m)	15.2	0.9	3.3	4.5	-4.7
Yesterday's 850 mb wind speed (PM) (ms^{-1})	4.7	5.7	4.6	8.4	3.4
850 mb wind speed (AM) (ms^{-1})	4.9	6.7	5.2	12.0	4.6
850 mb wind speed (PM) (ms^{-1})	3.9	4.7	4.1	11.3	3.8
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	1	4	3	1	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	1	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	3	1	4	3	3

Bins 7, 18, 20, and 34 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. Bind 26 is a Category 4 bin, which corresponds to the highest CART concentration range of greater than 104 ppb. While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin.

Bins 7, 18 and 20 have similar average values for previous day ozone concentration, maximum surface temperature and temperature aloft, surface relative humidity, and stability. There are differences, however, in wind speed and direction, both near the surface and aloft. Surface winds for Bin 7 are from the east and wind speeds are low. For this same bin, the upper air winds are primarily westerly to southerly and wind speeds are moderate. For Bin 18, surface winds are from the north with low to moderate wind speeds. Winds aloft are moderate and westerly to northerly. Bin 20 is characterized by westerly to southerly surface winds, with low to moderate wind speeds (lower than for Bin 18) and moderate westerly winds aloft. Thus, these three bins are likely to capture different source-receptor relationships. Another different among these bins is the average relative humidity aloft – high values for Bin 20 indicate cloud cover. The change in geopotential height is also very different for the three bins.

Bin 34 has very different characteristics overall. Days within this bin are characterized by much lower temperatures and stronger wind speeds that the other exceedance days. Winds aloft are from the north, while surface winds are from the southeast. Days within this bin are representative of transitional period (spring or fall) high ozone days.

Days within Bin 26 (the Category 4 bin) are characterized by very high ozone on the prior day. Temperatures (both the near the surface and aloft) are higher than for the other bins, while relative humidity is low. Stable lapse rates are also indicated and distinguish this bin from the other exceedance bins. Relatively low wind speeds near the surface and aloft and southerly to westerly winds round out the characteristics of this bin.

KNOXVILLE

For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-8a.

Table 1-8b considers the input parameter values for the Knoxville key bins.

Table 1-8a.
Summary of Input Parameters for Each CART Classification Category: Knoxville

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Knoxville (ppb)	62.0	73.5	87.6	99.3
Yesterday's maximum 8-hour ozone for Nashville (ppb)	51.3	66.1	80.3	89.0
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	46.6	60.3	75.0	82.9
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	51.6	69.2	89.1	96.8
Surface Meteorological Parameters				
Maximum surface temperature (°F)	74.5	81.8	88.0	90.1
Surface relative humidity at noon (%)	67.6	58.7	52.9	50.9
Surface wind speed from 7-10 LST (ms^{-1})	2.9	1.9	1.3	0.9
Surface wind speed from 10-13 LST (ms^{-1})	3.9	3.0	2.4	1.4
Surface wind speed from 13-16 LST (ms^{-1})	4.2	3.7	3.1	2.3
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	4	1	1	2
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	4	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	4	4
Maximum surface pressure (mb)	1018	1018	1019	1019
Upper-Air Meteorological Parameters (Nashville)				
Yesterday's 850 mb temperature (PM) (°C)	12.7	14.8	17.6	18.4
850 mb temperature (AM) (°C)	11.5	14.1	16.9	17.8
850 mb temperature (PM) (°C)	11.9	15.2	18.1	18.9
Temperature gradient (900 mb to surface; AM) (°C)	-1.45	-0.11	1.15	2.14
850 mb relative humidity (AM) (%)	73.9	68.7	63.2	60.0
850 mb relative humidity (PM) (%)	72.8	70.6	66.9	68.2
850 mb geopotential height gradient between Greensboro and Nashville (m)	1.9	1.1	-3.9	-4.3
Yesterday's 850 mb wind speed (PM) (ms^{-1})	9.2	6.7	4.5	4.0
850 mb wind speed (AM) (ms^{-1})	10.0	8.1	6.0	5.3
850 mb wind speed (PM) (ms^{-1})	8.3	7.0	5.1	4.5
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	3

High ozone in the Knoxville area is associated with the regional day-to-day build up of ozone.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. For all of these parameters, good correlation is indicated. Surface wind directions do not show a clear tendency across the categories, and tend, on average, to be westerly during the ozone season days included in the analysis. Average surface pressure does not vary across the classification categories.

The upper-air meteorological parameters (based here on Nashville) indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is also a very clear tendency for more stable (positive) lapse rates to be associated with higher ozone days. The difference in geopotential height between Greensboro and Nashville (defined such that a positive number indicates higher heights (pressures) over Greensboro) indicates that high ozone occurs with higher pressure over Nashville.

Lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations.

Table 1-8b examines the differences among the key exceedance bins and the parameters that result in different types of high ozone events.

Table 1-8b.
Summary of Exceedance Bin Characteristics for the Knoxville CART Analysis.

Bins 10, 16, 23, and 29 are Category 3 CART bins and Bin 27 is a Category 4 CART bin.

	Bin 10	Bin 16	Bin 23	Bin 29	Bin 27
Ozone Parameters					
Yesterday's maximum 8-hour ozone for Knoxville (ppb)	74.0	73.4	73.2	68.5	107.6
Yesterday's maximum 8-hour ozone for Nashville (ppb)	73.4	73.7	71.6	65.2	90.0
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	65.6	60.1	60.0	56.7	87.8
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	81.5	80.7	77.4	65.8	99.6
Surface Meteorological Parameters					
Maximum surface temperature (°F)	88.3	88.4	87.9	73.6	90.4
Surface relative humidity at noon (%)	55.9	58.2	62.8	89.2	50.8
Surface wind speed from 7-10 LST (ms^{-1})	1.5	1.6	1.7	2.0	1.0
Surface wind speed from 10-13 LST (ms^{-1})	2.5	2.1	2.7	2.9	1.6
Surface wind speed from 13-16 LST (ms^{-1})	3.1	3.2	3.2	3.2	2.4
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	4	4	2	1	2
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	2	4	4
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	1	4	4
Maximum surface pressure (mb)	1018	1018	1017	1016	1019
Upper-Air Meteorological Parameters (Nashville)					
Yesterday's 850 mb temperature (PM) (°C)	17.4	19.1	18.1	14.7	18.9
850 mb temperature (AM) (°C)	17.5	18.3	16.8	13.6	17.8
850 mb temperature (PM) (°C)	18.3	19.2	18.2	13.7	19.0
Temperature gradient (900 mb to surface; AM) (°C)	0.96	-0.53	-0.66	-1.31	2.3
850 mb relative humidity (AM) (%)	57.6	64.3	89.3	83.1	65.1
850 mb relative humidity (PM) (%)	73.3	71.6	75.6	75.6	67.9
850 mb geopotential height gradient between Greensboro and Nashville (m)	-5.5	-14.1	-3.9	10.6	2.0
Yesterday's 850 mb wind speed (PM) (ms^{-1})	4.6	5.7	5.2	7.7	4.2
850 mb wind speed (AM) (ms^{-1})	6.7	6.4	6.1	10.0	5.8
850 mb wind speed (PM) (ms^{-1})	5.5	4.8	5.2	8.2	5.0
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	1	4	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	4	4

Bins 10, 16, 23 and 29 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. Bin 27 is a Category 4 bin with concentrations greater than 105 ppb (for correctly classified days). While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin. The characteristics of and the differences among the bins is reminiscent of those for Nashville.

Bins 10, 16 and 23 have similar average values for previous day ozone concentration, maximum surface temperature, surface relative humidity, wind speed, and 900 mb to surface lapse rate. Bins 10 and 16 share similar wind characteristics, but Bin 16 shows a greater pressure differential between Greensboro and Nashville, with higher pressure over Nashville and higher 850 mb temperatures (likely the result of being under the influence of a high pressure system). Bins 10 and 23 have similar pressure differential and 850 mb temperatures, but Bin 23 differs from both Bins 10 and 16 in that the surface winds are from the east or north, rather than from the west. Winds aloft also have a southerly component during the afternoon hours, that is not indicate for the other two bins. Thus, these three bins represent three different combinations of two sets of vertical mixing characteristics and two different source-receptor relationships.

Bin 29 has very different characteristics overall. Days within this bin are characterized by lower ozone concentrations on the prior day, much lower temperatures, and stronger wind speeds that the other exceedance days. Winds aloft are from the west, while surface winds are from the north and west. Days within this bin are representative of transitional period (spring or fall) high ozone days.

Days within Bin 27 (the Category 4 bin) are characterized by very high ozone on the prior day. Temperatures (both the near the surface and aloft) are higher than for the other bins, while relative humidity is low. Stable lapse rates are also indicated and distinguish this bin from the other exceedance bins. Relatively low wind speeds near the surface and aloft and predominantly westerly winds round out the characteristics of this bin.

CHATTANOOGA

For four ranges of 8-hour ozone concentration (<65, 65-85, 85-105, and ≥105 ppb, comprising Categories 1 to 4 respectively), the corresponding values for several air quality and meteorological parameters are summarized in Table 1-9a.

Table 1-9b considers the input parameter values for the Chattanooga key bins.

Table 1-9a.
Summary of Input Parameters for Each CART Classification Category: Chattanooga

	Category 1	Category 2	Category 3	Category 4
Ozone Parameters				
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	52.5	68.6	81.9	90.1
Yesterday's maximum 8-hour ozone for Nashville (ppb)	57.4	75.3	84.3	94.7
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	59.6	80.4	91.6	106.4
Yesterday's maximum 8-hour ozone for Birmingham (ppb)	50.9	68.6	82.0	88.0
Surface Meteorological Parameters				
Maximum surface temperature (°F)	80.0	87.8	91.2	92.8
Surface relative humidity at noon (%)	61.8	50.9	46.3	43.3
Surface wind speed from 7-10 LST (ms^{-1})	1.8	1.0	0.6	0.2
Surface wind speed from 10-13 LST (ms^{-1})	3.0	2.3	1.7	1.0
Surface wind speed from 13-16 LST (ms^{-1})	3.6	3.0	2.5	2.6
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	3	3	3	1
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	3
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	4	4	3	4
Maximum surface pressure (mb)	1018	1019	1020	1019
Upper-Air Meteorological Parameters (Nashville)				
Yesterday's 850 mb temperature (PM) (°C)	13.7	16.1	17.6	18.2
850 mb temperature (AM) (°C)	12.7	15.6	17.0	17.9
850 mb temperature (PM) (°C)	13.3	16.8	18.5	19.1
Temperature gradient (900 mb to surface; AM) (°C)	-1.02	0.79	2.11	3.87
850 mb relative humidity (AM) (%)	72.3	63.8	60.6	55.3
850 mb relative humidity (PM) (%)	72.4	67.6	64.5	59.9
850 mb geopotential height gradient between Greensboro and Nashville (m)	1.6	-1.5	-5.1	-1.1
Yesterday's 850 mb wind speed (PM) (ms^{-1})	8.2	5.2	4.2	3.9
850 mb wind speed (AM) (ms^{-1})	9.4	6.6	5.8	5.0
850 mb wind speed (PM) (ms^{-1})	7.8	5.9	4.7	4.9
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	3
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	4	3	4

High ozone in the Chattanooga area is associated with relatively high ozone on the prior day—throughout the region. Thus, day-to-day build up or carryover of ozone is indicated for high ozone days.

The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Surface wind speeds for all three periods considered (0700 – 1000 LST, 1000 – 1300 LST, and 1300 – 1600 LST) tend to be lower for days with higher ozone concentrations. The differences between the Category 3 and 4 averages for surface temperature and wind speed are not as clear as for the other areas. Southerly surface wind directions are associated with the higher ozone categories. Surface pressure does not vary much across the classification categories.

The upper-air meteorological parameters (based here on Nashville) indicate that higher 8-hour ozone concentrations occur with higher 850 mb temperatures. There is a clear a tendency for more stable (positive) lapse rates to be associated with higher ozone days. Lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations. The biggest jump in the wind speeds occurs between low and moderate ozone concentrations (Categories 1 and 2).

Table 1-8b examines the differences among the key exceedance bins and the parameters that result in different types of high ozone events.

Table 1-9b.
Summary of Exceedance Bin Characteristics for the Chattanooga CART Analysis.

Bins 23 and 33 are Category 3 CART bins and Bin 26 is a Category 4 CART bin.

	Bin 23	Bin 33	Bin 26
Ozone Parameters			
Yesterday's maximum 8-hour ozone for Chattanooga (ppb)	84.5	92.3	89.0
Yesterday's maximum 8-hour ozone for Nashville (ppb)	78.7	94.8	89.2
Yesterday's maximum 8-hour ozone for Atlanta (ppb)	86.9	112.5	90.6
Yesterday's maximum 8-hour ozone for Birmingham (ppb)	81.6	91.6	80.7
Surface Meteorological Parameters			
Maximum surface temperature (°F)	87.9	94.2	92.5
Surface relative humidity at noon (%)	50.9	44.1	43.1
Surface wind speed from 7-10 LST (ms^{-1})	0.5	0.1	0.6
Surface wind speed from 10-13 LST (ms^{-1})	1.4	1.3	1.9
Surface wind speed from 13-16 LST (ms^{-1})	2.1	3.0	2.9
Surface wind direction from 7-10 LST (1=N, 2=E, 3=S, 4=W)	4	2	4
Surface wind direction from 10-13 LST (1=N, 2=E, 3=S, 4=W)	3	4	3
Surface wind direction from 13-16 LST (1=N, 2=E, 3=S, 4=W)	3	4	4
Maximum surface pressure (mb)	1020	1018	1020
Upper-Air Meteorological Parameters (Nashville)			
Yesterday's 850 mb temperature (PM) (°C)	15.2	19.0	18.9
850 mb temperature (AM) (°C)	15.2	18.8	17.6
850 mb temperature (PM) (°C)	16.6	19.8	18.8
Temperature gradient (900 mb to surface; AM) (°C)	2.22	4.26	1.82
850 mb relative humidity (AM) (%)	64.4	55.5	63.9
850 mb relative humidity (PM) (%)	66.5	58.6	61.4
850 mb geopotential height gradient between Greensboro and Nashville (m)	-3.2	-3.8	-10.1
Yesterday's 850 mb wind speed (PM) (ms^{-1})	5.0	4.0	4.0
850 mb wind speed (AM) (ms^{-1})	6.7	5.2	6.0
850 mb wind speed (PM) (ms^{-1})	5.4	4.9	4.7
Yesterday's 850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	4	3	2
850 mb wind direction (AM) (1=N, 2 = E, 3=S, 4=W)	4	4	4
850 mb wind direction (PM) (1=N, 2 = E, 3=S, 4=W)	3	4	4

Bins 23 and 33 are Category 3 bins and have average maximum 8-hour ozone concentrations greater than 84 ppb. Bin 26 is a Category 4 bin, with higher ozone concentrations. While many of the characteristics are similar for the exceedance bins, there are some differences. These provide insight into the factors influencing the exceedance days within each bin.

Bin 23 is described by moderate ozone levels on the prior day, very light surface winds from the south, and moderate winds aloft from the west and south.

Interestingly, Bin 33, a Category 3 bin, is associated with the highest prior day average ozone concentrations among the three bins. It also exhibits the highest surface temperatures and the greatest stability. Surface winds tend to be lower than for the other exceedance bins, especially during the morning and early afternoon hours and are primarily westerly. Moderate upper-air winds, also from the west characterize this bin, but with winds from the south on the previous evening.

For Bin 26 falls between these two bins, considering the average values of most of the parameters. The height difference from Greensboro to Nashville is more negative, indicating a stronger west to east pressure gradient over the area. Easterly winds aloft on the previous evening and southerly winds near the surface on during the mid-afternoon hours may also contribute to the differences in observed ozone for days within this bin.

Emissions Influencing Ozone Within the ATMOS Region

All of the ATMOS EAC areas are located in the mid-South portion of the continental U.S. Regional-scale modeling results performed by EPA (e.g., EPA, 2004) as well as the ATMOS regional modeling results presented later in this report indicate that ozone concentrations in this region are influenced by ozone and precursor transport from outside of the region. Emission source areas to the north, east, west, and south including major metropolitan areas to the northeast, north, northwest, southwest, and south of the domain ensure the potential for a contribution from regional-scale transport. As indicated in a previous section, ozone episodes are associated with a variety of upper-level wind directions and, thus, a range of potential transport conditions.

Within the region, there are numerous sources of NO_x, VOC, and CO emissions that likely also contribute to ozone production in the region and affect one or more of the EAC areas. Ozone precursor emissions from anthropogenic sources are the result of activity associated with transportation (both interstate and local), electrical generation, manufacturing/industry, and other population-related sources (household products, home heating, recreational equipment, etc.). A number of electrical generation stations, chemical and petrochemical industry sources, and gas compressor stations are located in the region. In addition, other sources such as barge and commercial shipping traffic along the Mississippi River, and furniture manufacturing facilities contribute to the emissions totals in specific portions of the region.

Plots of the anthropogenic NO_x and VOC emissions by source category are presented for each EAC region in Figure 1-13. In general, large sources of NO_x include electric generation, other industrial boilers, and mobile sources. The anthropogenic VOC emissions originate from a variety of area, industrial, and transportation-related sources.

Figure 1-13a.
Weekday Anthropogenic Emissions (tpd) in the Memphis EAC Area
by Species and Source Category

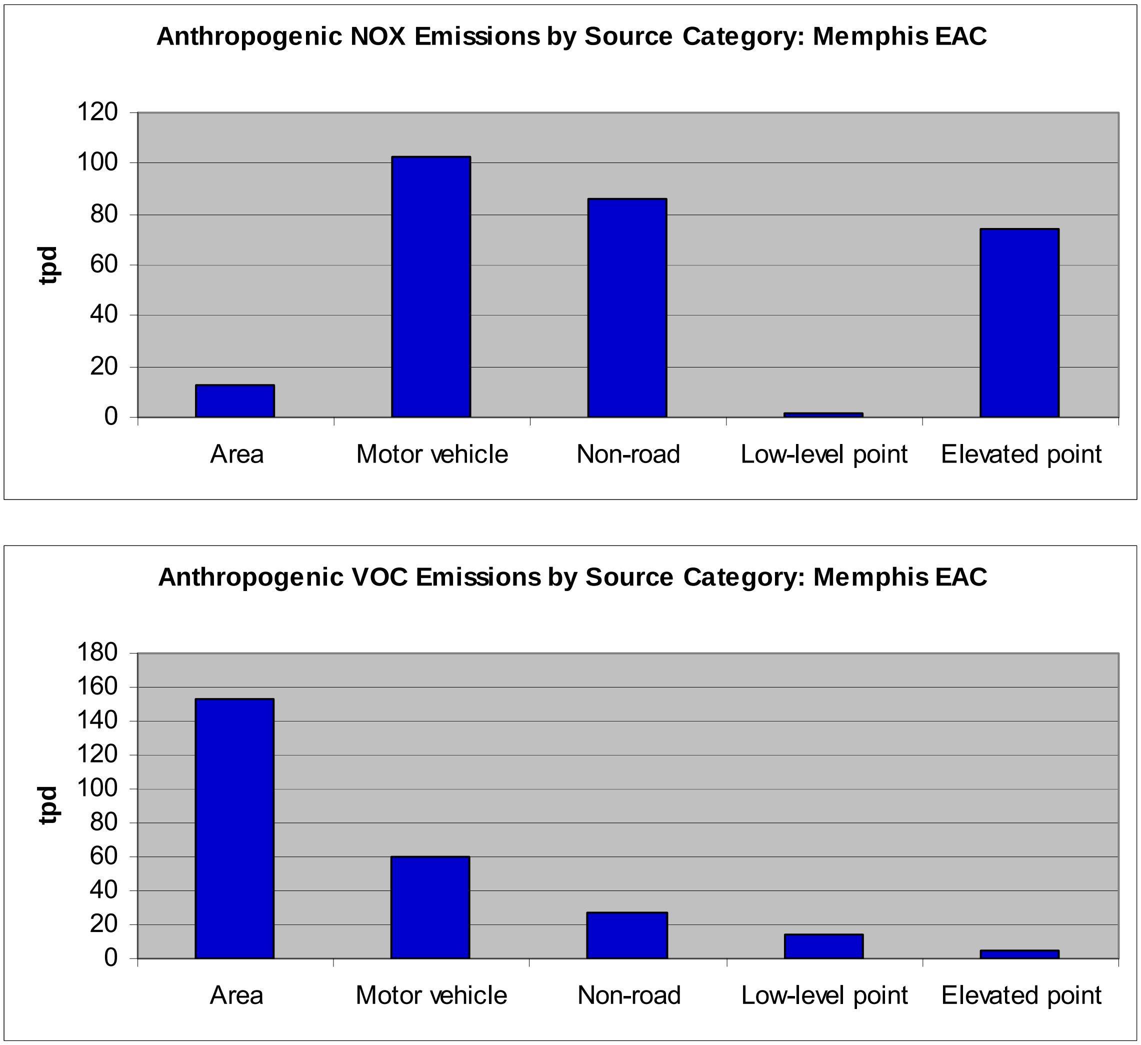
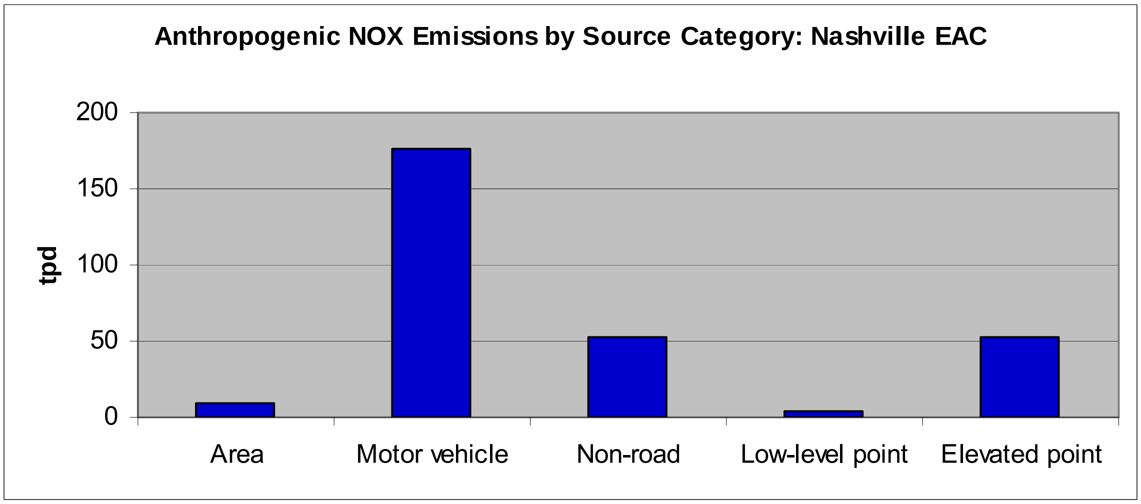


Figure 1-13b.
Weekday Anthropogenic Emissions (tpd) in the Nashville EAC Area by Species and Source Category



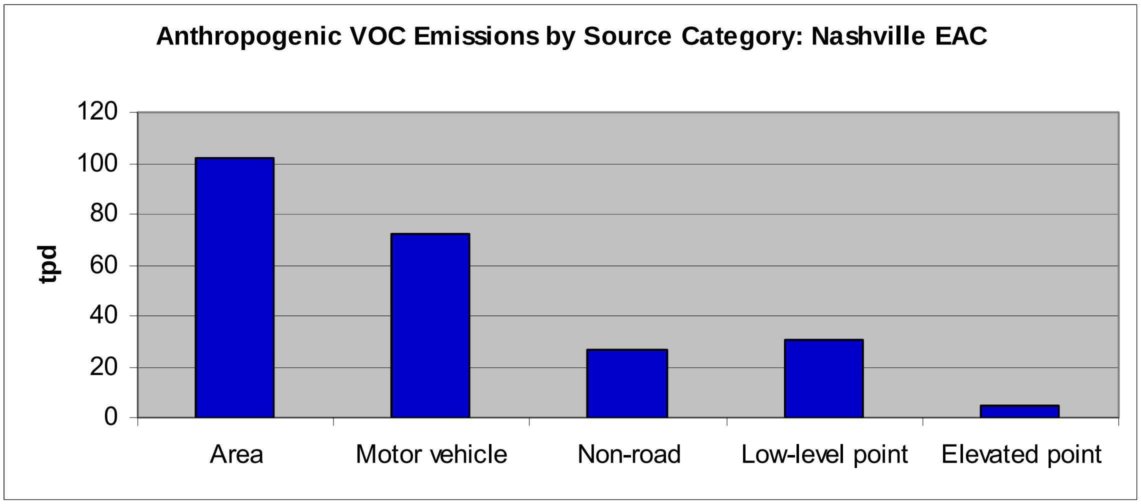
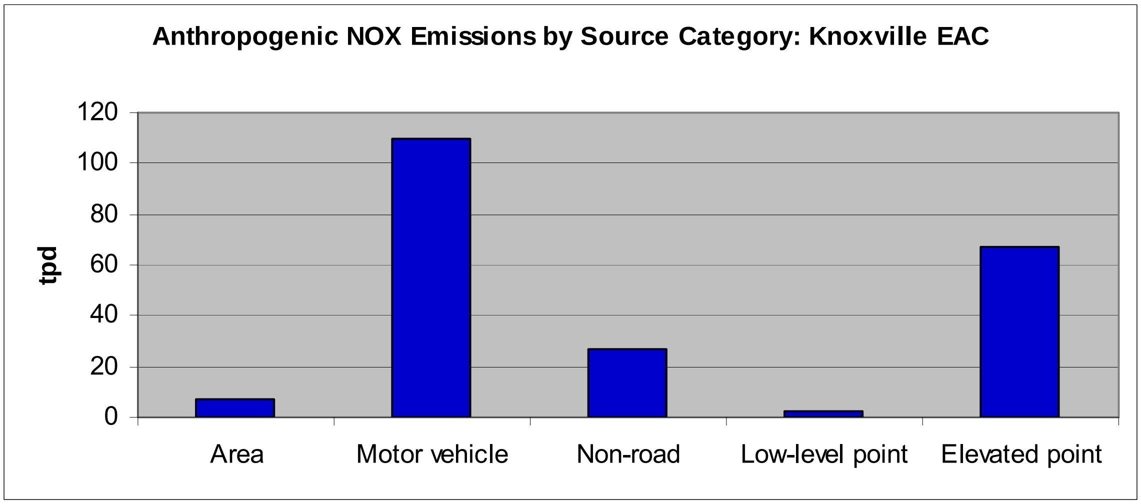


Figure 1-13c.
Weekday Anthropogenic Emissions (tpd) in the Knoxville EAC Area by Species and Source Category



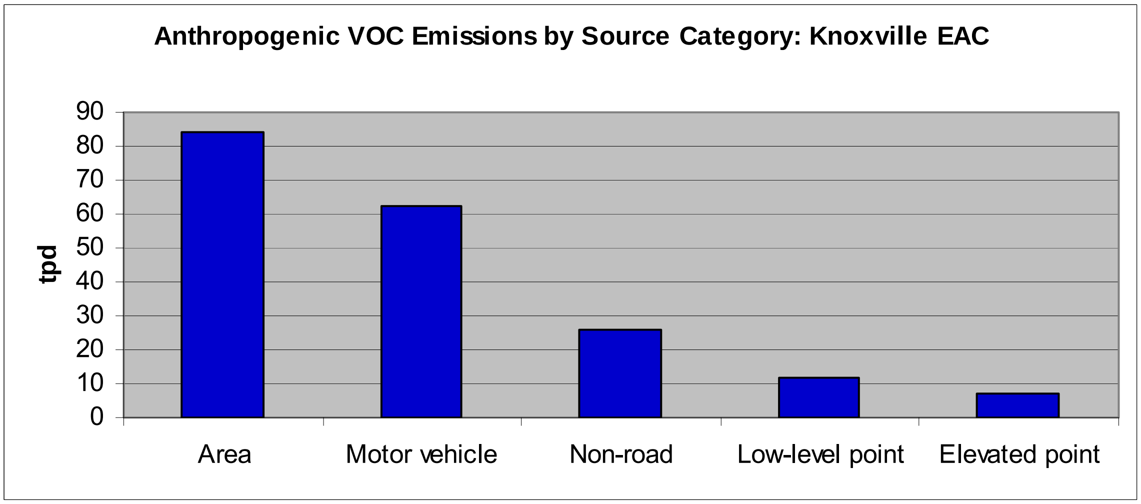
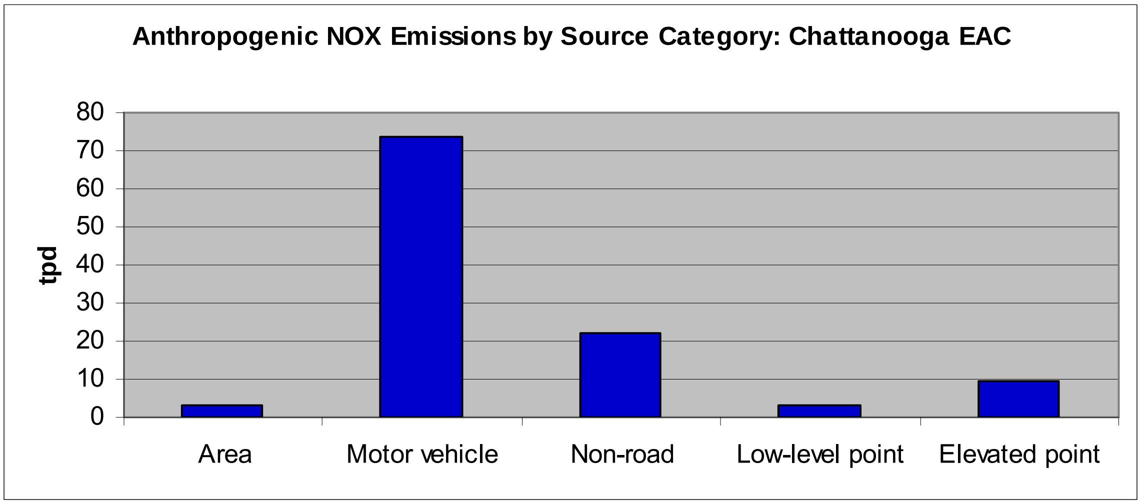


Figure 1-13d.
Weekday Anthropogenic Emissions (tpd) in the Chattanooga EAC Area by Species and Source Category



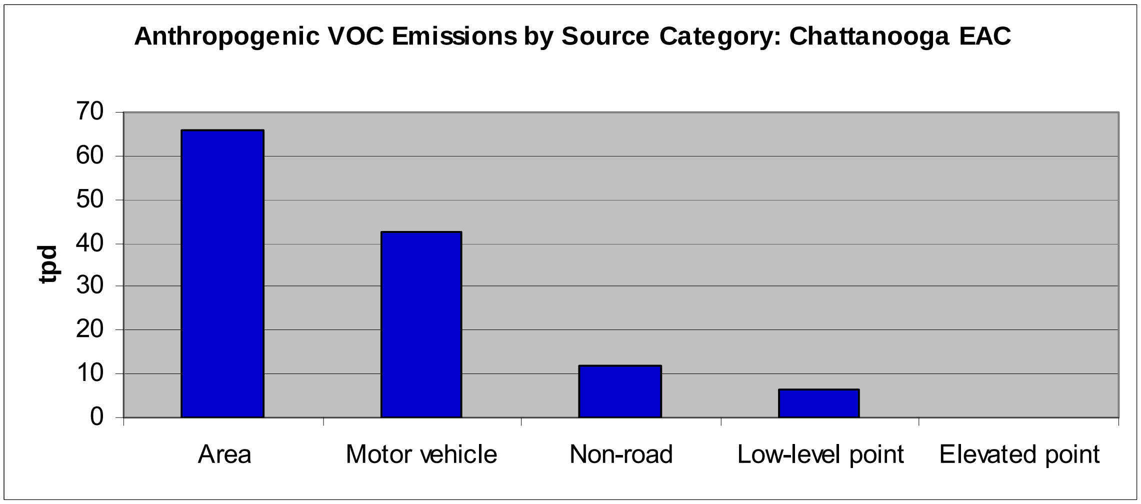
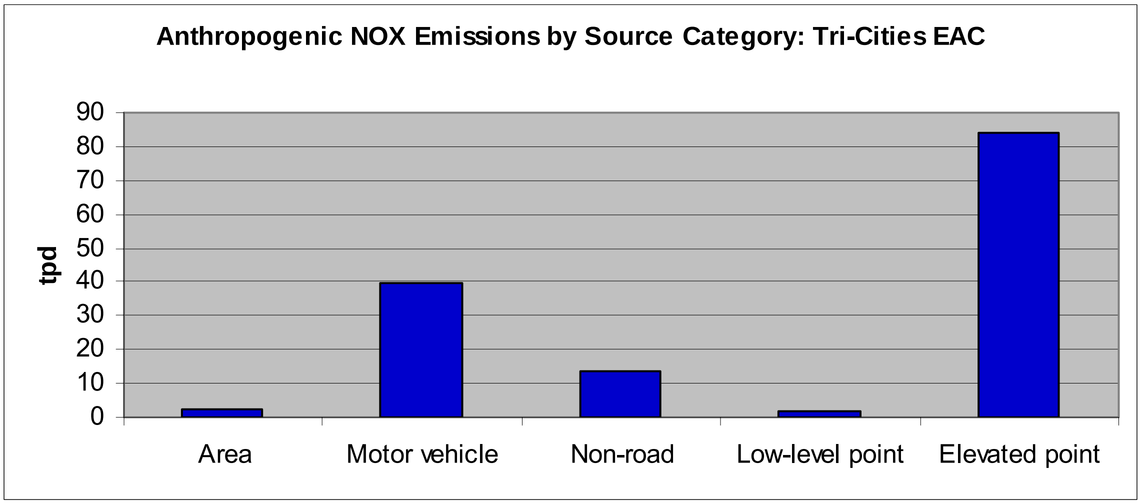
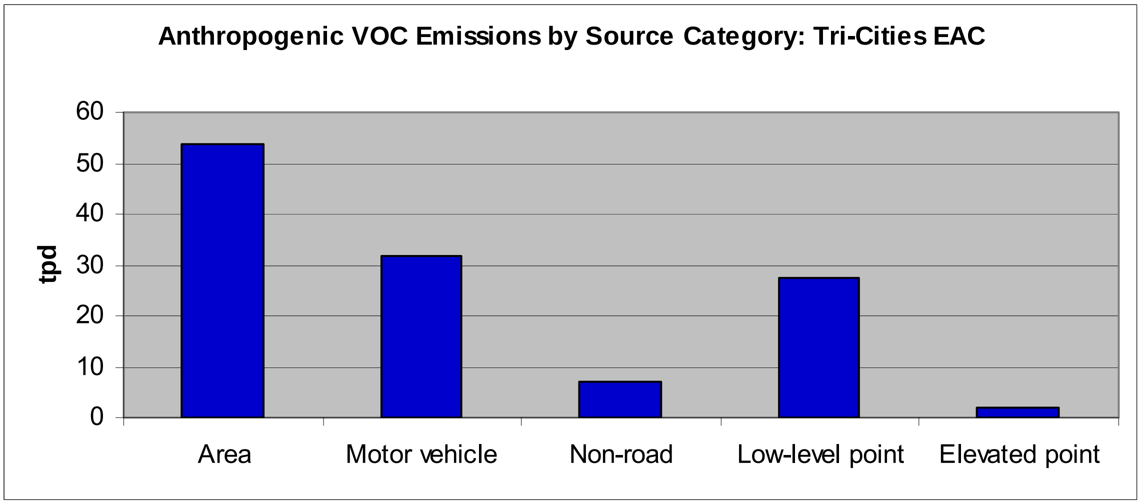


Figure 1-13e.
Weekday Anthropogenic Emissions (tpd) in the Tri-Cities EAC Area
by Species and Source Category





In addition to anthropogenic sources, the ATMOS region has a high percentage of VOC emissions from biogenic sources, which are emitted from the region’s extensive hardwood and softwood forests, other natural vegetation and from various crops that are raised in the region. The biogenic emissions in the ATMOS region make up about 90 percent of the total VOC emissions on a typical summer day. The percentage of the total VOC emissions from biogenic sources on a typical summer day is somewhat less for the EAC areas and is 71% for the Memphis area, 78% for the Nashville area, 79% for the Knoxville area (which includes portions of the GSM National Park), 86% for the Chattanooga area, and 79% for the Tri-Cities area.

There is some slight variation in emissions day to day during a typical summer, with some decreases in mobile emissions expected on weekend days and corresponding increases in non-road emissions, likely associated with the usage of recreational equipment. The anthropogenic and biogenic precursor emissions are affected by local and regional weather conditions, which affect the formation, transport, and deposition characteristics of ozone concentrations within the region.

Summary Conceptual Description of 8-Hour Ozone

In this section, we have begun to develop, through analysis of observed data and emission inventory information, a conceptual description of 8-hour ozone for the ATMOS region and the five EAC areas of interest.

Examination of 8-hour ozone data for the EAC areas for the 1996-2002 analysis period shows that

- All areas had some exceedance days, and the Memphis, Nashville, and Knoxville areas had 90th percentile values greater than 84 ppb.
- The Knoxville area experienced the greatest number of exceedance days (nearly as many as Atlanta).
- July and August are the peak ozone months for most areas, although Nashville and the Tri-Cities areas had more exceedance in June than in July.
- The years 1997, 1998 and 1999 were high ozone years for most of the areas; in contrast, ozone concentrations tended to be lowest for 2001.
- Same-day correlations among the areas of interest suggest that 8-hour ozone concentrations are subregionally correlated, presumably as the neighboring areas experience similar meteorological conditions.

Memphis

A more detailed analysis of the observed ozone data and meteorological conditions for the Memphis area provided some key findings.

Analysis of the available ozone data reveals that:

- All sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period. The Edmund Orgill Park site has the most number of exceedances and the DeSoto Co. site has the fewest. Currently the Marion site has the highest design value.
- The average diurnal profiles for ozone exceedance days vary among the sites. The Frayser site, an urban site, is characterized by a typical diurnal profile with a peak concentration during the midday hours. Later peaks at the other sites indicate some influence from ozone transport.

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- There is no one upper-air wind pattern associated with exceedances in the Memphis area. When only high ozone days in the Memphis area are considered, there is a discernable shift to more northerly and easterly components during the time of the morning sounding. The percentage of time that the winds are from the north, northeast, south, and southeast is greater for ozone exceedance days than for all ozone season days.

Other meteorological factors also contribute to the incidence of high ozone in the Memphis area. Results from an application of the Classification and Regression Tree (CART) tool enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. Key findings include:

- Yesterday's maximum 8-hour ozone value is an important indicator of the 8-hour ozone concentration. This implies the buildup or recirculation of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high pressure to the east, high 850 mb temperatures, stable lapse rates, lower wind speed, and a tendency for southerly wind directions aloft (compared to lower ozone concentration days).

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day's maximum ozone concentration.
- Stability characteristics.
- Surface wind speed and direction.
- Wind direction aloft.
- Cloud cover.

The differences in wind speed and wind direction, in particular, highlight that differences in exceedance meteorological and recirculation conditions can lead to different source-receptor and transport relationships.

Nashville

A more detailed analysis of the observed ozone data and meteorological conditions for the Nashville area provided some key findings.

Analysis of the available ozone data reveals that:

- All sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period, but the most number of exceedances by far were recorded at the Rockland Rd. monitoring site. This site also has the highest design value for the Nashville EAC area.
- The average diurnal profiles for ozone exceedance days are generally characterized by a typical diurnal profile with a peak concentration during the midday hours.

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- Similar to Memphis, the winds exhibit a range of wind directions on ozone exceedance days for Nashville, with a tendency for more southerly and easterly wind components on the exceedance days.

Other meteorological factors also contribute to the incidence of high ozone in the Nashville area. Results from an application of CART enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. Key findings include:

- Yesterday's maximum 8-hour ozone value is an important indicator of the 8-hour ozone concentration. This implies the buildup or recirculation of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures, stable lapse rates, clear skies, and lower wind speeds aloft.

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day's maximum ozone concentration.
- Stability characteristics.
- Surface wind speed and direction.
- Wind direction aloft.
- Cloud cover.
- Geopotential height tendency.

The differences in wind speed and wind direction, in particular, highlight that differences in exceedance meteorological and recirculation conditions can lead to different source-receptor and transport relationships. One of the exceedance bins is characterized by much lower temperatures and higher wind speeds and is representative of transitional period (spring or fall) high ozone days. Another of the bins is characterized by very high ozone on the prior day and otherwise very ozone conducive meteorological conditions. Days within this bin have the highest overall ozone concentrations.

Knoxville

A more detailed analysis of the observed ozone data and meteorological conditions for the Knoxville area provided some key findings.

Analysis of the available ozone data reveals that:

- All sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period. Several of the urban and GSM sites have more than 100 exceedance days and average annual maximum ozone concentrations greater than 100 ppb.
- The average diurnal profiles for ozone exceedance days are generally characterized by a typical diurnal profile with a peak concentration during the midday hours.
- Distinctly different diurnal profiles characterize sites located in the greater Knoxville area and in the GSM. The more urban sites show a mid-day peak. The elevated GSM sites show very flat diurnal profiles. The lack of variation throughout the day and specifically the lack of a distinct daytime peak indicate that ozone is transported into this area throughout the day (and not specifically formed during the daytime hours).

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- For exceedance days in the Knoxville area, the upper-level winds suggest a greater tendency for winds aloft to have a southerly component during high ozone days, especially at the time of the evening soundings. Westerly to southwesterly winds dominate the wind roses for the Knoxville area ozone exceedance days.

Other meteorological factors also contribute to the incidence of high ozone in the Knoxville area. Results from an application of CART enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. The results indicate that:

- High ozone in the Knoxville area is associated with the regional day-to-day build up of ozone.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures, stable lapse rates, high pressure to the west, and lower wind speeds and southerly wind directions aloft.

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day’s maximum ozone concentration.
- Stability and vertical mixing characteristics.
- Surface wind speed and direction.
- Wind direction aloft.
- Cloud cover.
- Upper-level pressure/height patterns.

Three of the key exceedance bins share many similar characteristic and differ primarily with regard to wind and vertical mixing parameters. As for Nashville, one of the exceedance bins is characterized by much lower temperatures and higher wind speeds and is representative of transitional period (spring or fall) high ozone days. Another of the bins is characterized by very high ozone on the prior day and otherwise very ozone conducive meteorological conditions. Days within this bin have the highest overall ozone concentrations.

Chattanooga

A more detailed analysis of the observed ozone data and meteorological conditions for the Chattanooga area provided some key findings.

Analysis of the available ozone data reveals that:

- Both long-term sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period, and experience high ozone about equally.
- The average diurnal profiles for ozone exceedance days are characterized by a typical diurnal profile with a peak concentration during the midday hours.

Comparison of the wind patterns for exceedance and non-exceedance days indicates that:

- Westerly to southerly winds are most common for exceedances days in the Chattanooga. Compared to the full ozone season, there is a greater tendency for winds from the south on ozone exceedance days.

Other meteorological factors also contribute to the incidence of high ozone in the Chattanooga area. Results from an application of the Classification and Regression Tree (CART) tool enabled an examination of the relative importance of the air quality and meteorological variables in segregating the days according to ozone concentration. Key findings include:

- High ozone in the Chattanooga area is associated with relatively high ozone on the prior day—throughout the region. Thus, day-to-day build up or carryover of ozone is indicated for high ozone days.
- The surface meteorological parameters indicate a correlation between higher ozone concentrations and higher temperatures, lower relative humidity, and lower wind speeds. Southerly surface wind directions are associated with the higher ozone categories.
- The upper-air meteorological parameters indicate that higher 8-hour ozone concentrations occur with high 850 mb temperatures and stable lapse rates. Compared to all ozone season days, lower wind speeds and a tendency for more southerly wind directions aloft are also aligned with higher 8-hour ozone concentrations.

Differences among the exceedance days suggest that the high ozone days comprise a variety of conditions, especially with respect to:

- Previous day’s maximum ozone concentration.
- Surface and upper-air wind direction.
- Geopotential height/pressure patterns.

The combined differences in wind direction and regional ozone concentrations on the prior day, especially for the Atlanta area, provide variations on the transport component of 8-hour ozone for the exceedance bins.

Tri-Cities

A more detailed analysis of the observed ozone data for the Tri-Cities area provided some key findings.

Analysis of the available ozone data reveals that:

- Both long-term sites recorded exceedances of the 8-hour ozone NAAQS during the 1996-2002 analysis period, and the Kingsport site tends to slightly higher ozone.
- The average diurnal profiles for ozone exceedance days are characterized by a typical diurnal profile with a peak concentration during the midday hours.

A detailed analysis of the meteorological conditions associated with high ozone in the Tri-Cities area was not performed, but it is expected, especially given the similarities between the results for Nashville and Knoxville and the geographical similarities to Knoxville, that the meteorological conditions associated with ozone exceedances in the Tri-Cities area are similar to those for Knoxville.

Episode Selection/Simulation Periods

Episode selection for the ATMOS EAC modeling/analysis was based on a review of historical meteorological and air quality data with emphasis on representing typical ozone exceedance events in the areas of interest. The episode selection was conducted in stages. First, in 2000, a primary multi-day simulation period was selected for the ATMOS modeling. This period was selected to optimize the representation of typical 8-hour ozone exceedance conditions and concentration levels for all of the areas of interest (which, for ATMOS, included all of the EAC areas with the exception of the Tri-Cities EAC area). A second multi-day simulation period was added in 2003, to enhance the robustness of the EAC modeling by including additional days and types of exceedance conditions. This episode was specifically selected to complement the first ATMOS simulation period in terms of representing different key meteorological conditions and providing additional exceedance days for certain areas. Finally, a third multi-day simulation period was added in 2004, as modeling databases from the State of Arkansas became available for use in the ATMOS study. This third simulation period includes additional exceedance days for all of the areas of interest and some variation on the exceedance meteorological conditions for certain of the areas. It provides important additional exceedance days for the Tri-Cities area.

Overall, the primary objective of the episode selection was to identify and assemble suitable periods for analysis and modeling related to the 8-hour ozone NAAQS for the ATMOS EAC areas of interest. Important considerations in selecting (and adding to) the episodes include (1) representing the range of meteorological conditions that accompany ozone exceedances, (2) representing the ozone concentration levels that characterize the nonattainment problem (and result in the designation of nonattainment), and (3) accounting for the frequency of occurrence of the exceedance meteorological regimes (to avoid using results from infrequent or extreme events to guide the decision making process).

The approach to episode selection is consistent with current (draft) EPA guidance (EPA, 1999a) on episode selection for 8-hour ozone attainment demonstration modeling. In this guidance, EPA lists the following as the most important criteria for choosing episodes:

- Monitored ozone concentrations comparable to the severity as implied by the form of the NAAQS.
- Representation of a variety of meteorological conditions observed to correspond to monitored ozone concentrations of the severity implied by the form of the NAAQS.
- Data availability.
- Selection of a sufficient number of days so that the modeled attainment test is based on several days.

EPA also provides several additional (secondary) criteria for episode selection:

- Episodes used in previous modeling exercises.
- Episodes drawn from the period on which the current design value is based.
- Observed concentrations are “close” to the design value for as many sites as possible.

- Episodes are appropriate for as many of the nonattainment areas as possible (when several areas are being modeled simultaneously).
- Episodes include weekend days.

Overview of the Methodology

The methodology used for selection of the first and second simulation periods was based on that developed for a similar study by Deuel and Douglas (1998) and used for the several other modeling studies including the Gulf Coast Ozone Study (GCOS) (Douglas et al. 2000). In selecting the first episode, days within the period 1990 to 1999 were considered. In selecting the second episode, days within the period 1996 to 2002 were considered. In both cases, the days were classified according to meteorological and air quality parameters using the Classification and Regression Tree (CART) analysis technique.

CART was applied separately for four of the five EAC areas: Memphis, Nashville, Knoxville, and Chattanooga. The results were reviewed with respect to classification accuracy and physical reasonableness. Once acceptable classification results were obtained, the information provided by CART was used to guide the episode selection.

For each area, the frequency of occurrence of ozone exceedances for each classification type was then determined. Only certain of the CART bins are associated with 8-hour ozone exceedances. To use the CART results to guide the episode selection analysis, we identified the exceedance bins with the most number of correctly classified days and designated these as key or primary bins. Specifically, we designated the CART bins with at least an average of one exceedance day per year for the analysis period as key exceedance bins.

An optimization procedure was applied to the selection of multi-day episodes for maximum achievement of the specified episode selection criteria (as outlined above) for as many areas as possible. Finally, a more detailed analysis of the episode days with respect to local meteorological conditions was conducted.

This integrated, multi-variate approach to episode selection ensures that the selected episodes represent the combined meteorological and air quality conditions associated with frequently occurring 8-hour ozone events.

The CART results also provide the basis for the development of an integrated “conceptual model” of 8-hour ozone. By examining the parameters associated with each classification category, and specifically the parameters and parameter values used to segregate the days into the various classification bins we can gain insight into the key differences between exceedance days and non-exceedance days, and the mechanisms contributing to high ozone events. We used this information on the relationships between air quality and meteorology to develop a conceptual model of 8-hour ozone for each area of interest, as presented in the previous section.

CART Application Procedures and Results

CART was applied for the period 1990-1999 and then, later in the course of the study, for the period 1996-2002. Here we present only the results from the more recent CART analysis in our discussion of the procedures and results. The procedures were identical for both analyses, the CART analysis results were comparable in both their content and accuracy, and, in both cases, the first (ATMOS) simulation period was easily identified as a very good candidate for regional scale modeling of the ATMOS region.

CART was applied separately for four of the five EAC areas: Memphis, Nashville, Knoxville, and Chattanooga. The classification (or dependent) variable for application of CART is daily maximum 8-hour average ozone concentration for the area of interest (the maximum of all sites within the area). This variable was assigned a value of 1 to 4, corresponding to a computed maximum 8-hour average ozone concentration of less than 65, 65 to less than 85, 85 to less than 105, or greater than or equal to 105 ppb. Thus, Categories 3 and 4 are the exceedance categories.

The ozone data were obtained from the U.S. EPA Aerometric Information and Retrieval System (AIRS). Note that sites with partial ozone records (relative to the analysis period) were not used in the CART analysis. This was done to avoid a changing basis for defining the maximum ozone concentration (and location), which could make it more difficult for CART to group/classify the days.

Surface and upper air meteorological data for sites representative of the regions of interest were obtained from the National Climatic Data Center (NCDC). Meteorological monitoring sites were assigned to each of the areas based on location and other geographical considerations. The sites are listed in Table 1-10.

In applying CART, it is necessary to construct a database of independent variables such that this relationship can be identified. The database that was used for each area consisted of only data for days for which a valid current-day daily maximum 8-hour ozone concentration for the area (this is the classification variable) was available. The air quality variables used in the CART are defined in Table 1-11. The surface meteorological variables used in the CART analysis are defined in Table 1-12, and the upper-air meteorological variables used the analysis are defined in Table 1-13.

Table 1-10.
Meteorological Monitoring Sites Used for CART for Each Area

CART Analysis Area	Surface Met Monitoring Site	Primary Upper-Air Met Monitoring Site
Memphis	Memphis	Little Rock
Nashville	Nashville	Nashville
Knoxville	Knoxville	Nashville
Chattanooga	Chattanooga	Nashville

Table 1-11.
Air Quality Variables Included in the CART Analysis

Variable Name	Description
(area)_8	*The classification variable*: a value of 1, 2, 3, or 4 depending on whether the maximum 8-hour ozone concentration over all sites in the urban area was <65, [65,85), [85,105), or ≥ 105 ppb.
ymx8o3_(area)	Yesterday's maximum 8-hour average ozone concentration in a given area.

Table 1-12.
Surface Meteorological Variables Included in the CART Analysis

Variable names are generic and vary slightly for each monitoring site.

Variable Name	Description
pmax	Maximum sea level pressure on the present day.
rh12	Surface relative humidity at noon.
tmax	Maximum surface temperature (ºC) for the present day.
wb710	Average surface wind direction bin from 0700 to 1000 LST (1=N, 2=E, 3=S, 4=W, 5=Calm[2]).
wb1013	Average surface wind direction bin from 1000 to 1300 LST.
wb1316	Average surface wind direction bin from 1300 to 1600 LST.
ws710	Average surface wind speed ms^{-1} from 0700 to 1000 LST.
ws1013	Average surface wind speed ms^{-1} from 1000 to 1300 LST.
ws1316	Average surface wind speed ms^{-1} from 1300 to 1600 LST.

Table 1-13.
Upper-Air Meteorological Variables Included in the CART Analysis

Variable names are generic and vary slightly for each monitoring site.

Variable Name	Description
wb85am	Wind direction bin value of 1 through 5, indicating that the wind direction corresponding to the morning sounding was from (in degrees) [315, 45), [45, 135),[135, 225), [225, 315), or calm[4] respectively.
wb85pm	Identical to above, but for the afternoons sounding.
ywb85pm	Identical to above, but for the previous afternoon's sounding.
ws85am	Upper-air 850 mb wind speed corresponding to the morning sounding.
ws85pm	Upper-air 850 mb wind speed corresponding to the afternoon sounding.
yws85pm	Upper-air 850 mb wind speed corresponding to the previous afternoon's sounding.
t85am	Upper-air 850 mb temperature corresponding to the morning sounding on the current day.
t85pm	Upper-air 850 mb temperature corresponding to the afternoon sounding on the current day.
y85pm	Upper-air 850 mb temperature corresponding to the afternoon sounding on the previous day.
rh85am	Upper-air 850 mb relative humidity corresponding to the morning sounding on the current day.
rh85pm	Upper-air 850 mb relative humidity corresponding to the afternoon sounding on the current day.
htthty	Difference between today's value and the value yesterday of the average of the morning and afternoon sounding heights above sea level of the 850 mb surface.
ht(s1)_(s2)85	The difference between the average of the morning and afternoon sounding heights about the level of the 850 mb surface at site #1 and site #2.
delt900	Difference between the temperature at 900 mb and the surface using the morning temperature sounding data.

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[2] Calm winds are reported as a wind speed of zero.

Classification accuracy is summarized in Tables 1-14a through d, for each of the four areas. For Memphis, 78 percent of the days are correctly classified, and 73 percent of the exceedance days are correctly classified in exceedance bins. For Nashville, 79 percent of the days are correctly classified, and 82 percent of the exceedance days are correctly classified in exceedance bins. For Knoxville, these same values are 73 and 78 percent for all days and exceedance days, respectively. For Chattanooga, classification accuracy is 83 percent for all days and 80 percent for exceedance days. Most days that are misclassified are placed into a bin of a neighboring category. In several cases, the exceedance bins contain days that did not report observed exceedances. One possible reason for this is that while the meteorological conditions may have been conducive to ozone, high ozone may not have been measured at one of the monitoring sites. Our goal in applying CART (based on prior applications) was 80 percent accuracy for both all days and exceedance days. This was met or nearly met for all four areas.

Table 1-14a.
Summary of Classification Accuracy for the Memphis CART Analysis

		True Class			
		1	2	3	4
C	1	596	68	2	0
A	2	131	299	38	0
R	3	3	25	86	0
T	4	0	2	5	16

Table 1–14b.
Summary of Classification Accuracy for Nashville CART Analysis

		True Class			
		1	2	3	4
C	1	597	102	1	0
A	2	70	289	28	0
R	3	6	50	108	0
T	4	0	5	10	15

Table 1–14c.
Summary of Classification Accuracy for the Knoxville CART Analysis

		True Class			
		1	2	3	4
C	1	311	92	2	0
A	2	106	428	58	0
R	3	3	63	152	1
T	4	1	6	19	39

Table 1–14d.
Summary of Classification Accuracy for the Chattanooga CART Analysis

		True Class			
		1	2	3	4
C	1	716	72	1	0
A	2	80	265	18	0
R	3	4	24	59	0
T	4	2	5	4	12

An important step in the use of the CART results for episode selection is the identification of key exceedance bins. Key bins were chosen for each ATMOS area based on frequency of occurrence, with a minimal requirement of at least seven exceedance days in the bin, equivalent to one day per year for the analysis period. The key bins are used to guide the episode selection, such that days are preferentially selected from the more populated exceedance bins and as many key bins as possible are represented. This ensures that the most frequently occurring conditions as well as the range of conditions associated with ozone exceedances are represented. The number of key bins for each area is as follows: Memphis – 3, Nashville – 5, Knoxville – 5, Chattanooga – 3. The average parameter values and the conditions associated with each key bin are discussed in the previous section on the conceptual description.

Episode Selection Procedures and Results

The episode selection algorithm requires that the candidate modeling episode days be grouped according to ozone concentration level, and further grouped according to meteorological characteristics. For this analysis, we used the CART analysis technique to classify and group the days according to ozone concentration and meteorological conditions. As described above, all days included in the analysis are placed in classification bins – each corresponding to a specific ozone concentration range and a particular set of meteorological parameters. For each area, some number of these bins corresponds to exceedance level 8-hour ozone concentrations.

The next step in episode selection procedure is to select days that are representative of the key meteorological regimes (i.e., regimes frequently associated with ozone exceedances, based on the number of days in the CART classification bins). Other criteria may also be applied to the selection of days (e.g., in this case we optimized the possibility that the maximum ozone concentrations for the days selected to represent an area are within 10 ppb of the design value for that area, or, alternatively, to maximize the number of sites for which the site-specific maximum ozone concentration is within 10 ppb of the site-specific design value). These criteria are optimized across the areas of interest.

The episode selection algorithm makes use of a numerical procedure called simulated annealing to find an optimal set of days to satisfy a set of episode selection criteria. In applying this technique, an initial set of days is chosen from a user-provided input list that consists of days from those CART bins that represent key meteorological/ozone exceedance regimes. Then individual days from this set are randomly changed. After each substitution, a “cost” function, which determines how well the episode selection criteria are met, is evaluated. The formulation of the cost function is described in detail by Deuel and Douglas (1998). If the cost with the new day is less than the cost with the previous day, the substitution is retained. If the cost with the new day is higher than the cost with the previous day, there is still some small probabilistic chance that the change will be retained. This allows the cost function to escape from a local minimum, until it settles into a minimum close to the global value. The chance of increasing the cost through substitution of new days, however, diminishes as the algorithm progresses.

The user must specify a cost function that determines the set of days. In this analysis, the cost function was designed to (1) minimize the differences between the daily maximum ozone concentration for the selected days and the design value for each area included in the analysis and (2) form multi-day episodes (consisting of sequences of consecutive episode days). The relative importance of (1) and (2) was specified (4:1) to favor representation of the design value.

In applying the episode selection algorithm, we used only days from those bins that had seven or more exceedance days (one per year) during the analysis period (1996-2002). These are the key bins or “regimes.”

In identifying the candidate episodes for modeling, we used the 2000-2002 design values for each area as a reference point[3]. The design-value-based criterion gave preference to days for which the maximum ozone concentration was within 10 ppb of the design value (DV) for a given area. The number of sites with maximum 8-hour ozone concentrations within 10 ppb of the site-specific design value was also examined, but was not used as an objective criterion in applying the algorithm.

Each area was considered separately and as part of an integrated analysis, designed such that the selected episode days are representative of not just one, but several or all of the areas of interest.

This approach was used to identify the first and second ATMOS episode periods. In selecting the first episode period, emphasis was placed on meeting the meteorological and design-value representativeness criteria for as many of the areas of interest and as many simulation days as possible. The 29 August–9 September 1999 simulation period was selected. In selecting the second episode period, emphasis was placed on complementing the August/September 1999

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[3] Note that for the first episode, the 1997-1999 design values were used and that these were generally higher than the 2000-2002 values, especially for Nashville. This results in the August/September episode being somewhat more severe than the other episodes.

simulation period such that the combined episode days improved the extent to which the criteria were met. We also reviewed ozone concentrations for candidate episode days for the Tri-Cities area, which was not considered in the full episode selection analysis and gave weight to those episodes with exceedances in this area. The 16-22 June 2001 simulation period was selected. The 4-10 July 2002 was a candidate episode for the ATMOS modeling analysis but satisfied fewer of the criteria than the June 2001 episode. However, this episode was added to the ATMOS modeling analysis, following the development of databases by ADEQ.

Characteristics of the episodes are summarized for each area in Table 1-15 below.

Table 1-15a.
Summary of ATMOS EAC Modeling Episodes Periods for Memphis.

The 2000-2002 8-hour ozone design value (DV) is 94 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Memphis 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	79.6	1	29
1999	8	30	71.7	0	29
1999	8	31	**96**	4	**17**
1999	9	1	**87.6**	1	**25**
1999	9	2	**95**	2	**17**
1999	9	3	**97.9**	3	9
1999	9	4	**106.8**	1	20
1999	9	5	64.9	0	33
1999	9	6	80.8	1	29
1999	9	7	**86.6**	3	11
1999	9	8	55.3	0	33
1999	9	9	49.3	0	7
2001	6	16	76.5	1	1
2001	6	17	77.6	0	**29**
2001	6	18	**91.4**	2	**29**
2001	6	19	83	2	**31**
2001	6	20	**93.9**	3	**17**
2001	6	21	57.8	0	33
2001	6	22	67.6	0	6
2002	7	4	78	0	**17**
2002	7	5	83.9	0	**29**
2002	7	6	78.5	0	18
2002	7	7	82.8	2	29
2002	7	8	**100**	3	21
2002	7	9	**88.1**	2	21
2002	7	10	77.5	1	29

Table 1–15b.
Summary of ATMOS EAC Modeling Episodes Periods for Nashville

The 2000-2002 8-hour ozone design value (DV) is 88 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Nashville 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	79.9	2	35
1999	8	30	70.3	0	35
1999	8	31	**92.1**	6	**7**
1999	9	1	**100.4**	3	31
1999	9	2	**103.1**	5	29
1999	9	3	**103.1**	6	25
1999	9	4	**110.1**	3	**26**
1999	9	5	**109.6**	1	**26**
1999	9	6	**96.8**	5	28
1999	9	7	80.5	4	**26**
1999	9	8	**90.3**	5	28
1999	9	9	60.1	0	35
2001	6	16	60.3	0	1
2001	6	17	78.3	2	**7**
2001	6	18	72.9	1	27
2001	6	19	**90**	6	**7**
2001	6	20	**103.3**	5	**18**
2001	6	21	58.7	0	36
2001	6	22	54.8	0	12
2002	7	4	81.4	2	13
2002	7	5	81.1	1	32
2002	7	6	**85.9**	4	**35**
2002	7	7	**92.6**	5	**34**
2002	7	8	83.2	1	**35**
2002	7	9	64.4	0	33
2002	7	10	67	0	9

Table 1–15c.
Summary of ATMOS EAC Modeling Episodes Periods for Knoxville

The 2000-2002 8-hour ozone design value (DV) is 98 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Knoxville 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	84.5	1	30
1999	8	30	82.5	1	30
1999	8	31	**88.5**	2	**23**
1999	9	1	**97.6**	2	20
1999	9	2	**104.1**	4	**23**
1999	9	3	**98.6**	4	25
1999	9	4	**101.6**	7	**23**
1999	9	5	83.6	0	**29**
1999	9	6	**86.9**	0	20
1999	9	7	**102.3**	2	**23**
1999	9	8	**95.1**	6	**27**
1999	9	9	**86.3**	0	14
2001	6	16	68	0	3
2001	6	17	81.3	1	**11**
2001	6	18	**95.3**	6	**23**
2001	6	19	**100.7**	7	**16**
2001	6	20	**103**	8	**26**
2001	6	21	**96.8**	7	**29**
2001	6	22	60.8	0	14
2002	7	4	**86.5**	1	**23**
2002	7	5	81.1	0	**23**
2002	7	6	**94.5**	4	**29**
2002	7	7	**95.8**	5	**23**
2002	7	8	**86.3**	0	20
2002	7	9	**93.8**	4	**29**
2002	7	10	71.1	0	30

Table 1–15d.
Summary of ATMOS EAC Modeling Episodes Periods for Chattanooga

The 2000-2002 8-hour ozone design value (DV) is 93 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS and key exceedance and similar/neighboring regimes are highlighted in bold.

Year	Month	Day	Chattanooga 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	77.3	0	16
1999	8	30	70.6	0	12
1999	8	31	79.3	0	9
1999	9	1	**98.1**	2	**26**
1999	9	2	82.4	1	**26**
1999	9	3	**107**	1	**33**
1999	9	4	**98.3**	2	**26**
1999	9	5	**88.6**	2	**26**
1999	9	6	70	0	**26**
1999	9	7	**89.6**	1	15
1999	9	8	**93.3**	1	**26**
1999	9	9	62.1	0	28
2001	6	16	48.5	0	1
2001	6	17	74.5	0	9
2001	6	18	82.6	1	13
2001	6	19	**89.4**	2	**26**
2001	6	20	**99**	2	**26**
2001	6	21	72.5	0	27
2001	6	22	36.3	0	10
2002	7	4	63.4	0	10
2002	7	5	79.4	0	16
2002	7	6	**86.8**	2	**26**
2002	7	7	76.9	0	28
2002	7	8	**85**	1	20
2002	7	9	**91.4**	2	**26**
2002	7	10	69.9	0	9

Table 1–15e.
Summary of ATMOS EAC Modeling Episodes Periods for Tri-Cities

The 2000-2002 8-hour ozone design value (DV) is 92 ppb. Shading denotes primary episode days with maximum 8-hour ozone concentrations within 10 ppb of the area-wide design value. Exceedances of the 8-hour NAAQS are highlighted in bold.

Year	Month	Day	Tri-Cities 8-hr O3 max	No. of area sites w/in 10 ppb of 8-hr site-specific DV	CART Bin
1999	8	29	65.4	0	NA
1999	8	30	64	0	NA
1999	8	31	54.1	0	NA
1999	9	1	81.9	1	NA
1999	9	2	77.6	0	NA
1999	9	3	57.1	0	NA
1999	9	4	67.1	0	NA
1999	9	5	26.5	0	NA
1999	9	6	24.9	0	NA
1999	9	7	58.8	0	NA
1999	9	8	73.5	0	NA
1999	9	9	61.1	0	NA
2001	6	16	55	0	NA
2001	6	17	72.8	0	NA
2001	6	18	81.5	0	NA
2001	6	19	**101.8**	1	NA
2001	6	20	**87.1**	2	NA
2001	6	21	**87.9**	2	NA
2001	6	22	54.1	0	NA
2002	7	4	54.6	0	NA
2002	7	5	60.5	0	NA
2002	7	6	65.5	0	NA
2002	7	7	**91.9**	1	NA
2002	7	8	80.5	1	NA
2002	7	9	**92.6**	1	NA
2002	7	10	69.9	0	NA

Summary of Modeling Episodes

The three episodes selected for this study each include two start-up days and one clean out day. The length of each episode was designed to capture the entire high ozone cycle for each area of interest as influence by the synoptic and mesoscale meteorological conditions. The episodes also include both weekdays and weekend days. The three selected episodes include:

- 29 August–9 September 1999, Sunday–Thursday.
- 16–22 June 2001, Saturday–Friday.
- 4–10 July 2002, Thursday–Wednesday.

Area-specific observations are summarized below.

Memphis

The three modeling episodes include 10 exceedance days and represent two of the three key exceedance meteorological regimes as well as several other high ozone regimes for Memphis. The episodes also include:

- Nine exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.
- Four additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 86 to 106 ppb.
- An average 8-hour ozone exceedance concentration of 94 ppb.

Nashville

The three modeling episodes include 12 exceedance days and represent four of the five key exceedance meteorological regimes for Nashville. The episodes also include:

- Six exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000–2002 design value (note that the 1999 episode was originally selected using the 1999 design value of 102 ppb—so many of the days are consistent with the design value during the 1997–1999 design value period, but not with the lower design value for 2000–2002).
- Four additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 85 to 110 ppb.
- An average 8-hour ozone exceedance concentration of 98 ppb.

Knoxville

The three modeling episodes include 18 exceedance days and represent four of the five key exceedance meteorological regimes as well as several other high ozone regimes for Knoxville. The episodes also include:

- Fourteen exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.

- Five additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 86 to 104 ppb.
- An average 8-hour ozone exceedance concentration of 95 ppb.

Chattanooga

The three modeling episodes include 11 exceedance days and represent two of the three key exceedance meteorological regimes for Chattanooga. The episodes also include:

- Ten exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.
- Two additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 85 to 107 ppb.
- An average 8-hour ozone exceedance concentration of 93 ppb.

Tri-Cities

The three modeling episodes include five exceedance days for the Tri-Cities area. The episodes also include:

- Five exceedance days with maximum 8-hour ozone concentrations within 10 ppb of the 2000-2002 design value.
- Three additional near-exceedance days.
- A range of 8-hour ozone exceedance concentrations from 87 to 101 ppb.
- An average 8-hour ozone exceedance concentration of 92 ppb.

Report Contents

The remainder of this document summarizes the methods and results of the ATMOS EAC photochemical modeling analysis. Section 2 references the EAC modeling protocol, which is included as an appendix. Section 3 presents a summary of the base-case emissions inventory preparation. Section 4 presents the meteorological modeling and input preparation, and Section 5 summarizes the air quality, land-use, and chemistry inputs. Section 6 presents the model performance evaluation. Section 7 presents the future-year modeling analysis. Section 8 presents the modeled attainment demonstration and Section 9 presents an evaluation of maintenance for 2012. Section 10 provides a summary of review procedures followed in the analysis. Finally, Section 11 presents a summary of data access procedures.

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2. Modeling Protocol

The modeling protocol document for the ATMOS EAC 8-hour ozone attainment demonstration modeling analysis was prepared in May 2003. The protocol document provides information regarding the organizational structure of the modeling study, study participants, communication structures, and the resolution of technical difficulties. It also provides detailed information on each element of the modeling analysis including selection of the primary modeling tools, methods and results of the episode selection analysis, modeling domain, model input preparation procedures, model performance evaluation, use of diagnostic and sensitivity analysis, future-year modeling, application of the EPA ozone attainment demonstration procedures, and documentation procedures. Archival and data acquisition procedures are also outlined in this document. The modeling protocol document is provided in Appendix A and is also available as a separate document (SAI, 2003).

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3. Base-Case Modeling Emission Inventory Preparation

This section discusses the development of the base- and current-year emission inventories for the three ATMOS modeling episode periods. The general procedures followed and emission-processing tools used in preparing these inventories are summarized in the ATMOS EAC modeling protocol (SAI, 2003).

For ease of reading, all figures and tables follow the text of this section.

Emissions Data

The modeling inventories for the ATMOS 2001 base- and current-year episodes were prepared based on the following information:

- Final 1999 National Emission Inventory (NEI) Version 2.
- Emissions data provided by states or counties for specific years.
- Episode-day-specific emissions data provided by individual facilities.

The 1999 NEI inventory includes annual and ozone season daily (available for some of the source categories and states) emissions for oxides of nitrogen (NO_x), volatile organic compounds (VOC), carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter with a diameter less than 10 and 2.5 microns (PM_{10} and $PM_{2.5}$) and ammonia (NH_3).

Efforts were made to obtain the latest information available for each state in the modeling domain and to incorporate these data into the modeling inventory as permitted by the EAC schedule and resource limitations. The updates received are presented below.

Overview of Emissions Processing Procedures

To facilitate development of the detailed emission inventories required for photochemical modeling for this analysis, EPA's UAM Emission Preprocessor System, Version 2.5 (EPS 2.5) was used. This system, developed by SAI under the sponsorship of the EPA's Office of Air Quality Planning and Standards, consists of series of computer programs designed to perform the intensive data manipulation necessary to adapt a county-level annual or seasonal emission inventory for modeling use. EPS 2.5 provides the capabilities, and allows for the evaluation of proposed control measures for meeting Reasonable Further Progress (RFP) regulations and special study concerns.

The core EPS 2.5 system consists of a series of FORTRAN modules that incorporate spatial, temporal, and chemical resolution into an emission inventory used for photochemical modeling. Point, area, non-road and on-road mobile source emissions data were processed separately through the EPS 2.5 system to facilitate both data tracking for quality control and the use of data in evaluating the effects of alternative proposed control strategies on predicted future air pollutant concentrations.

Chemical Speciation

All point, area, non-road mobile, and on-road motor vehicle emissions were chemically speciated from VOC into the Carbon Bond Mechanism species corresponding to the toxics version of the mechanism (CB-IV-tox), then converted to the CB-V species corresponding to the latest version of the mechanism (SAI, 2002). The CB-IV speciation profiles were generated based on the toxic compounds database, and profile weights data file prepared for a previous study (Ligocki et al., 1992, Ligocki and Whitten, 1992). The VOC speciation profile assignments and VOC to THC conversion factors have been updated using the latest information provided by EPA (EPA, 2002a)

Temporal Allocation

The temporal variation profiles (monthly, weekly, and diurnal) assigned in the EPS 2.5 default input files for the area and non-road mobile source categories were included in the modeling inventory. The default temporal profiles and profile assignments to the source categories have been updated using the latest information provided by EPA (EPA, 2001). If peak ozone season emissions data were provided in the input inventory, no additional seasonal adjustments were applied.

For on-road motor vehicles, the default weekly and diurnal profiles provided with EPS 2.5 were used to allocate daily emission rates by hour.

The operating schedule (month/year, days/week and hours/day) information included in the point-source input data for each source was processed through EPS 2.5 utility to generate source-specific weekly and diurnal temporal variation profiles. These profiles were used to allocate the annual emissions to the daily emissions, adjust the daily emission rates for the day of the week, and to allocate the adjusted daily emissions to the hours of the episode day.

Episode-specific hourly emission rates (e.g., point-source data provided by Southern Company) were incorporated directly into the modeling inventory.

Spatial Allocation

Point-source emissions were directly assigned to grid cells based on the source location coordinates included in the input emissions data for each source.

County-level area and non-road mobile emissions were allocated to grid cells using a combination of gridded spatial allocation surrogates and link locations. The gridded spatial allocation surrogates file includes fractions by grid cell of county area, population, and land-use for each county. To prepare this file, SAI obtained gridded land-use data from the United States Geological Survey (USGS, 1990). The land-use database, which has a spatial resolution of approximately 200 by 200 meters, includes data for over 30 land-use categories. These categories were combined with the land-use categories required by EPS 2.5 (e.g., urban, rural, residential, agriculture, deciduous forest, coniferous forest, water and etc.). Population data from the Census Bureau for 2000 were gridded based on the location of the centroid of each census block and included in the spatial allocation surrogate file.

County-level on-road mobile emissions were allocated to grid cells using gridded roadway type and population. This file was prepared based on the Tiger/Line database (U.S. Census Bureau, 1993, 1994). The link data for limited access primary roads, primary roads without limited access, and secondary roads were extracted from the database, and used to generate the gridded roadway type surrogate file. The airport location data from the database was used to spatially allocate the emissions from aircraft.

The spatial distribution surrogate assignments for area source categories have been updated using the latest information provided by EPA (EPA, 2002b).

Preparation of the Area and Non-Road Emission Inventory Component

Area and non-road source emissions for all the states included in the ATMOS modeling domain were generated based on the 1999 NEI Ozone Season Daily estimates with the following exceptions:

- 2001 area source data provided by Davidson County, Tennessee.
- 2000 area and non-road source data for four counties in Little Rock area (Faulkner, Lonoke, Pulaski and Saline Counties) provided by ADEQ.
- 2000 area and non-road source data for State of Texas provided by the Texas Commission on Environmental Quality (TCEQ).

County-level emissions estimates for the majority of non-road source emissions were developed using EPA’s Draft NONROAD2002a model (EPA, 2003) with the monthly maximum, minimum and average temperatures (calculated from the 1970-2000 30-year historical averages) by state for the episode period. Aircraft, commercial marine and locomotives were not included in the NONROAD model, and the emissions for the categories were taken from the 1999 NEI Version 2 data.

Modifications were made to the 1999 NEI data to correct identified errors or make some improvements to the database. The details are as follows:

- The emissions from commercial marine vessels in the Pensacola area (Escambia, Santa Rosa, Okaloosa and Walton counties in State of Florida; and Baldwin and Mobile counties in State of Alabama) were estimated based on the Peninsular Florida Ozone Study (Alpine Geophysics, 2003), and the emissions were spatially allocated to the shipping lanes.
- Used the NET 96 version 3 emission estimates for aircraft for Escambia and Santa Rosa counties, Florida (there are no aircraft emissions data for Santa Rosa County, and very low values for aircraft emissions for Escambia County in NEI99 Version 2 data base).
- Used the emission estimates for railroad for Pickens and Tuscaloosa counties, Alabama provided by ADEM.
- Used the emission estimates for commercial marine vessels for East Baton Rouge and Iberville Parishes, Louisiana provided in 1997/1999 LDEQ data

Preparation of the Mobile-Source Emission Inventory Component

The county-level emission estimates for the on-road mobile source emissions were developed using MOBILE6.

For States of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, South Carolina, North Carolina, Tennessee and Texas, state provided county-level daily VMT data, and 30-year historical average temperatures and humidity data for each month of the episode periods were used for the MOBILE6 runs. The details of state VMT data are as follows:

- States of Alabama (2000) and Arkansas (2000): VMT data prorated to 2001 using formulas provided by the states.
- States of Florida, Georgia, Mississippi, South Carolina, North Carolina, Tennessee and Texas: 2001 VMT data.
- State of Louisiana: 2000 VMT data.

For the other states within the modeling domain, the 2000 state-level VMT data provided by the Federal Highway Administration (FHWA) along with seasonal average temperatures were used for the MOBILE6 runs. The state-level VMT data were distributed to the county-level using the 2000 Census population as a surrogate.

The MOBILE6 input files were used to generate the emission factors for total organic gasses (TOG), NO_x, and CO. The county-level emissions were calculated for each vehicle class and roadway classification by multiplying the appropriate emission factor from MOBILE6 by the county-level VMT for that vehicle class and roadway classification using the program MVCALC.

Preparation of Point-Source Emission Inventory Component

The point source emissions were generated based on the following databases:

State of Tennessee

- 2001 point source data provided by Davidson County.
- 2000/2001 point source data provided by Knox County.
- 2001 point source data provided by Hamilton County (NEI99 Version 2 data with 1999 to 2001 facility closures).
- 2002 point source data provided by Shelby County.
- 1999 point source data for rest of 91 counties provided by University of Tennessee.
- 2001 point source data provided by Eastman Chemical Company located in Sullivan County, Tennessee.
- Gas compressor facility data provided by the various facilities, including actual emissions for large gas compressor stations for August/September 1999 and June 2001; actual 2001 emissions for small compressor stations; and revised stack parameters.

State of Mississippi

- 2001 point source data provided by MDEQ.

State of Texas

- 2000 point source data provided by TCEQ.

Facility-Specific Point Source Data

- Hourly day-specific data for June 2001 episode provided by Southern Company, which were also used for the current year inventories of the September 1999 and July 2002 episodes using day of week matches.
- Hourly day-specific data for June 2001 episode provided by TVA, which were also used for the current year inventories for the September 1999 and July 2002 episodes using day of week matches..
- Hourly day-specific data for June 2001 episode for three Entergy facilities (Independence, White Bluff and R S Nelson) provided by Entergy, which were also used for the current year inventories for the September 1999 and July 2002 episodes using day of week matches..

Other States

- 1999 NEI Version 2 point source data for other states.

The temporal profiles were applied to the annual emissions for each episode period.

The episode-specific point source data included hourly emission rates, and the information was used to calculate daily emissions, and create the episode-specific diurnal profiles for each source for each episode day. In addition to the location, stack height, and exit diameter, the point source data provided by Southern Company included hourly flow rate and exit temperature for each source, and this information was incorporated in the modeling inventory.

Estimation of Biogenic Emissions

The EPA's Biogenic Emission Inventory System (BEIS-2) was used to estimate day-specific biogenic emissions for the modeling analysis with the Version 3.1 of the Biogenic Emissions Landcover Database (BELD3). Gridded surrogates of land use/vegetation information were created at 4-km resolution for the entire modeling domain based on the 1-km BELD3 data. Biogenic emissions were then calculated using the 4-km resolution information. The use of BEIS-2 with the new high-resolution land use database is referred to as BEIS-2+. Temperature and solar radiation estimates were extracted from the output of the MM5 meteorological model.

Quality Assurance

Two levels of quality assurance were performed in preparing the emissions inventory. The first regards the inherent quality of the data input to EPS 2.5. The base year inventory database used to develop the UAM-V modeling inventories, along with the available documentation were reviewed. The review consist of an overall assessment of the inventory to ensure that the minimum data requirements and quality standards set forth in *Emission Inventory Requirements for Ozone State Implementation Plans* (EPA-450/4-91-010, March 1991) are met. For example, emissions summaries were made for area and point sources from NEI 99 Version 2 database for the ATMOS states, compared with emissions from NET 96 Version 3 database and available state-specific data. It was concluded that point source data provided by MDEQ include more complete information for stack parameters, and the MDEQ point source data were used for State of Mississippi instead of NEI 99 Version 2 database.

The second phase of this effort involved verifying that all required processing steps were completed in an appropriate order. For the future-year modeling inventory, the review focused on the control assumptions and projection factors used to estimate future-year emission rates. The summary message files produced by each EPS 2.5 module were reviewed to identify any warning or error messages indicating potential problems in processing and to verify input and output emission totals for each processing step.

Graphic representations of the spatial variation in each component (e.g., area source emissions, biogenic emissions) of the final UAM-V ready modeling inventory files were prepared and reviewed for reasonableness.

After the inventory components were completed and merged, the emissions were summarized by major inventory component for all grids in the modeling domain for each of the episode days. The final review was performed before the UAM-V modeling.

Summary of the Modeling Emission Inventories

The emission summaries for the base- and current-year emissions for the two ATMOS episodes are presented in Table 3-1 through Table 3-6

- Table 3-1 through Table 3-3 for the base case August/September 1999 episode.
- Table 3-4 through Table 3-6 for the current-year June 2001 episode.
- Table 3-7 through Table 3-9 for the current-year July 2002 episode.

The emission summaries are given by species (NO_x, VOC and CO) and by major source category. The low-level emissions include anthropogenic (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are in tons per day.

Graphical depictions of the emissions are provided for Grid 3 in various figures that follow the tables. Biogenic VOC emission estimates derived using the BEIS-2+ algorithm differ by episode day due to different ambient temperatures. Figure 3-1 presents emission density plot of biogenic VOC emissions for one representative day for the June 2001 episode.

Anthropogenic emissions do not vary as much day-to-day as biogenic emissions. Figures 3-2a and 3-2b present NOx and VOC emission density plots for total low-level anthropogenic emissions, respectively, for 18 June 2001, illustrating emissions for a typical weekday for the episode. Figures 3-3a and 3-3b present NO_x and VOC emissions, respectively, for elevated point sources for 18 June 2001 for ATMOS Grid 1. The locations of the circles depict the location of the sources while the size of the circles represents the magnitude of the emissions.

Table 3-1.
Summary of August/September Current-Year (2001) Emissions (tons/day) in Grid 1.

NOX	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	1927	2111	2111	2111	2111	2111	1989	1927	1927	2111	2111	2111
Motor vehicle	8395	10094	10294	10194	10394	11094	9595	8395	8395	10294	10194	10394
Non-road	4627	5850	5850	5850	5850	5850	4627	4627	4627	5850	5850	5850
Low-level point	1717	1840	1840	1840	1840	1840	1760	1717	1717	1840	1840	1840
Biogenic	3411	3014	3040	3319	3475	3421	3406	3248	3239	3177	3016	2809
All low-level	20078	22910	23135	23314	23670	24316	21376	19914	19905	23272	23012	23004
Elevated point	13454	14628	14648	14632	14630	14542	14186	13454	13454	14648	14632	14630
Total Anthropogenic	30121	34524	34743	34628	34825	35437	32155	30121	30121	34743	34628	34825
TOTAL	33532	37538	37782	37946	38300	38858	35561	33369	33360	37920	37644	37635

VOC	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	12648	12652	12652	12652	12652	12652	12649	12648	12648	12652	12652	12652
Motor vehicle	5938	7140	7281	7211	7352	7847	6787	5938	5938	7281	7211	7352
Non-road	3758	2461	2461	2461	2461	2461	3758	3758	3758	2461	2461	2461
Low-level point	1897	2839	2839	2839	2839	2839	2081	1897	1897	2839	2839	2839
Biogenic	136177	93572	88106	97692	99489	96235	91448	84182	96556	92786	85907	72467
All low-level	160419	118665	113340	122855	124794	122034	116724	108424	120798	118020	111070	97771
Elevated point	514	611	611	611	610	609	544	514	514	611	611	610
Total Anthropogenic	24756	25704	25845	25775	25915	26409	25819	24756	24756	25845	25775	25915
TOTAL	160933	119276	113951	123466	125405	122644	117267	108938	121312	118632	111681	98382

CO	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	10853	10904	10904	10904	10904	10904	10870	10853	10853	10904	10904	10904
Motor vehicle	57871	69584	70961	70273	71650	76473	66139	57871	57871	70961	70273	71650
Non-road	31028	29499	29499	29499	29499	29499	31028	31028	31028	29499	29499	29499
Low-level point	3215	3508	3508	3508	3508	3508	3315	3215	3215	3508	3508	3508
All low-level	102968	113495	114873	114184	115562	120384	111352	102968	102968	114873	114184	115562
Elevated point	4392	4713	4712	4709	4706	4696	4614	4392	4392	4712	4709	4706
Total Anthropogenic	107360	118208	119585	118893	120268	125080	115966	107360	107360	119585	118893	120268
TOTAL	107360	118208	119585	118893	120268	125080	115966	107360	107360	119585	118893	120268

Table 3-2.
Summary of August/September Current-Year (2001) Emissions (tons/day) in Grid 2

NOX	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	905	997	997	997	997	997	936	905	905	997	997	997
Motor vehicle	3581	4306	4391	4349	4434	4732	4093	3581	3581	4391	4349	4434
Non-road	1785	2236	2236	2236	2236	2236	1785	1785	1785	2236	2236	2236
Low-level point	626	670	670	670	670	670	640	626	626	670	670	670
Biogenic	1074	928	880	959	969	960	993	990	1002	952	900	858
All low-level	7971	9138	9175	9212	9307	9597	8447	7887	7899	9248	9153	9196
Elevated point	6048	6276	6280	6286	6290	6204	6182	6048	6048	6280	6286	6290
Total Anthropogenic	12945	14486	14576	14539	14628	14841	13636	12945	12945	14576	14539	14628
TOTAL	14018	15414	15455	15499	15597	15801	14629	13935	13947	15528	15440	15485

VOC	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	5292	5293	5293	5293	5293	5293	5292	5292	5292	5293	5293	5293
Motor vehicle	2328	2799	2854	2827	2882	3076	2660	2328	2328	2854	2827	2882
Non-road	1390	900	900	900	900	900	1390	1390	1390	900	900	900
Low-level point	800	1278	1278	1278	1278	1278	895	800	800	1278	1278	1278
Biogenic	84768	58404	52616	57869	57446	57926	63006	52505	61920	57271	52025	41736
All low-level	94577	68673	62941	68166	67799	68472	73243	62314	71729	67596	62323	52089
Elevated point	224	277	277	277	277	276	239	224	224	277	277	277
Total Anthropogenic	10034	10547	10602	10574	10630	10823	10477	10034	10034	10602	10574	10630
TOTAL	94801	68950	63218	68443	68076	68749	73482	62538	71953	67873	62600	52366

CO	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	5668	5690	5690	5690	5690	5690	5675	5668	5668	5690	5690	5690
Motor vehicle	24192	29089	29665	29377	29953	31969	27649	24192	24192	29665	29377	29953
Non-road	10911	10584	10584	10584	10584	10584	10911	10911	10911	10584	10584	10584
Low-level point	1056	1112	1112	1112	1112	1112	1076	1056	1056	1112	1112	1112
All low-level	41827	46474	47050	46762	47338	49354	45310	41827	41827	47050	46762	47338
Elevated point	1614	1692	1689	1686	1684	1678	1642	1614	1614	1689	1686	1684
Total Anthropogenic	43442	48166	48740	48448	49022	51032	46953	43442	43442	48740	48448	49022
TOTAL	43442	48166	48740	48448	49022	51032	46953	43442	43442	48740	48448	49022

Table 3-3.
Summary of August/September Current-Year (2001) Emissions (tons/day) in Grid 3.

NOX	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	269	293	293	293	293	293	277	269	269	293	293	293
Motor vehicle	1718	2066	2107	2087	2127	2271	1964	1718	1718	2107	2087	2127
Non-road	673	874	874	874	874	874	673	673	673	874	874	874
Low-level point	126	139	139	139	139	139	130	126	126	139	139	139
Biogenic	378	336	314	353	377	375	362	363	358	346	327	306
All low-level	3163	3707	3727	3744	3810	3951	3406	3148	3143	3758	3719	3738
Elevated point	1783	1926	1936	1910	1920	1885	1860	1783	1783	1936	1910	1920
Total Anthropogenic	4568	5297	5349	5302	5353	5461	4903	4568	4568	5349	5302	5353
TOTAL	4946	5633	5663	5655	5730	5836	5266	4931	4926	5694	5629	5658

VOC	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	2252	2253	2253	2253	2253	2253	2253	2252	2252	2253	2253	2253
Motor vehicle	1042	1253	1278	1266	1291	1377	1191	1042	1042	1278	1266	1291
Non-road	640	412	412	412	412	412	640	640	640	412	412	412
Low-level point	314	498	498	498	498	498	359	314	314	498	498	498
Biogenic	33636	25595	21501	26083	28484	28505	29671	24904	25682	25391	24251	16207
All low-level	37884	30012	25943	30513	32938	33046	34113	29153	29931	29833	28680	20661
Elevated point	118	145	145	145	145	145	121	118	118	145	145	145
Total Anthropogenic	4366	4562	4587	4574	4599	4686	4564	4366	4366	4587	4574	4599
TOTAL	38002	30157	26088	30657	33083	33191	34234	29270	30048	29978	28825	20806

CO	010829	010830	010831	010901	010902	010903	010904	010905	010906	010907	010908	010909
Area	2302	2309	2309	2309	2309	2309	2304	2302	2302	2309	2309	2309
Motor vehicle	11283	13566	13835	13701	13969	14909	12895	11283	11283	13835	13701	13969
Non-road	5030	4932	4932	4932	4932	4932	5030	5030	5030	4932	4932	4932
Low-level point	195	213	213	213	213	213	203	195	195	213	213	213
All low-level	18810	21021	21289	21155	21424	22364	20433	18810	18810	21289	21155	21424
Elevated point	795	854	854	853	854	852	803	795	795	854	853	854
Total Anthropogenic	19605	21875	22143	22008	22278	23216	21236	19605	19605	22143	22008	22278
TOTAL	19605	21875	22143	22008	22278	23216	21236	19605	19605	22143	22008	22278

Table 3-4.
Summary of June 2001 Base Case Emissions (tons/day) in Grid 1.

NOX	010616	010617	010618	010619	010620	010621	010622
Area	1989	1927	2111	2111	2111	2111	2111
Motor vehicle	9584	8386	10083	10282	10183	10382	11081
Non-road	5484	5484	7127	7127	7127	7127	7127
Low-level point	1790	1746	1860	1860	1860	1860	1860
Biogenic	3468	3466	3640	3313	2979	2964	2958
All low-level	22314	21009	24821	24694	24260	24444	25138
Elevated point	15228	14447	15738	15758	15743	15740	15652
Total Anthropogenic	34073	31989	36920	37139	37024	37221	37832
TOTAL	37542	35455	40560	40452	40003	40185	40790

VOC	010616	010617	010618	010619	010620	010621	010622
Area	12649	12648	12652	12652	12652	12652	12652
Motor vehicle	6839	5984	7195	7337	7266	7408	7907
Non-road	6897	6897	3591	3591	3591	3591	3591
Low-level point	2082	1900	2831	2831	2831	2831	2831
Biogenic	132346	140983	155781	121735	96098	83973	78561
All low-level	160813	168411	182050	148146	122438	110456	105542
Elevated point	548	518	607	607	607	606	605
Total Anthropogenic	29014	27945	26875	27018	26947	27088	27586
TOTAL	161360	168928	182657	148753	123045	111062	106147

CO	010616	010617	010618	010619	010620	010621	010622
Area	10870	10853	10904	10904	10904	10904	10904
Motor vehicle	66566	58245	70032	71419	70726	72113	76966
Non-road	48550	48550	40822	40822	40822	40822	40822
Low-level point	3338	3239	3552	3552	3552	3552	3552
All low-level	129324	120887	125310	126697	126004	127391	132244
Elevated point	4654	4434	4753	4752	4749	4746	4735
Total Anthropogenic	133978	125321	130064	131449	130752	132136	136980
TOTAL	133978	125321	130064	131449	130752	132136	136980

Table 3-5.
Summary of June 2001 Base Case Emissions (tons/day) in Grid 2.

NOX	010616	010617	010618	010619	010620	010621	010622
Area	936	905	997	997	997	997	997
Motor vehicle	4082	3571	4294	4379	4337	4422	4719
Non-road	2017	2017	2567	2567	2567	2567	2567
Low-level point	638	623	670	670	670	670	670
Biogenic	1009	1075	1116	1063	980	912	869
All low-level	8681	8192	9645	9677	9552	9569	9824
Elevated point	6667	6531	6759	6764	6770	6773	6688
Total Anthropogenic	14339	13647	15288	15378	15341	15430	15642
TOTAL	15348	14723	16404	16441	16321	16342	16511

VOC	010616	010617	010618	010619	010620	010621	010622
Area	5292	5292	5293	5293	5293	5293	5293
Motor vehicle	2702	2364	2843	2899	2871	2927	3124
Non-road	2412	2412	1233	1233	1233	1233	1233
Low-level point	898	803	1274	1274	1274	1274	1274
Biogenic	82542	93498	100850	76477	61065	50946	43749
All low-level	93846	104369	111493	87176	71736	61674	54674
Elevated point	241	226	271	271	271	271	270
Total Anthropogenic	11546	11097	10914	10970	10942	10998	11195
TOTAL	94088	104595	111764	87447	72007	61944	54944

CO	010616	010617	010618	010619	010620	010621	010622
Area	5675	5668	5690	5690	5690	5690	5690
Motor vehicle	27988	24490	29446	30029	29738	30321	32362
Non-road	15862	15862	13329	13329	13329	13329	13329
Low-level point	1078	1058	1118	1118	1118	1118	1118
All low-level	50604	47079	49583	50166	49875	50458	52499
Elevated point	1655	1627	1701	1698	1695	1693	1687
Total Anthropogenic	52259	48706	51284	51865	51569	52151	54186
TOTAL	52259	48706	51284	51865	51569	52151	54186

Table 3-6.
Summary of June 2001 Base Case Emissions (tons/day) in Grid 3.

NOX	010616	010617	010618	010619	010620	010621	010622
Area	277	269	293	293	293	293	293
Motor vehicle	1960	1715	2062	2103	2082	2123	2266
Non-road	747	747	974	974	974	974	974
Low-level point	132	129	142	142	142	142	142
Biogenic	350	389	400	391	374	336	307
All low-level	3465	3247	3871	3903	3865	3868	3983
Elevated point	1929	1852	1996	2006	1980	1990	1955
Total Anthropogenic	5045	4711	5467	5518	5471	5522	5630
TOTAL	5395	5099	5867	5909	5845	5858	5938

VOC	010616	010617	010618	010619	010620	010621	010622
Area	2253	2252	2253	2253	2253	2253	2253
Motor vehicle	1215	1063	1279	1304	1291	1317	1405
Non-road	1023	1023	530	530	530	530	530
Low-level point	364	319	503	503	503	503	503
Biogenic	32242	38969	39530	33605	31571	24887	16452
All low-level	37096	43626	44094	38195	36148	29489	21143
Elevated point	122	118	137	137	137	137	137
Total Anthropogenic	4976	4775	4701	4727	4714	4739	4828
TOTAL	37217	43744	44231	38331	36285	29626	21280

CO	010616	010617	010618	010619	010620	010621	010622
Area	2304	2302	2309	2309	2309	2309	2309
Motor vehicle	13089	11453	13770	14043	13907	14179	15134
Non-road	6651	6651	5729	5729	5729	5729	5729
Low-level point	200	191	211	211	211	211	211
All low-level	22243	20596	22020	22293	22156	22429	23383
Elevated point	802	794	848	848	847	848	846
Total Anthropogenic	23045	21390	22868	23140	23003	23277	24230
TOTAL	23045	21390	22868	23140	23003	23277	24230

Table 3-7.
Summary of July 2002 Current-Year (2001) Emissions (tons/day) in Grid 1.

NOX	010704	010705	010706	010707	010708	010709	010710
Area	1927	2111	1989	1927	2111	2111	2111
Motor vehicle	8340	11021	9531	8340	10028	10226	10127
Non-road	5398	6995	5398	5398	6995	6995	6995
Low-level point	1746	1860	1790	1746	1860	1860	1860
Biogenic	4236	3944	3766	3962	4238	4206	3747
All low-level	21648	25931	22474	21373	25233	25399	24841
Elevated point	14447	15652	15228	14447	15738	15758	15743
Total Anthropogenic	31858	37640	33936	31858	36733	36951	36836
TOTAL	36094	41584	37702	35820	40971	41157	40583

VOC	010704	010705	010706	010707	010708	010709	010710
Area	12648	12652	12649	12648	12652	12652	12652
Motor vehicle	6044	7986	6907	6044	7267	7411	7339
Non-road	6725	3518	6725	6725	3518	3518	3518
Low-level point	1900	2831	2082	1900	2831	2831	2831
Biogenic	145738	141756	139354	149280	157141	141002	119165
All low-level	173055	168743	167718	176596	183408	167414	145504
Elevated point	518	605	548	518	607	607	607
Total Anthropogenic	27834	27592	28911	27834	26875	27019	26947
TOTAL	173573	169348	168266	177114	184015	168021	146111

CO	010704	010705	010706	010707	010708	010709	010710
Area	10853	10904	10870	10853	10904	10904	10904
Motor vehicle	58780	77674	67178	58780	70676	72076	71376
Non-road	47454	39912	47454	47454	39912	39912	39912
Low-level point	3239	3552	3338	3239	3552	3552	3552
All low-level	120326	132042	128840	120326	125044	126444	125744
Elevated point	4434	4735	4654	4434	4753	4752	4749
Total Anthropogenic	124760	136777	133494	124760	129797	131196	130492
TOTAL	124760	136777	133494	124760	129797	131196	130492

Table 3-8.
Summary of July 2002 Current-Year (2001) Emissions (tons/day) in Grid 2.

NOX	010704	010705	010706	010707	010708	010709	010710
Area	905	997	936	905	997	997	997
Motor vehicle	3535	4672	4041	3535	4251	4335	4293
Non-road	1987	2521	1987	1987	2521	2521	2521
Low-level point	623	670	638	623	670	670	670
Biogenic	1203	1179	1137	1124	1166	1198	1145
All low-level	8254	10040	8738	8175	9606	9722	9627
Elevated point	6531	6688	6667	6531	6759	6764	6770
Total Anthropogenic	13582	15548	14268	13582	15199	15287	15252
TOTAL	14784	16727	15405	14706	16365	16486	16396

VOC	010704	010705	010706	010707	010708	010709	010710
Area	5292	5293	5292	5292	5293	5293	5293
Motor vehicle	2407	3181	2751	2407	2894	2951	2923
Non-road	2352	1209	2352	2352	1209	1209	1209
Low-level point	803	1274	898	803	1274	1274	1274
Biogenic	87514	90505	90960	92573	96242	92838	76053
All low-level	98367	101463	102253	103427	106912	103566	86752
Elevated point	226	270	241	226	271	271	271
Total Anthropogenic	11080	11227	11534	11080	10942	10999	10970
TOTAL	98594	101733	102495	103653	107183	103836	87023

CO	010704	010705	010706	010707	010708	010709	010710
Area	5668	5690	5675	5668	5690	5690	5690
Motor vehicle	24860	32850	28411	24860	29891	30483	30187
Non-road	15502	13037	15502	15502	13037	13037	13037
Low-level point	1058	1118	1078	1058	1118	1118	1118
All low-level	47088	52695	50667	47088	49736	50328	50032
Elevated point	1627	1687	1655	1627	1701	1698	1695
Total Anthropogenic	48716	54383	52322	48716	51437	52026	51727
TOTAL	48716	54383	52322	48716	51437	52026	51727

Table 3-9.
Summary of July 2002 Current-Year (2001) Emissions (tons/day) in Grid 3.

NOX	010704	010705	010706	010707	010708	010709	010710
Area	269	293	277	269	293	293	293
Motor vehicle	1690	2233	1931	1690	2032	2072	2052
Non-road	735	955	735	735	955	955	955
Low-level point	129	142	132	129	142	142	142
Biogenic	426	444	438	410	423	438	438
All low-level	3247	4067	3513	3232	3845	3900	3880
Elevated point	1852	1955	1929	1852	1996	2006	1980
Total Anthropogenic	4674	5578	5004	4674	5418	5468	5422
TOTAL	5099	6022	5442	5084	5841	5906	5860

VOC	010704	010705	010706	010707	010708	010709	010710
Area	2252	2253	2253	2252	2253	2253	2253
Motor vehicle	1088	1438	1243	1088	1308	1334	1321
Non-road	997	519	997	997	519	519	519
Low-level point	319	503	364	319	503	503	503
Biogenic	32335	42509	45719	40079	41123	41730	38171
All low-level	36991	47222	50576	44735	45706	46339	42768
Elevated point	118	137	122	118	137	137	137
Total Anthropogenic	4775	4850	4979	4775	4720	4746	4733
TOTAL	37109	47359	50698	44854	45843	46476	42904

CO	010704	010705	010706	010707	010708	010709	010710
Area	2302	2309	2304	2302	2309	2309	2309
Motor vehicle	11674	15427	13342	11674	14037	14315	14176
Non-road	6502	5605	6502	6502	5605	5605	5605
Low-level point	191	211	200	191	211	211	211
All low-level	20669	23552	22348	20669	22162	22440	22301
Elevated point	794	846	802	794	848	848	847
Total Anthropogenic	21463	24398	23150	21463	23010	23288	23148
TOTAL	21463	24398	23150	21463	23010	23288	23148

Figure 3-1.
Biogenic VOC Emissions in Grid 3

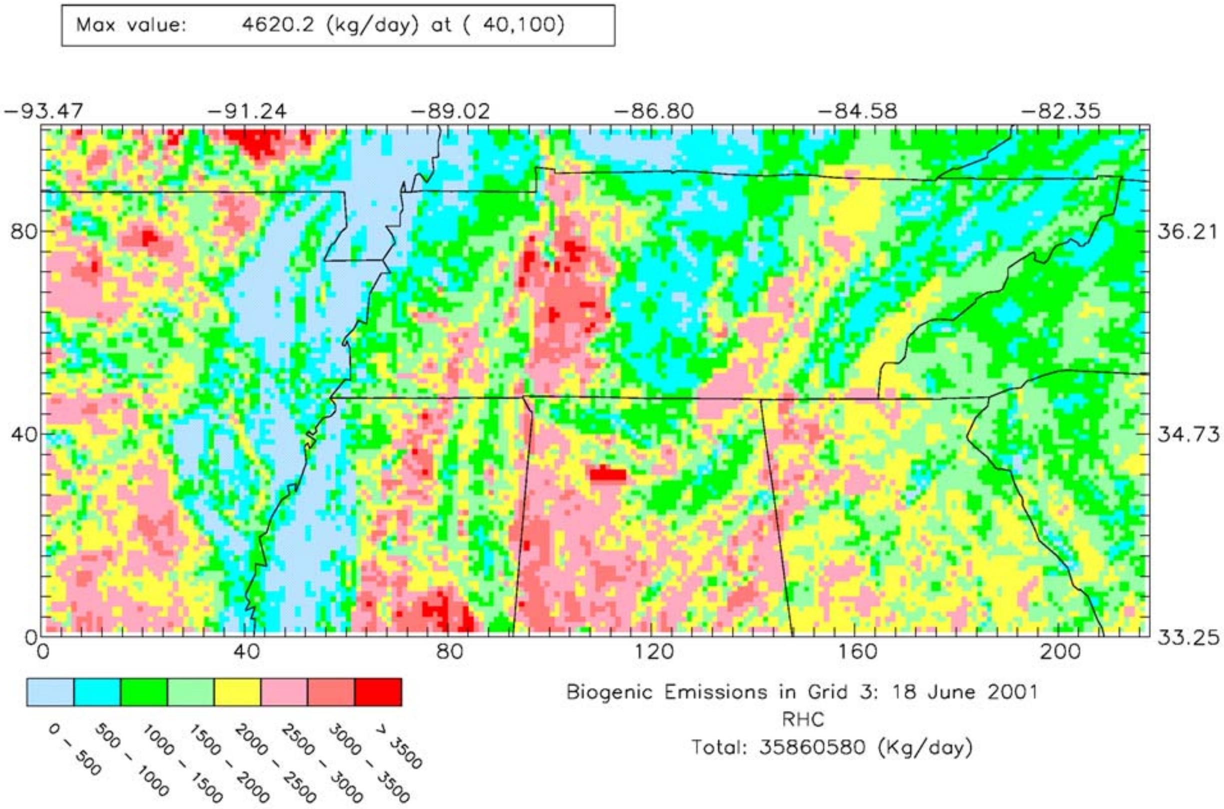


Figure 3-2a
Low-level Anthropogenic NO_x Emissions in Grid 3

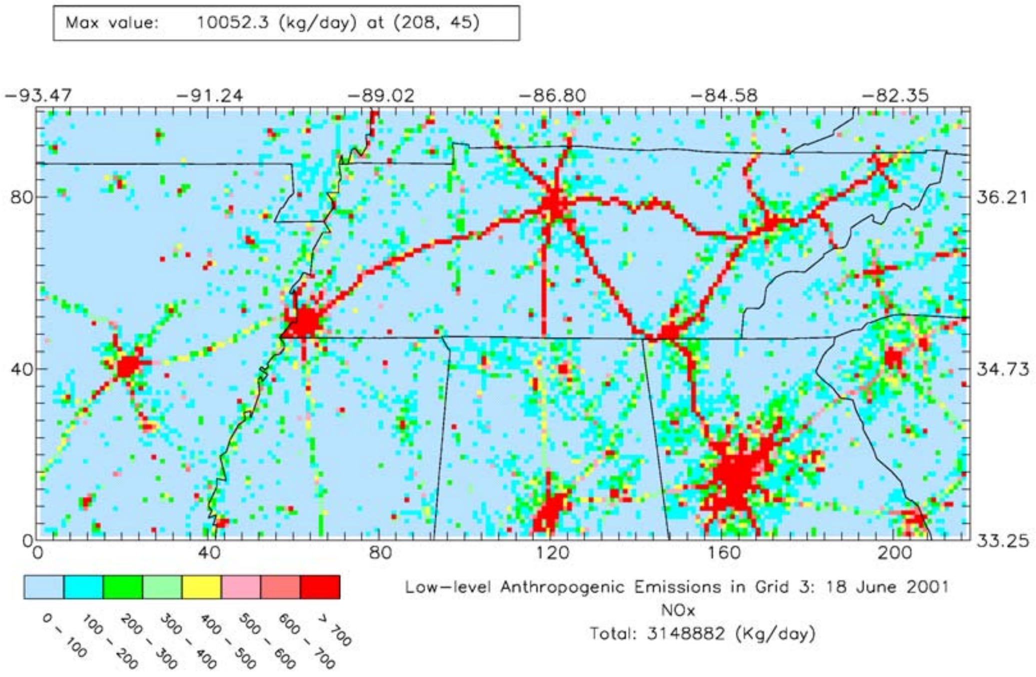


Figure 3-2b
Low-level Anthropogenic VOC Emissions in Grid 3

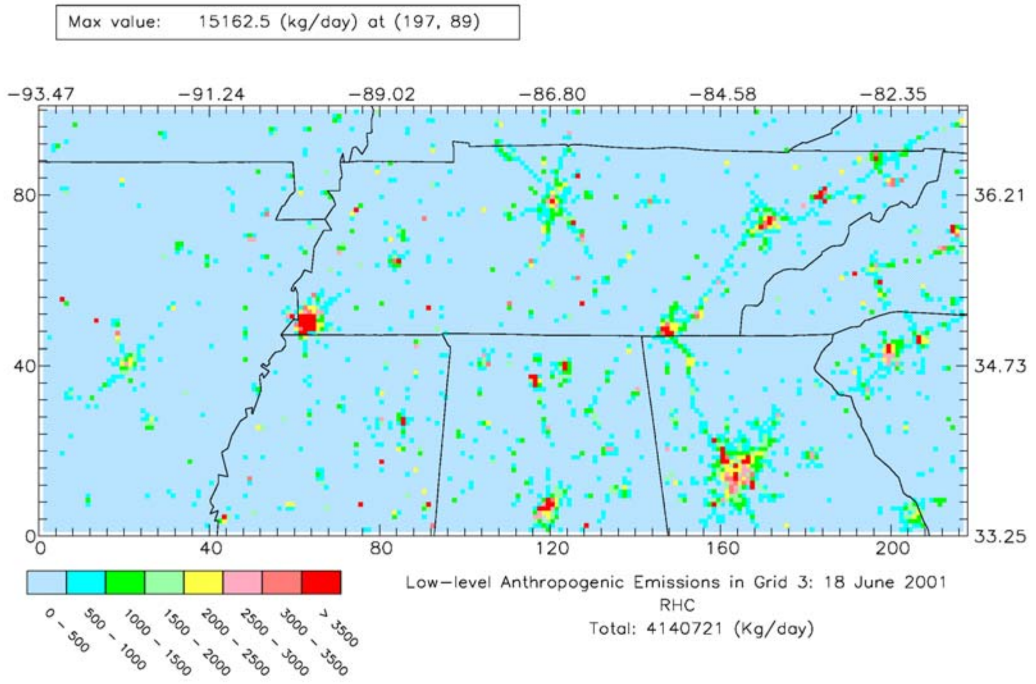


Figure 3-3a.
Elevated Point Source NO_x Emissions in Grid 1

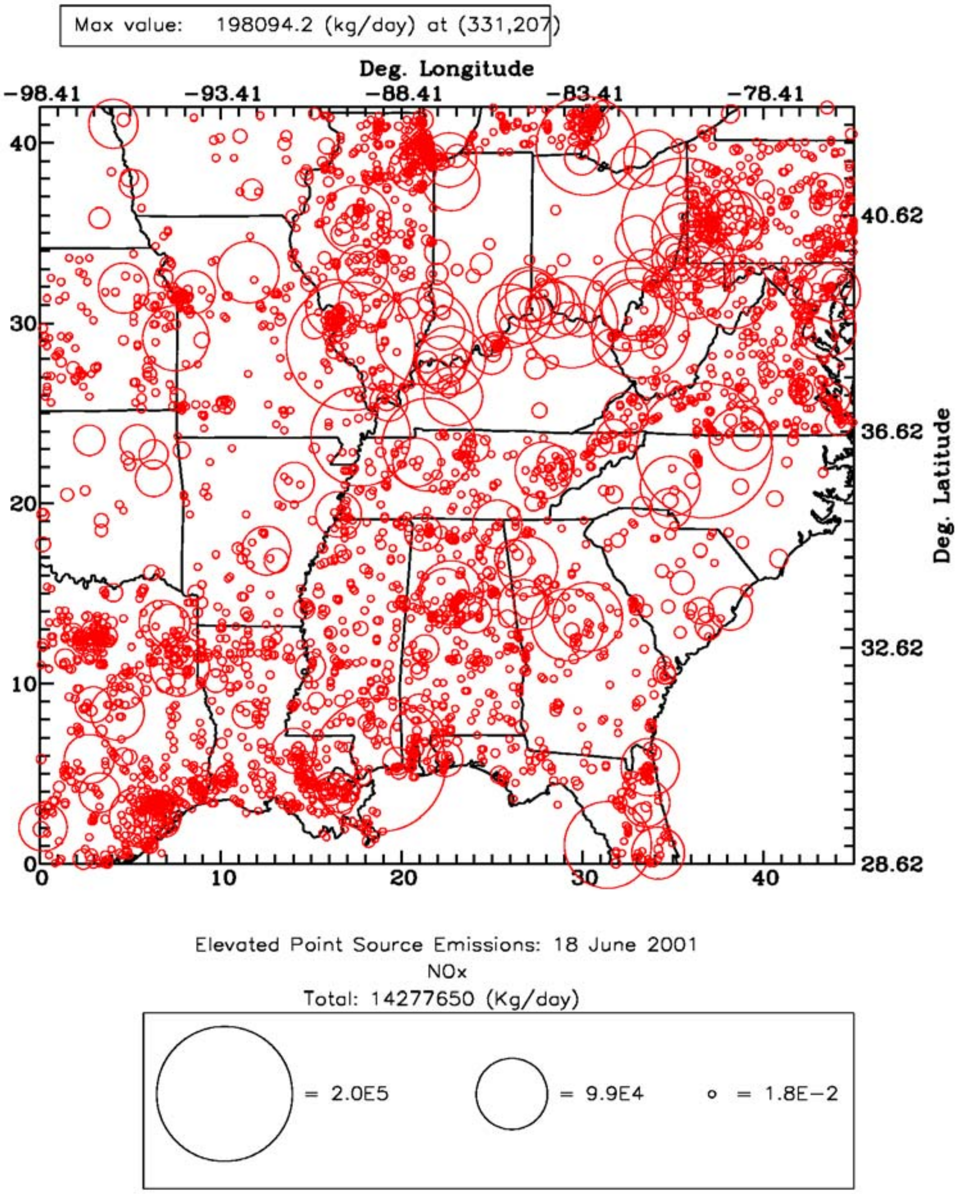
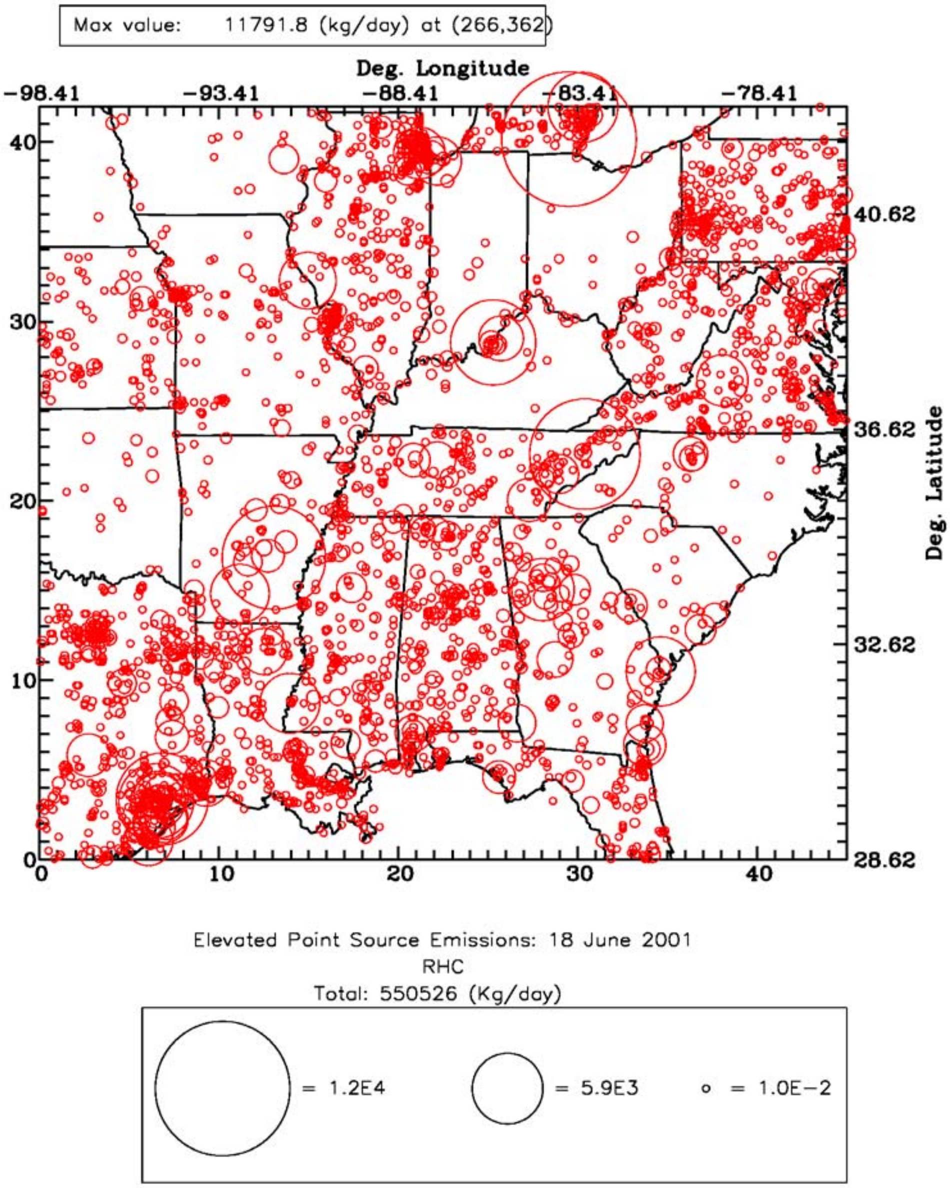


Figure 3-3b
Elevated Point Source VOC Emissions in Grid 1



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4. Meteorological Modeling and Input Preparation

The UAM-V photochemical model requires hourly, gridded input fields of wind, temperature, water-vapor concentration, pressure, vertical exchange coefficients (K_v), cloud cover, and rainfall rate. These meteorological inputs were prepared for the ATMOS UAM-V application using the Fifth Generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (MM5).

MM5 is a state-of-the-science dynamic meteorological modeling system that has been used in numerous previous air quality modeling applications. Key features of the MM5 modeling system that are relevant to its use in this study include multiple nested-grid capabilities, incorporation of observed meteorological data using a four-dimensional data-assimilation technique, a detailed treatment of the planetary boundary layer, and the ability to accurately simulate features with non-negligible vertical velocity components, such as the sea breeze and terrain-generated airflows (a non-hydrostatic option). The MM5 modeling system is widely used for meteorological research and air quality modeling studies and is currently supported by NCAR.

The MM5 application procedures and results are presented in this section of the report. For ease of reading all tables and figures follow the text of this section.

Overview of the Meteorological Modeling Procedures

MM5 Application Procedures

A general description of this three-dimensional, prognostic meteorological model is found in Anthes and Warner (1978); many of the new features are described by Dudhia et al. (2001). Version 3 of MM5 was used.

For this application, the MM5 modeling system was applied for a nested-grid modeling domain that encompasses the UAM-V modeling domain as shown in Figure 1-2. The MM5 modeling domain as shown in Figure 1-3 consists of an extended outer grid with approximately 108 km horizontal resolution and three inner (nested) grids with approximately 36, 12, and 4 km resolution. The inner grids encompass the UAM-V grids with the same resolution. A one-way nesting procedure in which information from the simulation of each outer grid was used to provide boundary conditions for the inner grids was employed.

The vertical grid is defined using the MM5 sigma-based vertical coordinate system. The layer thickness increases with height such that high resolution is achieved within the planetary boundary layer. The vertical layer heights (the half sigma layers) for application of MM5 are listed in Table 1-2.

To facilitate the realistic simulation of processes within the atmospheric boundary layer, the MRF high-resolution PBL scheme was employed. This scheme is compatible with the UAM-V formulation and requirements for specification of vertical exchange coefficients (as discussed below). The PBL parameterization also requires use of a multi-layer soil temperature model (an otherwise optional feature of MM5). The RRTM radiative scheme was used for the MM5 application.

For the coarser grids specified for this application, the Kain-Fritsch cumulus parameterization scheme (Kain and Fritsch, 1990) was used to parameterize the effects of convection on the simulated environment. This feature was not employed for the high-resolution (4-km) grid where an explicit moisture scheme was used.

For this study, three-dimensional analysis nudging was used to promote agreement between the observed data and the simulation results. Using this approach the simulated variables are relaxed or “nudged” toward an objective analysis that incorporates the observed data. The nudging coefficients were specified to achieve moderate nudging of the wind and temperature fields (2.5×10^{-4} or 1×10^{-4}, depending on the grid scale) and weaker to moderate nudging of moisture fields (1×10^{-5} to 5×10^{-5}) toward the observational analyses.

Vertical exchange coefficients (K_vs) for input to UAM-V were extracted directly from the MM5 model. Our version of the MM5 modeling system included the output of the internally calculated vertical exchange coefficients (K_v), as calculated using the MRF PBL scheme. These values are written to a separate MM5 output file. The K_v values for this scheme are intended to represent non-local or multi-scale diffusion coefficients (rather than local diffusion coefficients) and are therefore most suitable for use with the UAM-V modeling system. The K_v values were used to specify the vertical exchange coefficients required by the UAM-V modeling system. The direct use of the MM5-derived K_v values avoids the need to calculate the K_vs outside of MM5, and use of the various assumptions that are required for these calculations. Our prior testing of several schemes showed this scheme to be the best choice for combined MM5/UAM-V modeling.

For each simulation period, the model was initialized at 0000 GMT on the first day of the period. Thus, each MM5 simulation period includes a five-hour initialization period, before the output was used to prepare inputs for the UAM-V model. For the three outer grids, the MM5 was run continuously for the multi-day simulation period. For the higher-resolution grid, the model was reinitialized after each three days of simulation. Each re-initialization also included an additional 5-hour initialization period. Re-initialization was necessary to avoid the build up of non-meteorological noise in the simulation results that tended to occur after approximately 3 to 3 ½ days of simulation. The input fields from each simulation were inspected to ensure that piecing together the simulations did not create discontinuities in the meteorological inputs (the use of FDDA will alleviate this possibility). In any event, the junctures occur at midnight—a time that is not especially important in photochemical modeling.

The time step used for the simulations ranged from several minutes for the outermost (approximately 108 km) grid to 9 -12 seconds for the innermost (approximately 4 km) grid.

The data for preparation of the terrain, initial and boundary condition, and FDDA input files for this application were obtained from NCAR. The MM5 input files were prepared using the preprocessor programs that are part of the MM5 modeling system (Gill, 1992).

Meteorological data for the application of MM5 were also obtained from NCAR. These include the National Center for Environmental Prediction (NCEP) global analysis and surface and upper air wind, temperature, moisture, and pressure data for all routine monitoring sites within the domain. The sites include National Weather Service (NWS) sites, buoys, and a few international monitoring sites. Sea-surface temperature data were also obtained from NCAR. These data comprise the standard data set for application of the MM5 modeling system and were used for data assimilation as well as for the evaluation of the modeling results.

Preparation of UAM-V Ready Meteorological Fields

Following the application of MM5, the simulation results were plotted and reviewed using a variety of graphical and statistical analysis tools. We reviewed static plots of wind, temperature, specific humidity, vertical exchange coefficients, cloud-cover, and rainfall for selected domains, hours, and vertical levels. The number and type of plots varied by episode day, as needed to assess various aspects of the episode-specific meteorological conditions. The output was also examined using a view/animation graphics tool designed for use with MM5. At this stage the MM5 results were also compared visually and statistically with observed wind, temperature, and moisture data—to identify geographical areas or time periods for which the model output did not represent the data well and as a check on the effectiveness of the data assimilation.

The MM5 output was then postprocessed to correspond to the UAM-V modeling domain and the units and formats required by the modeling system, using the MM52UAMV postprocessing software. Wind, temperature, water-vapor concentration, pressure, vertical exchange coefficient, cloud-cover, and rainfall-rate input files containing hourly, gridded estimates of these variables were derived from the MM5 output. Surface temperature and solar radiation were postprocessed for use in preparing the biogenic emissions estimates.

Discussion of Procedures Used to Diagnose and Correct Problems and Improve Meteorological Fields

There are no specific criteria as to what constitutes an acceptable set of meteorological inputs for photochemical modeling. For this study, we relied on comparison with observed meteorological data and achievement of reasonable UAM-V simulation results to guide our diagnosis and correction of problems and to improve the meteorological fields.

August/September 1999

Throughout the course of the ATMOS modeling analysis for this episode, modifications were being made to the MM52UAMV postprocessing software for other applications, and updated versions of the software were applied to the wind fields for this project as they became available. Overall, the diagnostic analysis included several components:

- An additional lower layer (25 m) was added to the vertical structure for the UAM-V ready meteorological fields in an attempt to simulate conditions in the surface layer (not applied in final fields).
- The effects of omitting land-use based minimums for the vertical diffusion coefficients were examined (not omitted in the final fields).
- The effects of omitting smoothing of the UAM-V wind fields was examined (not applied in the final fields).

- Overestimation of cloud cover for selected days was improved by re-running MM5 with different moisture nudging parameters (rain and cloud fields can have dramatic effects on the UAM-V results—primarily by affecting the K_v fields)
- The vertical diffusion coefficients were normalized, to ensure that the maximum value represented by MM5 was also represented in the UAM-V ready K_v fields
- Similarity theory was applied to estimate surface wind speed (and average winds within the lowest UAM-V model layer)

A brief discussion of each of these last three items, which were applied in the final fields follows.

In applying MM5 for the August/September 1999 simulation period, we found that the model did not adequately simulate the surface temperatures for key locations in the eastern portion of the ATMOS fine-grid modeling domain for 1-3 September. We reran the fine-grid simulation for these three days using an enhanced moisture-nudging coefficient (5×10^{-5}). Greater nudging of the moisture fields significantly improved the simulation of the temperature fields.

For each horizontal grid cell, the vertical profile of the K_vs determines the diffusive mixing within the vertical column. For this application, the K_vs were output (hourly) by MM5 for each horizontal grid cell and MM5 layer. These were then interpolated to the UAM-V layers (layer interface levels) for use by the photochemical model. To avoid excessive smoothing of the maximum MM5-derived K_v value (a possible result of interpolation), the K_v values were renormalized for each level based on the ratio of the MM5-derived maximum value and the interpolated maximum value. In this way, both the magnitude and vertical variation in K_v, as simulated by MM5, were retained in the UAM-V ready fields. In testing this technique, we found the difference between the interpolated and renormalized values to be greatest over varied terrain—where large K_v values are sometimes associated with terrain-induced vertical motions. Incorporating this modification into the meteorological inputs for the ATMOS application resulted in a slight increase in ozone at certain sites and a slight improvement in model performance. This modified postprocessing procedure was applied for all grids and was used to prepare the final base-case input fields.

Most applications of MM5, including this one, use a lowest layer for the calculation of winds that is approximately 30 to 40 m above ground level (this varies in accordance with the pressure-based sigma coordinate system). On the other hand, the lowest UAM-V layer is typically 50 m in thickness and the wind speeds for this layer are intended to represent approximately 25 m above ground. For this application, the MM5-derived wind speeds were adjusted using similarity theory (e.g., as described by Panofsky and Dutton, 1984) to better represent the winds at the 25 m level. Using this approach, the wind speed profile within the surface layer is estimated based on similarity theory—which accounts for the effects of turbulence on atmospheric variables within the lowest portion of the atmospheric boundary layer. The MM5-derived speed is then adjusted (based on this profile) to represent the wind speed at the 25 m level. The result is a slight reduction in wind speed for the lowest UAM-V layer (compared to a straight mapping of the MM5 wind to this layer). For this application, the effects of the wind speed adjustment on the UAM-V simulated ozone concentrations were very small. Nevertheless, this approach represents a potentially improved use of the MM5 results and was used to prepare the final base-case input fields.

June 2001 and July 2002

For the initial MM5 application for both simulation periods, we found the surface- level wind fields for the 4-km resolution grid to be relatively noisy (i.e., characterized by somewhat randomly directed winds that were sometimes or even frequently different from the observations). This occurred despite the re-initialization of the model every three days (as described above). To try to improve the stability and quality of the surface wind fields, we reran MM5 for the innermost domain with a smaller time step (9 seconds instead of 12 seconds). In a second simulation, we also increased the nudging coefficient for moisture (from 10^{-5} to 5×10^{-5}). These two changes to the MM5 inputs reduced the noisiness and provided a better representation of the surface winds. The increased moisture nudging was also intended to improve the representation of the surface temperatures, which were overestimated in the initial simulations.

In addition, we specifically conducted some diagnostic testing of postprocessing procedures and assumptions for the wind and K_v input fields. Our standard ATMOS postprocessing procedures and assumptions (as discussed above) were used without further modification, however, in the final base-case simulations.

Presentation and Evaluation of the MM5 Results

In this section we present the MM5 results corresponding to those that were used in the final UAM-V base-year (or base-case) simulation. The plots presented here were selected to illustrate the meteorological conditions associated with the modeling episode period as well as to provide information regarding the ability of the MM5 modeling system to represent some of the key meteorological features.

In presenting the results, we first focus on transport patterns described by the wind fields. Plots of the MM5-derived upper-air wind fields are provided to illustrate transport patterns (for later interpretation of the UAM-V simulation results) and to allow a comparison of the simulated wind fields with observations. For these plots, the display time of 0700 EST was chosen based on observed data availability (this corresponds to 1200 GMT) and the vertical level of approximately 300 m was selected to illustrate regional transport patterns within the boundary layer. The MM5 plots are shown for selected/key episode days.

Plots of surface temperatures compare the simulated surface temperatures with observed values and allow a review of the diurnal profiles and day-to-day differences.

Finally, statistical measures summarize the overall ability of MM5 to represent the key meteorological parameters.

29 August–9 September 1999

The ability of the MM5 modeling system to represent the observed wind fields is illustrated for 29 August–9 September in Figure 4-1. The winds for approximately 300 m agl are plotted for the 12-km resolution regional-scale grid. The observed wind vectors are overplotted in bold. On a few of the days, observed data appears to be in error (note wind vector over central Oklahoma on the 30th), but in general, there is good agreement between the simulated and observed winds and the MM5 model replicates well the observed wind patterns for this level. The wind fields depict the northerly movement of Hurricane Dennis from the eastern coast of Florida on the 29th of August to over North Carolina on the 5th of September. For the 29th and the 30th, the winds are primarily northeasterly. Hurricane Dennis is well defined off the eastern coast of

Georgia/South Carolina. Wind fields for 31 August through 2 September are characterized by clockwise circulation at this level. Northeasterly and easterly components dominate the wind field on the 3rd. Hurricane Dennis again appears in the wind fields of the 4th, off the South Carolina/North Carolina coast and moves onshore over North Carolina on the 5th. Counter-clockwise circulation associated with Hurricane Dennis is the major feature in the wind fields on the 5th. A northerly wind component dominates the winds on the 6th . The remains of the hurricane is evident over the northeastern portion of the domain on this day also. Winds on the 7th are weaker and continued northerly. On the 8th, winds are very light over Tennessee at this level, and evidence of a high pressure system is indicated by the clockwise circulation over western Tennessee. Winds on 9 September are also generally from the north and northwest.

MM5 derived surface temperatures are compared with observed values for several monitoring sites in the 4-km grid (Memphis, Nashville, Knoxville, and Chattanooga) in Figure 4-2. Observed temperatures are generally well simulated by the model. Notable exceptions do however occur. Maximum temperatures are overestimated at the Memphis site on the 2nd of September and underestimated at Chattanooga on the same day.

MM5-derived mixing heights are compared with those estimated using the upper-air temperature sounding data for Nashville in Table 4-1. The MM5-derived values were estimated from the vertical exchange coefficient (K_v) profiles, an example of which is presented in Figure 4-3. This figure shows the K_v profile for Nashville for 0900, 1200, 1500, and 1800 CST on 31 August. From these plots, the mixing height is estimated to be the level at which the value of K_v drops to ten percent of its maximum value. The example profiles exhibit expected vertical distributions and indicate that the maximum effective mixing heights are approximately 700 m at 0900 CST, 1200 m at 1200 CST, 1625 m at 1500 CST, and 0 m at 1800 CST. The corresponding values from the upper-air sounding were estimated from the temperature soundings by extending a line with a constant temperature lapse rate equal to the dry adiabatic lapse rate upward from the surface temperature. The intersection with the temperature sounding is the observation-based mixing height. This simple method for estimating mixing heights is not expected to give reliable values when the upper air temperature structure changes significantly during the day. Thus, this comparison is intended only to provide qualitative information as to the reasonableness of the MM5-derived mixing height values.

A comparison of the MM5-based and observation-based values in Table 4-1 for 1500 CST shows that for those days for which reliable estimates could be obtained using both methods, the MM5-based mixing heights are both higher and lower than the observation-based estimates. The values for MM5 appear reasonable and are more consistent day-to-day than the observation based values. The MM5-derived estimates are lower than the observation-based values by about 20 –25 percent for 29 August and 1-2 September, and considerably higher than the observation-based estimate for 6 September. Since we are comparing two different results from two different methodologies, this comparison cannot be used directly to assess the quality of the MM5 fields, as there are two many uncertainties inherent in both estimates. This comparison was conducted in order that it might provide perspective later in the modeling analysis, especially regarding the over or underestimation of ozone on certain days.

Statistical summaries of the MM5 results are presented in Table 4-2. Daily values of the mean simulated and observed values for temperature, specific humidity, wind direction and wind speed are presented along with the calculated mean residual. The residuals were calculated by comparing the MM5 results with observed data, and represent averages for the 4-km or innermost MM5 domain. The summaries are presented for the surface layer and two upper-layers. While there are more data within the surface layer, there is a mismatch between the model level and the level at which the measurements are taken. For winds, the difference in height of the simulated and observed values is about 20 m. For temperature and specific humidity, the difference is about 25 m. We did not adjust for these differences, thus, some difference between the simulated and observed values for the surface layer is expected.

The statistical measures indicate that the mean values of all parameters are generally well represented by MM5 for all simulation days. Surface temperatures are underestimated on average by about 0.5 to 1.5 degrees at the surface and well represented at the upper levels. There is some tendency for underestimation of the specific humidity, but the bias is small. Surface wind speeds are generally overestimated by MM5, but the bias is typically less than 1 ms^{-1}, with some exceptions. In some cases, the overestimation of wind speed carries upward to the 300 m layer. Wind directions are well represented aloft (with a bias of less than 20 degrees) and less well represented near the surface—likely due to the very low wind speeds. A bias on the order of 10 to 30 degrees characterizes the agreement with the surface winds. Under low wind speed conditions, such as those that characterize this episode period, the errors in wind direction are not very meaningful.

In summary, the MM5 results for the 29 August to 9 September modeling episode period represent observed conditions well.

16–22 June 2001

The ability of the MM5 modeling system to represent the observed wind fields is illustrated for 16–22 June 2001 in Figure 4-4. The winds for approximately 300 m agl are plotted for the 12-km resolution regional-scale grid. The observed wind vectors are overplotted in bold. In general, there is good agreement between the simulated and observed winds and the MM5 model replicates well the observed wind patterns for this level.

The simulation period begins with a high-pressure system over Little Rock that is manifested in the wind fields by an anticyclonic flow pattern. Winds over Tennessee are from the north. As the system migrates northeastward, the winds over Tennessee become easterly by the 18th, and then southerly by the following day. Finally westerly to northwesterly winds develop on the 22nd as a cold front moves through Arkansas and into Tennessee.

MM5 derived surface temperatures are compared with observed values for several monitoring sites in the 4-km grid (Memphis, Nashville, Knoxville, and Chattanooga) in Figure 4-5. The simulated values are very well simulated. The diurnal profiles and day-to-day differences in the profiles are well represented at all sites, especially considering the last one or two (depending on the site) simulation days.

MM5-derived mixing height are compared with those estimated using the upper-air temperature sounding data for Nashville in Table 4-3. At 1500 CST, MM5-based mixing heights are generally lower than observation-based values. This is especially true for 19 and 20 June. However, since we are comparing two different results from two different methodologies, this comparison cannot be used directly to assess the quality of the MM5 fields, as there are two many uncertainties inherent in both estimates. This comparison was conducted in order that it might provide perspective later in the modeling analysis, especially regarding the over or underestimation of ozone on certain days.

Statistical summaries of the MM5 results are presented in Table 4-4. The statistical measures indicate that the mean values of all parameters are generally represented by MM5 for all simulation days. Temperatures are overestimated on average by about 0.5 to 1 degrees at all levels. There is some tendency for underestimation of the specific humidity, but the bias is small. The very light wind speeds that characterize the surface fields for all days are overestimated by MM5. There is also some overestimation of wind speeds aloft for the 19th and 20th. The bias in wind speed is typically less than 1 ms^{-1}, with some exceptions. Wind directions are well represented aloft (with a bias of less than 10 degrees) and less well represented near the surface—likely due to the very low wind speeds. A bias on the order of 10 to 20 degrees characterizes the agreement with the surface winds. Under low wind speed conditions, such as those that characterize this episode period, the bias in wind direction is not very meaningful.

In summary, the MM5 results for the June 2001 modeling episode period represent observed conditions well.

4–10 July 2002

The winds for approximately 300 m agl are plotted for the 12-km resolution regional-scale grid in Figure 4-6. The observed wind vectors are overplotted in bold. In general, there is good agreement between the simulated and observed wind fields for this level. For some days, the MM5 wind speeds are higher than observed.

The simulation period begins with a convergence zone over Tennessee on the 4th, with northeasterly winds in the eastern part of the state and northerly to westerly winds in the western part of the state and into Arkansas. There is some disagreement with the observed winds for the hour and level shown in the plot. The wind direction shifts to northeasterly on the 5th and remains easterly to northeasterly through the 7th. This is followed by a transition to southeasterly, southerly and then southwesterly on the 8th and 9th. Westerly winds on the 10th mark the end of the ozone episode through the domain. The transition to westerly flow takes place earlier further aloft. The evolution of the airflow patterns is similar in many respects to those for June 2001 simulation period as well as to the first part of the August/September 1999 simulation periods and is driven by the west-to-east migration of a high pressure system across the domain.

MM5 derived surface temperatures are compared with observed values for several monitoring sites in the 4-km grid (Memphis, Nashville, Knoxville, and Chattanooga) in Figure 4-7. Underestimation occurs at Nashville on the 8th and at Chattanooga on the 6th and 10th. Otherwise, the diurnal profiles and day-to-day differences in the profiles are well represented at all sites, especially considering the last one or two (depending on the site) simulation days.

MM5-derived mixing height are compared with those estimated using the upper-air temperature sounding data for Nashville in Table 4-5. A comparison of the MM5-based and observation-based values in Table 4-5 shows that MM5-based mixing heights at 1500 CST MM5-based mixing heights appear reasonable and are quite similar to observation-based values several of the days. The MM5-derived values are lower than the observation-based estimates on the 8th and higher on the 9th. The MM5-derived values are also more consistent day-to-day than the observation-based values.

Statistical summaries of the MM5 results for the July 2002 episode period are presented in Table 4-6. The statistical measures indicate that the mean values of all parameters are well represented by MM5 for all simulation days and all levels. Temperatures are overestimated on average by about 1 to 2 degrees at the surface with smaller differences aloft. This episode is more humid than the June 2001 episode and the higher specific humidities are well represented; the bias is small (generally less than 1 gkg^{-1}). As for the June 2001 simulation period, the light wind speeds that characterize the surface fields for all days are overestimated by MM5. There is also some overestimation of wind speeds aloft for several of the simulation days. The bias in wind speed is typically less than 1 ms^{-1}, with some exceptions. Wind directions are well represented aloft (with a bias of less than 10 degrees) and less well represented near the surface—likely due to the low wind speeds. A bias on the order of 10 to 20 degrees quantifies the agreement with the surface winds for most days. Under low wind speed conditions, such as those that characterize this episode period, the errors in wind direction are not very meaningful.

In summary, the MM5 results for the July 2002 modeling episode period represent observed conditions well.

Quality Assurance of the Meteorological Inputs

The MM5 results were evaluated using mostly graphical analysis. The overall evaluation of the MM5 results included the following elements. For the outer grids, examination of the MM5 output focused on representation of the regional-scale meteorological features and airflow patterns and included a comparison with weather maps. A more detailed evaluation of the results for the inner (high-resolution) grid emphasized representation of the observed data, terrain-induced and other local meteorological features, and vertical mixing parameters. To the extent possible, the modeling results were compared with observed data. In the absence of data (e.g., for unmonitored areas and for not-measured parameters such as K_v), the MM5 results were examined for physical reasonableness as well as spatial and temporal consistency.

Comparison with the observed data was primarily used to examine the model’s ability to represent key meteorological features such as the wind speeds as directions aloft and site-specific temperatures. The UAM-V ready meteorological inputs were also plotted and examined to ensure that the characteristics and features present in the MM5 output were retained following the postprocessing step. The ability of the MM5 model to reproduce observed precipitation patterns was qualitatively assessed by comparing the simulated and observed rainfall patterns (based on NWS data)—some rainfall occurred during the episode periods and this was reflected in the MM5.

The following graphical summaries were prepared to facilitate the review/evaluation of the meteorological inputs:

- 3-dimensional visualizations of the MM5 output using the Environmental WorkBench software (an enhanced version of VIS-5D).
- x-y cross-section plots of the MM5 wind fields for several levels and times with observations overplotted for MM5 Grids 1, 2, and 3.
- x-y cross-section plots of the UAM-V ready wind, temperature, vertical exchange coefficient, cloud-cover, and rainfall-rate fields for several times and levels (as appropriate).

On two occasions during the course of the modeling analysis, we enhanced the MM5 to UAM-V software for other applications, and re-processed the fields using enhanced versions of the software.

Finally, the process analysis feature of UAM-V was also used for the August/September 1999 simulation period to further examine the role of the meteorological inputs in determining the simulated concentration patterns and levels (and their contribution to good or poor model performance). The role of meteorology in the diagnostic analysis for UAM-V is discussed in more detail in Section 6.

Table 4-1.
Comparison of MM5-Derived and Observation Data Derived Mixing Heights at Nashville for 29 August–09 September 1999

Date	1500 CST	
	MM5 Derived	Observation Derived
29 August	1629	2085
30 August	1211	NA*
31 August	1570	1420
1 September	1630	2125
2 September	1558	2010
3 September	1568	1775
4 September	1631	NA
5 September	1630	NA
6 September	1583	805
7 September	1240	1090
8 September	NA	NA
9 September	1584	NA

* NA indicates that a reliable estimate could not be derived.

Table 4-2a.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 29 August 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.5	299.2	-0.7
300 m	298.2	298.3	-0.1
1200 m	292.6	292.5	0.2
Specific Humidity (gkg-1)			
Surface	14.6	13.4	1.2
300 m	14.1	13.0	1.1
1200 m	12.0	11.0	1.0
Wind Direction (degrees)			
Surface	37.7	31.0	7.6
300 m	41.1	34.5	2.6
1200 m	46.3	42.9	2.8
Wind Speed (ms-1)			
Surface	3.8	2.4	1.3
300 m	7.0	5.9	0.7
1200 m	7.0	5.9	0.7

Table 4-2b.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 30 August 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	296.8	297.4	-0.6
300 m	295.0	296.1	-1.0
1200 m	295.0	296.1	-1.0
Specific Humidity (gkg-1)			
Surface	10.3	10.0	0.3
300 m	10.3	10.1	0.2
1200 m	9.2	9.0	0.2
Wind Direction (degrees)			
Surface	39.4	33.6	9.3
300 m	37.8	29.3	10.1
1200 m	32.8	24.6	13.2
Wind Speed (ms-1)			
Surface	5.1	3.5	1.6
300 m	8.6	6.0	2.2
1200 m	8.7	9.0	-0.2

Table 4-2c.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 31 August 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	294.4	294.8	-0.4
300 m	293.5	293.3	0.2
1200 m	289.8	289.7	0.0
Specific Humidity (gkg-1)			
Surface	8.5	8.2	0.3
300 m	7.5	7.4	0.1
1200 m	6.0	6.1	-0.1
Wind Direction (degrees)			
Surface	69.1	64.7	8.2
300 m	61.0	61.6	4.9
1200 m	48.4	41.0	21.9
Wind Speed (ms-1)			
Surface	3.3	1.9	1.1
300 m	5.0	4.6	-0.7
1200 m	4.1	2.9	-0.3

Table 4-2d.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 1 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	295.8	296.4	-0.6
300 m	295.7	296.2	-0.5
1200 m	291.6	291.4	0.2
Specific Humidity (gkg-1)			
Surface	11.0	10.2	0.7
300 m	9.8	8.8	1.0
1200 m	7.5	7.4	0.2
Wind Direction (degrees)			
Surface	85.0	65.6	26.0
300 m	44.2	37.1	3.1
1200 m	19.8	8.5	4.3
Wind Speed (ms-1)			
Surface	0.9	0.3	0.5
300 m	1.8	1.2	-0.6
1200 m	3.3	3.4	-0.7

Table 4-2e.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 2 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.7	297.9	-0.2
300 m	297.4	298.0	-0.6
1200 m	292.6	292.8	-0.2
Specific Humidity (gkg-1)			
Surface	11.9	11.2	0.7
300 m	10.0	9.4	0.5
1200 m	7.9	7.4	0.5
Wind Direction (degrees)			
Surface	57.7	42.9	15.4
300 m	40.0	19.0	-15.4
1200 m	39.3	29.6	8.3
Wind Speed (ms-1)			
Surface	0.8	0.5	0.3
300 m	2.3	2.6	-0.5
1200 m	4.2	3.6	-0.2

Table 4-2f.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 3 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.9	298.7	-0.8
300 m	297.6	297.8	-0.3
1200 m	292.7	292.7	0.0
Specific Humidity (gkg-1)			
Surface	11.8	11.3	0.5
300 m	10.6	10.2	0.4
1200 m	8.6	8.5	0.1
Wind Direction (degrees)			
Surface	62.3	47.4	17.8
300 m	59.4	48.5	16.2
1200 m	60.9	51.8	9.8
Wind Speed (ms-1)			
Surface	1.8	1.1	0.7
300 m	3.3	3.1	-0.1
1200 m	4.9	5.1	-0.9

Table 4-2g.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 4 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.4	298.7	-1.3
300 m	297.3	297.5	-0.2
1200 m	292.2	292.2	0.0
Specific Humidity (gkg-1)			
Surface	12.2	11.7	0.5
300 m	11.5	12.3	-0.9
1200 m	10.7	10.3	0.5
Wind Direction (degrees)			
Surface	29.3	11.9	19.0
300 m	10.5	7.2	-5.1
1200 m	21.4	20.2	4.6
Wind Speed (ms-1)			
Surface	1.4	0.8	0.7
300 m	4.1	4.3	-0.9
1200 m	5.0	4.9	-1.1

Table 4-2h.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 5 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.2	298.7	-1.5
300 m	296.5	296.0	0.6
1200 m	292.1	292.1	0.1
Specific Humidity (gkg-1)			
Surface	13.2	12.9	0.3
300 m	13.1	12.4	0.7
1200 m	11.7	11.0	0.6
Wind Direction (degrees)			
Surface	315.0	307.5	31.8
300 m	354.7	349.1	12.4
1200 m	1.7	0.3	9.4
Wind Speed (ms-1)			
Surface	2.8	1.9	0.7
300 m	5.1	5.2	-0.6
1200 m	4.4	5.8	-2.9

Table 4-2i.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 6 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.4	298.9	-0.5
300 m	297.1	297.6	-0.4
1200 m	292.8	292.9	-0.1
Specific Humidity (gkg-1)			
Surface	12.7	13.1	-0.4
300 m	13.0	13.1	-0.1
1200 m	10.3	10.9	-0.6
Wind Direction (degrees)			
Surface	318.7	328.3	35.3
300 m	303.7	267.7	14.5
1200 m	306.1	288.8	5.2
Wind Speed (ms-1)			
Surface	2.5	1.0	1.2
300 m	2.6	2.6	0.0
1200 m	3.3	4.3	-1.0

Table 4-2j.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 7 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.2	298.4	-1.2
300 m	297.9	298.6	-0.6
1200 m	293.4	293.7	-0.3
Specific Humidity (gkg-1)			
Surface	12.9	12.4	0.5
300 m	12.5	12.5	0.0
1200 m	10.5	10.5	0.0
Wind Direction (degrees)			
Surface	126.6	153.7	6.4
300 m	194.9	219.0	-8.8
1200 m	259.2	276.9	1.4
Wind Speed (ms-1)			
Surface	0.5	0.5	0.7
300 m	1.3	1.2	0.4
1200 m	2.0	2.5	-0.7

Table 4-2k.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 8 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.4	297.8	-0.4
300 m	297.3	297.5	-0.1
1200 m	292.5	292.3	0.2
Specific Humidity (gkg-1)			
Surface	12.6	12.7	-0.1
300 m	11.2	12.3	-1.1
1200 m	9.2	9.8	-0.6
Wind Direction (degrees)			
Surface	223.1	281.3	31.7
300 m	307.9	273.1	15.1
1200 m	313.5	291.9	20.1
Wind Speed (ms-1)			
Surface	0.2	0.4	0.3
300 m	0.8	1.3	-0.6
1200 m	1.5	2.6	-0.9

Table 4-2l.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 9 September 1999

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	295.5	296.1	-0.6
300 m	294.4	293.7	0.7
1200 m	290.9	290.7	0.2
Specific Humidity (gkg-1)			
Surface	11.6	11.5	0.2
300 m	10.8	10.2	0.6
1200 m	6.9	8.9	-2.0
Wind Direction (degrees)			
Surface	353.6	338.3	38.6
300 m	19.3	20.6	-4.8
1200 m	19.8	22.4	-18.2
Wind Speed (ms-1)			
Surface	2.0	1.3	0.7
300 m	3.5	4.2	-1.0
1200 m	3.5	3.4	-0.1

Table 4-3.
Comparison of MM5-Derived and Observation Data Derived Mixing Heights at Nashville for 16-22 June 2001

Date	1500 CST	
	MM5 Derived	Observation Derived
16 June	1196	1590
17 June	1613	1700
18 June	1194	1500
19 June	1146	2500
20 June	1161	2275
21 June	NA*	2550
22 June	1193	950

* NA indicates that a reliable estimate could not be derived.

Table 4-4a.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 16 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.2	297.5	0.8
300 m	296.9	297.0	-0.1
1200 m	290.6	289.9	0.7
Specific Humidity (gkg-1)			
Surface	12.1	12.2	-0.1
300 m	11.1	11.2	-0.1
1200 m	8.0	8.6	-0.6
Wind Direction (degrees)			
Surface	311.7	305.6	22.3
300 m	334.2	320.9	14.8
1200 m	349.9	331.7	13.7
Wind Speed (ms-1)			
Surface	1.9	1.0	1.1
300 m	4.2	4.5	0.1
1200 m	5.1	4.7	0.7

Table 4-4b.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 17 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	299.0	298.2	0.9
300 m	297.7	297.6	0.1
1200 m	291.7	291.0	0.6
Specific Humidity (gkg-1)			
Surface	10.3	11.5	-1.1
300 m	9.1	9.5	-0.4
1200 m	6.2	7.0	-0.8
Wind Direction (degrees)			
Surface	23.2	24.9	9.4
300 m	22.2	18.4	3.0
1200 m	38.1	33.1	8.4
Wind Speed (ms-1)			
Surface	1.2	0.4	1.1
300 m	3.2	3.5	-0.5
1200 m	4.9	4.5	0.2

Table 4-4c.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 18 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	299.4	298.5	0.9
300 m	298.0	298.1	-0.1
1200 m	291.2	291.0	0.2
Specific Humidity (gkg-1)			
Surface	11.9	11.9	-0.1
300 m	10.2	10.5	-0.2
1200 m	8.1	8.3	-0.2
Wind Direction (degrees)			
Surface	134.4	153.2	-3.1
300 m	116.7	103.3	12.0
1200 m	123.3	119.5	-7.0
Wind Speed (ms-1)			
Surface	2.1	1.4	1.3
300 m	4.2	4.2	-0.3
1200 m	5.0	4.1	0.9

Table 4-4d.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 19 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.9	298.4	0.5
300 m	297.2	297.5	-0.3
1200 m	290.4	290.2	0.3
Specific Humidity (gkg-1)			
Surface	11.9	12.8	-0.9
300 m	10.5	11.6	-1.1
1200 m	9.0	9.3	-0.3
Wind Direction (degrees)			
Surface	158.7	154.6	14.5
300 m	156.7	147.7	2.7
1200 m	147.7	133.4	13.5
Wind Speed (ms-1)			
Surface	2.3	1.0	1.3
300 m	4.8	3.8	0.4
1200 m	4.6	3.2	1.0

Table 4-4e.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 20 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	298.2	297.6	0.6
300 m	296.8	296.4	0.4
1200 m	290.4	290.0	0.4
Specific Humidity (gkg-1)			
Surface	12.3	13.4	-1.1
300 m	11.5	12.4	-0.9
1200 m	9.7	10.3	-0.7
Wind Direction (degrees)			
Surface	177.7	136.7	21.6
300 m	196.8	195.3	8.6
1200 m	215.5	197.5	-5.6
Wind Speed (ms-1)			
Surface	0.9	0.4	0.7
300 m	2.5	2.2	-0.5
1200 m	1.5	1.0	-0.2

Table 4-4f.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 21 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	297.3	296.7	0.6
300 m	296.3	296.3	0.1
1200 m	290.1	289.7	0.4
Specific Humidity (gkg-1)			
Surface	12.6	13.5	-0.9
300 m	11.8	13.3	-1.4
1200 m	10.2	10.7	-0.5
Wind Direction (degrees)			
Surface	250.2	255.4	20.8
300 m	230.4	242.5	4.0
1200 m	258.2	259.2	7.7
Wind Speed (ms-1)			
Surface	1.1	0.9	0.4
300 m	3.5	4.6	-1.1
1200 m	4.1	4.3	-0.3

Table 4-4g.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 22 June 2001

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	289.6	288.8	0.8
300 m	294.1	293.5	0.6
1200 m	287.9	287.7	0.2
Specific Humidity (gkg-1)			
Surface	12.0	12.3	-0.3
300 m	11.2	12.2	-1.0
1200 m	9.5	9.2	0.3
Wind Direction (degrees)			
Surface	308.4	299.5	29.8
300 m	301.0	285.2	19.0
1200 m	301.0	285.2	19.0
Wind Speed (ms-1)			
Surface	1.0	0.8	0.6
300 m	2.2	3.3	-0.7
1200 m	3.0	4.3	-1.4

Table 4-5.
Comparison of MM5-Derived and Observation Data Derived Mixing Heights at Nashville for 04–10 July 2002

Date	1500 CST	
	MM5 Derived	Observation Derived
04 July	2037	1850
05 July	NA*	2030
06 July	1187	1050
07 July	1191	1050
08 July	1212	1930
09 July	1197	675
10 July	1205	NA

* NA indicates that a reliable estimate could not be derived.

Table 4-6a.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 4 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.2	299.4	1.9
300 m	298.5	298.3	0.2
1200 m	292.3	292.1	0.3
Specific Humidity (gkg-1)			
Surface	17.6	15.2	2.4
300 m	15.9	14.6	1.3
1200 m	12.7	12.0	0.8
Wind Direction (degrees)			
Surface	34.1	64.7	23.3
300 m	3.5	4.0	2.2
1200 m	46.0	63.1	5.8
Wind Speed (ms-1)			
Surface	0.6	0.1	0.2
300 m	0.8	0.7	-1.1
1200 m	2.5	2.0	-0.4

Table 4-6b.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 5 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	2.5	2.0	-0.4
300 m	300.0	299.9	0.2
1200 m	293.3	292.9	0.5
Specific Humidity (gkg-1)			
Surface	15.7	15.5	0.1
300 m	14.2	15.8	-1.6
1200 m	12.0	12.6	-0.6
Wind Direction (degrees)			
Surface	46.7	40.9	10.0
300 m	58.0	49.0	17.0
1200 m	60.3	64.4	-1.1
Wind Speed (ms-1)			
Surface	1.4	0.4	0.8
300 m	1.6	1.2	-0.5
1200 m	4.0	3.4	0.2

Table 4-6c.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 6 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.5	300.8	0.7
300 m	299.8	300.2	-0.5
1200 m	293.4	293.2	0.2
Specific Humidity (gkg-1)			
Surface	15.9	14.9	1.0
300 m	14.8	14.7	0.1
1200 m	11.8	12.0	-0.2
Wind Direction (degrees)			
Surface	60.7	52.1	10.7
300 m	70.4	74.7	13.6
1200 m	66.3	74.0	1.7
Wind Speed (ms-1)			
Surface	2.5	1.5	1.0
300 m	3.2	2.6	-0.4
1200 m	4.4	3.1	0.7

Table 4-6d.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 7 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	300.9	300.0	0.9
300 m	299.4	299.8	-0.4
1200 m	293.2	293.3	-0.1
Specific Humidity (gkg-1)			
Surface	14.0	14.0	0.1
300 m	14.0	14.3	-0.4
1200 m	11.5	11.8	-0.3
Wind Direction (degrees)			
Surface	89.4	80.2	9.4
300 m	95.4	80.2	9.3
1200 m	84.6	83.1	-1.6
Wind Speed (ms-1)			
Surface	2.3	1.4	0.8
300 m	4.2	3.6	0.2
1200 m	4.6	3.3	1.1

Table 4-6e.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
8 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.5	300.1	1.4
300 m	298.8	299.1	-0.2
1200 m	292.6	292.1	0.5
Specific Humidity (gkg-1)			
Surface	15.5	14.1	1.4
300 m	14.8	14.0	0.8
1200 m	11.0	11.8	-0.8
Wind Direction (degrees)			
Surface	153.5	155.1	5.6
300 m	158.7	154.8	9.6
1200 m	147.6	164.1	8.1
Wind Speed (ms-1)			
Surface	1.4	0.8	0.6
300 m	2.9	2.8	0.2
1200 m	2.4	1.7	0.9

Table 4-6f.
Comparison of MM5-Simulated and Observed Meteorological Parameters:
9 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	302.0	300.6	1.4
300 m	299.3	299.3	0.1
1200 m	292.8	292.3	0.5
Specific Humidity (gkg-1)			
Surface	15.2	15.2	-0.1
300 m	14.7	15.0	-0.3
1200 m	12.1	12.3	-0.2
Wind Direction (degrees)			
Surface	219.3	218.5	6.4
300 m	225.3	222.4	14.8
1200 m	243.5	239.8	9.3
Wind Speed (ms-1)			
Surface	2.4	1.5	0.7
300 m	4.2	4.1	-0.7
1200 m	3.6	2.8	0.6

Table 4-6g.
Comparison of MM5-Simulated and Observed Meteorological Parameters: 10 July 2002

Site Name	Simulated Mean	Observed Mean	Mean Residual (Bias)
Temperature (K)			
Surface	301.4	299.9	1.5
300 m	299.1	298.8	0.4
1200 m	292.9	292.7	0.2
Specific Humidity (gkg-1)			
Surface	16.1	15.9	0.2
300 m	14.9	15.3	-0.4
1200 m	12.9	12.5	0.4
Wind Direction (degrees)			
Surface	245.4	241.0	32.6
300 m	251.8	253.4	5.2
1200 m	251.8	253.4	5.2
Wind Speed (ms-1)			
Surface	1.5	1.0	-0.2
300 m	3.6	4.1	-1.3
1200 m	3.8	4.2	-0.4

Figure 4-1a.
MM5-Derived 12-km Wind Field for 0700 EST on 29 August 1999 at Approximately 300 m agl

Observations are overplotted in bold

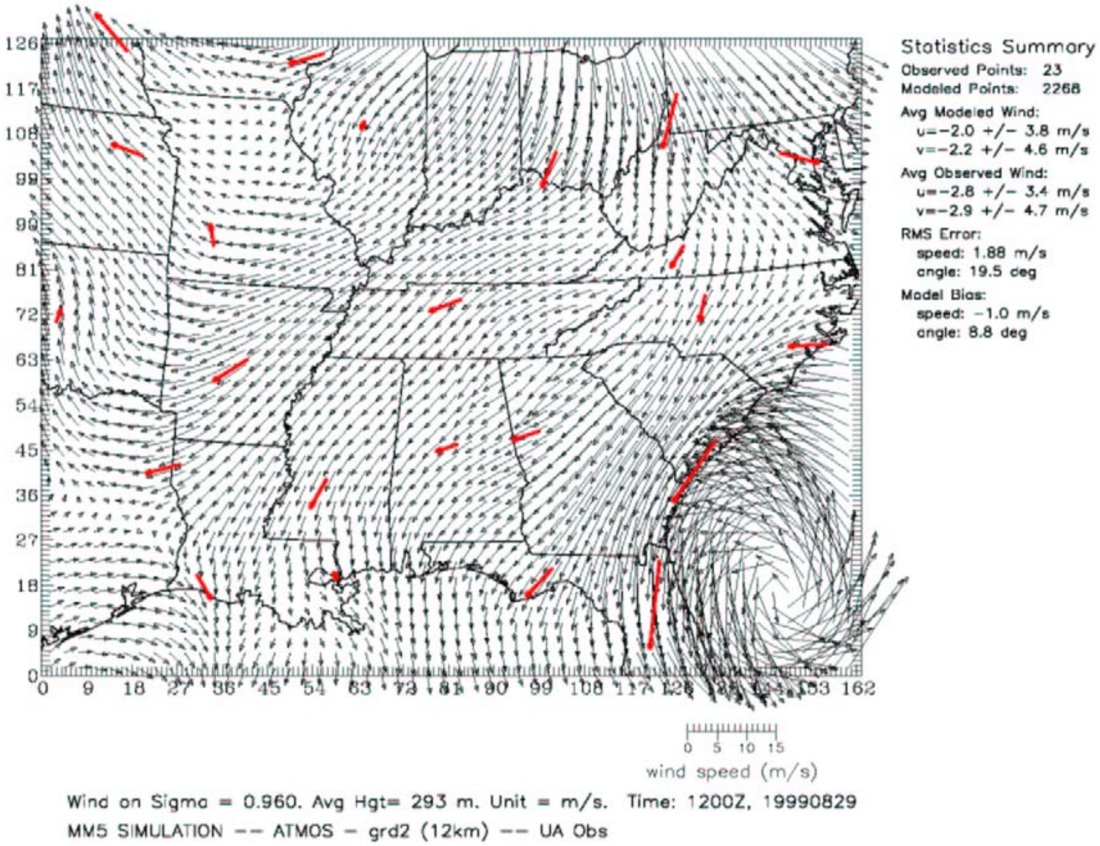


Figure 4-1b.
MM5-Derived 12-km Wind Field for 0700 EST on 30 August 1999
at Approximately 300 m agl.

Observations are overplotted in bold

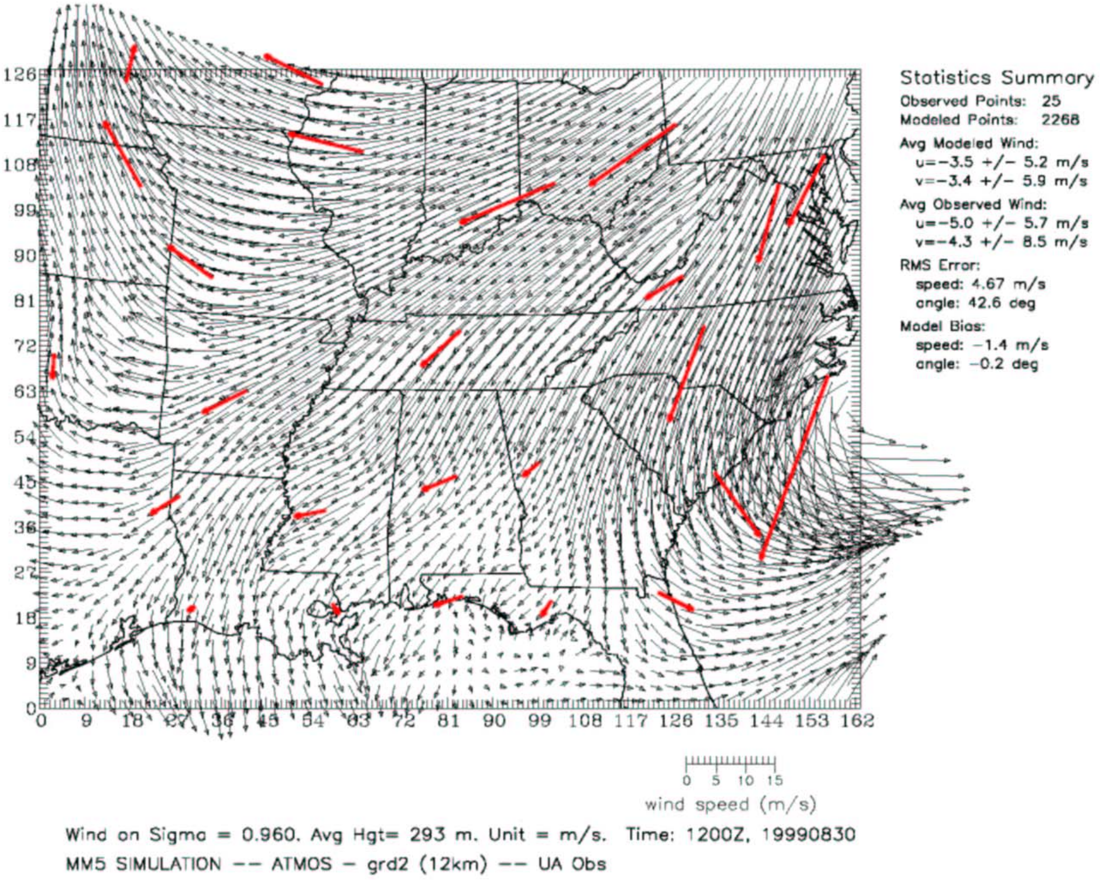


Figure 4-1c.
MM5-Derived 12-km Wind Field for 0700 EST on 31 August 1999
at Approximately 300 m agl.

Observations are overplotted in bold

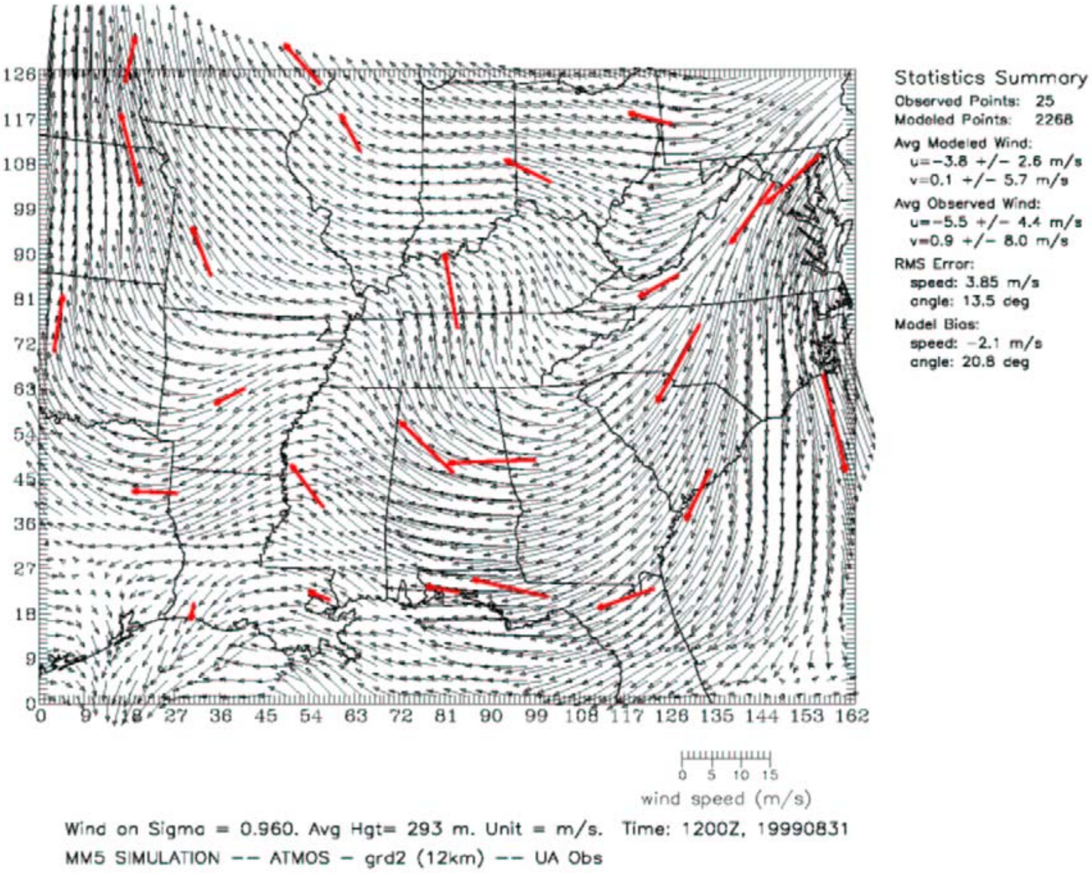
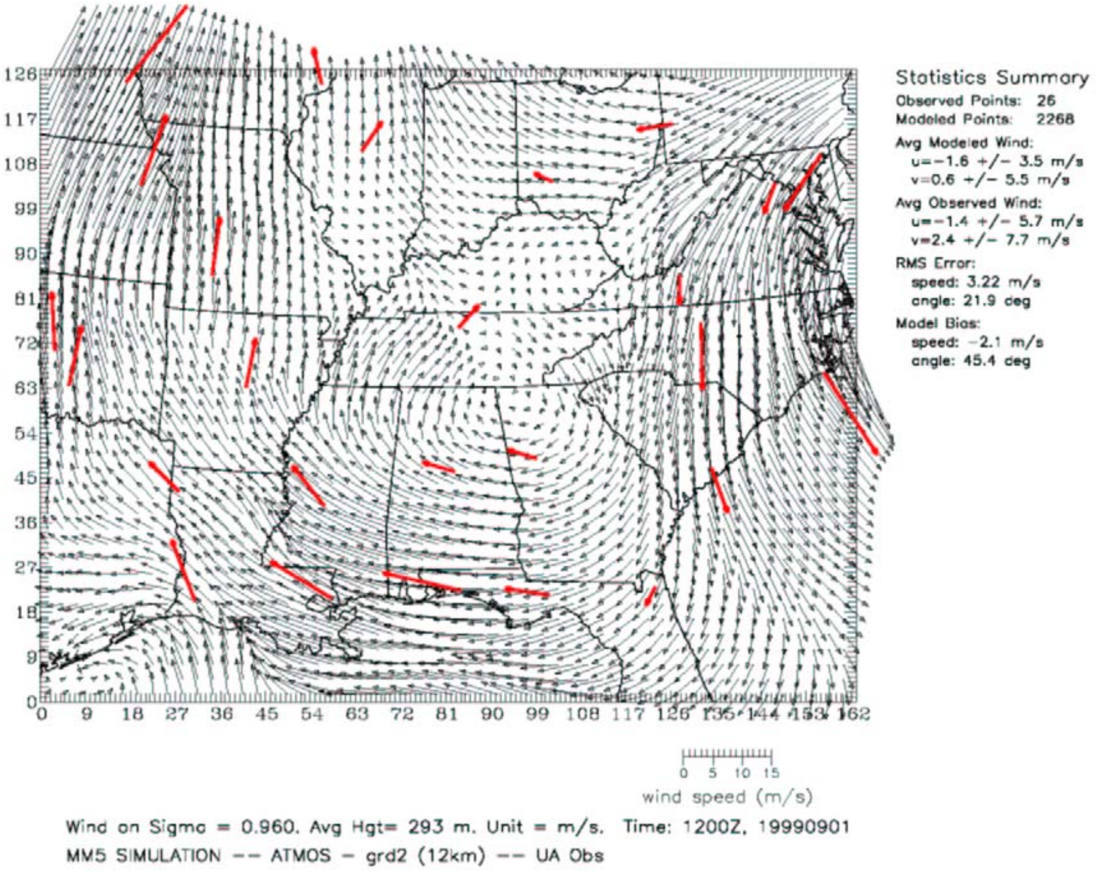


Figure 4-1d.
MM5-Derived 12-km Wind Field for 0700 EST on 1 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold



Statistics Summary
Observed Points: 26
Modeled Points: 2268
Avg Modeled Wind:
u=-1.6 +/- 3.5 m/s
v=0.6 +/- 5.5 m/s
Avg Observed Wind:
u=-1.4 +/- 5.7 m/s
v=2.4 +/- 7.7 m/s
RMS Error:
speed: 3.22 m/s
angle: 21.9 deg
Model Bias:
speed: -2.1 m/s
angle: 45.4 deg

Wind on Sigma = 0.960. Avg Hgt= 293 m. Unit = m/s. Time: 1200Z. 19990901
MM5 SIMULATION -- ATMOS - grd2 (12km) -- UA Obs

Figure 4-1e.
MM5-Derived 12-km Wind Field for 0700 EST on 2 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

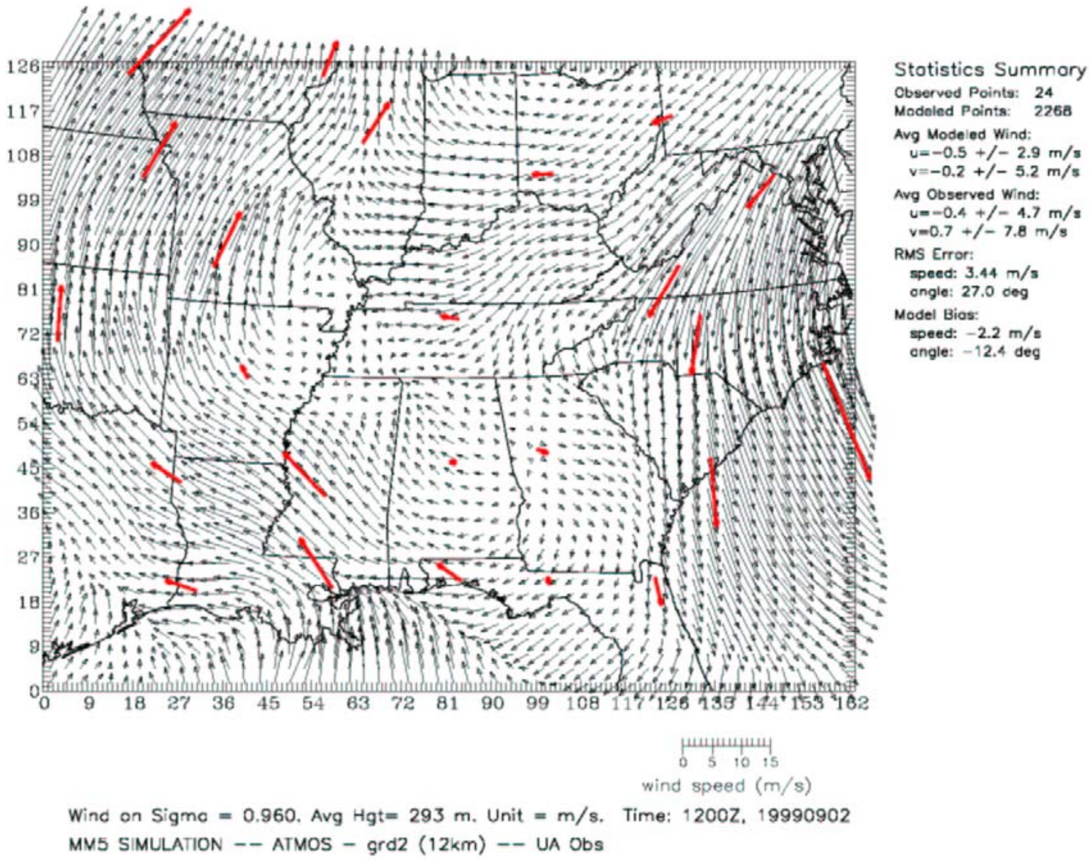


Figure 4-1f.
MM5-Derived 12-km Wind Field for 0700 EST on 3 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

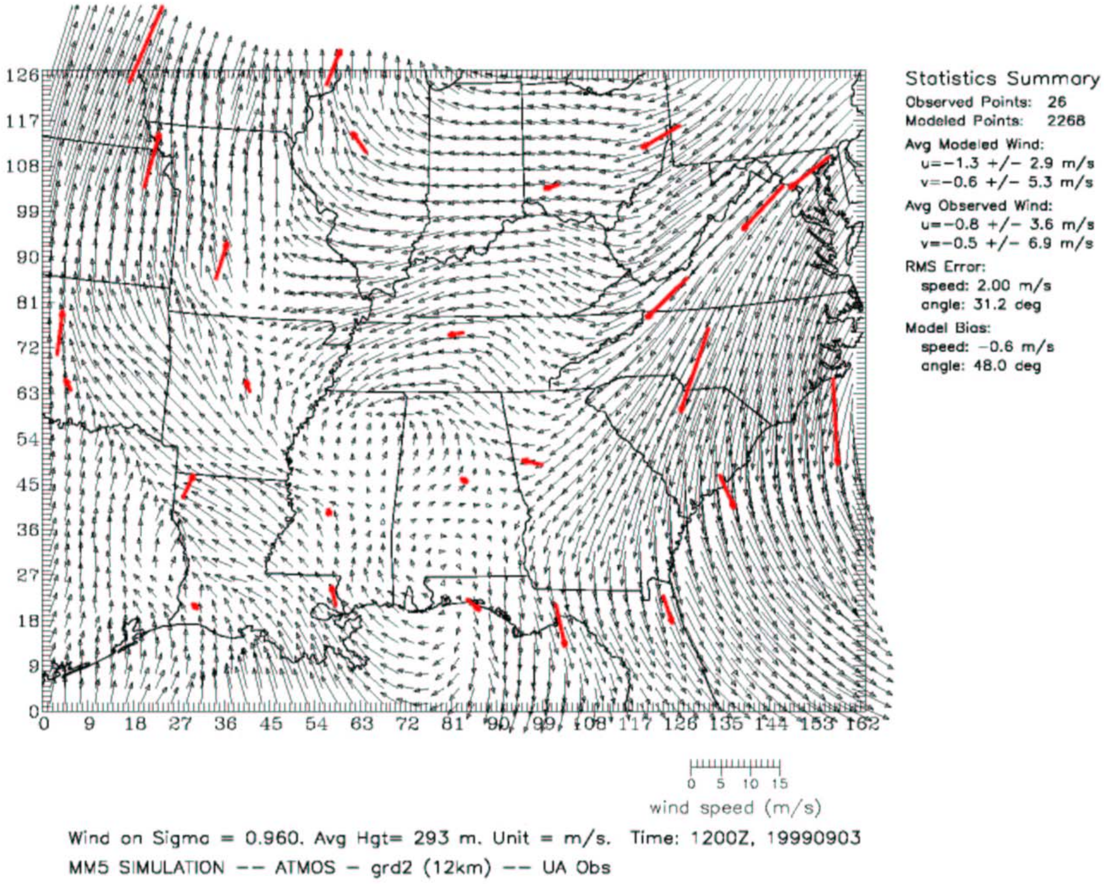


Figure 4-1g.
MM5-Derived 12-km Wind Field for 0700 EST on 4 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

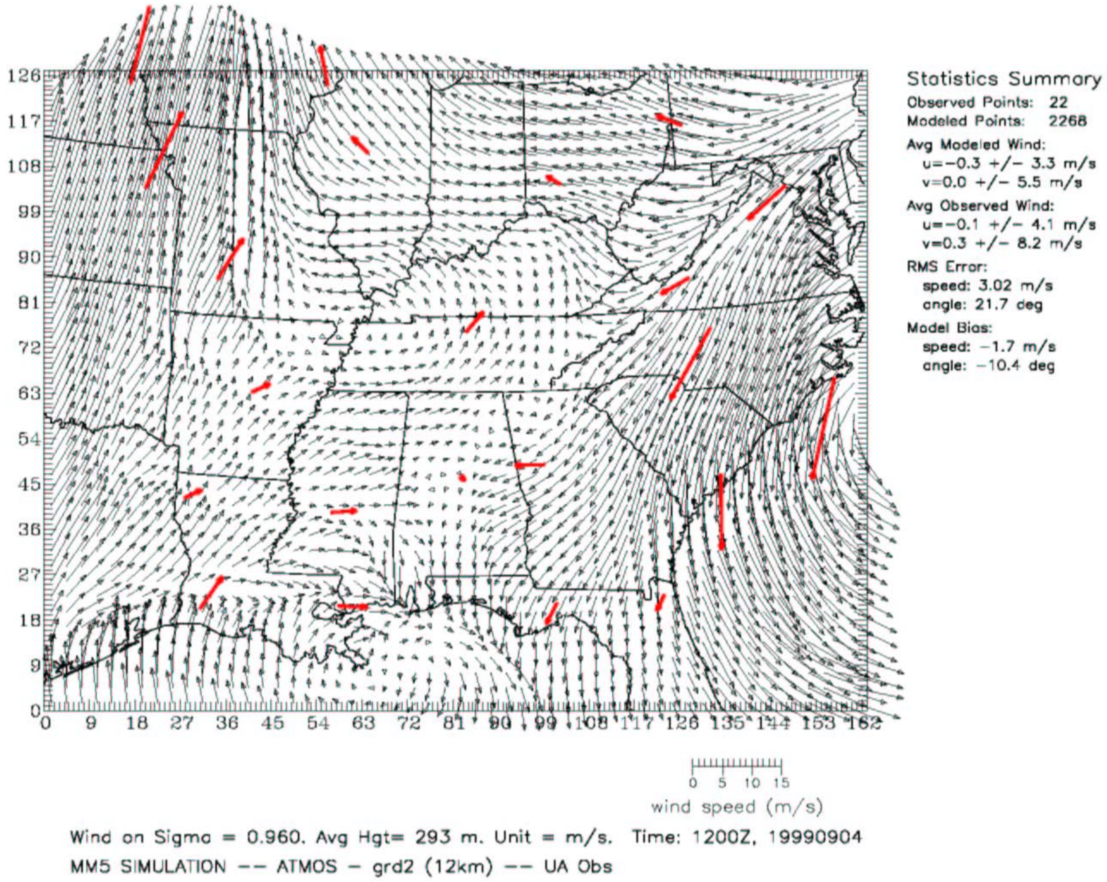
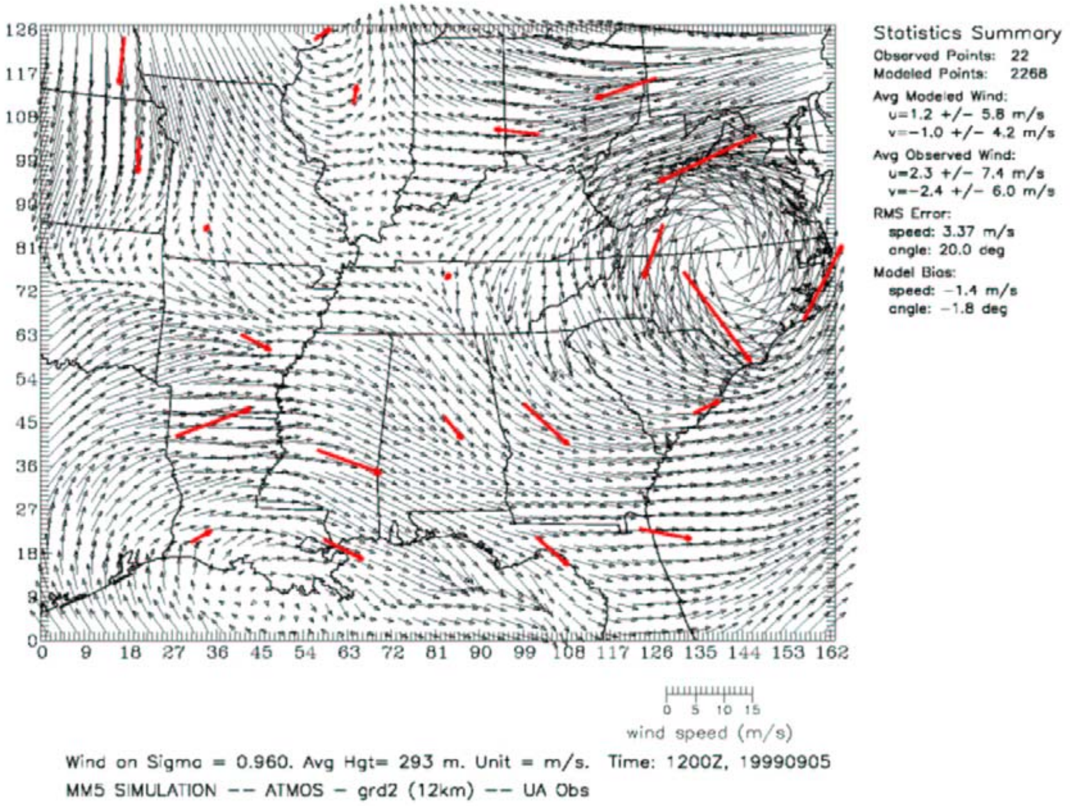


Figure 4-1h.
MM5-Derived 12-km Wind Field for 0700 EST on 5 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold

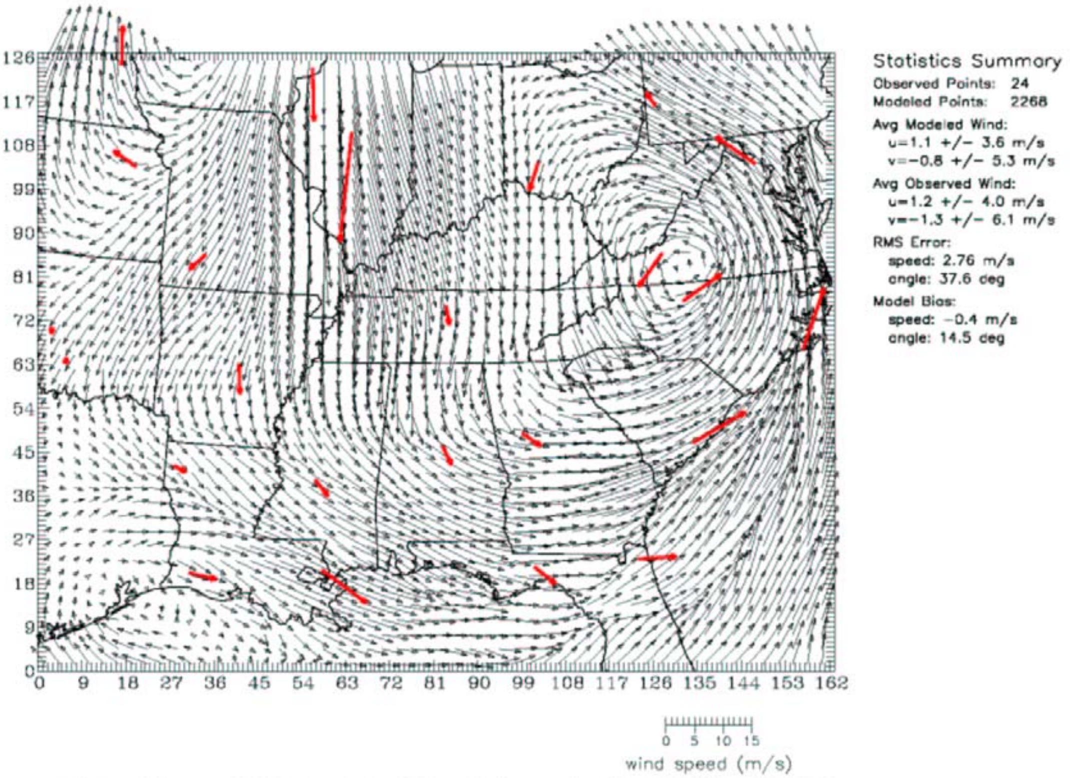


Statistics Summary
Observed Points: 22
Modeled Points: 2268
Avg Modeled Wind:
u=1.2 +/- 5.8 m/s
v=-1.0 +/- 4.2 m/s
Avg Observed Wind:
u=2.3 +/- 7.4 m/s
v=-2.4 +/- 6.0 m/s
RMS Error:
speed: 3.37 m/s
angle: 20.0 deg
Model Bias:
speed: -1.4 m/s
angle: -1.8 deg

Wind on Sigma = 0.960. Avg Hgt= 293 m. Unit = m/s. Time: 1200Z, 19990905
MM5 SIMULATION -- ATMOS - grd2 (12km) -- UA Obs

Figure 4-1i.
MM5-Derived 12-km Wind Field for 0700 EST on 6 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold



Statistics Summary
Observed Points: 24
Modeled Points: 2268
Avg Modeled Wind:
u=1.1 +/− 3.6 m/s
v=−0.8 +/− 5.3 m/s
Avg Observed Wind:
u=1.2 +/− 4.0 m/s
v=−1.3 +/− 6.1 m/s
RMS Error:
speed: 2.76 m/s
angle: 37.6 deg
Model Bias:
speed: −0.4 m/s
angle: 14.5 deg

Wind on Sigma = 0.960. Avg Hgt= 293 m. Unit = m/s. Time: 1200Z, 19990906
MM5 SIMULATION -- ATMOS - grd2 (12km) -- UA Obs

Figure 4-1j.
MM5-Derived 12-km Wind Field for 0700 EST on 7 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold

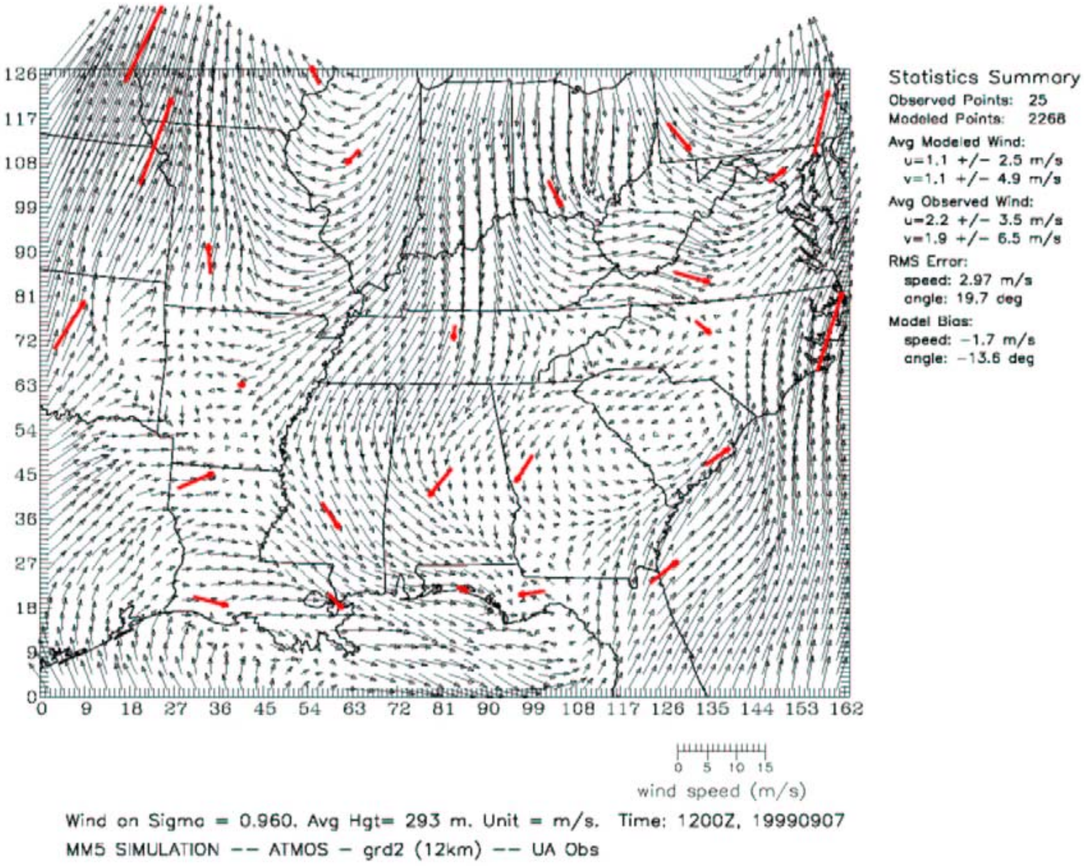
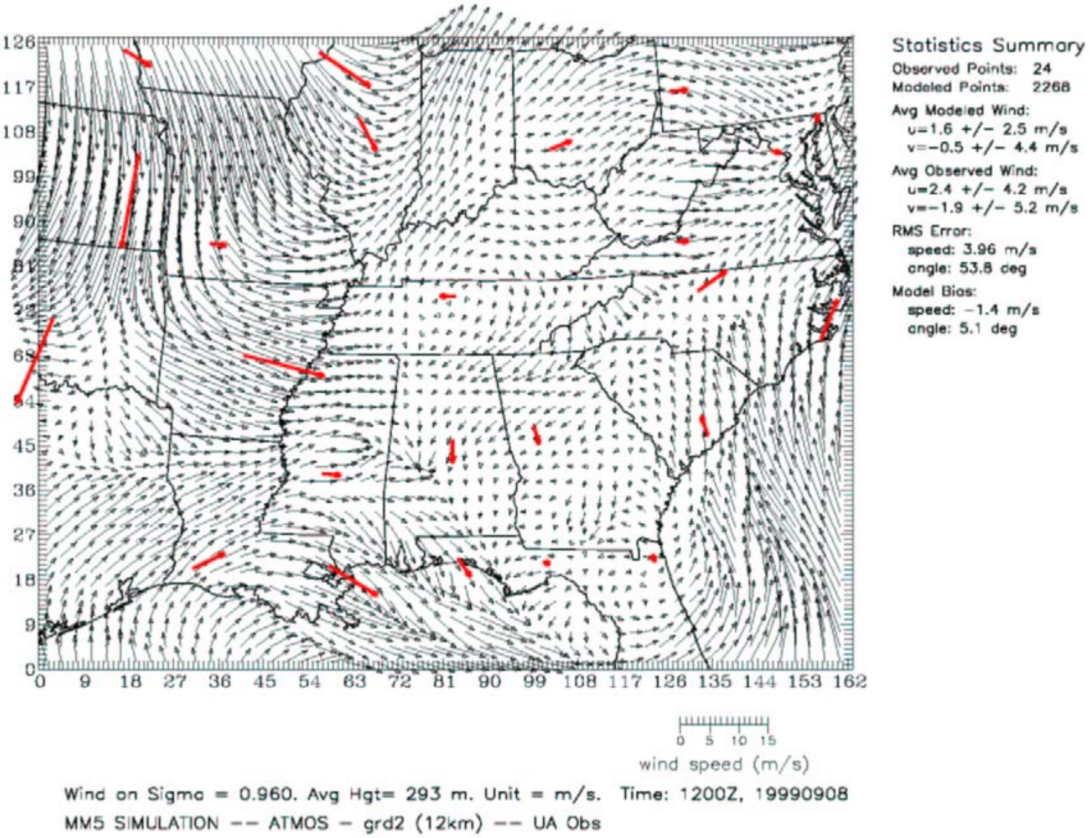


Figure 4-1k.
MM5-Derived 12-km Wind Field for 0700 EST on 8 September 1999 at Approximately 300 m agl.

Observations are overplotted in bold



Statistics Summary
Observed Points: 24
Modeled Points: 2268
Avg Modeled Wind:
u=1.6 +/- 2.5 m/s
v=-0.5 +/- 4.4 m/s
Avg Observed Wind:
u=2.4 +/- 4.2 m/s
v=-1.9 +/- 5.2 m/s
RMS Error:
speed: 3.96 m/s
angle: 53.8 deg
Model Bias:
speed: -1.4 m/s
angle: 5.1 deg

Wind on Sigma = 0.960. Avg Hgt= 293 m. Unit = m/s. Time: 1200Z, 19990908
MM5 SIMULATION -- ATMOS - grd2 (12km) -- UA Obs

Figure 4-1l.
MM5-Derived 12-km Wind Field for 0700 EST on 9 September 1999
at Approximately 300 m agl.

Observations are overplotted in bold

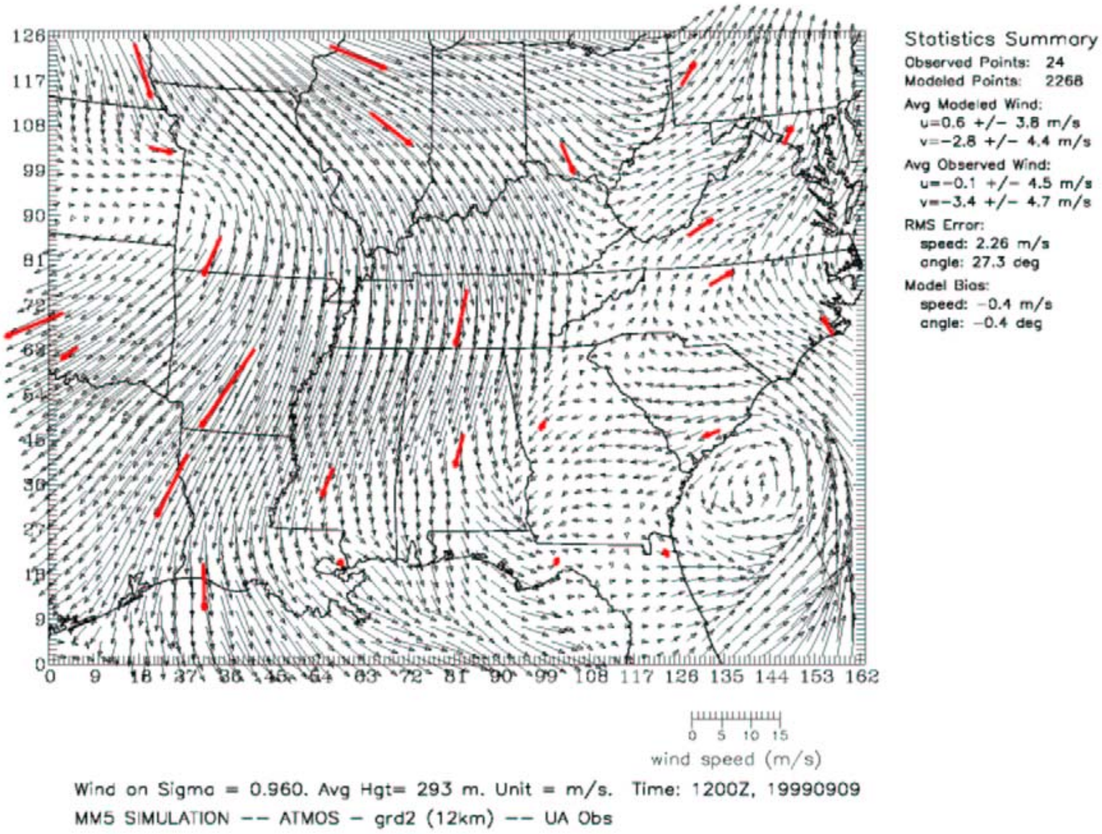


Figure 4-2.
Simulated and Observed Temperatures at Memphis, Nashville, Knoxville, and Chattanooga for 29 August to 9 September 1999

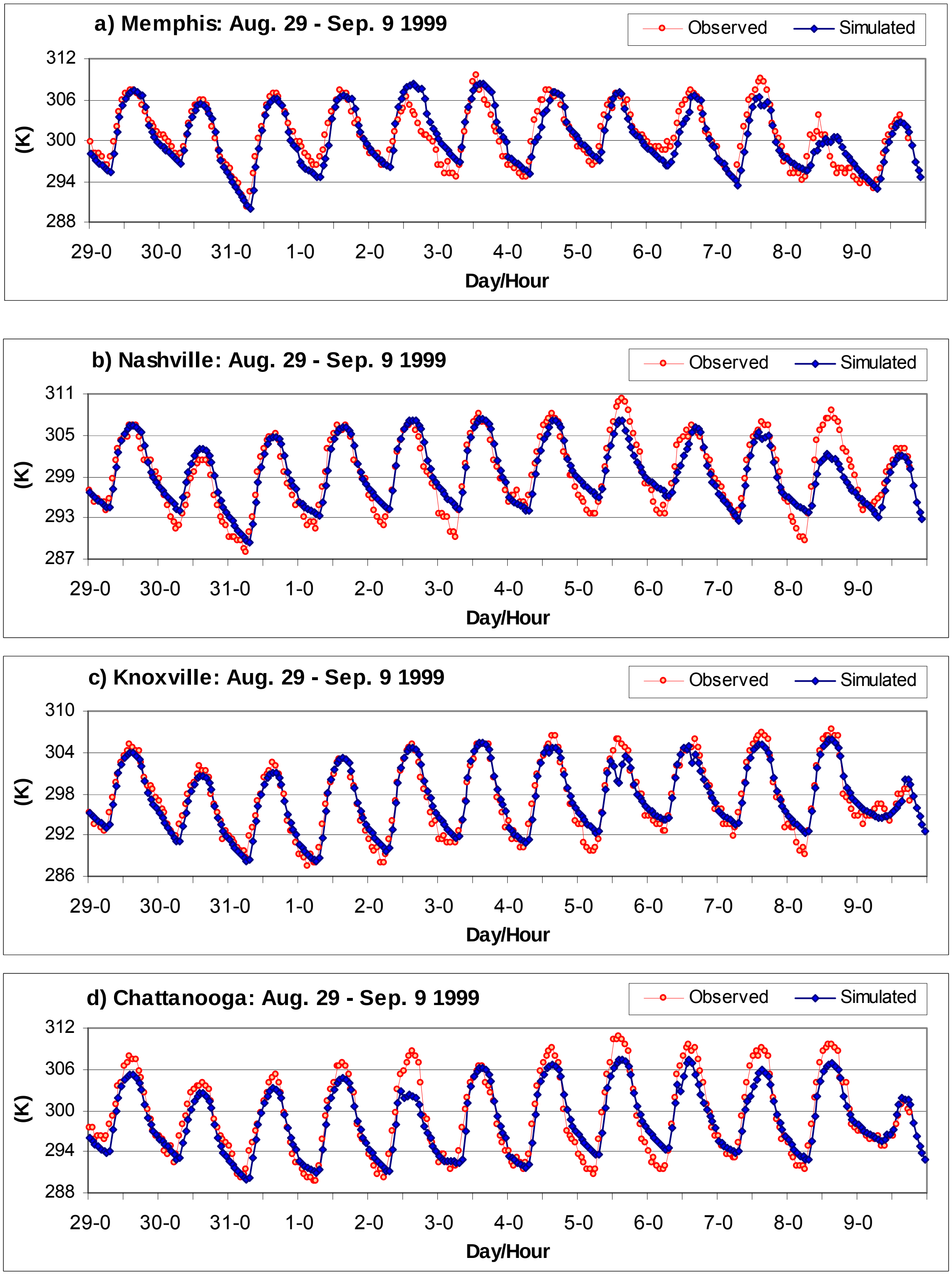
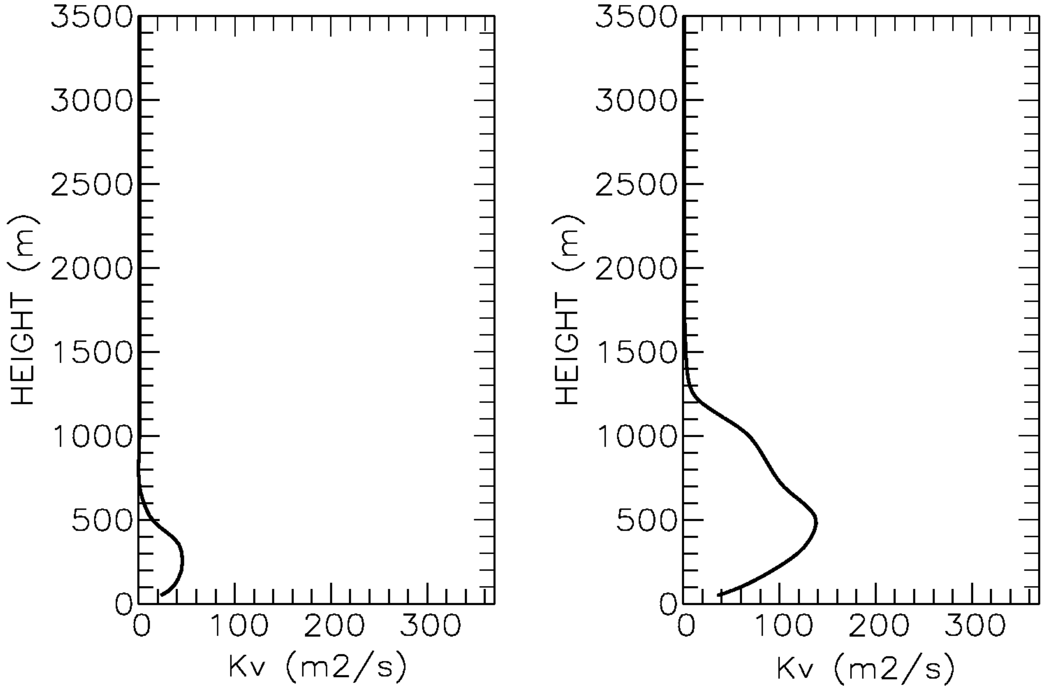
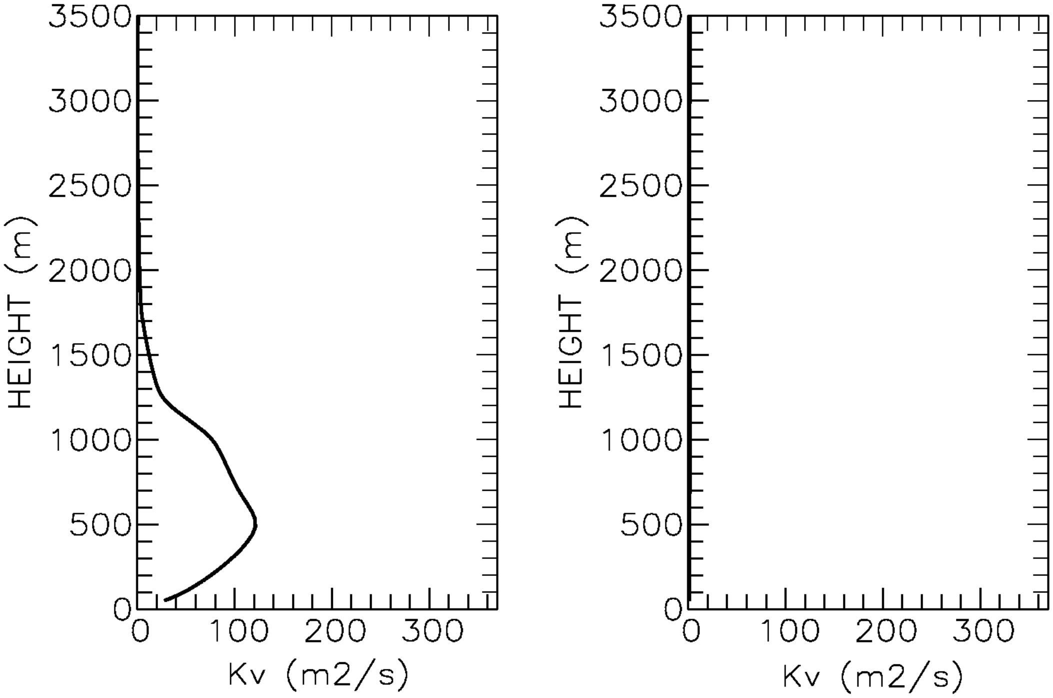


Figure 4-3.
K_v Profiles for Nashville, TN on 31 August 1999



a) 0900 CST

b) 1200 CST



c) 1500 CST

d) 1800 CST

Figure 4-4a.
MM5-Derived 12-km Wind Field for 0700 EST on 16 June 2001
at Approximately 300 m agl.

Observations are overplotted in bold

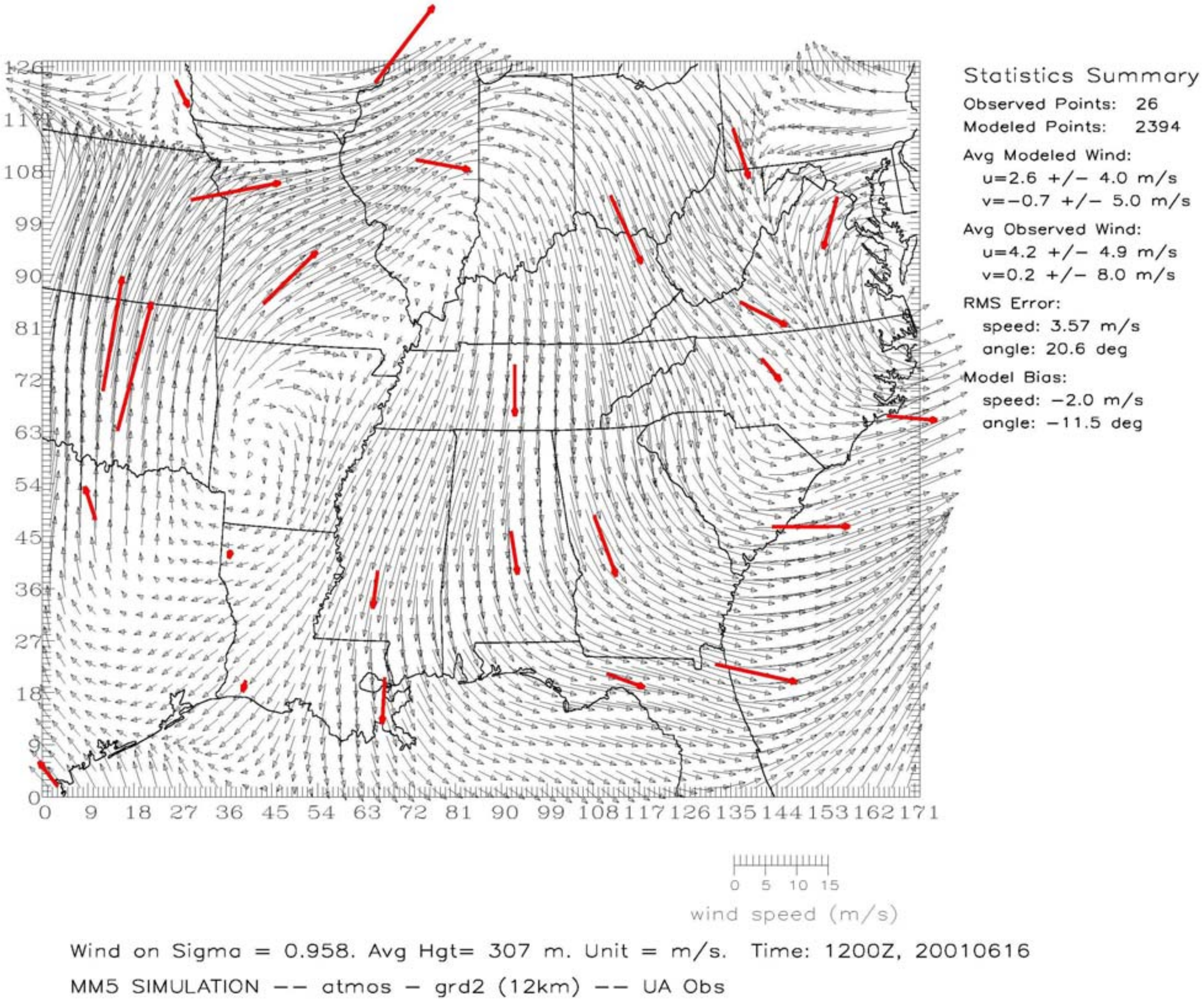


Figure 4-4b.
MM5-derived 12-km wind field for 0700 EST on 17 June 2001
at 300 m agl.

Observations are overplotted in bold.

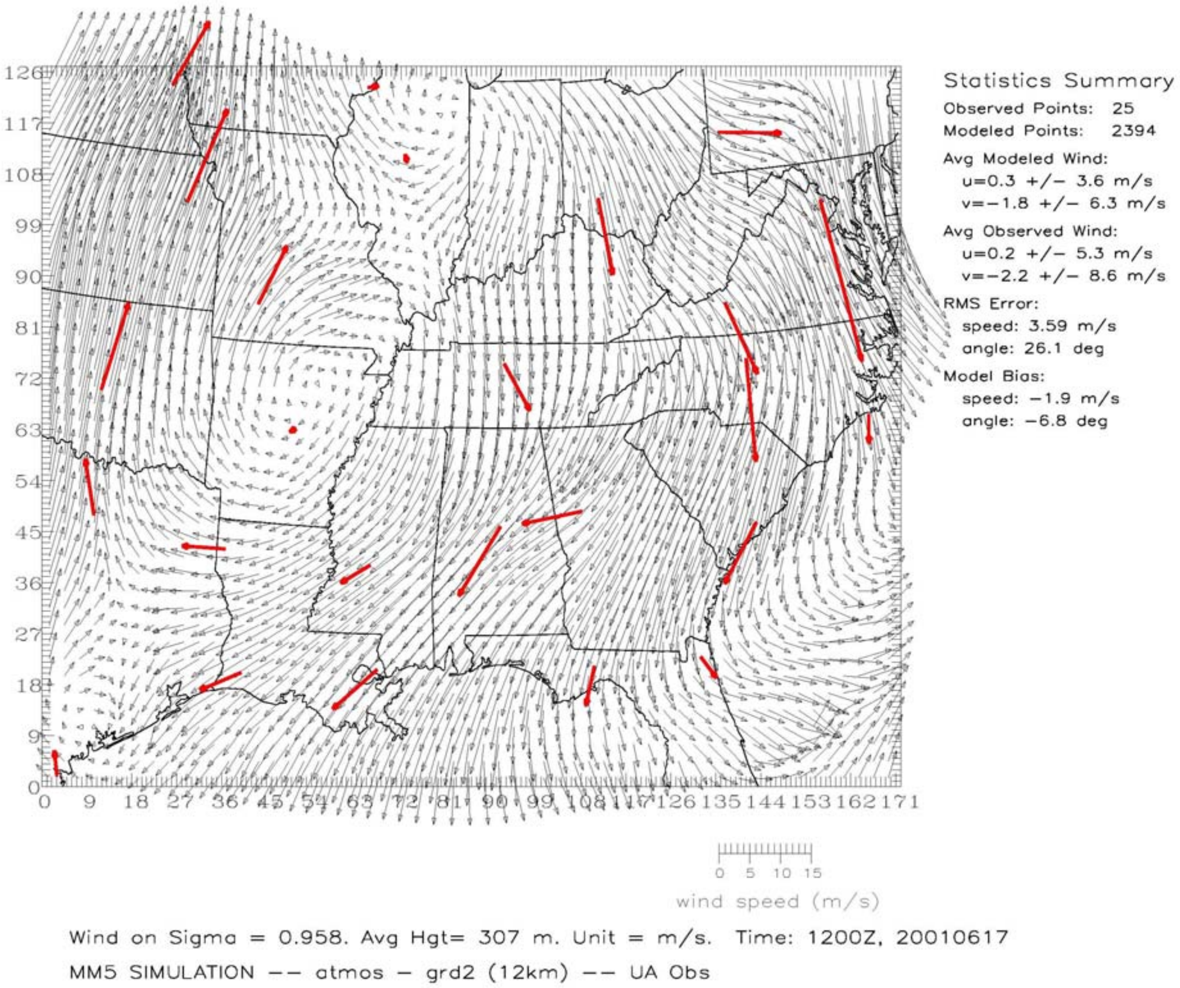


Figure 4-4c.
MM5-derived 12-km wind field for 0700 EST on 18 June 2001
at 300 m agl.

Observations are overplotted in bold.

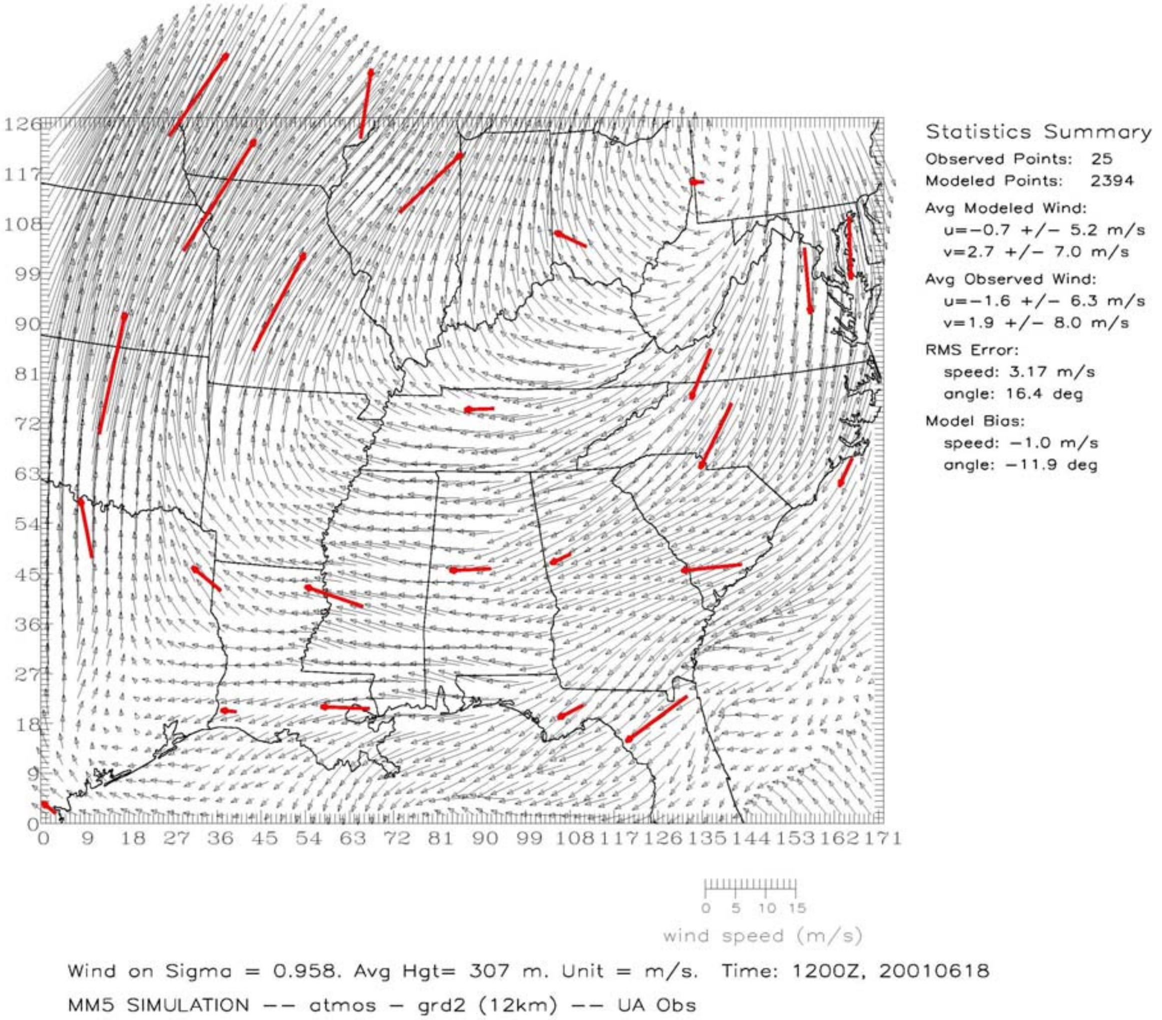


Figure 4-4d.
MM5-derived 12-km Wind Field for 0700 EST on 19 June 2001 at 300 m agl.

Observations are overplotted in bold.

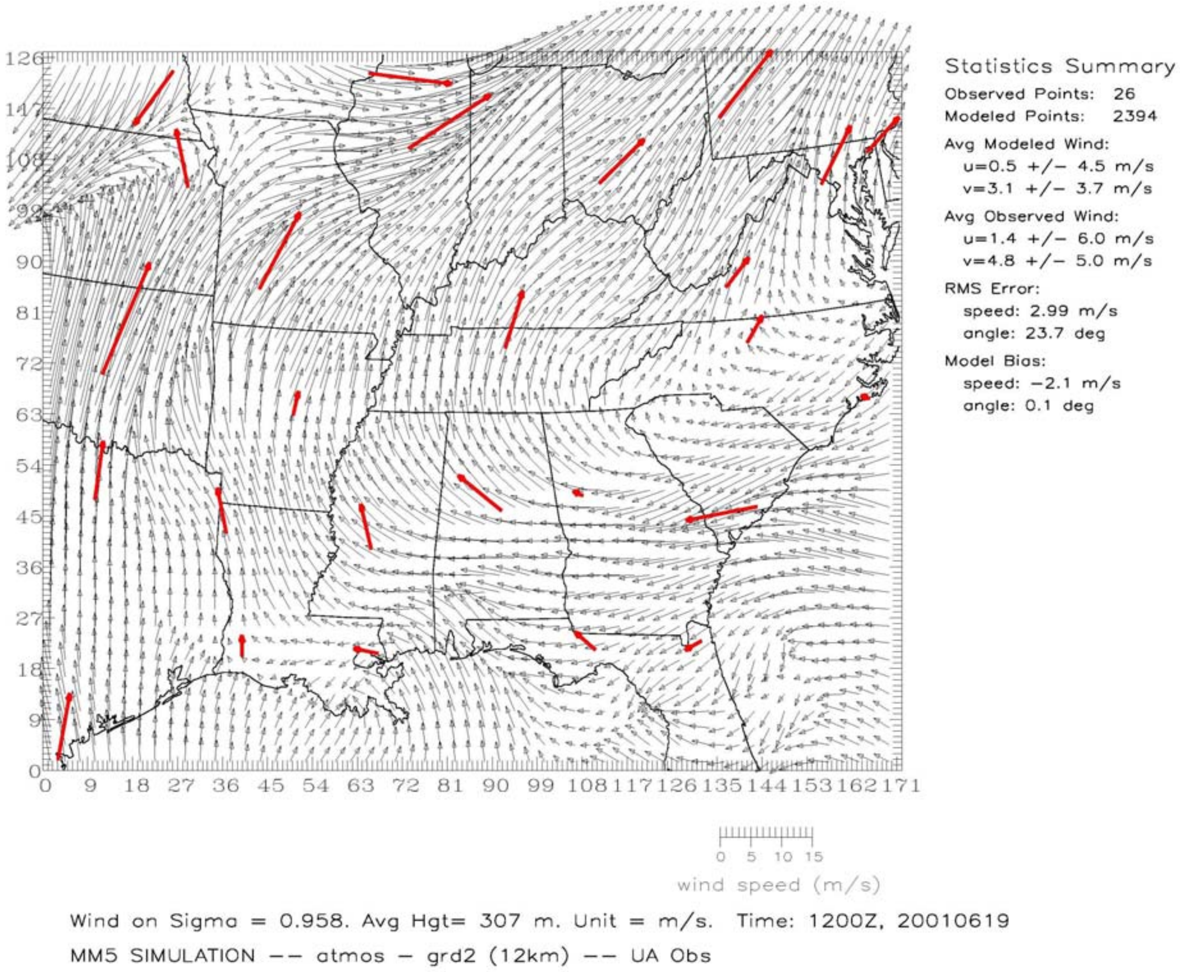


Figure 4-4e.
MM5-derived 12-km wind field for 0700 EST on 20 June 2001
at 300 m agl.

Observations are overplotted in bold.

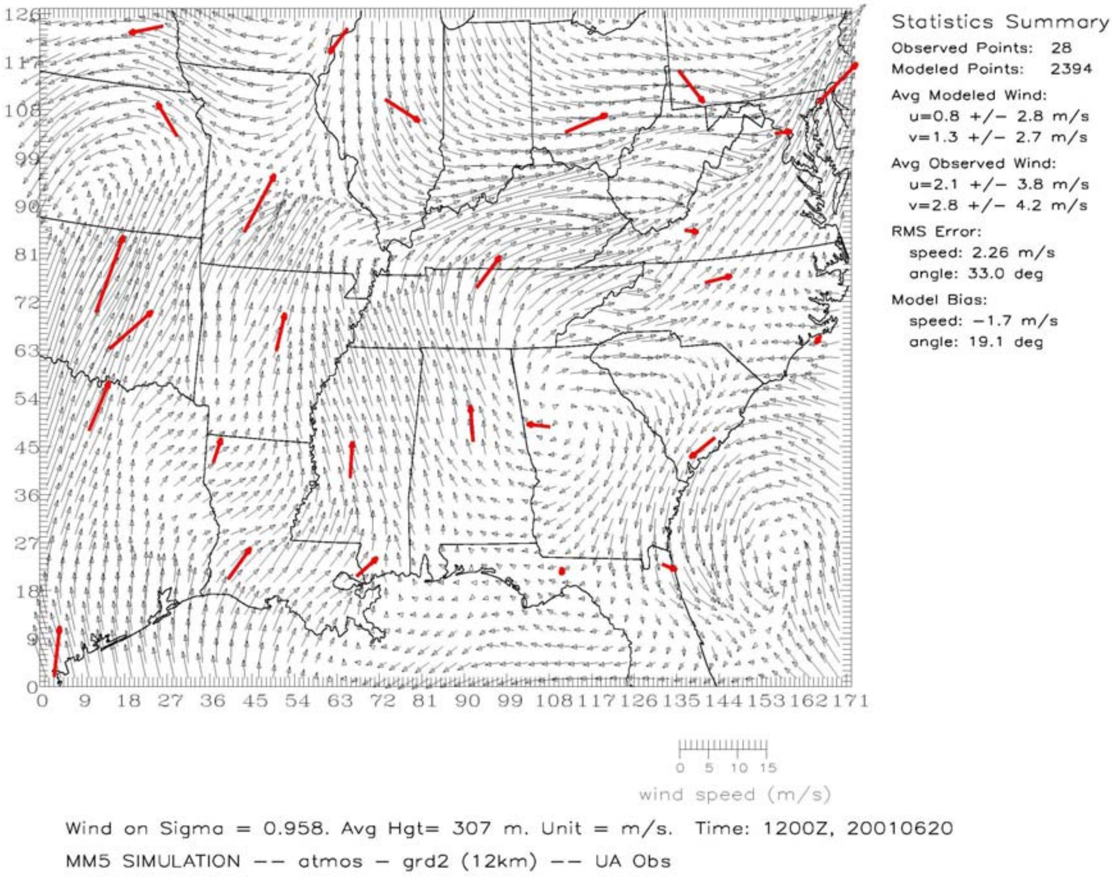


Figure 4-4f.
MM5-derived 12-km wind field for 0700 EST on 21 June 2001
at 300 m agl.

Observations are overplotted in bold.

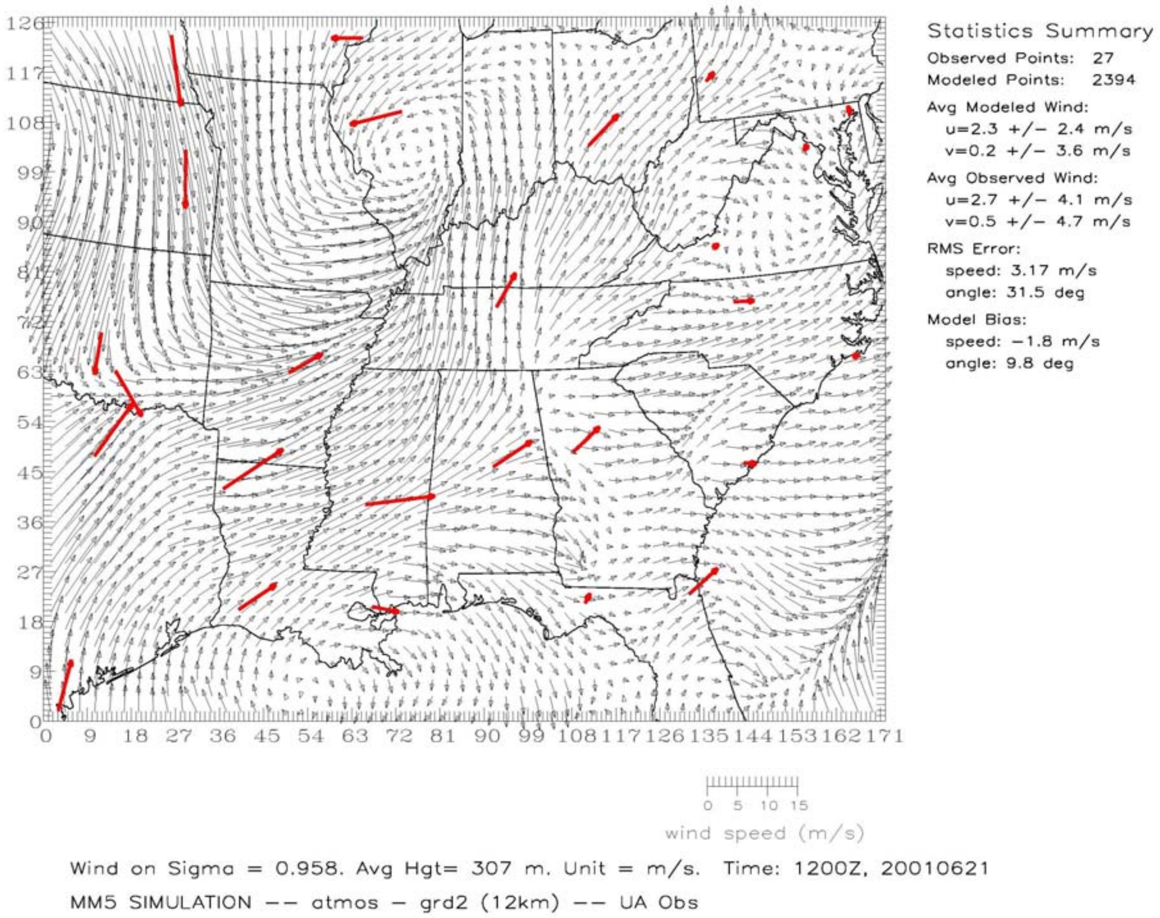
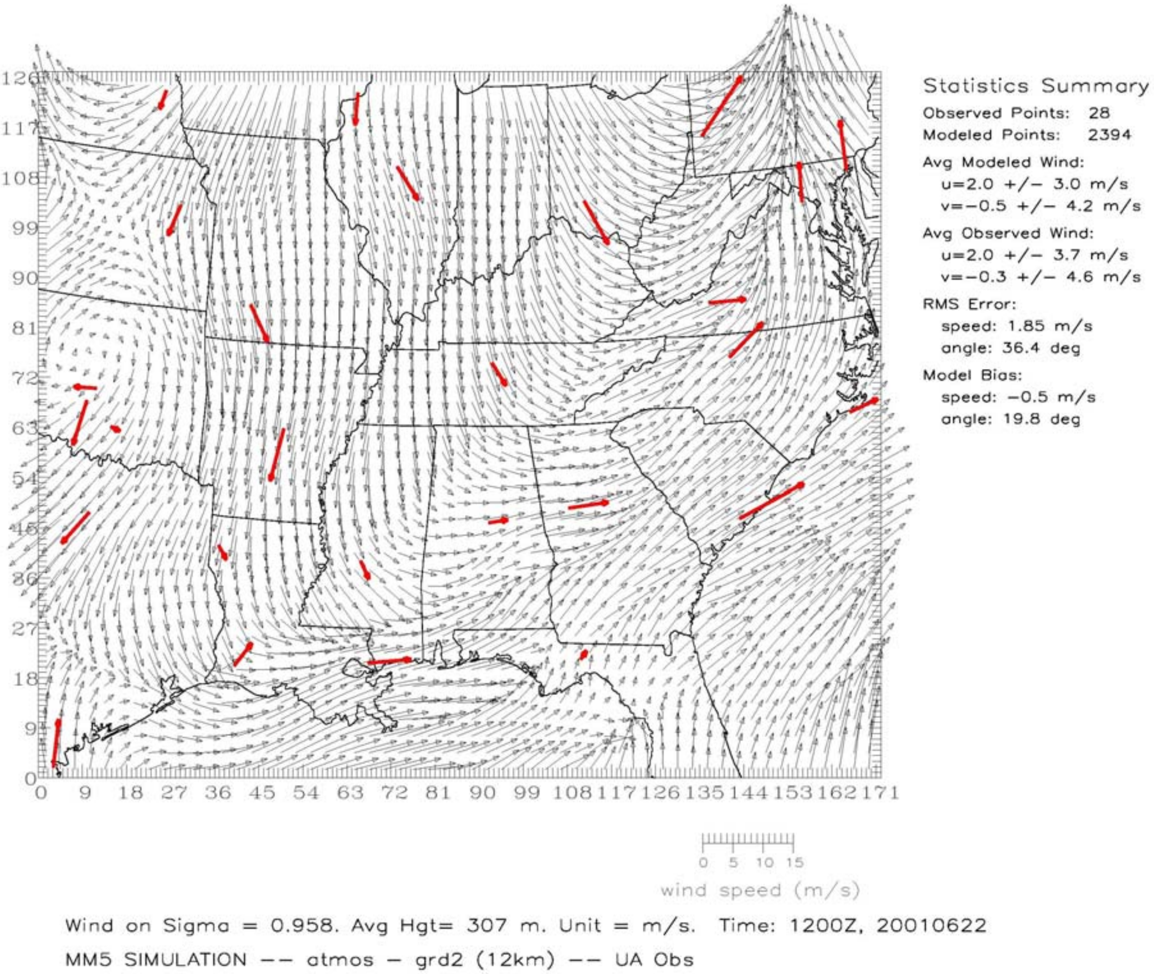


Figure 4-4g.
MM5-derived 12-km wind field for 0700 EST on 22 June 2001
at 300 m agl.

Observations are overplotted in bold.



Statistics Summary
Observed Points: 28
Modeled Points: 2394
Avg Modeled Wind:
u=2.0 +/− 3.0 m/s
v=−0.5 +/− 4.2 m/s
Avg Observed Wind:
u=2.0 +/− 3.7 m/s
v=−0.3 +/− 4.6 m/s
RMS Error:
speed: 1.85 m/s
angle: 36.4 deg
Model Bias:
speed: −0.5 m/s
angle: 19.8 deg

Wind on Sigma = 0.958. Avg Hgt= 307 m. Unit = m/s. Time: 1200Z, 20010622
MM5 SIMULATION -- atmos - grd2 (12km) -- UA Obs

Figure 4-5.
Simulated and Observed Temperatures at Memphis, Nashville, Knoxville, and Chattanooga for 16–22 June 2001

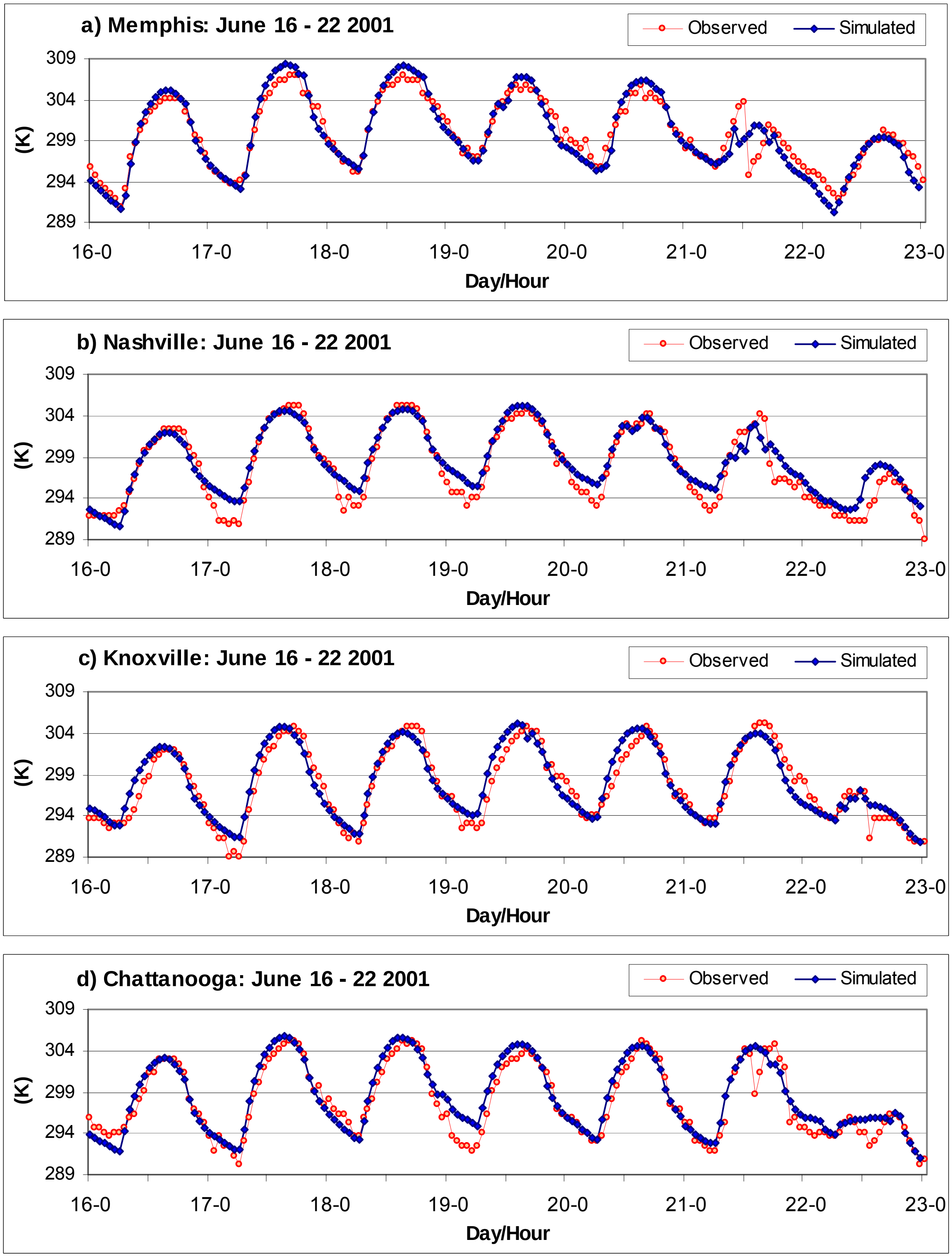


Figure 4-6a.
MM5-Derived 12-km Wind Field for 0700 EST on 4 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold

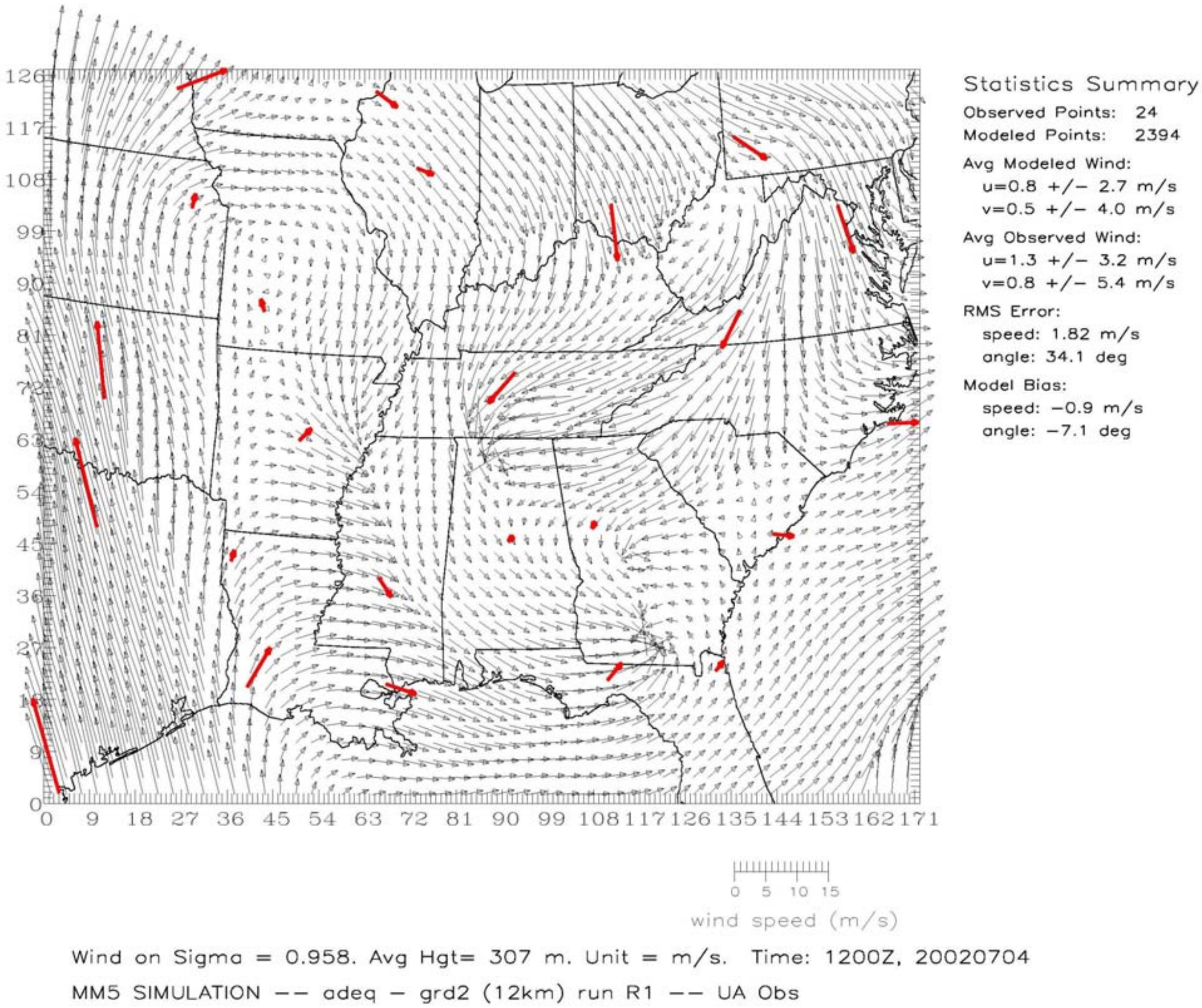
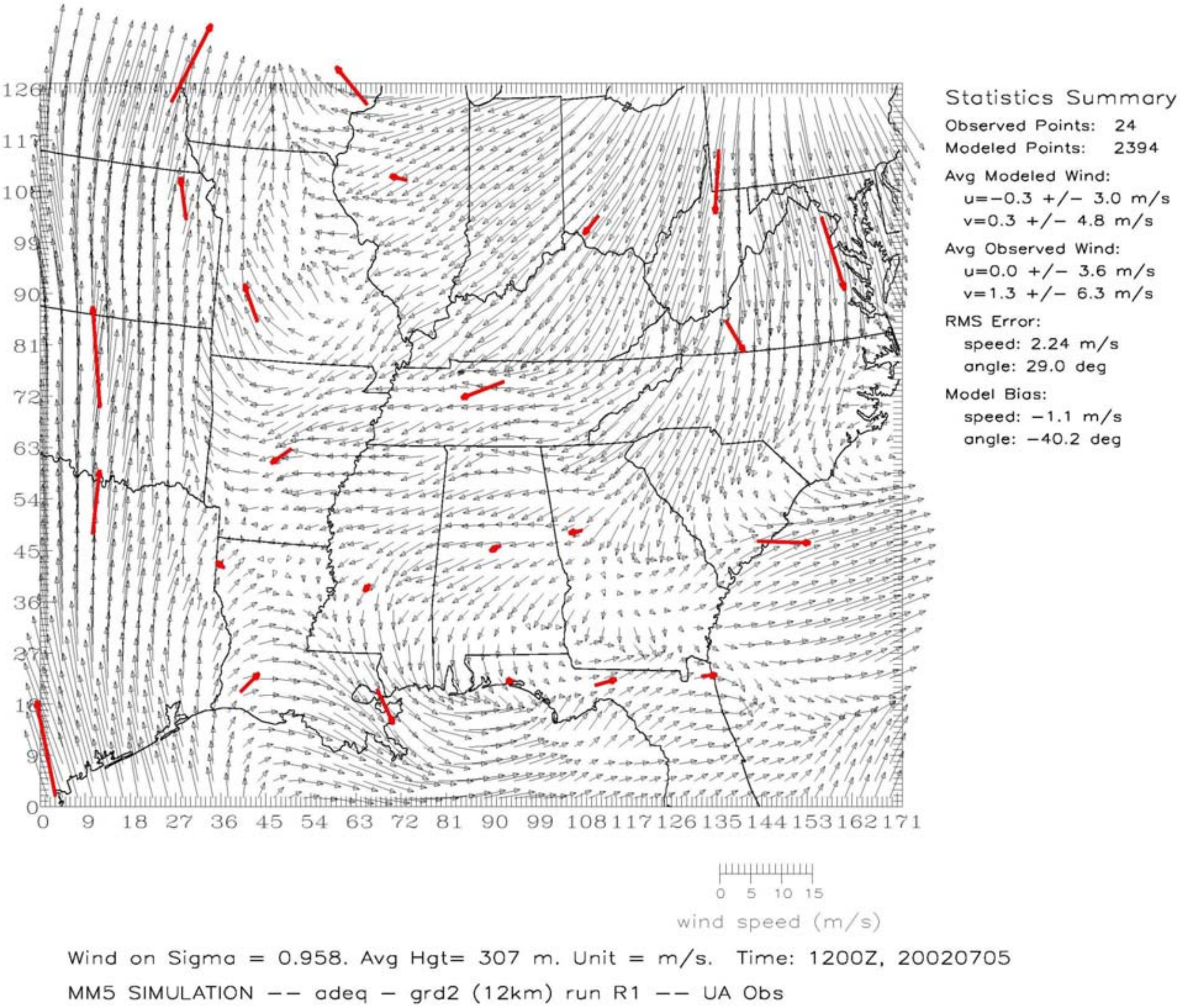


Figure 4-6b.
MM5-derived 12-km wind field for 0700 EST on 5 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.



Statistics Summary
Observed Points: 24
Modeled Points: 2394
Avg Modeled Wind:
u=−0.3 +/− 3.0 m/s
v=0.3 +/− 4.8 m/s
Avg Observed Wind:
u=0.0 +/− 3.6 m/s
v=1.3 +/− 6.3 m/s
RMS Error:
speed: 2.24 m/s
angle: 29.0 deg
Model Bias:
speed: −1.1 m/s
angle: −40.2 deg

Wind on Sigma = 0.958. Avg Hgt= 307 m. Unit = m/s. Time: 1200Z, 20020705
MM5 SIMULATION -- adeq - grd2 (12km) run R1 -- UA Obs

Figure 4-6c.
MM5-derived 12-km wind field for 0700 EST on 6 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

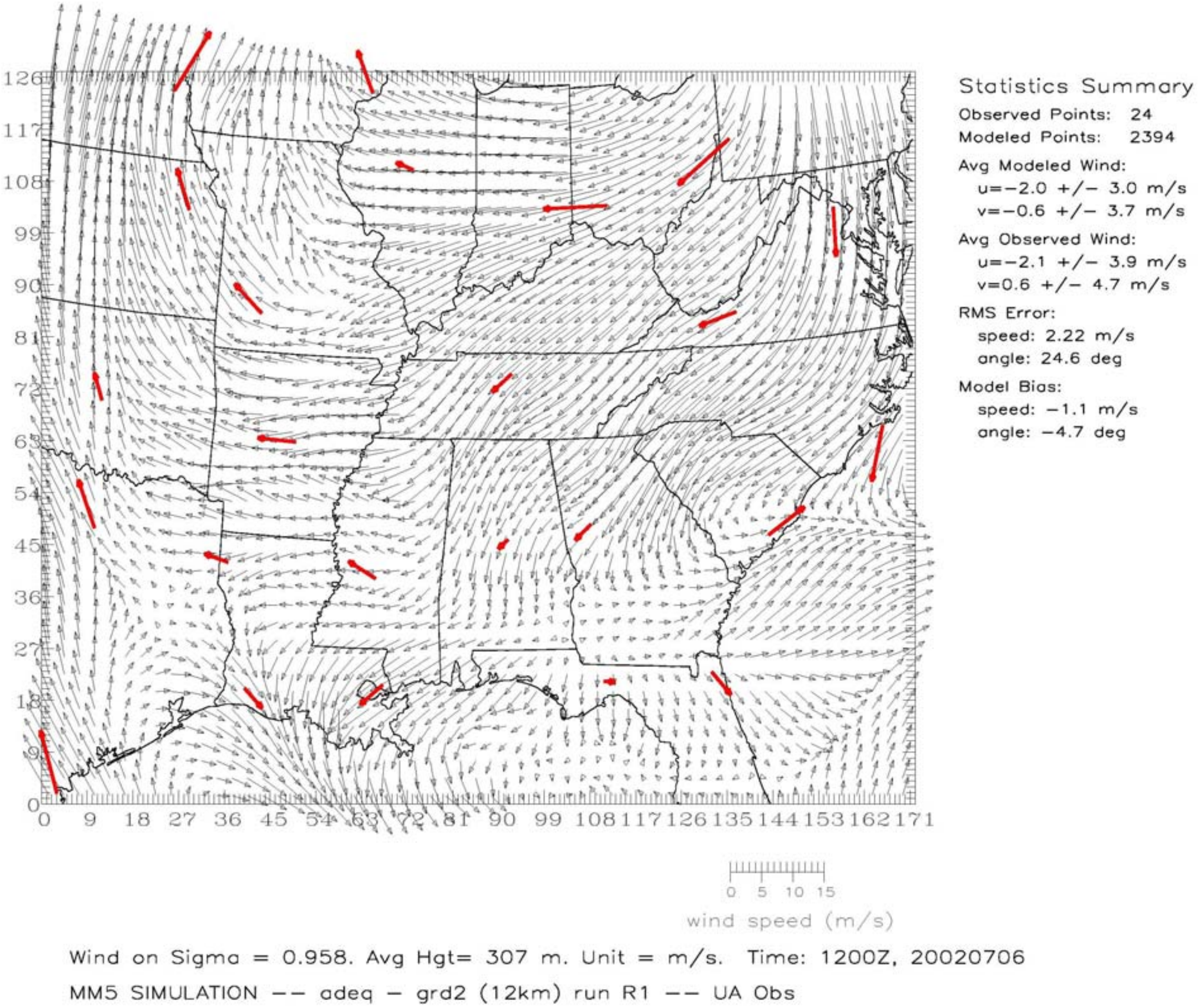
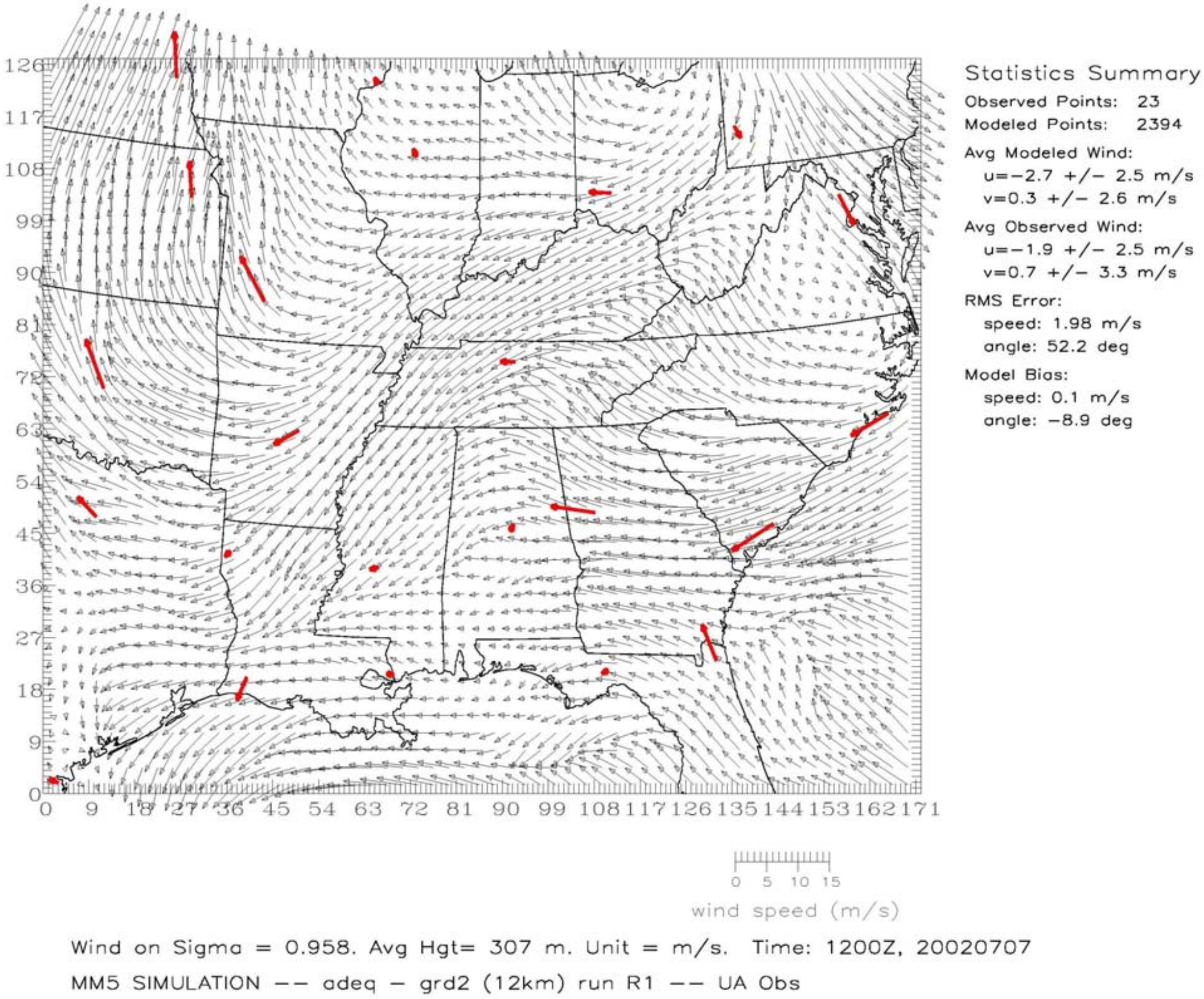


Figure 4-6d.
MM5-derived 12-km Wind Field for 0700 EST on 7 July 2002 at Approximately 300 m agl.

Observations are overplotted in bold.

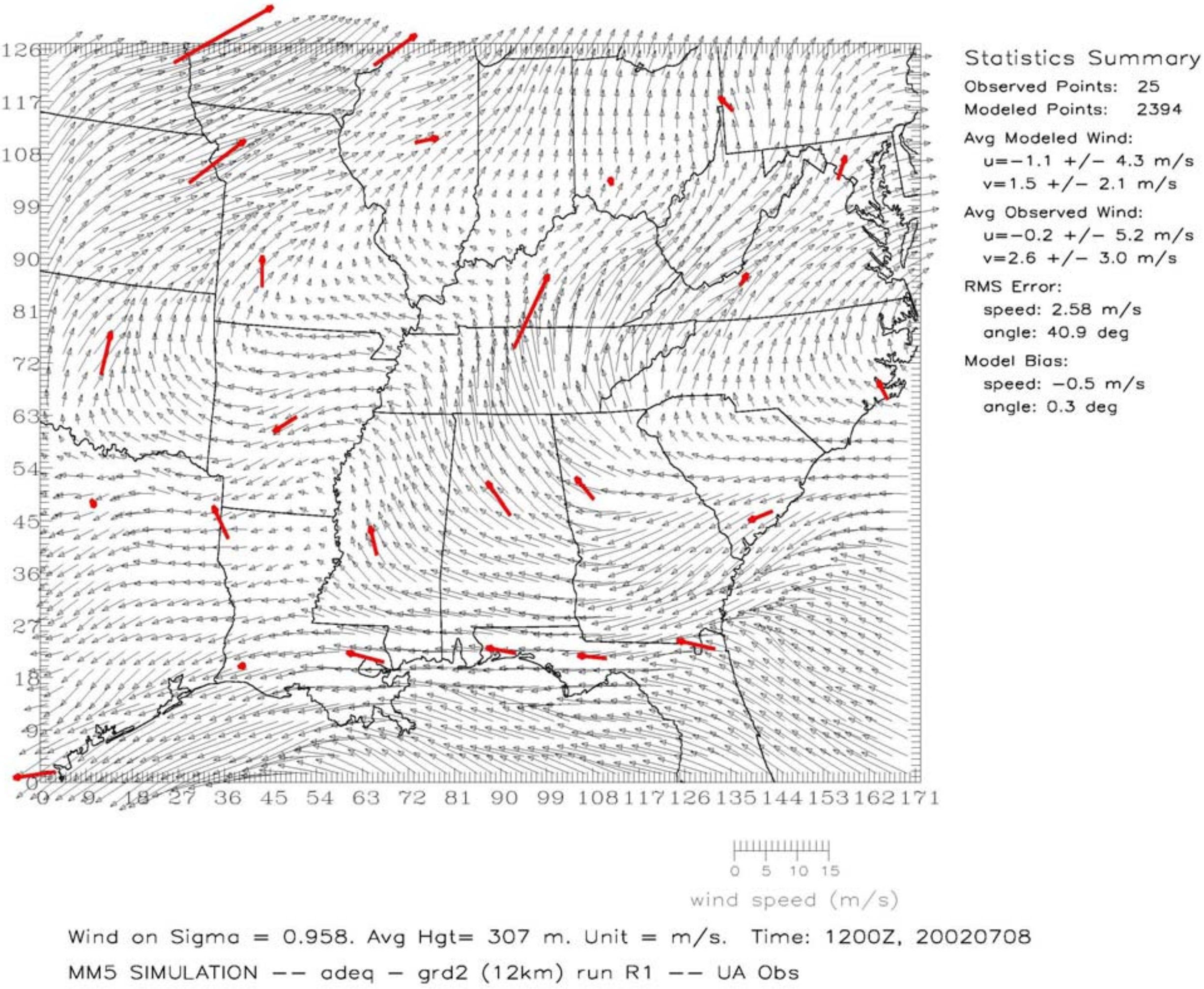


Statistics Summary
Observed Points: 23
Modeled Points: 2394
Avg Modeled Wind:
u=−2.7 +/− 2.5 m/s
v=0.3 +/− 2.6 m/s
Avg Observed Wind:
u=−1.9 +/− 2.5 m/s
v=0.7 +/− 3.3 m/s
RMS Error:
speed: 1.98 m/s
angle: 52.2 deg
Model Bias:
speed: 0.1 m/s
angle: −8.9 deg

Wind on Sigma = 0.958. Avg Hgt= 307 m. Unit = m/s. Time: 1200Z, 20020707
MM5 SIMULATION -- adeq - grd2 (12km) run R1 -- UA Obs

Figure 4-6e.
MM5-derived 12-km Wind Field for 0700 EST on 8 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.



Statistics Summary
Observed Points: 25
Modeled Points: 2394
Avg Modeled Wind:
u=−1.1 +/− 4.3 m/s
v=1.5 +/− 2.1 m/s
Avg Observed Wind:
u=−0.2 +/− 5.2 m/s
v=2.6 +/− 3.0 m/s
RMS Error:
speed: 2.58 m/s
angle: 40.9 deg
Model Bias:
speed: −0.5 m/s
angle: 0.3 deg

Wind on Sigma = 0.958. Avg Hgt= 307 m. Unit = m/s. Time: 1200Z, 20020708
MM5 SIMULATION -- adeq - grd2 (12km) run R1 -- UA Obs

Figure 4-6f.
MM5-derived 12-km Wind Field for 0700 EST on 9 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

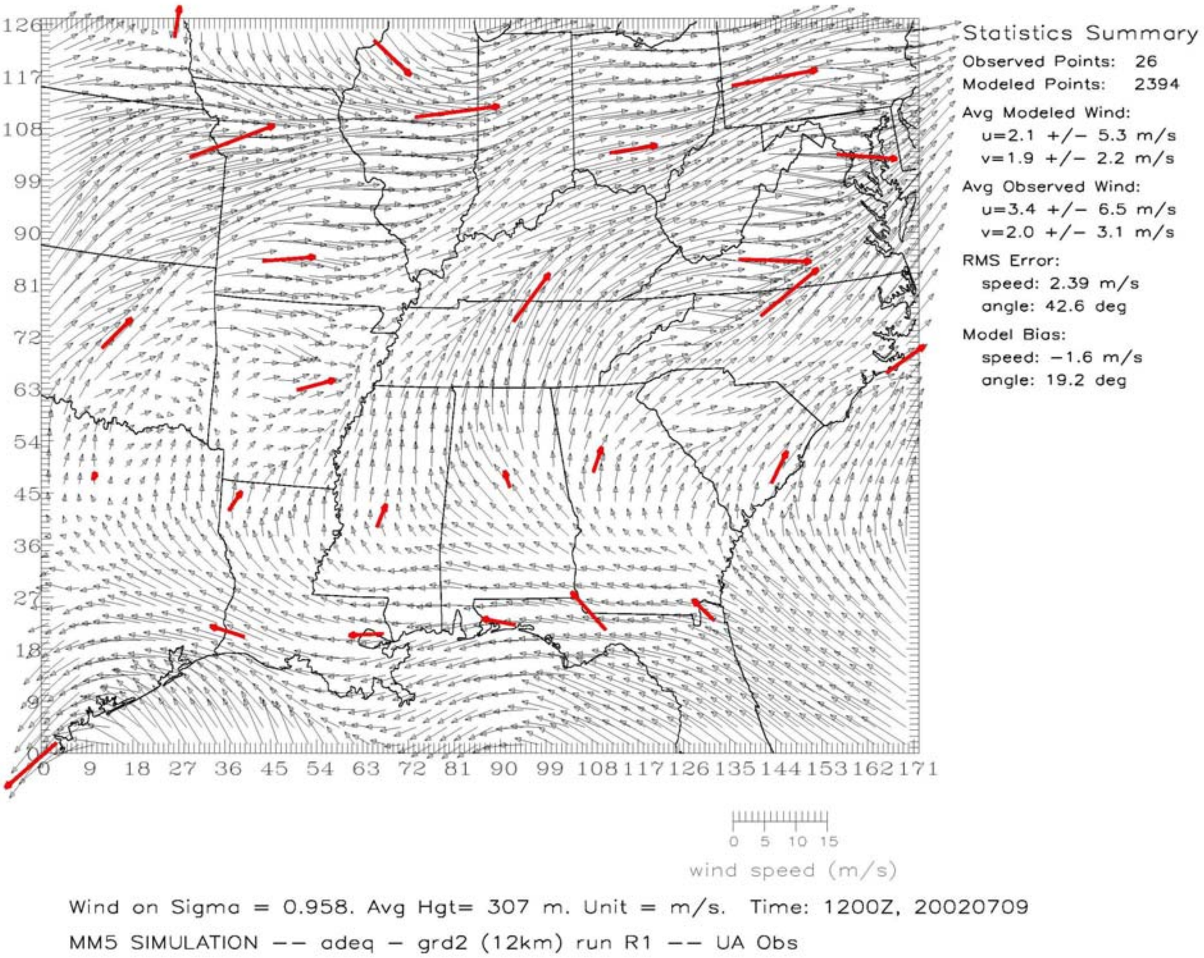


Figure 4-6g.
MM5-derived 12-km Wind Field for 0700 EST on 10 July 2002
at Approximately 300 m agl.

Observations are overplotted in bold.

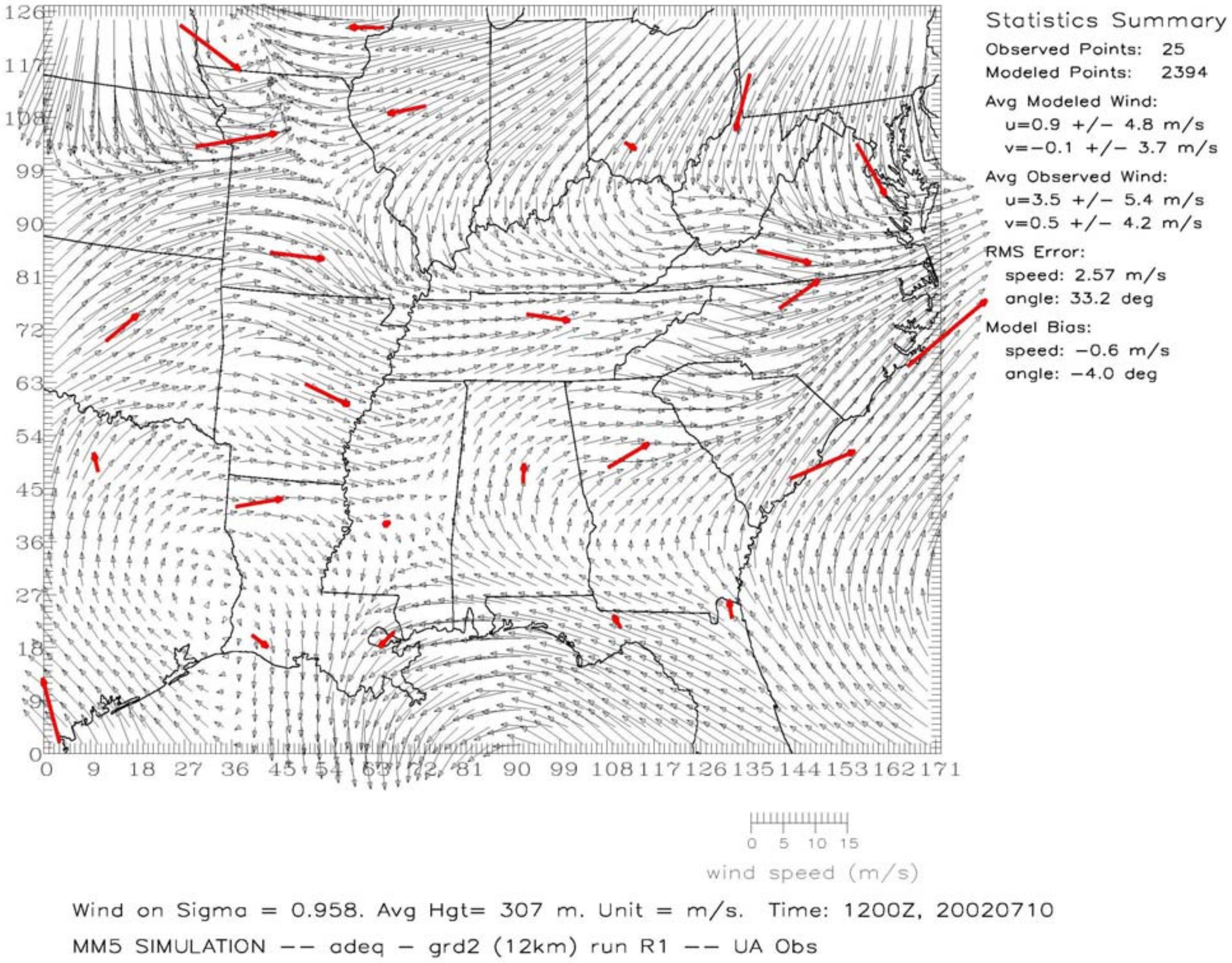
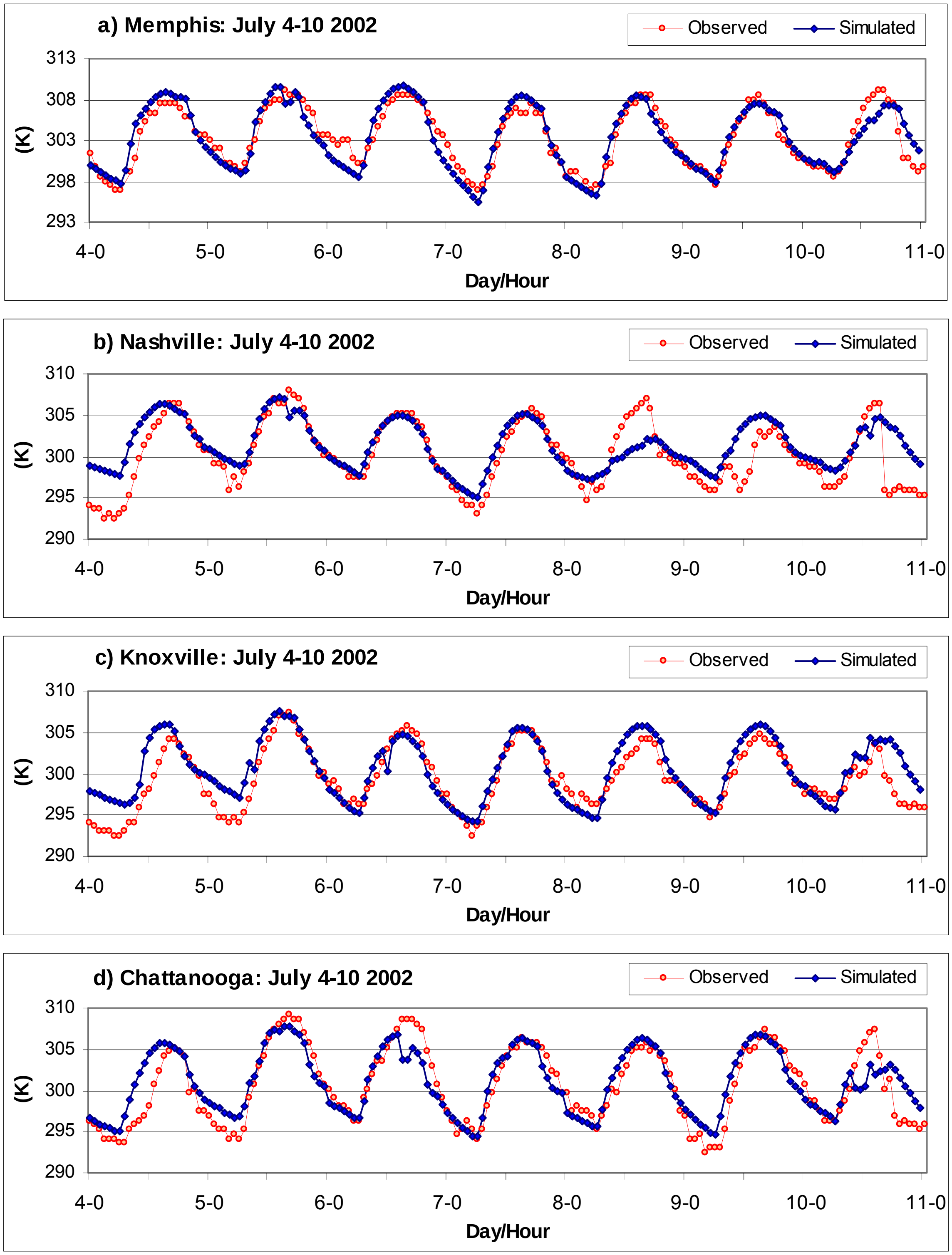


**Figure 4-7.
Simulated and Observed Temperatures at Memphis, Nashville, Knoxville, and Chattanooga
for 04–10 July 2002**



5. Air Quality, Land-Use, and Chemistry Input Preparation

The UAM-V modeling system requires information on pollutant concentrations throughout the domain at the first hour of the first day of the simulation, and along the lateral and top boundaries of the domain for each hour of the simulation days. It also requires land-use data, albedo and ozone column values, photolysis rates, and chemical reaction rates. The UAM-V model obtains this information from input files that will be described in this section.

All figures are included following the text in this section.

Air Quality Related Inputs

Three UAM-V air quality input files define the initial and boundary pollutant concentrations for each of the UAM-V state species. The initial conditions file specifies the initial concentration for each species at the initial time of the simulation. The boundary conditions file specifies the concentration for each species along the lateral boundaries of the modeling domain for each hour of the simulation period. The top concentration files contain similar values for the species along the top boundary of the modeling domain for each simulation day.

Initial Conditions

For the ATMOS modeling domain, initial condition inputs for each simulation period were prepared using observed pollutant concentration data from all available monitoring sites located within the modeling domain. The observed data consisting of measurements of ozone, NO, NO_2, and CO were obtained from the EPA Aerometric Information Retrieval System (AIRS). The first (hourly) measurement for the first day of the simulation period was used to specify the initial concentration for each species. If data for the first hour were missing, data for the second hour were used instead.

Observed data were interpolated to the lowest model layer of the modeling domain (Grid 1) using the standard UAM-V preprocessor program. This program relies on bilinear interpolation to estimate values of each species for each grid cell of the modeling domain. The surface layer values were extended to the second layer of the model (which ranges from 50 to 100 m above ground). Above this layer, EPA default values for each pollutant species (EPA, 1991) were used for the initial conditions for most species. For NO_x and CO some lower values than the EPA default values were used. The initial values are 40 ppb for ozone, 1 ppb for NOx (0 ppb for NO and 1 ppb for NO_2), 25 ppb for hydrocarbons (divided among the lumped hydrocarbon species represented in the CB-V mechanism, using a consistent approach to that listed in EPA (1991)), and 200 ppb for CO. The initial value for ozone was later adjusted to 65 ppb based on the results of the “self-generating boundary conditions” technique that will be described later in this section.

Boundary Conditions

The nested-grid, regional-scale modeling domain was designed, in part, to reduce the effects of uncertainty in the boundary conditions on the simulation results for the area of interest. The idea is that if the boundaries are far away enough from the area of interest, the impact of the boundary conditions will be absorbed by activity within the domain before they reach the area of interest. Lateral boundary conditions are specified for the outermost domain (Grid 1). Top boundary conditions are specified for all domains in a single file. For this study, the lateral and top boundary concentrations for all pollutants were initially set equal to the values listed for the initial conditions. These were assumed to be representative of continental-scale background values.

The value for ozone in the boundary and top concentration files was then updated for each simulation day. Using self-generating ozone boundary condition technique, an average ozone concentration from the upper layer of the modeling domain is calculated for the last hour of each day and is used to specify the ozone boundary value (along the lateral and top boundaries) for each subsequent day. Following the first full simulation for each modeling episode period, the self-generated values of ozone were analyzed and the initial value of ozone of 40 ppb for the boundary conditions was increased to approximately 60 ppb (this varied by episode) based on the calculated value for the subsequent days and the general trend followed by the ozone value throughout the simulation. In this manner, regional-scale build-up and/or lowering of ozone concentrations are represented in the simulations. The ozone boundary conditions for each of the simulation periods remained around 60-65 ppb for the entire period.

Land-Use Inputs

UAM-V requires a gridded land-use file for the full domain and each of the sub-domains, in order to calculate deposition rates. The file was prepared using a 200-m resolution land-use database obtained from the U.S. Geological Survey (USGS). Each of the categories in the USGS land-use database was assigned to one of the eleven UAM-V land use categories: urban, agricultural, range, deciduous forest, coniferous forest (including wetlands), mixed forest, water, barren land, non-forest wetlands, mixed agricultural and range, and rocky (low shrubs). The UAM-V land-use categories along with the surface roughness and albedo values for each category are listed in Table 5-1.

Table 5-1.
Land-Use Categories Recognized by UAM-V.
Surface roughness and UV albedo values are given for each category.

Category	Land-Use Description	Surface Roughness (m)	Albedo
1	Urban	3.00	0.08
2	Agricultural	0.25	0.05
3	Range	0.05	0.05
4	Deciduous forest	1.00	0.05
5	Coniferous forest including wetland	1.00	0.05
6	Mixed forest	1.00	0.05
7	Water	0.0001	0.04
8	Barren land	0.002	0.08
9	No forest wetlands	0.15	0.05
10	Mixed agricultural and range	0.10	0.05
11	Rocky (low shrubs)	0.10	0.05

The fraction of each of the eleven categories was then calculated for each grid cell and domain. A separate land-use file was prepared for each nested-grid sub-domain. Much of the modeling domain is assigned to the agricultural and forest land-use categories.

Chemistry Parameters

In combination with the albedo/haze/ozone column file, two additional inputs determine the chemical rates used by UAM-V. Photolysis rates are calculated as a function of albedo/haze/ozone column, height, and zenith angle. Photolysis rates were calculated with the photolysis rates preprocessor program using the values of albedo, haze, and total ozone column for the full domain, as provided by the albedo/haze/ozone processor program.

Additional chemistry parameters determine the rates and temperature dependence for the remaining reactions. Chemical reaction rates, activation energies, and maximum/minimum species concentrations from the validation data of the CB-V chemical mechanism against smog chamber data, were used along with appropriate updates for the enhanced treatment of radical-radical termination reactions, isoprene, and toxics chemistry.

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6. Model Performance Evaluation

The first stage in the application of the UAM-V modeling system for ozone air quality assessment purposes consists of an initial simulation and a series of diagnostic and sensitivity simulations. These simulations are aimed at examining the effects of uncertainties in the inputs on the simulation results, identifying deficiencies in the inputs, and investigating the sensitivity of the modeling system to changes in the inputs. Model performance for each simulation is assessed through graphical and statistical comparison of the simulated pollutant concentrations with the observed data obtained from available monitoring stations located throughout the domain. The results of this comparison are used to assess whether the model is able to adequately replicate the air quality characteristics of the simulation period, and to determine whether additional diagnostic and sensitivity simulations are needed.

Once the results of the graphical, statistical, and sensitivity analysis show acceptable performance of the model for a given simulation, that simulation is called the “base-case” simulation and the modeling analysis moves to the next stage. This next stage consists of projection and modification of the emission inputs to assess the effects of emission changes on future air quality. Reasonable model performance is critical to reliable use of the modeling system for such an assessment. Thus considerable time and effort are spent in the design and conduct of the base-case diagnostic and sensitivity analysis and in the evaluation of the base-case simulation.

The base-case application of the UAM-V modeling system for the ATMOS modeling episode periods included an initial simulation, several diagnostic/sensitivity simulations, a final base-case simulation, and graphical and statistical analysis of each set of modeling results, including comparison with observed air quality data. This report presents the procedures and results of the base-case modeling analysis for the 29 August – 9 September 1999, 16-22 June 2001, and 4-10 July 2002 ATMOS episode periods. The discussion centers on ozone, the primary pollutant of interest.

For ease of reading, all figures and tables follow the text of this section.

August/September 1999 Episode

Initial Simulation Results

The initial simulation serves several purposes. Initial application of the UAM-V model can reveal format problems or simple errors in the input files or parameters. The results of this simulation provide a basis to check for problems in the input files and to guide the input review and refinement that occur throughout the base-case modeling effort.

For the ATMOS episode of 29 August- 9 September 1999, the initial simulation is characterized by some underestimation of the ozone concentrations for the Memphis, Nashville, and high-elevation Knoxville (GSM) monitoring sites. For 1-4 September, concentrations are underestimated throughout the domain, but overestimated in the Chattanooga area. Key statistical measures calculated using the hourly ozone data for Grids 1, 2 and 3 (refer to Figure 1-2) are all within the recommended ranges provided by EPA guidance for all of the simulation days, but indicate consistent underestimation of the ozone concentrations.

Diagnostic and Sensitivity Analysis

Based on the initial simulation results, the diagnostic and sensitivity analysis for this episode period was initially designed to examine possible improvements to the meteorological input fields, use of an alternative vertical layer structure, and improved representation of the initial and boundary conditions. Subsequent diagnostic and sensitivity simulations incorporated updates to the emission inventories and examined the sensitivity of the modeling system to uncertainty in the emissions (specifically, the biogenic emissions). In total, eight full and eight partial simulations were run as part of the base-case modeling analysis for the August/September 1999 simulation period.

Meteorology Related Diagnostic and Sensitivity Simulations

The meteorology related diagnostic and sensitivity simulations focused first on improving the MM5 results for selected simulation days, and then on examining and updating the postprocessing procedures used to transform the outputs from MM5 into inputs for UAM-V. The UAM-V process analysis technique was also used to support the diagnostic analysis for this simulation period.

As discussed in Section 4 of this document, we found that the initial application of MM5 for this simulation period did not adequately simulate the surface temperatures for key locations in the eastern portion of the ATMOS fine-grid modeling domain for 1-3 September. Temperatures were as much as 6 to 8 degrees (C) cooler than the maximum observed values for Nashville, Knoxville, and Chattanooga in the MM5 outputs. We reran the fine-grid simulation for these three days using an enhanced moisture-nudging coefficient (5×10^{-5}). This resulted in higher temperatures and much better agreement with the temperature observations for these as well as other areas.

The remaining meteorology related diagnostic and sensitivity simulations examined different options for postprocessing the MM5 results. Two diagnostic simulations addressed better use of the MM5 results for input to the UAM-V. Specifically, a new procedure for interpolating the vertical exchange coefficients (K_vs) from the MM5 levels to the UAM-V layer interface levels was applied. The vertical exchange coefficients were normalized, to ensure that the maximum value represented by MM5 was also represented in the UAM-V ready K_v fields. This resulted in some slight improvement of the simulated ozone concentrations at the Knoxville area sites (those located in more varied terrain). Similarity theory was applied to estimate surface wind speed (and average winds within the lowest UAM-V model layer). This also resulted in a slight improvement of the ozone concentrations. Both of these changes to the MM5 postprocessing procedures were retained for the final base-case simulation.

Two simulations examined the sensitivity of the simulation results to the specification of postprocessing parameters. First, the MM5 postprocessing procedures include some nominal smoothing of the wind fields. Specifically, four passes through a 4-point smoother is typically applied. To examine whether this affected the transport characteristics of the wind fields, especially for the urban plumes, the usual smoothing of the wind fields was removed. Second, a different (and more stringent) divergence minimization criterion was used to determine the effects of this somewhat arbitrary parameter on the simulation results. In both, cases the changes to the simulated ozone concentrations were very small. These changes to the postprocessing parameters/assumptions were not retained for the final base-case simulation.

Modeling Domain Related Diagnostic Simulation

To examine the causes of higher than observed ozone concentrations during the nighttime hours for some of the monitoring sites, the lowest layer of the model was divided into two layers, creating an additional surface layer with a 25 m thickness. The idea was that a thinner surface layer would better simulate the titration of ozone during the nighttime hours by NO emissions, and thus the lower ozone concentrations during these hours at the urban sites. The results showed very little difference in ozone concentrations, both domain-wide and at the monitoring sites. The UAM-V layer structure was not changed as a result of this diagnostic test.

Initial and Boundary Condition Related Diagnostic and Sensitivity Simulations

It is usual during the course of a diagnostic analysis to confirm that the effects of the initial and boundary conditions are minimal and that the uncertainty inherent in both of these inputs does not overwhelm the effects of emissions or confound the effects of the emissions changes. Several diagnostic and sensitivity simulation were conducted for the August/September 1999 ATMOS simulation period to examine and refine these inputs.

The initial conditions represent the concentrations of all modeled species for all grid cells at the initial simulation time. We examined the sensitivity of the modeling results to the specification of the initial conditions and attempted to improve the representation of the initial pollutant values at the monitoring site locations. We re-interpolated the observations to the domain using a smaller radius of influence, thus limiting the influence of the observations to a smaller area around the monitors. The change in simulated ozone concentration due to the change in initial conditions was limited to the first two (start-up) days. The initial ozone concentrations, however, were not better represented.

The boundary condition sensitivity simulations examined the setting of the ozone boundary concentration. The UAM-V uses a self-generating ozone boundary condition approach in which the user must specify the initial value for ozone and then it is calculated each for each day as the average of the simulated ozone concentrations aloft – for the final hour of the previous day and averaged over the entire modeling domain. This approach is discussed in more detail in Section 5 of this document. Values of 40, 55, 65, and 75 ppb were tested. The first three values were the result of running the UAM-V and examining the level at which the ozone values remained steady after several days of simulation. The fourth value was based on the analysis of aircraft data from the 1995 Southern Oxidant Study (over Nashville) and was used primarily to examine whether higher ozone aloft would improve the agreement with the observed values at the higher elevation sites in the GSM National Park. Increasing the ozone boundary value from 40 to 55 to 65 ppb generally increased ozone concentrations throughout the domain, and provided slightly higher values and slightly improved model performance for monitoring sites within the ATMOS Grid 3 domain. The site-specific ozone concentrations were increased by at most about 5 ppb, when the ozone boundary value was changed from 40 to 65 ppb. Since other parameters were also changed in between this change in boundary values, the 5 ppb value is just an estimate. A value of 65 ppb was used for the base-case simulation. Use of an even higher value improved the representation of the ozone concentrations for the higher elevation sites, but was not retained for the final base-case simulation.

Emissions Related Diagnostic and Sensitivity Simulations

Several updates to the emissions inventories were incorporated into the base-case modeling for this simulation period. These included the use of the MOBILE6 model for the estimation of emissions from on-road mobile sources; updated point source emissions, including for electric generating unit and industrial sources; updated VMT estimates; and updated biogenic emissions (using newly released high-resolution crop/land-use data). These were incorporated throughout modeling analysis. One additional emissions related sensitivity simulation was conducted to examine the effects of uncertainty in the biogenic emission on the modeling results. In this simulation isoprene emissions were increased by 50 percent and the model was rerun for the first 6 days of the simulation period. This resulted in an increase in the simulated ozone concentrations of about 5 to 10 ppb (in some cases greater), especially downwind of the urban areas (where NO_x emissions are also present). These results highlight that some of the uncertainty in the modeling results is due to the known uncertainty in the biogenic emissions.

Process Analysis

The UAM-V process analysis technique was used to examine and quantify the importance of the various simulation processes to the base-case simulation results for the August/September 1999 simulation periods and to aid in the diagnosis of model performance issues. The UAM-V process analysis feature increases the amount of information that is saved during a photochemical simulation. In addition to the standard UAM-V output (the net species concentrations), additional information is saved indicating the individual contributions of the various physical and chemical process to the net concentrations. This additional information that is saved represents and quantifies the contributions from the following processes: chemistry, dry deposition, addition of material from the UAM-V plume-in-grid submodule, vertical advection, horizontal advection and diffusion (combined), and vertical diffusion.

The process analysis results suggest that all three of the expected primary ozone formation pathways contribute to the high simulated ozone concentrations in the area of interest:

- Ozone is produced aloft and transferred down to the surface by vertical diffusion and vertical advection.
- Local photochemical production of ozone also contributes to the daytime ozone levels.
- Some horizontal, perhaps regional-scale, transport, is also indicated.

Among the contributing processes, horizontal advection is most variable among the sites and the days. This suggests that some of the site-to-site and day-to-day variation in model performance is related to a similar variation in wind direction accuracy.

The results also indicate that the representation of the terrain, and specifically, the terrain-generated airflow features is important to good model performance at the GSM sites. Vertical advection (both positive and negative) is more important for these sites than for the other sites included in the analysis.

Diagnostic analysis for this episode was concluded when acceptable model performance was achieved and further improvement was not expected (given the limitations of the data and modeling tools).

Assessment of Model Performance

We employed a variety of graphical and statistical analysis techniques to assess model performance for the ATMOS simulations. In presenting the results of this assessment, we first focus on 1-hour ozone concentration patterns and statistical measures for the full modeling domain and each subdomain. This provides perspective on regional-scale model performance and whether the model is able to capture day-to-day variability in the concentration patterns and values. We then examine the hourly concentrations for each area and site of interest. It is important that the model capture the hourly variations and 1-hour peaks in order to reliably represent the 8-hour average values. We then examine the performance of the model in representing 8-hour ozone concentrations throughout the domain and for each area and site of interest.

Plots comparing simulated and observed concentrations across the domain provide a qualitative basis for assessing the ability of the model to emulate the spatial concentration patterns. Figure 6-1 displays daily maximum simulated ozone concentrations for Grid 1, for each simulation day of the August/September 1999 simulation period. The isopleths represent the 1-hour maximum simulated ozone concentrations and the numerical values represent the corresponding maximum observed concentrations. The domain-wide maximum and minimum values are provided in the upper right-hand corner of the plot. Note that the simulated values are derived from the results for all grids, not just Grid 1. These plots emphasize the variability of the concentrations throughout the region (both simulated and observed) that are attributable to the variable distribution of emissions sources. Notice that for areas covered by finer grids, the higher resolution translates into additional complexity in the ozone concentration patterns.

Figure 6-2 gives a closer look at daily maximum simulated ozone for Grid 3. The contours are reasonably consistent with the observed values with some notable underestimation of ozone in the Knoxville and GSM areas on several of the simulation days. Packed contours are often visible where several closely located observed values span a significant range, indicating a steep gradient or peak in ozone concentration.

Time-series plots comparing the simulated and observed values at the monitoring sites demonstrate how well the timing and magnitude of the simulated values matched the observations. The time-series plots in Figure 6-3 compare hourly simulated and observed ozone concentrations for the monitoring sites in the Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities areas. In these plots, the boxes represent the observed values, the solid line represents the simulated values (interpolated to the monitoring site location), and the shaded areas represent the range of concentrations in the nine cells surrounding the grid cell in which the monitoring site is located. Plots for all days span two pages.

Overall the time series show fair to good model performance for most sites on most days. For the Memphis area, the simulation follows the observed diurnal cycle fairly well, with some underestimation on the 4th and 7th in particular. The high peak value on the 3rd at Marion is captured by the nine cells around the site, represented by a relatively wide shaded region, though the modeled peak at the site's own grid cell is rather low. The Nashville time series show some daytime underestimation and nighttime overestimation, and one incident of daytime overestimation at Rockland Road on the 1st of September. The model does a generally good job of reflecting the observed ozone profile, including double peaks and nighttime cleanout. The model has greater difficulty at the Knoxville sites, predicting a flatter profile than observed for several sites. For other sites, the profile is similar but the model underestimates peak values on some days. For Chattanooga, results are generally good with less or later overnight ozone clear-out on some days, and some underestimation of high values. For the Tri-Cities area the model shows good performance for the first half of the episode, overestimation of some low daytime values on the 5th and the 6th, and an unrealistic peak of about 200 ppb at Kingsport on the 9th.

Observed and simulated values for each day are further displayed as x-y scatter plots in Figure 6-4. These show reasonable correlation between simulated and observed values, with typically overestimation of low values and underestimation of high values.

Table 6-1 defines the statistical measures used to evaluate the model's ability to represent 1-hour ozone. While there are no strict criteria regarding what constitutes acceptable model performance, EPA guidance provides recommended ranges for the following: domain-wide unpaired accuracy of the peak (± 20 percent), normalized bias (± 15 percent) and normalized gross error (≤ 35 percent). We assume a consistent range for assessing the average accuracy of the peak (± 20 percent). For 8-hour ozone we also calculated two additional metrics: accuracy of the 8-hour maximum values averaged (1) over all sites in a given domain and (2) over all days for a given site; this should also be within ± 20 percent.

Table 6-2 provides the value of the 1-hour ozone metrics for all days of the August/September 1999 simulation period. The measures are calculated for Grids 1, 2, and 3 using observed values from all sites in the grid. Values of the statistical measures that are outside of the EPA recommended ranges are shaded. The first two days are considered startup days for mediating the effects of uncertainty in initial conditions.

With one exception, the average accuracy, normalized bias, and normalized gross error are all within EPA recommendations for all grids and all days. The normalized bias shows a predominance of underestimation over all grids.

For 8-hour ozone, we focus on Grid 3. The domain-wide daily average accuracy is given in Table 6-3a, and the site-specific average accuracy values are given in Table 6-3b. In both cases, these measures are calculated over all non-start-up simulation days. These values are consistently within EPA suggested bounds. The site-specific values refer to the performance of the model (on average) for each monitoring station over all the simulation days. Here we matched the observed value with the simulated value at the site (in the first column) and then with the maximum 8-hour value within the 9-grid cells surrounding the site (second column). As expected, there is a tendency for a more positive value (less underestimation or more overestimation) when this metric is extended to the nine cells surrounding the site, as the metric then captures the high end of ozone gradients over a larger spatial range, and compares these to the same point-specific observed values. In this case the tendency to underestimation of 8-hour peak values is apparent even if the 9-cell average accuracy is examined, but the statistics are generally within or close to the recommended range. Kingsport is an exception, with the 9-cell overestimation driven by the extreme simulated peak near that site on the 9th.

June 2001 Episode

Initial Simulation Results

For the 16-22 June 2001 simulation period, the initial simulation showed good to very good representation of the observed ozone concentrations for most sites and days. Ozone concentrations are underestimated on the 20th and overestimated on the 22nd (the clean-out day). The statistical measures of model performance are within the EPA recommended ranges on all but the last simulation day. One problematic feature is that the timing and magnitude of the ozone concentrations at certain downwind sites is not well simulated. The diagnostic analysis examined the wind patterns, to see if better representation of the surface winds could improve the simulation profiles. We also refined the specification of the boundary conditions.

Diagnostic and Sensitivity Analysis

Based on the initial simulation results, the diagnostic and sensitivity analysis for this episode period was initially designed to examine the influence of initial conditions, meteorological inputs, and biogenic emissions.

Meteorology Related Diagnostic and Sensitivity Simulations

To examine the causes of the underestimation of ozone for 20 June, several sensitivity simulations were run for the 20th only, testing the effect of changes to meteorological UAM-V inputs. In applying MM5 for this episode, we prepared two sets of inputs for 20 June – one set based on the third day of a three day simulation for 18-20 June, and one based on the first day of a three-day simulation for 20-22 June. In the initial simulation, the meteorological fields for 20 June were based on the second set of MM5 outputs. We also tested the use of the first set of outputs. We have found in past studies that for MM5, a different set of initial conditions (corresponding to a different start time) can result in improved representation of the meteorological conditions. This may be due to the build up of non-meteorological noise in the simulation as it progresses, or just that the alternate initial conditions provide a better basis for simulating the important features. The best results were achieved using the first set of MM5 outputs.

Reanalysis of the wind fields for 20 June, in which the resulting fields are recombined with the observed data to improve their representation in the field was also attempted. This did not improve the simulation results for this day. As an additional sensitivity test, we also modified wind fields by applying factors applied to each layer. This reduction in wind speed produced higher ozone for 20 June and allowed us to understand the causes of the underestimation of ozone for that day.

For this episode, we also tested and adopted the MM5 postprocessing procedures used for the August/September 1999 simulation period. Specifically, the K_v fields were normalized such that the maximum value in the vertical profile provided by MM5 was retained in the inputs to UAM-V. In addition, a similarity theory based approach was used to calculate the surface layer wind speeds.

Boundary Condition Related Diagnostic Simulation

The initial ozone boundary condition was increased from 40 to 65 ppb. While the first day of the initial simulation began with 40 ppb as the ozone value along the boundary, subsequent days generated boundary ozone values closer to 65 ppb. By setting first day's boundary ozone close to the apparent stable value arrived at by the model, we avoid arbitrary specification of the boundary condition (in the absence of upper-air pollutant concentration data). Small increases in the simulated ozone concentrations resulted from this change in the ozone boundary concentration.

Emissions Related Sensitivity Simulation

For this simulation period, we were concerned that higher than observed MM5-modeled temperatures were producing biogenic VOC values that were potentially biased high for some of the simulation days. To examine the effect on simulated ozone, we reduced the biogenic isoprene emissions by 25 percent. Ozone concentrations were reduced throughout the domain by as much as 2 to 5 ppb. This reveals the influence of possible uncertainties in the biogenic emissions. Other updates to the 2001 emissions were also incorporated into the inventory during the course of the base-case modeling analysis.

Diagnostic analysis for this episode was concluded when acceptable model performance was achieved and further improvement was not expected (especially considering the schedule for the EAC modeling). The base-case simulation is described in the following section.

Assessment of Base-Case Model Performance

Plots comparing simulated and observed concentrations across the domain provide a qualitative basis for assessing the ability of the model to emulate the spatial concentration patterns. Figure 6-5 plots daily maximum simulated ozone concentrations for Grid 1, for each simulation day of the June 2001 simulation period. The contours show reasonable agreement with observed values, with some evident overestimation in the coarse-resolution part of the full domain on the last few days of the episode.

Figure 6-6 displays daily maximum simulated ozone for Grid 3. Grid 3 shows a generally better match between observed and simulated data, relative to Grid 1. Peak simulated values on the June 20 and 21 plots appear near clusters of observed values whose range indicates a local ozone peak, but the contours seem to indicate overestimation at these sites.

Time-series plots in Figure 6-7 compare hourly simulated and observed ozone concentrations for the monitoring sites in the Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities areas. For Memphis, model performance as indicated by the time series appears very good. For Nashville, the model does not capture nighttime ozone clean-out for multiple sites, but the simulation matches daytime values reasonably well. The same is true for some Knoxville sites on some days. During the second half of the episode model performance is good to very good at all sites except Cades Cove, where the flat simulated profile misses the observed nighttime clean-out. Chattanooga and Tri-Cities also show mostly good model performance, with some underestimation on the 20th.

Observed and simulated values for each day are further displayed as x-y scatter plots in Figure 6-8. The scatter plots indicate mostly overestimation, particularly of low values, with more underestimation of the highest values occurring on the 19th and 20th relative to the rest of the episode.

Table 6-4 provides the value of the 1-hour ozone metrics for all days of the June 2001 simulation period. The measures are calculated for Grids 1, 2, and 3 using observed values from all sites in the grid. Values of the statistical measures that are outside of the EPA recommended ranges are shaded. The first two days are considered startup days for the simulation period. While unpaired accuracy is usually outside EPA recommended bounds, this may only indicate peak values not captured by the monitoring network. Only the last, clean-out episode day exceeds the EPA suggested range for average accuracy; high values at some sites are probably lingering in the modeled episode longer than in the historical episode.

The domain-wide daily average accuracy for 8-hour ozone is given for Grid 3 in Table 6-5a, and the site-specific average accuracy values are given in Table 6-5b. In both cases, these measures are calculated over all non-start-up simulation days. The overestimate of last day values indicated by 1-hour average accuracy is reflected in the 8-hour domain-wide average accuracy values. The site-specific values refer to the performance of the model (on average) for each monitoring station over all the simulation days. Here we matched the observed value with the simulated value at the site (in the first column) and then with the maximum 8-hour value within the 9-grid cells surrounding the site (second column). These site-specific metrics show the model overestimating in Memphis and Nashville, both over- and underestimating at Knoxville and Chattanooga, and underestimating at in the Tri-Cities area. The single-cell metric exceeds EPA recommendations only at Cades Cove. If the search for peak values extends to the 9-cell area, even higher values enter the calculation, and thus the 9-cell metric is outside EPA's suggested bounds for two additional sites.

July 2002 Episode

Initial Simulation Results

This third ATMOS simulation period was adapted for use in ATMOS following a review and evaluation of model performance for the ADEQ modeling analysis. The initial simulation for ADEQ showed good to very good performance throughout the domain, with some overestimation of ozone on the final simulation day. The diagnostic and sensitivity simulations mentioned below were done as part of the ADEQ modeling analysis; then the model was run only once for the ATMOS modeling domain. The discussion of model performance refers to this run.

Diagnostic and Sensitivity Analysis

Based on the initial simulation results, the diagnostic and sensitivity analysis for this episode period was initially designed to examine the influence of initial//boundary conditions, meteorological inputs, and biogenic emissions.

The second simulation, increased the first-day ozone boundary condition from 40 to 60 ppb, after consideration of model-generated boundary conditions in the same way as described above for the June 2001 episode.

In parallel to the June 2001 simulation, we also tested the influence of biogenic emissions and meteorological fields, respectively. We incorporated a 25% reduction in low-level ISOP emissions. We also tested and adopted the use of the ATMOS MM5 postprocessing procedures.

Diagnostic analysis for this episode was concluded when acceptable model performance was achieved and further improvement was not expected. The inputs for ADEQ base-case simulation were then adapted to the ATMOS domain.

Assessment of Base-Case Model Performance

Plots comparing simulated and observed concentrations across the domain provide a qualitative basis for assessing the ability of the model to emulate the spatial concentration patterns. Figure 6-9 plots daily maximum simulated ozone concentrations for Grid 1, for each simulation day of the July 2002 simulation period. The contours and observed values on these plots are reasonably matched, with packed contours—steep simulated ozone gradients—in regions of multiple monitoring sites, where high values are likely to be seen in general. For these days the observed values are somewhat lower than the contours predict, with more complex patterns in the high-resolution part of the grid, best examined in the next set of plots.

Figure 6-10 displays daily maximum simulated ozone for Grid 3. The fine grid contours show multiple high ozone peaks, roughly corresponding to nearby high observed values in some instances, although some local peaks are not covered by the monitoring network. The time series plots provide a closer view of the sites of interest.

Time-series plots in Figure 6-11 compare hourly simulated and observed ozone concentrations for the monitoring sites in the Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities areas. For Memphis and Nashville, these plots show generally good to very good model performance, with some overestimation of nighttime values. For Knoxville, simulated ozone cuts a flatter-than-observed profile for Cades Cove, and to a lesser degree Cove Mountain and Clingman's Dome. In general the time series show good representation of the Knoxville sites during the latter half of the episode, with some underestimation of nighttime values. Chattanooga time series show good model performance, as do the time series for Tri-Cities during the second half of the episode.

Observed and simulated values for each day are further displayed as x-y scatter plots in Figure 6-12. The scatter plots show a tendency to overestimation on most days, with more of a balance on days with more high observed values.

Table 6-6 provides the value of the 1-hour ozone metrics for all days of the July 2002 simulation period. The measures are calculated for Grids 1, 2, and 3 using observed values from all sites in the grid. Values of the statistical measures that are outside of the EPA recommended ranges are shaded. The first two days are considered startup days for the simulation period. Average accuracy is within the recommended range for all days for Grids 2 and 3, and for all but one day for Grid 1. Both underestimation and overestimation occurs throughout the episode.

The domain-wide daily average accuracy for 8-hour ozone is given for Grid 3 in Table 6-6a, and the site-specific average accuracy values are given in Table 6-6b. In both cases, these measures are calculated over all non-start-up simulation days. Domain-wide average accuracy is generally good, except for the overestimation on the last day, when observed ozone values are lower. The site-specific values refer to the performance of the model (on average) for each monitoring station over all the simulation days. Here we matched the observed value with the simulated value at the site (in the first column) and then with the maximum 8-hour value within the 9-grid cells surrounding the site (second column). These metrics show good model performance for the Memphis, Chattanooga, and Tri-Cities sites. There is a tendency to overestimate at the Nashville sites and at Cades Cove in Knoxville, probably during nighttime values, although the statistics incorporate a 40 ppb cut-off.

Composite Analysis for Site-Specific 8-Hour Ozone

Modeling results for all three episode combined are used in the attainment test to calculate the relative reduction factors and estimated future-year design values (this is discussed in Section 8 of the report). Table 6-8 summarizes model performance for each site using all three of the simulations periods and the site-specific unpaired accuracy metric. For the most part, the metrics fall squarely within the EPA suggested bounds for acceptable performance. Overall the simulations tend to underestimate at Memphis, Knoxville, Chattanooga, and Tri-Cities, and both over- and underestimate at Nashville.

These results indicate that the combined use of days provides an excellent basis for application of the attainment test procedures.

Table 6-1.
Metrics Used for Model Performance Evaluation for the ATMOS Modeling Analysis

Metric	Definition
Threshold value	The minimum observation value used to calculate statistics
Maximum observation (ppb)	Maximum concentration at an observation site
Maximum domain-wide simulation (ppb)	The maximum simulated concentration in the domain
Mean observation value (ppb)	The average observed concentration above the threshold value
Mean simulation value (ppb)	The average simulated concentration corresponding to observations above the threshold
Unpaired accuracy of the peak	$\frac{S_{Max} - O_{Max}}{O_{Max}}$ where S_{Max} is the maximum simulated value and O_{Max} is the maximum observation.
Average accuracy of the peak	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_{Ml} - O_{Ml})\big/O_{Ml}$ where S_{Ml} and O_{Ml} are the maximum simulated and observed values at site l.
Normalized bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/O_l$ where N is the number of data pairs, and S_l and O_l are the simulated and observed values at site l, respectively.
Normalized gross error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/O_l$
Root mean square error (ppb)	$\sqrt{\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)^2}$

Table 6-2a.
Model Performance Statistics for 1-Hour Ozone for the August-September 1999 Base Case Simulation, for the 36 km UAM-V Modeling Domain (Grid 1)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
8/29	110	110.2	38.9	43.0	0.2%	-0.9%	-8.5%	22.9%	15.9
8/30	178	133.3	36.0	48.5	-25.1%	8.9%	-1.3%	20.6%	15.5
8/31	171	125.1	35.2	47.1	-26.8%	4.7%	-1.3%	21.7%	16.1
9/1	127	151.5	40.0	48.0	19.3%	-2.8%	-5.8%	20.3%	16.1
9/2	166	168.0	40.4	47.1	1.2%	-7.6%	-11.2%	26.4%	24.0
9/3	144.4	155.8	40.0	46.1	7.9%	-13.5%	-14.5%	27.1%	24.3
9/4	143	172.7	40.3	49.1	20.8%	-6.2%	-11.9%	24.4%	21.2
9/5	123	132.8	34.9	48.3	7.9%	4.0%	-10.5%	28.9%	24.9
9/6	155	120.5	34.0	49.6	-22.3%	12.4%	7.4%	23.8%	16.1
9/7	137	154.8	32.2	49.5	13.0%	15.5%	10.7%	25.1%	17.6
9/8	135	151.0	33.6	46.9	11.9%	6.5%	-1.7%	30.2%	22.7
9/9	117	202.3	30.5	46.8	72.9%	16.3%	8.3%	26.8%	17.3

Table 6-2b.
Model Performance Statistics for 1-Hour Ozone for the August-September 1999 Base Case Simulation, for the 12 km UAM-V Modeling Domain (Grid 2)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
8/29	105	110.2	44.2	43.4	5.0%	-12.0%	-14.5%	20.7%	15.8
8/30	116	133.3	44.1	48.4	14.9%	1.4%	-3.0%	15.6%	11.1
8/31	110	119.3	42.1	49.1	8.4%	-0.1%	-5.1%	20.2%	15.3
9/1	127	151.5	45.6	50.9	19.3%	-8.1%	-10.1%	20.2%	17.6
9/2	158	168.0	46.6	48.0	6.3%	-16.7%	-17.5%	29.2%	28.2
9/3	144.4	155.8	45.0	47.4	7.9%	-13.4%	-13.8%	29.6%	26.6
9/4	143	172.7	46.4	52.4	20.8%	-0.1%	-8.3%	25.6%	22.9
9/5	123	132.8	42.3	50.4	7.9%	-4.1%	-10.5%	23.4%	20.4
9/6	127	120.5	37.7	50.6	-5.1%	6.5%	3.5%	21.7%	16.1
9/7	137	154.8	39.0	50.5	13.0%	1.6%	0.8%	20.8%	17.2
9/8	135	151.0	39.9	48.9	11.9%	-5.3%	-9.3%	27.8%	23.2
9/9	115	202.3	33.2	45.9	75.9%	9.9%	1.6%	23.1%	15.6

Table 6-2c.
Model Performance Statistics for 1-Hour Ozone for the August-September 1999 Base Case Simulation, for the 4 km UAM-V Modeling Domain (Grid 3)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
8/29	105	107.9	51.2	46.3	2.8%	-16.1%	-18.7%	22.2%	17.0
8/30	116	126.8	52.3	50.8	9.3%	-9.1%	-8.0%	14.2%	11.2
8/31	110	119.3	48.7	51.7	8.4%	-5.7%	-7.6%	19.7%	15.4
9/1	127	151.5	50.5	53.1	19.3%	-9.3%	-12.4%	21.5%	19.8
9/2	158	168.0	52.0	53.9	6.3%	-15.8%	-14.4%	23.8%	23.8
9/3	144.4	155.8	47.7	50.9	7.9%	-10.2%	-8.4%	26.0%	23.5
9/4	131	172.7	51.3	55.0	31.8%	-4.2%	-6.2%	22.6%	20.1
9/5	123	132.8	47.8	52.6	7.9%	-9.4%	-9.6%	20.2%	19.6
9/6	127	120.5	44.6	53.3	-5.1%	-3.8%	-2.4%	20.9%	17.0
9/7	115	154.8	45.9	53.8	34.6%	-3.7%	-5.7%	21.7%	19.3
9/8	135	151.0	46.7	54.1	11.9%	-9.8%	-9.3%	24.9%	21.5
9/9	115	202.3	39.4	45.8	75.9%	1.4%	-8.1%	22.6%	16.5

Table 6-3a.
Domain-wide Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; August-September 1999 Episode

Day	Domain-wide average accuracy of the 8-hour ozone peak (%)	9-cell domain-wide average accuracy of the 8-hour ozone peak (%)
31	-1.9%	2.6%
1	-10.1%	-3.6%
2	-13.7%	-6.7%
3	-8.6%	1.4%
4	-3.9%	2.9%
5	-10.4%	-5.6%
6	-2.2%	3.0%
7	-2.2%	5.6%
8	-10.2%	-3.0%
9	3.0%	14.1%

Table 6-3b.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; August-September 1999 Episode

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	-10.1%	-1.7%
Edmond Orgill Park, TN	-11.8%	-7.8%
Frayser, TN	-14.1%	-5.2%
Marion, AR	-7.6%	2.8%
Nashville EAC		
Cottontown Wright's Farm, TN	-21.1%	-16.1%
Dickson County, TN	-9.3%	-5.3%
East Nashville Health Center, TN	-18.2%	-2.9%
Fairview, TN	-9.3%	-4.9%
Cedars of Lebanon State Park	3.8%	6.8%
Percy Priest Dam, TN	-13.3%	-0.1%
Rockland Road, TN	-5.1%	-0.7%
Rutherford County, TN	-14.9%	-11.9%
Knoxville EAC		
Anderson County, TN	-1.6%	4.6%
Cades Cove, TN	-3.8%	-0.8%
Clingman's Dome, TN	-18.8%	-16.7%
Cove Mountain, TN	-22.9%	-20.7%
East Knox, TN	-9.7%	-6.5%
Jefferson County, TN	-2.0%	2.5%
Look Rock (1), TN	-19.5%	-14.9%
Look Rock (2), TN	-21.1%	-16.6%
Spring Hill, TN	-23.4%	-7.2%
Chattanooga EAC		
Chattanooga VAAP, TN	-9.6%	0.6%
Sequoyah, TN	-9.1%	-0.9%
Tri-Cities EAC		
Kingsport, TN	-2.3%	23.1%
Sullivan County, TN	-0.4%	9.6%

Table 6-4a.
Model Performance Statistics for 1-Hour Ozone for the June 2001 Base Case Simulation, for the 36 km UAM-V Modeling Domain (Grid 1)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
6/16	156	123.9	36.0	46.7	-20.6%	12.3%	12.0%	19.0%	12.9
6/17	100	131.6	44.7	54.8	31.6%	5.7%	6.4%	15.8%	11.7
6/18	137	147.6	49.4	56.5	7.7%	-2.0%	0.7%	15.4%	12.4
6/19	143	146.7	50.1	56.3	2.6%	-2.6%	-2.4%	17.1%	13.6
6/20	136	160.3	41.0	50.6	17.9%	-0.5%	-0.7%	21.7%	15.8
6/21	123	158.3	35.9	49.2	28.7%	7.7%	5.0%	23.3%	16.1
6/22	106	132.3	34.6	52.3	24.9%	26.3%	22.8%	28.6%	17.1

Table 6-4b.
Model Performance Statistics for 1-Hour Ozone for the June 2001 Base Case Simulation, for the 12 km UAM-V Modeling Domain (Grid 2)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
6/16	87	112.7	36.7	46.7	29.5%	12.0%	11.8%	18.2%	11.5
6/17	100	131.6	45.7	56.6	31.6%	3.5%	6.3%	15.0%	11.4
6/18	114	147.6	49.6	58.0	29.5%	-2.2%	1.3%	14.3%	11.6
6/19	121	146.7	49.8	56.7	21.2%	-3.2%	-1.6%	16.7%	13.8
6/20	119	160.3	44.3	52.0	34.7%	-5.6%	-3.3%	21.0%	16.3
6/21	123	158.3	39.7	52.4	28.7%	14.4%	10.3%	24.1%	17.0
6/22	93	132.3	34.1	52.9	42.3%	28.0%	27.8%	29.9%	17.7

Table 6-4c.
Model Performance Statistics for 1-Hour Ozone for the June 2001 Base Case Simulation, for the 4 km UAM-V Modeling Domain (Grid 3)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
6/16	87	111.6	38.0	49.5	28.3%	14.9%	14.7%	18.8%	11.5
6/17	100	130.9	48.2	59.1	30.9%	2.6%	4.5%	14.6%	10.8
6/18	114	147.6	50.9	61.9	29.5%	4.5%	5.5%	16.4%	13.6
6/19	110	146.7	51.8	57.1	33.3%	-4.9%	-4.1%	16.7%	14.2
6/20	115	160.3	48.5	55.4	39.4%	-4.2%	-2.9%	20.5%	17.0
6/21	108	158.3	42.7	57.4	46.6%	18.3%	13.6%	24.9%	17.7
6/22	82	127.3	34.3	54.5	55.3%	32.2%	27.9%	30.0%	17.4

Table 6-5a.
Domain-wide Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; June 2001 Episode

Day	Domain-wide average accuracy of the 8-hour ozone peak (%)	9-cell domain-wide average accuracy of the 8-hour ozone peak (%)
18	5.4%	10.2%
19	-7.4%	-2.2%
20	-2.0%	6.8%
21	19.1%	25.9%
22	36.8%	42.7%

Table 6-5b.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; June 2001 Episode

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	5.7%	10.8%
Edmond Orgill Park, TN	1.0%	3.7%
Frayser, TN	7.4%	15.4%
Marion, AR	1.3%	7.1%
Nashville EAC		
Cedars of Lebanon State Park	0.6%	3.1%
Cottontown Wright's Farm, TN	10.4%	17.2%
East Nashville Health Center, TN	18.4%	38.3%
Fairview, TN	6.2%	8.2%
Percy Priest Dam, TN	6.3%	19.5%
Rockland Road, TN	19.4%	24.4%
Rutherford County, TN	0.5%	3.9%
Knoxville EAC		
Anderson County, TN	-5.4%	0.1%
Cades Cove, TN	24.4%	27.2%
Clingman's Dome, TN	-7.9%	-4.8%
Cove Mountain, TN	-9.9%	-6.6%
East Knox, TN	6.0%	12.3%
Jefferson County, TN	-1.3%	6.6%
Look Rock, TN	1.2%	5.6%
Chattanooga EAC		
Chattanooga VAAP, TN	6.2%	13.7%
Meigs County, TN	-12.2%	-6.5%
Sequoyah, TN	7.1%	12.3%
Tri-Cities EAC		
Kingsport, TN	-3.6%	4.5%
Sullivan County, TN	-8.2%	-0.3%

Table 6-6a.
Model Performance Statistics for 1-Hour Ozone for the July 2002 Base Case Simulation, for the 36 km UAM-V Modeling Domain (Grid 1)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
7/4	119	133.8	38.8	44.7	12.4%	-0.7%	-6.5%	22.8%	17.6
7/5	128	163.1	38.0	52.6	27.4%	13.9%	8.6%	21.7%	15.7
7/6	116	170.9	41.9	54.4	47.3%	10.5%	8.9%	22.0%	15.9
7/7	115	161.2	44.6	56.2	40.2%	6.4%	7.5%	19.5%	14.8
7/8	135	165.6	47.4	54.4	22.7%	-1.0%	-0.9%	19.3%	16.0
7/9	135	141.8	41.9	53.4	5.0%	4.1%	2.3%	21.1%	16.2
7/10	114	140.5	35.2	54.4	23.3%	23.9%	22.0%	28.6%	18.3

Table 6-6b.
Model Performance Statistics for 1-Hour Ozone for the July 2002 Base Case Simulation, for the 12 km UAM-V Modeling Domain (Grid 2)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
7/4	119	133.8	42.2	45.0	12.4%	-6.0%	-7.8%	22.8%	18.5
7/5	128	163.1	45.5	56.1	27.4%	3.1%	4.5%	19.7%	15.8
7/6	110	170.9	50.8	56.8	55.3%	-1.8%	-0.1%	18.3%	15.0
7/7	111	161.2	50.9	57.0	45.3%	0.2%	1.5%	16.5%	13.1
7/8	127	165.6	49.3	54.5	30.4%	-2.7%	-1.6%	18.6%	15.4
7/9	128	141.8	43.2	54.2	10.8%	5.6%	5.0%	20.9%	16.0
7/10	105	140.5	37.3	54.8	33.8%	18.5%	19.4%	28.2%	18.7

Table 6-6c.
Model Performance Statistics for 1-Hour Ozone for the July 2002 Base Case Simulation, for the 4 km UAM-V Modeling Domain (Grid 3)

Shading indicates that the calculated statistical measure is outside the EPA recommended range for acceptable model performance.

Sim. day	Max. observed ozone (ppb)	Max. simulated ozone (ppb)	Mean observed ozone (ppb)	Mean simulated ozone (ppb)	Unpaired accuracy of peak (%)	Avg. accuracy of peak (%)	Normalized bias (%)	Normalized gross error (%)	RMS error (ppb)
7/4	119	122.4	43.2	44.7	2.9%	-11.3%	-11.7%	22.2%	17.9
7/5	121	163.1	45.9	57.0	34.8%	5.7%	4.2%	19.7%	15.7
7/6	110	170.9	52.2	62.3	55.3%	5.2%	5.8%	18.3%	15.1
7/7	109	161.2	53.7	59.2	47.9%	2.7%	2.6%	18.3%	14.6
7/8	110	147.1	49.6	53.4	33.7%	-2.5%	-0.7%	18.4%	14.1
7/9	117	141.8	42.3	54.8	21.2%	11.7%	10.2%	24.3%	18.0
7/10	102	140.5	38.2	55.7	37.8%	18.1%	20.2%	27.8%	18.7

Table 6-7a.
Domain-wide Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; July 2002 Episode

Day	Domain-wide average accuracy of the 8-hour ozone peak (%)	9-cell domain-wide average accuracy of the 8-hour ozone peak (%)
6	7.1%	12.5%
7	4.7%	9.9%
8	-0.6%	6.0%
9	15.6%	22.8%
10	27.8%	36.3%

Table 6-7b.
Site-Specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; July 2002 Episode

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	5.2%	7.9%
Edmond Orgill Park, TN	-8.8%	-5.0%
Frayser, TN	-3.7%	3.4%
Marion, AR	-4.7%	-1.0%
Nashville EAC		
Cottontown Wright’s Farm, TN	-2.1%	4.4%
East Nashville Health Center, TN	37.0%	56.6%
Fairview, TN	14.1%	21.3%
Cedars of Lebanon State Park	17.0%	23.3%
Percy Priest Dam, TN	32.3%	45.9%
Rockland Road, TN	18.7%	24.2%
Rutherford County, TN	-2.6%	-1.2%
Knoxville EAC		
Anderson County, TN	-1.4%	2.1%
Cades Cove, TN	25.2%	29.1%
Clingman’s Dome, TN	-12.5%	-9.0%
Jefferson County, TN	-4.8%	-0.1%
Knox County, TN	-5.1%	0.9%
Knoxville, TN	-6.2%	0.3%
Look Rock, TN	-4.6%	0.8%
Sevier County, TN	-9.9%	-4.9%
Chattanooga EAC		
Chattanooga VAAP, TN	4.6%	12.5%
Meigs County, TN	-10.0%	-1.9%
Sequoyah, TN	4.5%	10.5%
Tri-Cities EAC		
Kingsport, TN	-4.0%	7.5%
Sullivan County, TN	-5.2%	0.5%

Table 6-8.
Site-specific Average Accuracy of 8-Hour Peak Ozone Concentration for Sites in the EAC Areas; All Episodes Combined, Excluding Startup Days

Site	Site-specific average accuracy of the 8-hour ozone peak (%)	9-cell site-specific average accuracy of the 8-hour ozone peak (%)
Memphis EAC		
DeSoto County, MS	-1%	4%
Edmond Orgill Park, TN	-7.9%	-4.2%
Frayser, TN	-6.1%	2.1%
Marion, AR	-4.6%	2.9%
Nashville EAC		
Cedars of Lebanon State Park	6.6%	10.4%
Cottontown Wright's Farm, TN	-8.8%	-3.0%
Dickson County, TN	-9.3%	-5.3%
East Nashville Health Center, TN	4.1%	21.4%
Fairview, TN	0.4%	4.9%
Percy Priest Dam, TN	2.8%	16.2%
Rockland Road, TN	7.0%	11.8%
Rutherford County, TN	-8.4%	-5.8%
Knoxville EAC		
Anderson County, TN	-2.3%	3.0%
Cades Cove, TN	8.9%	11.9%
Clingman's Dome, TN	-14.5%	-11.8%
Cove Mountain, TN	-16.4%	-13.2%
East Knox, TN	-4.6%	0.1%
Jefferson County, TN	-2.6%	2.9%
Look Rock (1), TN	-10.6%	-5.8%
Look Rock (2), TN	-21.1%	-16.6%
Spring Hill, TN	-17.7%	-4.7%
Chattanooga EAC		
Chattanooga VAAP, TN	-2.5%	6.5%
Meigs County, TN	-11.0%	-3.9%
Sequoyah, TN	-2.1%	4.9%
Tri-Cities EAC		
Kingsport, TN	-3.1%	13.6%
Sullivan County, TN	-3.9%	4.3%

Figure 6-1a.
Daily Maximum 1-Hour Ozone, Grid 1,
August 29, 1999

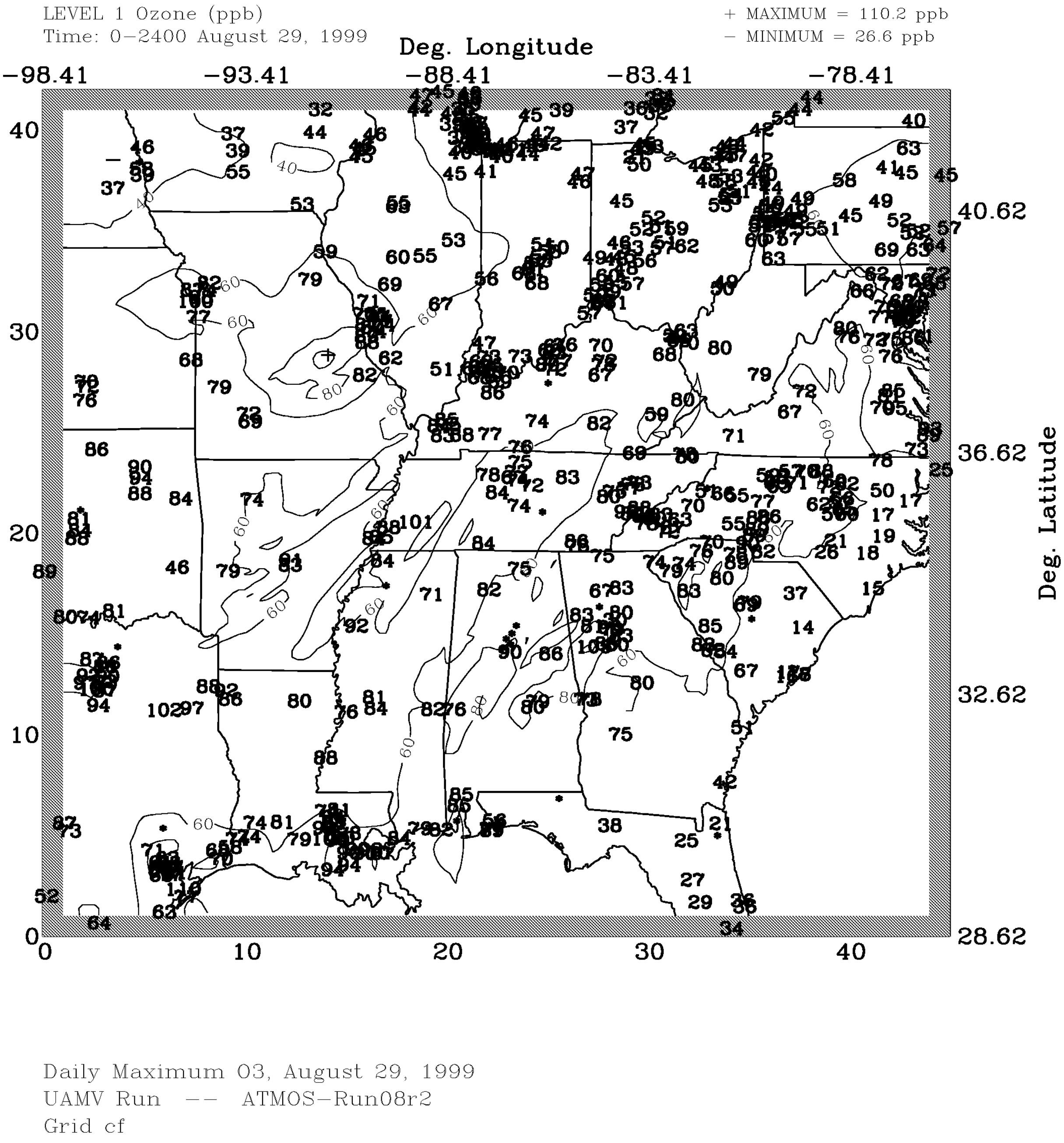


Figure 6-1b.
Daily Maximum 1-Hour Ozone, Grid 1,
August 30, 1999

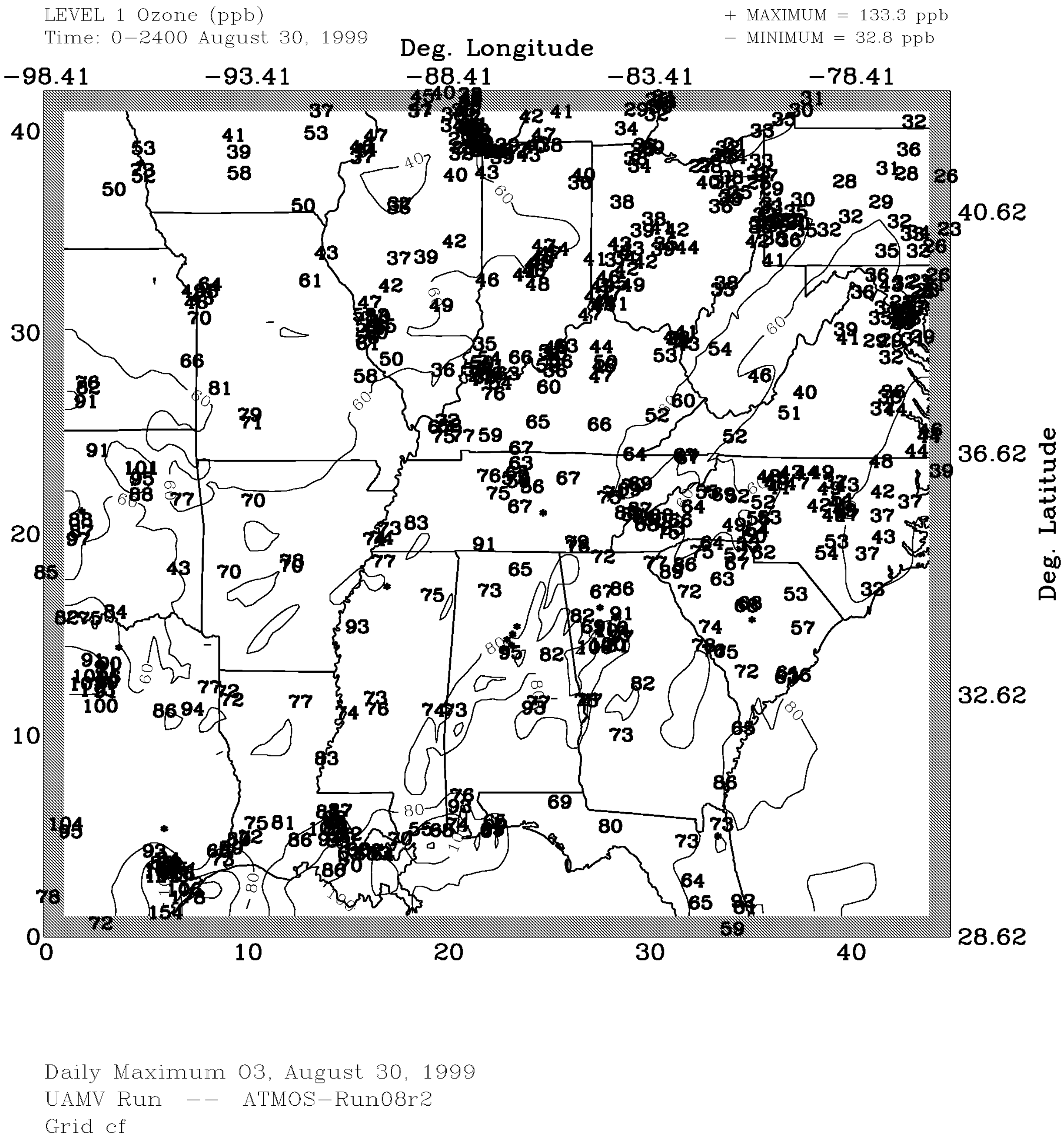


Figure 6-1c.
Daily Maximum 1-Hour Ozone, Grid 1,
August 31, 1999

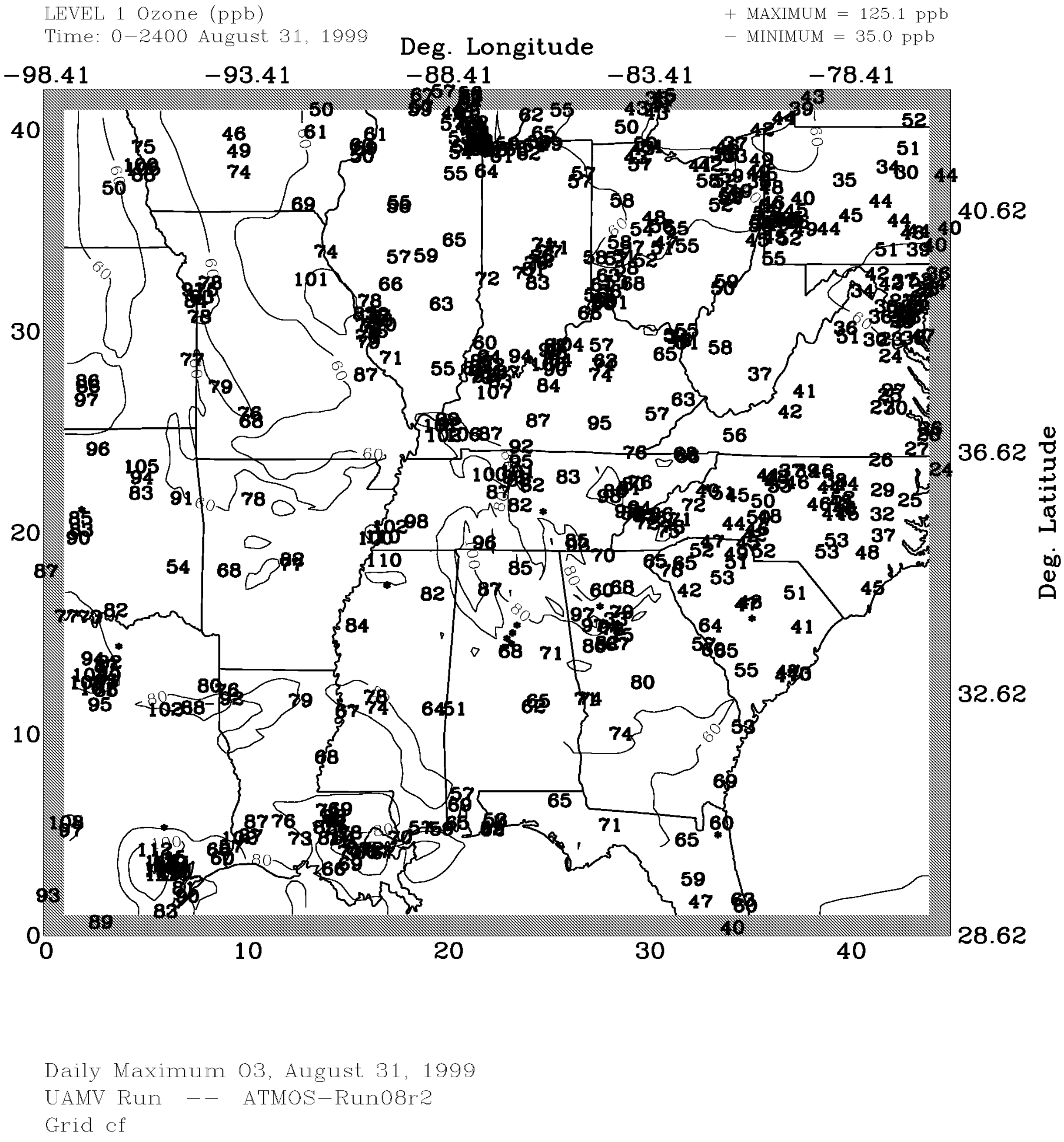


Figure 6-1d.
Daily Maximum 1-Hour Ozone, Grid 1,
September 1, 1999

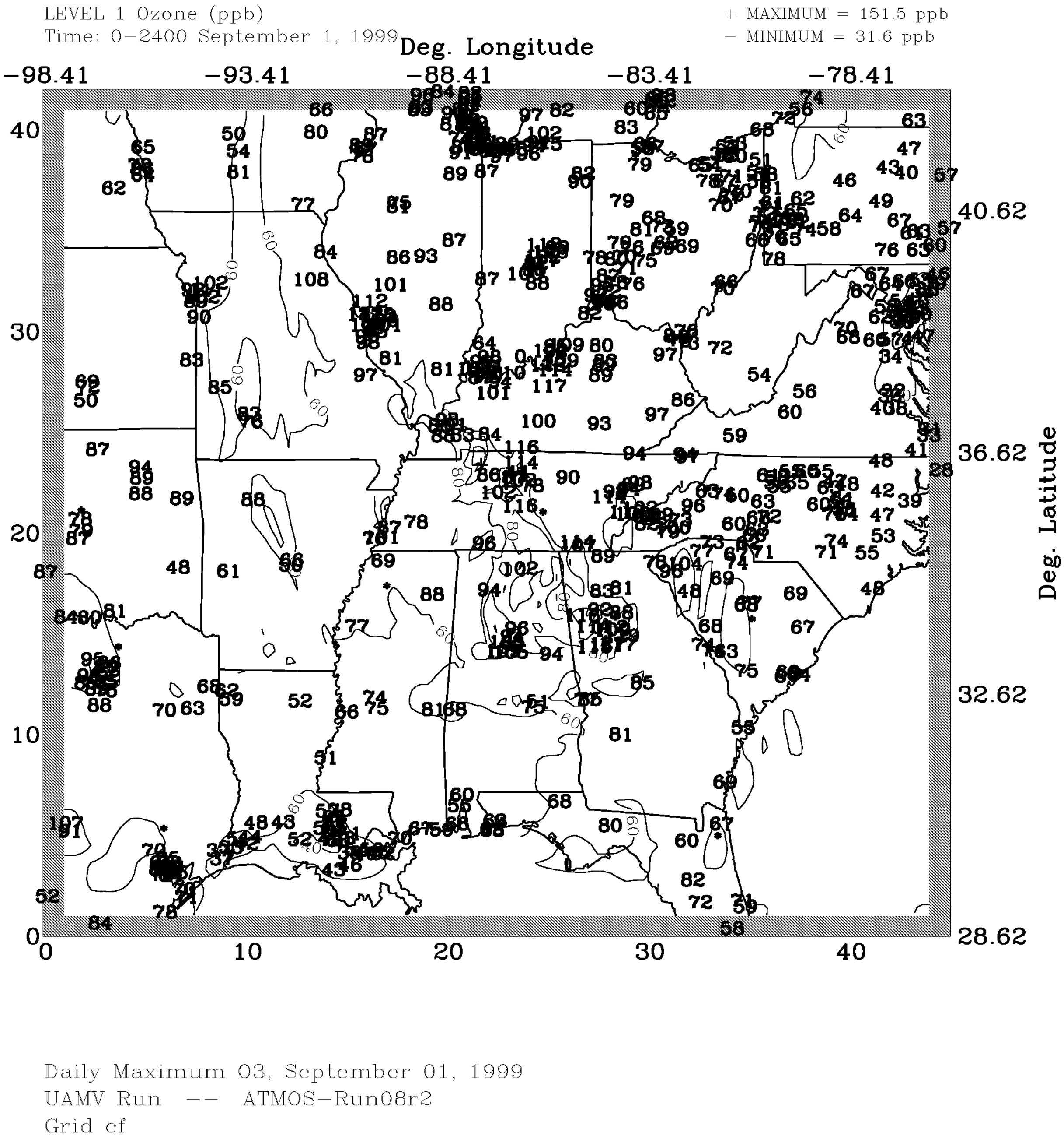


Figure 6-1e.
Daily Maximum 1-Hour Ozone, Grid 1,
September 2, 1999

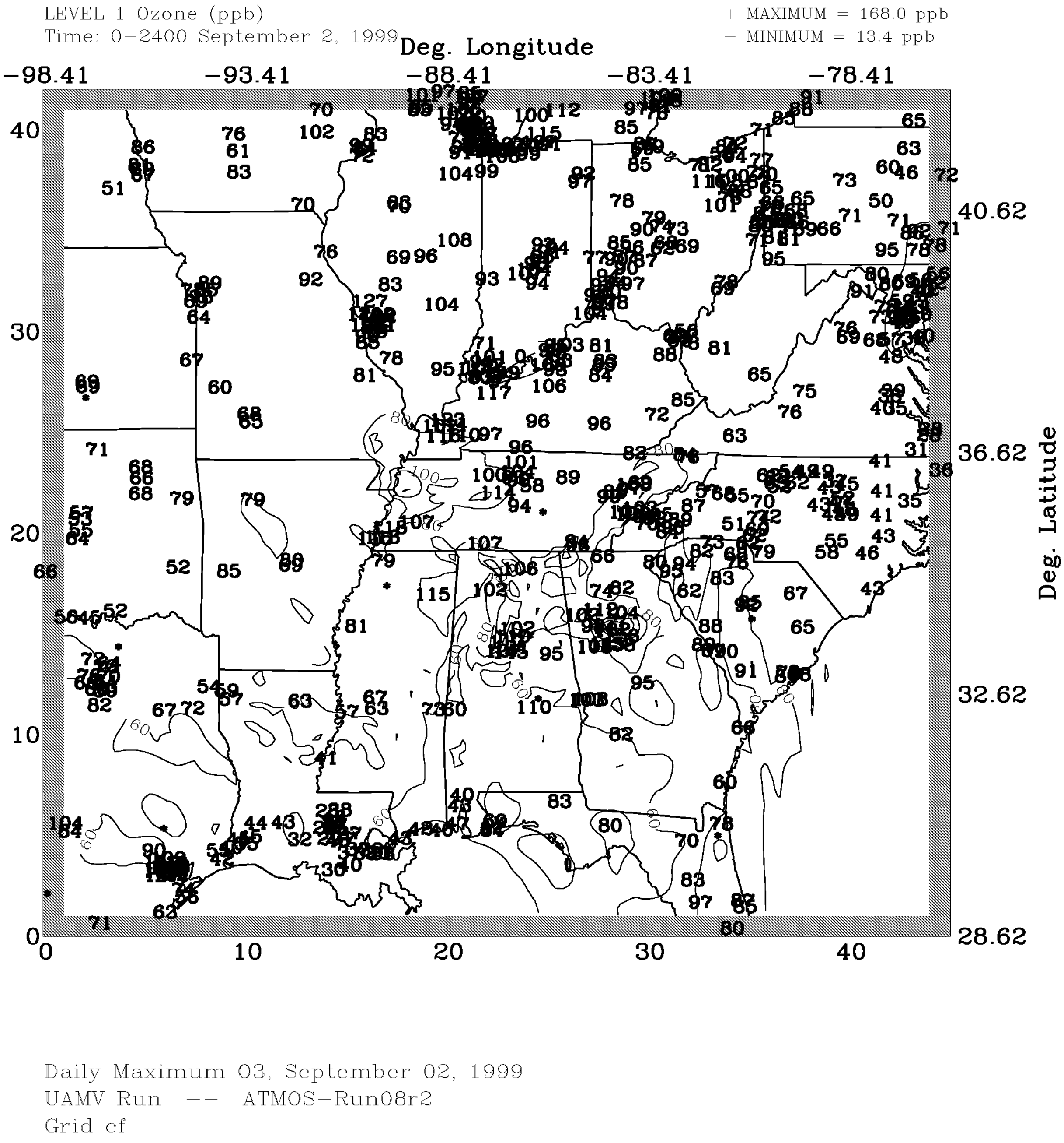


**Figure 6-1f.
Daily Maximum 1-Hour Ozone, Grid 1,
September 3, 1999**

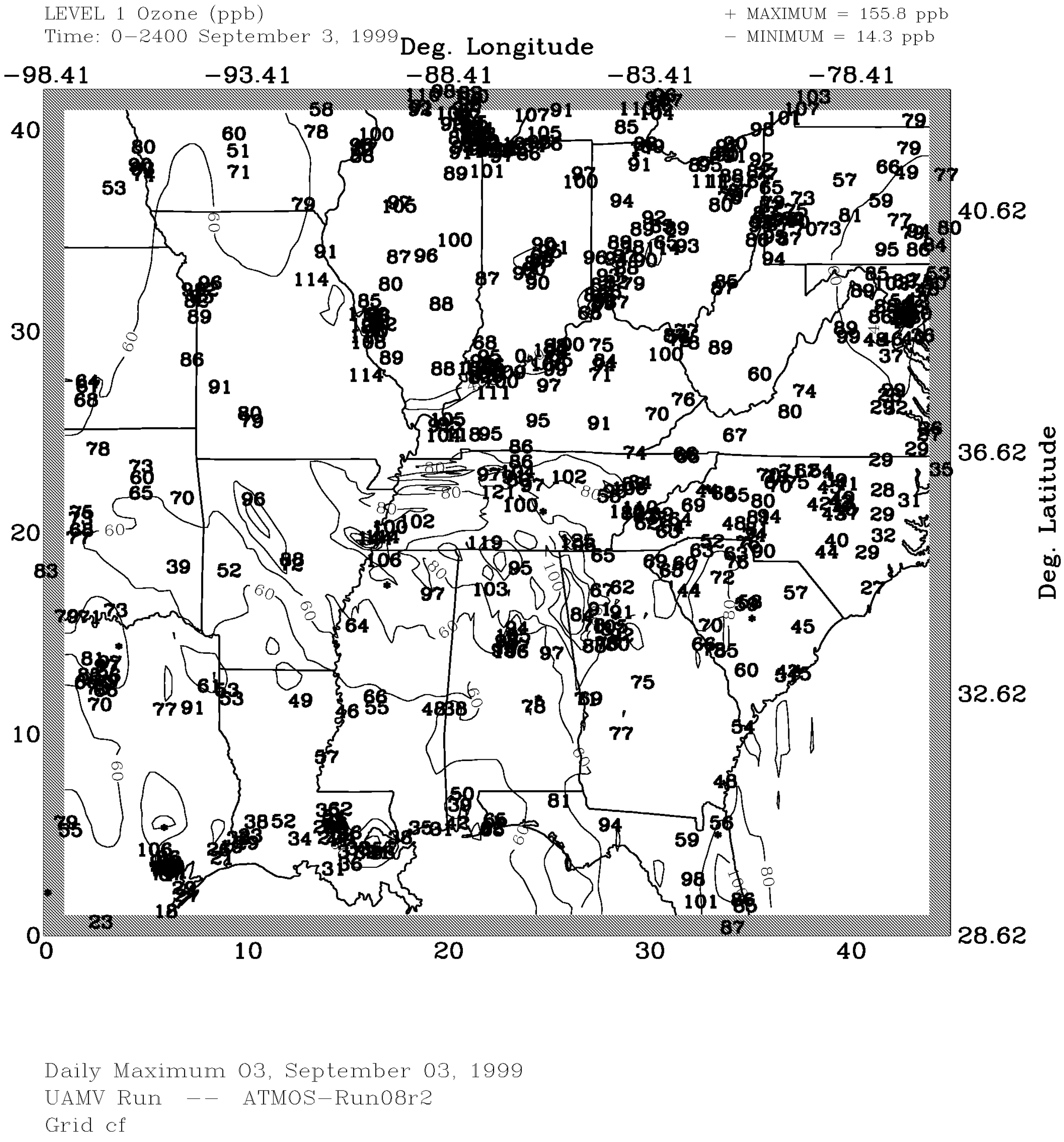


Figure 6-1g.
Daily Maximum 1-Hour Ozone, Grid 1,
September 4, 1999

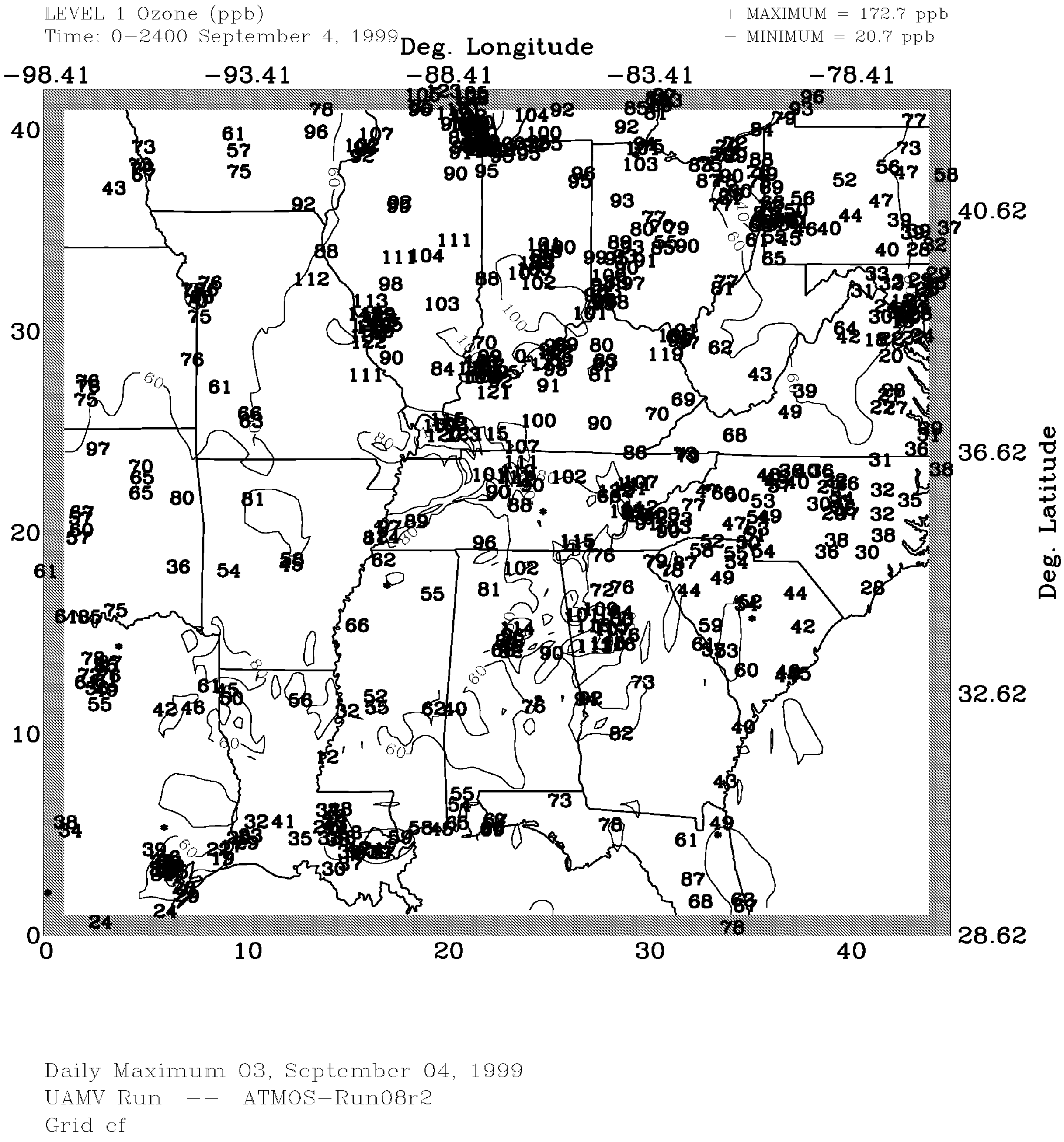
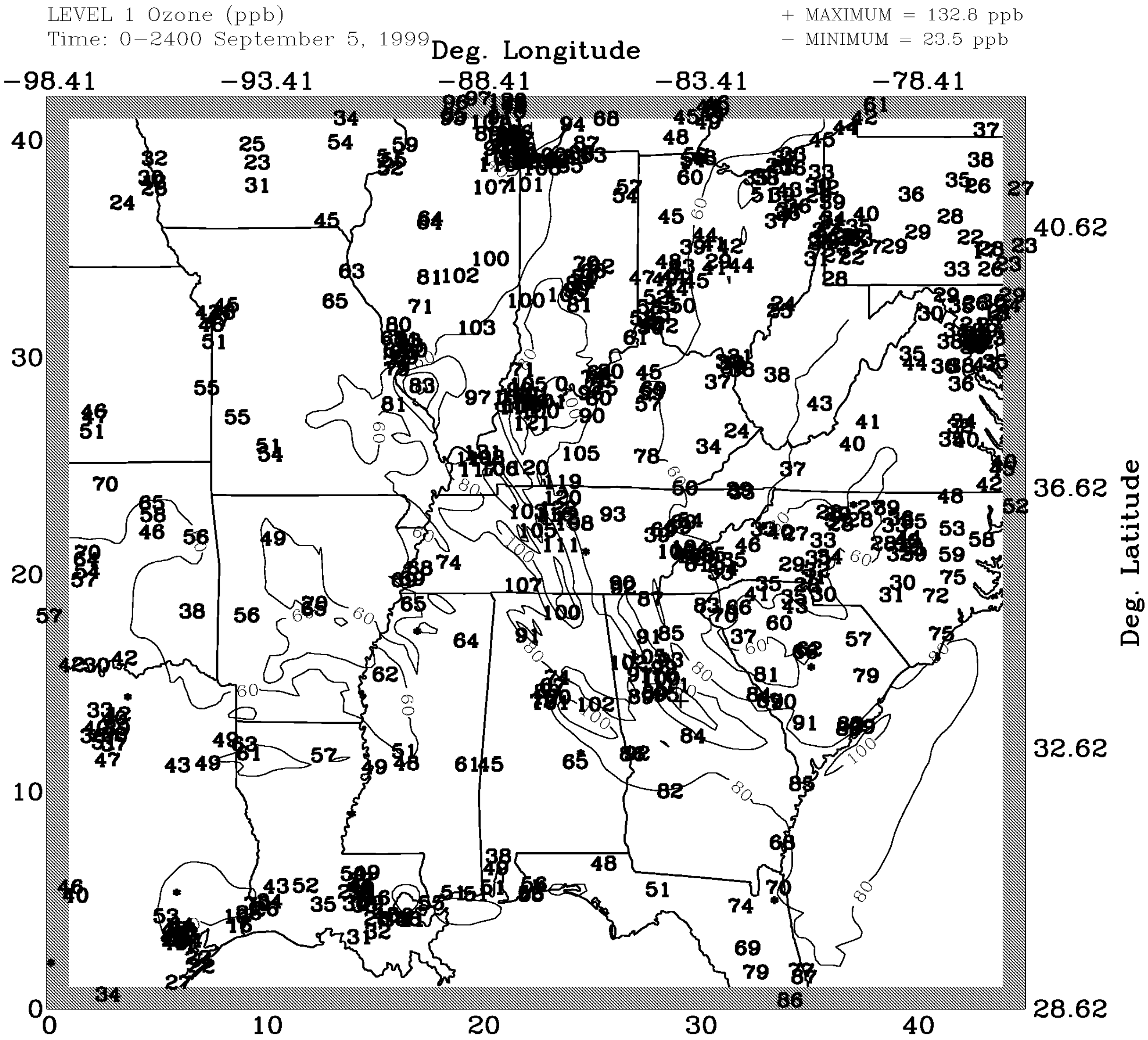


Figure 6-1h.
Daily Maximum 1-Hour Ozone, Grid 1,
September 5, 1999



Daily Maximum O3, September 05, 1999
UAMV Run -- ATMOS–Run08r2
Grid cf

Figure 6-1i.
Daily Maximum 1-Hour Ozone, Grid 1,
September 6, 1999

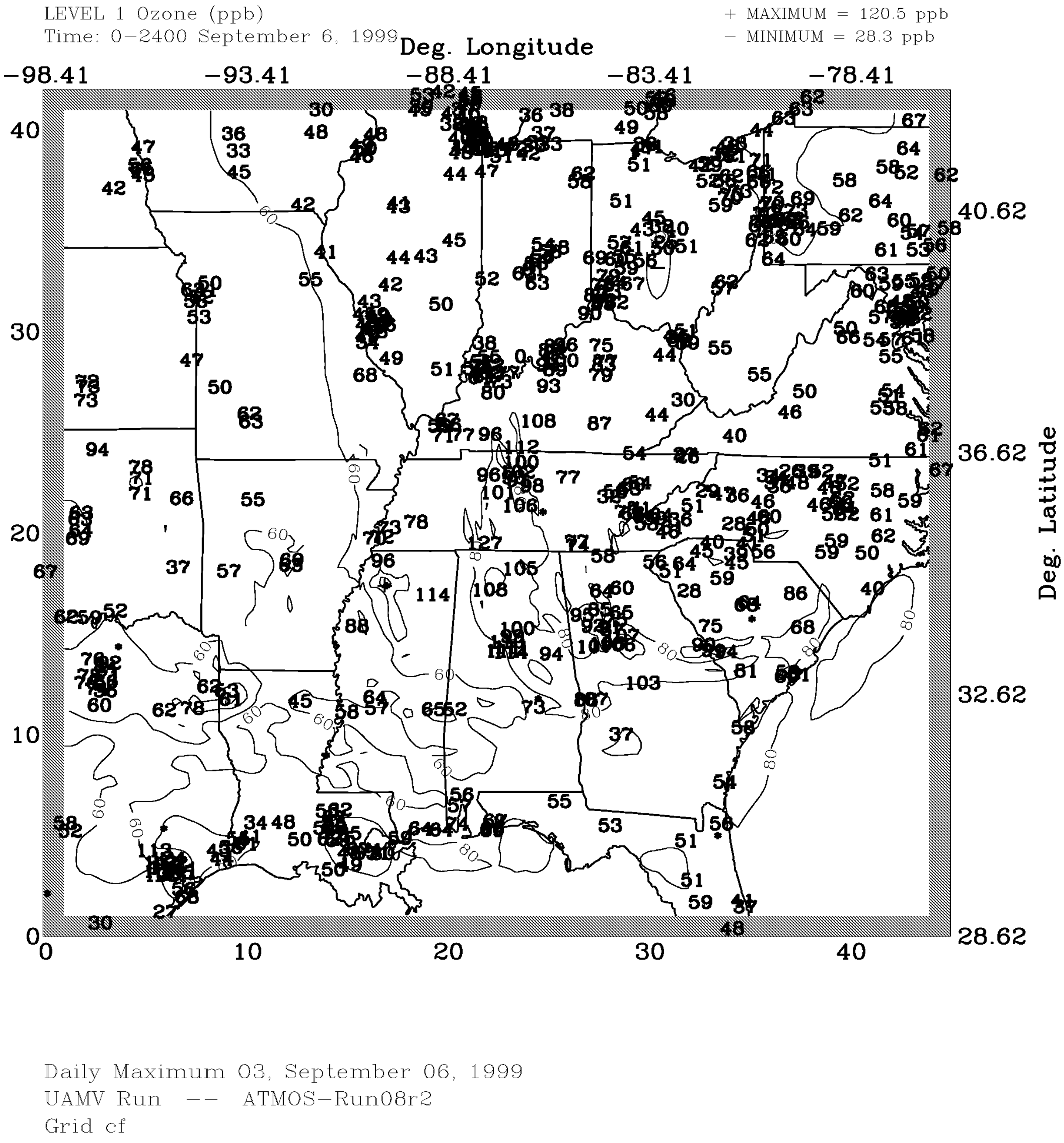
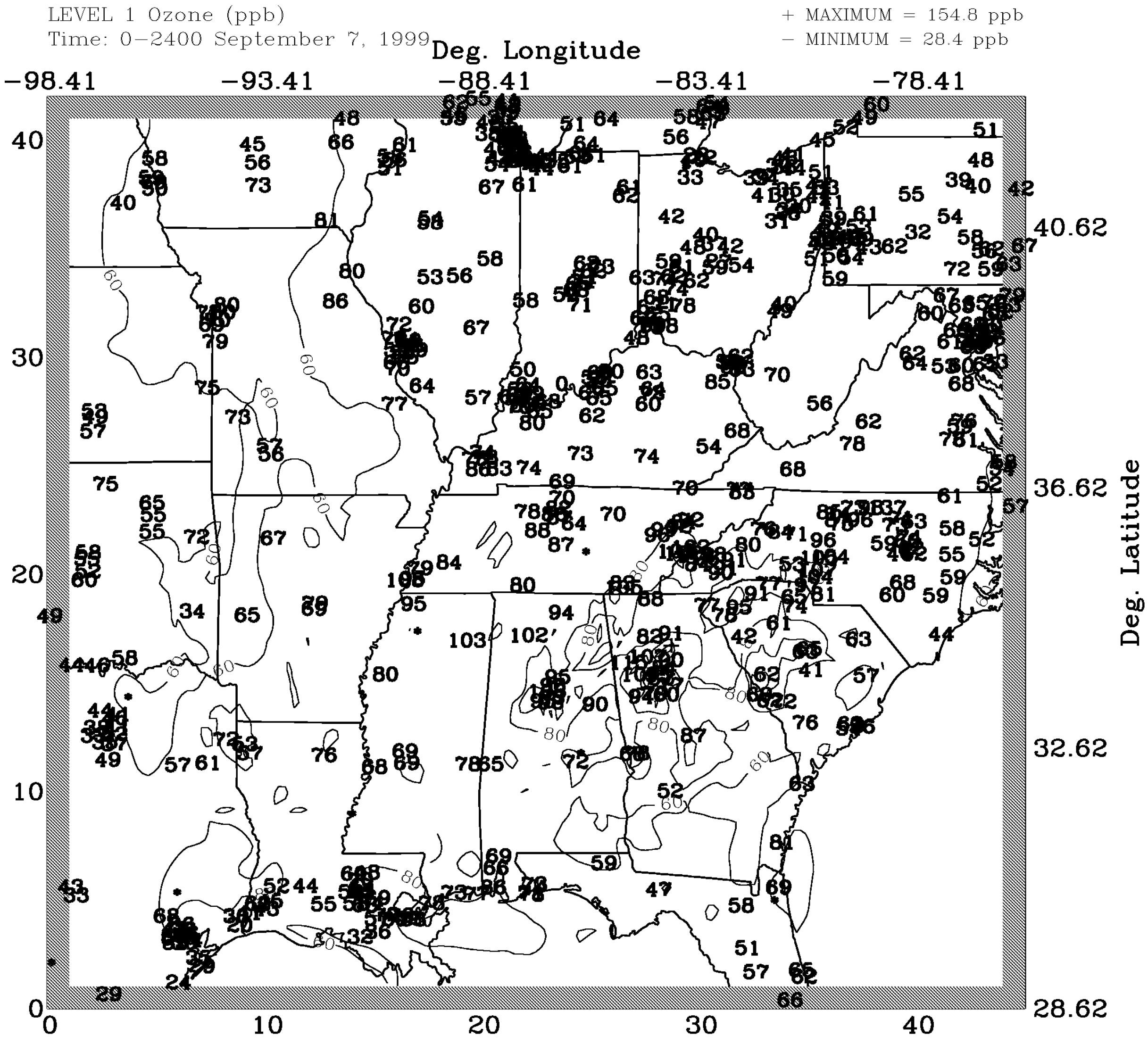


Figure 6-1j.
Daily Maximum 1-Hour Ozone, Grid 1,
September 7, 1999



Daily Maximum O3, September 07, 1999
UAMV Run -- ATMOS−Run08r2
Grid cf

Figure 6-1k.
Daily Maximum 1-Hour Ozone, Grid 1,
September 8, 1999

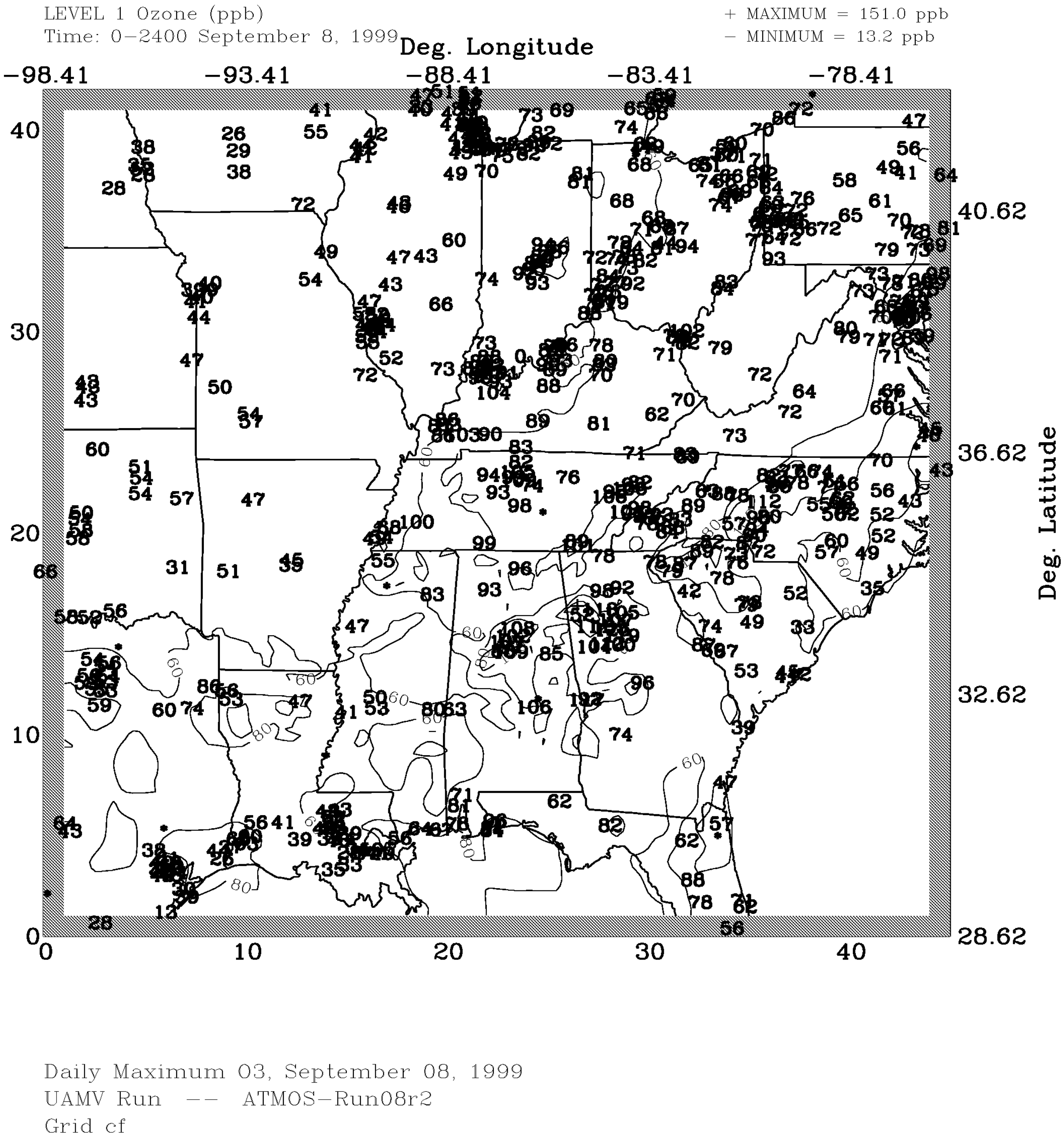


Figure 6-1l.
Daily Maximum 1-Hour Ozone, Grid 1,
September 9, 1999

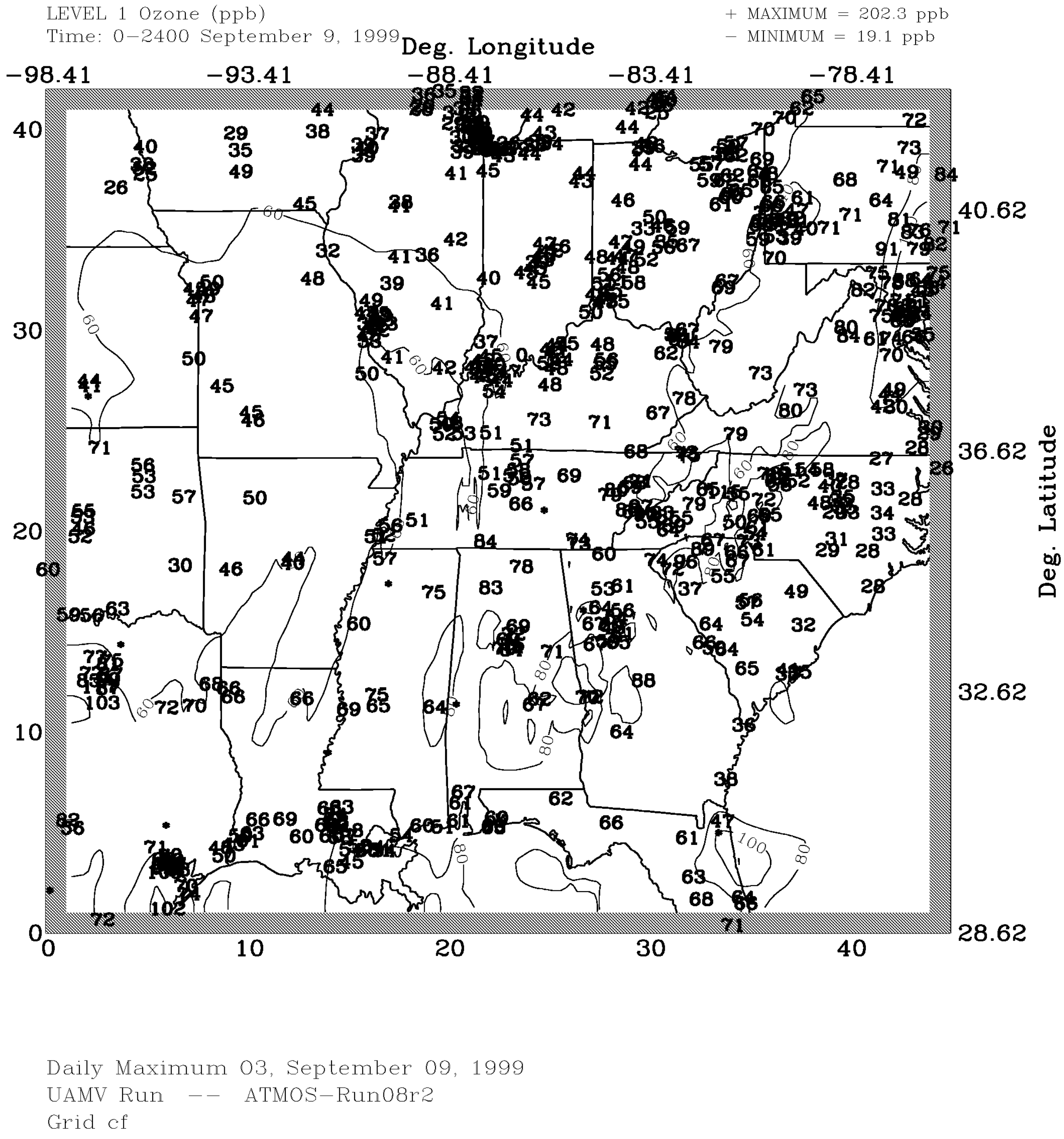


Figure 6-2a.
Daily Maximum 1-Hour Ozone, Grid 3,
August 29, 1999

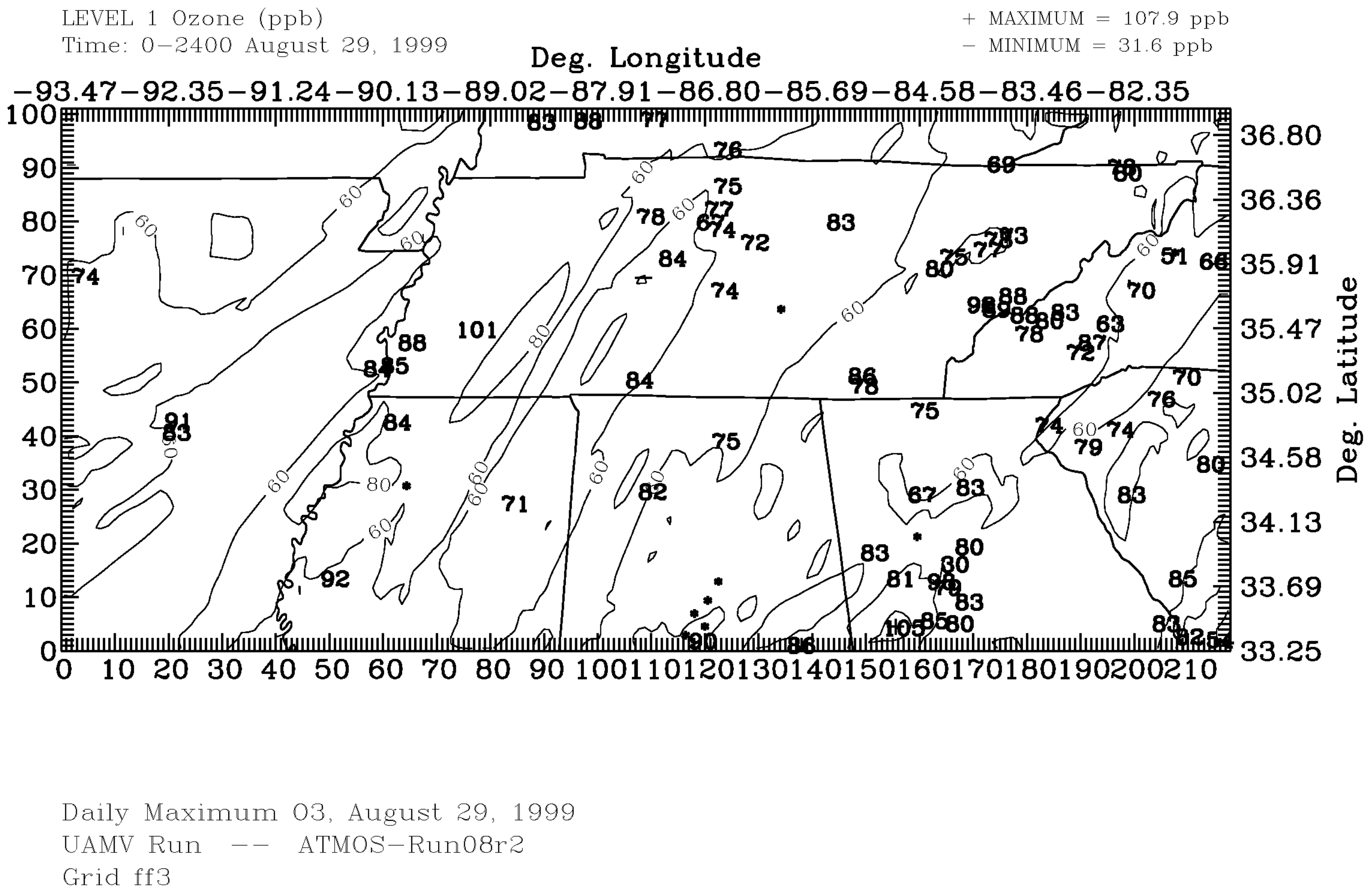


Figure 6-2b.
Daily Maximum 1-Hour Ozone, Grid 3,
August 30, 1999

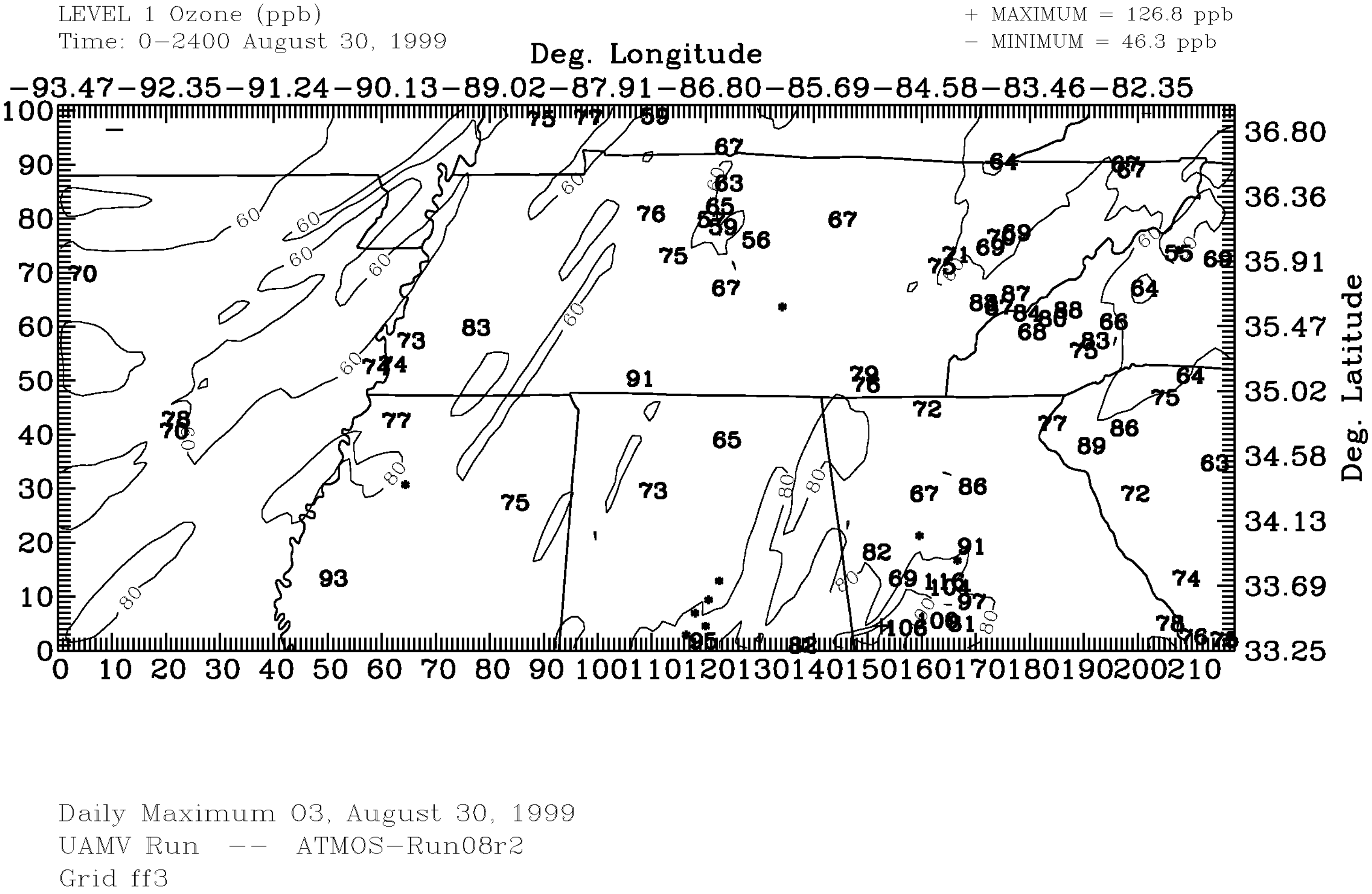


Figure 6-2c.
Daily Maximum 1-Hour Ozone, Grid 3,
August 31, 1999

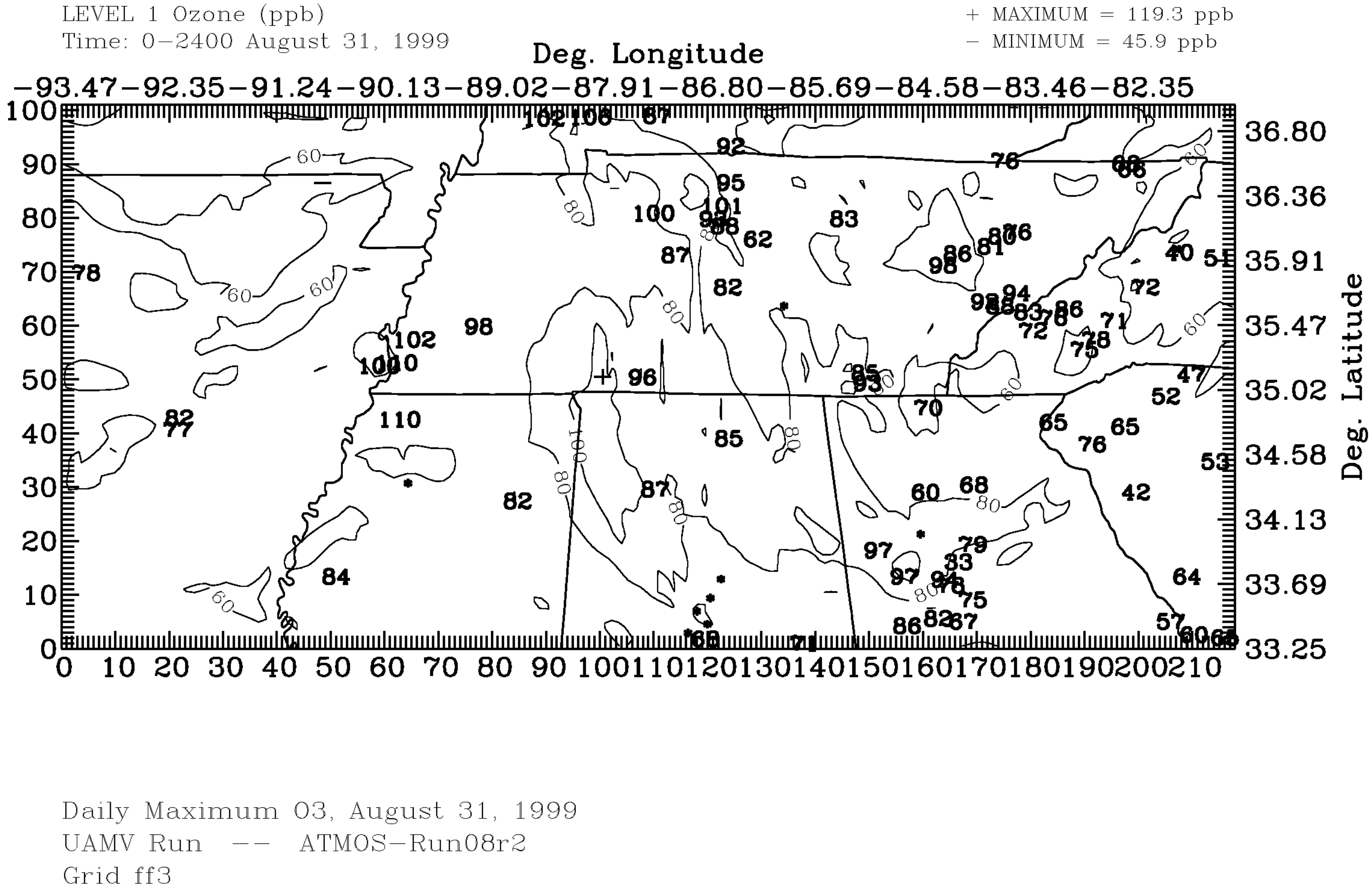


Figure 6-3d.
Daily Maximum 1-Hour Ozone, Grid 3,
September 1, 1999

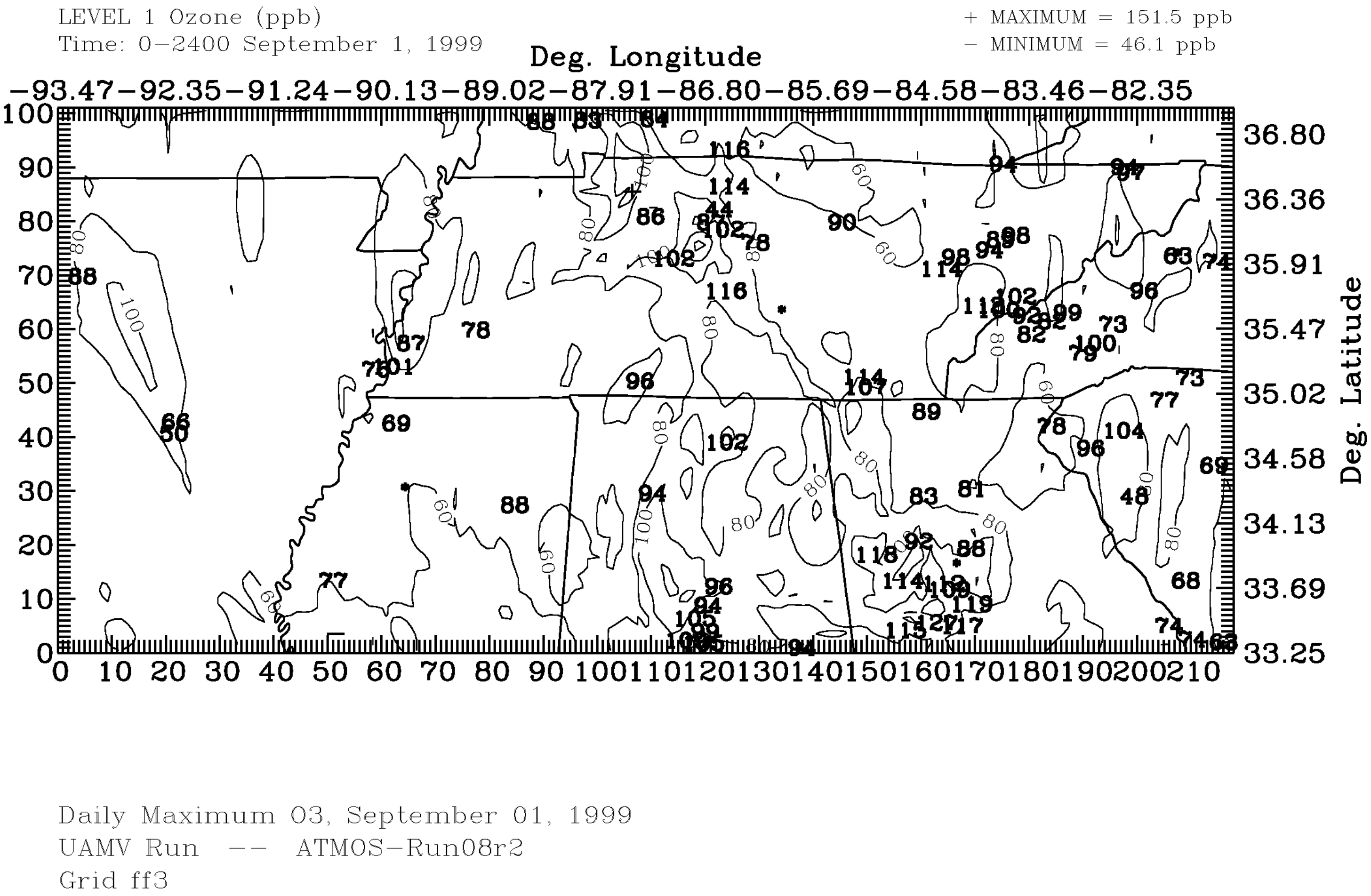


Figure 6-3e.
Daily Maximum 1-Hour Ozone, Grid 3,
September 2, 1999

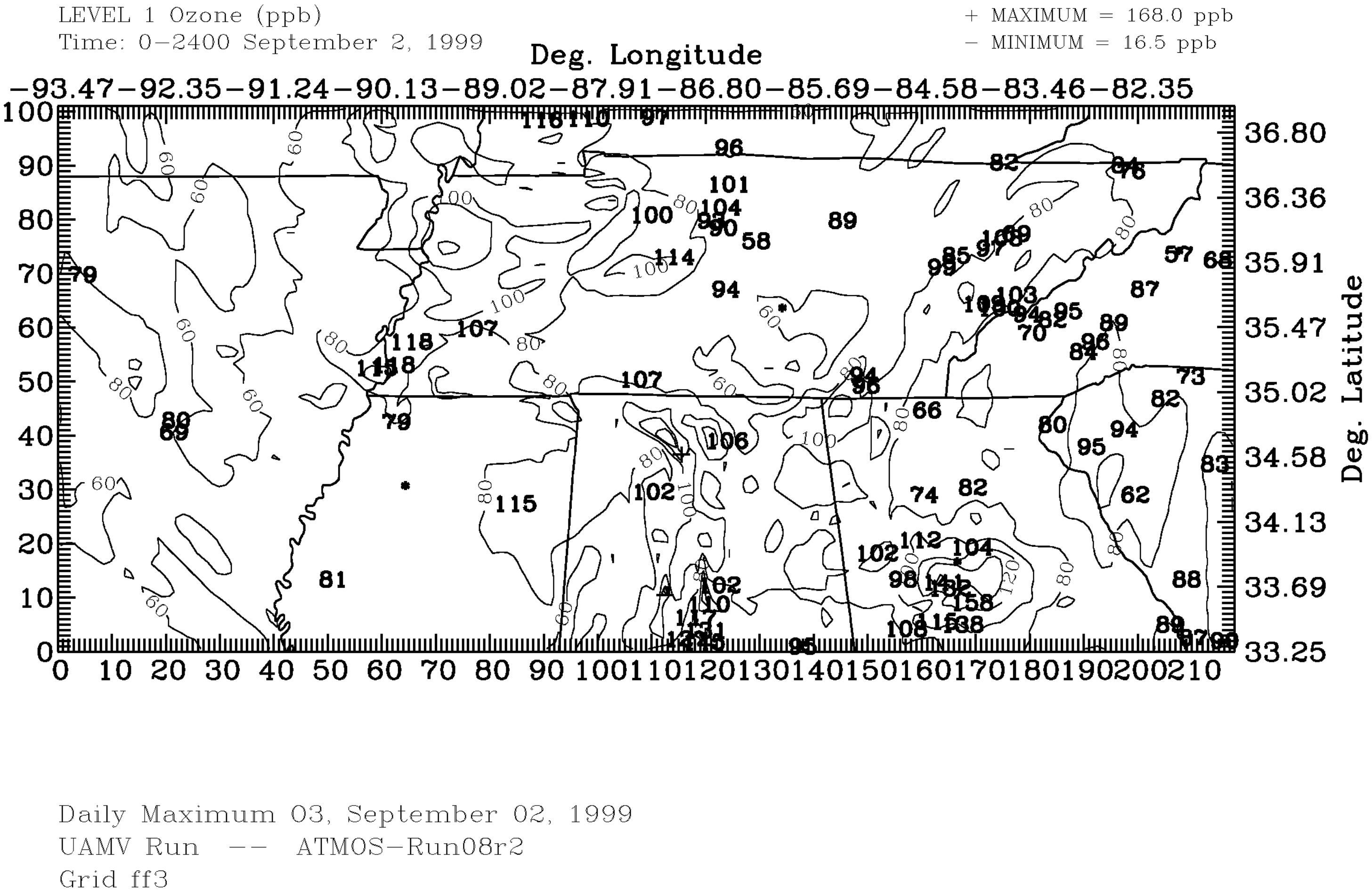


Figure 6-3f.
Daily Maximum 1-Hour Ozone, Grid 3,
September 3, 1999

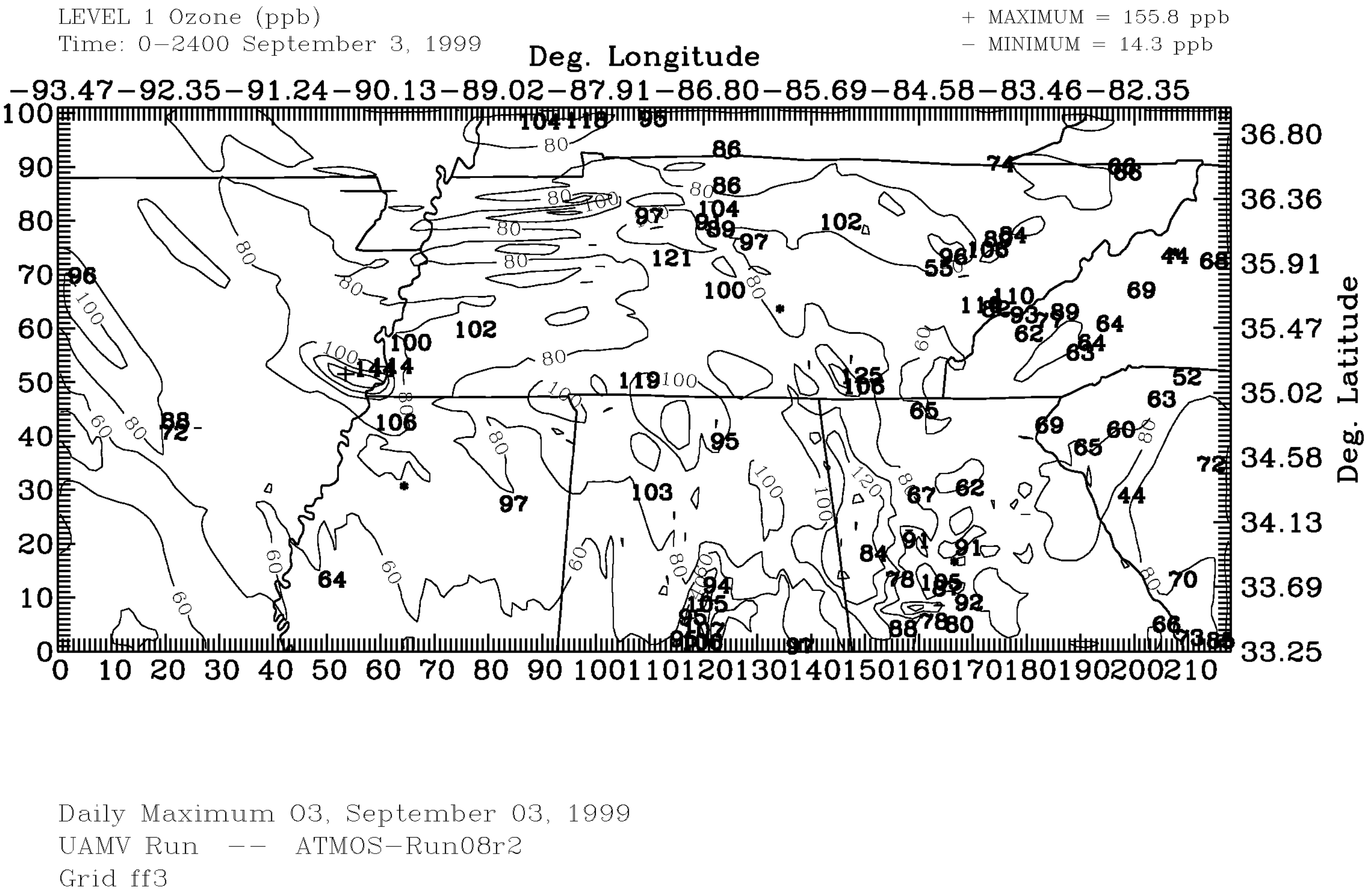
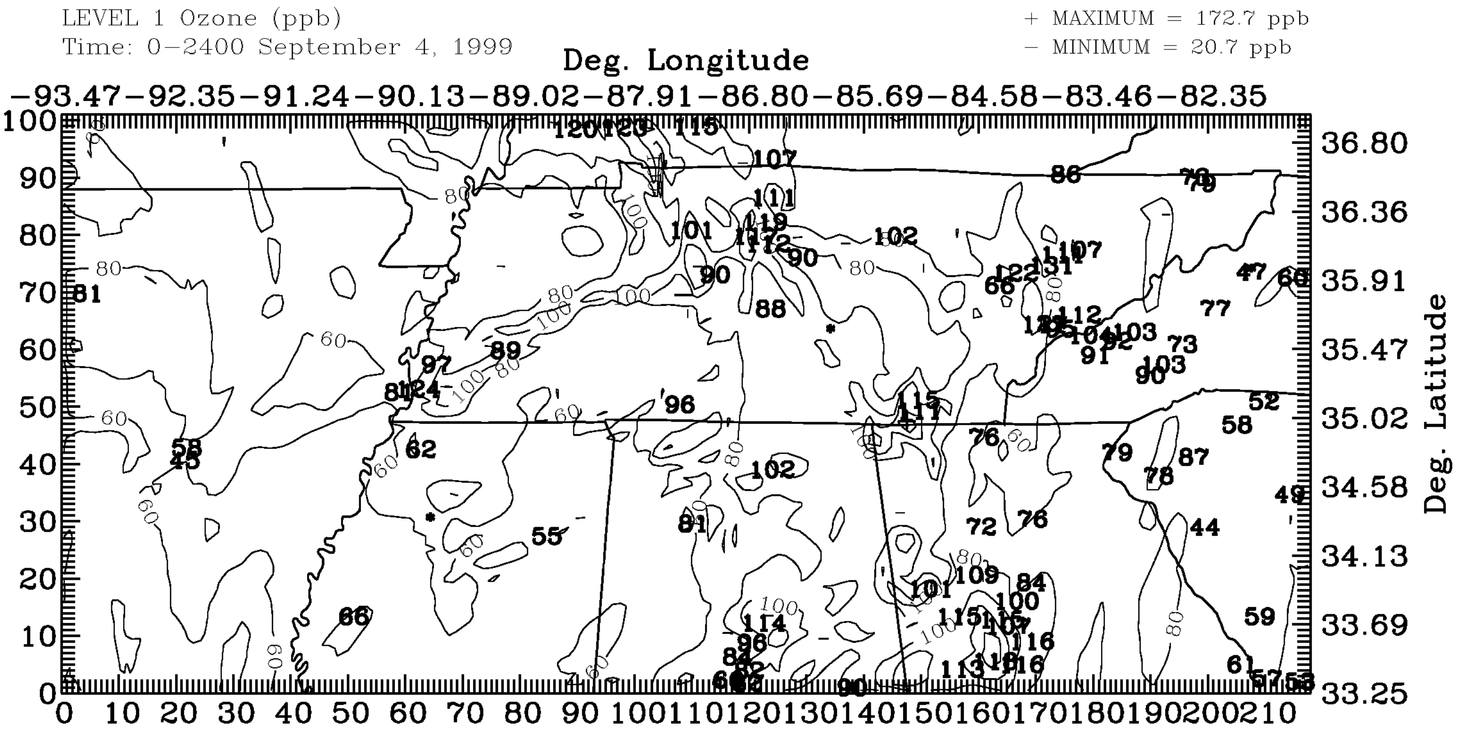


Figure 6-2g.
Daily Maximum 1-Hour Ozone, Grid 3,
September 4, 1999



Daily Maximum O3, September 04, 1999
UAMV Run –– ATMOS–Run08r2
Grid ff3

Figure 6-2h.
Daily Maximum 1-Hour Ozone, Grid 3,
September 5, 1999

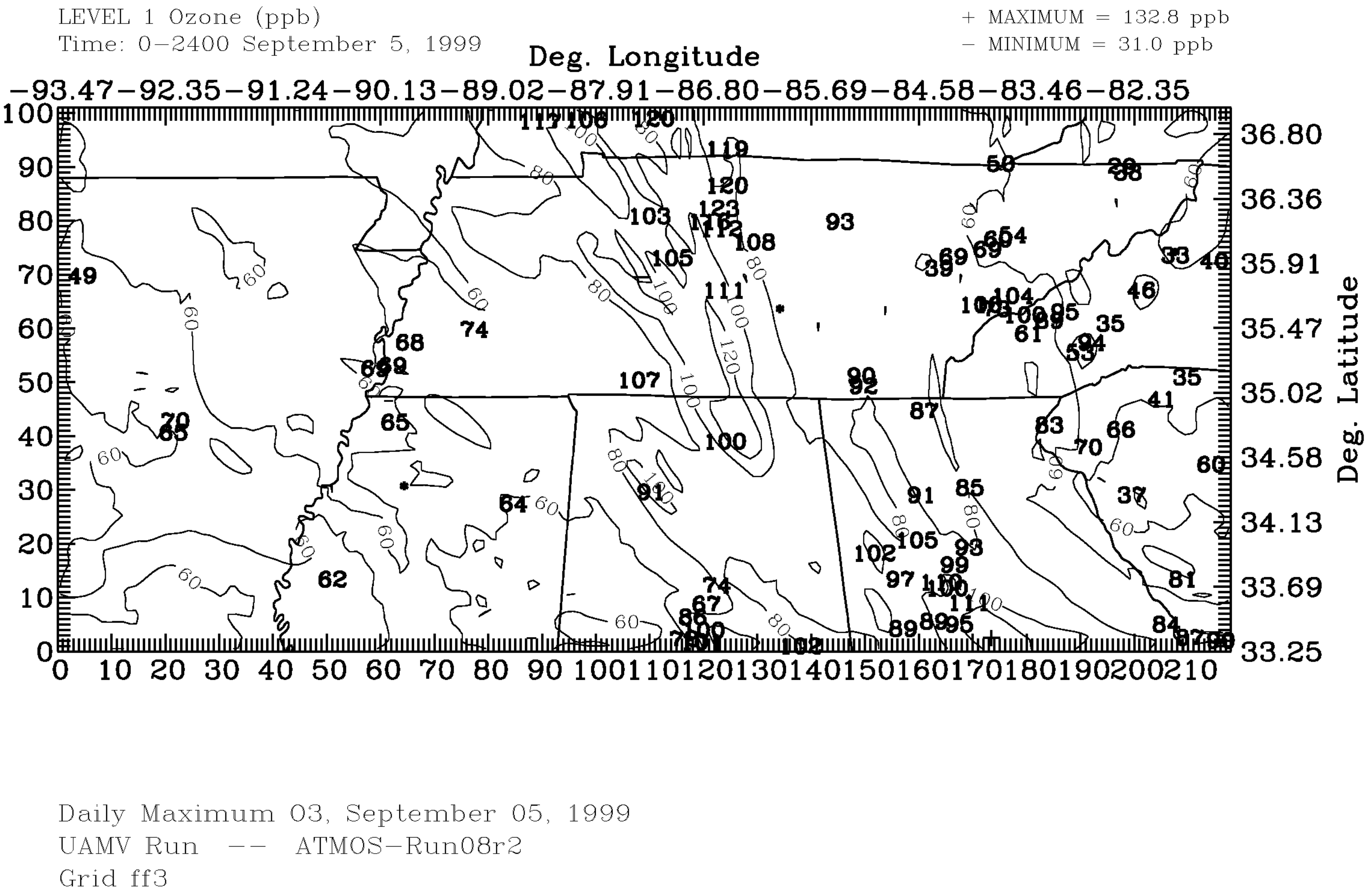


Figure 6-2i.
Daily Maximum 1-Hour Ozone, Grid 3,
September 6, 1999

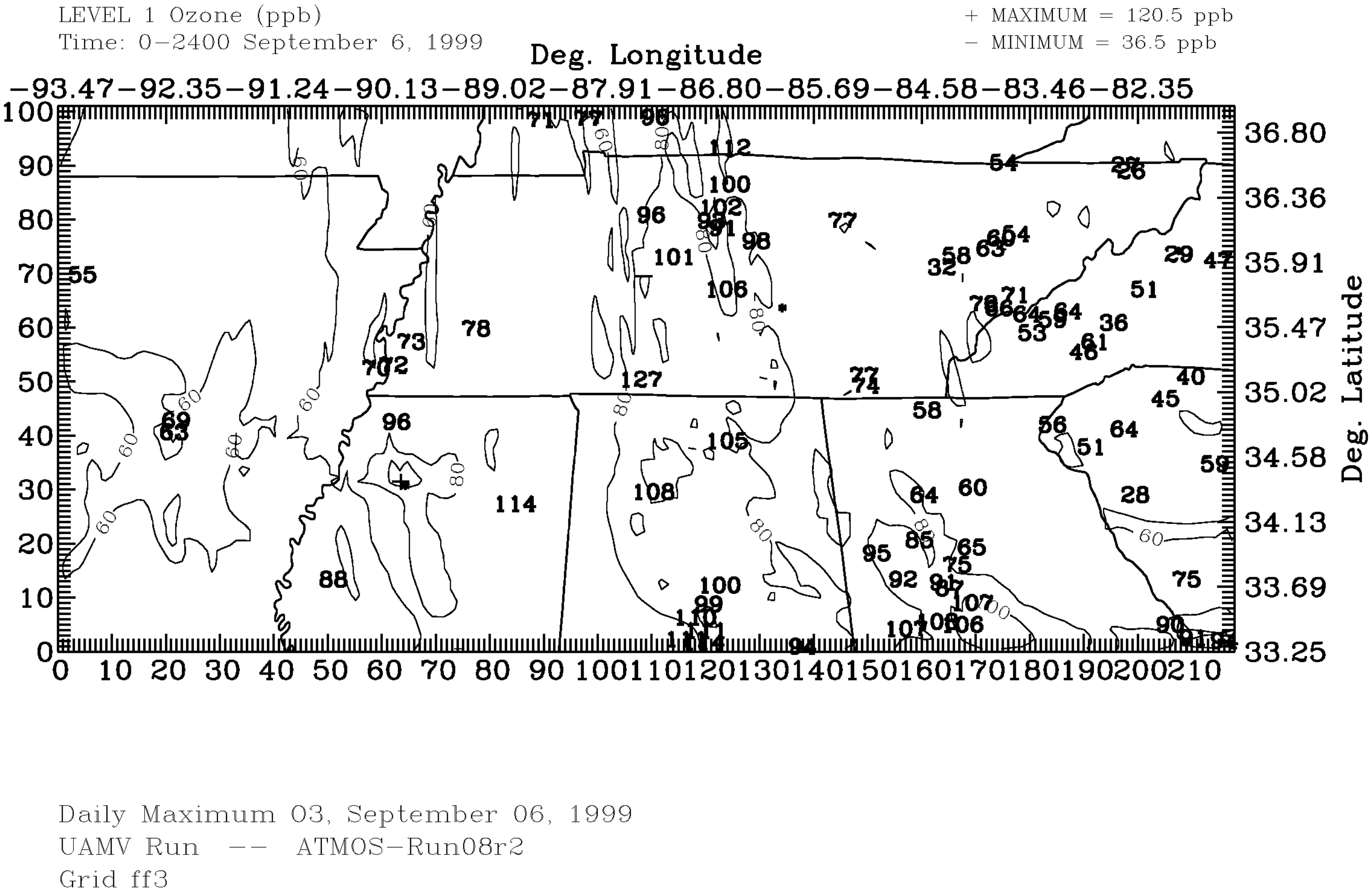


Figure 6-2j.
Daily Maximum 1-Hour Ozone, Grid 3,
September 7, 1999

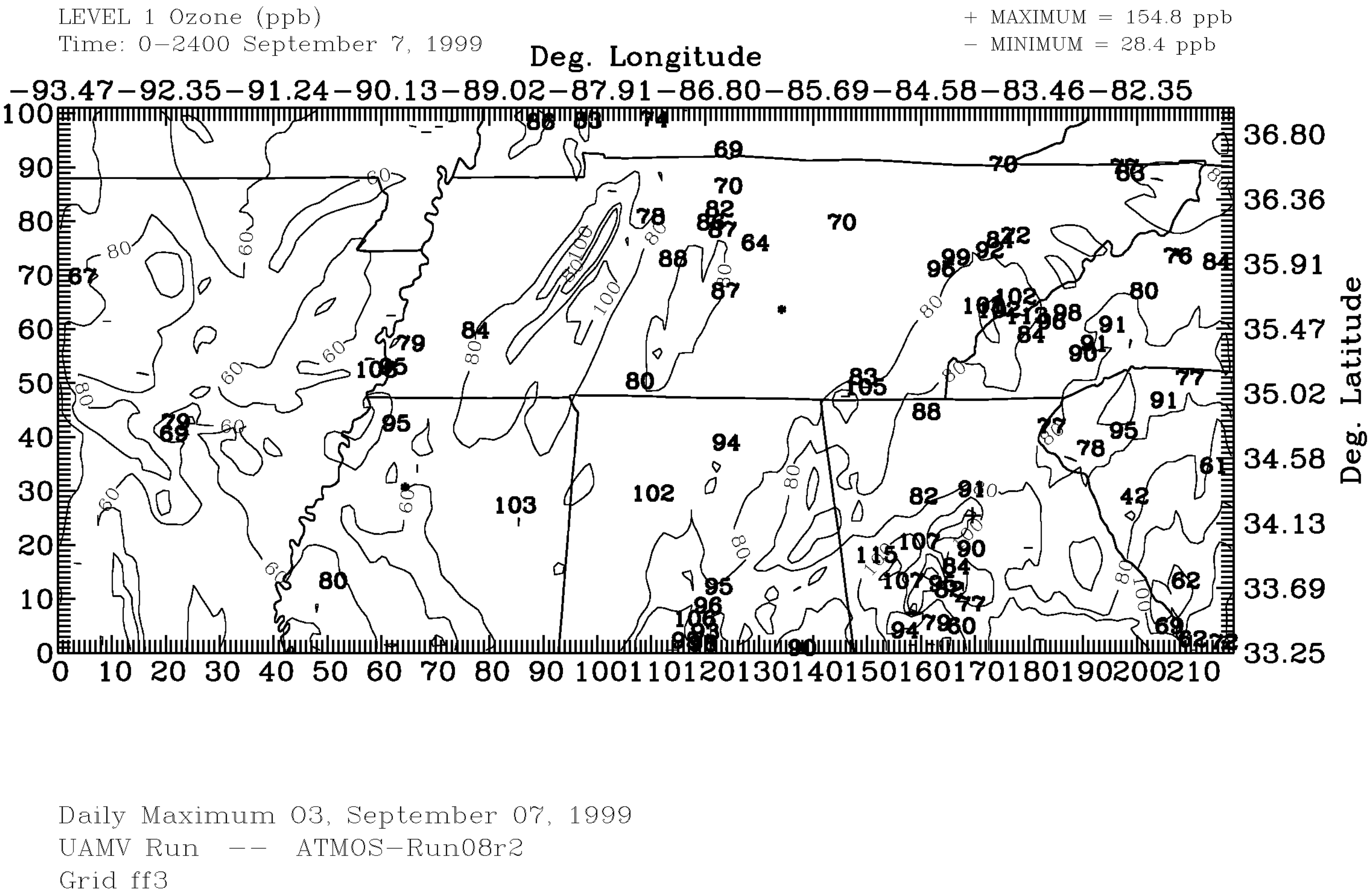


Figure 6-2k.
Daily Maximum 1-Hour Ozone, Grid 3,
September 8, 1999

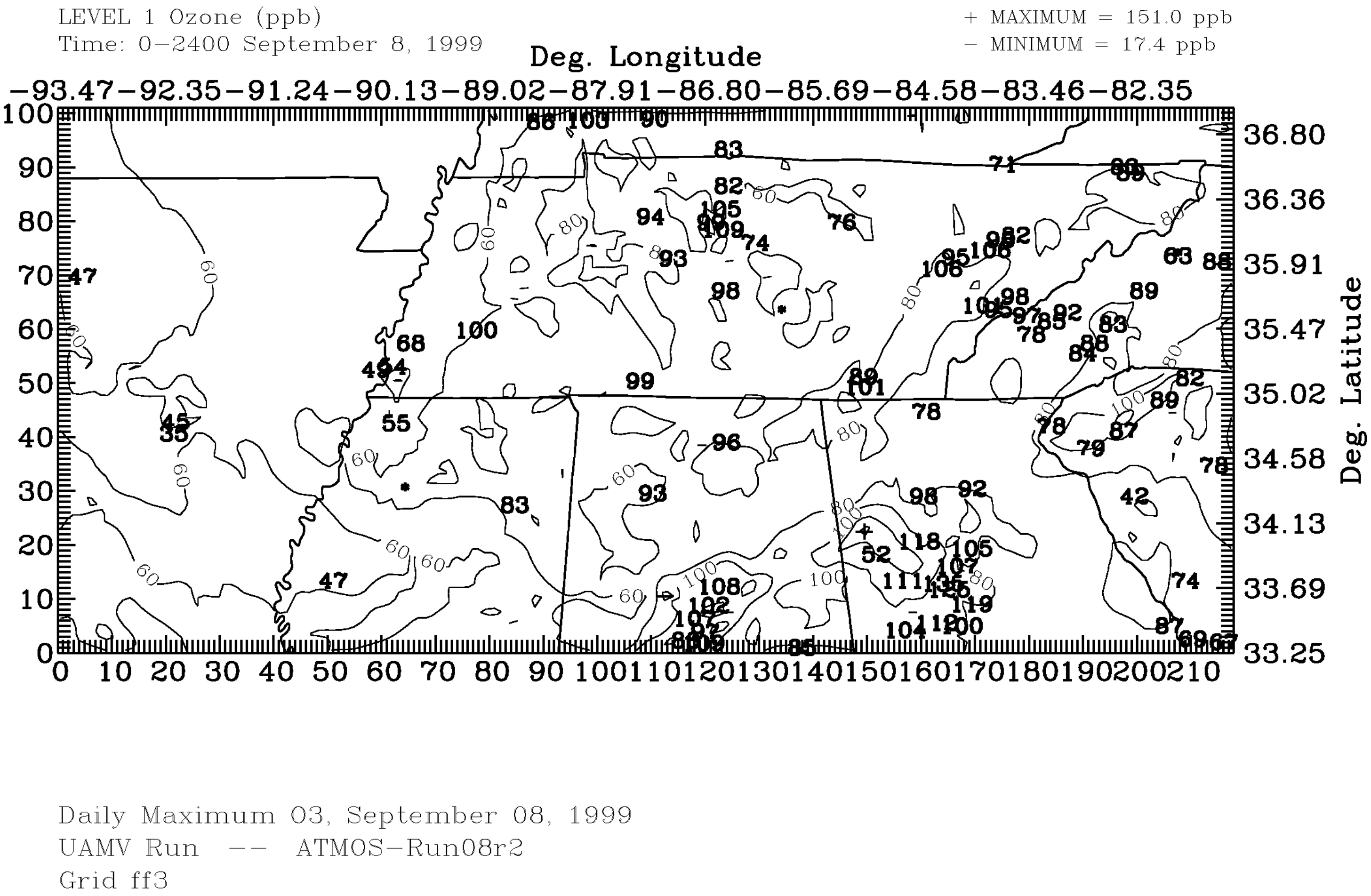


Figure 6-2l.
Daily Maximum 1-Hour Ozone, Grid 3,
September 9, 1999

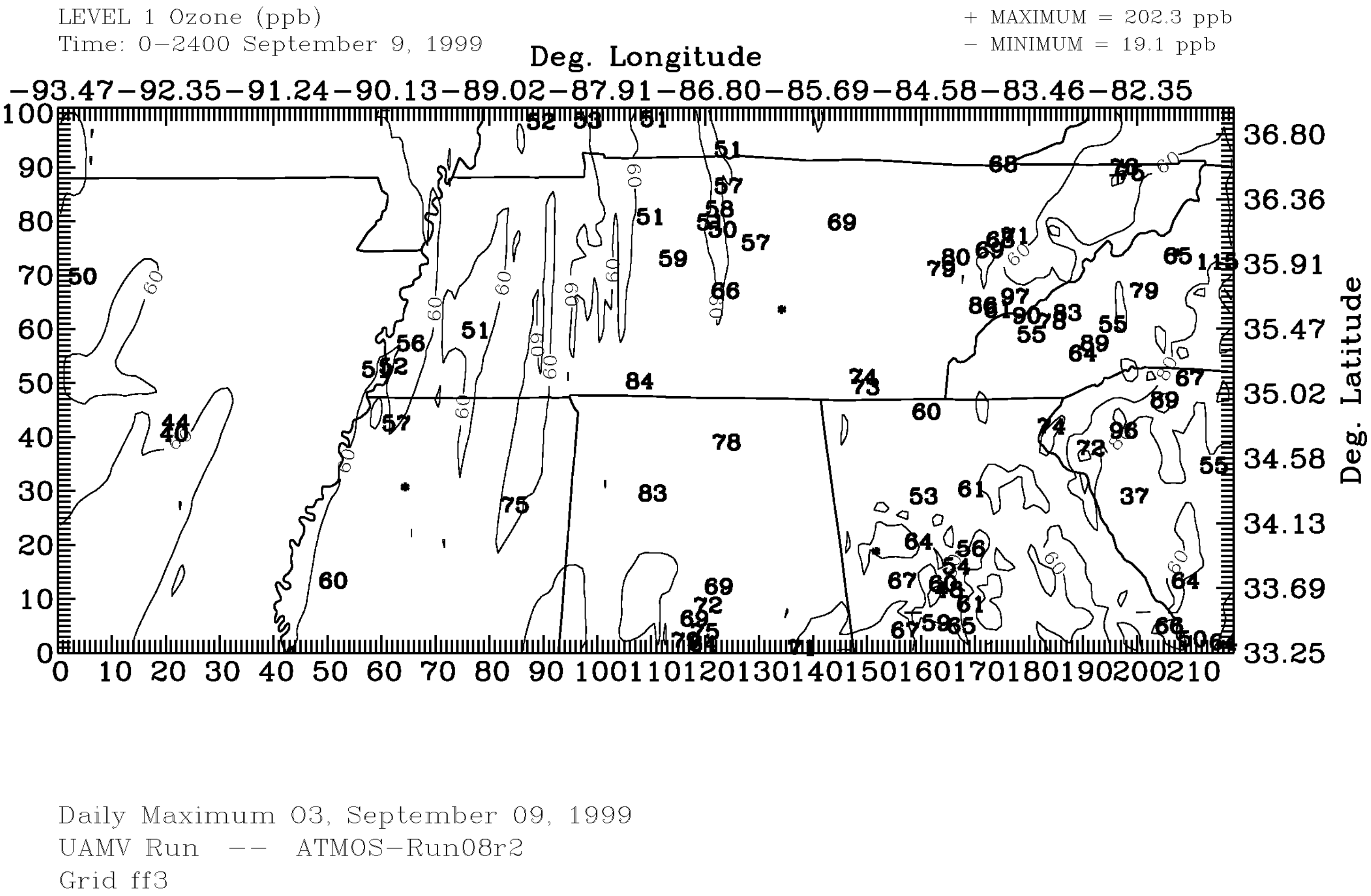


Figure 6-3a.
1999 Episode Time Series: Memphis EAC Area,
August 29 to September 3, 1999

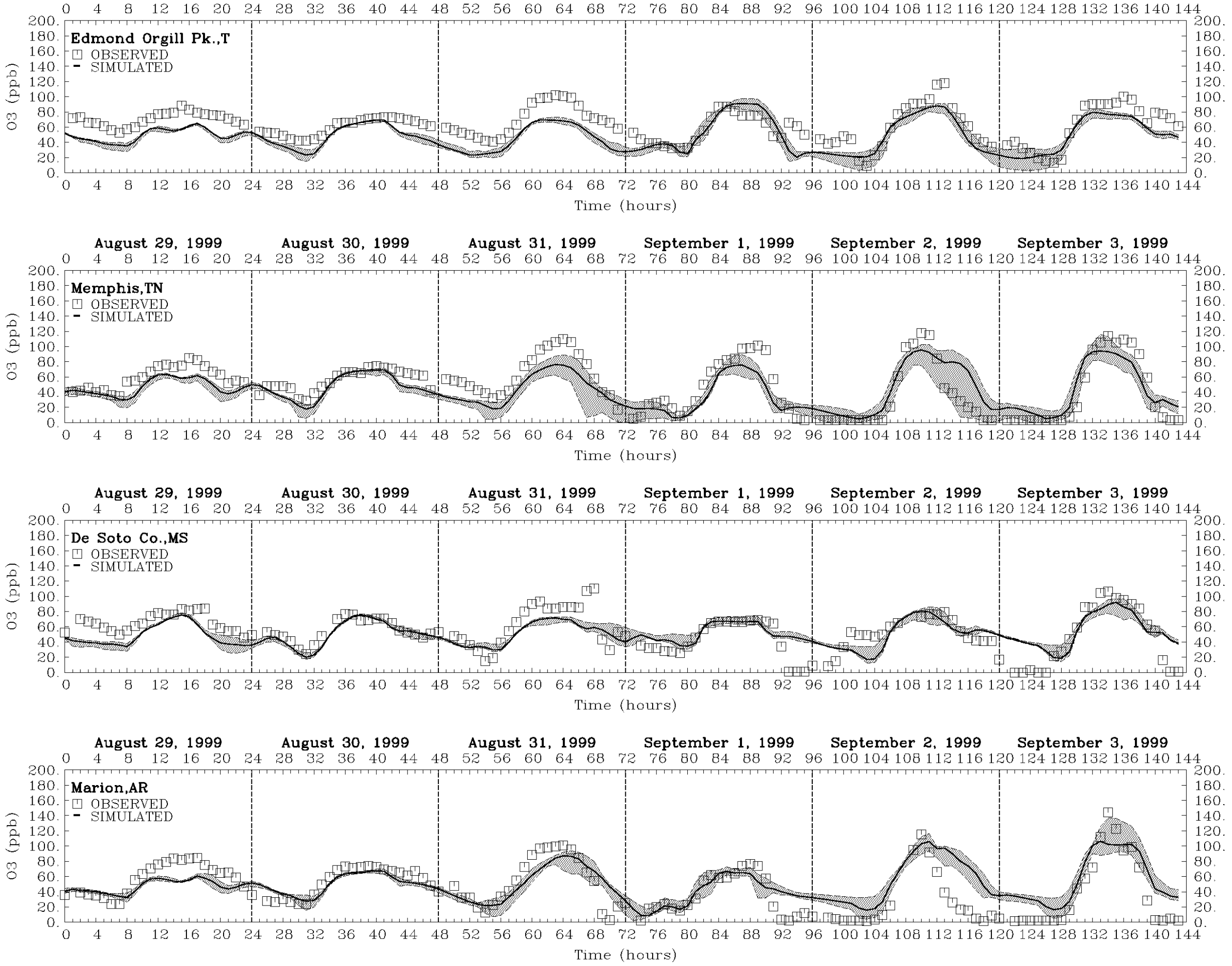


Figure 6-3b.
1999 Episode Time Series: Memphis EAC Area, September 4-9, 1999

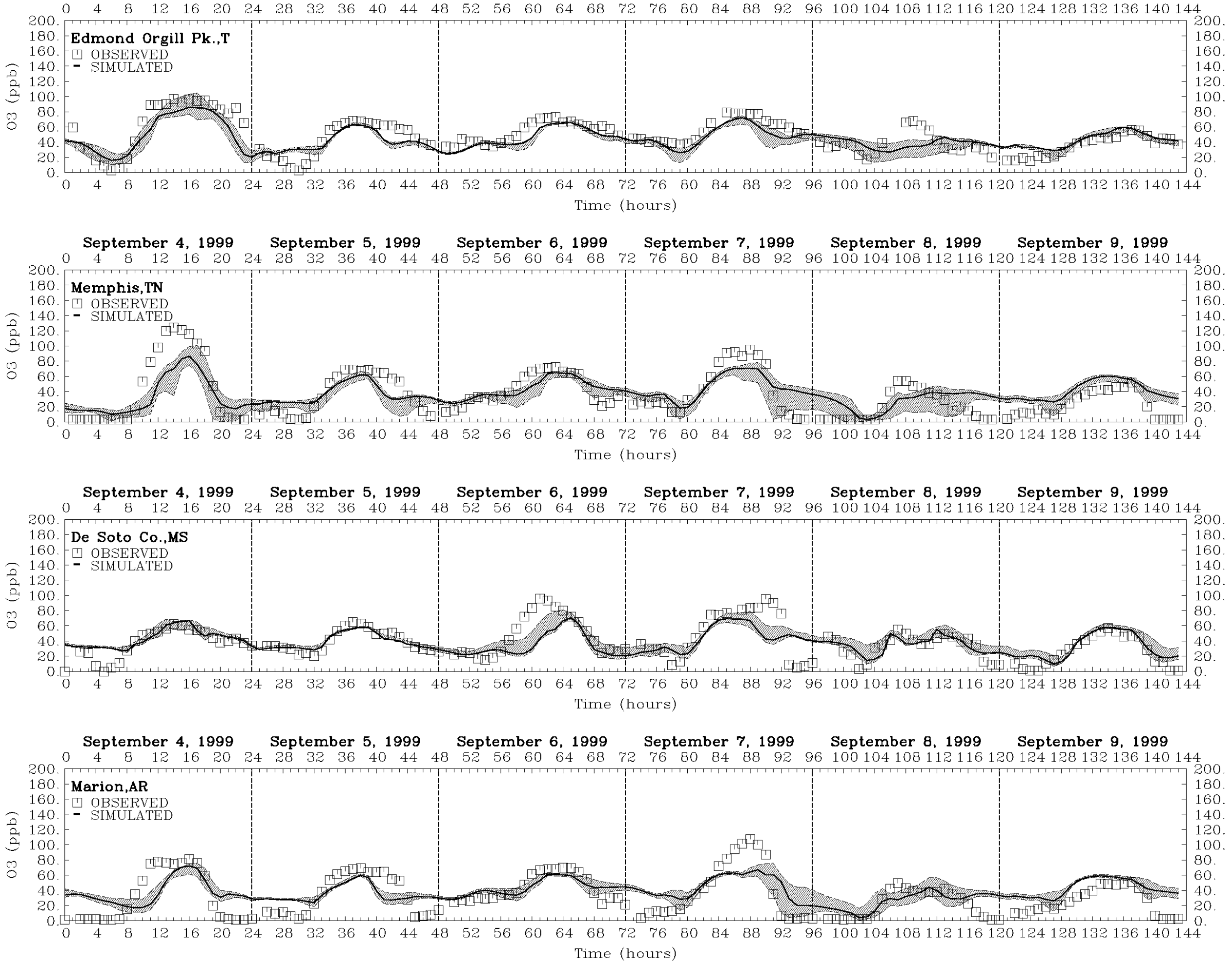


Figure 6-3c.
1999 Episode Time Series: Nashville EAC Area,
August 29 to September 3, 1999

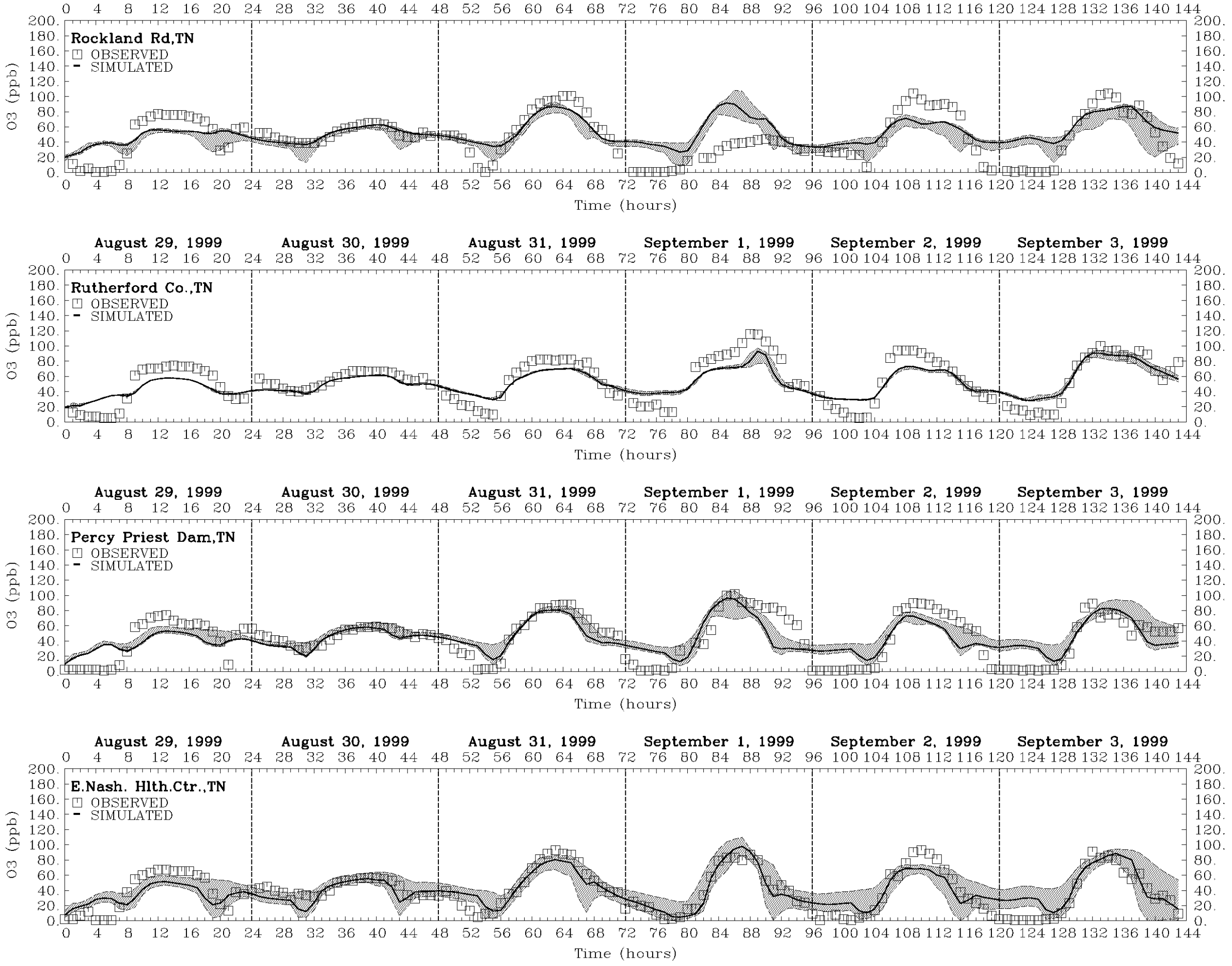


Figure 6-3d.
1999 Episode Time Series: Nashville EAC Area *(continued)*,
August 29 to September 3, 1999

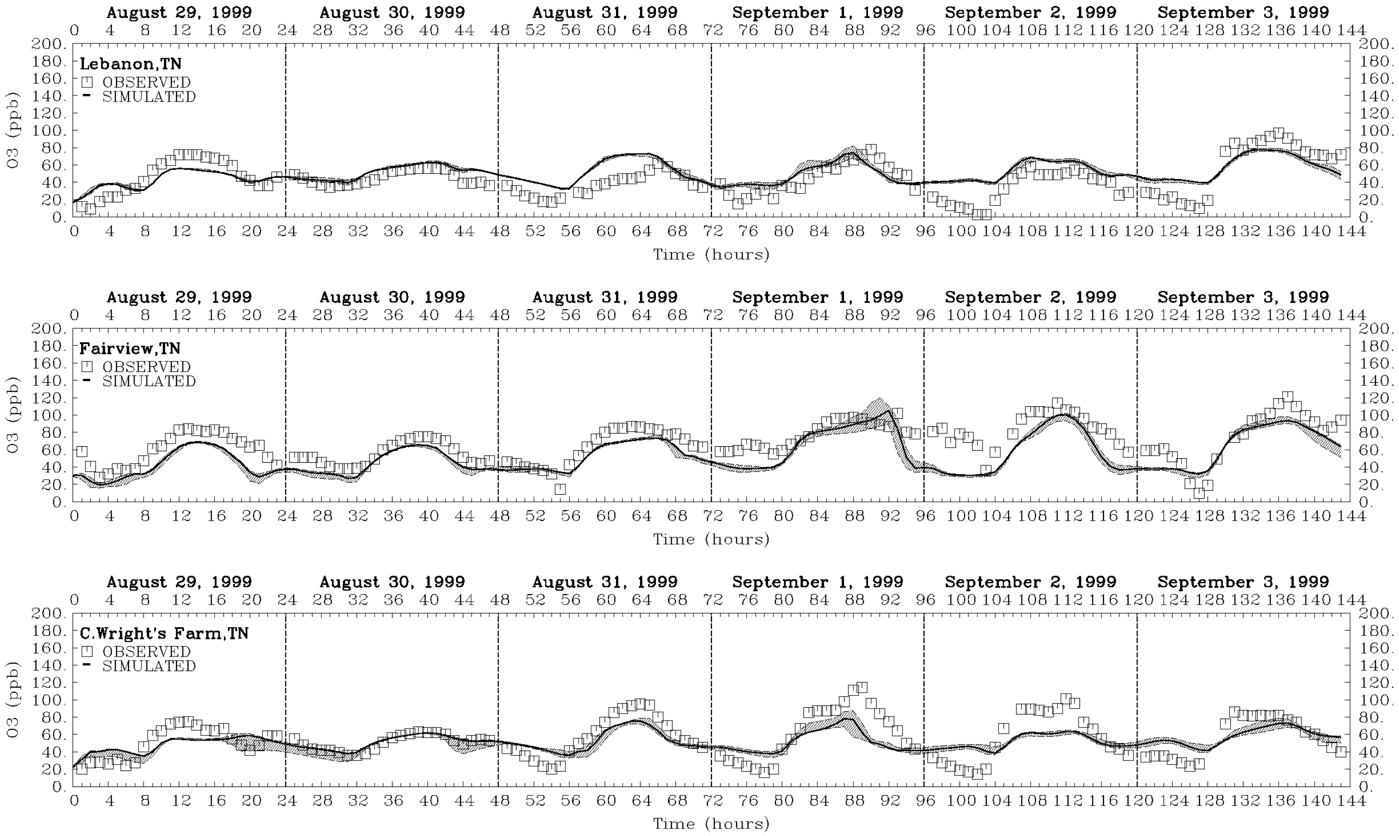


Figure 6-3e.
1999 Episode Time Series: Nashville EAC Area,
September 4-9, 1999

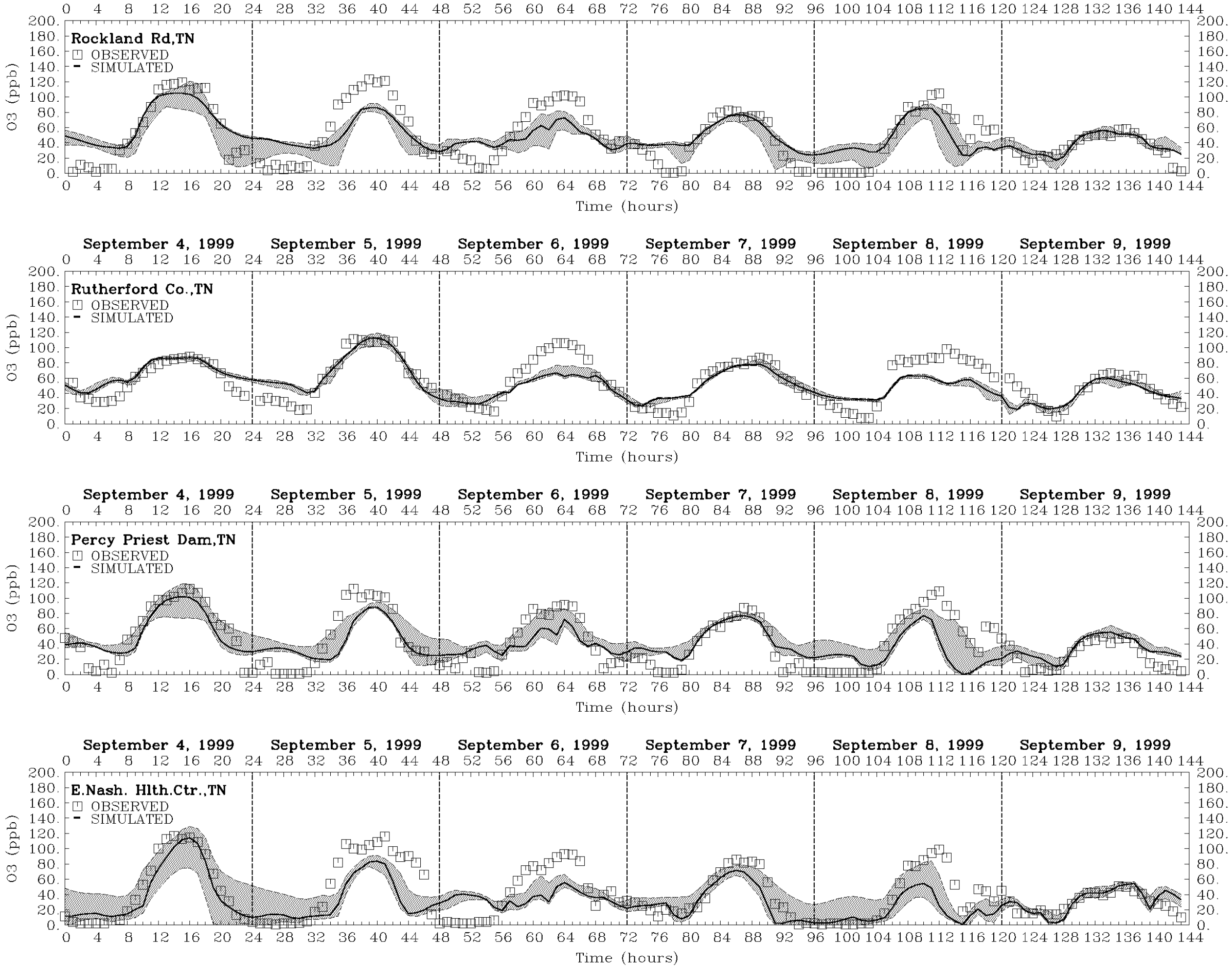


Figure 6-3f.
1999 Episode Time Series: Nashville EAC Area *(continued)*, September 4–9, 1999

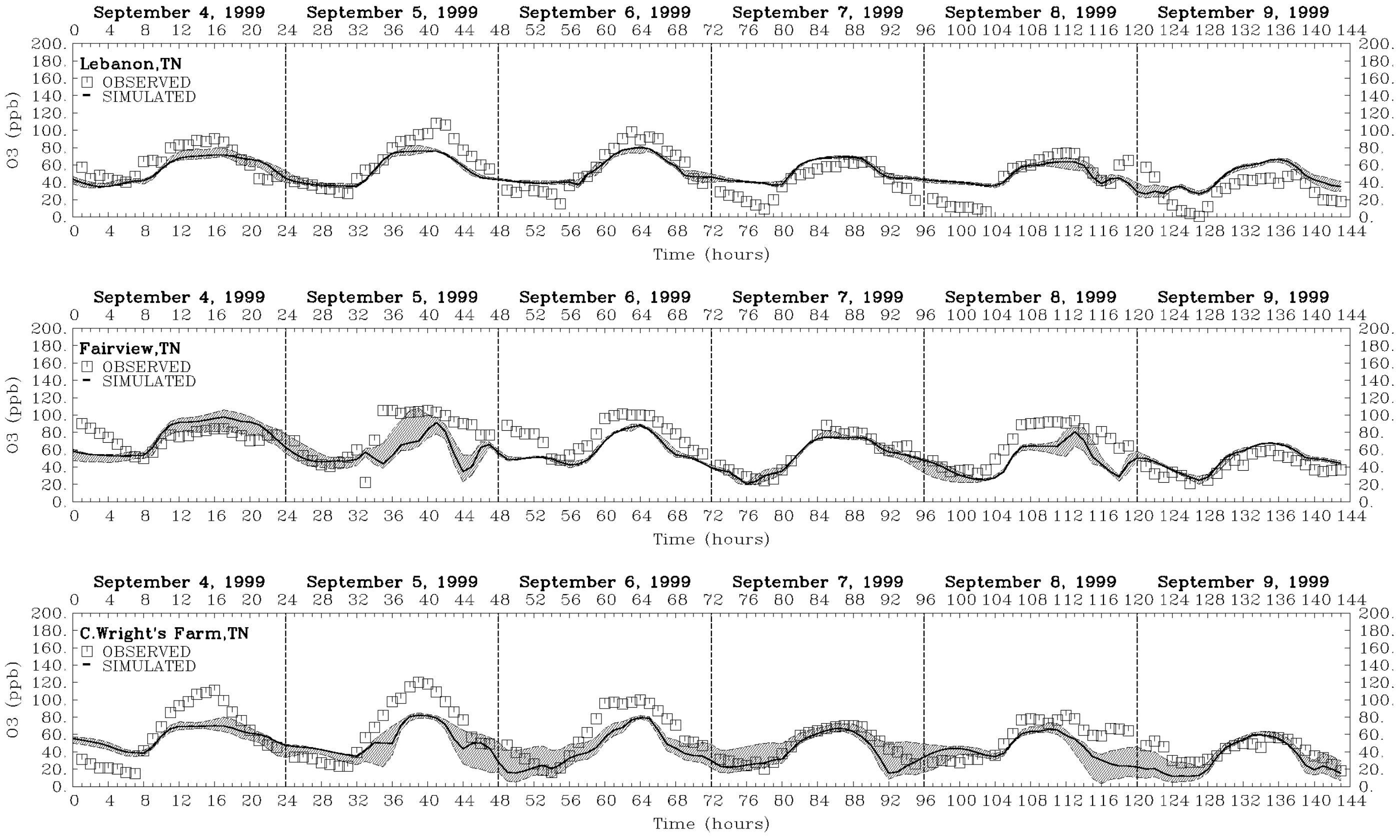


Figure 6-3g.
1999 Episode Time Series: Knoxville EAC Area,
August 29 to September 3, 1999

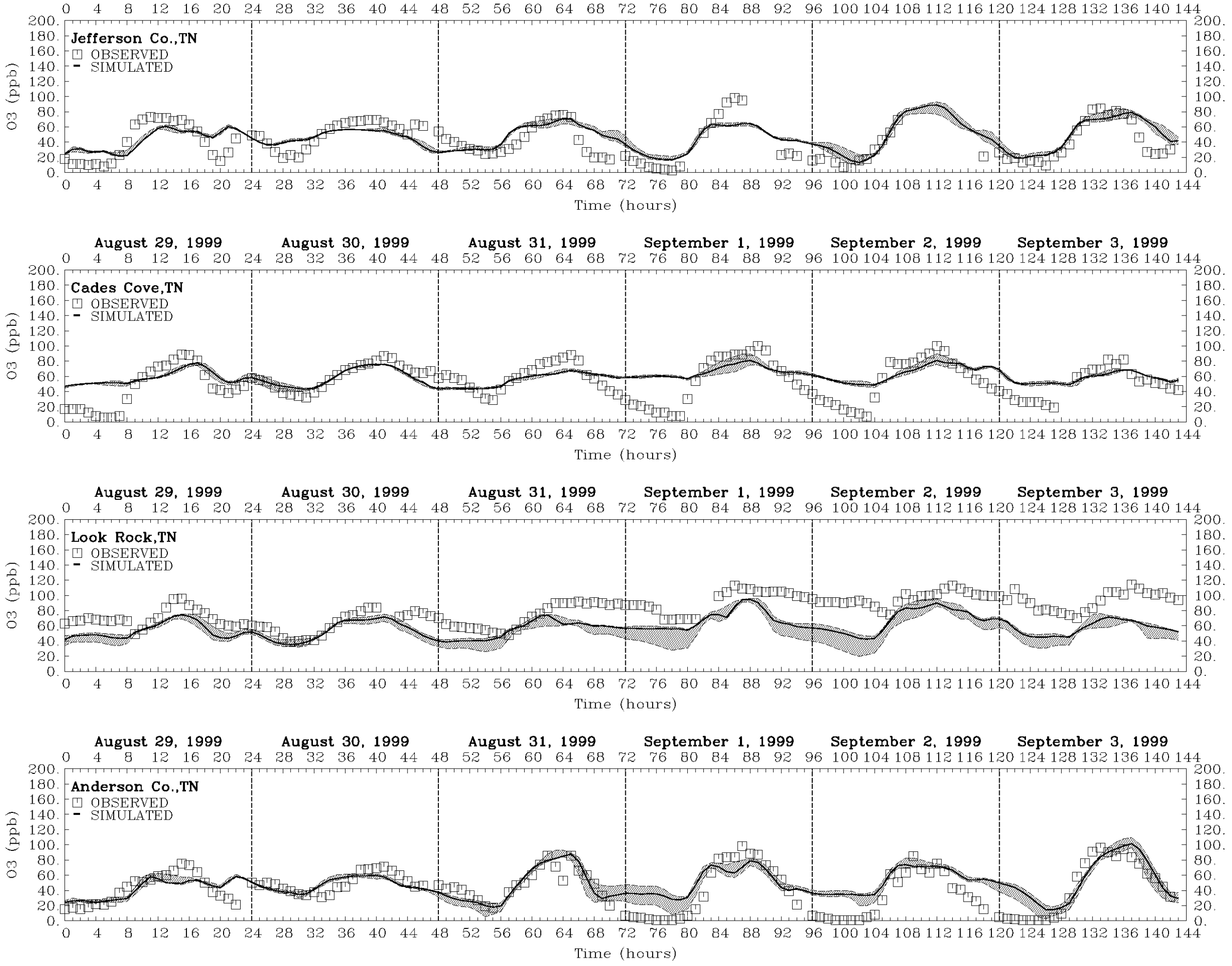


Figure 6-3h.
1999 Episode Time Series: Knoxville EAC Area *(continued)*,
August 29 to September 3, 1999

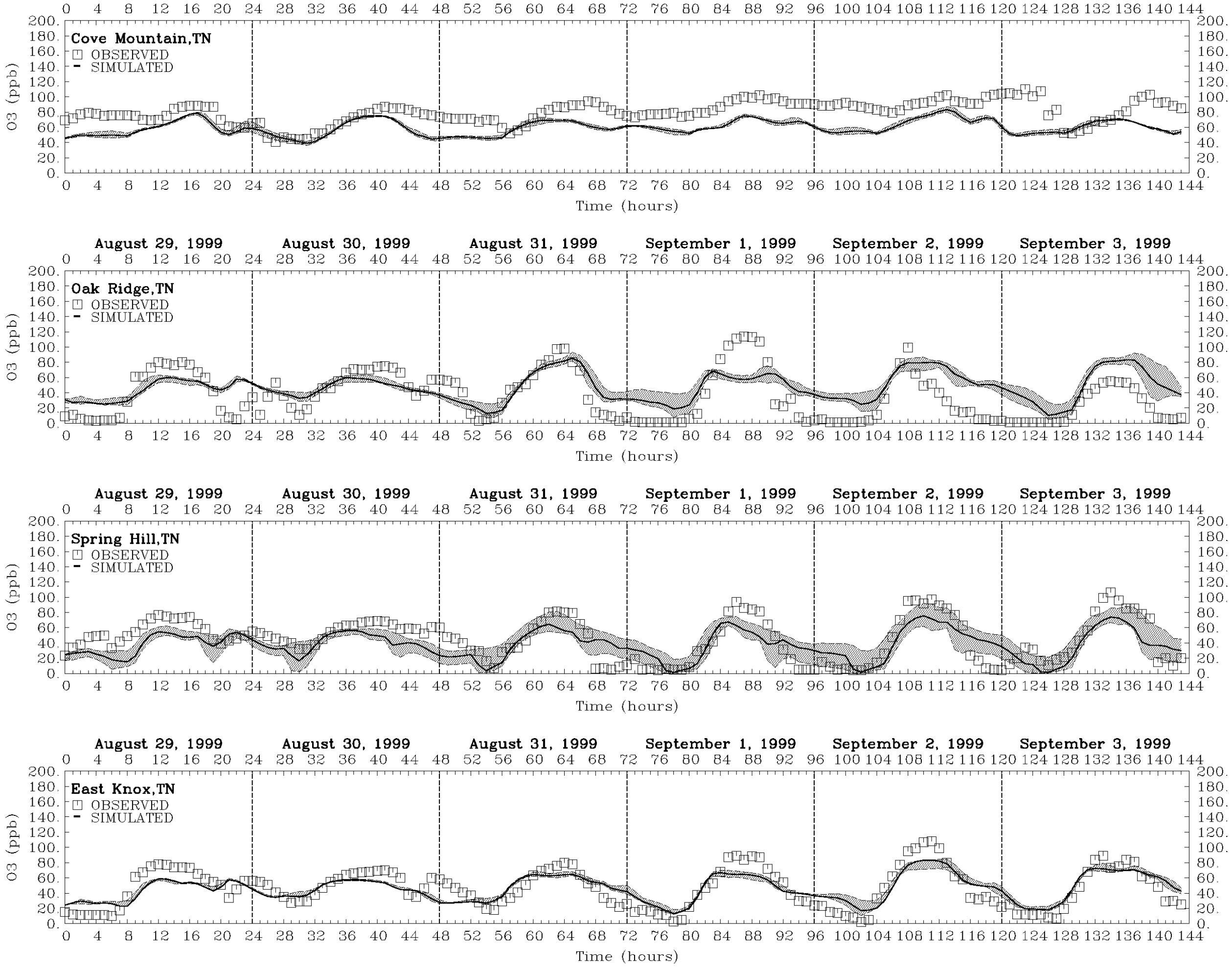


Figure 6-3i.
1999 Episode Time Series: Knoxville EAC Area, September 4-9, 1999

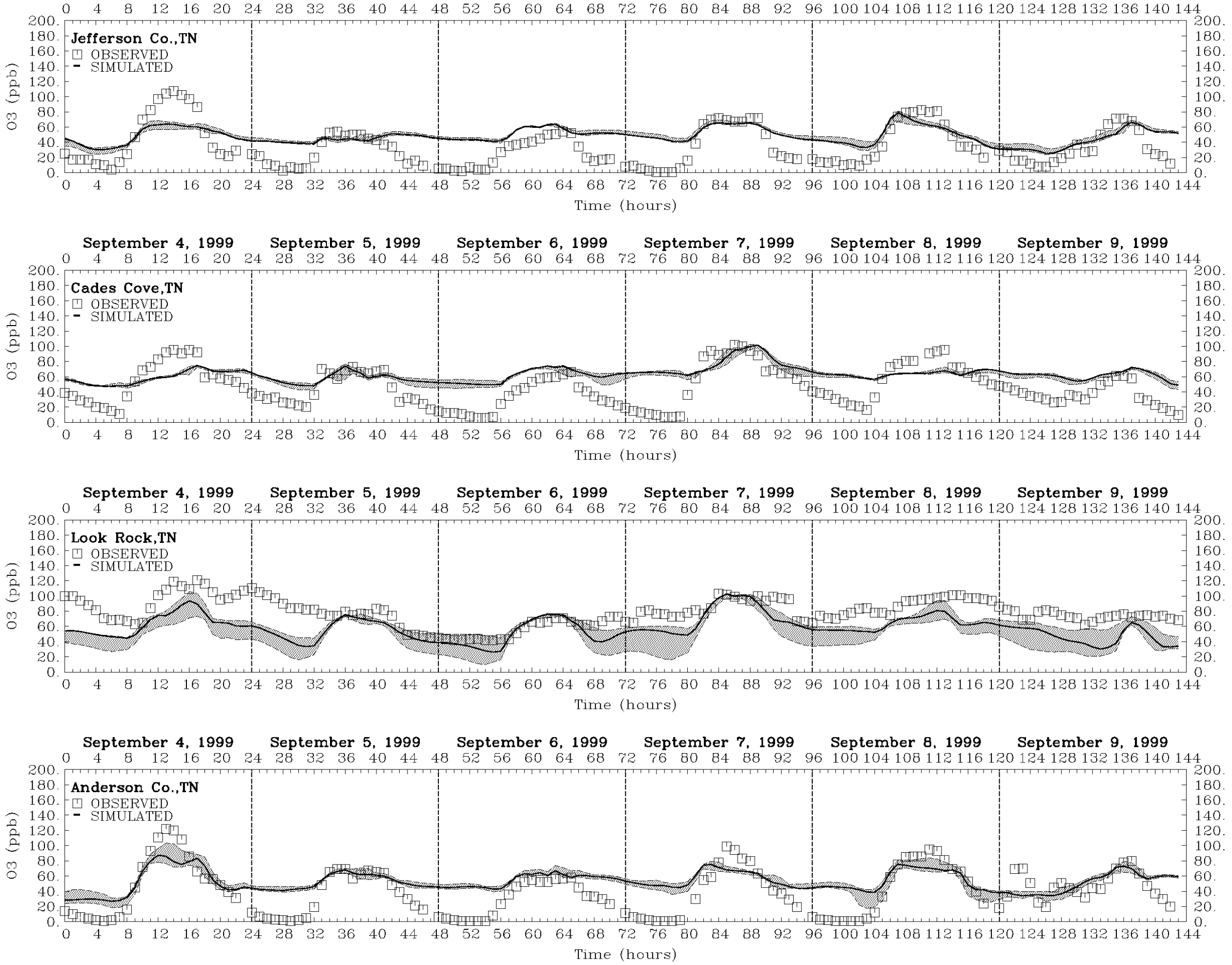


Figure 6-3j.
1999 Episode Time Series: Knoxville EAC Area ***(continued)*****,**
September 4-9, 1999

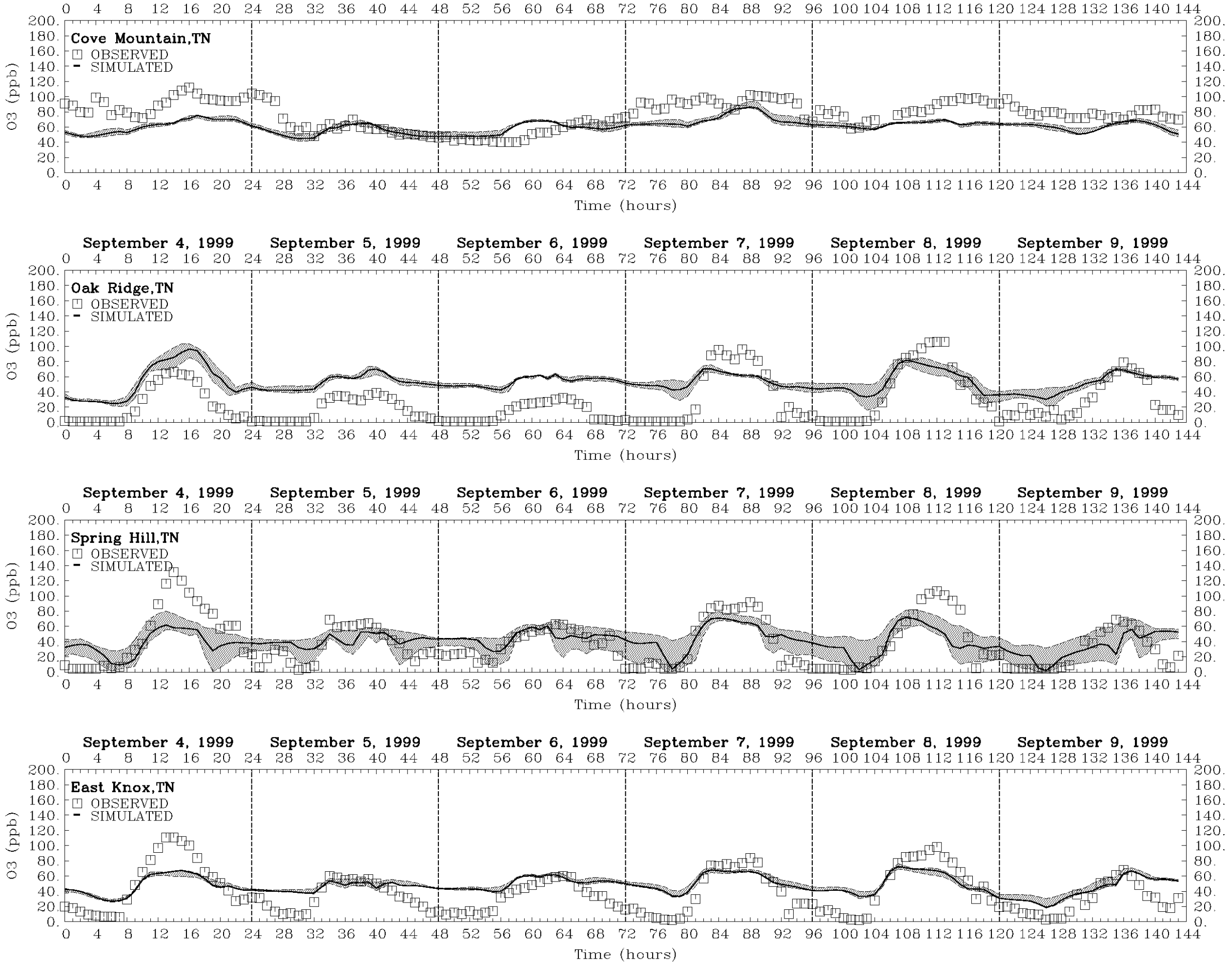


Figure 6-3k.
1999 Episode Time Series: Chattanooga EAC Area, August 29 to September 3, 1999

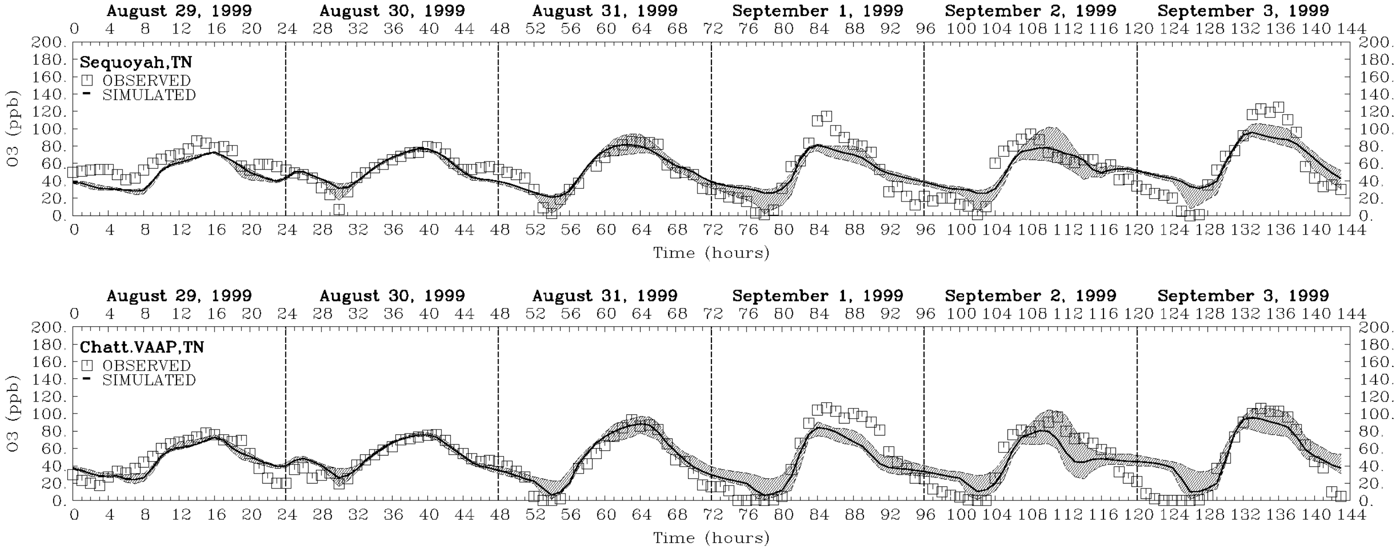


Figure 6-3l.
1999 Episode Time Series: Chattanooga EAC Area, September 4-9, 1999

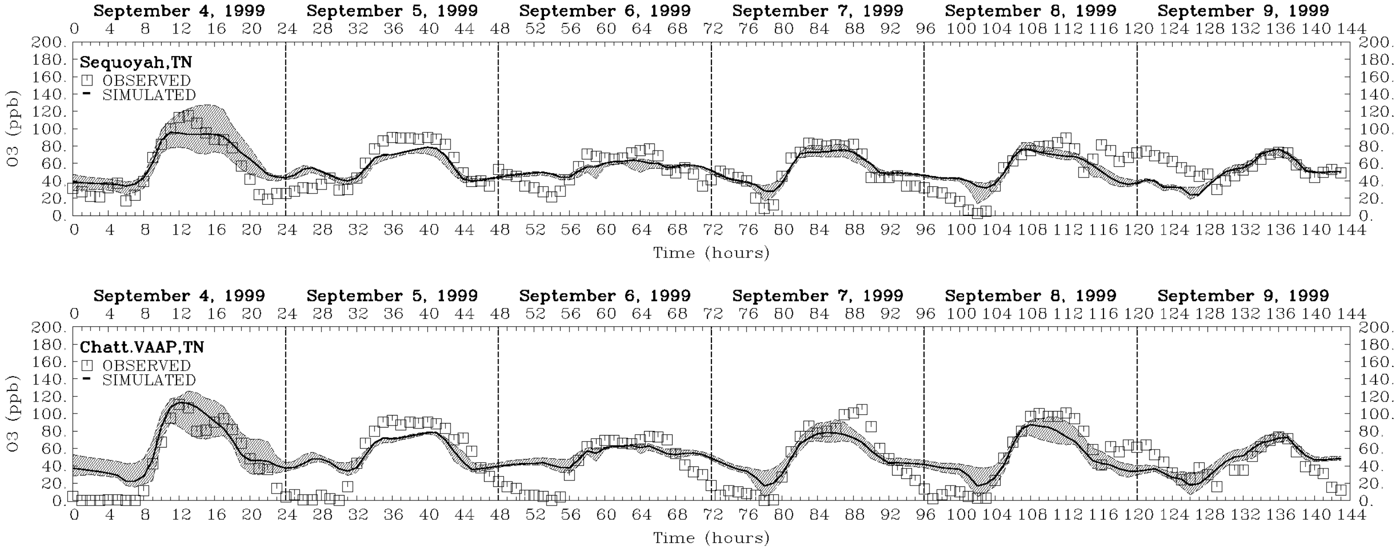


Figure 6-3m.
1999 Episode Time Series: Tri-Cities EAC Area,
August 29 to September 3, 1999

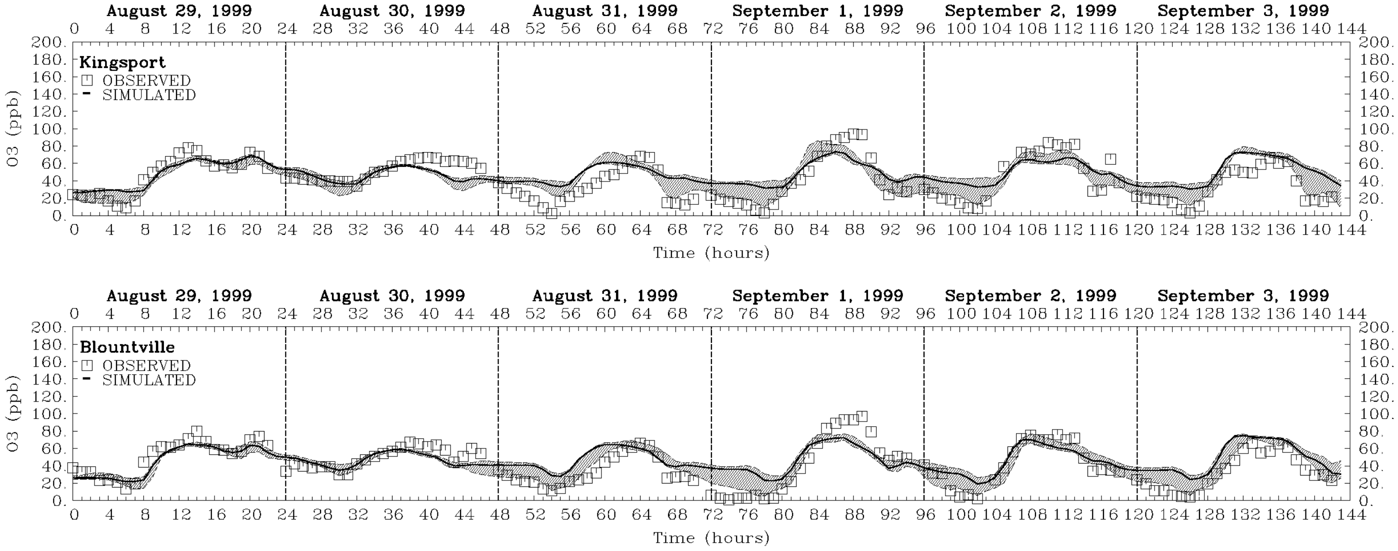


Figure 6-3n.
1999 Episode Time Series: Tri-Cities EAC Area, September 4-9, 1999

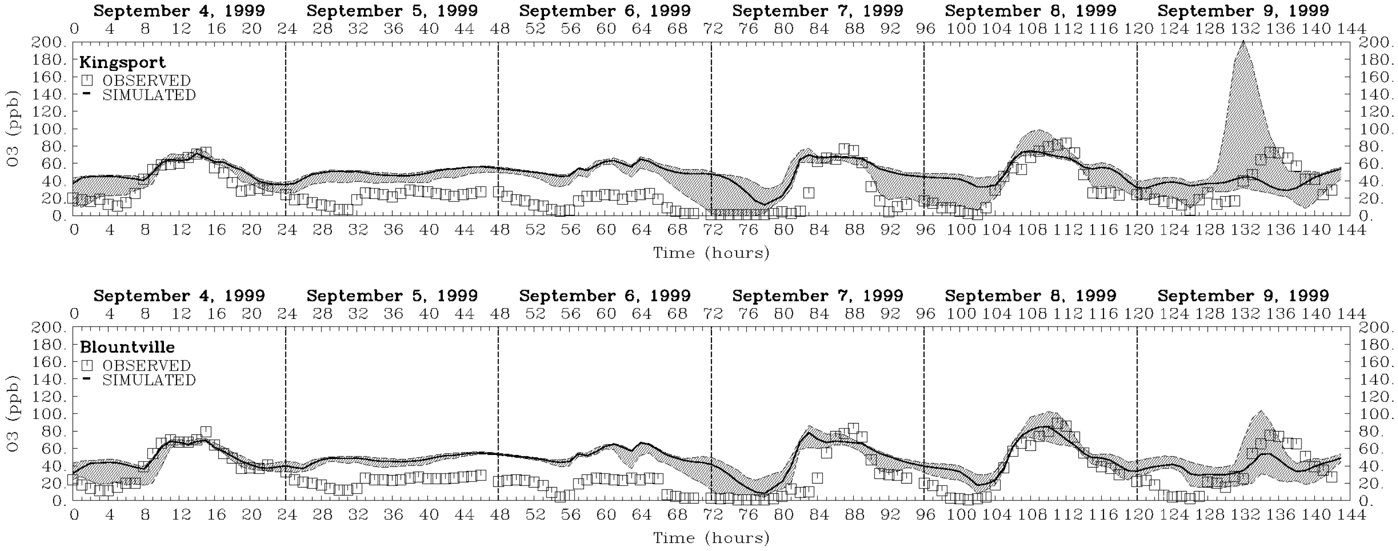


Figure 6-4a.
Scatter Plot: August 29, 1999

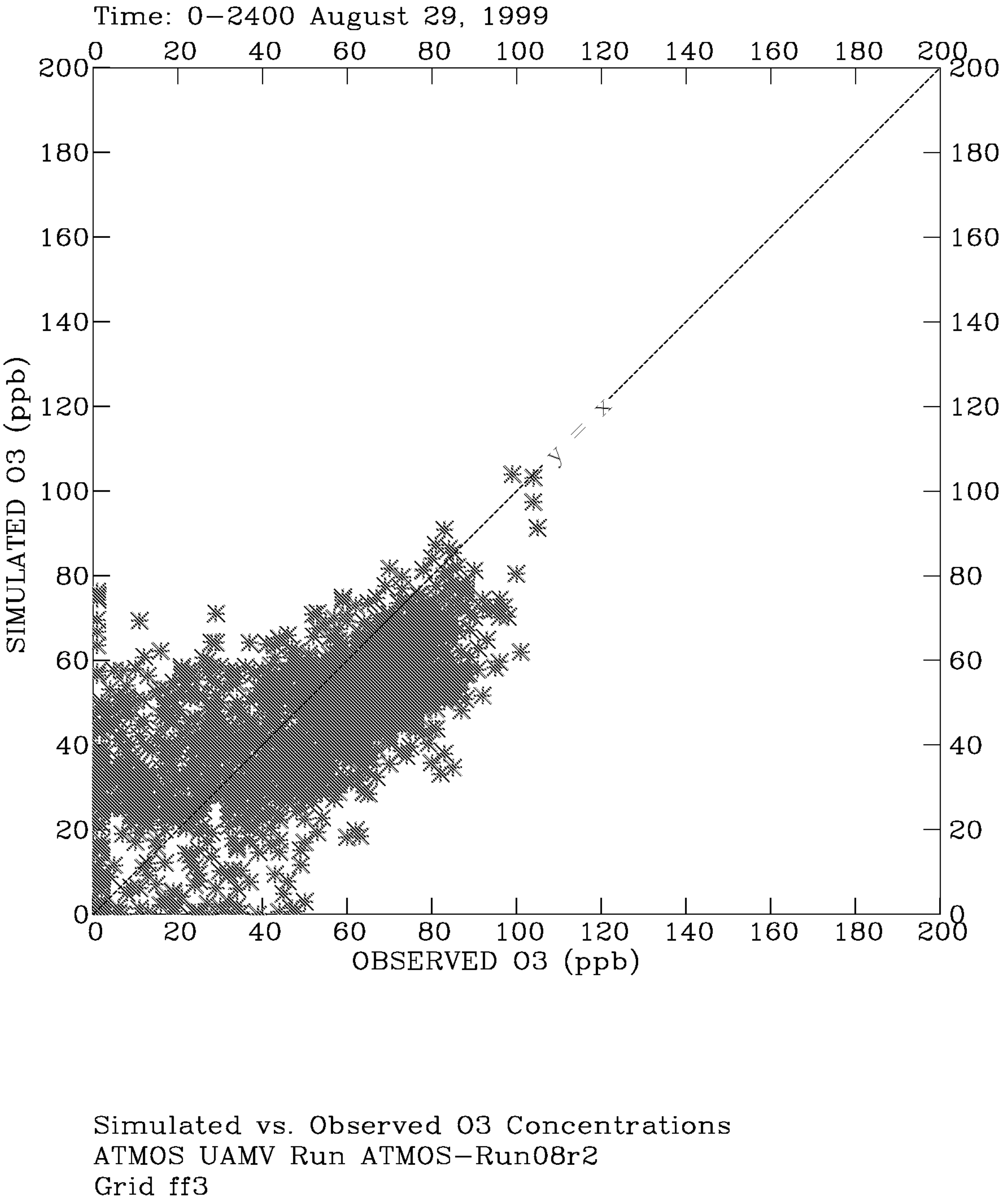
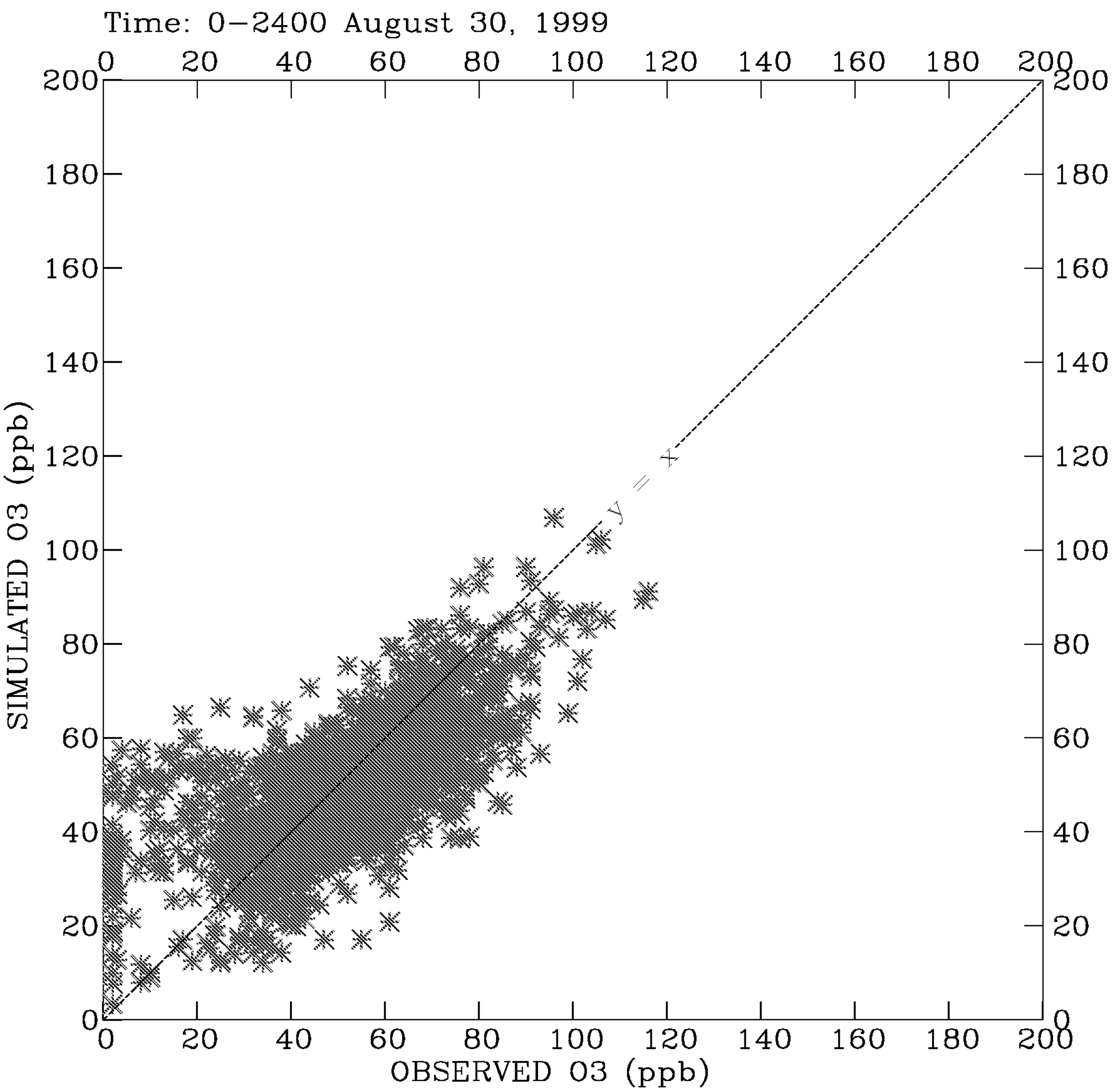


Figure 6-4b.
Scatter Plot: August 30, 1999



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4c.
Scatter Plot: August 31, 1999

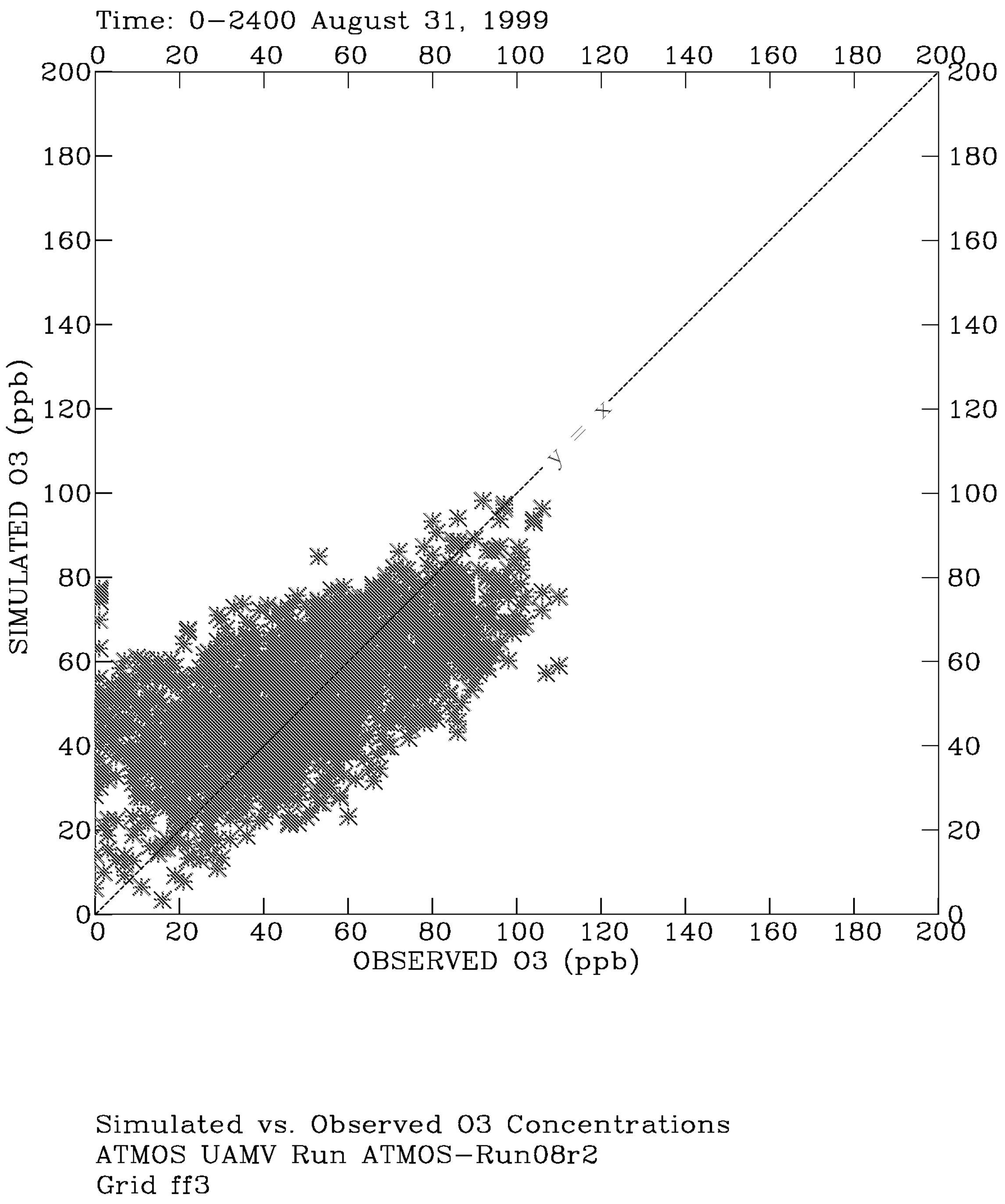
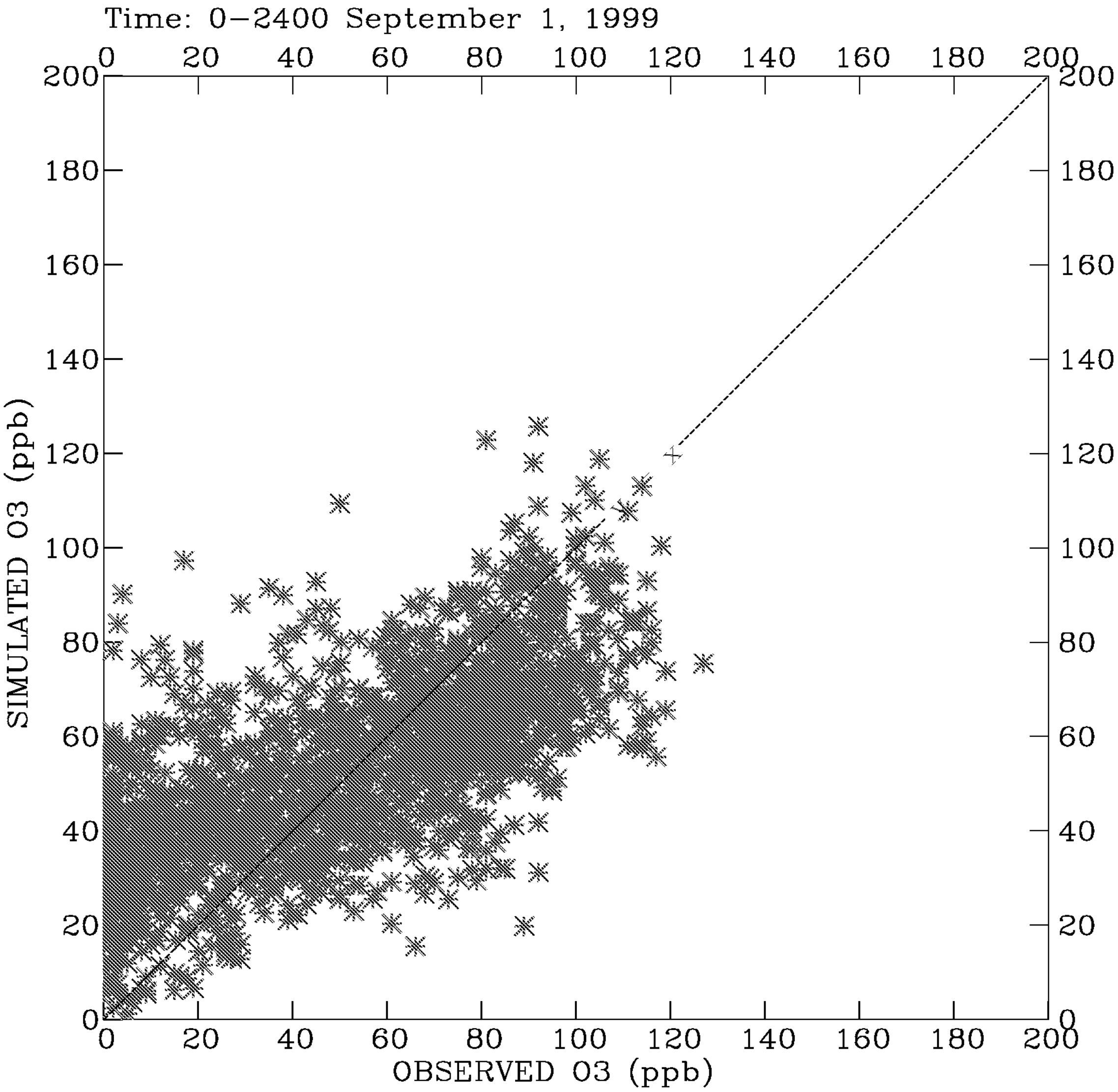


Figure 6-4d.
Scatter Plot: September 1, 1999



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4e.
Scatter Plot: September 2, 1999

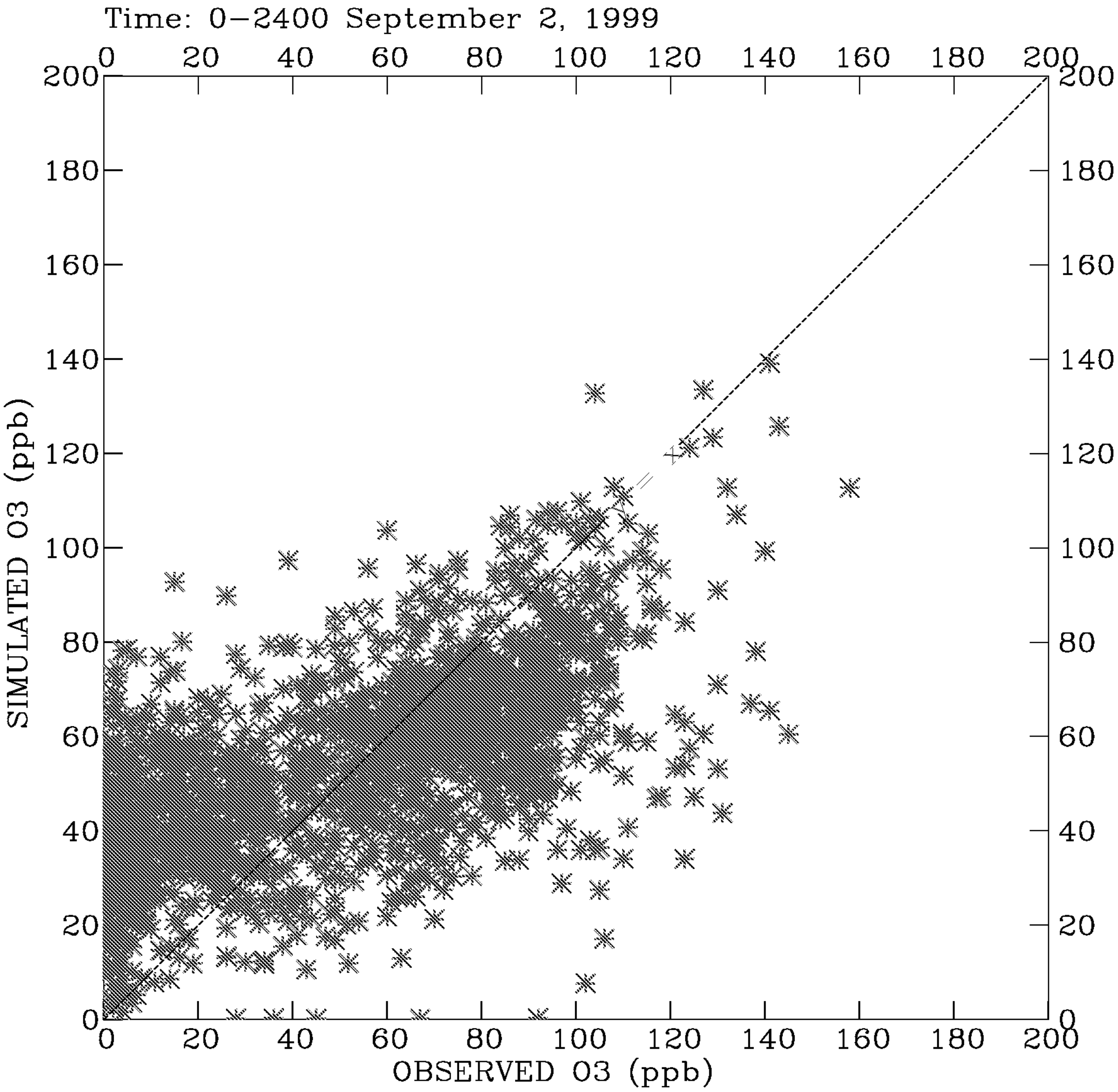


Figure 6-4f.
Scatter Plot: September 3, 1999

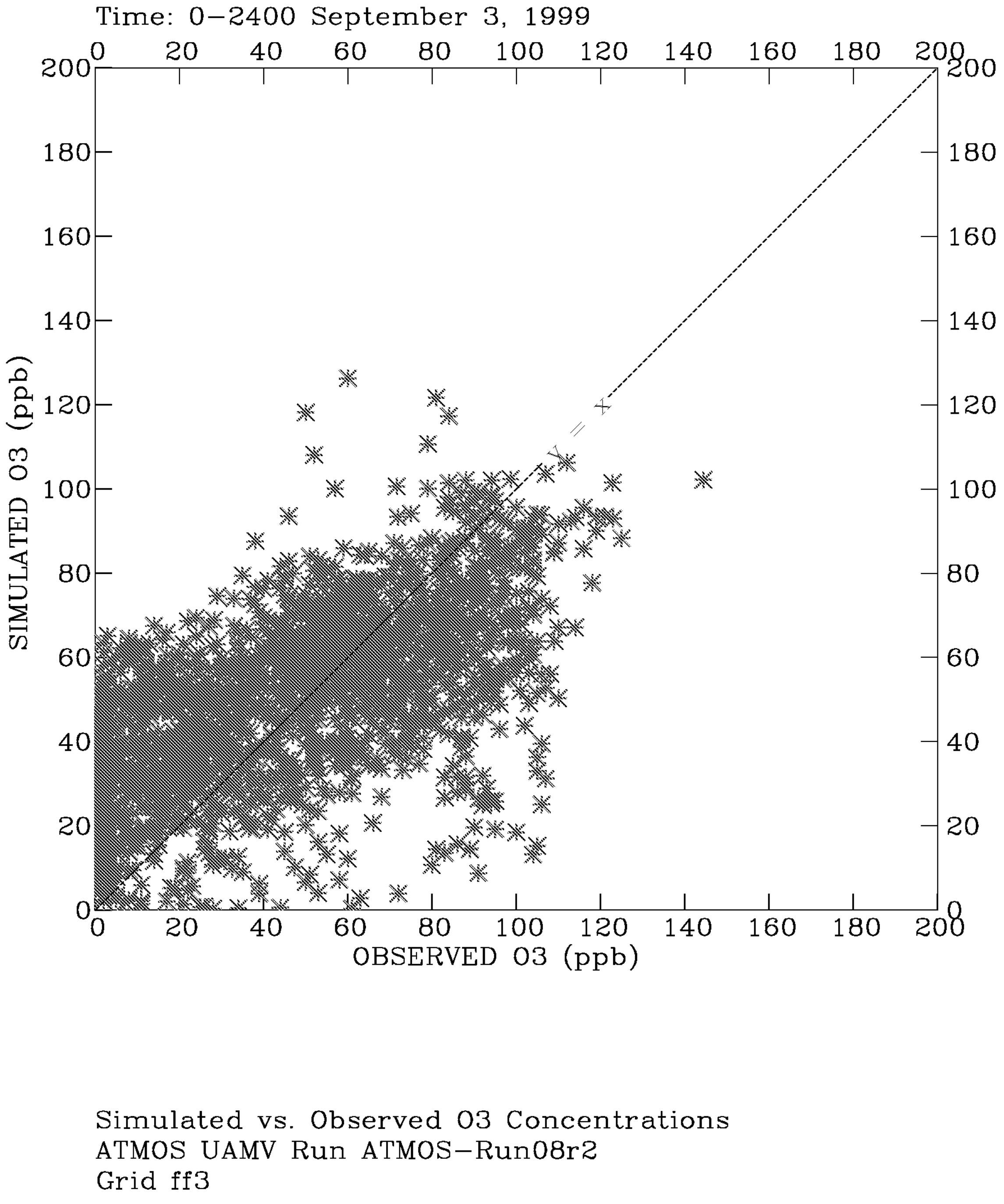


Figure 6-4g.
Scatter Plot: September 4, 1999

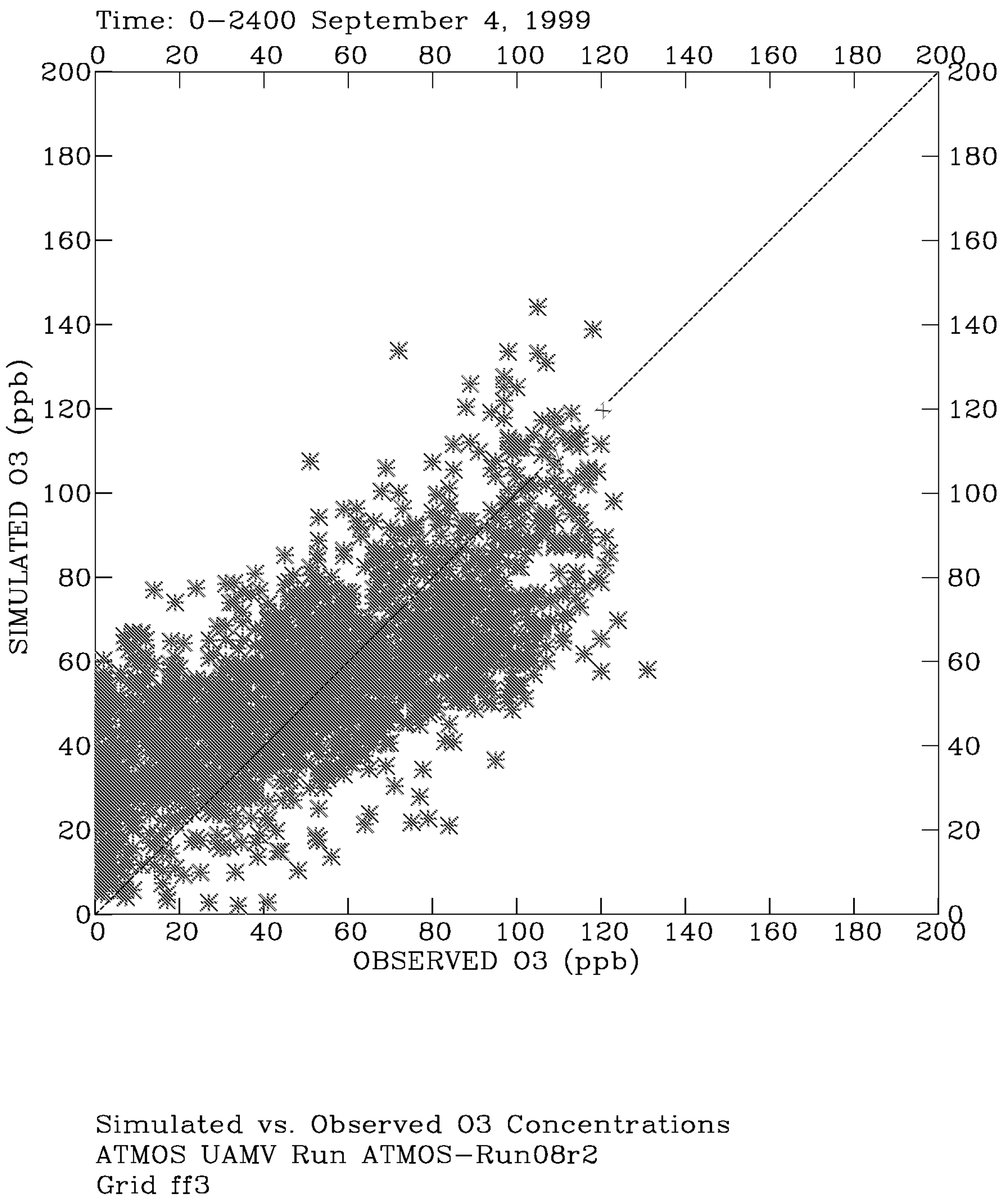
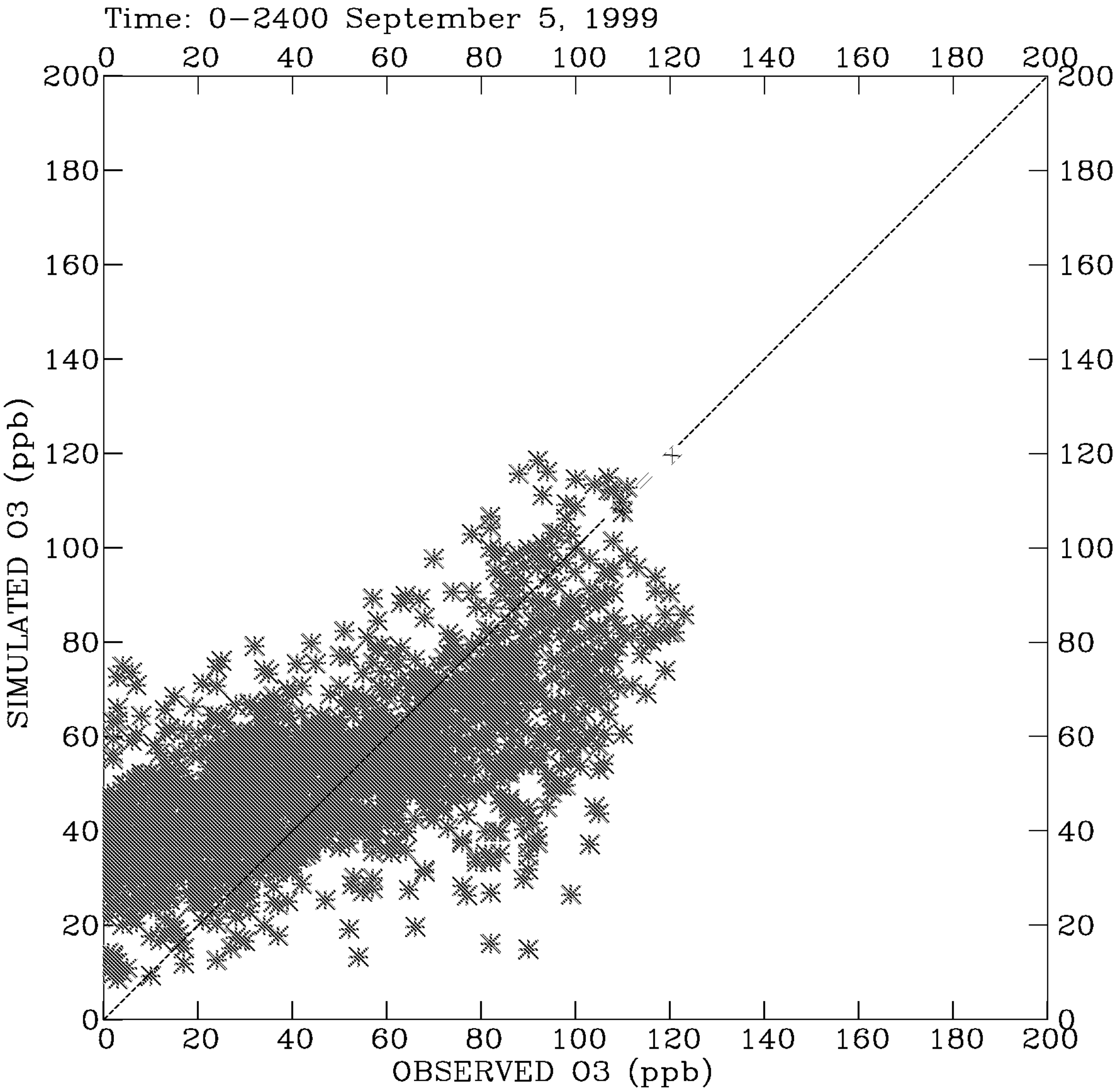


Figure 6-4h.
Scatter Plot: September 5, 1999



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4i.
Scatter Plot: September 6, 1999

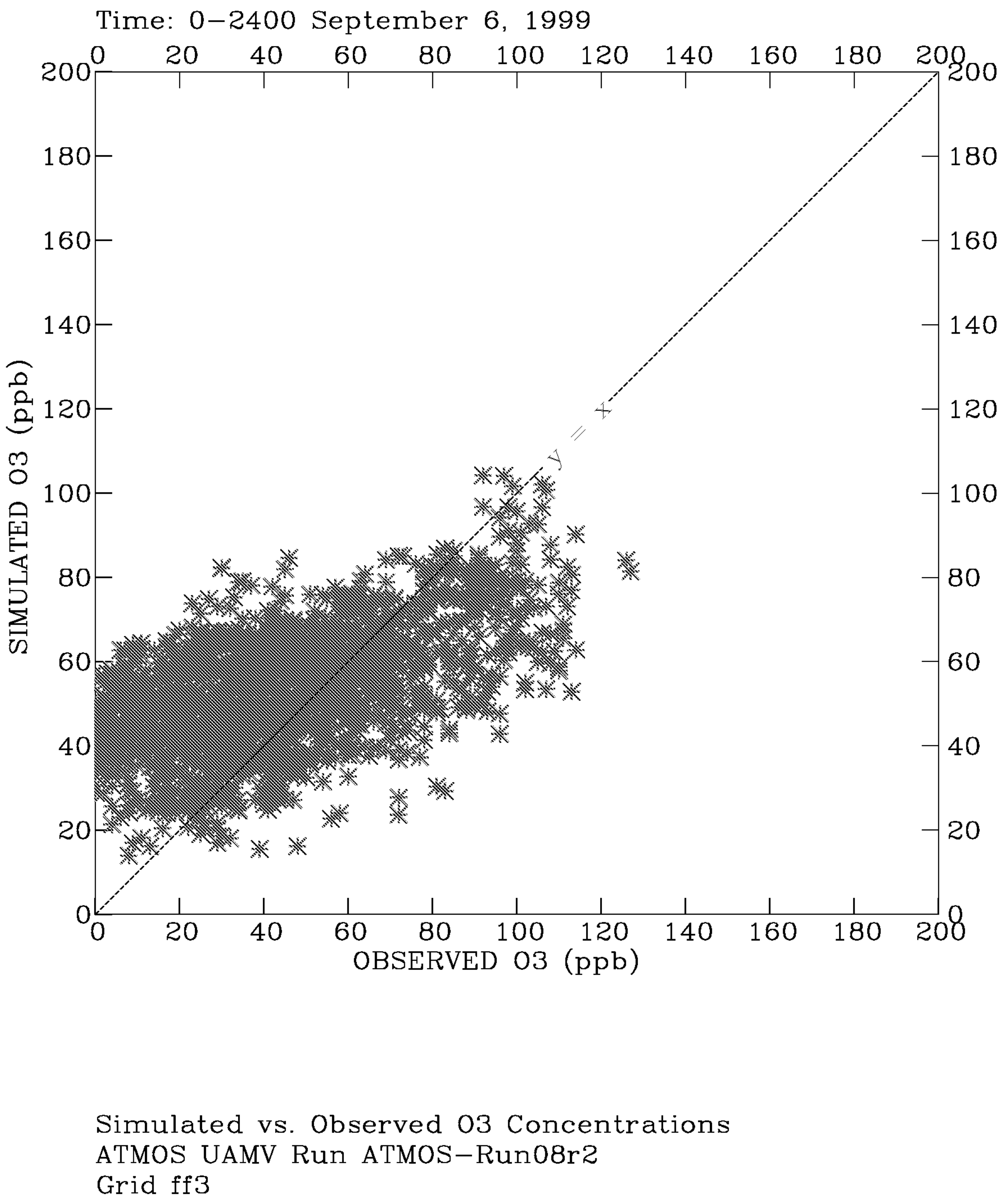
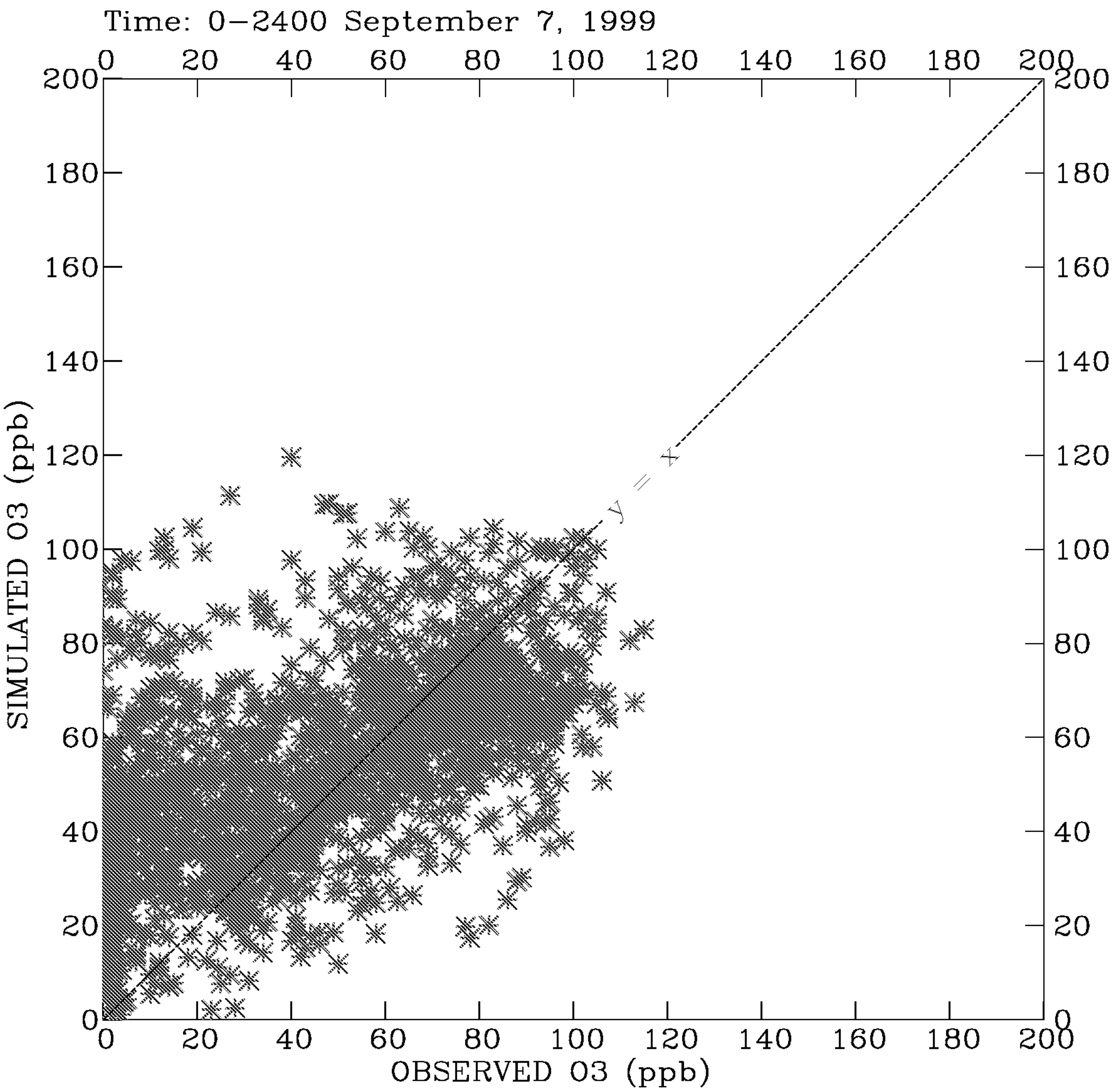


Figure 6-4j.
Scatter Plot: September 7, 1999



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-4k.
Scatter Plot: September 8, 1999

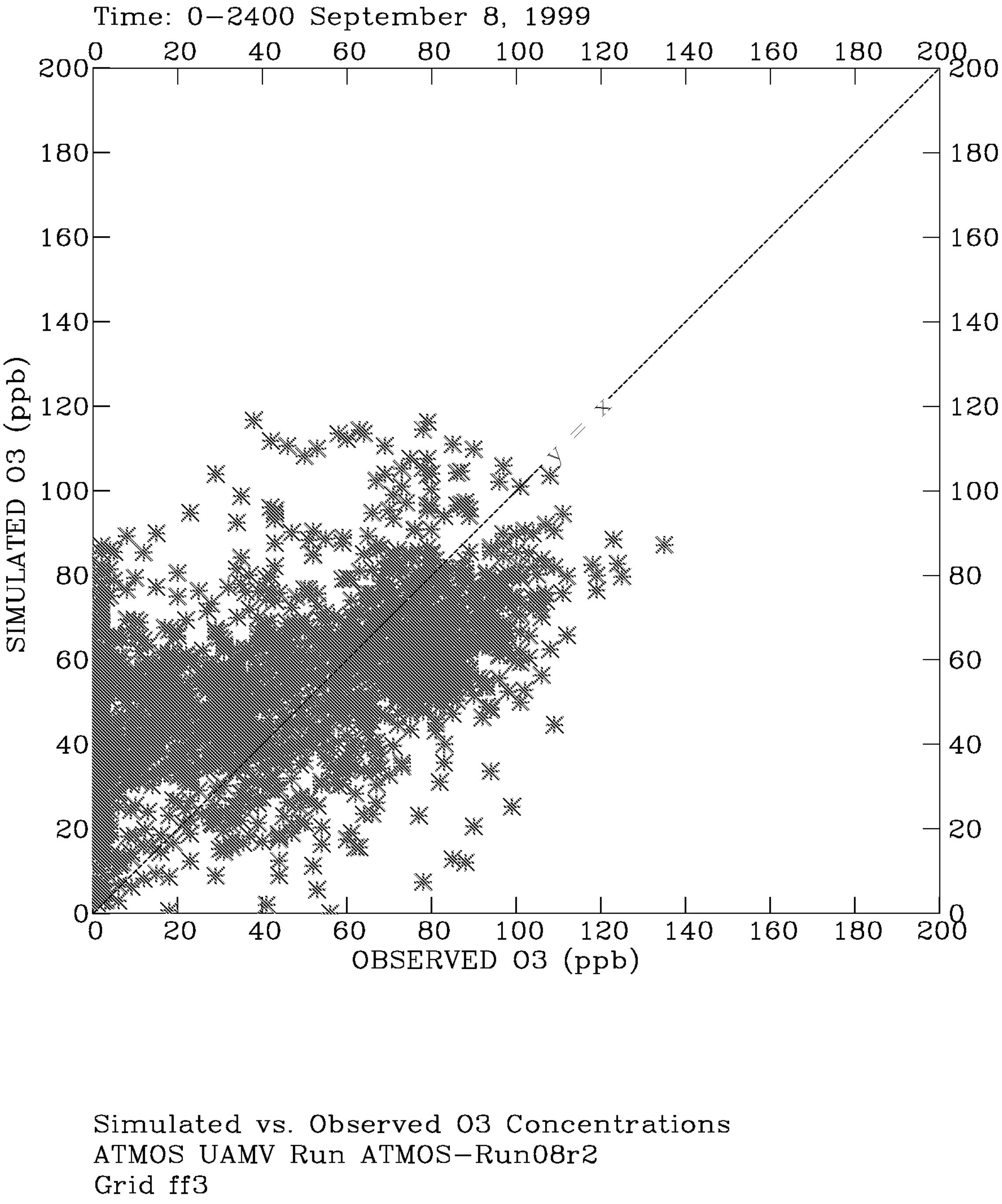
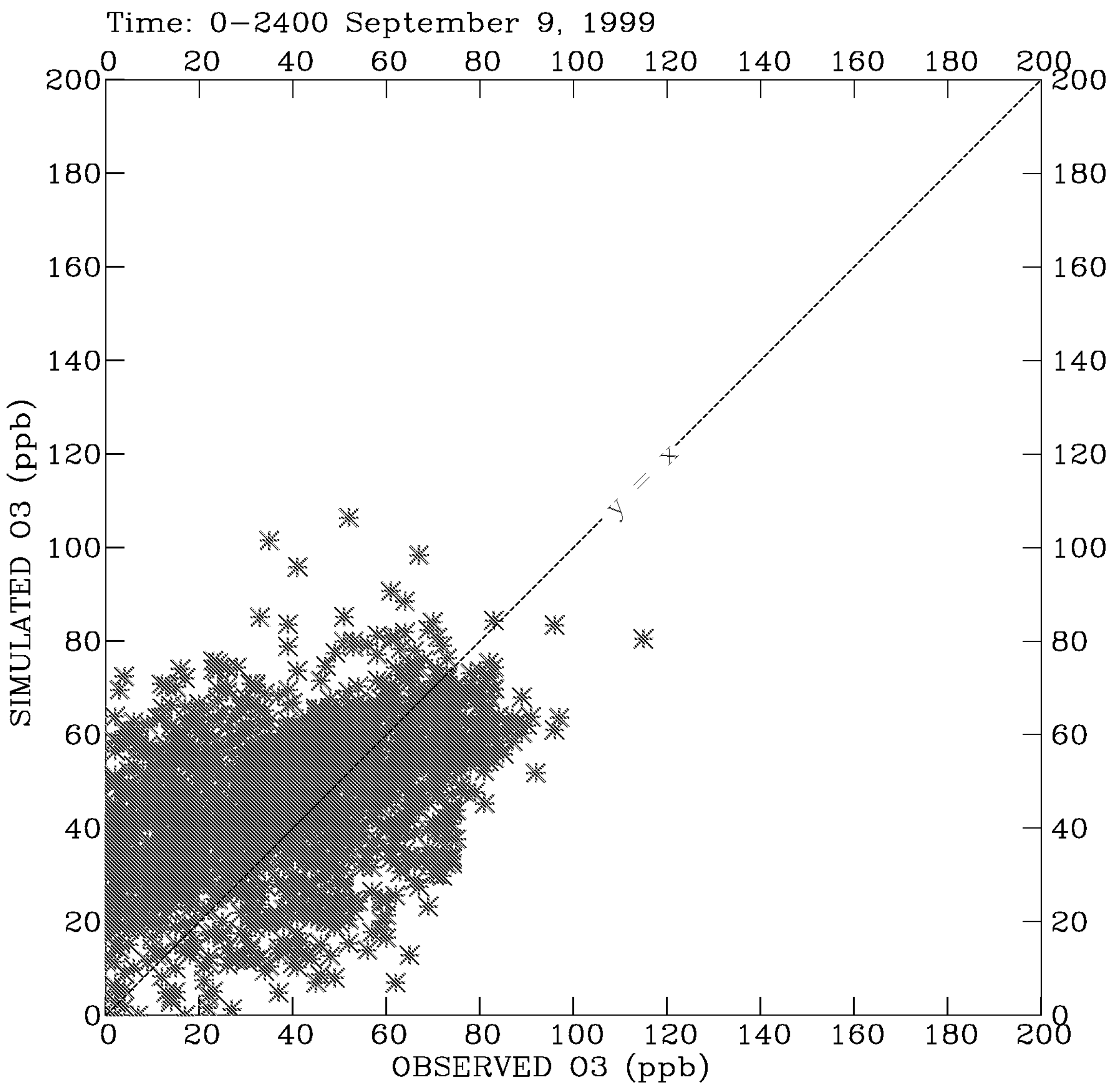


Figure 6-4l.
Scatter Plot: September 9, 1999



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run08r2
Grid ff3

Figure 6-5a.
Daily Maximum 1-Hour Ozone, Grid 1,
June 16, 2001

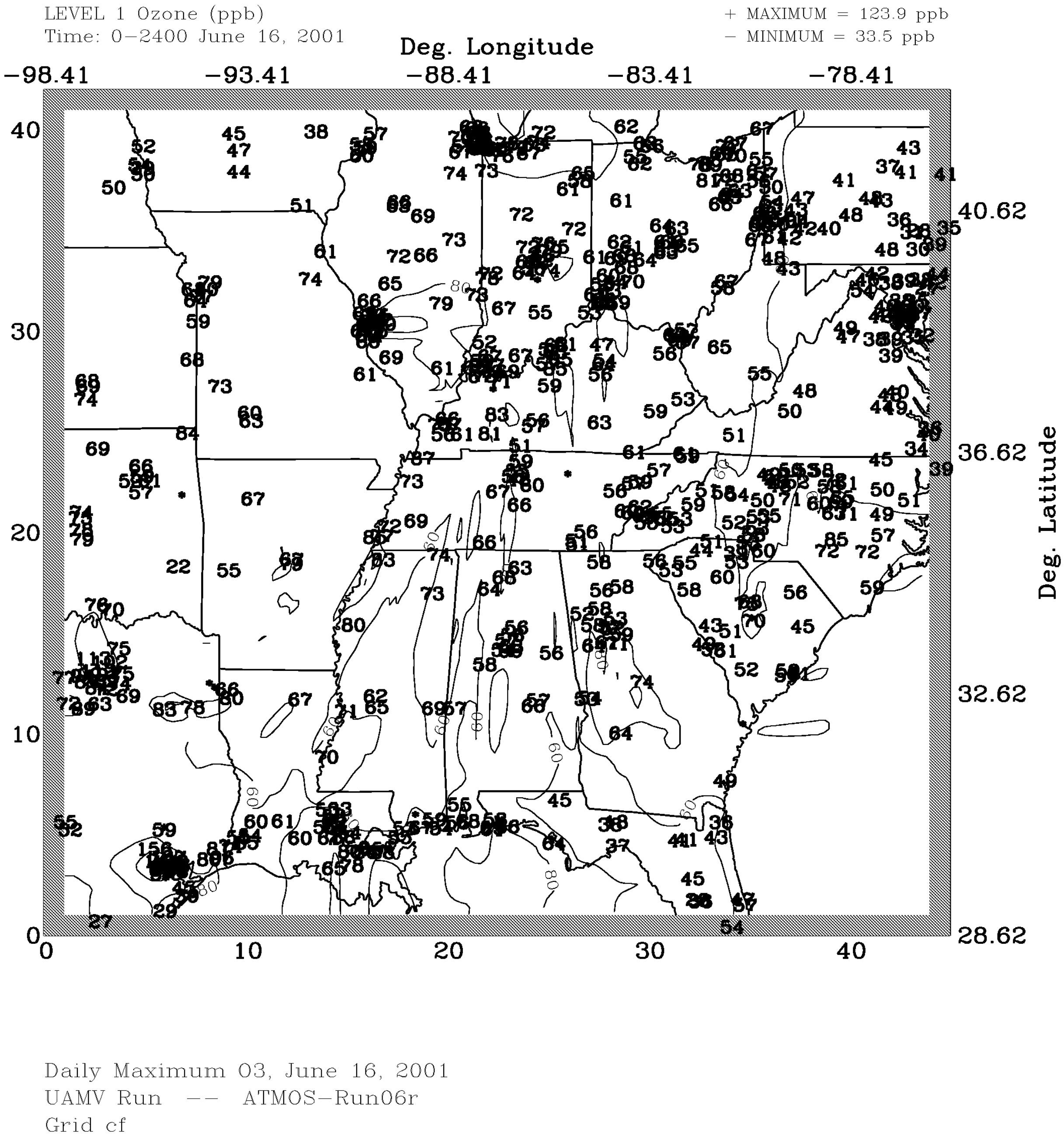


Figure 6-5b. Daily Maximum 1-Hour Ozone, Grid 1, June 17, 2001

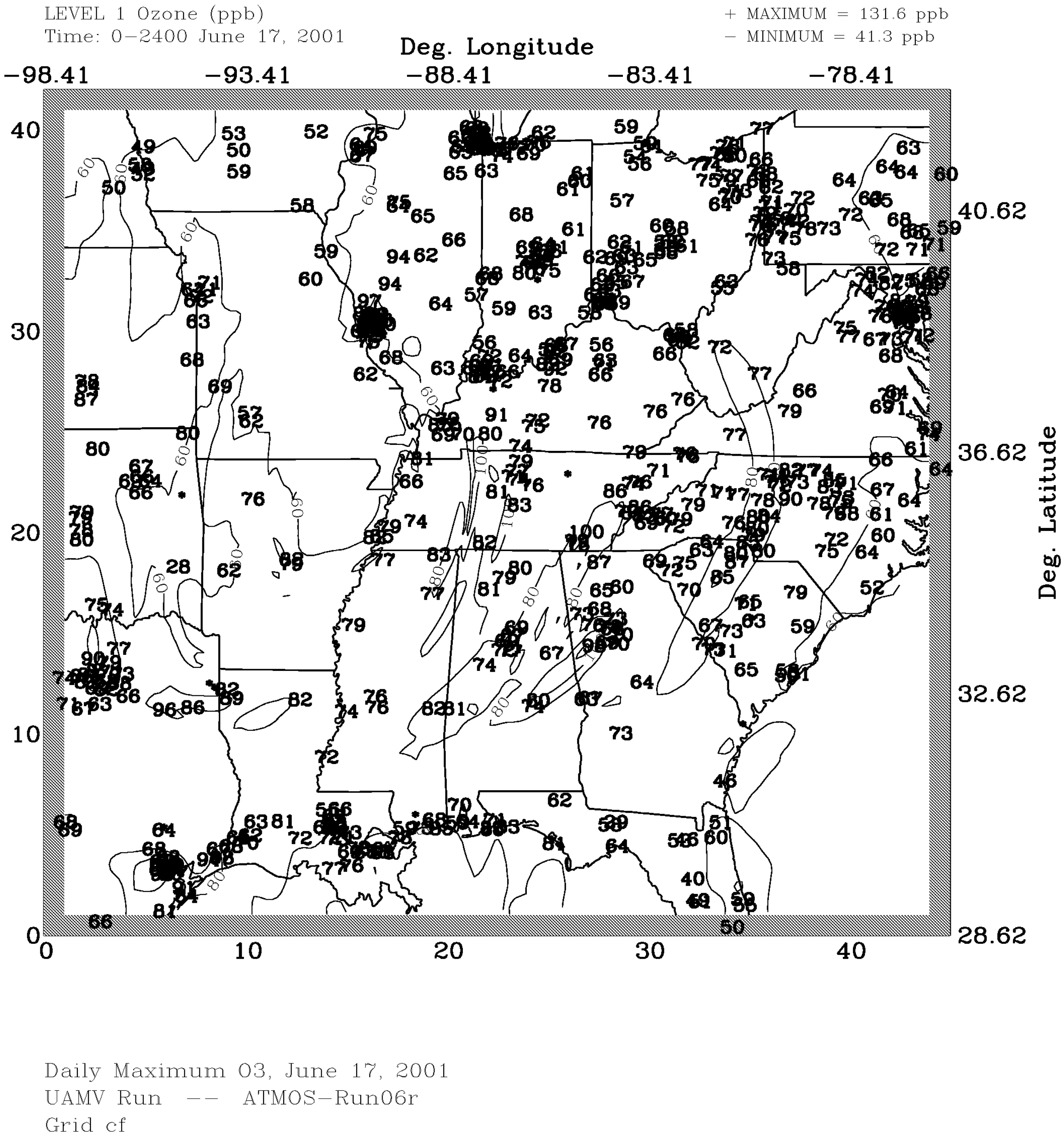


**Figure 6-5c.
Daily Maximum 1-Hour Ozone, Grid 1,
June 18, 2001**

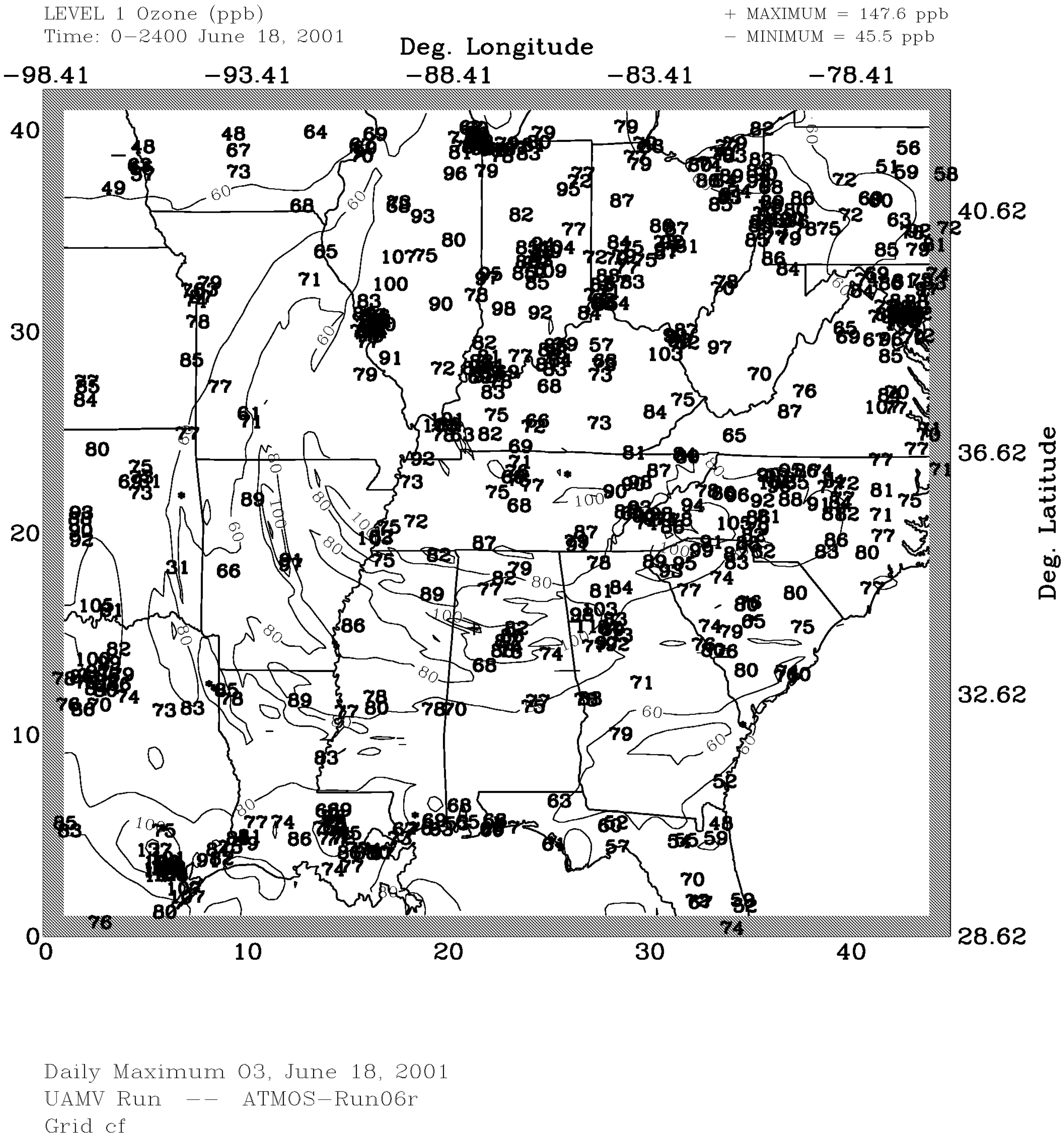


Figure 6-5d.
Daily Maximum 1-Hour Ozone, Grid 1,
June 19, 2001

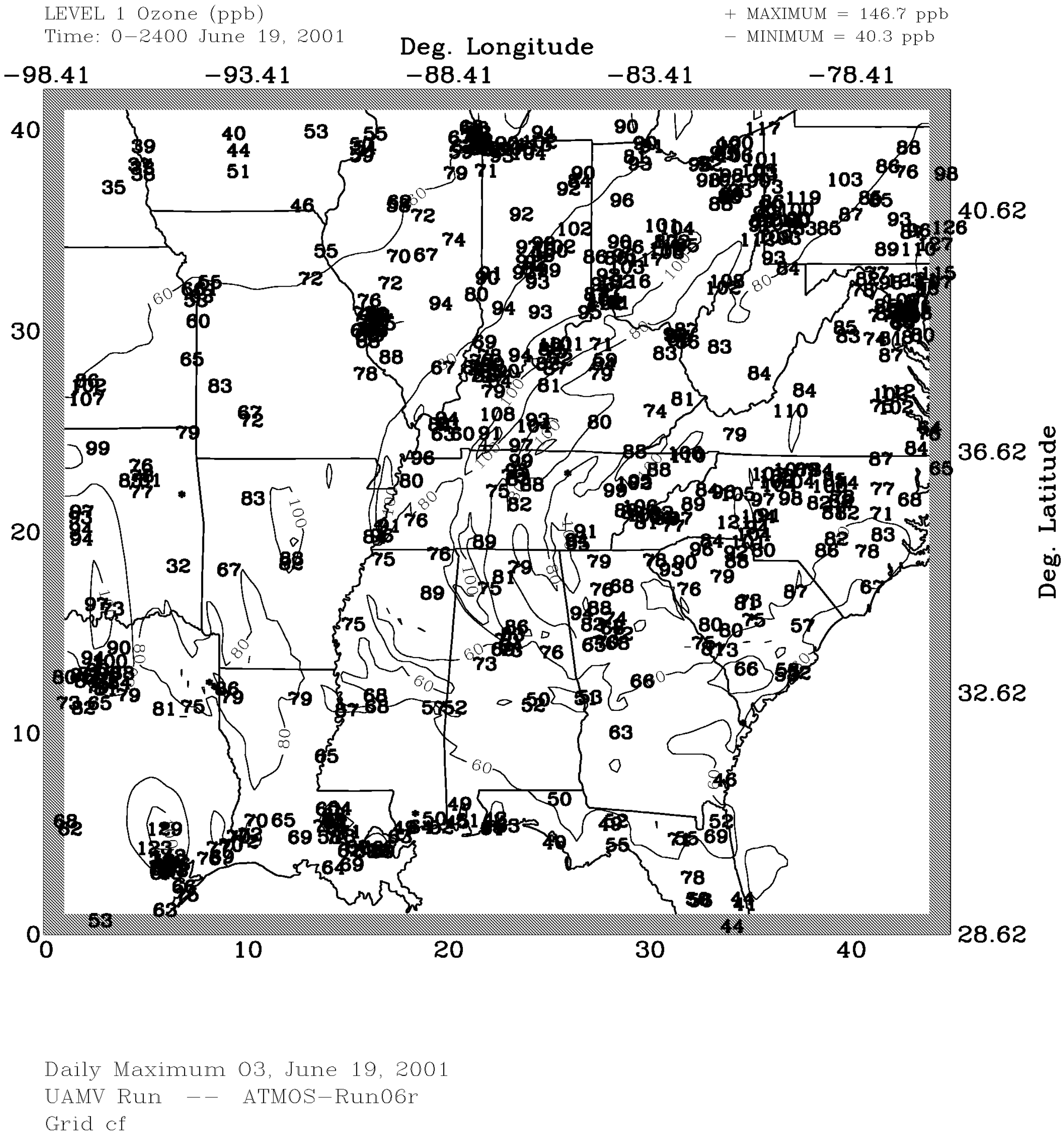


**Figure 6-5e.
Daily Maximum 1-Hour Ozone, Grid 1,
June 20, 2001**

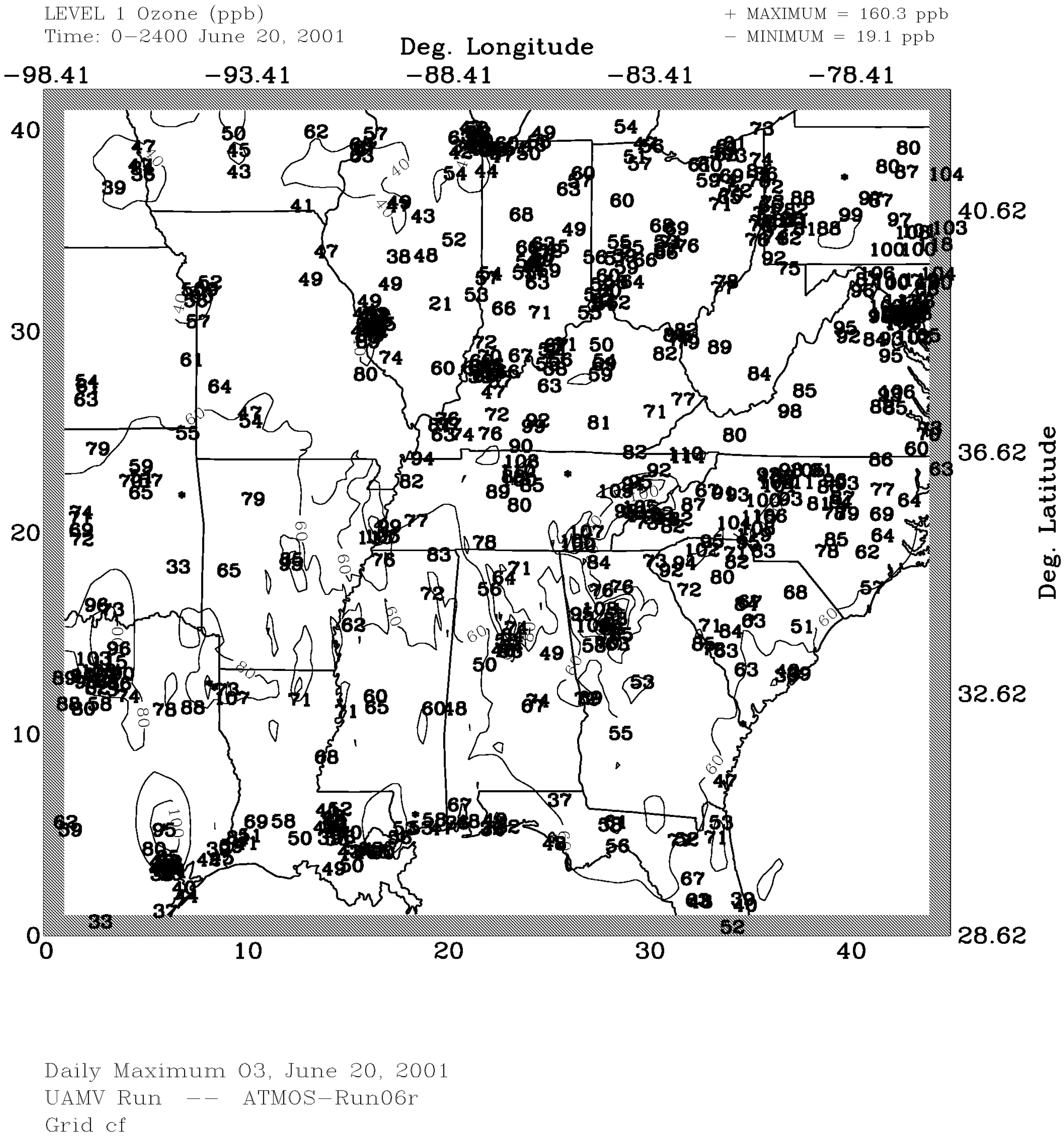


Figure 6-5f.
Daily Maximum 1-Hour Ozone, Grid 1,
June 21, 2001

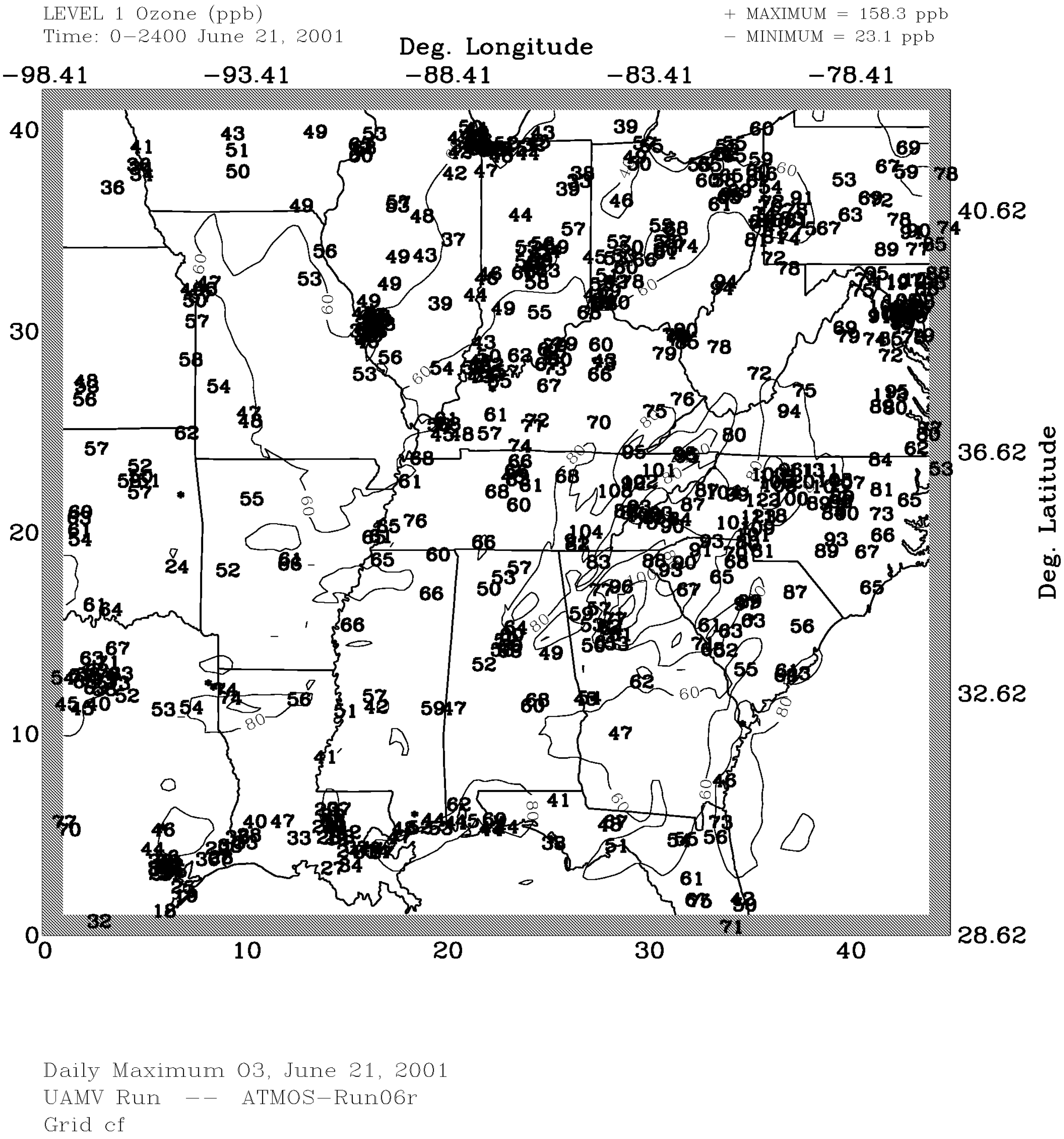


Figure 6-5g.
Daily Maximum 1-Hour Ozone, Grid 1,
June 22, 2001

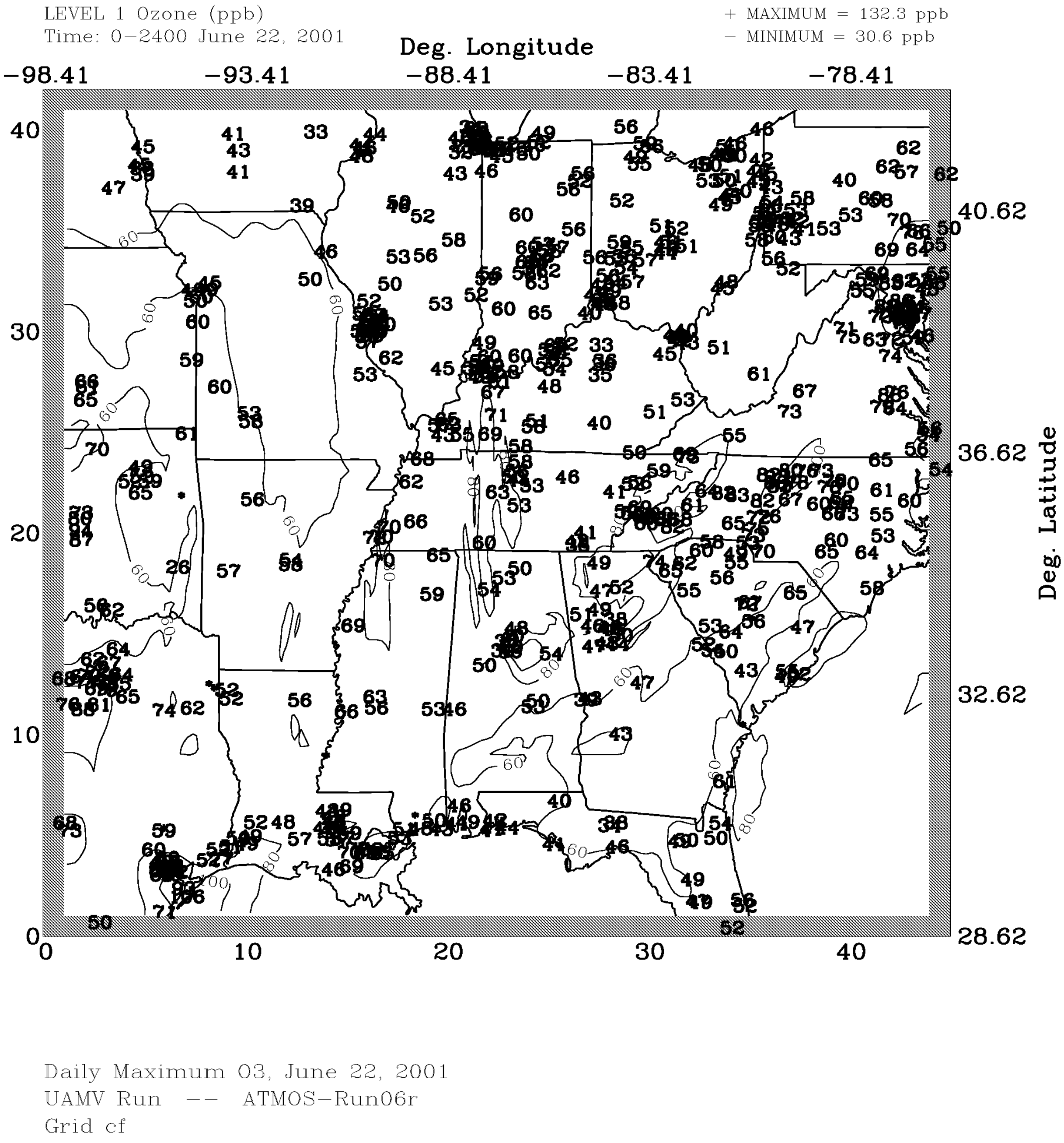


Figure 6-6a.
Daily Maximum 1-Hour Ozone, Grid 3,
June 16, 2001

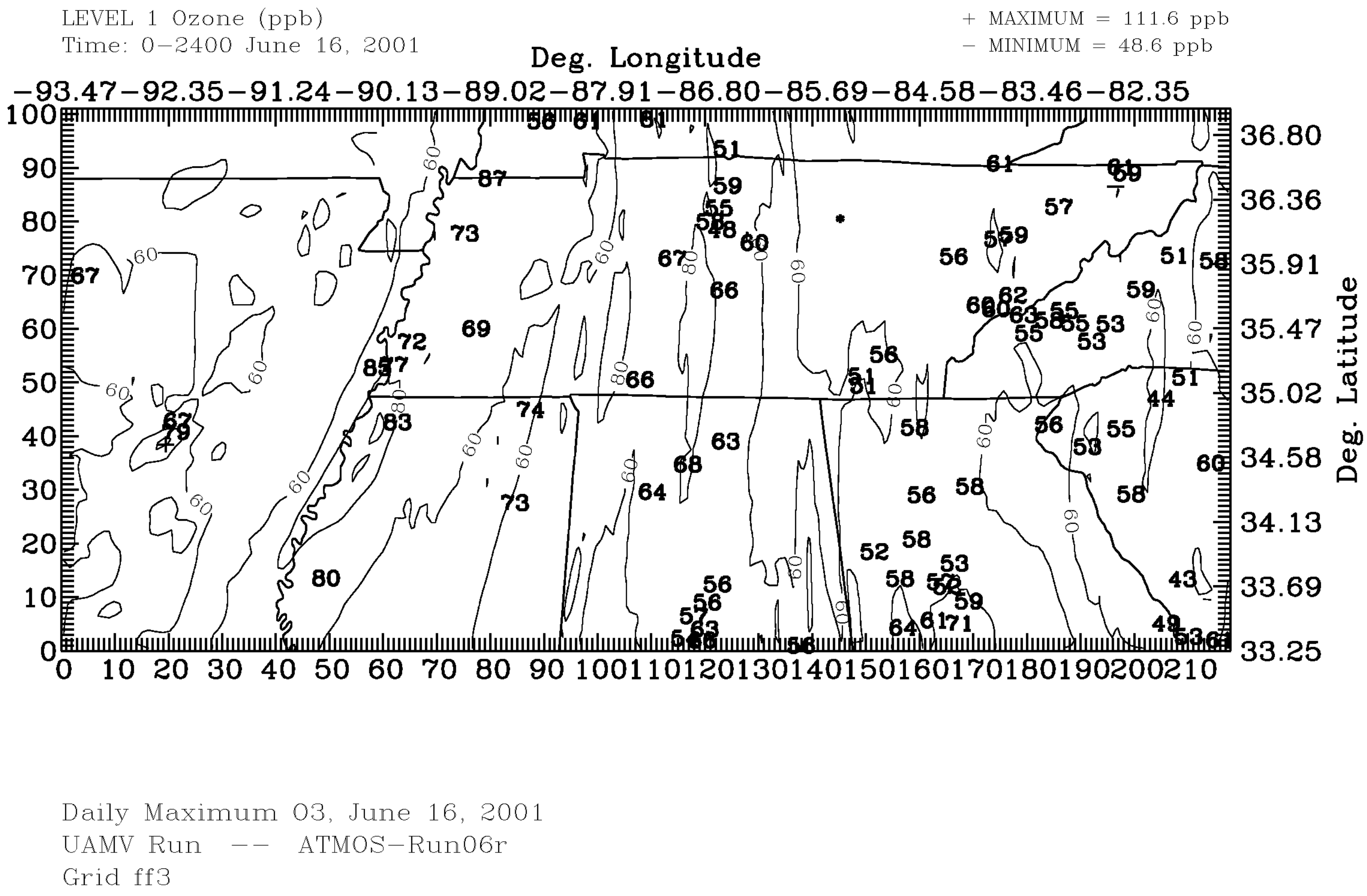


**Figure 6-6b.
Daily Maximum 1-Hour Ozone, Grid 3,
June 17, 2001**

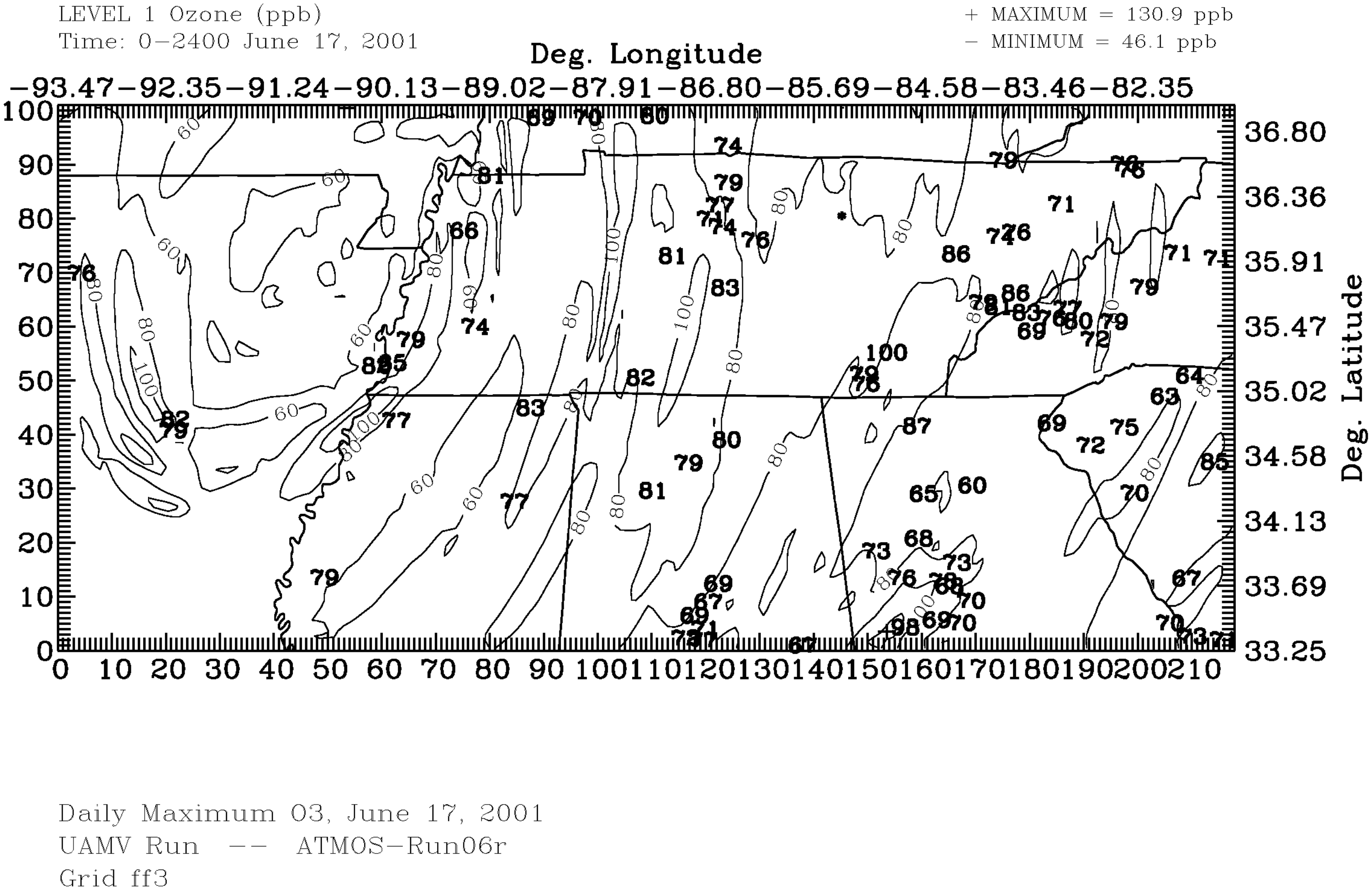


Figure 6-6c.
Daily Maximum 1-Hour Ozone, Grid 3
June 18, 2001

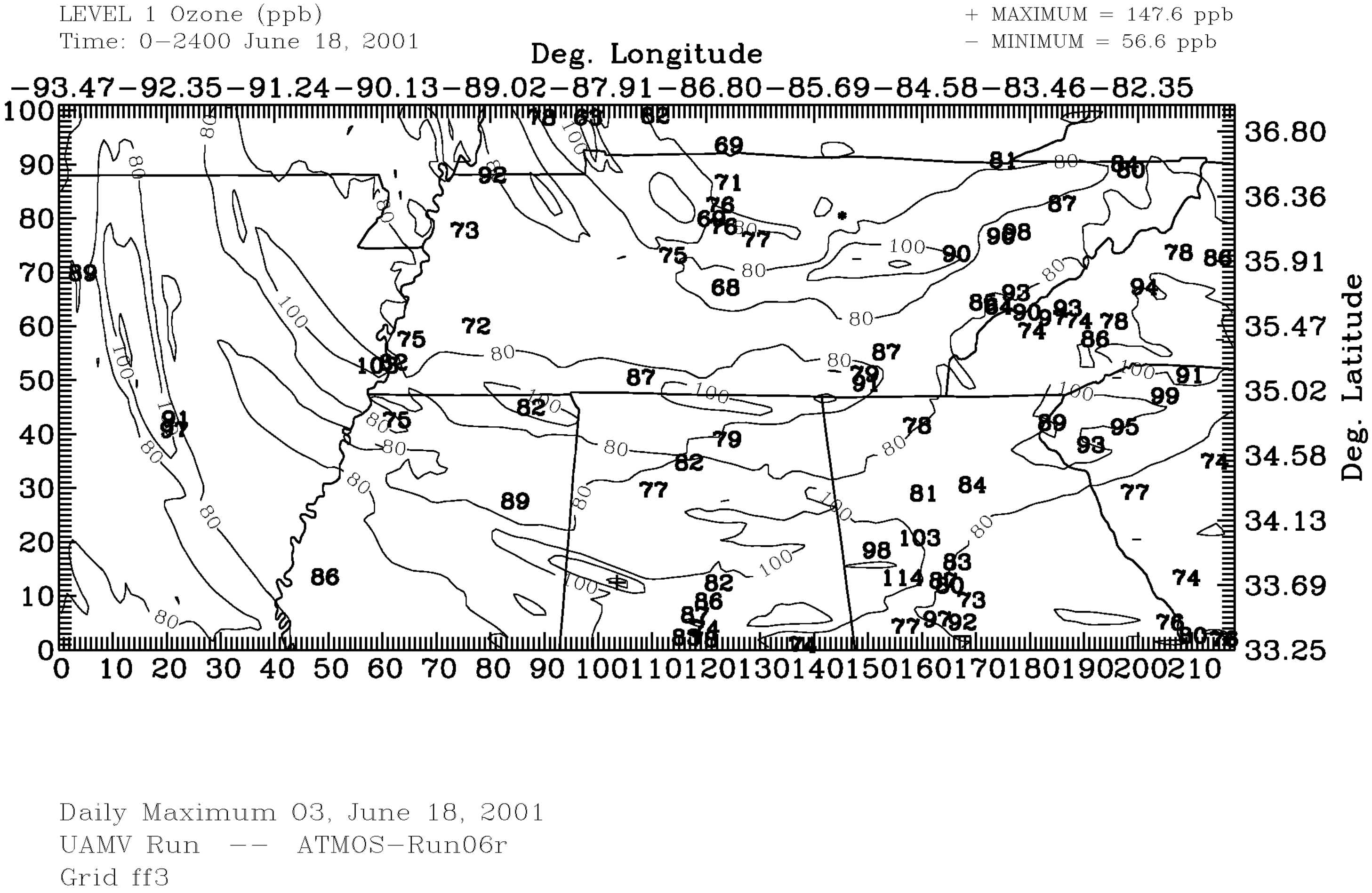


Figure 6-6d.
Daily Maximum 1-Hour Ozone, Grid 3
June 19, 2001

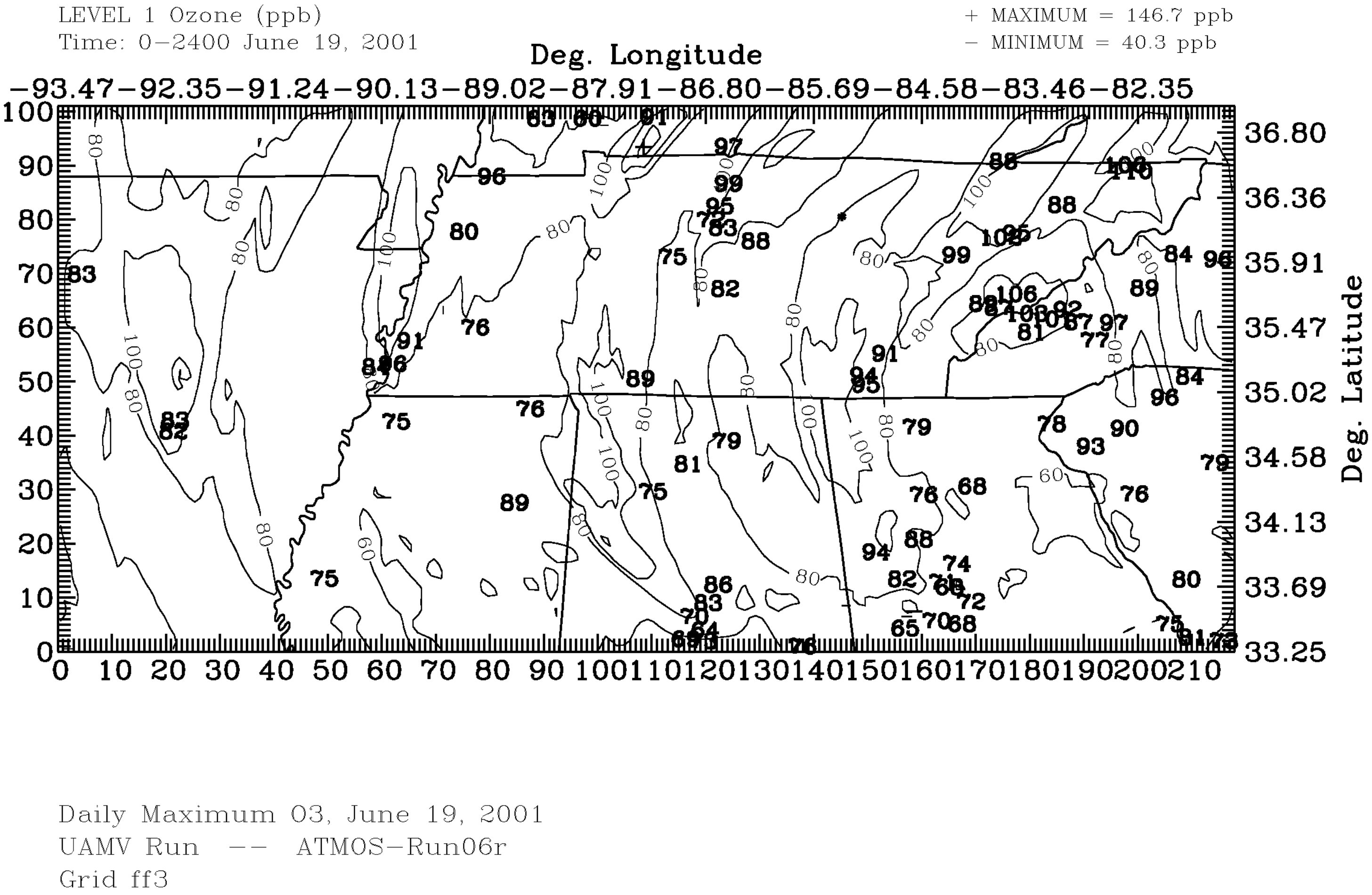
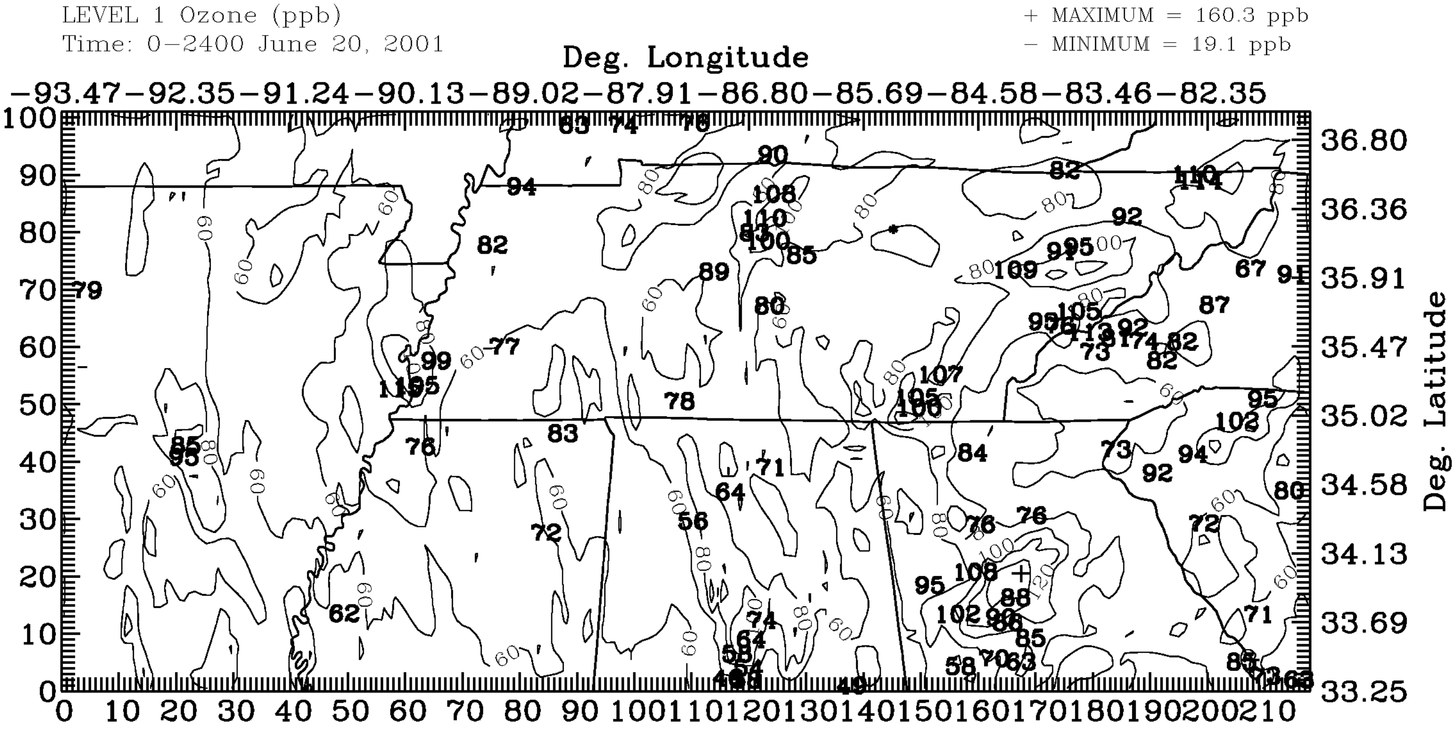
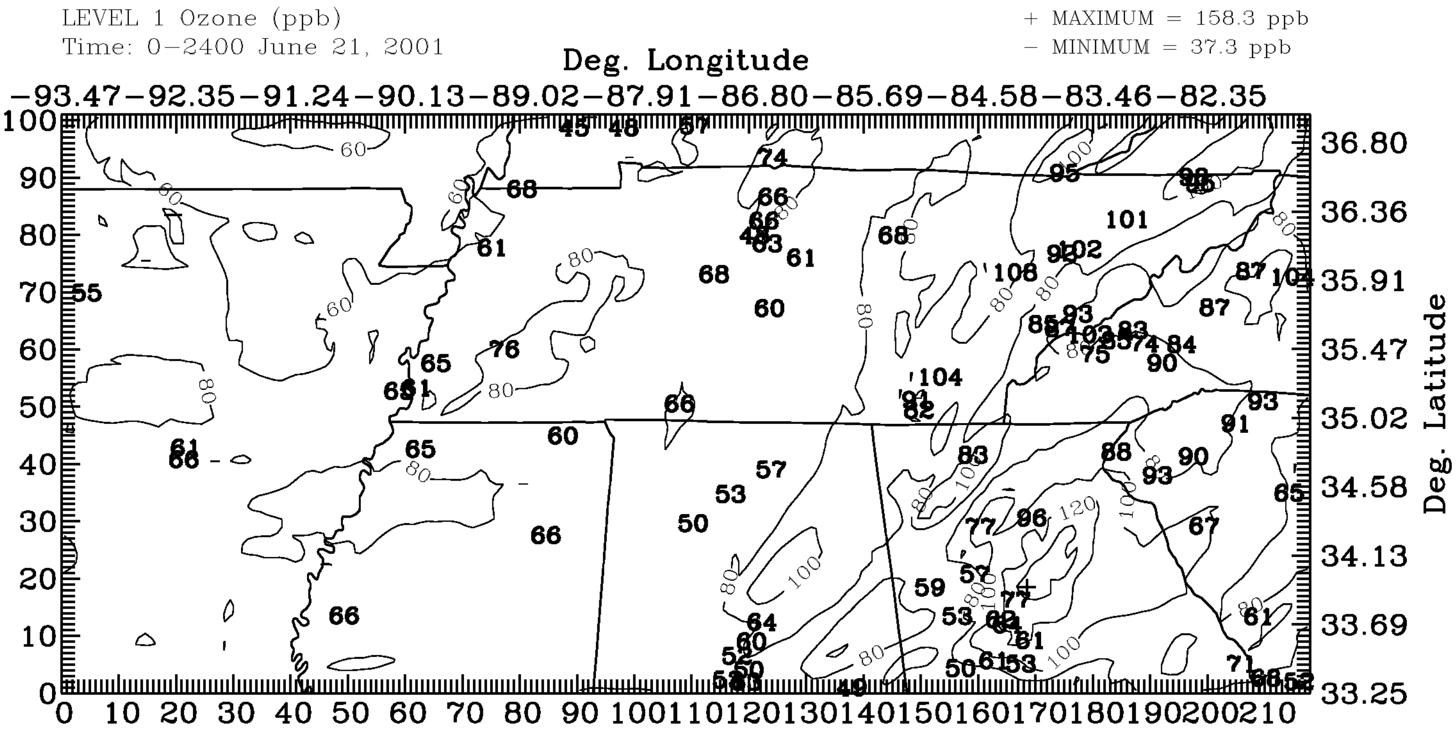


Figure 6-6e.
Daily Maximum 1-Hour Ozone, Grid 3
June 20, 2001



Daily Maximum O3, June 20, 2001
UAMV Run –– ATMOS–Run06r
Grid ff3

Figure 6-6f.
Daily Maximum 1-Hour Ozone, Grid 3
June 21, 2001

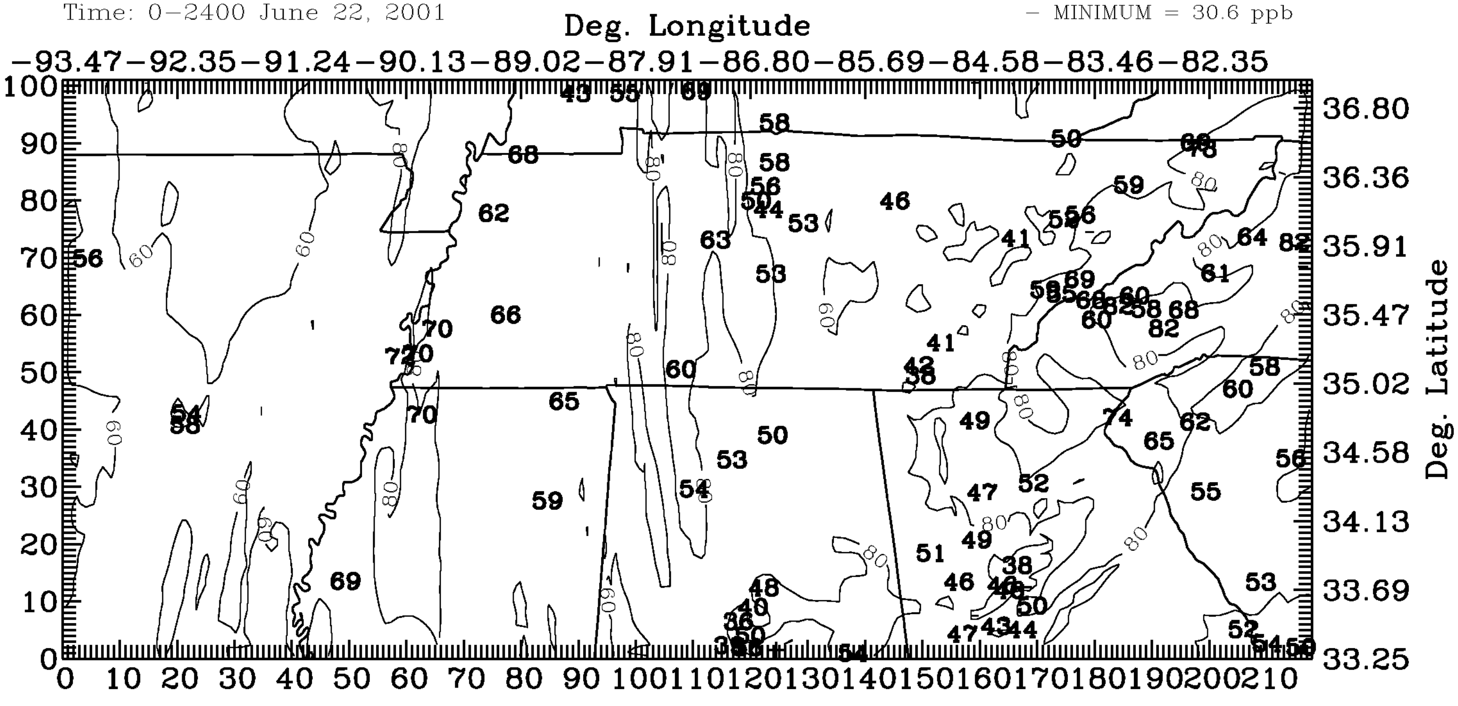


Daily Maximum O3, June 21, 2001
UAMV Run -- ATMOS-Run06r
Grid ff3

Figure 6-6g.
Daily Maximum 1-Hour Ozone, Grid 3
June 22, 2001

LEVEL 1 Ozone (ppb)
Time: 0–2400 June 22, 2001

+ MAXIMUM = 127.3 ppb
– MINIMUM = 30.6 ppb



Daily Maximum O3, June 22, 2001
UAMV Run –– ATMOS–Run06r
Grid ff3

Figure 6-7a.
2001 Episode Time Series: Memphis EAC area
June 16-19, 2001

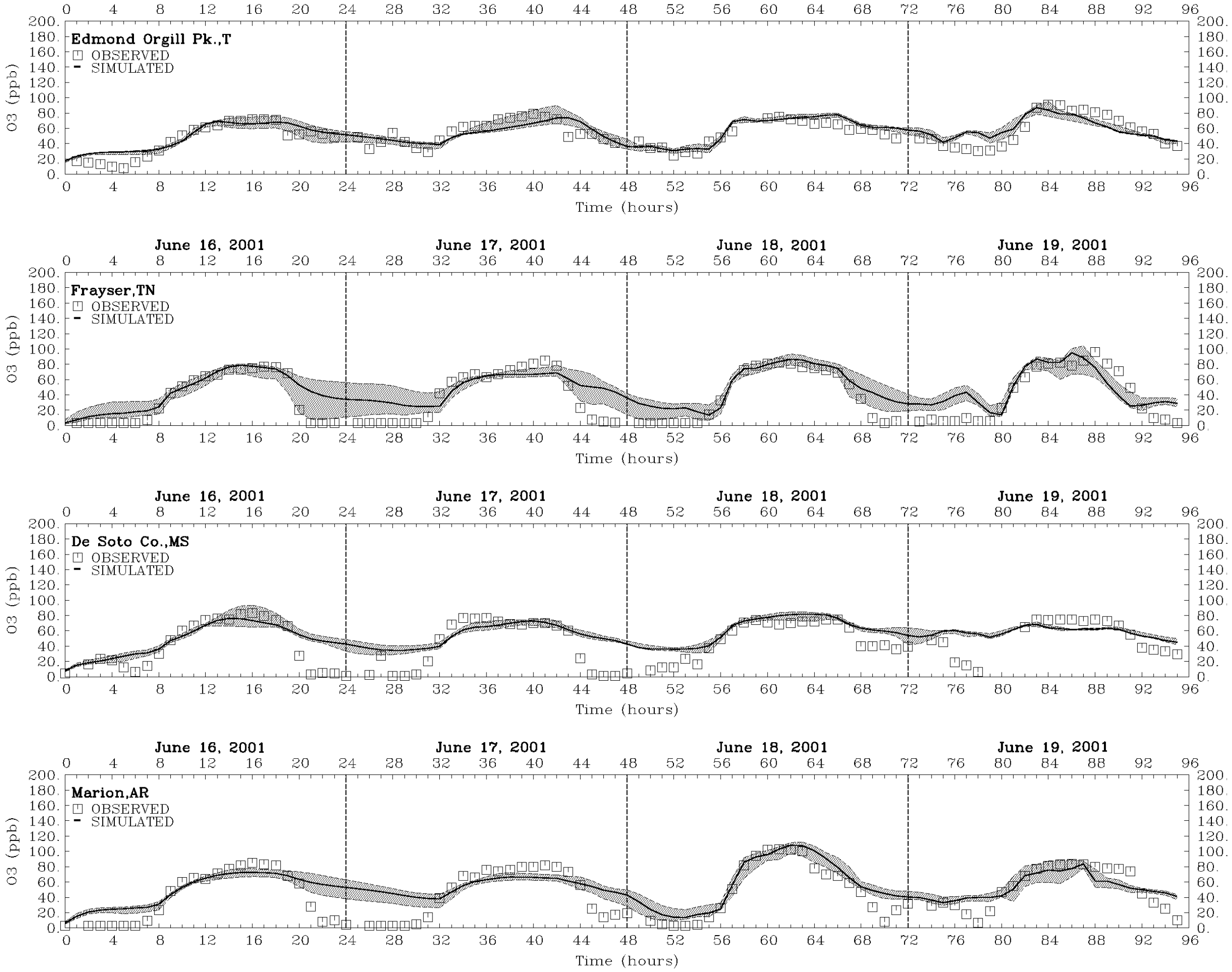


Figure 6-7b.
2001 Episode Time Series: Memphis EAC Area,
June 19-22, 2001

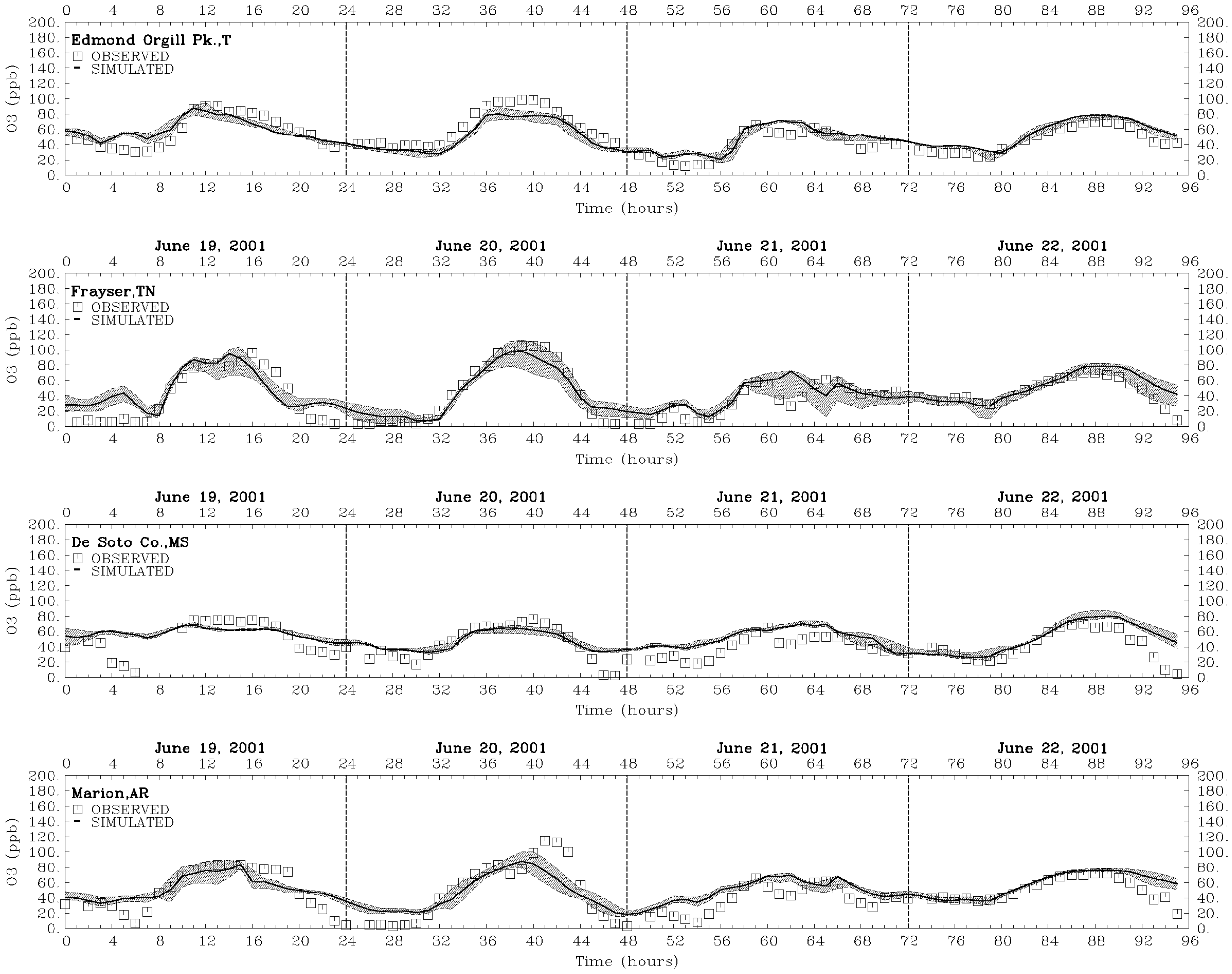


Figure 6-7c.
2001 Episode Time Series: Nashville EAC Area,
June 16-19, 2001

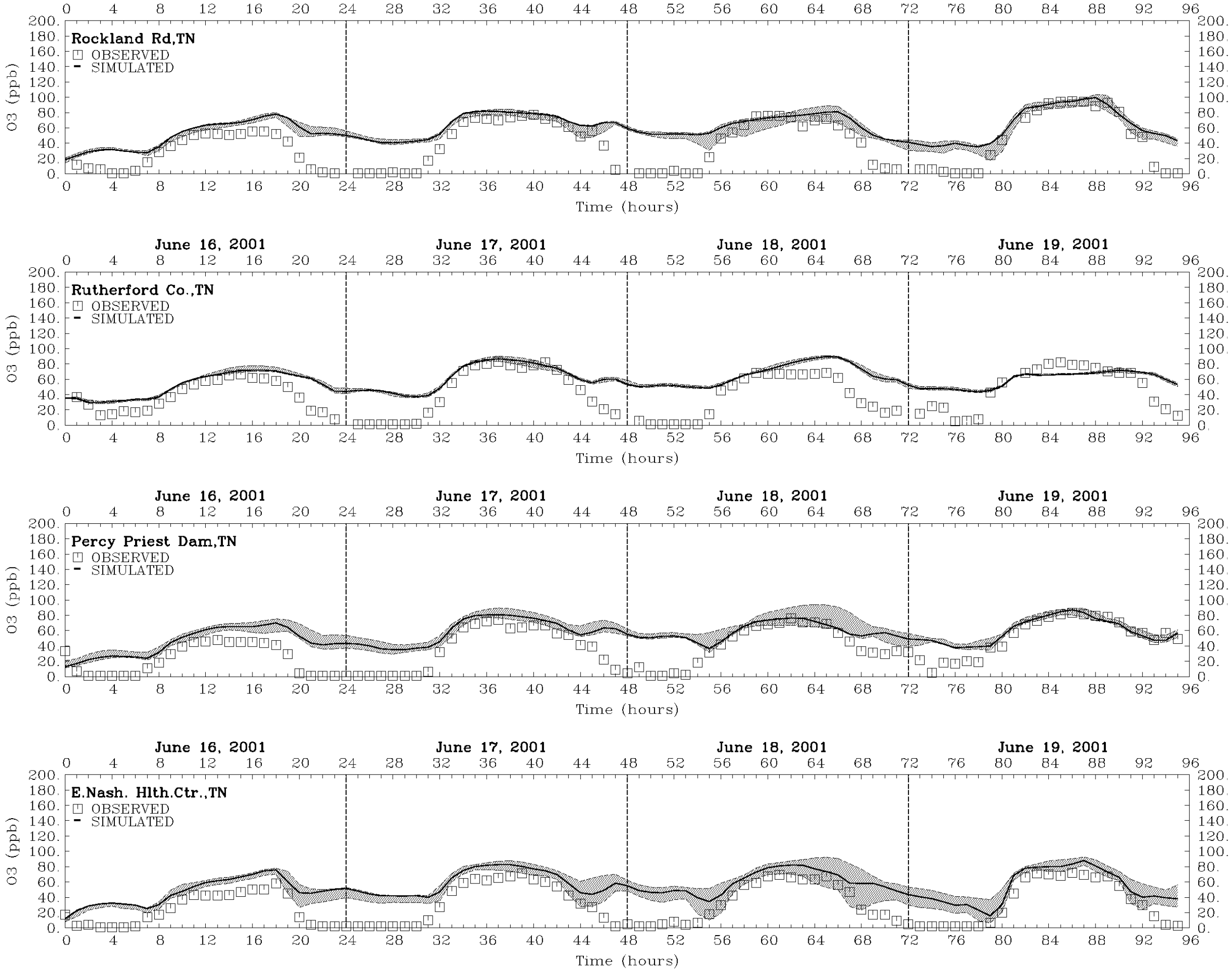


Figure 6-7d.
2001 Episode Time Series: Nashville EAC Area *(continued)*, June 16-19, 2001

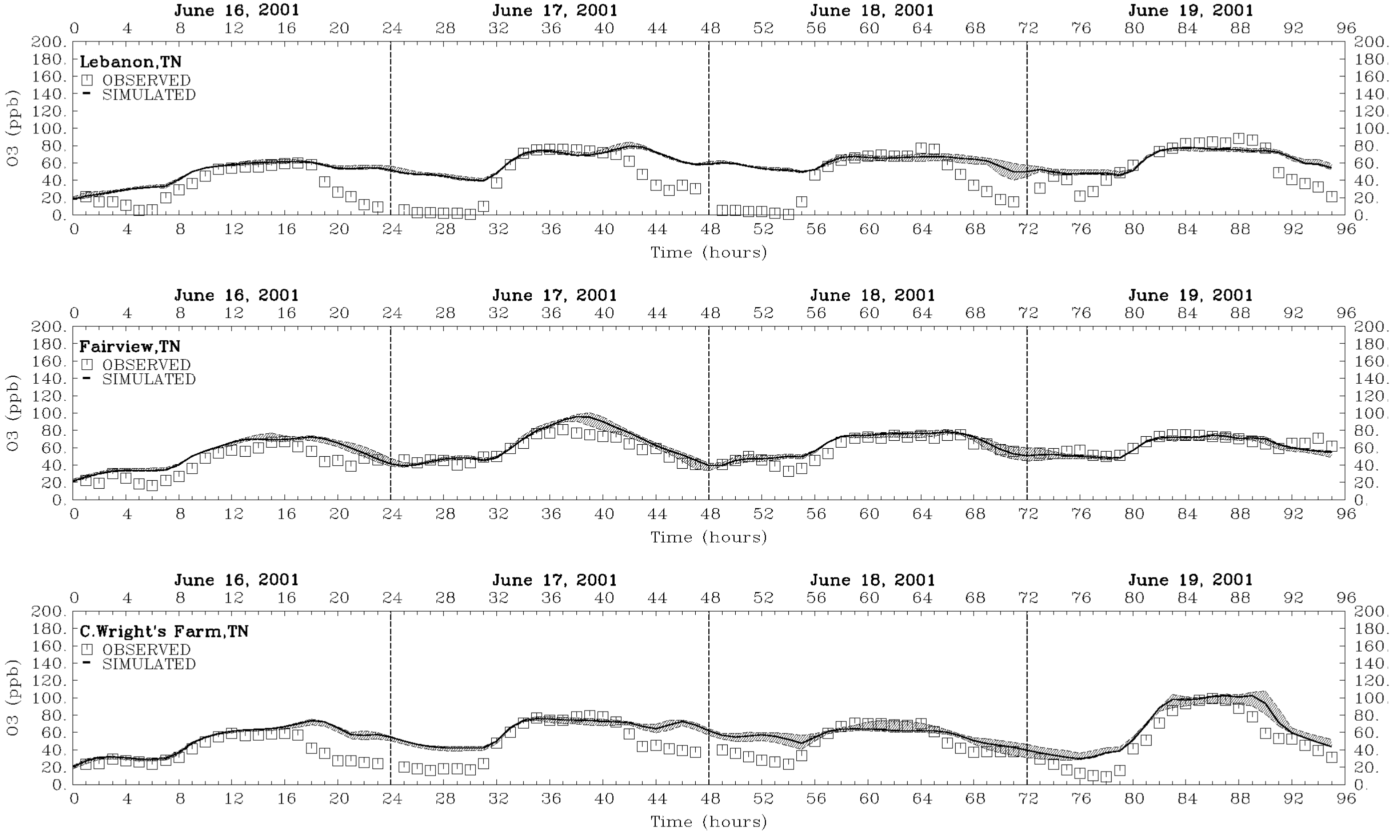


Figure 6-7e.
2001 Episode Time Series: Nashville EAC Area,
June 19-22, 2001

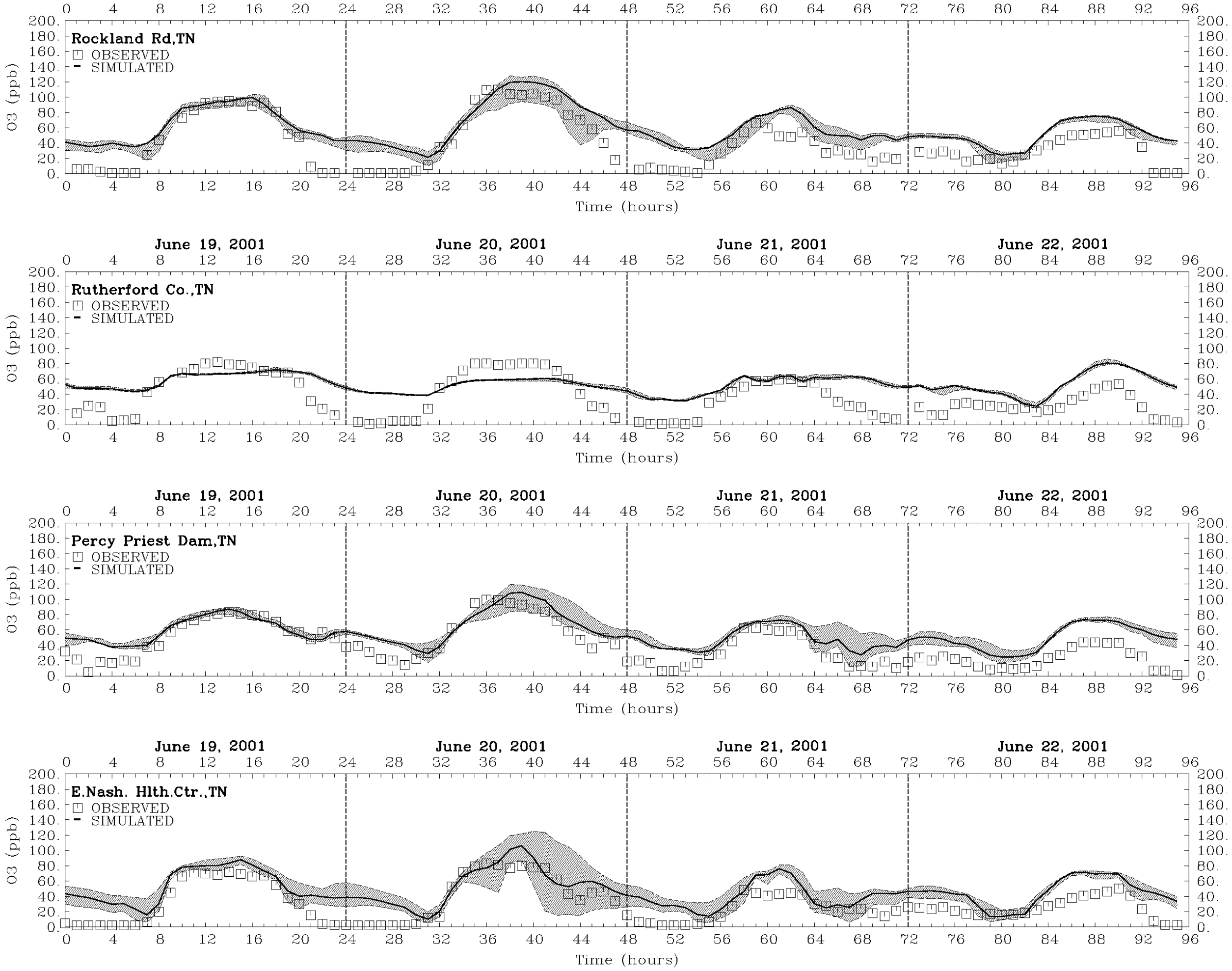
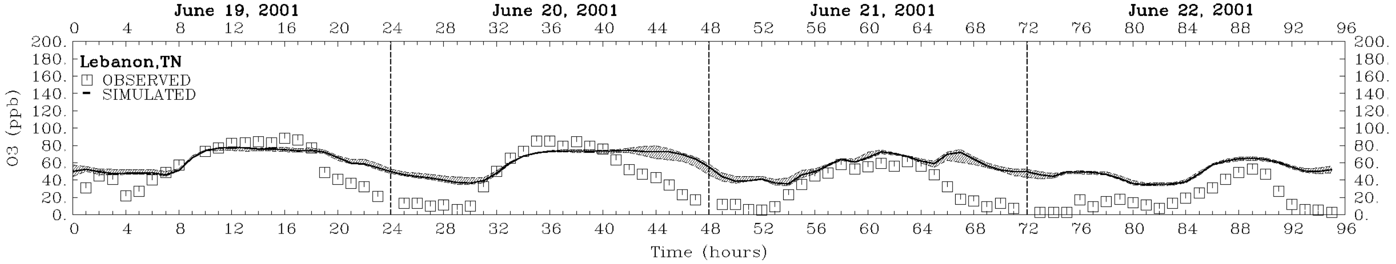
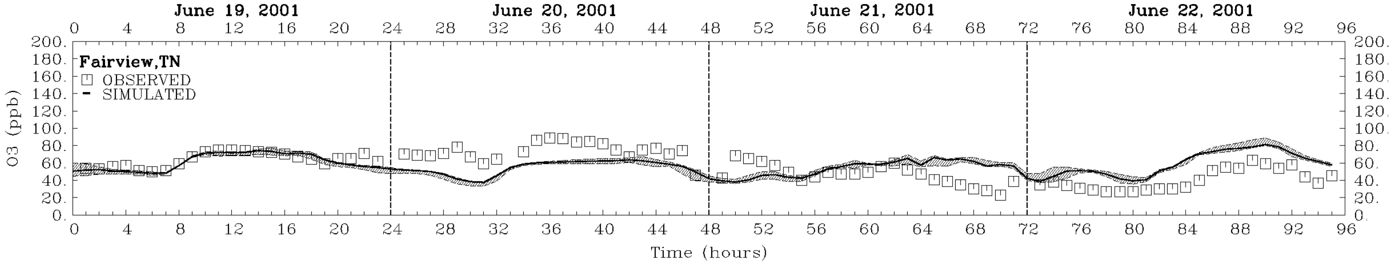


Figure 6-7f.
2001 Episode Time Series: Nashville EAC Area *(continued)*,
June 19-22, 2001





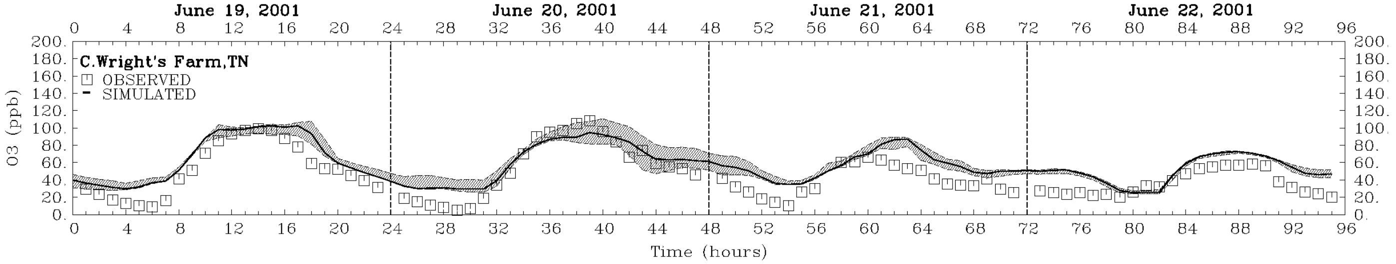


Figure 6-7g.
2001 Episode Time Series: Knoxville EAC Area,
June 16-19, 2001

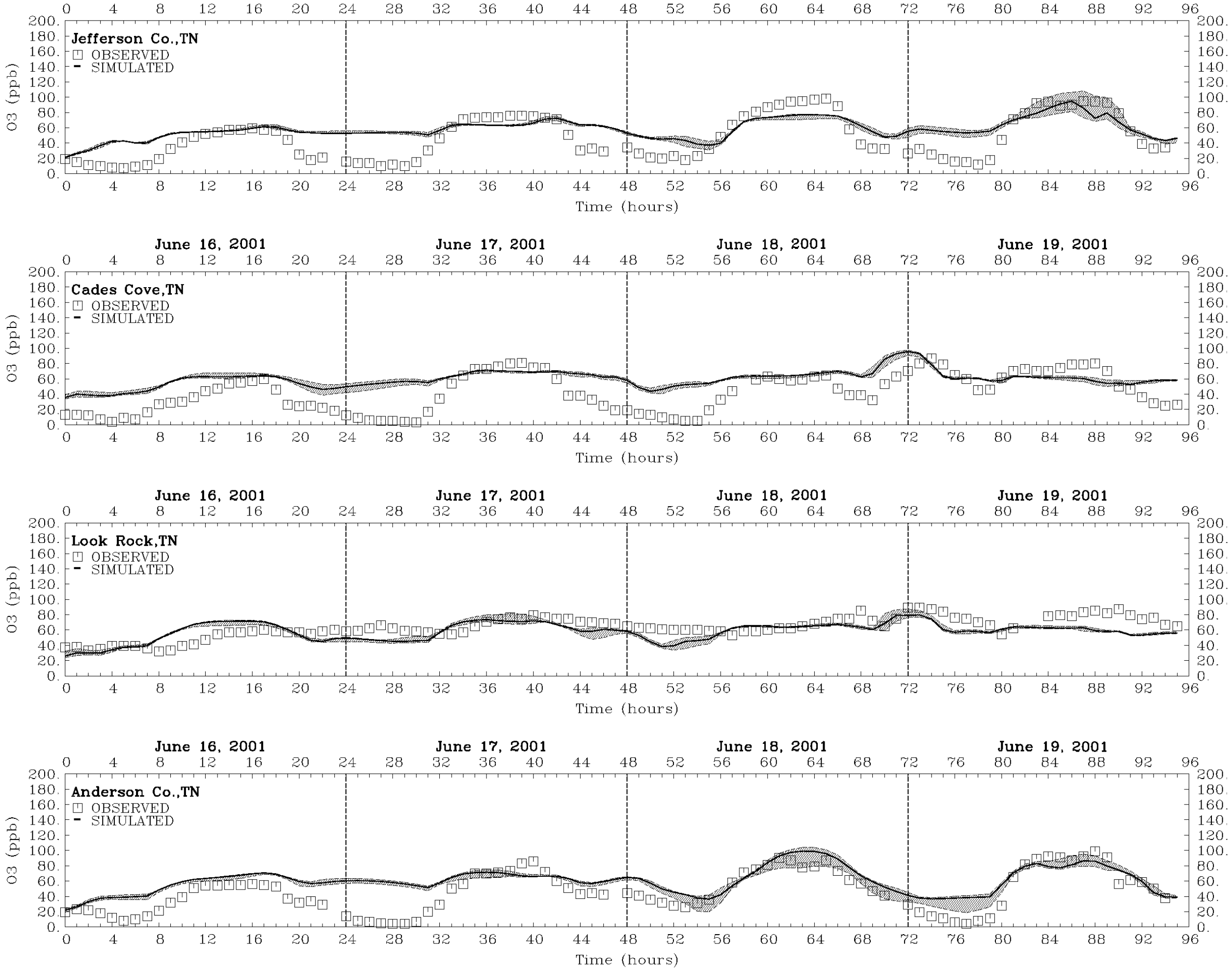


Figure 6-7h.
2001 Episode Time Series: Knoxville EAC Area *(continued)*,)
June 16-19, 2001

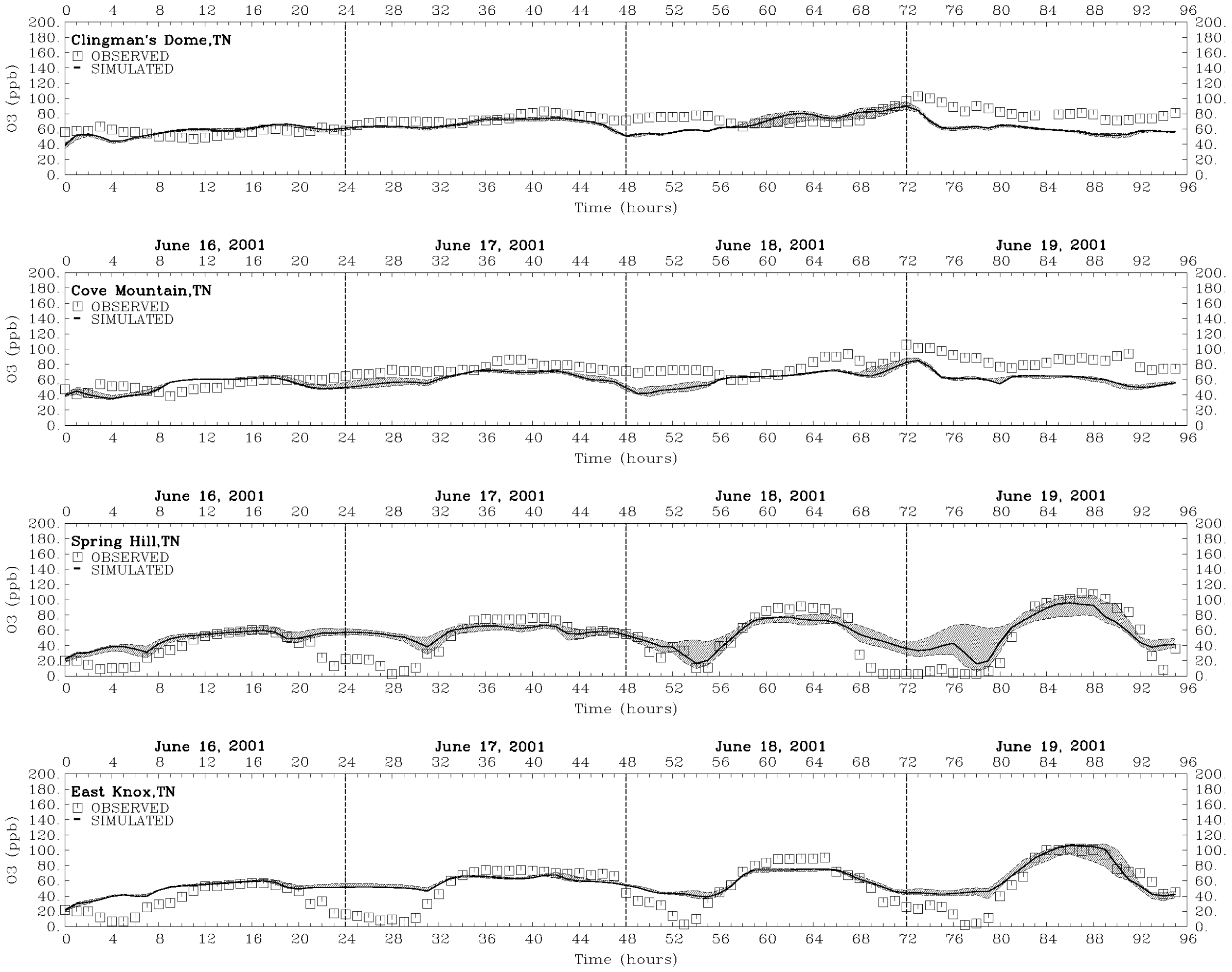


Figure 6-7i.
2001 Episode Time Series: Knoxville EAC Area, June 19-22, 2001

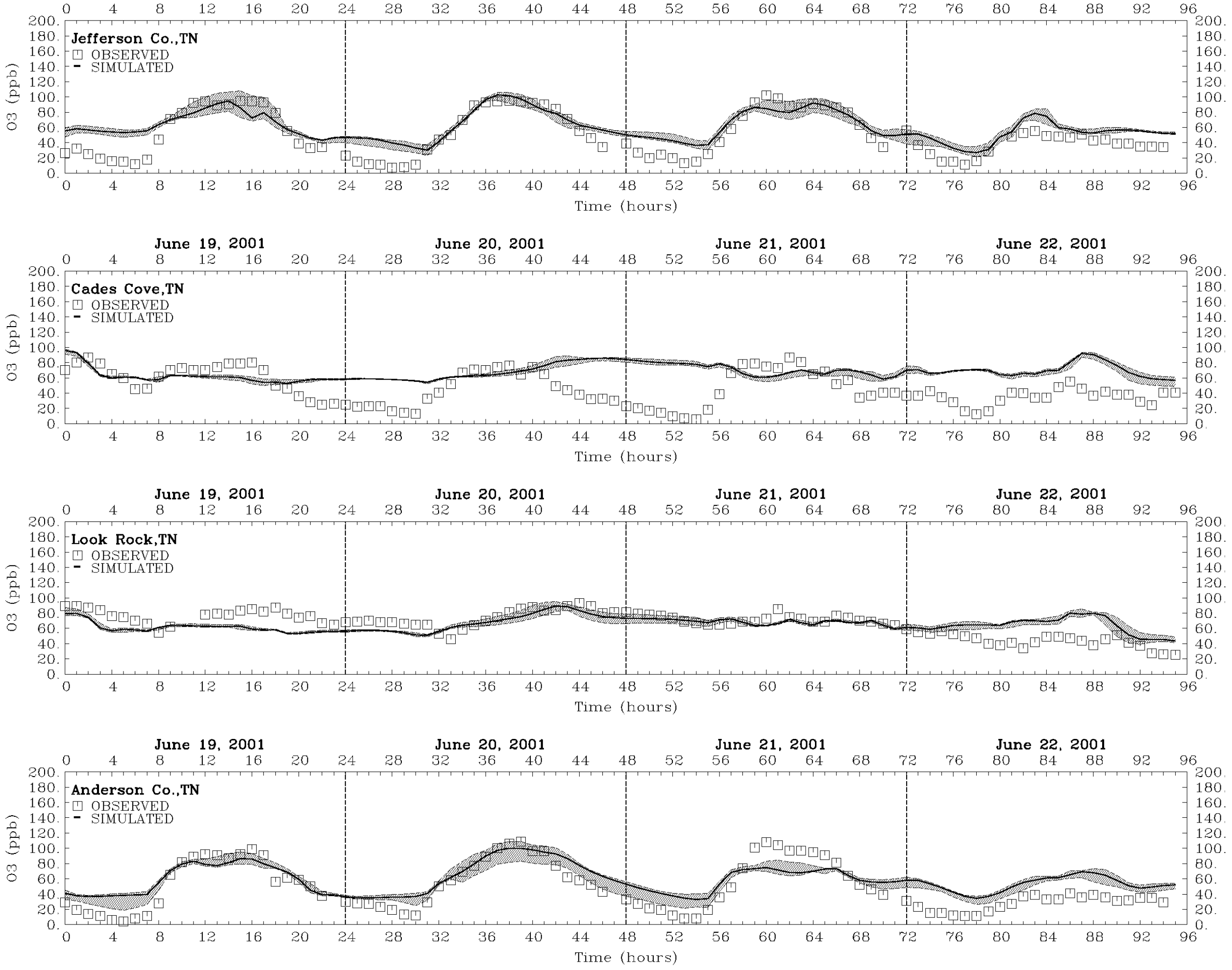


Figure 6-7j.
2001 Episode Time Series: Knoxville EAC Area *(continued)*,
June 19-22, 2001

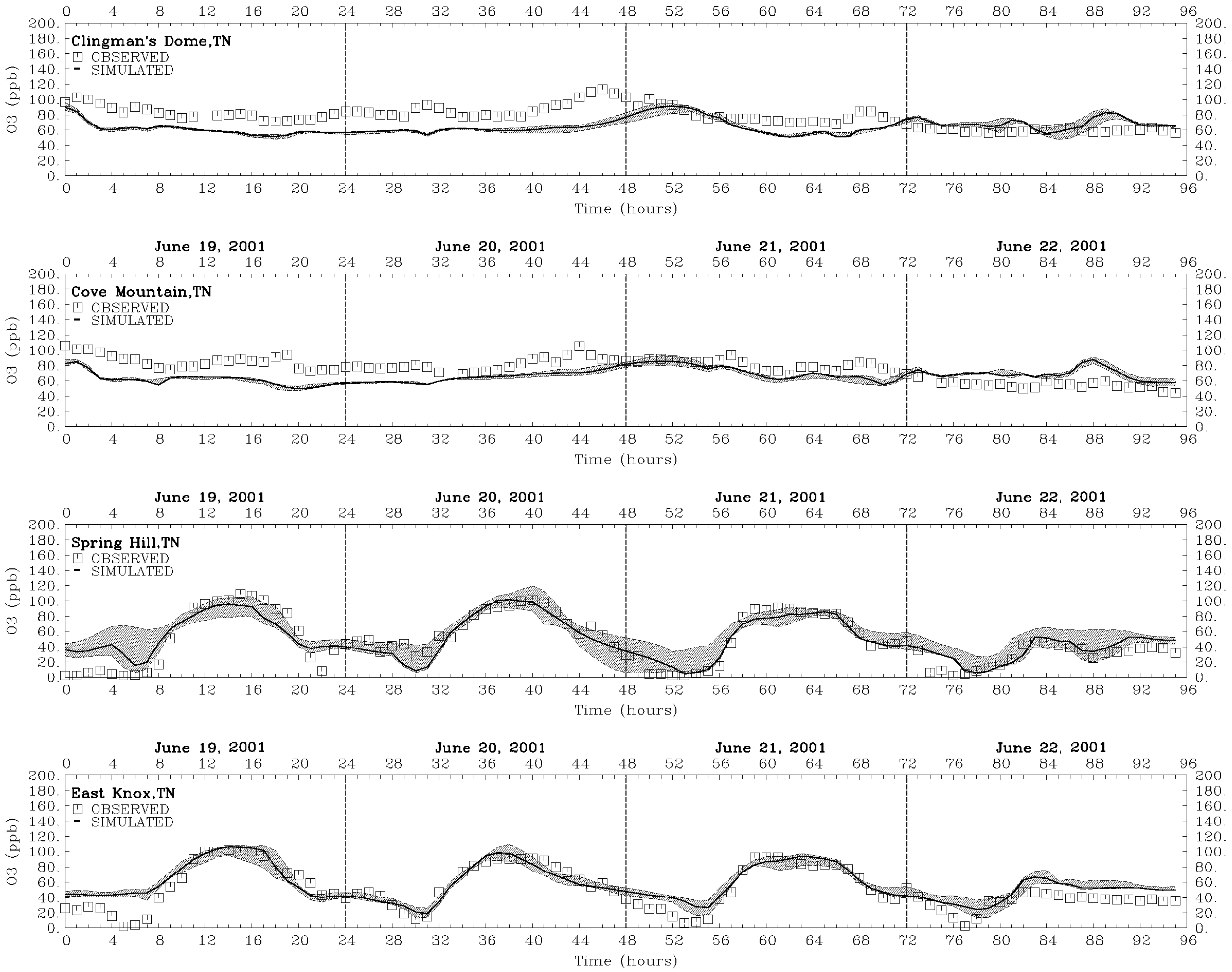


Figure 6-7k.
2001 Episode Time Series: Chattanooga EAC Area,
June 16-19, 2001

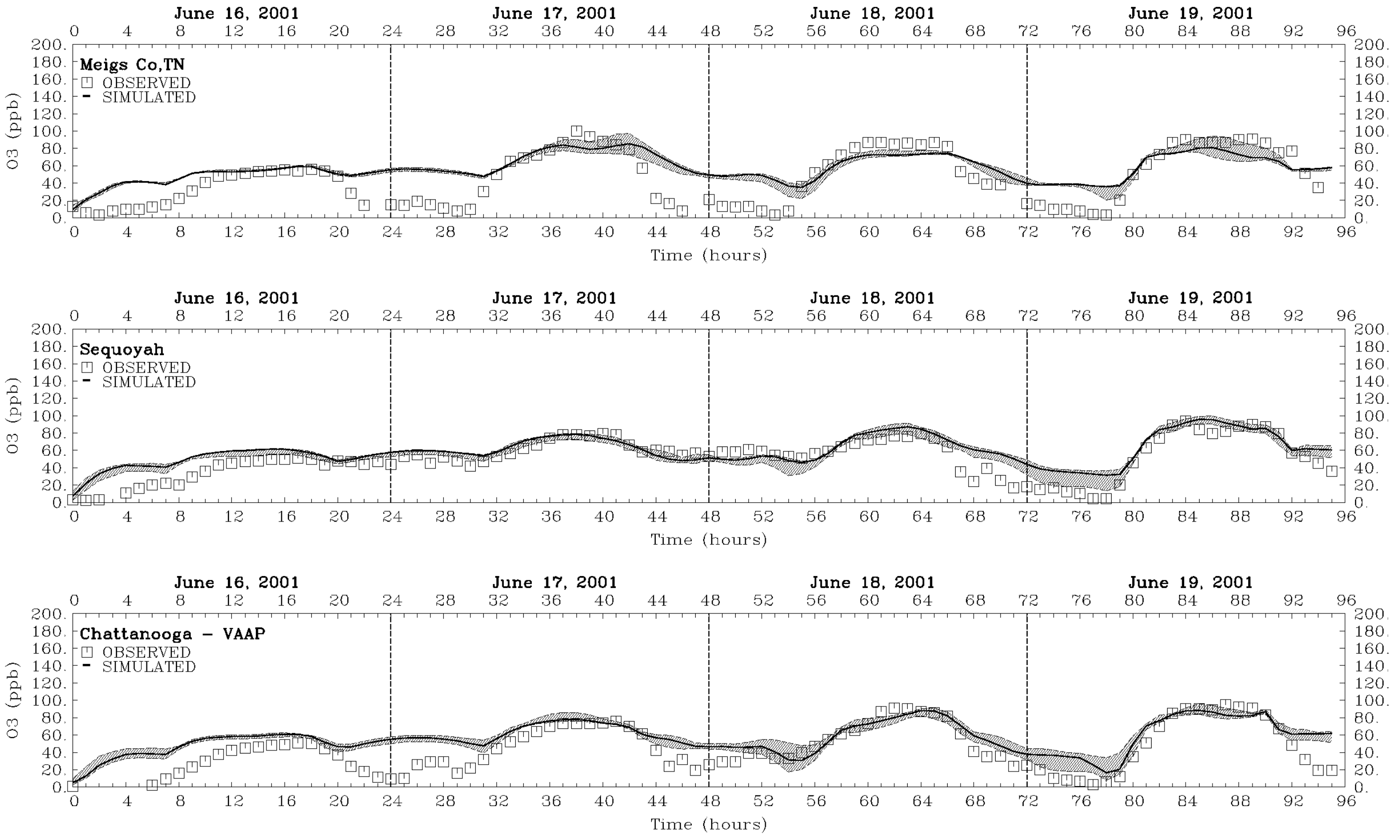


Figure 6-7l.
2001 Episode Time Series: Chattanooga EAC Area,
June 19-22, 2001

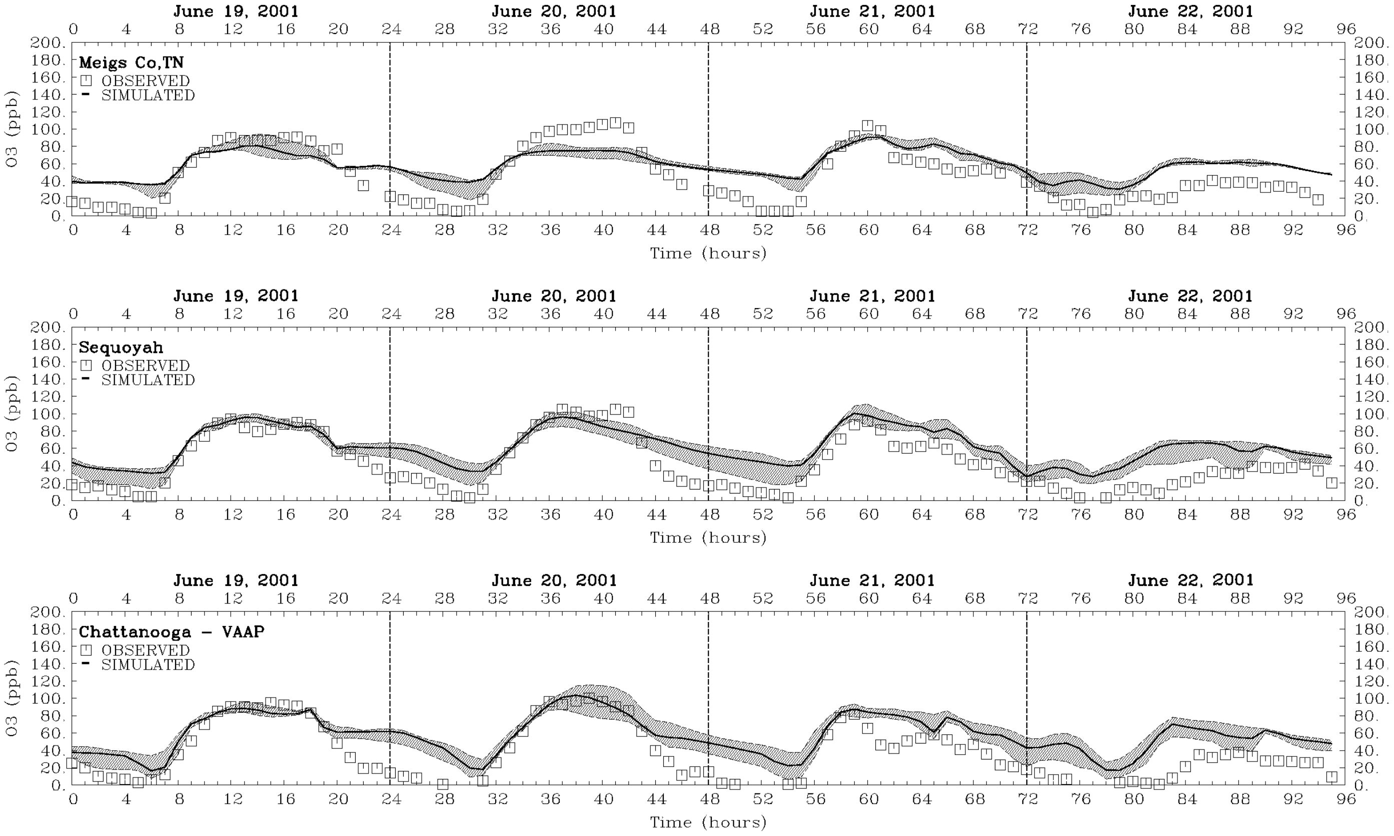


Figure 6-7m.
2001 Episode Time Series: Tri-Cities EAC Area, June 16-19, 2001

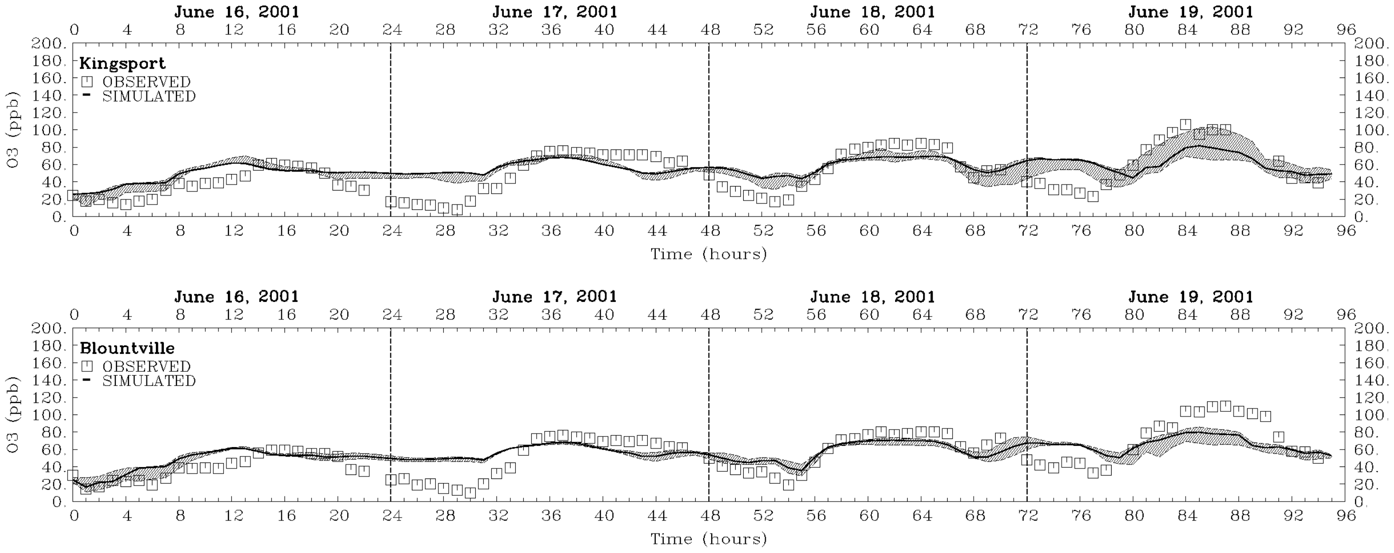


Figure 6-7n.
2001 Episode Time Series: Tri-Cities EAC Area,
June 19-22, 2001

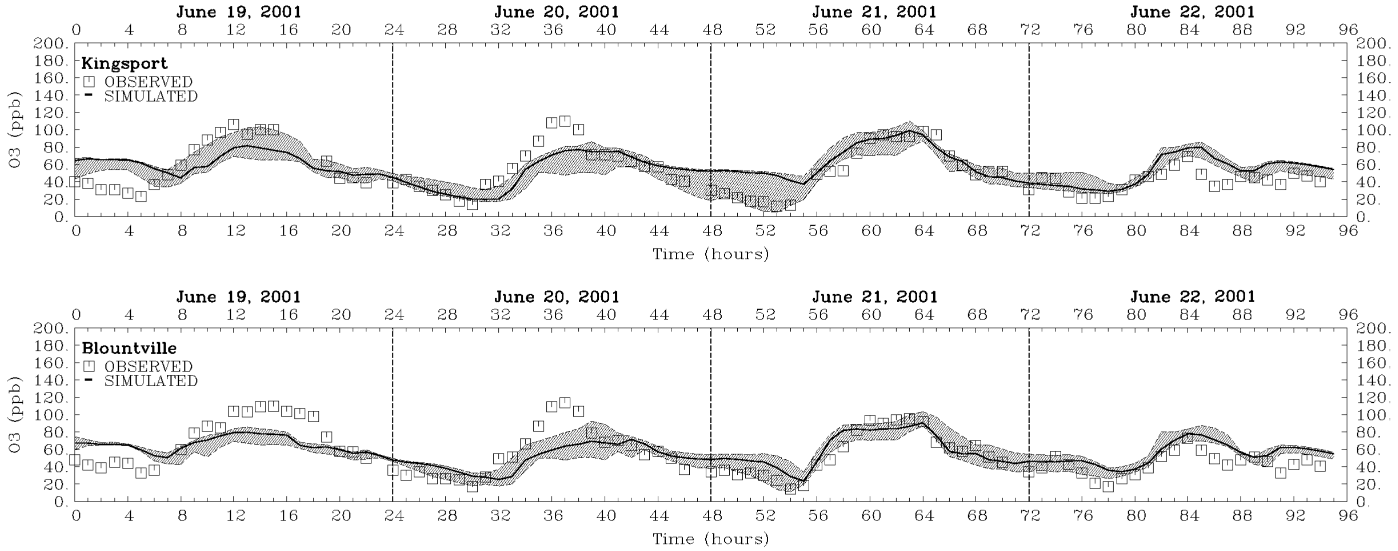
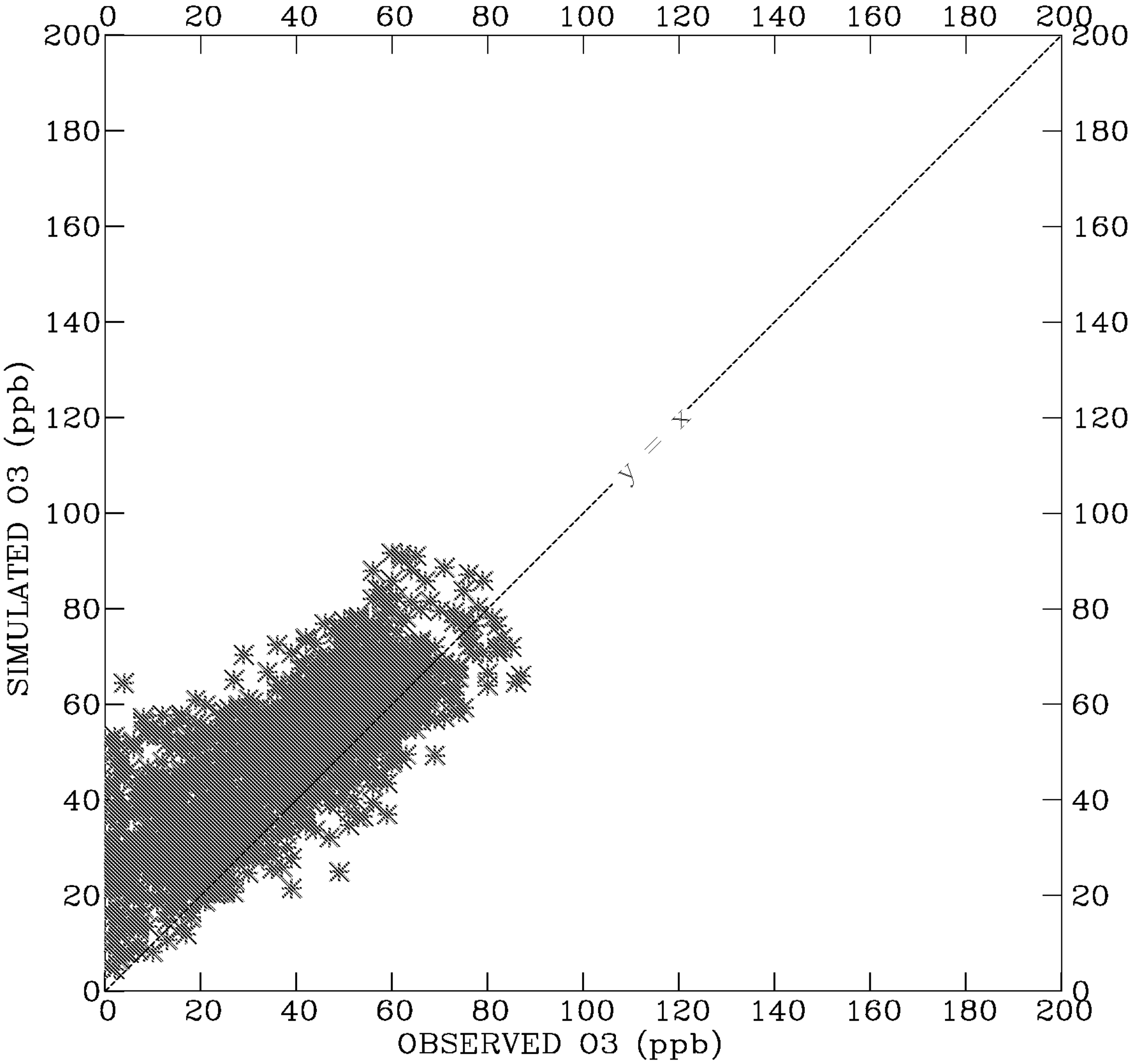


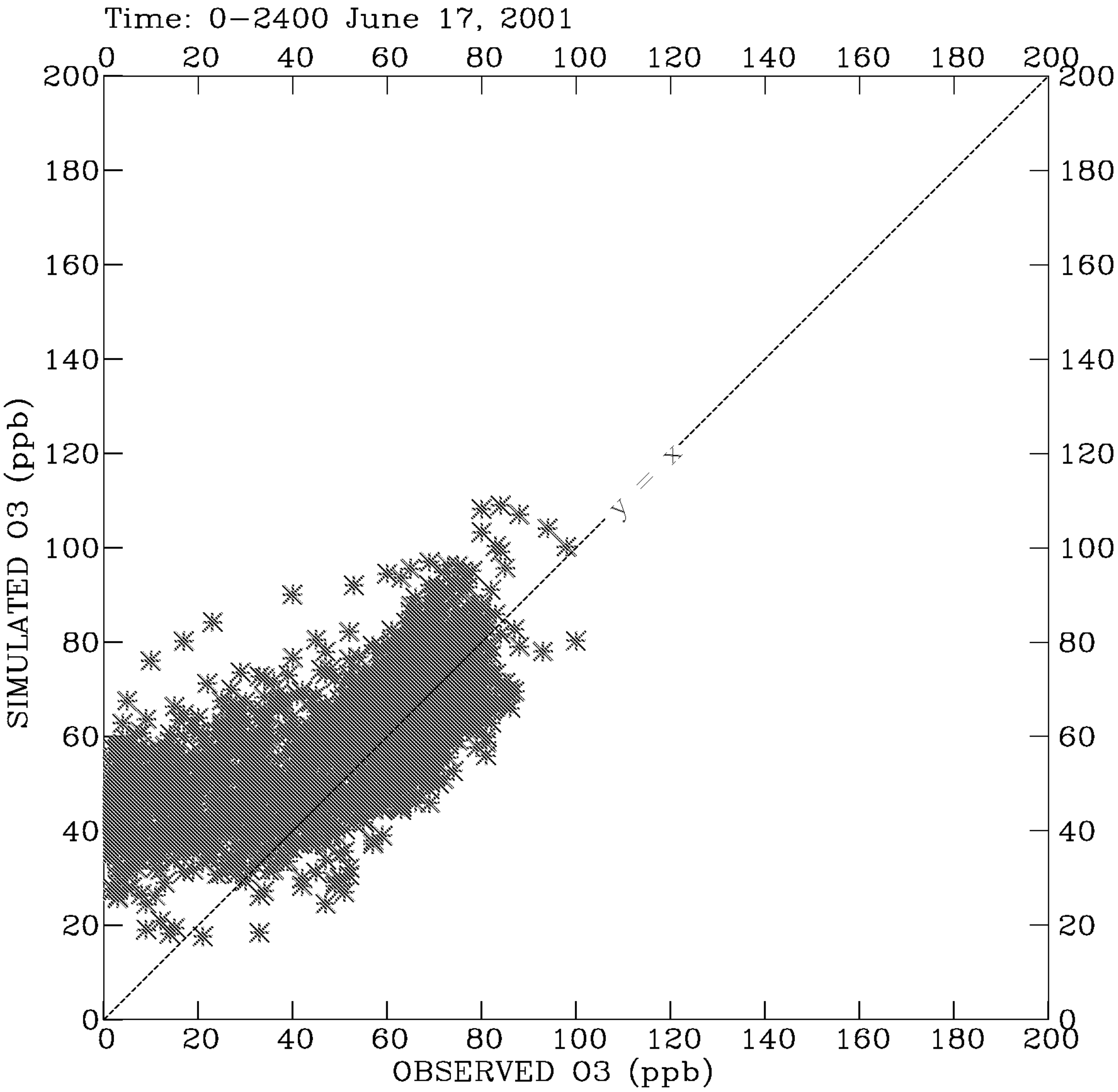
Figure 6-8a.
Scatter Plot: June 16, 2001

Time: 0-2400 June 16, 2001



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS-Run06r
Grid ff3

Figure 6-8b.
Scatter Plot: June 17, 2001



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run06r
Grid ff3

Figure 6-8c.
Scatter Plot: June 18, 2001

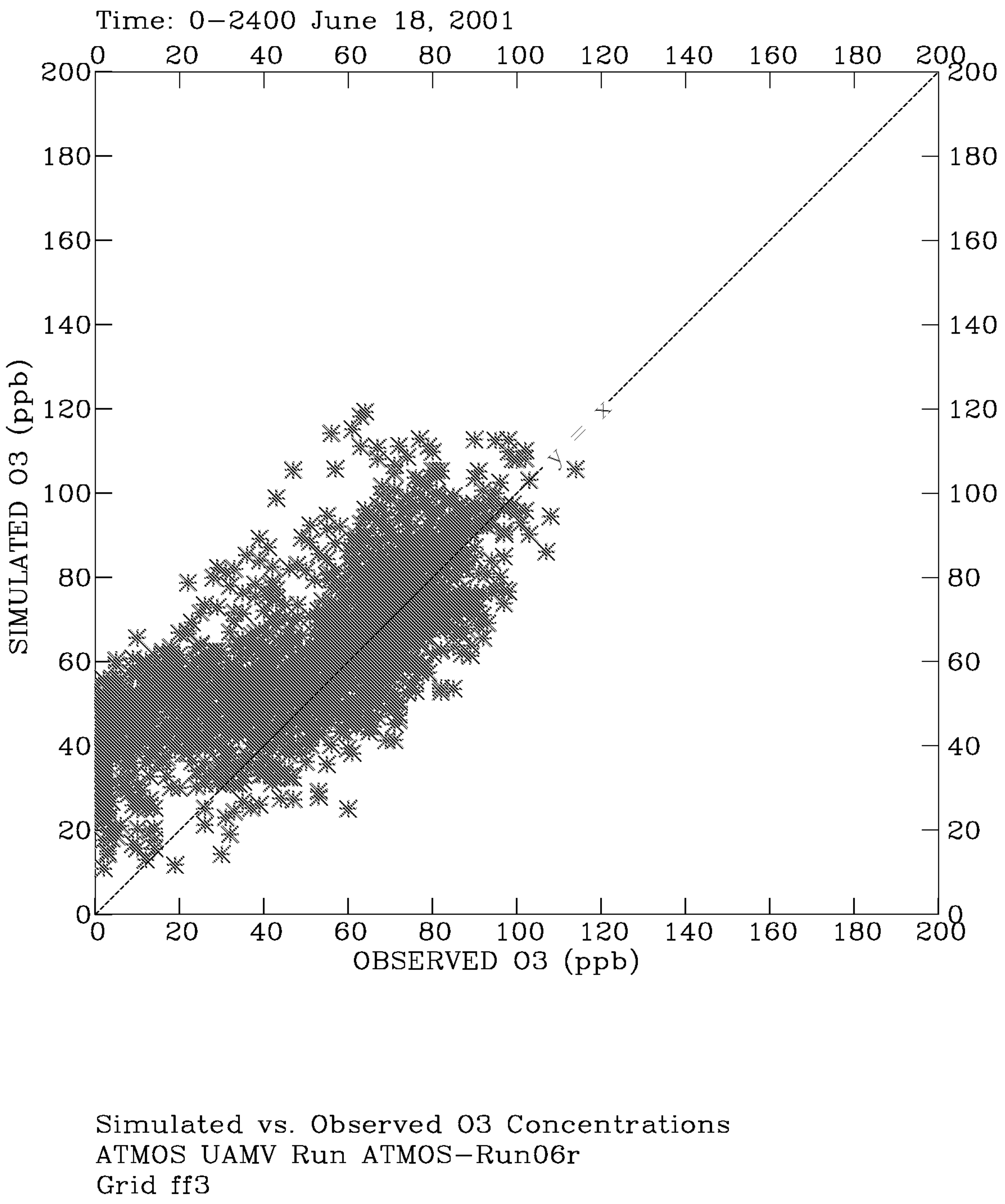
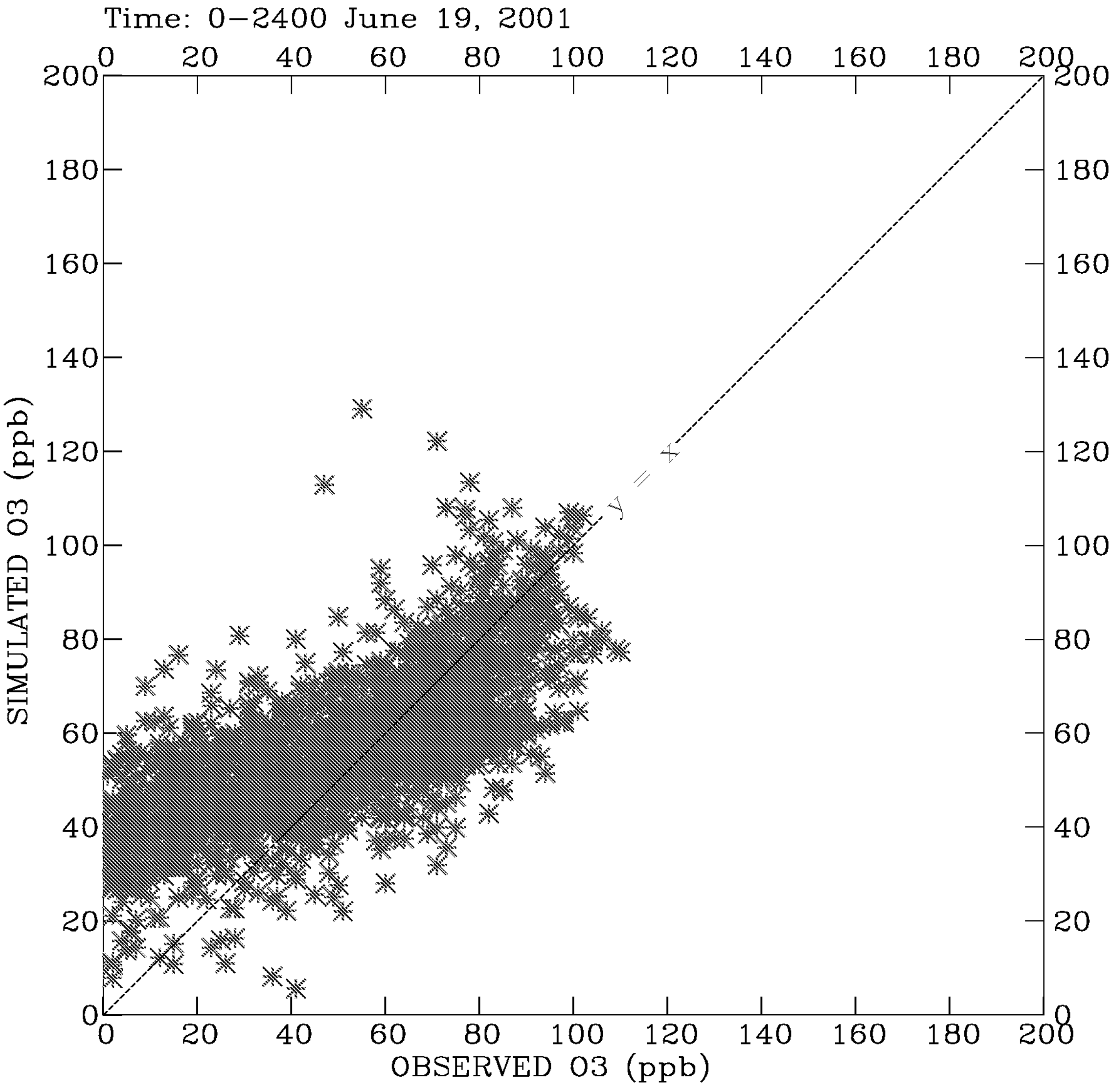


Figure 6-8d.
Scatter Plot: June 19, 2001



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run06r
Grid ff3

Figure 6-8e.
Scatter Plot: June 20, 2001

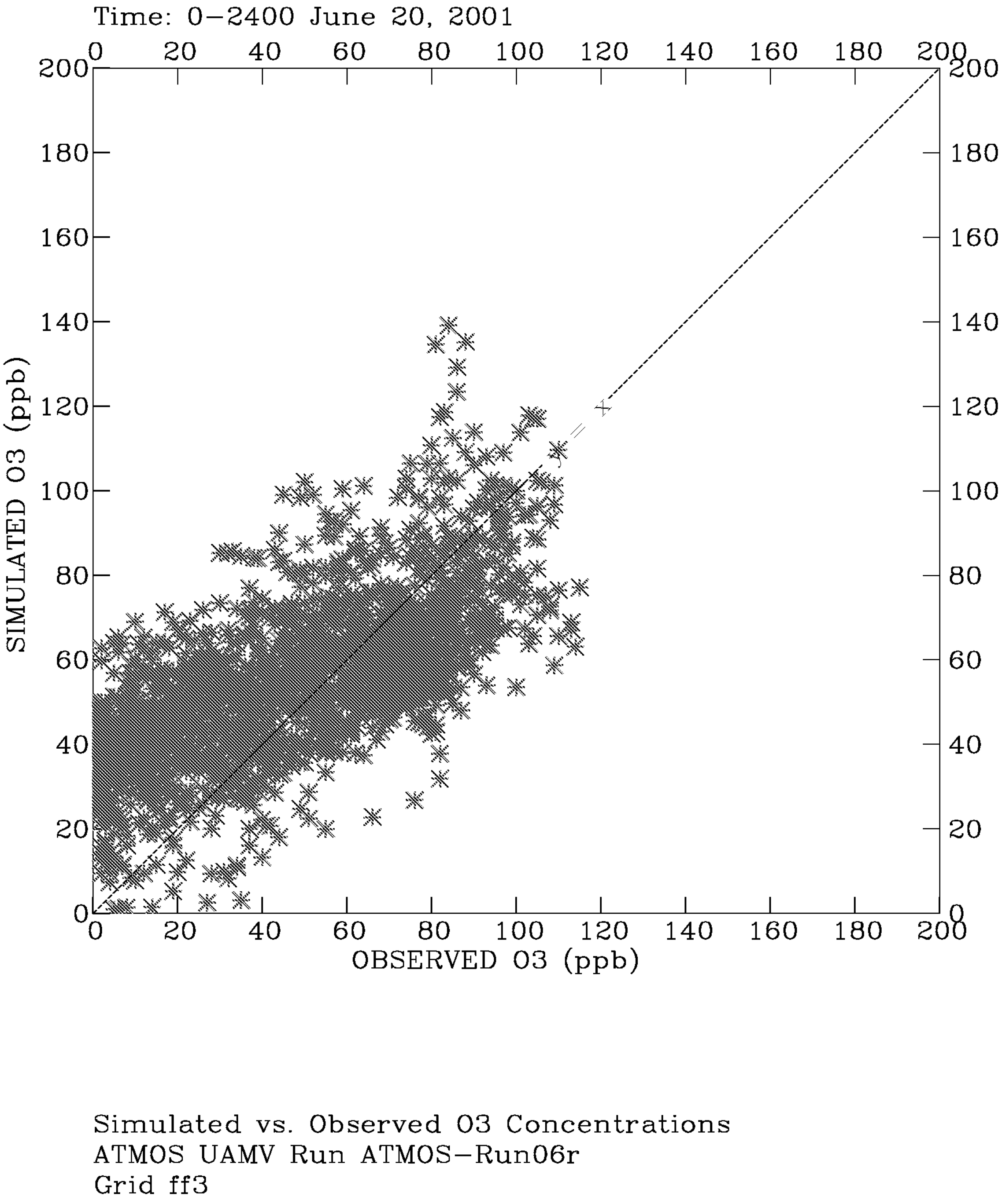
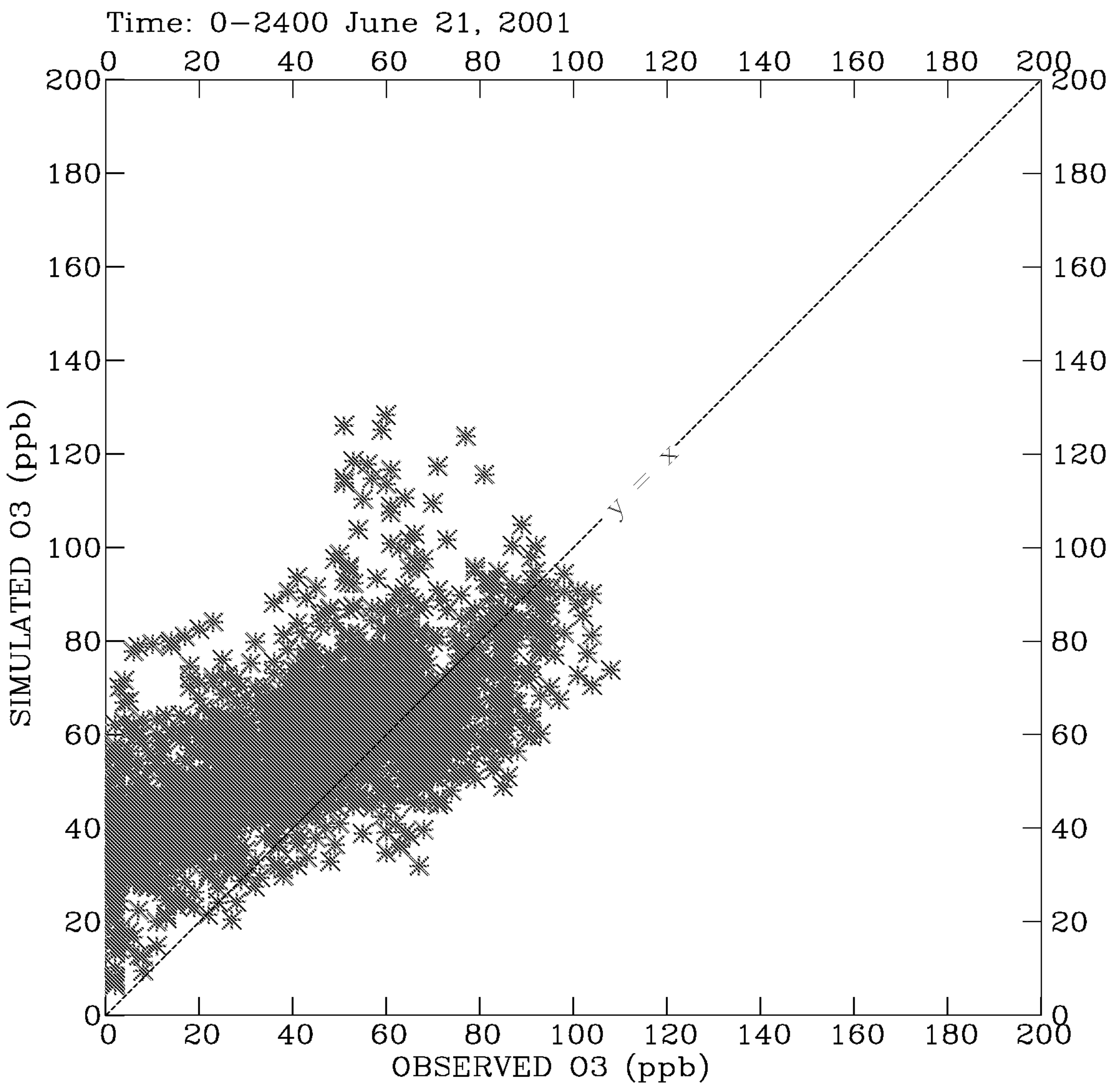
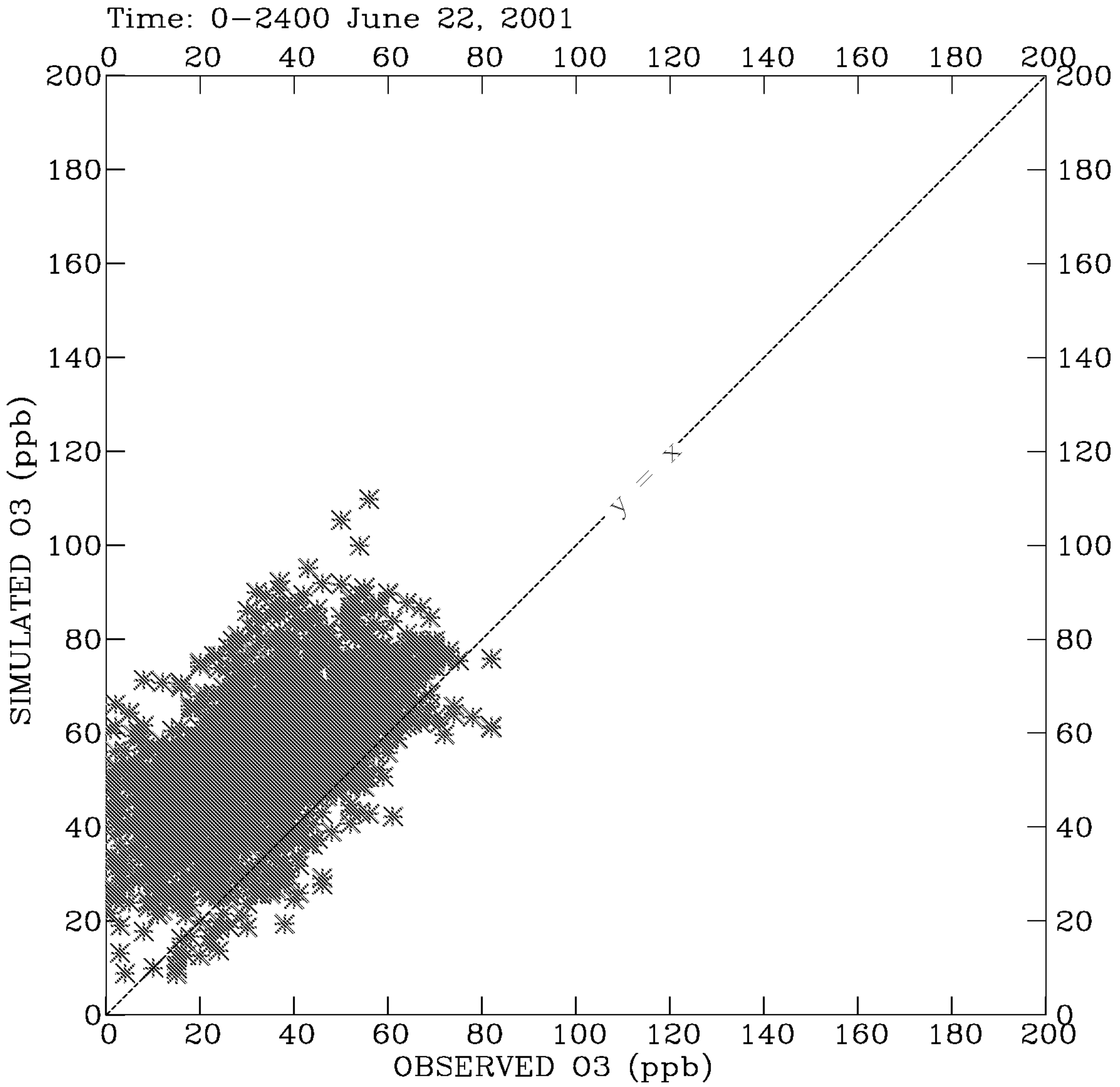


Figure 6-8f.
Scatter Plot: June 21, 2001



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run06r
Grid ff3

Figure 6-8g.
Scatter Plot: June 22, 2001



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS–Run06r
Grid ff3

**Figure 6-9a.
Daily Maximum 1-Hour Ozone, Grid 1,
July 4, 2002**

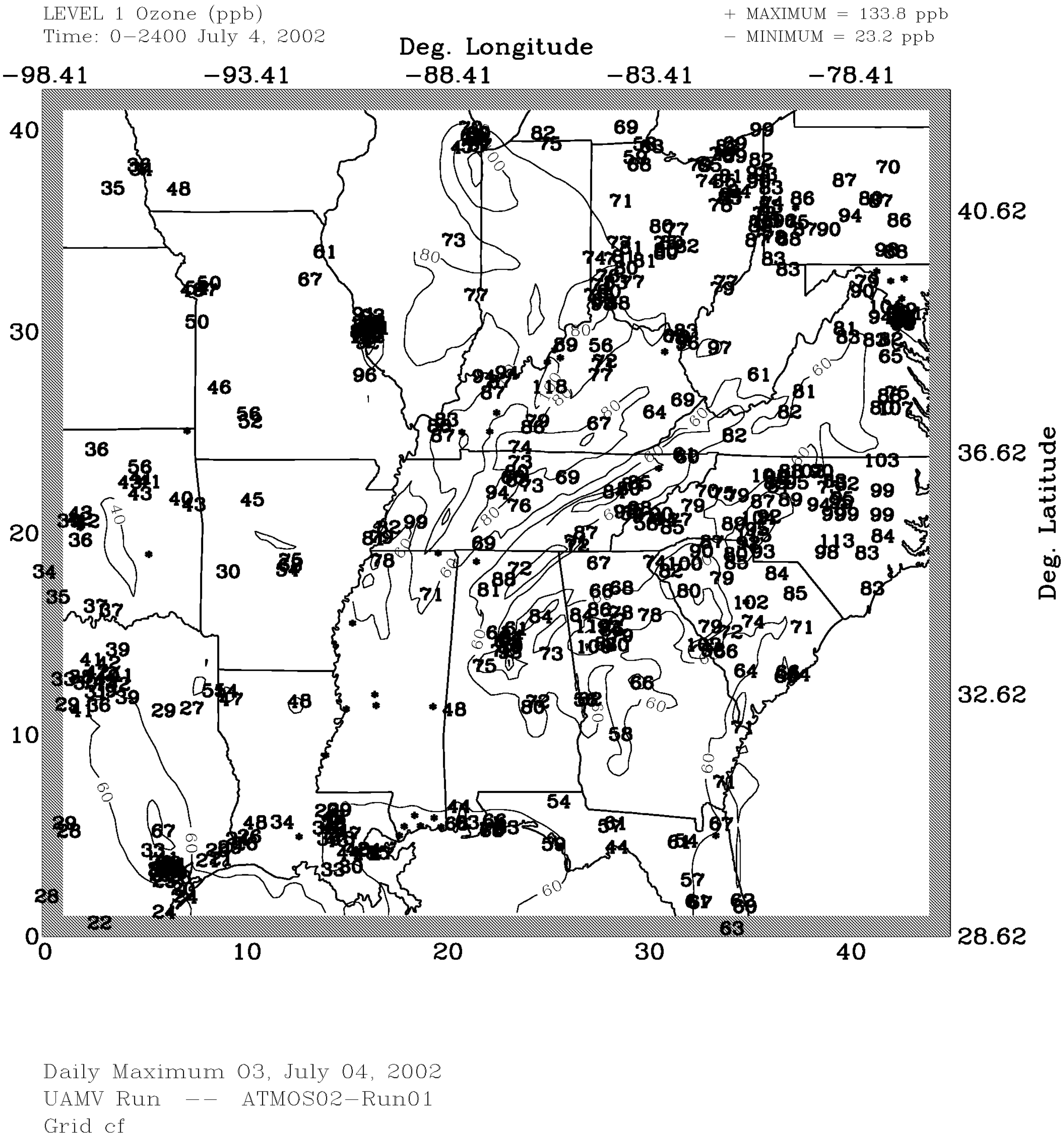


Figure 6-9b.
Daily Maximum 1-Hour Ozone, Grid 1,
July 5, 2002

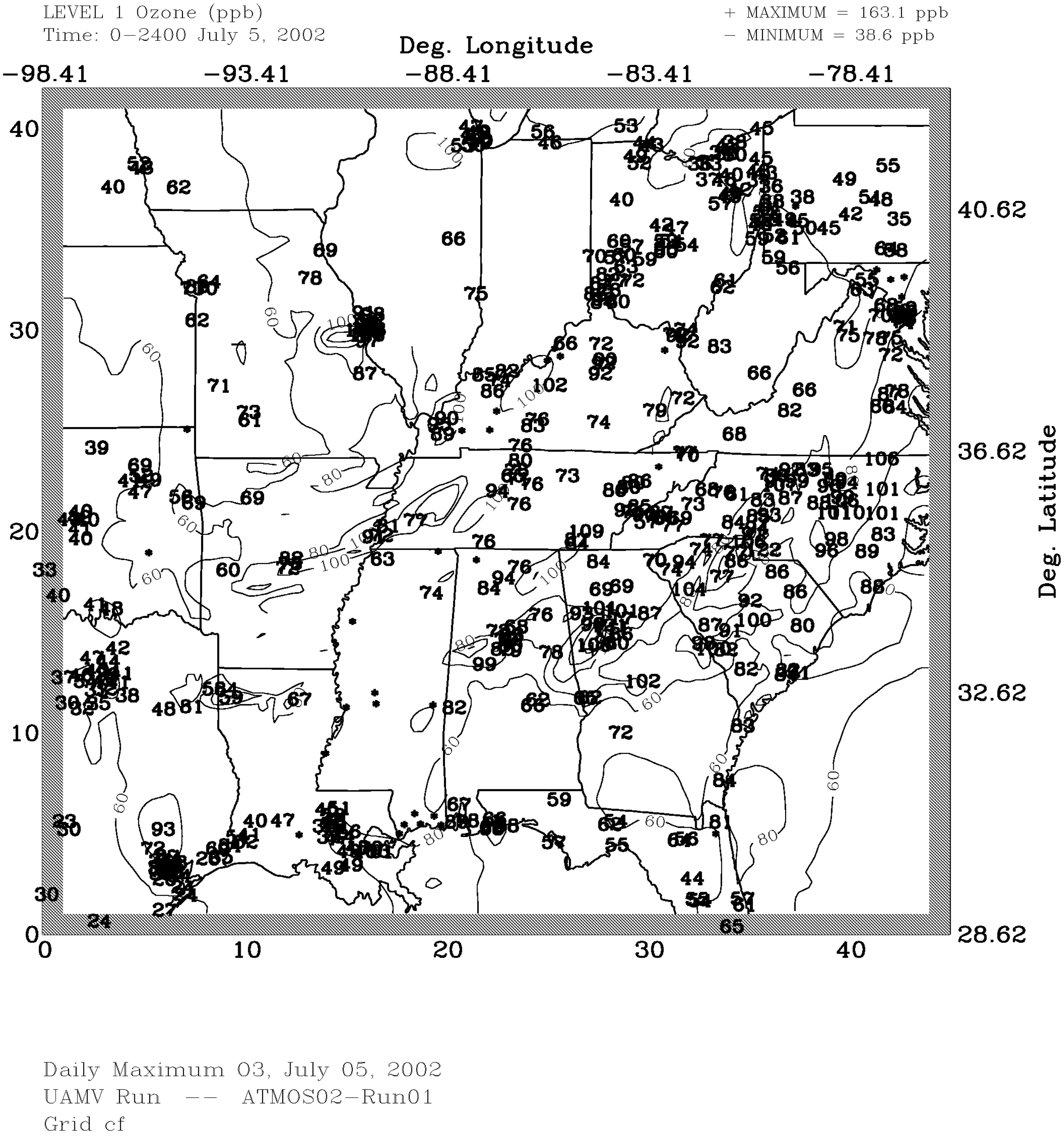


Figure 6-9c.
Daily Maximum 1-Hour Ozone, Grid 1,
July 6, 2002

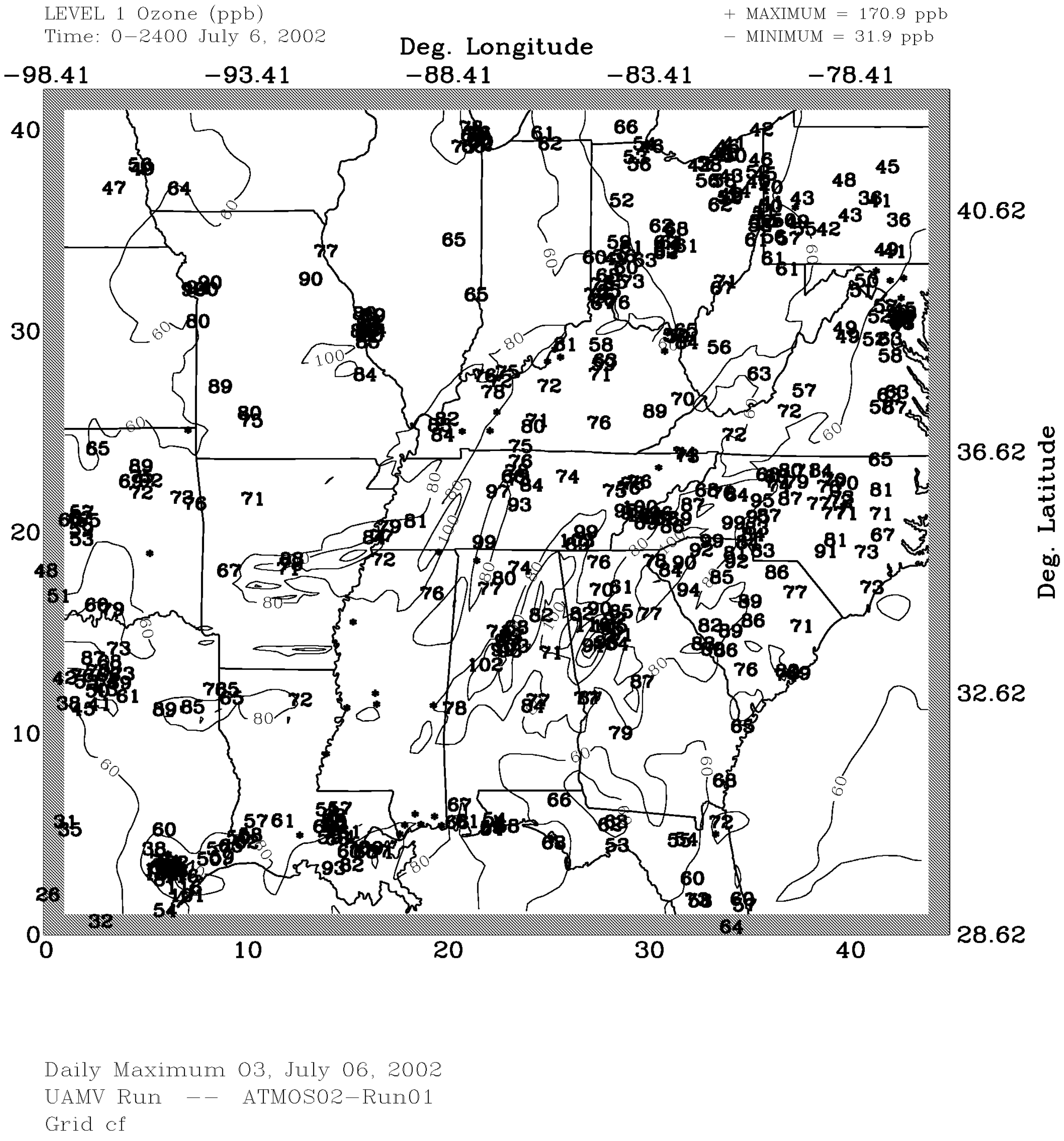
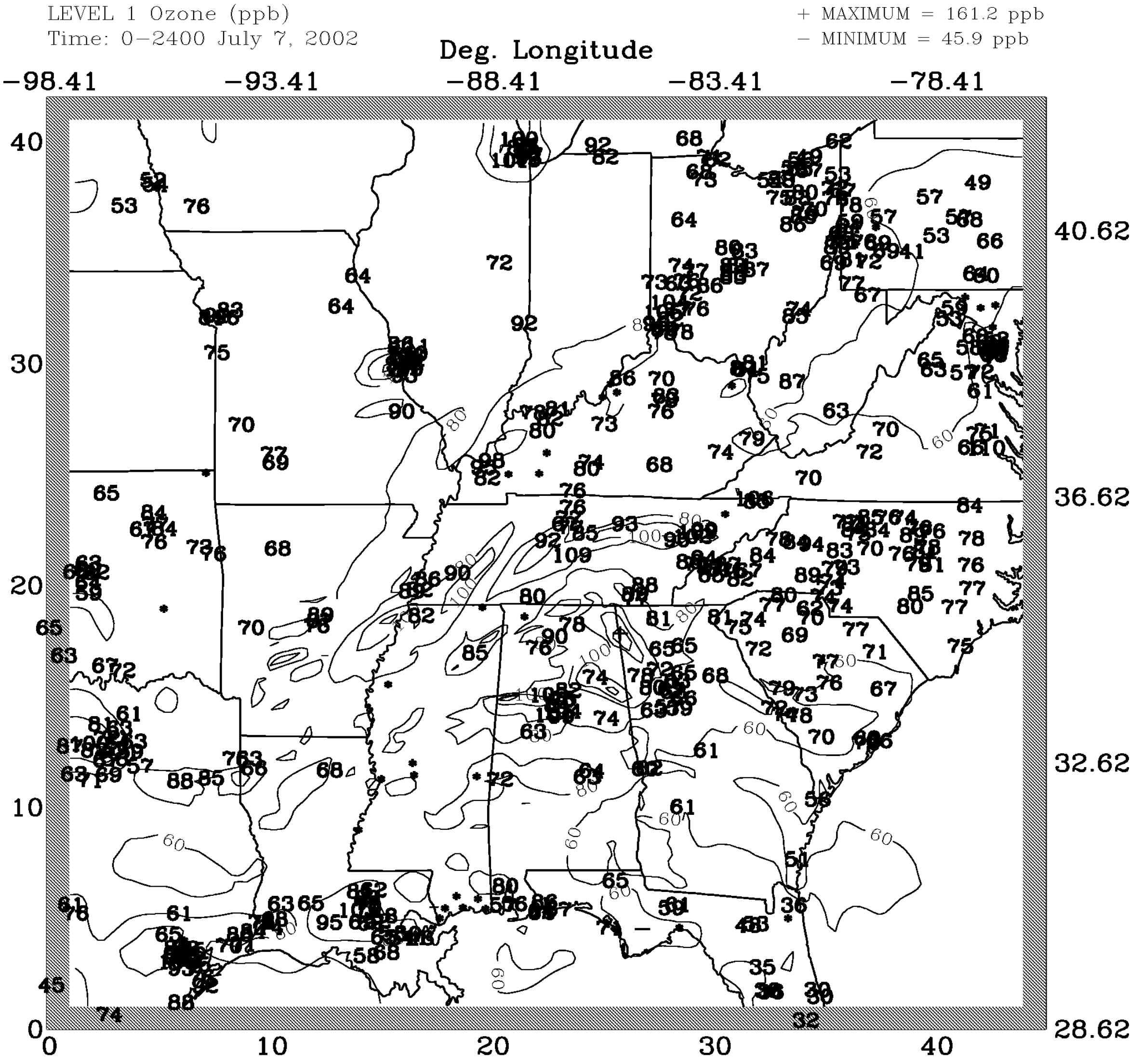


Figure 6-9d.
Daily Maximum 1-Hour Ozone, Grid 1,
July 7, 2002



Daily Maximum O3, July 07, 2002
UAMV Run -- ATMOS02–Run01
Grid cf

**Figure 6-9e.
Daily Maximum 1-Hour Ozone, Grid 1,
July 8, 2002**

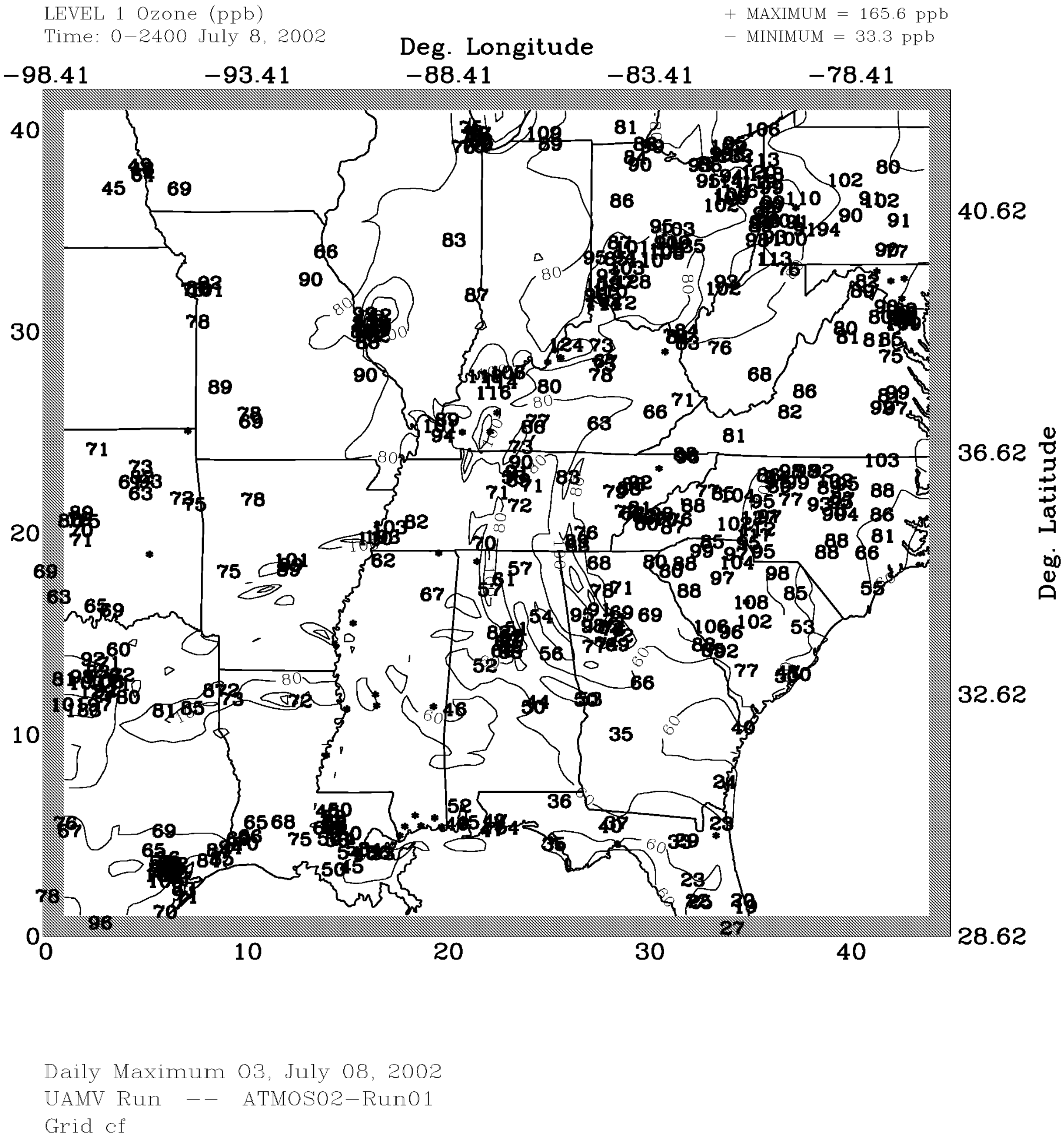


Figure 6-9f.
Daily Maximum 1-Hour Ozone, Grid 1,
July 9, 2002

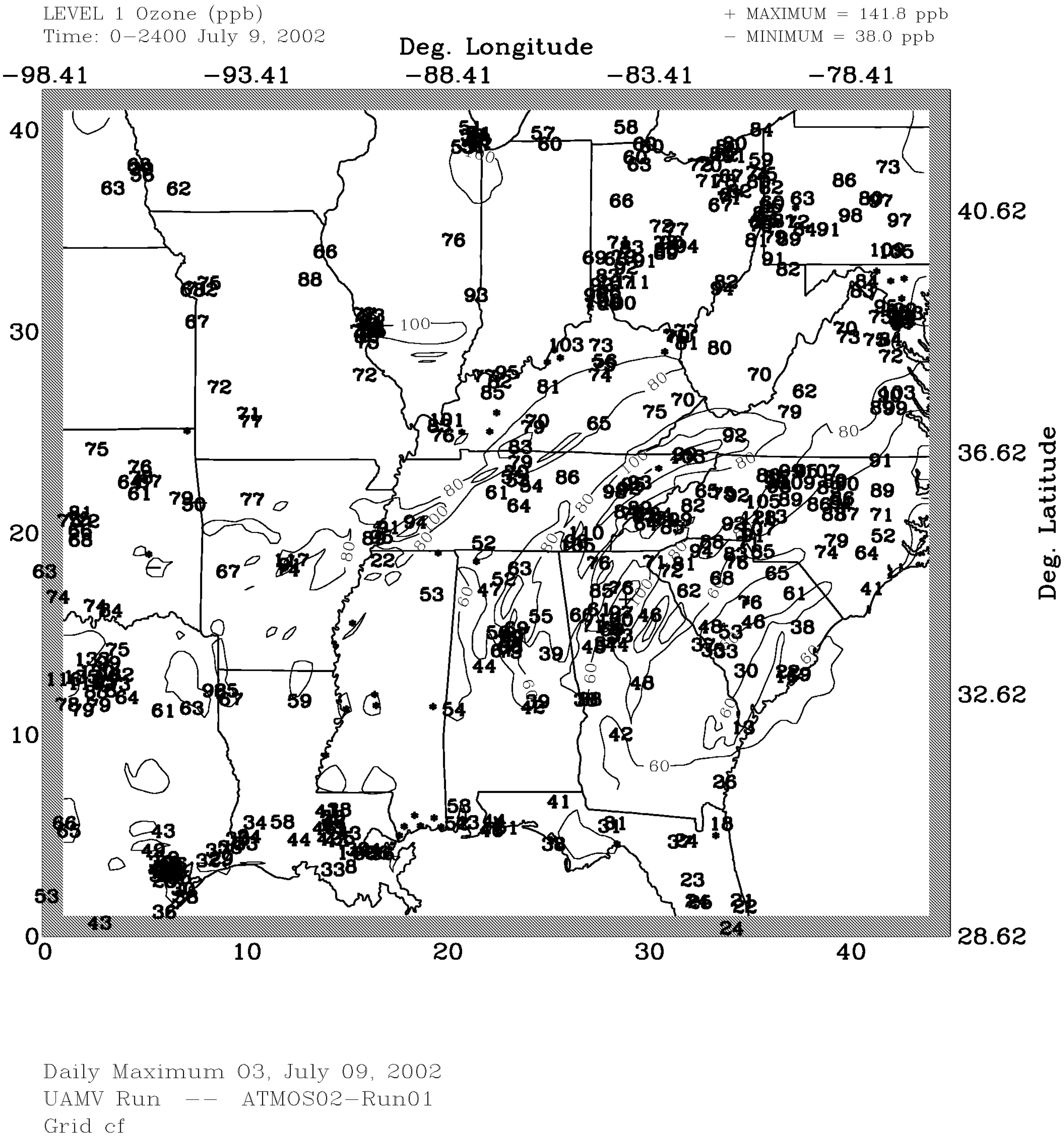


Figure 6-9g.
Daily Maximum 1-Hour Ozone, Grid 1,
July 10, 2002

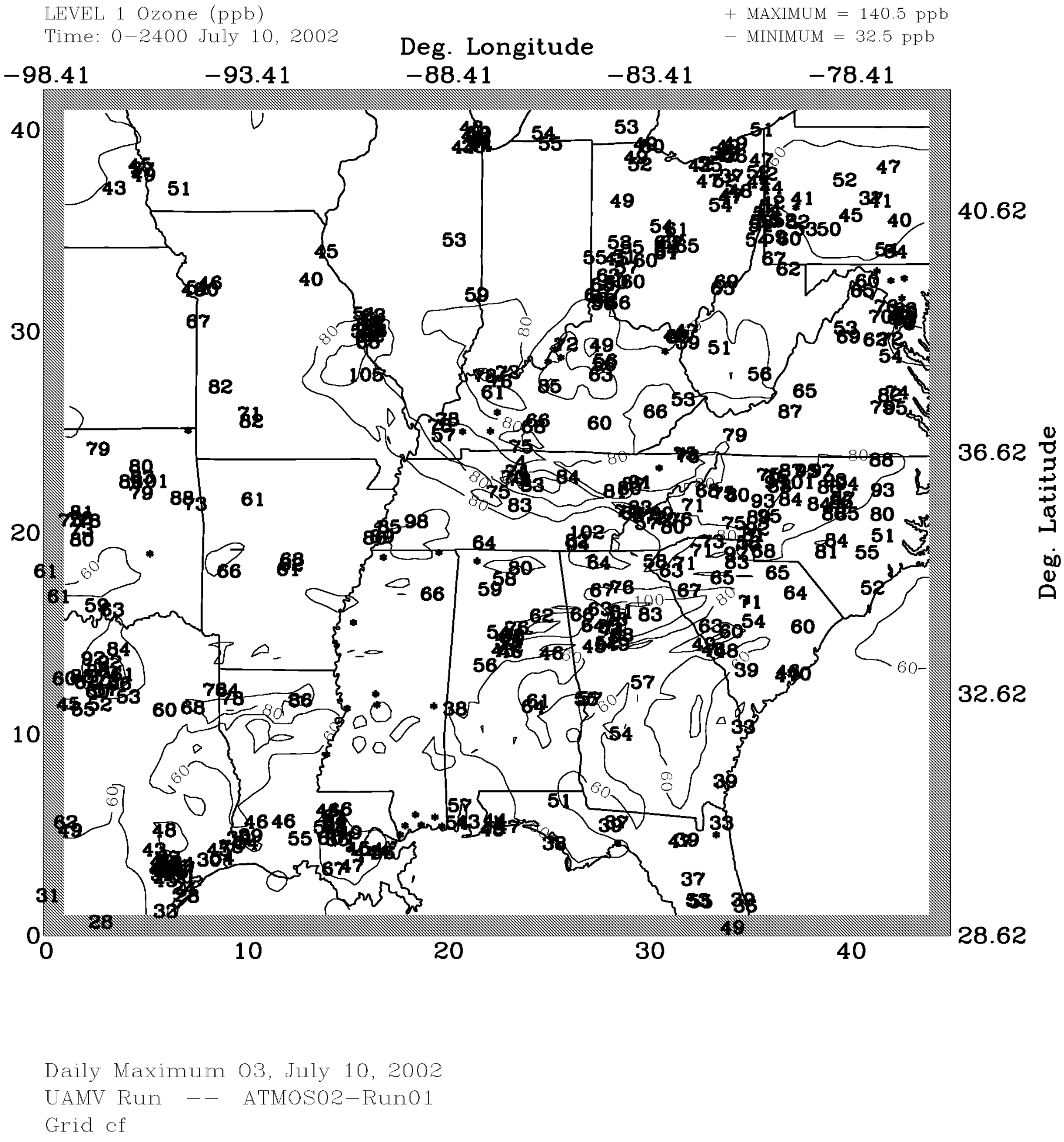


Figure 6-10a.
Daily Maximum 1-Hour Ozone, Grid 3
July 4, 2002

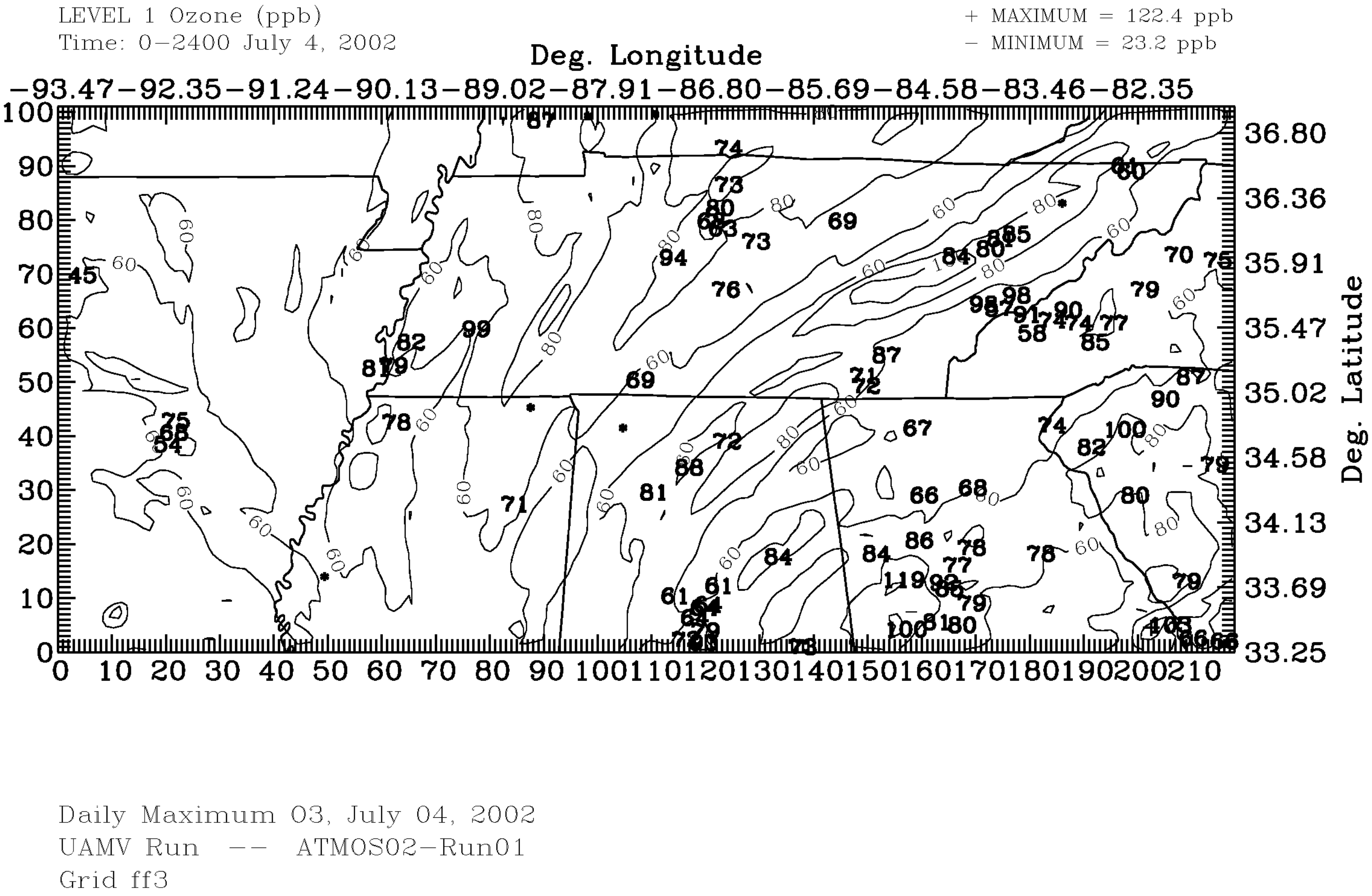


Figure 6-10b.
Daily Maximum 1-Hour Ozone, Grid 3
July 5, 2002

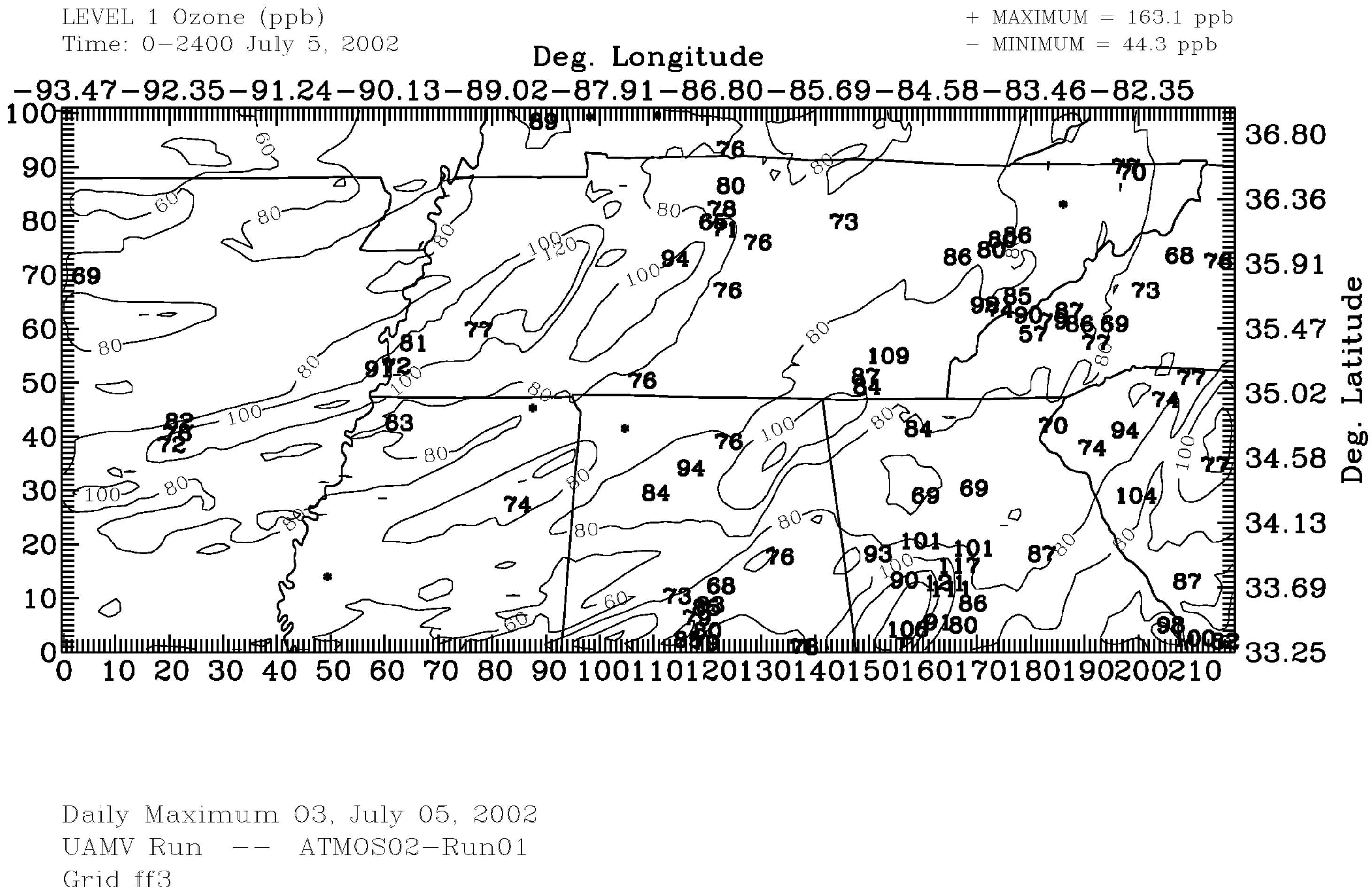


**Figure 6-10c.
Daily Maximum 1-Hour Ozone, Grid 3,
July 6, 2002**

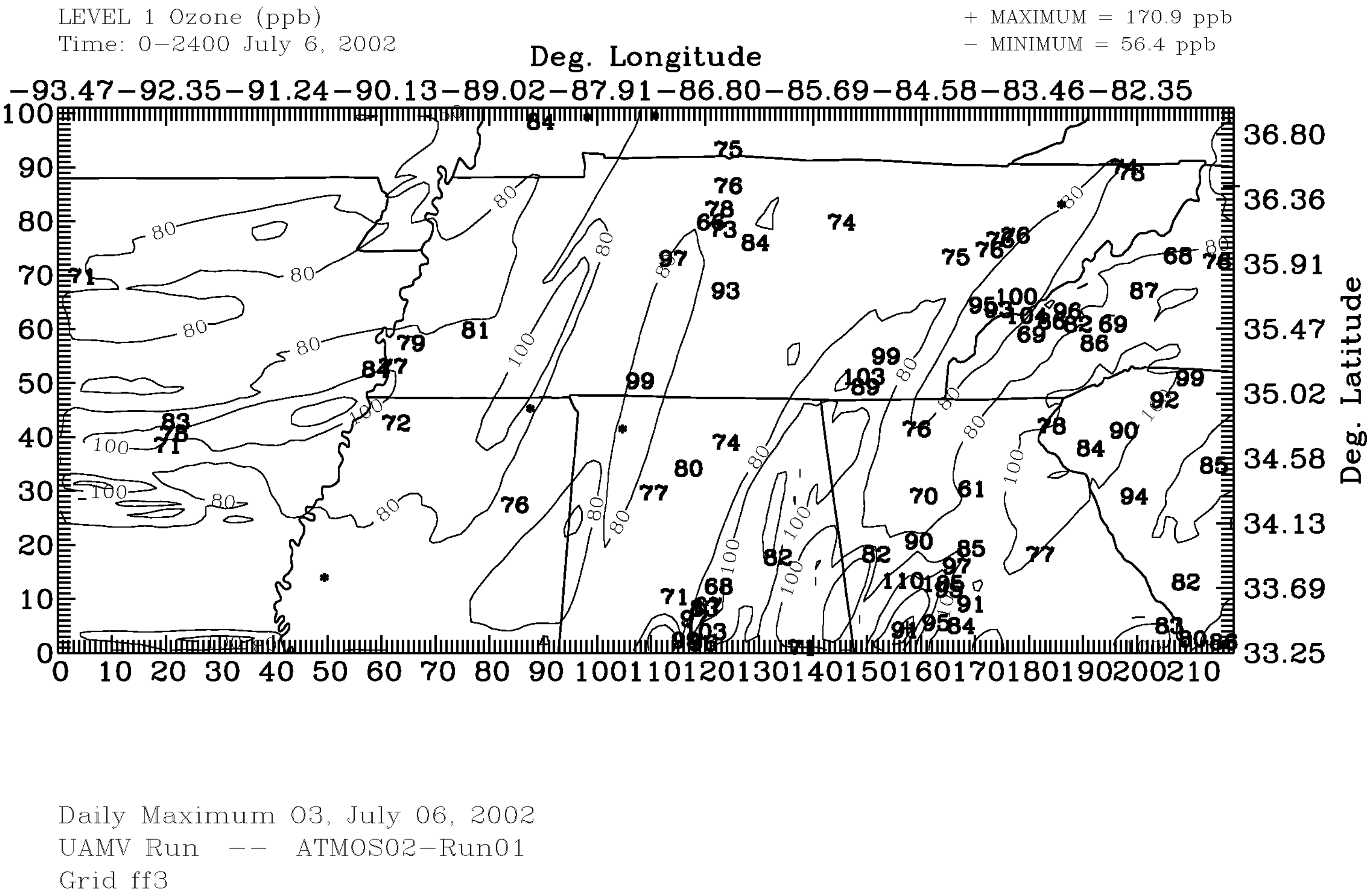


Figure 6-10d.
Daily Maximum 1-Hour Ozone, Grid 3,
July 7, 2002

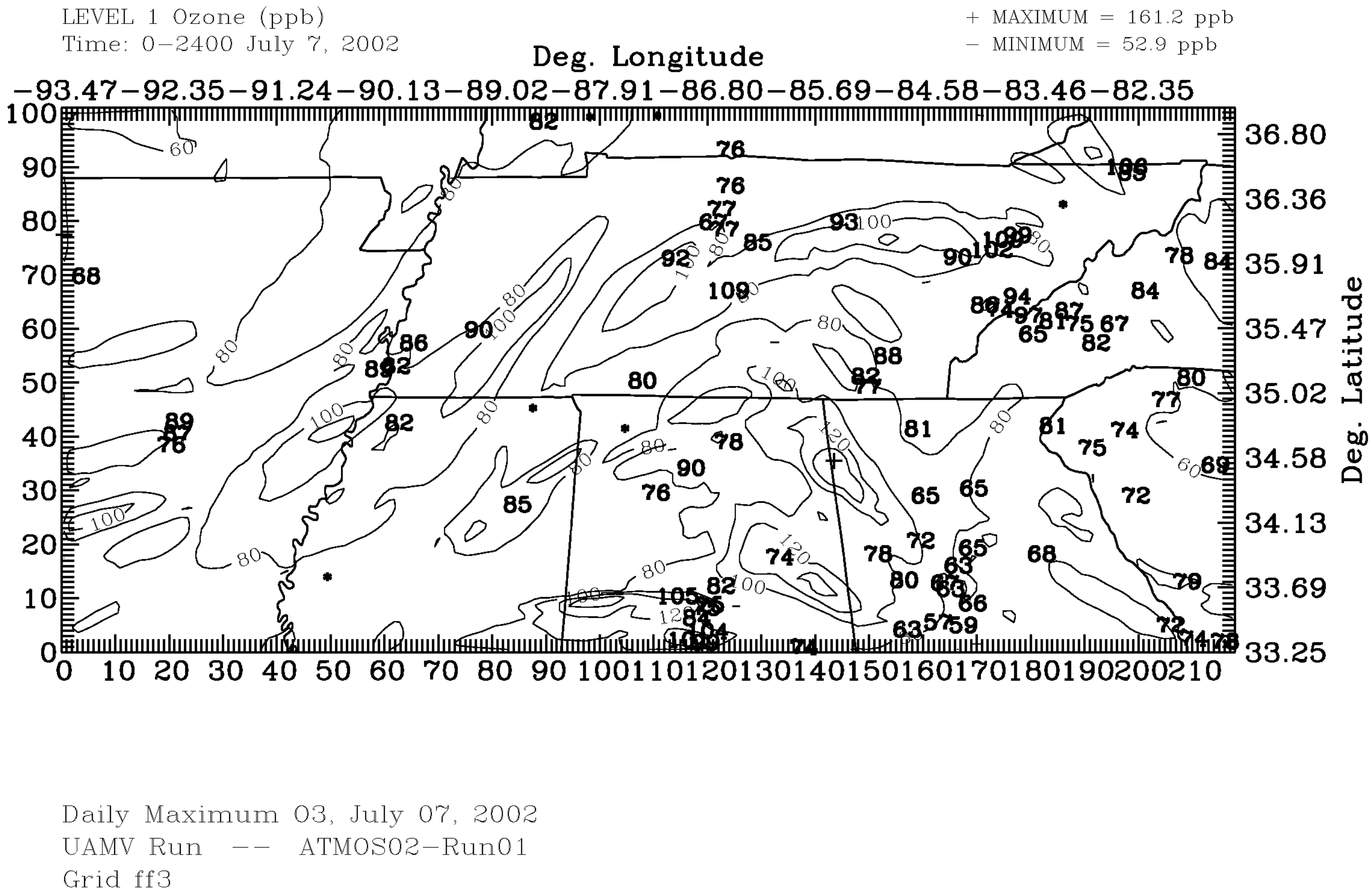


Figure 6-10e.
Daily Maximum 1-Hour Ozone, Grid 3,
July 8, 2002

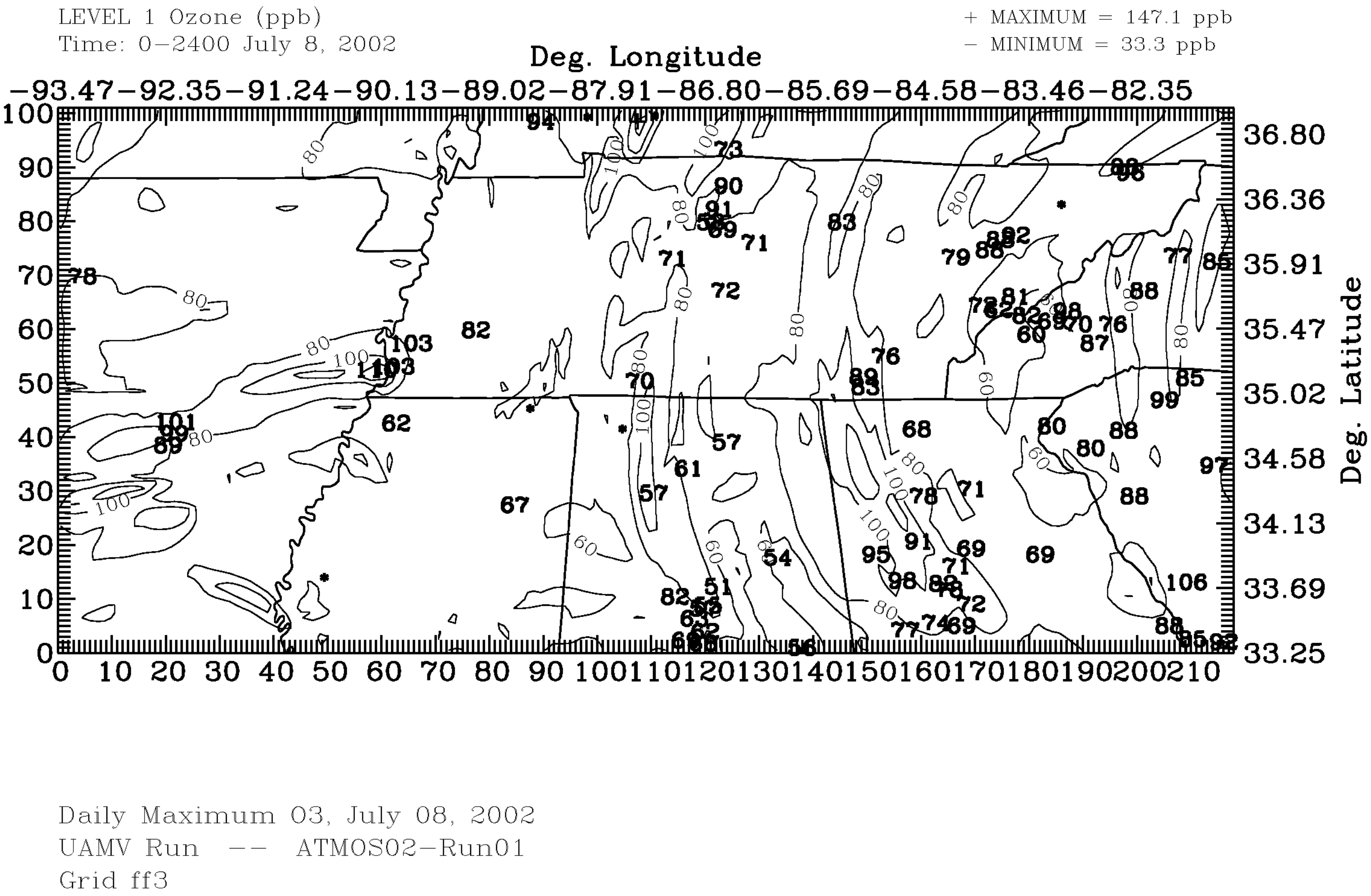
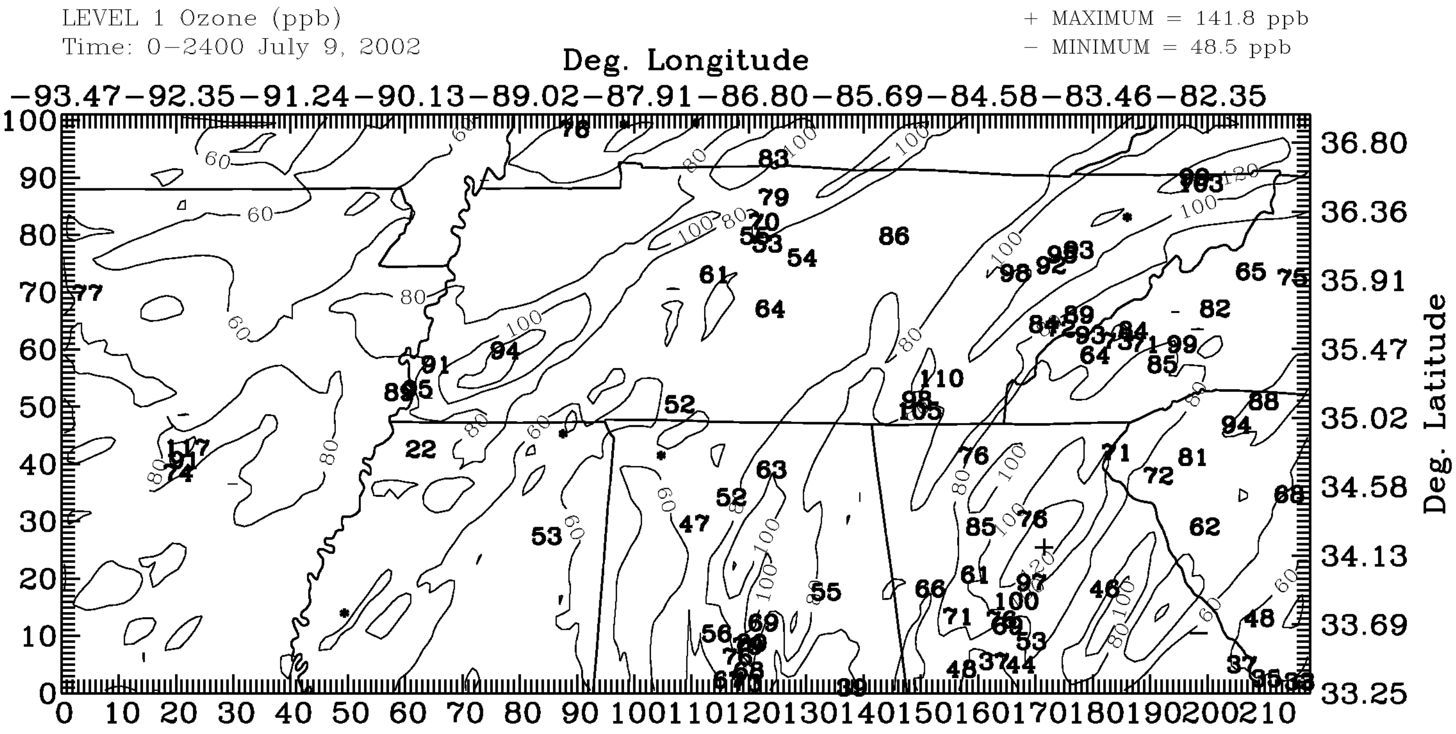


Figure 6-10f.
Daily Maximum 1-Hour Ozone, Grid 3,
July 9, 2002



Daily Maximum O3, July 09, 2002
UAMV Run -- ATMOS02–Run01
Grid ff3

Figure 6-10g.
Daily Maximum 1-Hour Ozone, Grid 3,
July 10, 2002

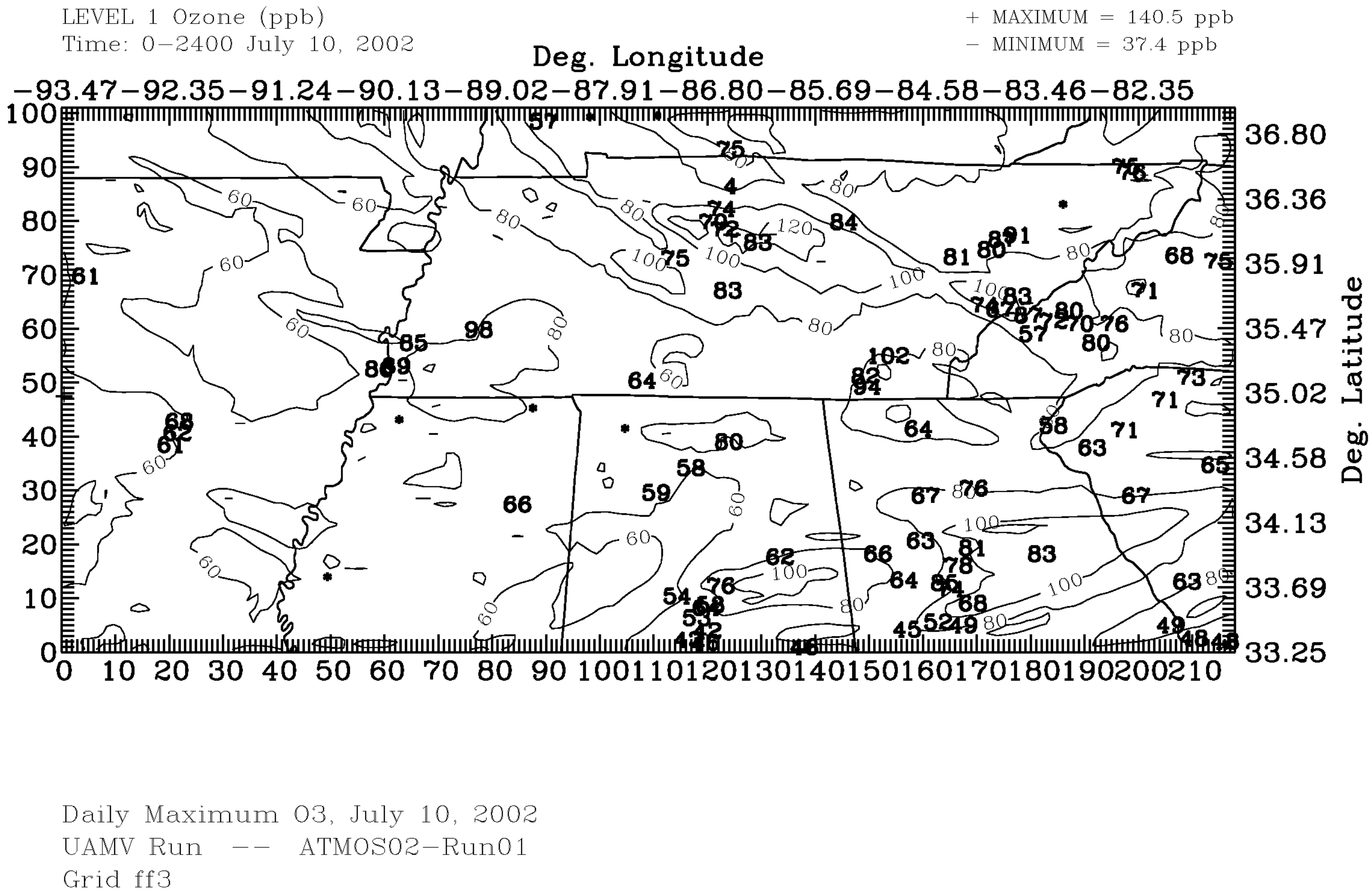


Figure 6-11a.
2001 Episode Time Series: Memphis EAC Area, July 4-7, 2002

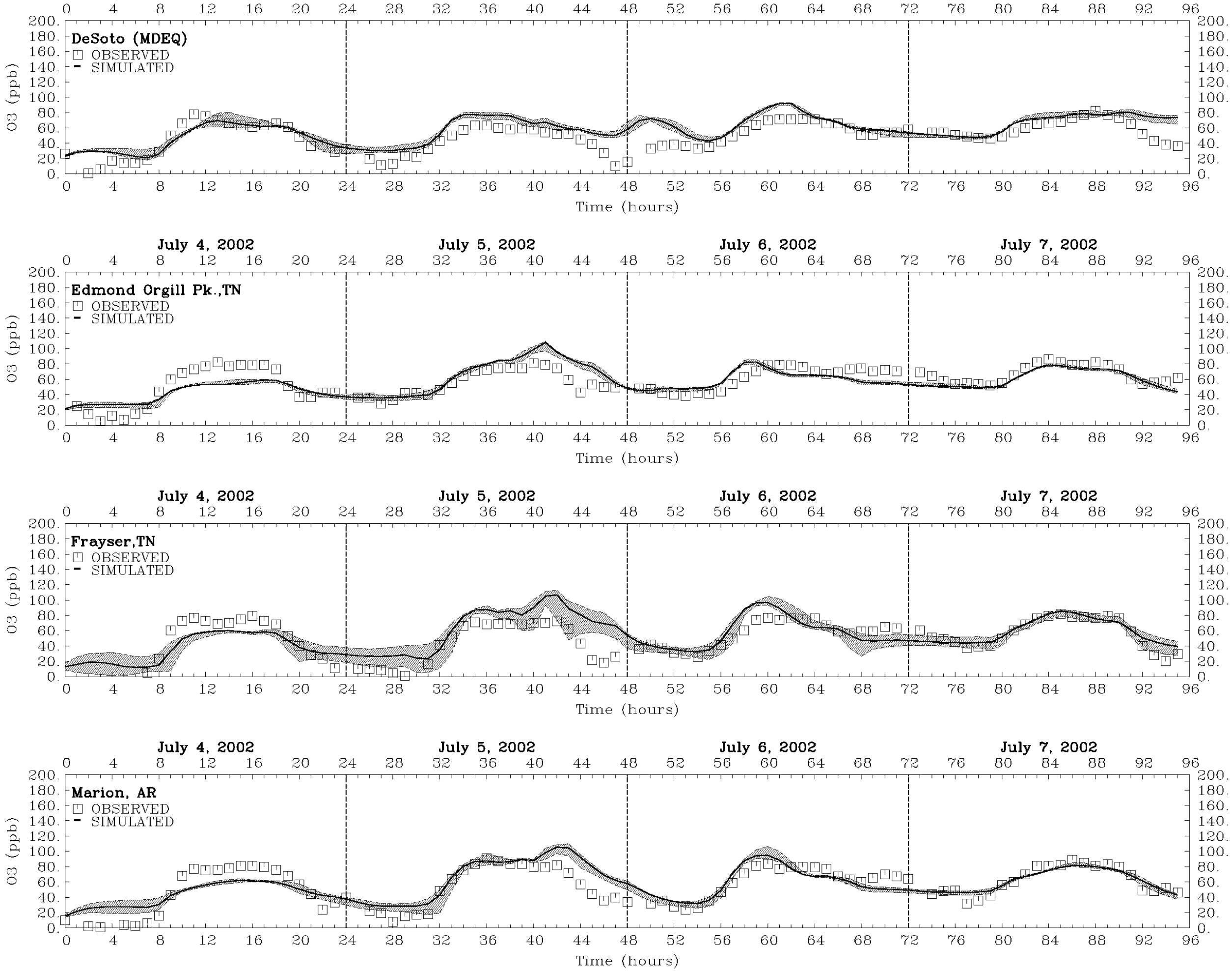


Figure 6-11b.
2001 Episode Time Series: Memphis EAC Area,
July 7-10, 2002

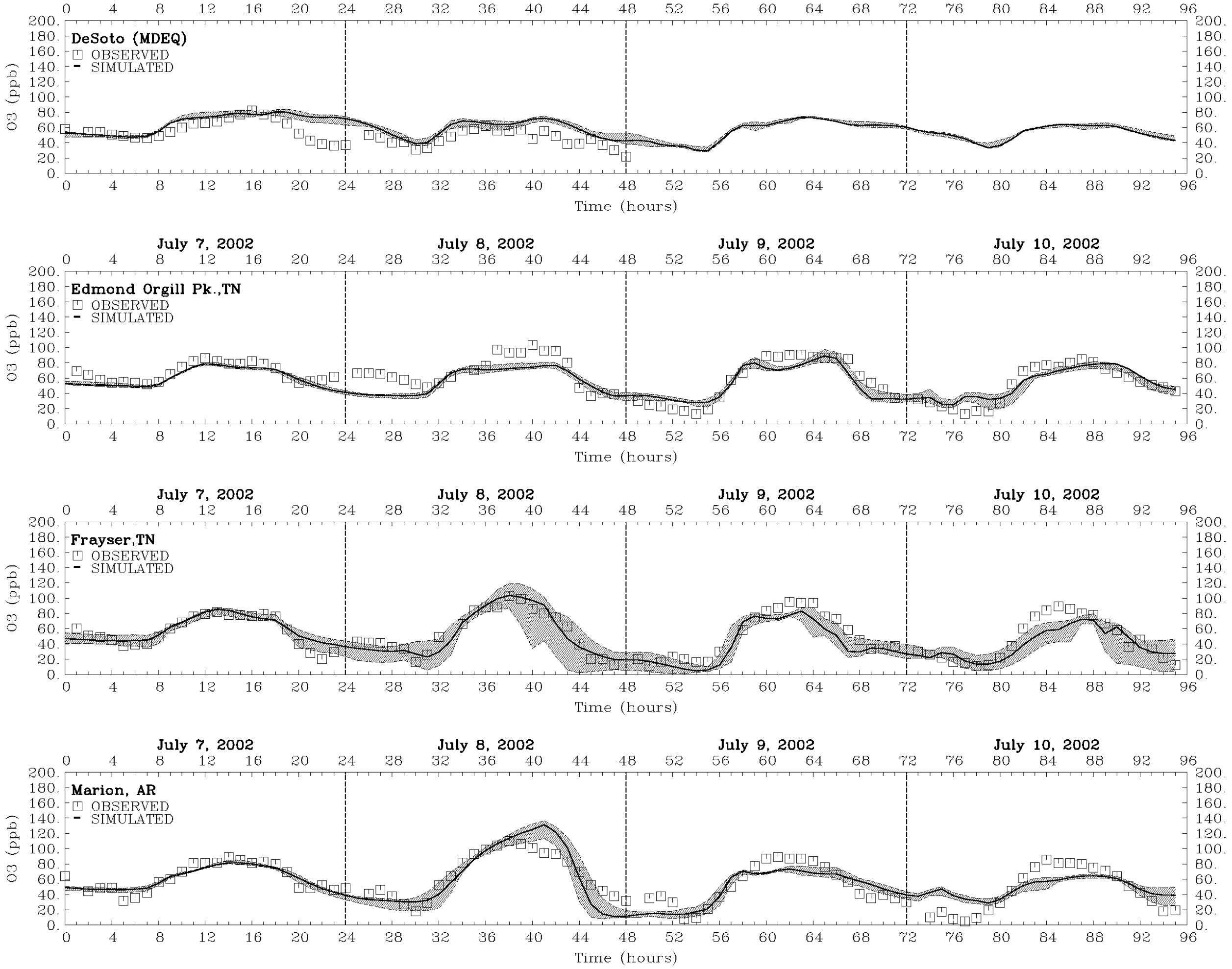


Figure 6-11c.
2001 Episode Time Series: Nashville EAC Area,
July 4-7, 2002

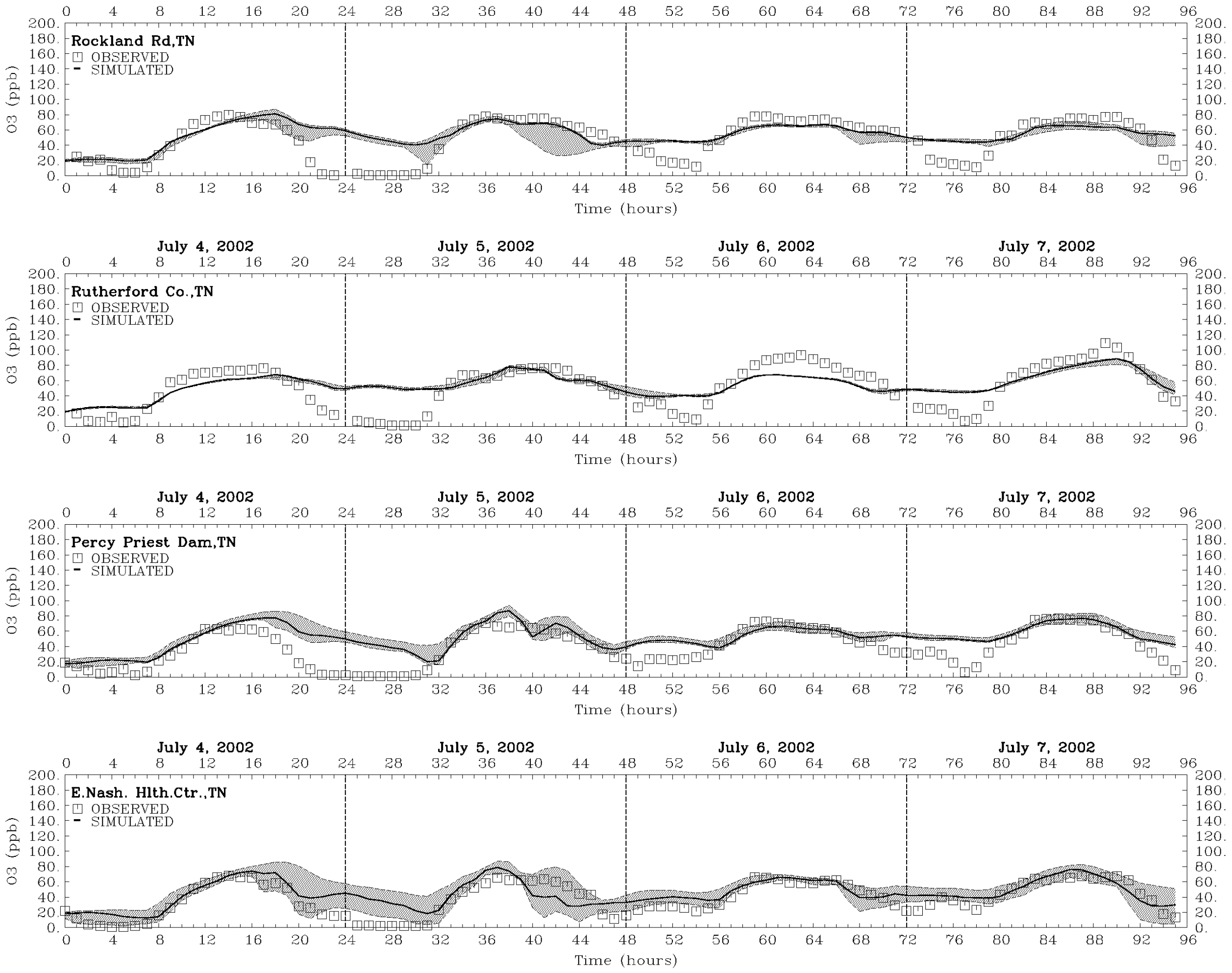


Figure 6-11d.
2001 Episode Time Series: Nashville EAC Area ***(continued)*****,**
July 4-7, 2002

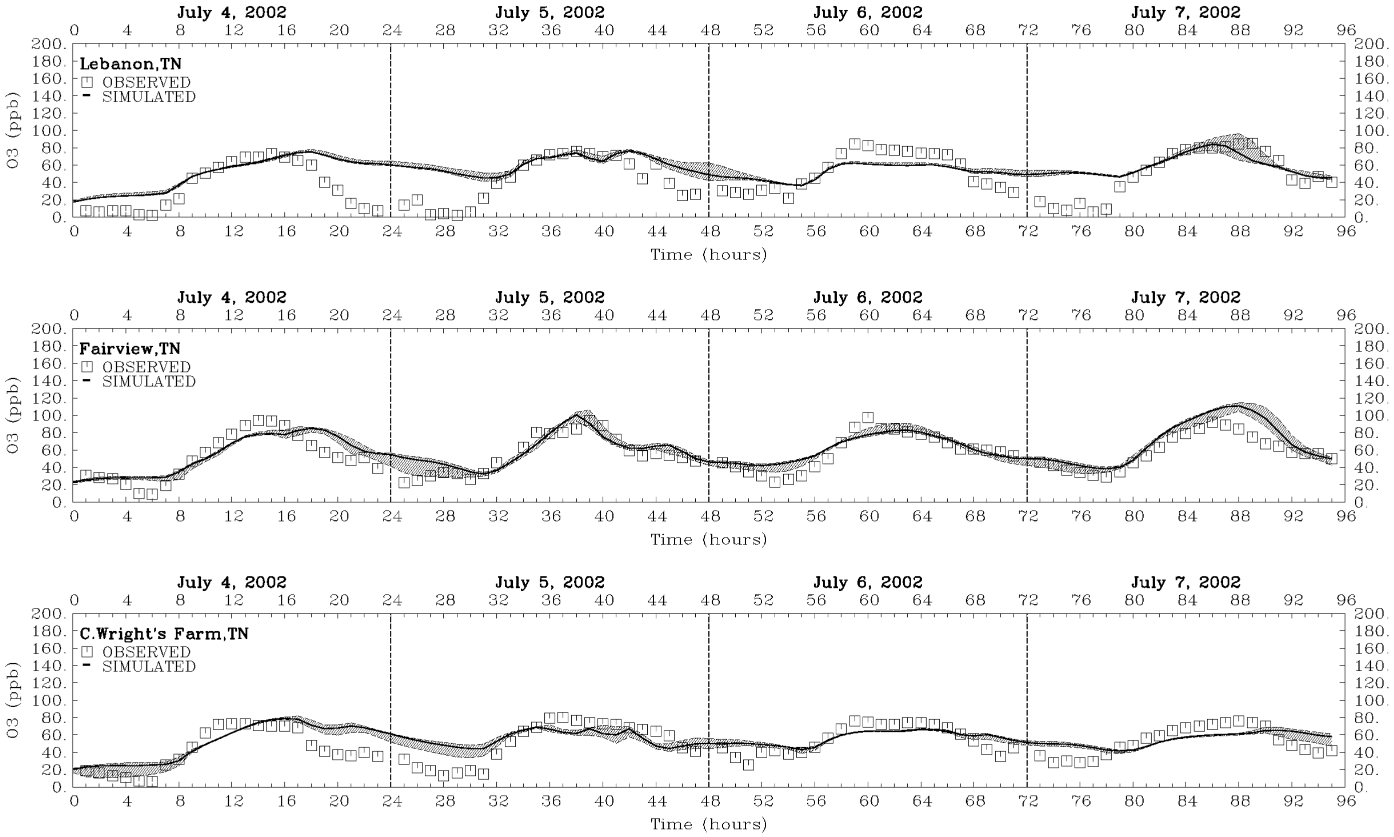


Figure 6-11e.
2001 Episode Time Series: Nashville EAC Area,
July 7-10, 2002

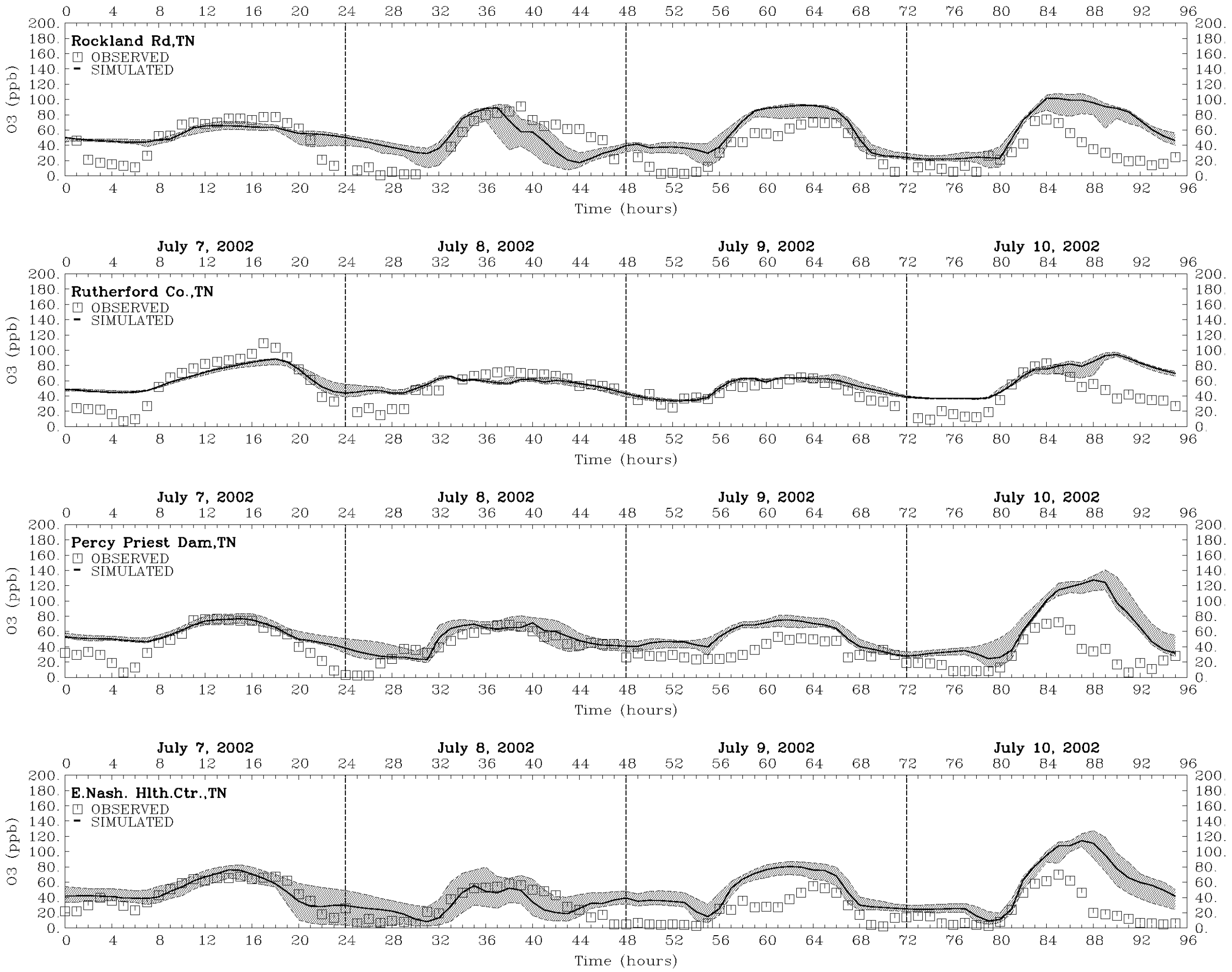


Figure 6-11f.
2001 Episode Time Series: Nashville EAC Area *(continued)*, July 7-10, 2002

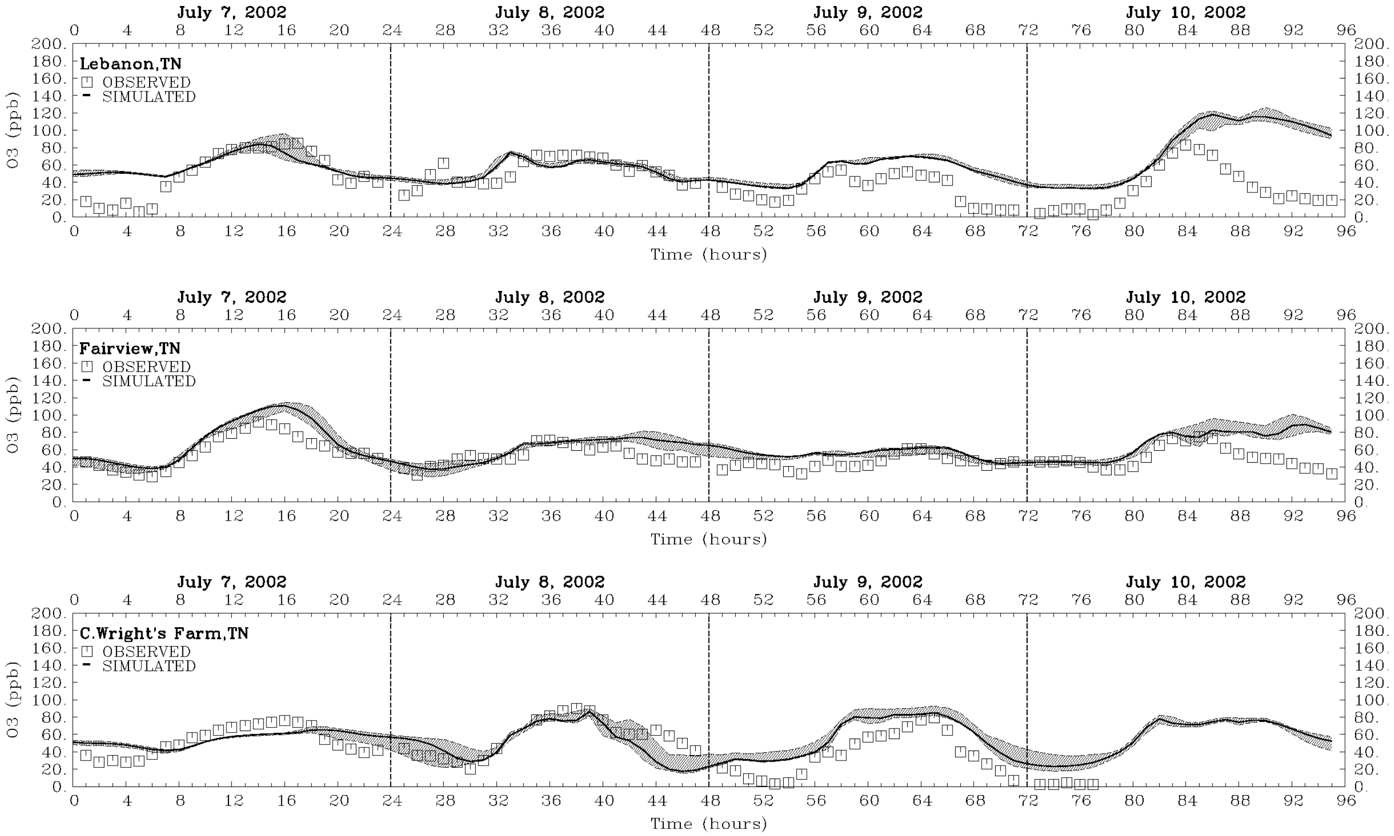


**Figure 6-11g.
2001 Episode Time Series: Knoxville EAC Area,
July 4-7, 2002**

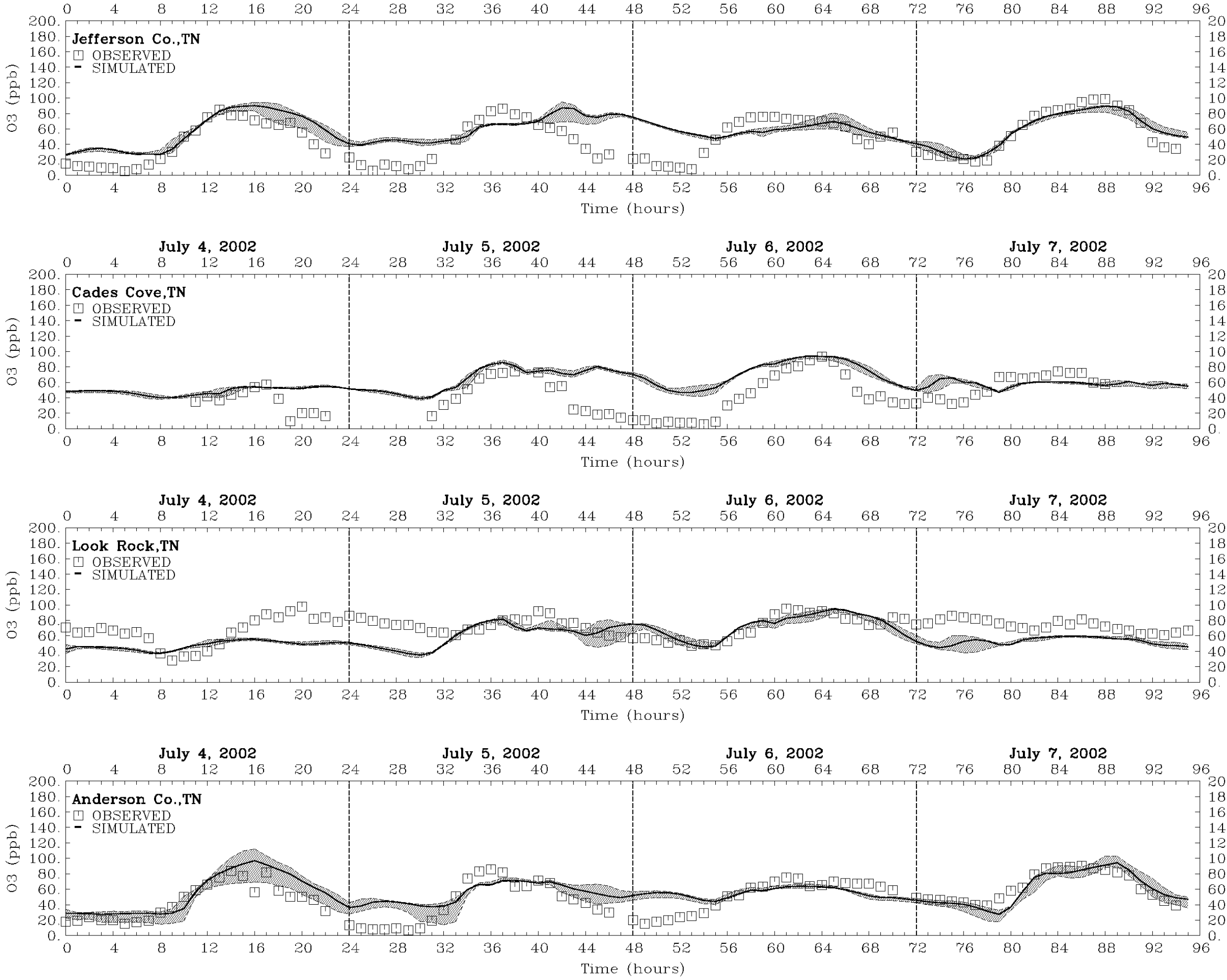


Figure 6-11h.
2001 Episode Time Series: Knoxville EAC Area *(continued)*,
July 4-7, 2002

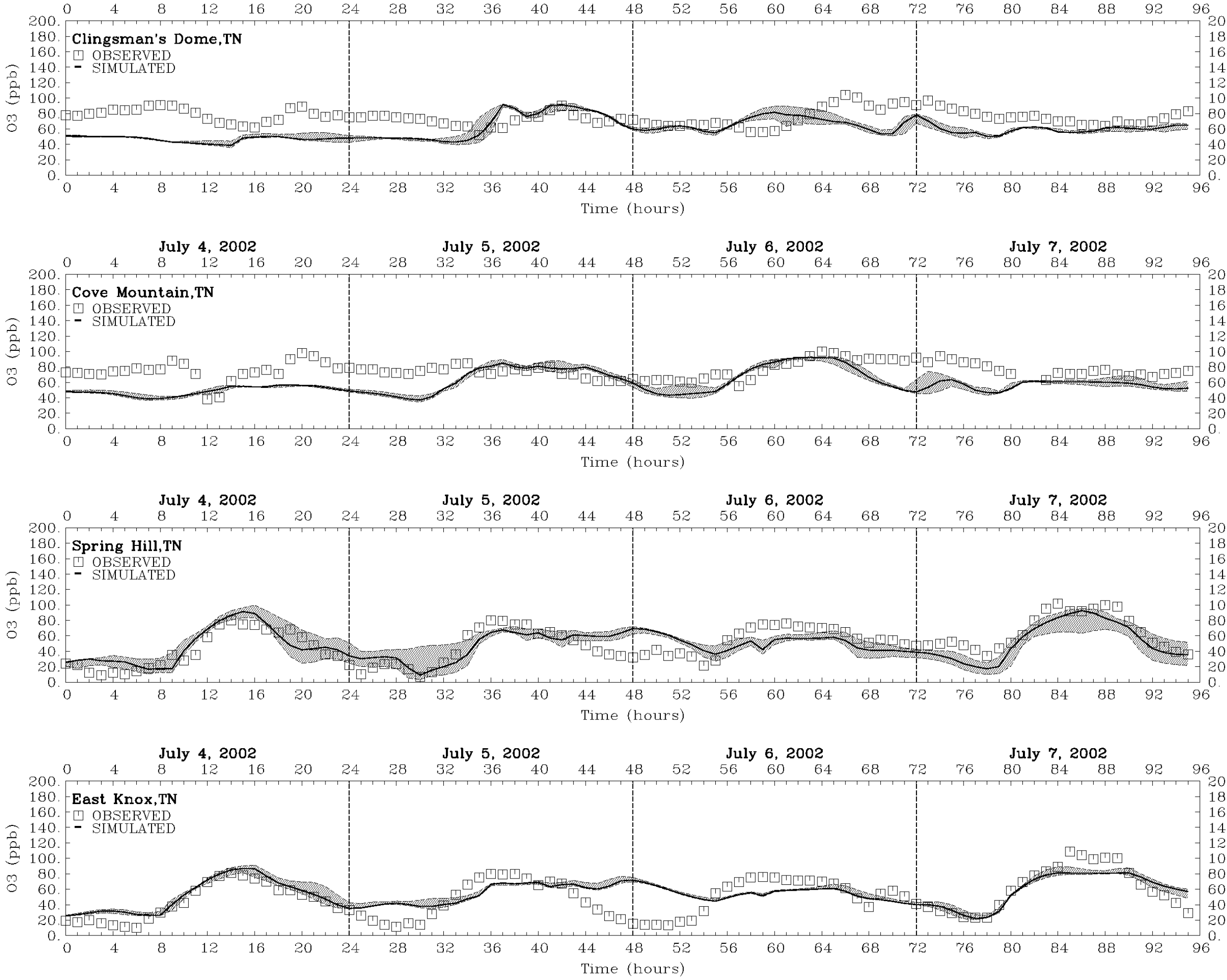


Figure 6-11i.
2001 Episode Time Series: Knoxville EAC Area, July 7-10, 2002

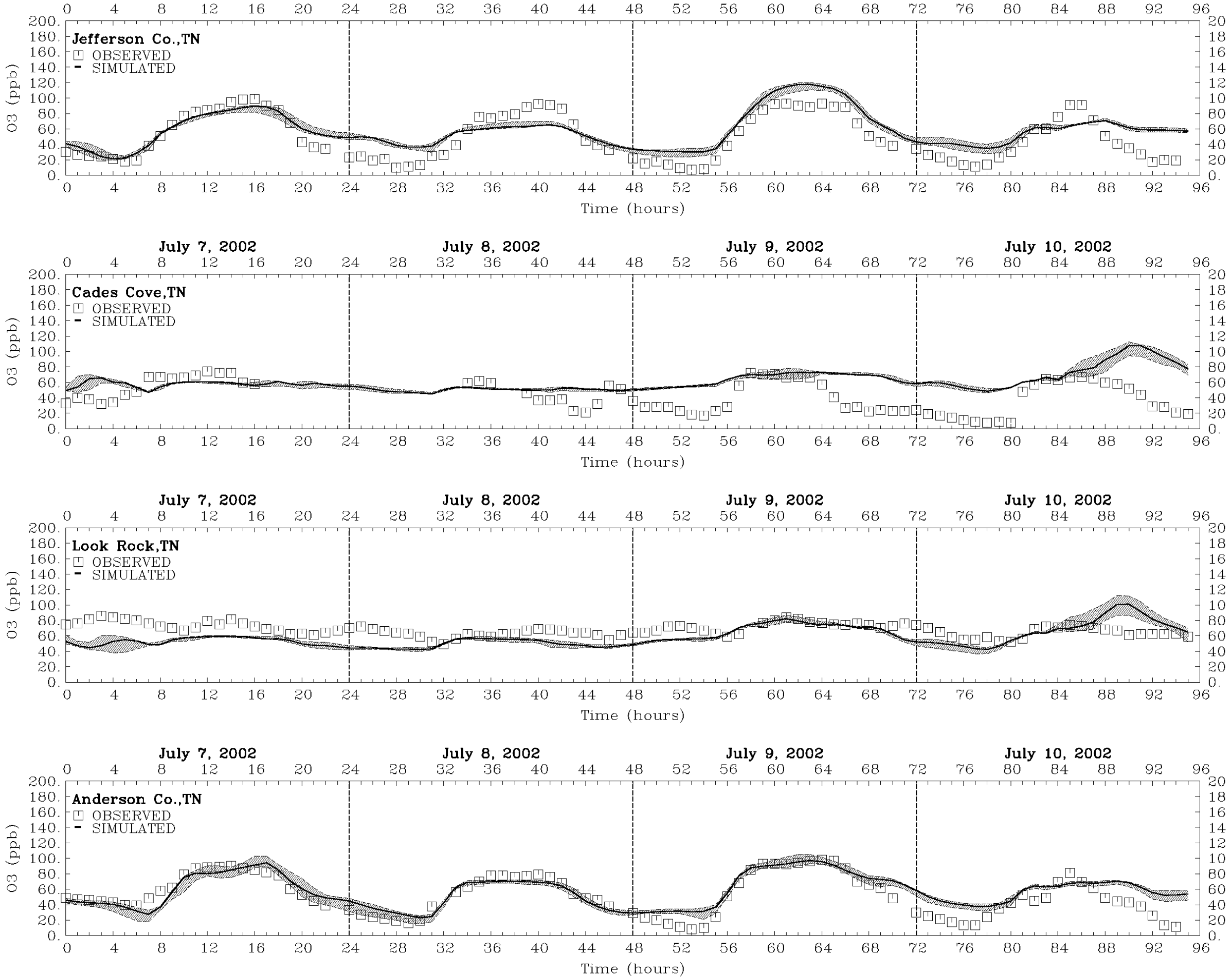


Figure 6-11j.
2001 Episode Time Series: Knoxville EAC Area *(continued)*,
July 7-10, 2002

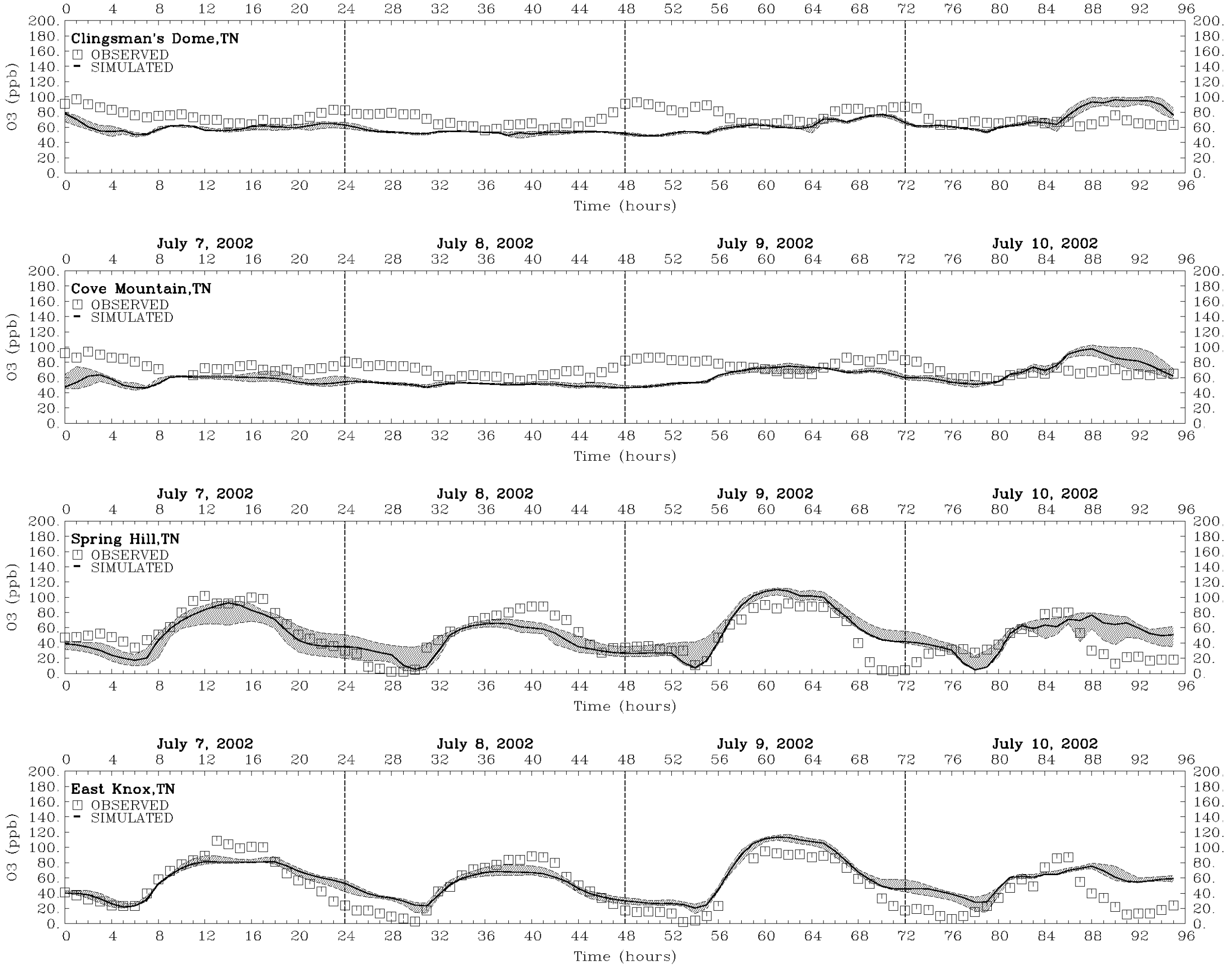


Figure 6-11k.
2001 Episode Time Series: Chattanooga EAC Area,
July 4-7, 2002

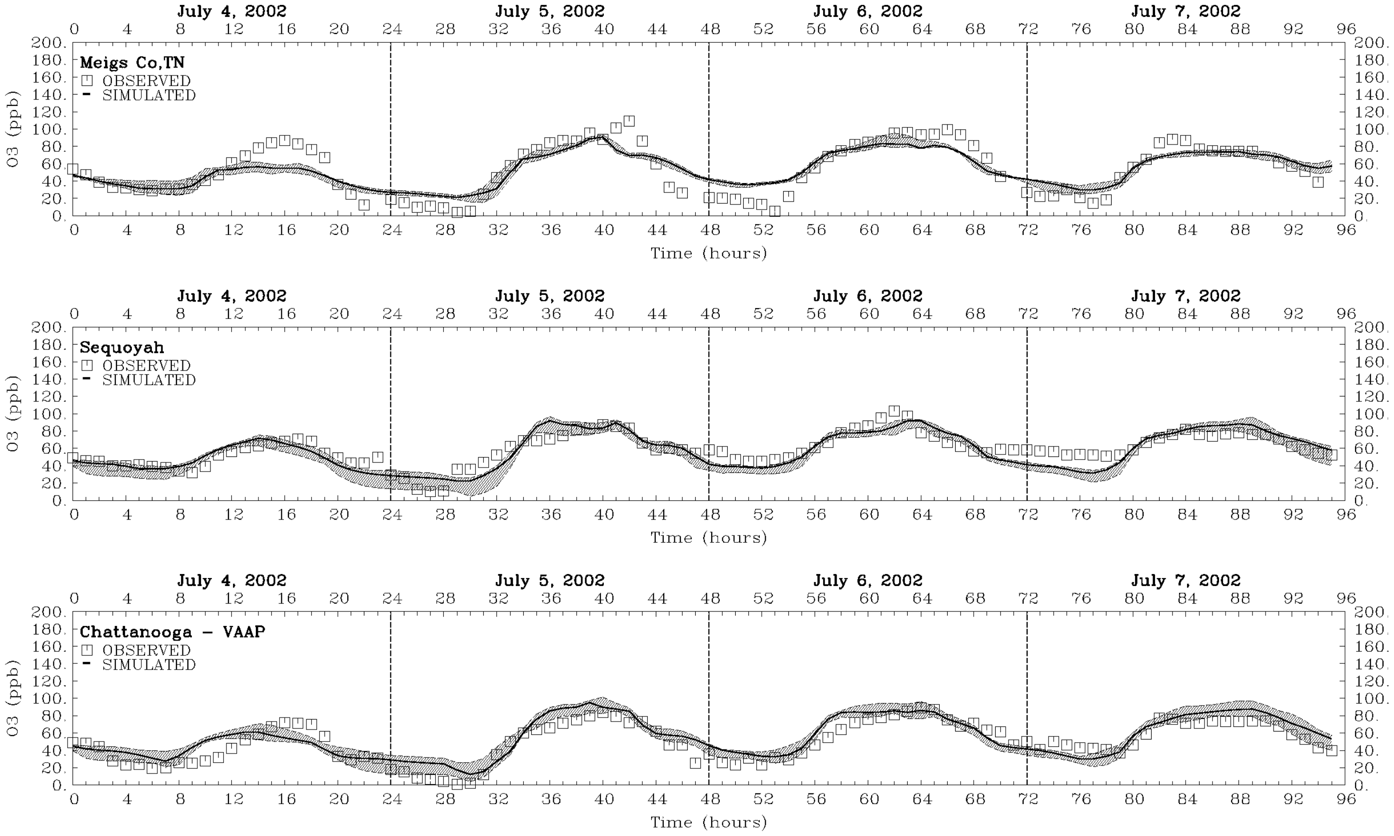


Figure 6-11l.
2001 Episode Time Series: Chattanooga EAC Area, July 7-10, 2002

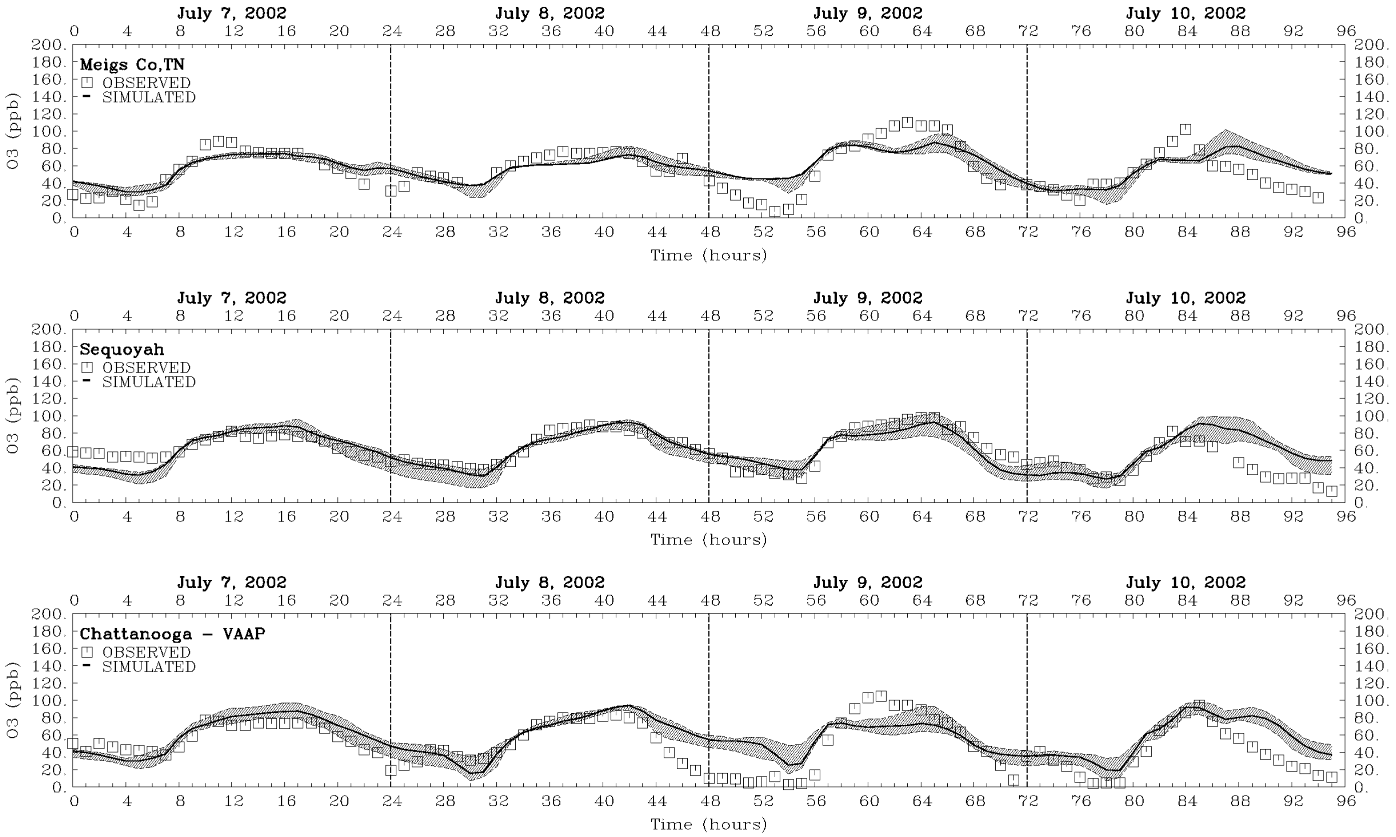


Figure 6-11m.
2001 Episode Time Series: Tri-Cities EAC Area,
July 4-7, 2002

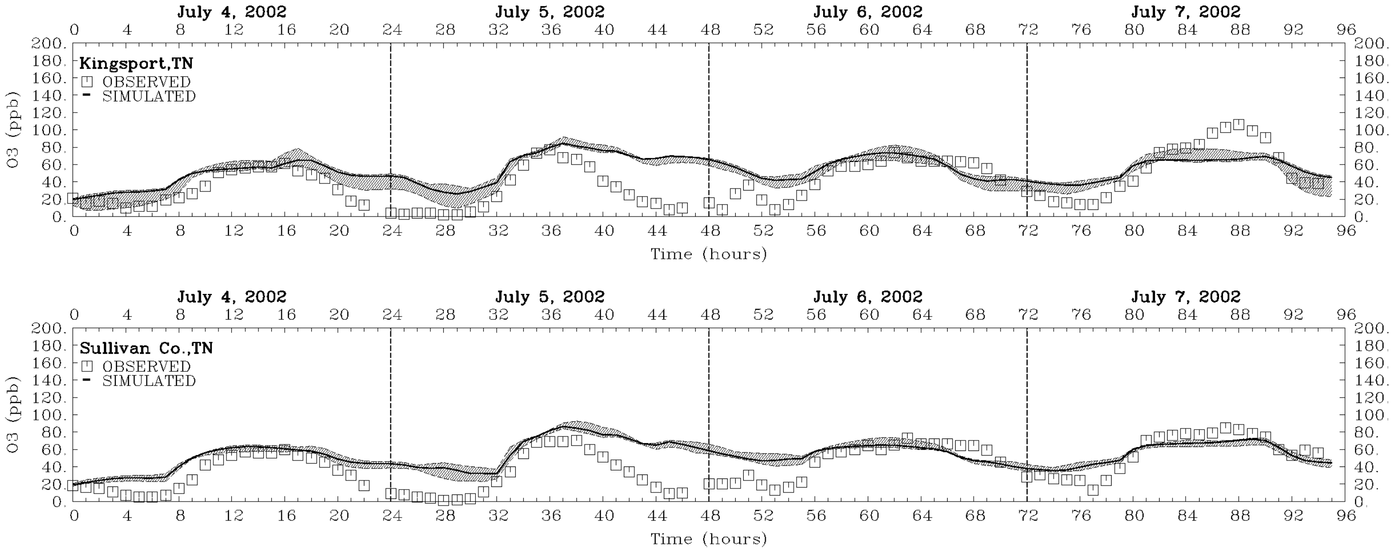


Figure 6-11n.
2001 Episode Time Series: Tri-Cities EAC Area, July 7-10, 2002

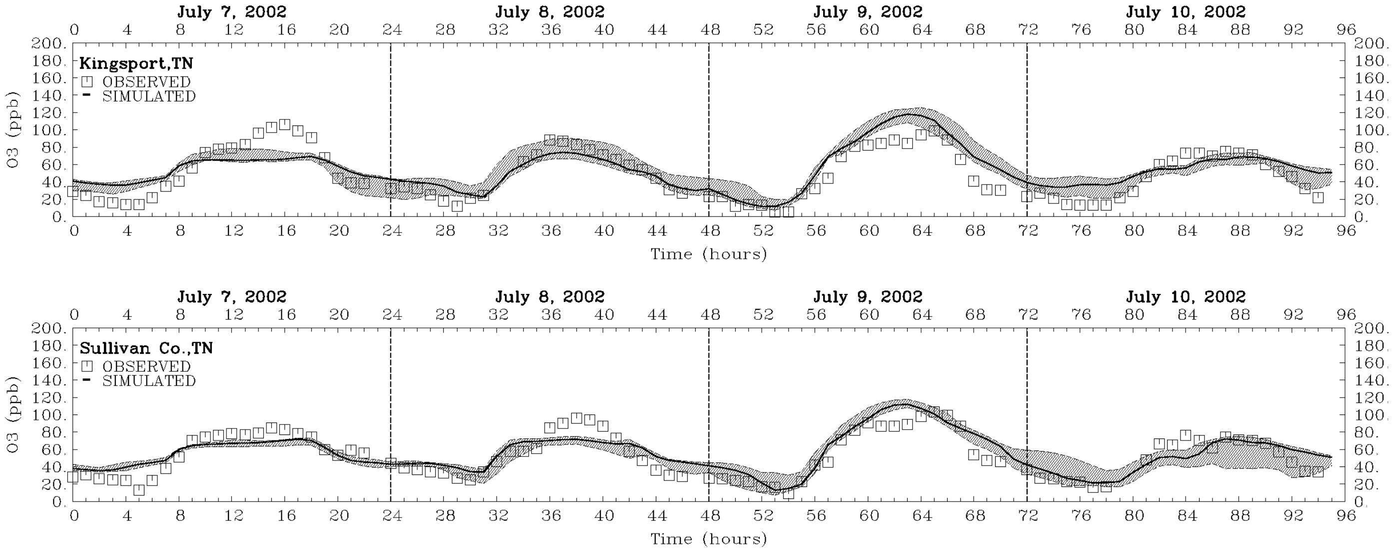
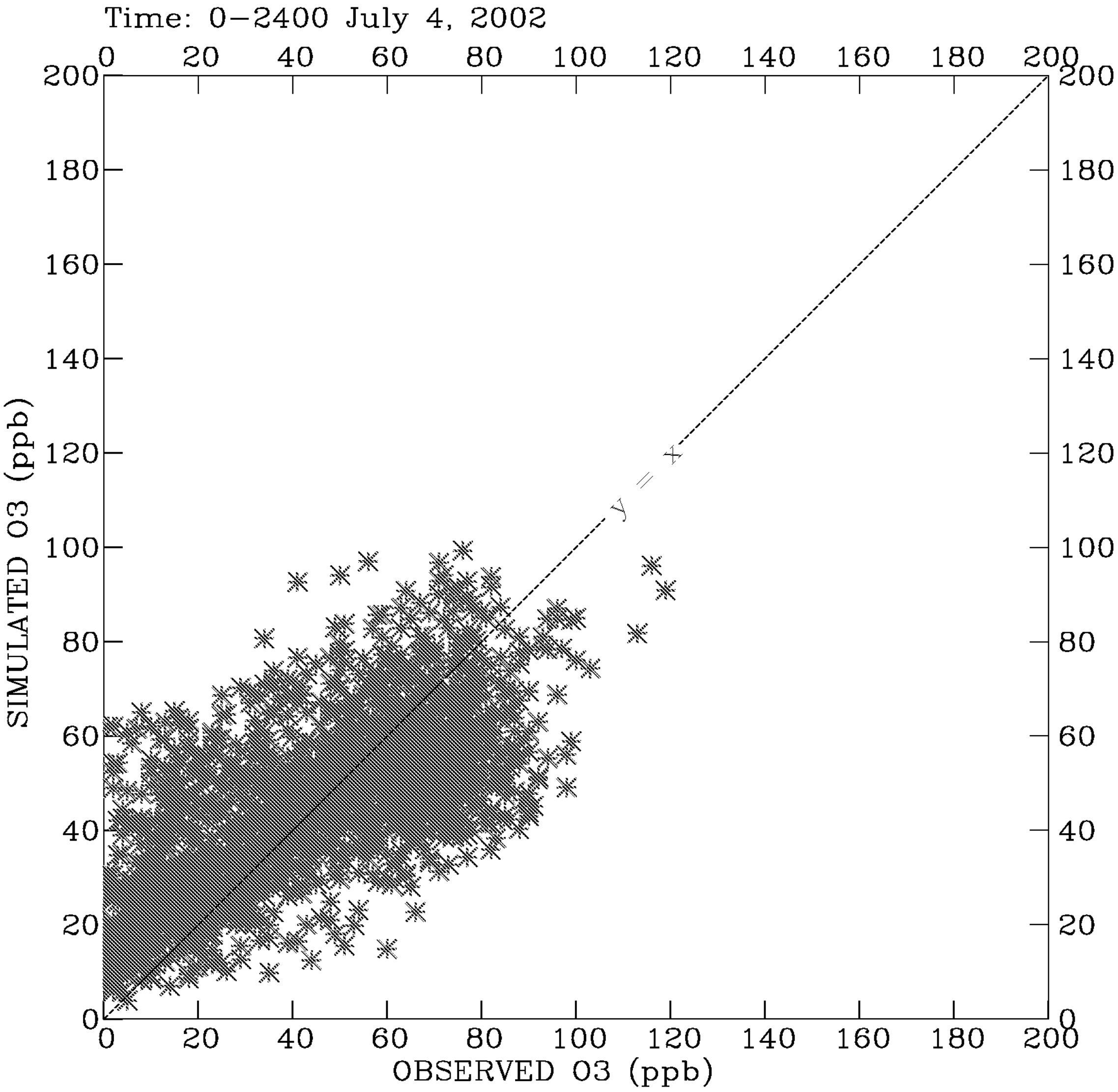


Figure 6-12a.
Scatter Plot: July 4, 2002



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12b.
Scatter Plot: July 5, 2002

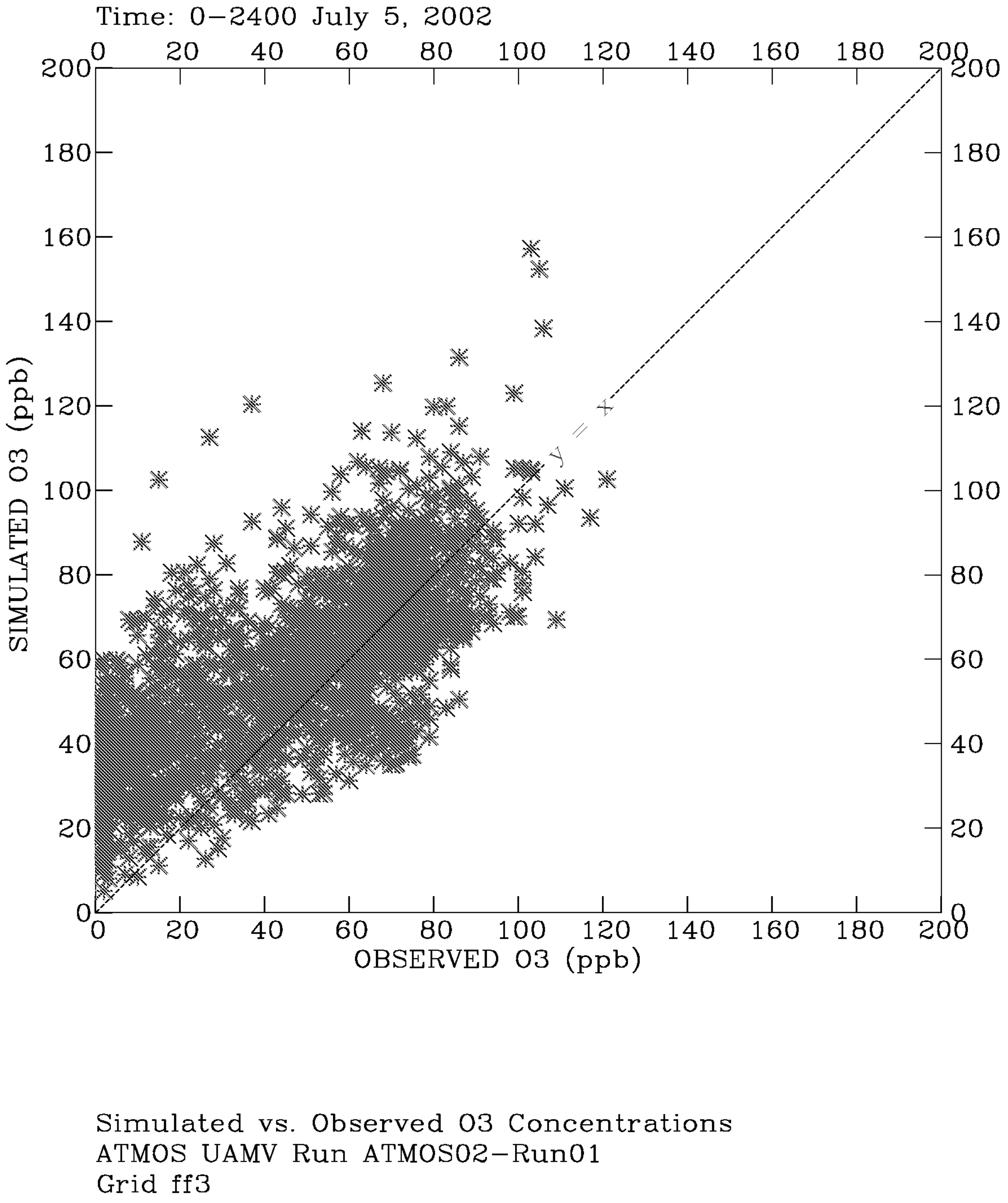


Figure 6-12c.
Scatter Plot: July 6, 2002

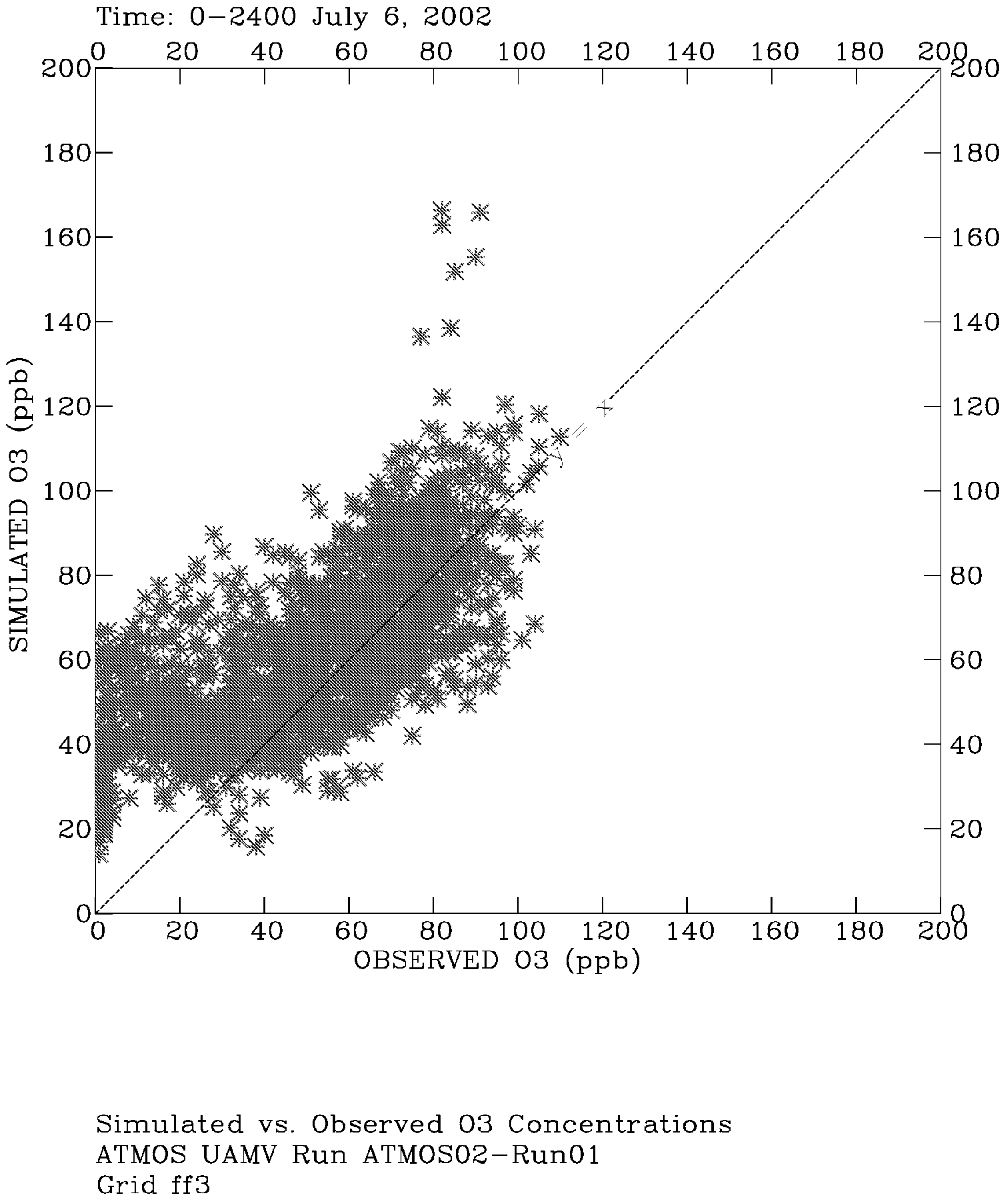
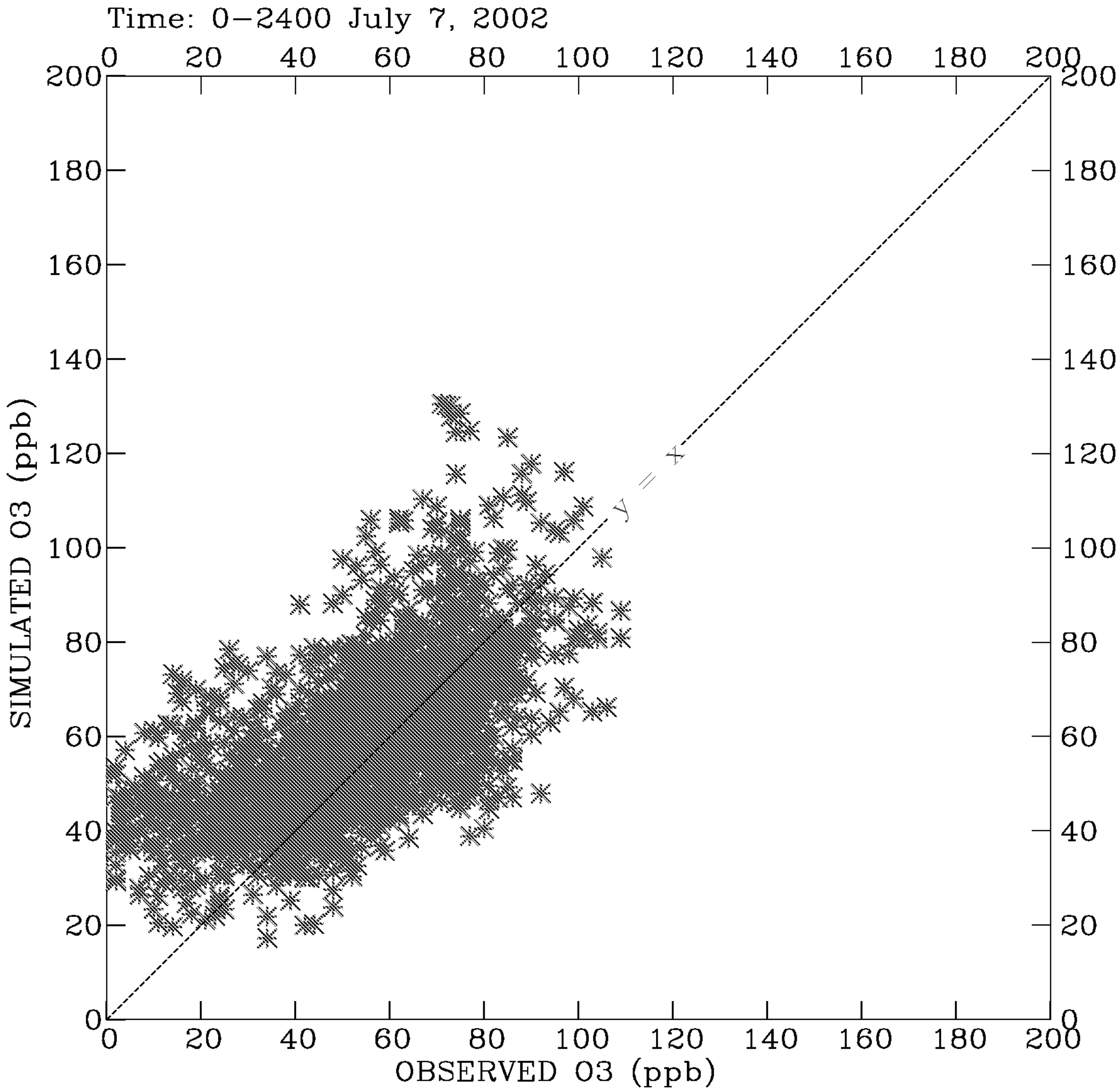


Figure 6-12d.
Scatter Plot: July 7, 2002



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12e.
Scatter Plot: July 8, 2002

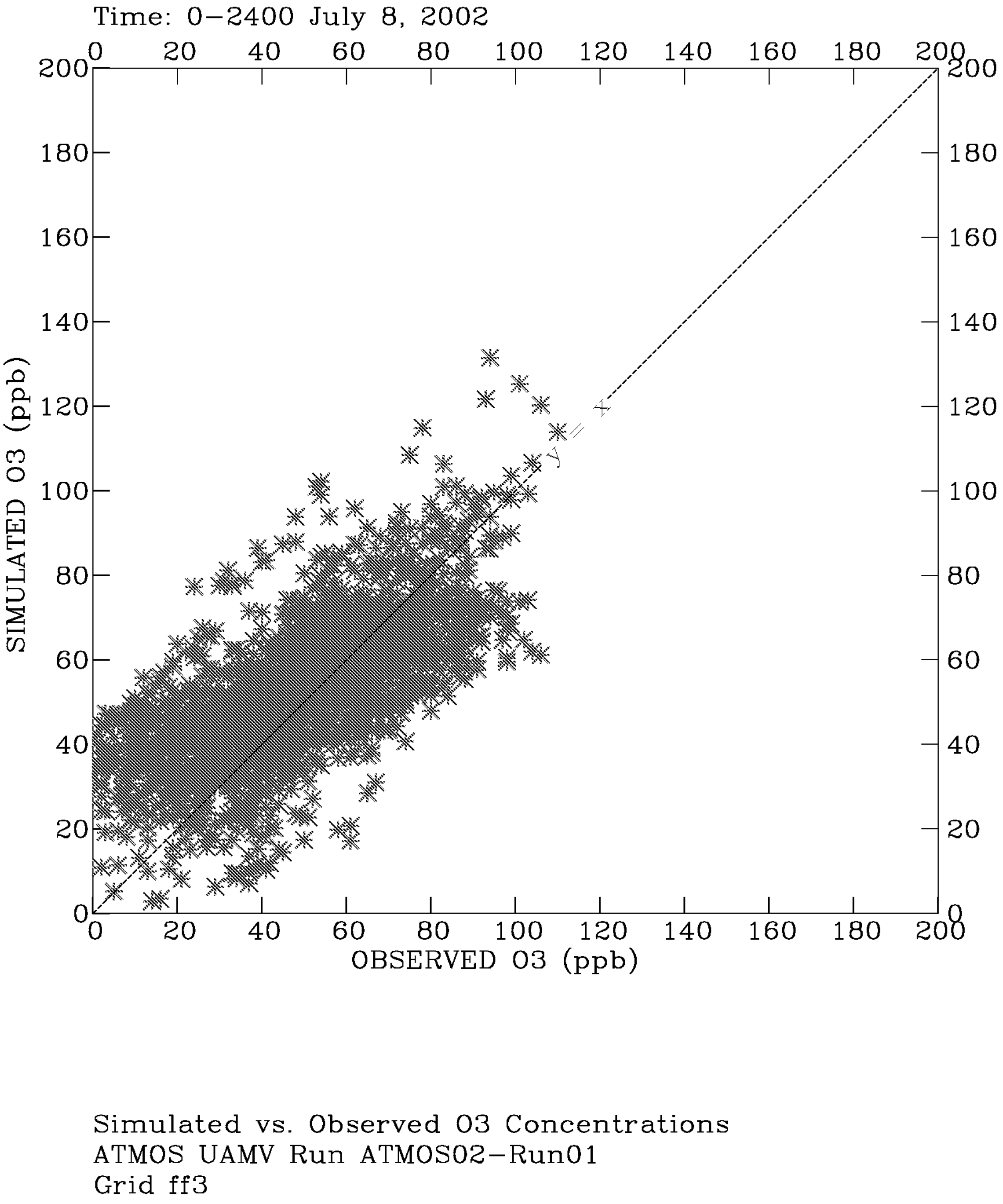
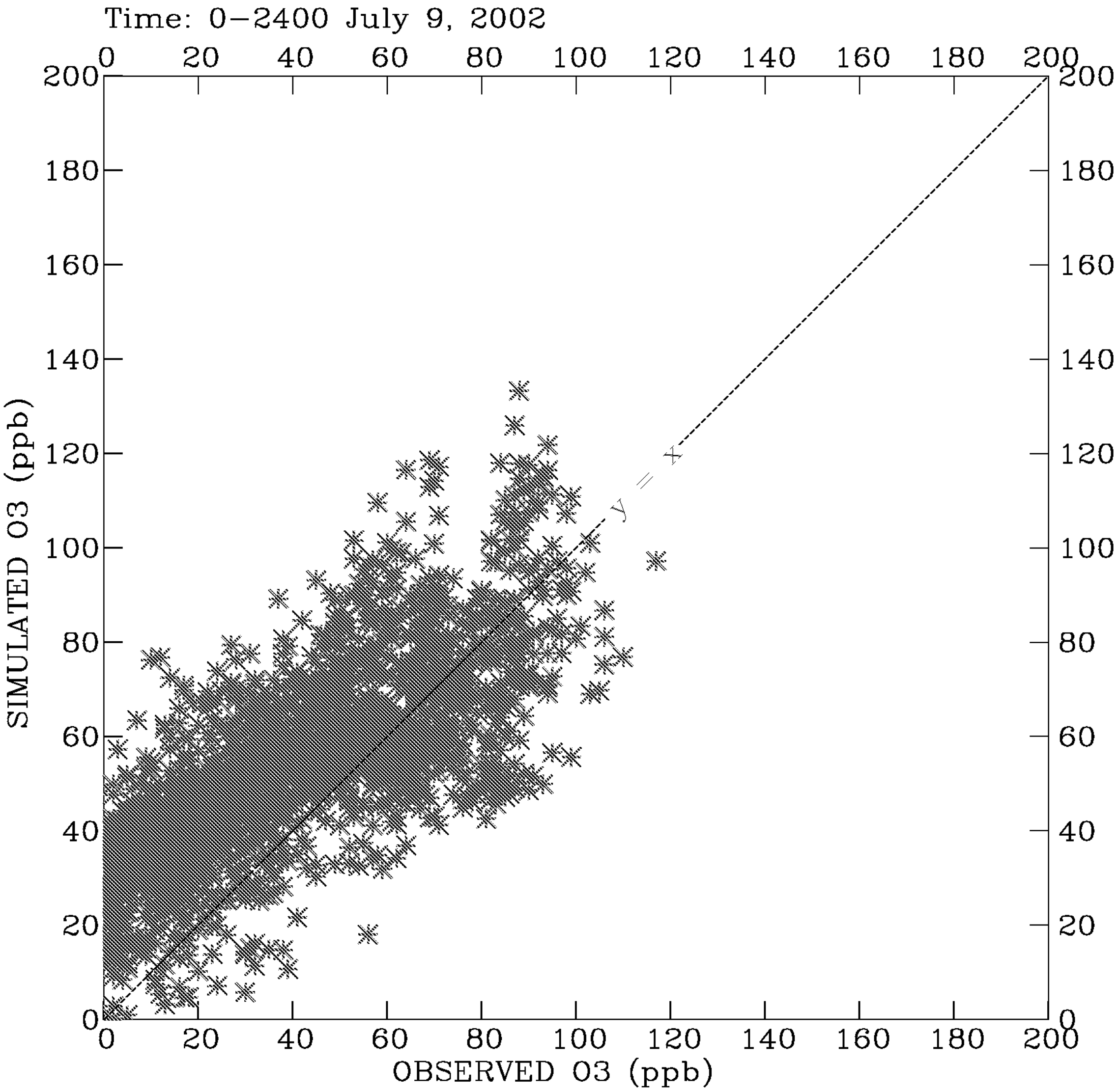
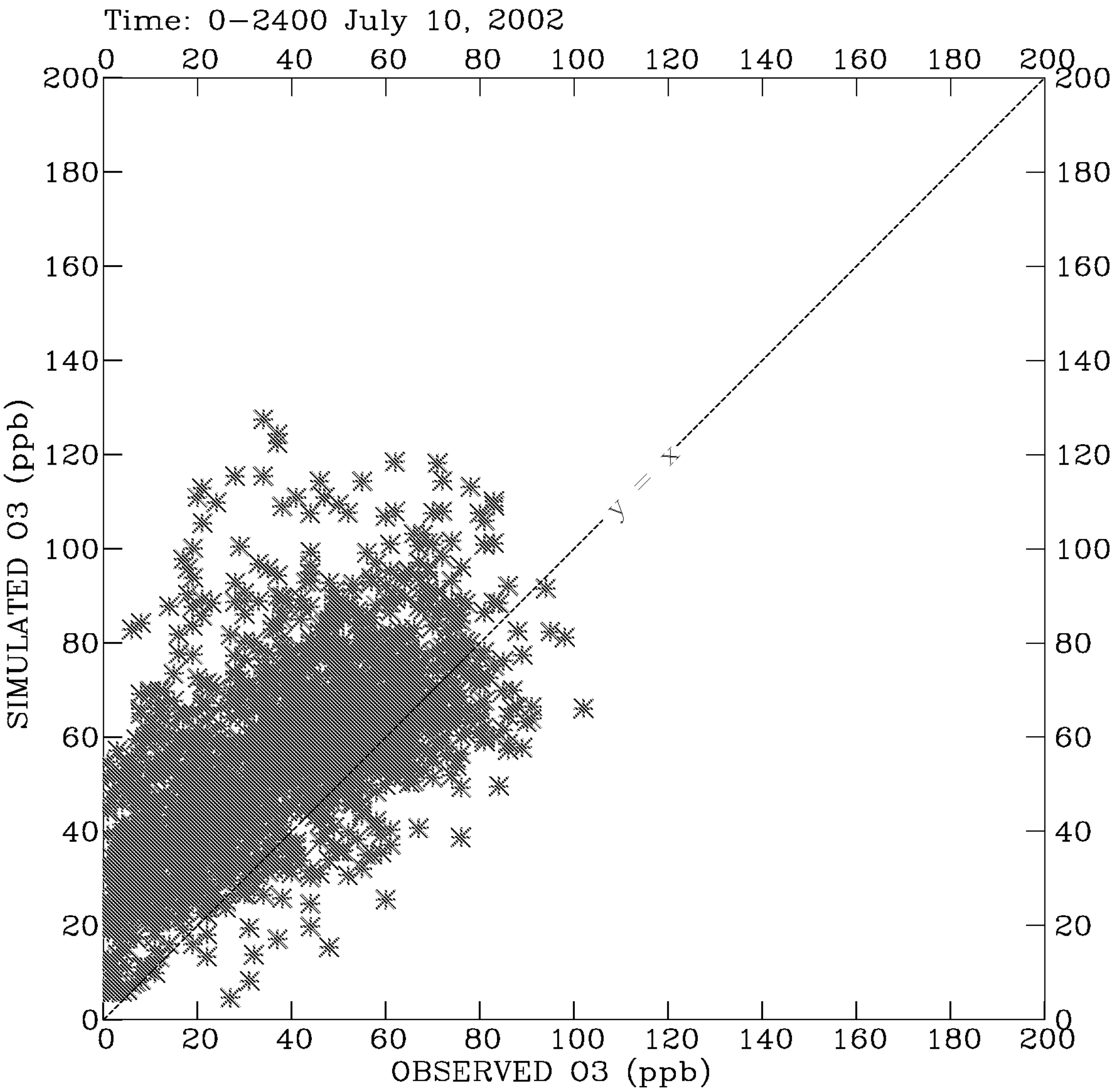


Figure 6-12f.
Scatter Plot: July 9, 2002



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

Figure 6-12g.
Scatter Plot: July 10, 2002



Simulated vs. Observed O3 Concentrations
ATMOS UAMV Run ATMOS02–Run01
Grid ff3

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7. Future-Year Modeling Application

The ATMOS EAC future-year modeling analysis included the development of future-year emission inventories (2007 and 2012), and the application of the UAM-V modeling system for a "current" year of 2001, two future years (2007 and 2012), as well as a number of EAC control measure sensitivity simulations. In addition to the 2007 baseline scenario, emissions for 2012 were developed, as required by EPA, to assess the effects of growth and as an evaluation of expected maintenance of the standard five years beyond 2007.

The UAM-V modeling system was run for the two ATMOS episodes and a third episode provided by the Arkansas DEQ using current-year (2001) emissions. This allowed the combination of results in applying the EPA modeled attainment test procedures, despite the different base years. Many of the comparisons presented in this section also rely on the 2001 current-year results as the basis for comparison. Following the preparation of the 2007 baseline emission inventory, future-year baseline simulations for 2007 were run and the results were compared with the base- and current-year simulation results. Following completion of the 2007 baseline scenario, two types of future-year simulations were conducted:

- The UAM-V Ozone and Precursor Tagging Methodology (OPTM) was applied to the 2007 baseline simulation to assess the contribution to ozone concentrations from NO_x and VOC emissions from various source categories or source areas within the ATMOS modeling domain.
- Control-strategy simulations for 2007 were used to examine and quantify the effects of specific emissions changes (for selected sources and source categories) for selected EAC measures.

Following a discussion of the future-year emission inventory preparation, the future-year modeling results are presented and discussed in this section.

For ease of reading, all figures follow the text in this section.

Overview of ADVISOR

Before discussing the future year emission inventory preparation and presenting the future-year simulation results, we first introduce the ACCESS™ Database for Visualizing and Investigating Strategies for Ozone Reduction (ADVISOR) analysis tool that was used in the ATMOS EAC modeling analysis to examine and display the emissions and modeling results. The ATMOS ADVISOR is included as electronic attachment to this report.

ATMOS ADVISOR

The ATMOS ADVISOR is an interactive database tool that contains information for review, comparison, and assessment of the UAM-V base and sensitivity simulations. The database contains emissions and simulated ozone concentrations (as represented by several different metrics) for all of the UAM-V modeling grids and selected geographical subregions and monitoring site locations. The ADVISOR database also supports application of draft EPA ozone attainment demonstration procedures (including the calculation of site-specific relative reduction factors and estimated design values) that were developed by EPA for use in 8-hour ozone attainment demonstration modeling.

The ATMOS EAC ADVISOR metrics include:

- Maximum 1-hour ozone concentration (ppb).
- Maximum 8-hour ozone concentration (ppb).
- Number of grid cell·hours with maximum 1-hour ozone concentrations ≥ 125 ppb.
- Number of grid cells with maximum 8-hour ozone concentrations ≥ 85 ppb.
- Total ozone exposure (ppb·grid cell·hour).
- 1-hour ozone exceedance exposure (ppb·grid cell·hour) for 1-hour ozone concentrations ≥ 125 ppb.
- 8-hour ozone exceedance exposure (ppb·grid cell) for 8-hour ozone concentrations ≥ 85 ppb.
- Population[4] exposure (ppb·person hours) to 1-hour ozone concentrations ≥ 125 ppb.
- Population exposure (ppb·person) to 8-hour ozone concentration ≥ 85 ppb.
- Total and component emissions (NO_x, VOC).

Options for displaying the metrics include:

- Value.
- Difference (relative to a selected base simulation such as the future-year baseline).
- Percentage difference.
- Effectiveness (change in ozone metric relative to the change in emissions[5], again relative to a selected base simulation).
- Relative reduction factor.
- Estimated design value.

- Observed ozone concentrations are also displayed.

Geographies consisting of grids, subregions, and monitoring sites include:

- Grid 1: Outer 36 km X 36 km grid.
- Grid 2: Intermediate 12 km X 12 km grid.
- Grid 3: Inner 4 km x 4 km inner grid.
- Sumner, Davidson, Wilson, & Rutherford Counties, TN (Nashville).
- Knox, Anderson, Jefferson, Sevier, and Blount Counties, TN (Knoxville).
- Shelby, DeSoto, and Crittenden Counties (Memphis).
- Shelby County, TN.

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[4] Population estimates are based on 2000 U.S. Census data.

[5] The change in emissions can be calculated for a different geographical area than the change in ozone metric.

- DeSoto County, MS.
- Crittenden County, AR.
- Lee County, MS (Tupelo).
- Pulaski County, AR (Little Rock).
- Hamilton County, TN; Walker and Catoosa Counties, GA (Chattanooga).
- Nashville EAC Area: (Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson counties).
- Knoxville EAC Area: (Anderson, Blount, Know, Loudon, Sevier, Union, and Jefferson counties).
- Chattanooga EAC Area: (Hamilton, Marion and Meigs, counties (Tennessee), and Walker and Catoosa counties, (Georgia)).
- Memphis EAC Area: Shelby, Tipton, and Fayette counties (Tennessee); Crittenden County, (Arkansas); De Soto County, (Mississippi).
- Tri-Cities EAC Area: (Carter, Hawkins, Johnson, Sullivan, Unicoi, and Washington counties).
- Haywood County.
- Lawrence County.
- Putnam County.

In addition to these specific areas, the ozone monitoring sites in the ATMOS Grid 3 are also included in the ADVISOR database.

An estimate of the modeling system noise, as calculated for certain of the metrics, is also included as a display option in the ADVISOR database. This feature is intended to provide perspective on the meaningfulness of the simulated ozone reductions.

In this report, the simulation results are presented and compared using three primary metrics or indicators:

- Maximum 8-hour ozone concentration is the simulated maximum 8-hour average ozone concentration for a given “geography” (grid, subregion, or monitoring site) and time period. The units are ppb.
- 8-hour ozone exceedance exposure is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied.
- The estimated design value (EDV) is an estimate of the 8-hour ozone design value for a selected monitoring site and future-year scenario. It is calculated as the current design value multiplied by a relative reduction factor (RRF), where the RRF is the ratio of the future-year-scenario to base-year 8-hour ozone concentration in the vicinity of the monitoring site. This metric will primarily be used to discuss the results from the application of the draft 8-hour ozone attainment demonstration procedures in the next section of this report. The units are ppb.

Additional metrics are used to assess and compare the modeling results, as suggested in EPA's 8-hour modeling guidance document. The metrics below are intended for use in a relative sense, comparing the base case (or current year) simulation with the future year simulation:

- The number of grid cells for which the daily maximum 8-hour concentration is greater than 84 ppb.
- The number of hours where the 1-hour concentration is greater than 84 ppb in each grid cell.
- The 1-hour exceedance exposure for concentrations greater than 84 ppb. The units are ppb, with grid-cell and day implied.

Future-Year Emission Inventory Preparation

This section discusses the methodologies followed in preparing the future-year baseline emission inventory for 2007.

Emission Inventory Growth Factors

The projection of the ATMOS EAC base year emission inventory to the future years required the use of economic growth factors. These are applied to the various industrial sectors and source categories to reflect expected future growth (or decline) in industrial activity and resulting emissions. There are five sets of factors available for use in projecting emission inventories for air quality modeling. The Bureau of Economic Analysis (BEA) provides three such sets, while another two sets are available in EPA's Economic Growth Analysis System (EGAS). For ozone SIP modeling exercises, EPA guidance does not state a preference regarding which set to use, but does recommend that local growth information be considered in the selection and use of such factors. The BEA projection series provides state-level personal earnings, employment, and gross state product (GSP - value added) data for selected years through the year 2045, and the projection factors are available at 2-digit SIC code level for point sources and 4-digit ASC code level for area sources. The latest set of growth factors provided by BEA was issued in 1995—BEA no longer publishes growth factors. The EGAS system includes both BEA factors and two other sets of growth factors that purportedly provide more detailed information—geographically and by source category. The EGAS provides the county-level growth factors for area sources at the 10-digit ASC code level, and growth factors for point sources at the 2-digit SIC code level with associated fuel type or 8-digit SCC code. The two sets of factors provided by EGAS are from the Bureau of Labor Statistics (BLS) and from Wharton Econometric Forecasting Associates (WEFA). Although the EGAS system purports to provide growth factors by county, for the State of Tennessee and all other surrounding states, all of the factors contained in the latest version of EGAS are the same for all counties within each state—there are no county-to-county differences.

For the ATMOS EAC modeling analysis, the future-year emission inventories for 2007 and 2012 were developed using economic growth factors provided by the BEA. Specifically, the state-specific GSP factors were used for all states (except Louisiana, where employment factors were used) within the modeling domain. The selection of the BEA factors was not based on any assessment of the quality or accuracy of BEA vs. EGAS. EPA guidance does recommend that value added projections be used and BEA's GSP factors are a measure of value added and a more complete measure of growth than BEA's earnings factors, which are only one component of GSP. The BEA GSP factors have been used recently by EPA in ozone and particulate matter modeling conducted to support national rulemaking for the Tier 2 engine and fuel sulfur standards, the nonroad diesel engine rulemaking, the Clear Skies Initiative (CSI), and most recently, in the Interstate Air Quality Rule (IAQR) modeling analysis (EPA, 2004).

Area-Source and Non-road Emissions

Area Source Projection

The future-year growth estimates for area sources were based on Bureau of Economic Analysis (BEA) projections of Gross State Product (GSP) for all states except for the State of Louisiana, which was based on the Employment (BEA, 1995). The BEA projections were applied at the 4-digit ASC level for area sources, and represent growth between the current year (2001) and 2007. The BEA growth factors are presented in Appendix B (Tables B-1 through B-6 for all states excluding the State of Louisiana), and BEA employment growth factors for the State of Louisiana are presented in Table B-7.

Area Source Controls

For fuel combustion sources, energy adjustment factors, which were developed from the U.S. Department of Energy (DOE) publication *Annual Entergy Outlook 1999* (DOE, 1998), were applied to the baseline emissions to account for expected increases in fuel and process efficiency in 2007. The adjustment factors are presented in Table B-8.

VOC controls were applied to area sources using information provided by EPA. The controls include federal initiatives, such as VOC content limits for consumer solvents, Title III Maximum Achievable Control Technology (MACT) assumptions, and Title I Reasonably Available Control Technology (RACT) assumptions that were not applied in the base year inventory. These controls are presented in Table B-9.

Table B-10 shows the VOC and CO controls applied for residential wood combustion, and Table B-11 lists the control efficiencies applied to account for VOC reductions associated with onboard vapor recovery systems and Stage II controls at gasoline service stations (percentage reductions for counties required to have Stage II controls, and counties that do not have Stage II controls).

All emissions due to open burning were eliminated for the 45 counties in Northern Georgia (Georgia Department of Natural Resources Environmental Protection Division: Georgia's State Implementation Plan for the Atlanta Ozone Non-attainment Area, July 17, 2001) (GDNR, 2001), and 8 counties in the State of Alabama by a seasonal ban. The 45 counties in Northern Georgia are 13 non-attainment and 32 additional counties (eliminated both prescribed and slash burning for Bartow, Carroll, Hall, Newton, Spalding and Walton counties; and eliminated slash burning for Banks, Barrow, Butts, Chattooga, Clarke, Dawson, Floyd, Gordon, Haralson, Heard, Jackson, Jasper, Jones, Lamar, Lumpkin, Madison, Meriwether, Monroe, Morgan, Oconee, Pickens, Pike, Polk, Putnam, Troup and Upson counties). The 8 counties in Alabama are Jefferson, Shelby, Baldwin, Lawrence, Madison, Mobile, Montgomery, and Morgan.

Non-road Source Emissions

County-level emission estimates for the majority of non-road mobile source emissions were developed using EPA's draft NONROAD2002a (EPA, 2003) model with the maximum, minimum and average temperatures (calculated from the 1970-2000 30-year historical averages) by state for each month of the episode periods.

Emissions from aircraft, commercial marine and locomotives were projected from the current year (2001) to year 2007 using the BEA GSP growth factors for all states except for the State of Louisiana, which were based on the Employment.

The 2000 non-road mobile source emissions for four counties in State of Arkansas were projected to 2007 using the BEA GSP growth factors.

Emissions for State of Texas

The area and non-road source emissions data for 2007 were obtained from TCEQ, and incorporated into the future-year inventories for all Texas counties included in the modeling domain. The data provided information for preparing the 2007 Mid-Course Review (MCR) Phase I Emissions Inventory including associated growth and controls for NO_x, VOC and CO.

Mobile-Source Emissions

The on-road mobile source emissions were prepared using MOBILE6.2. For the states of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, South Carolina, North Carolina, Tennessee and Texas, each state provided estimated 2007 county-level daily VMT forecasts. The 30-year historical average temperatures and humidity data for each month of the episode periods were used in calculating emission factors with MOBILE6.2. For all other states in the domain, the on-road mobile source emissions were prepared using MOBILE6.2 and state-level 2007 VMT information provided by the Federal Highways Administration (FHWA). The state-level VMT data were distributed to the county-level using the 2000 Census population as a surrogate.

The MOBILE6.2 input files were used to generate the emission factors for total organic gases (TOG), NO_x, and CO. The county-level emissions were calculated for each vehicle class and roadway classification by multiplying the appropriate emission factor from MOBILE6.2 by the county-level VMT for that vehicle class and roadway classification using the EPS 2.5 program MVCALC.

Point-Source Emissions

Point Source Emission Data Source

The 2007 point source emissions were developed based on the following data:

STATE OF TENNESSEE

- Applied future year growth and controls on the county-specific current year (2001) emissions data.
- Applied 6% growth rate to the base case level emissions for various gas compressor station sources located in the state (June 2001 and August/September 1999 emissions as base case level for larger gas compressors; and 2002 emissions as base case level for smaller gas compressors).

STATE OF MISSISSIPPI

- Applied future year growth and controls on the current emissions data, and included the emissions estimates for the facilities currently under construction that will be operating in 2007.

STATE OF TEXAS

- Incorporated point source emissions estimates included in the TCEQ 2007 MCR Phase I Emissions Inventory.

FACILITY-SPECIFIC DATA

- Incorporated the hourly emissions estimates for 2007 provided by TVA, and assumed that the combustion turbines (CTs) only operate 4 hours on the three intermediate days of each episode: September 6-8 for the August/September 1999 episode; June 18-20 for the June 2001 episode; and July 6-8 for the July 2002 episode.
- Incorporated 2007 emissions estimates provided by Eastman Chemical Company.
- Incorporated 2007 emissions estimates for Williams Refining & Marketing LLC provided by Shelby County, Tennessee.
- Incorporated hourly emissions estimates for 2007 September and July episode periods provided by Southern Company for the West Florida Ozone Study (WFOS) modeling analysis (SAI, 2004) using day of week matches.
- Kept the emissions for the Entergy facilities (located in States of Arkansas, Louisiana and Mississippi) at the base case level.

OTHER STATES

- Applied future year growth and controls on the final 1999 NEI version 2 data.

Point Source Growth

The future year growth for the point sources was based on the BEA projections. The BEA projections were applied at the 2-digit SIC level for point sources, and represent growth between the current year and 2007. The detailed BEA GSP projections are presented in Tables B-12 through B-18 for all states (excluding the State of Louisiana), and BEA employment growth factors for the State of Louisiana are presented in Table B-19.

Point Source Controls

For fuel combustion sources, energy adjustment factors, which were developed from DOE publication *Annual Energy Outlook 1999*, were applied to the baseline emissions to account for expected increases in fuel and process efficiency in 2007. The adjustment factors are presented in Table B-20.

The CAA controls included in Federal initiatives were applied to the non-utility point sources, as shown in Table B-21. In addition, the MACT controls for NOx and VOC were applied to the non-utilities. The MACT control assumptions are listed in Tables B-22 and B-23.

NO_x SIP Call Control

The emissions controls required by the EPA's Regional NO_x SIP Call were emulated for the point sources located in the modeling domain covered by SIP Call, i.e., the States of Alabama, Georgia, Illinois, Indiana, Kentucky, Maryland, Michigan, Missouri, North Carolina, New York, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia and West Virginia, and District of Columbia. The NO_x SIP Call controls were applied to the point sources located north of the 32-degree latitude line in the states of Alabama and Georgia.

The Electric Generation Unit (EGU) and non-EGU point sources subject to the NO_x SIP Call in the point source inventory needed to be identified in order to apply NO_x emissions controls. EPA's " Development of Emissions Budget Inventories for Regional Transport NO_x SIP Call Technical Amendment Version" (EPA, 1999b) provided lists of EGU and non-EGU point sources, and the data were utilized to identify the EGU and non-EGU sources in the point source inventory.

ELECTRIC GENERATING UNITS (EGUS)

The point sources included in the inventory were matched with the EGUs included in the EPA's Emission Budget Inventory for Regional Transport NO_x SIP Call. The facility name, FIPS code, plant ID, and point ID provided in the EGU data file were used to complete the match. In many cases, the plant and point IDs are not consistent in both inventories. The EGUs in the point source inventory were identified by automated selection of matching the FIPS code and plant ID, followed by detailed manual unit-by-unit matching process. In the end, a small portion of the EGU units in the EPA's data file could not be found in the NEI version 2 point database. However, the major NO_x emitters listed in the EPA's EGU data file were successfully identified in the point source inventory, i.e., all the EGUs located in the States of Alabama, Georgia and Tennessee, and the major NO_x emitters located in the States of Kentucky, Indiana, Illinois, Missouri, North Carolina, South Carolina, Ohio, Pennsylvania, Virginia and West Virginia.

The NO_x control factors for the EGUs were calculated using the 1996 NO_x emission rates (lb/MMBtu) provided in the EPA's EGU data file for each source, and a uniform emission rate of 0.15 lb/MMBtu for the year of 2007.

NON-EGUS

The point sources included in the inventory were matched with the large-size non-EGUs included in the EPA's Emission Budget Inventory for Regional Transport NO_x SIP Call. The FIPS code, plant ID, point ID and Source Classification Codes (SCC) provided in the non-EGU data file were used to complete the match. In some cases, the point IDs are not consistent in both inventories, and non-EGUs in the point source inventory were identified by matching with FIPS, plant ID and SCC. In the end, a small portion of the non-EGU sources in the EPA's data file could not be found in the point source inventory by the FIPS code, plant ID, point ID and SCC matches, although some of the sources may be located outside the modeling domain in the states which are only partially included in the domain.

The NO_x emission reductions were calculated for the large-size non-EGU sources in the specific source categories listed in Table B-24 provided by EPA (EPA, 1999b).

Summary of the Modeling Emission Inventories

The summaries of the 2007 baseline emissions are presented in Appendix B for each modeling episode as follows:

- Table B-25 through Table B-27 for the August/September 1999 episode.
- Table B-28 through Table B-30 for the June 2001 episode.
- Table B-31 through Table B-33 for the July 2002 episode.

The emission summaries are given by species (NO_x, VOC and CO) and by major source category. The low-level emissions include anthropogenic (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are tons per day.

Figure 7-1 presents component emission totals for NOx, VOC, and CO for Grid 3 for a typical weekday (18 June 2001) comparing the current year 2001 emissions with the 2007 baseline emissions. For Grid 3, the expected changes in emissions in 2007 result in a 26 percent reduction in anthropogenic NOx emissions, a 16 percent reduction in anthropogenic VOC emissions, and a 17 percent reduction in CO emissions. Figures 7-2 through 7-6 present total emissions for each of the EAC areas for 2001 and 2007. These plots are presented using the same scale so that the totals can be compared between the EAC areas.

Future-Year Boundary Conditions Preparation

For the future-year modeling analysis, with the exception of the emission inventories (and the boundary conditions which are “self-generating”), all inputs for the future-year simulations are identical to those for the corresponding base-case simulation. Through use of the “self-generating” ozone boundary conditions technique (as discussed in Section 5), the boundary condition values for ozone were also indirectly modified for the future-year scenarios. The baseline ozone values used for the boundary conditions are typically 1 to 2 ppb lower than the base-case values, depending upon the simulation day.

Future-Year Baseline Simulation Results

As outlined above, the ATMOS EAC future-year baseline simulation incorporates the effects of population and industry growth (or, in some cases, decline) as well as national or statewide control measures or programs that are expected to be in place by 2007. Only the emissions inputs were directly modified for the future-year baseline simulation. However, through use of the “self-generating” ozone boundary conditions technique, the boundary condition values for ozone were also indirectly modified for the future-year scenarios.

The baseline simulation results provide the starting point for assessment of the effects of further emission reductions on future ozone air quality. The future-year baseline simulation results for Grid 3 indicate both increases and decreases in maximum 8-hour ozone relative to the base-case simulation. There are widespread decreases and isolated areas of increase. The magnitude and pattern of the differences vary from day to day.

Table 7-1 summarizes the results of the 2007 baseline simulation, as illustrated by four 8-hour and 1-hour metrics. The results are provided for Grid 3 and for all of the EAC areas using all of the non-startup days for the three episodes. The results indicate that with the expected reductions in emissions in 2007, there is a 45 to 80% reduction in the value of these metrics compared to the 2001 simulation. The reductions vary across the EAC areas.

Another metric that is important in assessing and demonstrating simulated attainment in the future year is the estimated design value (EDV). Table 7-2 presents the maximum EDV's for each of the EAC areas. These are presented for the monitoring sites within each area where the maximum observed DV occurs for the 2000-2002 and 2001-2003 periods. The EDV's are calculated for concentrations within 15-km of the monitoring site and within the 9 grid-cell area surrounding the site. For the Knoxville EAC, the EDV's are calculated for the local Knoxville site (Spring Hill) and for a site located in the adjacent Great Smoky Mountains area (Clingman's Dome), which is an elevated site. Using the 2000-2002 observed DV, two of the six EAC areas show EDVs less than or equal to 84 ppb for the 2007 baseline simulation. According to EPA guidance, the 2000-2002 DVs should be used in calculating the EDVs, since 2001 is the current year. When the 2001-2003 DVs are used, four of the six EAC areas show calculated EDV's of less than or equal to 84 ppb.

Emission Tagging Simulations

For the ATMOS EAC modeling analysis, the OPTM approach was used to examine the contributions from selected emission source regions and source categories to simulated ozone for the 2007 baseline simulation within and surrounding each of the EAC areas. Emissions from specific areas within the modeling domain and corresponding to specific source categories were tracked using separate tags.

Overview of the Ozone and Precursor Tagging Methodology (OPTM)

Ozone modeling has been used for many years to assist in developing emissions control strategies that effectively reduce ozone. Sensitivity simulations, in which some emissions are omitted from the model input files, are often used to estimate the contribution of various categories of emissions or source regions on simulated ozone concentrations. These are generally referred to as "zero-out" sensitivity simulations. All other inputs are typically the same as for the baseline simulation. The change in ozone is then interpreted as the amount of ozone attributed to the particular emissions category.

Modelers have recognized some drawbacks to the sensitivity simulation methodology for estimating ozone contributions. First of all, a separate simulation must be set up and run for each category that is to be investigated. Second, since the response of the ozone chemistry may be quite non-linear for significant changes in the emissions, the estimated change in ozone may be valid for only the specific change in emissions that was simulated. That is, if the elimination of a category of emissions resulted in a 20 ppb change in ozone, it does not necessarily follow that elimination of half that amount of emissions would result in a 10 ppb change in ozone.

In order to augment the information available from sensitivity simulations, we developed the Ozone and Precursor Tagging Methodology (OPTM). OPTM provides estimates of the contribution of emissions from specified source categories or source regions to the simulated ozone concentrations. The estimates are made for the existing conditions within the simulation and do not require that the system be perturbed (e.g., zeroed out) in order to make the estimate. In addition, estimates for several categories can be made in a single simulation.

Ozone exists in the atmosphere in a dynamic equilibrium with NO and NO_2. NO_2 is photolyzed by sunlight to form NO and a free oxygen atom that combines with an oxygen molecule to form ozone. The ozone and NO recombine rapidly to reform the NO_2 and oxygen molecules. Since it is the oxidized form of the molecules that contribute directly to the ozone present at a given time, a useful quantity to consider is the amount of oxidant present, the sum of NO_2 and ozone. While ozone may drop rapidly when fresh NO emissions are added to the system, the amount of oxidant varies more slowly. When the NO emissions are added, ozone is converted to NO_2, but the sum of NO_2 and ozone stays the same. The amount of oxidant present varies slowly, increasing due to the interaction of VOCs, NO_x and sunlight, and decreasing through removal processes such as deposition and conversion to nitric acid. The OPTM system tracks the amount of oxidant (the sum of NO_2 and ozone) formed from various tagged source categories as a method of estimating the contributions to ozone.

In order to estimate the contributions to ozone, OPTM sets up several new tracer species in a simulation that are used to tag emissions or chemical products. The total emissions of VOC and NO_x from the desired categories are tagged. For illustration, we will assume that there are two categories (Category 1 and Category 2), with VOC-1 and NOX-1 and VOC-2 and NOX-2 corresponding to the two categories. In addition to these emissions tracers, oxidant tracers called OXN-1, OXV-1, OXN-2, and OXV-2 are added. These correspond to the oxidant produced from NO_x and VOC in each of the two categories.

All of the tracers are advected (transported throughout the domain) in the same manner as the other modeled species. They also undergo deposition, but a deposition velocity is not calculated for the tracers. Instead, the fractional change of oxidant (meaning NO2 + O3) is calculated due to the effects of deposition, and this same fractional change is applied to the oxidant tracers. Similarly, the VOC and NO_X tracers are adjusted according to the change in the total VOC and NO_X.

A crucial step in the OPTM system is the calculation of the change in oxidant during the chemistry step of the model. Prior to the chemistry step, total VOC, total NO_X, and total oxidant are calculated. The chemistry step is then called as usual, using the standard CB-V species (NO, NO_2, O_3, PAR, OLE, TOL, etc.). After the chemistry step, new values of total VOC, NO_X, and oxidant are calculated so that the change in VOC, NO_X, and oxidant (ΔVOC, ΔNOX, and ΔOX) can be calculated.

The change in OXN-1 is ΔOX*NOX-1/(NOX-1 + NOX-2), where the NOX-1 and NOX-2 values correspond to the beginning of the time step. Similarly, the change in OXV-1 is ΔOX*VOC-1/(VOC-1 + VOC-2). The same calculations are made for the Category 2 tracers.

The changes in the VOC and NOX tracers are also calculated. The change in VOC-1 is ΔVOC/VOC * VOC-1 and the change in NOX-1 is ΔNOX/NOX*NOX-1, with corresponding calculations for the Category 2 tracers.

The simulation proceeds as usual from this point.

After the simulation is complete, the ozone attributed to a source category is calculated using both the calculated ozone concentration and the oxidant tracer concentrations, as follows:

- Ozone attributed to Category 1 NO_x = O3*OXN-1/(OXN-1 + OXN-2).
- Ozone attributed to Category 2 NO_x = O3*OXN-2/(OXN-1 + OXN-2).
- Ozone attributed to Category 1 VOC = O3*OXV-1/(OXV-1 + OXV-2).
- Ozone attributed to Category 2 VOC = O3*OXV-2/(OXV-1 + OXV-2)..

The OPTM tags can be defined to represent geographic areas or assigned to categories of emissions (such as mobile, elevated point source, low-level, etc.) There is no explicit limit to the number of VOC or NO_x tags that can be set up within a single simulation.

ATMOS OPTM Results

The ATMOS EAC modeling analysis included three sets of tagging simulations, which tracked contributions to ozone from different emissions sources and source regions. For the August 1999 and July 2001 episodes, the 2007 baseline run was redone under each of three scenarios, called AT-1, AT-2, & AT-3. For the AT-3 scenario, a third episode (July 2002) was also simulated. The specific tags for each scenario are as follows:

SCENARIO AT-1:

- On-road mobile source emissions from five EAC areas (Memphis, Nashville, Knoxville, Chattanooga, and Tri-Cities).
- Other low-level emissions from the five EAC areas.
- Elevated point source emissions from all point sources in Tennessee and all TVA sources.
- All other emissions, including biogenic emissions.

SCENARIO AT-2:

- Anthropogenic emissions from Shelby County, TN sources.
- Anthropogenic emissions from Crittenden County, AR sources.
- Anthropogenic emissions from DeSoto County, MS sources.
- All other emissions (including all biogenic emissions).

SCENARIO AT-3:

- Anthropogenic emissions from the Atlanta 45-county area.
- Anthropogenic emissions from the Birmingham 2-county area.
- All other anthropogenic emissions from the Grid 3.
- All other anthropogenic emissions.
- All biogenic emissions.

In each case, NO_x and VOC emissions are tagged explicitly and each scenario also included an additional tag for all emissions not otherwise tagged in that scenario. In total, the first ATMOS tagging scenario provided a comparison of contribution from anthropogenic emissions from the five EAC areas for three source categories (on-road, elevated, and low-level emissions), the second compared the contribution of emissions from three counties within the Memphis EAC area, and the third tracked emissions from the Atlanta and Birmingham areas, areas within Grid 3, in all other regions in the modeling domain, and from biogenic sources. These simulations provided information regarding the relative contribution of the emissions to observed and simulated ozone in the EAC areas by geographic area and source category as well as the effects of emissions from outside the areas of interest, and was used to guide the selection of control measures (e.g., NO_x vs. VOC controls) based on their expected relative effectiveness in reducing ozone in the EAC areas.

For the AT-1 simulation, Figure 7-7 provides an example of the contributions of each of the tagged source categories for NO_x and VOC emissions on simulated 8-hour ozone exceedance exposure in the Memphis EAC area. This figure is a combination of all non-start-up days for the two episodes. The figure indicates that NO_x emissions from mobile sources and other low-level sources contribute equally to ozone exceedance for the combined August 1999 and July 2001 periods, and that NO_x from TVA and other elevated sources contributes less. For VOC emissions, the low-level sources contribute more to ozone exposure than the mobile or elevated sources. The largest contributor to ozone exceedance exposure in the Memphis EAC area is contributions from biogenic emissions within or around the area or other sources outside the EAC area. As a second example, Figure 7-8 presents contributions in the Nashville EAC area. Contributions from low-level NO_x emissions are somewhat smaller for the Nashville area.

The results for the AT-1 simulation can be summarized as follows:

- On-road mobile source NO_x emissions are important contributors for all areas.
- Other low-level NO_x emissions contribute less than on-road mobile, but other low-level VOC emissions tend to be more important than mobile VOCs.
- Contribution from elevated NO_x is typically less than that for on-road mobile but greater than that for other low-level NO_x sources.
- Relative contributions to the maximum 8-hour ozone value varies from day to day.
- The contribution from all other (including biogenic) sources ranges from about 50 – 80% for NO_x and from about 80-100% for VOC.

For the AT-2 simulation, Figure 7-9 shows the contribution in Shelby County from anthropogenic emissions located in Shelby, Crittenden, and DeSoto Counties. The largest contributor to ozone exceedance exposure in Shelby County among the tagged emissions is from emissions in Shelby County, with much smaller contributions for emissions in Crittenden and DeSoto Counties. Figure 7-10 shows the contribution in Crittenden County from anthropogenic emissions located in Shelby, Crittenden, and DeSoto Counties. The largest contributor to ozone exceedance exposure in Crittenden County is from emissions in Shelby County, with smaller contributions for emissions in Crittenden and DeSoto Counties. The results for the AT-2 simulation can be summarized as follows:

- For the ATMOS simulation days, emissions from Shelby Co. contribute to 8-hour ozone in Shelby, Crittenden, and DeSoto Co.
- Local (same-county) emissions are also important, especially during peak 8-hour ozone periods.
- Background and transported ozone and precursors are important factors for all three counties.

For the AT-3 scenario, emissions in the Greater Atlanta area, the Birmingham area, the rest of Grid 3, the area outside of Grid 3, and biogenic emissions, were all tagged separately. The AT-3 scenario was run for all three ATMOS episodes. Figure 7-11 depicts the contribution of NO_x and

VOC emissions from these areas/source categories to 8-hour ozone exceedance exposure for the Chattanooga EAC area. For these episodes, there is some contribution to 8-hour ozone exceedance in this area from the Atlanta-area NO_x emissions. There is also a significant contribution from NO_x emissions within Grid 3, and an even larger contribution from sources outside of Grid 3. For VOC emissions, there is a very slight contribution from the Atlanta area, with the largest contributors being sources outside Grid 3 and biogenic sources. Figure 7-12 shows the contribution to simulated 8-hour maximum concentrations at the Sequoyah monitor, located in Chattanooga, at three different simulation times. The pie charts depict the contributions from each of the tagged emissions. For these dates and times, the contribution from the Atlanta area NOx emissions is fairly significant, contributing 11 to 21 percent of the simulated 8-hour maximum concentration for these periods. The contribution from NO_x emissions outside of Grid 3, however, dominates for these periods. For VOC emissions, the contribution from biogenic emissions is comparable to that of VOCs from outside of Grid 3. The results of the AT-3 simulation can be summarized as follows:

- Emissions from the Atlanta metropolitan area contribute to ozone exceedances in Knoxville and Chattanooga.
  - Of the NO_x contributing to the 8-hour exceedance exposure, about 20% overall is attributed to emissions from Atlanta.
  - Of the NO_x contributing to the peak 8-hour values, about 5-15% is attributed to Atlanta on certain exceedance days.
- Background and transported ozone and precursors are important factors for all areas.
- Approximately 40 to 60% of the ozone is attributed to biogenic VOC emissions.

Attainment-Strategy Simulations

The ambitious EAC schedule precluded an extensive emission-reduction sensitivity analysis using the 2007 baseline inventory. However, in the previous phase of ATMOS, a number of emission reduction sensitivity simulations were conducted for a 2010 baseline. The results of these simulations indicated the following: 1) reductions of NOx emissions are more effective in reducing ozone concentrations than similar percentage reductions in VOC emissions, 2) local emission reductions are more effective in reducing local ozone concentrations, and 3) the ATMOS EAC areas are affected, to some extent, by precursor emissions and ozone formed outside the areas, and the extent of the contribution varies from day to day and among the EAC areas.

Between 2001 and 2007, the expected emission reductions showed significant reductions in the simulated 1-hour and 8-hour ozone metrics, however, based on the calculated EDVs, the 2007 baseline simulation did not show simulated attainment for all EAC areas. Thus, more reductions are required for these areas. On the basis of the information derived from the 2010 emission reduction sensitivity analysis and the OPTM tagging simulations, a series of attainment strategy simulations were identified and conducted for the three ATMOS modeling episodes. Representatives from each of the areas first prepared a list of potential local EAC control measures. For the Tennessee EAC areas, the University of Tennessee (UT) provided assistance in identifying and quantifying the EAC measures. A summary of the potential measures for the Nashville EAC is presented by UT (2003). The list of potential measures is presented in Table 7-3.

Prior to having the measures selected by each of the groups, a strategy sensitivity simulation was conducted to assess the sensitivity to emission reductions in each of the EAC counties. This scenario, referred to as AS-1, involved the following reductions: a 5% reduction in all anthropogenic sources of NO_x, VOC, and CO in all EAC counties with the following exceptions: Chattanooga EAC reductions of 5% coming from area sources only, and for Davidson County of the Nashville EAC, a 5% reduction in area sources, a 1% reduction in low-level point and non-road sources, and a 2% reduction in mobile emissions. This scenario was conducted for the 2007 baseline simulations of the August 1999 and June 2001 episodes. The results for AS-1 indicate that 8-hour exceedance exposure is reduced by 10 percent while EDV’s are reduced by about 1 ppb for the Memphis, Nashville, and Knoxville areas and unchanged in the Chattanooga and Tri-Cities areas.

After quantification of the list of potential emission reduction measures, a second strategy simulation has conducted in which reductions were made in all EAC areas reflecting all possible measures from the list. This scenario, AS-2, is referred to as the “all measures” scenario and was conducted for the August 1999 and June 2001 episodes. Figure 7-14 presents NOx and VOC emission totals comparing the 2007 Baseline emissions with the AS-2 emissions. Imposing all potential EAC measures in 2007 results in approximately a 5 to 8 percent reduction in NO_x emissions and as much as a 10 percent reduction in VOC emissions in these areas. The AS-2 simulation resulted in reductions in 8-hour exceedance exposure of from 12 to 50 percent compared to the 2007 baseline, while EDVs are reduced approximately 2 ppb for the Memphis, Knoxville, and Chattanooga area and unchanged for the Nashville and Tri-Cities EAC areas.

Following the AS-2 scenario, each of the EAC areas re-visited the list and the commitments that could be made in each of the EAC counties and in local jurisdictions. The next scenario (AS-3) assessed the effects of a reduced set of measures, which included less emission reductions. The results for AS-3 show model responses between the AS-1 and AS-2 scenarios. Following the AS-3 scenario, the EAC areas prepared a final list of measures that would be adopted as part of the EAC program. This final scenario, AS-4, assessed the effects of a slightly different set of EAC measures than AS-3 and included fewer emission reductions compared to the AS-2 “all measures” scenario.

Table 7-4 presents the local measures selected by each of the EAC areas for the AS-4 attainment strategy scenario. The expected reductions (tpd) are presented for NO_x, VOC, and CO emissions for each county contained in the EAC area. The AS-4 scenario was run for the three ATMOS episodes and the results are presented in the next section of this report.

Table 7-1a.
Comparison of the ATMOS Current Year (2001)
and Future Year Baseline (2007) Simulation Results for All Non-startup Days

Grid/Area	8-hr Exceedance Exposure			# Grid-cells where max 8-hr > 84 ppb		
	2001	2007	% Reduction	2001	2007	% Reduction
Grid 3	4502274	1342820	70	41602	14798	64
Memphis EAC	92093	44429	51	766	460	40
Nashville EAC	208109	65140	69	2079	887	57
Knoxville EAC	140359	24169	83	1358	517	62
Chattanooga EAC	204711	56174	73	1741	693	60
Tri-Cities EAC	60247	18187	70	411	207	50

Table 7-1b.
Comparison of the ATMOS Current Year (2001) and Future Year Baseline (2007) Simulation Results for All Non-startup Days

Grid/Area	# Grid Cell Hours where 1-Hr Concs > 84 ppb			1-Hr Exceedances Exposure for Concs > 84 ppb		
	2001	2007	% Reduction	2001	2007	% Reduction
Grid 3	388289	151316	61	3800105	1290141	66
Memphis EAC	7514	4227	44	77821	40541	48
Nashville EAC	18777	8752	53	176247	66871	62
Knoxville EAC	11554	5093	56	111972	30180	73
Chattanooga EAC	14858	6453	57	154244	50725	67
Tri-Cities EAC	5015	2382	53	47512	16342	66

Table 7-2.
Maximum Observed and Estimated Design Values (EDVs) for the ATMOS EAC Areas for the 2007 Baseline Simulation

Site	2000–2002			2001–2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Memphis EAC (Marion)	94	89	88	92	87	87
Nashville EAC (Rockland Rd.)	88	81	82	86	79	80
Knoxville EAC (Spring Hill)	96	90	90	92	86	86
Knoxville EAC (Clingman’s Dome)	98	89	87	92	84	82
Chattanooga EAC (Sequoyah)	93	86	86	87	80	80
Tri-Cities EAC (Kingsport)	92	85	84	86	79	79

Table 7-3.
List of Potential EAC Emission Reductions Measures for the ATMOS EAC Areas

Area Sources

- Open burning ban -residential garbage
- Open burning ban -yard waste
- Open burning ban - land clearing
- Stage I controls at gas stations
- Stage II controls at gas stations

Onroad Mobile Sources

- Smoking vehicle ban
- HOV lane expansion
- Rideshare programs
- Traffic signal synchronization
- Roadside assistance program
- New greenways/bikeways
- Low emission fleets (on-road)
- Reduce school bus idling
- Improve bus ridership
- New rail service
- Land use controls to reduce VMT
- Air Quality Action Day measures
- Anti-idling Legislation
- Cetane Additive to Diesel
- Inspection & Maintenance (OBD only) I/M.
- Inspection & Maintenance OBDII and Idle I/M
- Intelligent transportation systems
- Lower gas RVP (from 9 to 7.8)
- Lower interstate truck speeds by 10 mph
- Ozone Action Day (Reduce VMT 1%)
- Traffic Flow Improvement
- Transit (increase bus ridership 5%)
- Trip Reduction Programs
- Truck stop electrification
- Voluntary Control Measures

Nonroad Mobile Sources

- Replace Construction Equipment
- New airport vehicles

Point Sources

- 50 Ton NOx/Year RACT Rule

Table 7-4a.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Memphis EAC Area

Control Measures by Source Category	Fayette, TN			Shelby, TN			Tipton, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TP D
Area									
Open Burning Ban - Land clearing	0.000	0.000	0.000	0.300	7.170	13.140	0.000	0.000	0.000
Onroad Mobile									
Intelligent transportation sys (CMAQ Report)	0.000	0.000	0.000	0.159	0.061	0.660	0.000	0.000	0.000
Lower interstate truck speeds by 10 mph.	0.000	0.000	0.000	5.900	0.000	0.000	0.000	0.000	0.000
Anti-idling Legis. (1% veh idle 5 min/day)	0.000	0.000	0.000	0.012	0.012	0.079	0.000	0.000	0.000
Voluntary Control Measures	0.000	0.000	0.000	0.676	0.449	0.833	0.000	0.000	0.000
Point Sources	0.000	0.000	0.000	4.900	0.245	0.000	0.000	0.000	0.000
Reductions by Source Category									
Area	0.000	0.000	0.000	0.300	7.170	13.140	0.000	0.000	0.000
Mobile Source	0.000	0.000	0.000	6.747	0.522	1.572	0.000	0.000	0.000
Elev. Point	0.000	0.000	0.000	4.900	0.245	0.000	0.000	0.000	0.000

Control Measures by Source Category	Crittenden, AR			De Soto, MS		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area						
Open Burning – land clearing/debris	0.000	0.000	0.000	0.175	0.407	5.929
Stage I Controls at Gas Stations.	0.000	0.485	0.000	0.000	0.000	0.000
Nonroad Mobile						
Construction Equipment (All New).	0.110	0.010	0.050	0.000	0.000	0.000
Reductions of Maintenance on Action Days	0.000	0.000	0.000	0.100	0.020	0.400
Onroad Mobile						
Truck stop electrification	0.036	0.003	0.276	0.000	0.000	0.000
Ozone Action Day (Reduce VMT 1%)	0.024	0.032	0.353	0.000	0.000	0.000
Truck idling reductions	0.000	0.000	0.000	0.100	0.050	0.600
Reductions by Source Category						
Area	0.000	0.485	0.000	0.175	0.407	5.929
Mobile Source	0.060	0.035	0.629	0.100	0.050	0.600
Nonroad Mobile	0.110	0.010	0.050	0.100	0.020	0.400

Table 7-4b.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Nashville EAC Area

Control Measure by Source Category	Davidson, TN			Rutherford, TN			Sumner, TN			Williamson, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area												
-const. Land clear (open burning).	0.111	0.423	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Onroad Mobile												
-HOV lane expansion	0.012	0.015	0.174	0.005	0.006	0.071	0.000	0.000	0.000	0.000	0.000	0.000
-trip reduction plans	0.040	0.051	0.578	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.017	0.193
-rideshare programs	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014
-traffic signal synchronization	0.091	0.110	0.679	0.038	0.050	0.305	0.033	0.038	0.225	0.018	0.023	0.143
-roadside assistance program	0.031	0.031	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-new greenways/bikeways	0.010	0.012	0.140	0.007	0.009	0.105	0.007	0.009	0.105	0.007	0.009	0.105
-reduce school bus idling	0.007	0.001	0.007	0.003	0.000	0.002	0.003	0.000	0.003	0.003	0.000	0.002
-improve bus ridership	0.010	0.012	0.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-new rail service	0.021	0.037	0.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-land use controls to reduce VMT	0.260	0.110	1.340	0.090	0.030	0.360	0.040	0.020	0.210	0.050	0.020	0.260
-AQAD measures	0.510	0.220	2.680	0.170	0.060	0.720	0.080	0.040	0.410	0.110	0.040	0.510
Reductions by Source Category												
Area	0.111	0.423	3.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Onroad Mobile	0.992	0.600	6.504	0.314	0.157	1.577	0.164	0.108	0.966	0.202	0.110	1.226

Control Measure by Source Category	Wilson, TN			Cheatham, TN			Dickson, TN			Robertson, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Onroad Mobile												
-rideshare programs	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014	0.001	0.001	0.014
-traffic signal synchronization	0.015	0.018	0.105	0.000	0.000	0.000	0.008	0.015	0.080	0.005	0.008	0.050
-new greenways/bikeways	0.007	0.009	0.105	0.007	0.009	0.105	0.007	0.009	0.105	0.007	0.009	0.105
-reduce school bus idling	0.002	0.000	0.002	0.001	0.000	0.001	0.001	0.000	0.001	0.001	0.000	0.001
-new rail service	0.021	0.037	0.420	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-land use controls to reduce VMT	0.050	0.020	0.210	0.030	0.010	0.130	0.030	0.020	0.160	0.060	0.020	0.210
-AQAD measures	0.110	0.030	0.430	0.060	0.020	0.270	0.060	0.030	0.330	0.120	0.030	0.430
Reductions by Source Category												
Onroad Mobile	0.206	0.115	1.285	0.100	0.041	0.520	0.107	0.076	0.690	0.195	0.068	0.810

Table 7-4c.
Emissions Reductions the AS-4 EAC Attainment Strategy: Knoxville EAC Area

Control Measure by Source Category	Anderson, TN			Blount, TN			Jefferson, TN			Knox, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area												
Open Burning Ban –residential garbage	0.012	0.015	0.178	0.019	0.022	0.265	0.008	0.009	0.111	0.000	0.000	0.000
Open Burning Ban -yard waste	0.003	0.019	0.100	0.005	0.028	0.148	0.002	0.012	0.062	0.000	0.000	0.000
Open Burning Ban - land clearing	0.178	0.692	4.700	0.265	1.026	4.800	0.111	0.430	3.200	0.955	3.706	21.500
Nonroad Mobile												
Construction Equipment (14.3 % New).	0.014	0.002	0.006	0.027	0.003	0.011	0.019	0.002	0.008	0.140	0.017	0.063
Onroad Mobile												
Truck stop electrification, 30% occupancy	0.012	0.001	0.011	0.000	0.000	0.000	0.171	0.016	0.144	0.300	0.029	0.253
Transit (increase bus ridership 5%)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.012
Trip Reduction Programs	0.000	0.000	0.000	0.019	0.025	0.000	0.000	0.000	0.000	0.091	0.125	0.000
Traffic Flow Improvement	0.005	0.005	0.000	0.007	0.007	0.000	0.004	0.004	0.000	0.017	0.018	0.000
Ozone Action Day (Reduce VMT 1%)	0.027	0.035	0.393	0.032	0.041	0.463	0.028	0.037	0.414	0.157	0.204	2.281
Point												
50 Ton NOx/Year RACT Rule												
Becromal & Chestnut Landfill	0.350	0.000	0.000									
Alcoa				0.500	0.000	0.000						
UT, St. Marys, Tamko, TSD, & CEMEX										1.580	0.013	0.280
Kimberly Clarke & Trigen; Staley & Viskase												
Dan River												
Reductions by Source Category												
Area Sources	0.194	0.725	4.978	0.288	1.076	5.213	0.120	0.451	3.373	0.955	3.706	21.500
Onroad Mobile	0.044	0.041	0.404	0.057	0.074	0.463	0.203	0.057	0.558	0.567	0.376	2.546
Nonroad Mobile	0.014	0.002	0.006	0.027	0.003	0.011	0.019	0.002	0.008	0.140	0.017	0.063
Elev. Point	0.350	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	1.580	0.000	0.280

Table 7-4c.
Emissions Reductions the AS-4 EAC Attainment Strategy: Knoxville EAC Area *(continued)*

Control Measure by Source Category	Loudon, TN			Sevier, TN			Union, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area									
Open Burning Ban –residential garbage	0.007	0.008	0.098	0.012	0.015	0.178	0.003	0.004	0.045
Open Burning Ban -yard waste	0.002	0.010	0.055	0.003	0.019	0.100	0.001	0.005	0.025
Open Burning Ban - land clearing	0.098	0.379	1.900	0.178	0.690	3.200	0.045	0.173	1.100
Nonroad Mobile									
Construction Equipment (14.3 % New).	0.007	0.001	0.003	0.033	0.004	0.015	0.002	0.000	0.000
Onroad Mobile									
Truck stop electrification, 30% occupancy	0.129	0.012	0.109	0.026	0.002	0.022	0.000	0.000	0.000
Traffic Flow Improvement	0.003	0.003	0.000	0.007	0.008	0.000	0.001	0.001	0.000
Ozone Action Day (Reduce VMT 1%)	0.024	0.032	0.353	0.032	0.041	0.462	0.004	0.005	0.056
Point									
50 Ton NOx/Year RACT Rule									
Becromal & Chestnut Landfill									
Alcoa									
UT, St. Marys, Tamko, TSD, & CEMEX									
Kimberly Clarke & Trigen; Staley & Viskase	3.550								
Dan River				0.190					
Reductions by Source Category									
Area Sources	0.106	0.398	2.052	0.194	0.724	3.478	0.048	0.181	1.169
Onroad Mobile	0.156	0.047	0.461	0.065	0.051	0.484	0.005	0.006	0.056
Nonroad Mobile	0.007	0.001	0.003	0.033	0.004	0.015	0.002	0.000	0.000
Elev. Point	3.550	0.000	0.000	0.190	0.000	0.000	0.000	0.000	0.000

Table 7-4d.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Chattanooga EAC Area

Control Measures by Source Category	**Hamilton, TN**			**Marion, TN**			**Meigs, TN**		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TP D
Area									
Open Burning Ban -yard waste	0.140	0.506	9.600	0.000	0.000	0.000	0.000	0.000	0.000
Open Burning Ban - Land clearing	0.440	1.102	6.320	0.000	0.000	0.000	0.000	0.000	0.000
Stage I Controls at Gas Stations	0.000	2.468	0.000	0.000	0.485	0.000	0.000	0.058	0.000
Nonroad Mobile									
Construction Equipment (10% New)	0.053	0.007	0.024	0.008	0.001	0.004	0.001	0.001	0.005
Onroad Mobile									
Cetane to Diesel (-3% NOx)(10% effective)	0.110	0.000	0.000	0.039	0.000	0.000	0.000	0.000	0.000
Anti-idling Legis. (1% veh idle 5 min/day)	0.004	0.004	0.027	0.000	0.000	0.002	0.000	0.000	0.001
Transit (increase bus ridership 10%)	0.003	0.004	0.043	0.000	0.000	0.000	0.000	0.000	0.000
Ozone Action Day (Reduce VMT 1%)	0.124	0.161	1.796	0.024	0.032	0.353	0.003	0.004	0.042
Reductions by Source Category									
Area	0.580	4.076	15.920	0.005	0.485	0.000	0.000	0.058	0.000
Onroad Mobile	0.241	0.157	1.866	0.064	0.028	0.355	0.003	0.004	0.043
Nonroad Mobile	0.053	0.007	0.024	0.008	0.001	0.004	0.001	0.001	0.005

Control Measures by Source Category	Catoosa, GA			Walker, GA		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area						
Open Burning Ban -residential garbage	0.040	0.194	0.120	0.050	0.218	0.150
Open Burning Ban -yard waste	0.000	0.000	0.000	0.003	0.016	0.085
Open Burning Ban - land clearing	0.370	1.102	4.870	0.000	0.000	0.000
Stage I Controls at Gas Stations	0.000	0.000	0.000	0.000	0.323	0.000
Nonroad Mobile						
Construction Equipment (10% New)	0.006	0.001	0.003	0.012	0.001	0.005
Onroad Mobile						
Anti-idling Legis. (1% veh idle 5 min/day)	0.001	0.001	0.005	0.001	0.001	0.005
Ozone Action Day (Reduce VMT 1%)	0.024	0.031	0.342	0.016	0.021	0.235
Reductions by Source Category						
Area	0.410	1.296	4.990	0.053	0.557	0.235
Onroad Mobile	0.024	0.029	0.346	0.017	0.021	0.240
Nonroad Mobile	0.006	0.001	0.003	0.012	0.001	0.005

Table 7-4e.
Emissions Reductions for the AS-4 EAC Attainment Strategy: Tri-Cities EAC Area

Control Measure by Source Category	Carter, TN			Hawkins, TN			Johnson, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area									
Open Burning Ban –residential garbage	0.049	0.060	0.700	0.060	0.070	0.860	0.030	0.037	0.440
Open Burning Ban -yard waste	0.002	0.013	0.071	0.003	0.016	0.087	0.001	0.008	0.044
Open Burning Ban - land clearing	0.074	0.272	0.650	0.070	0.257	1.500	0.023	0.084	0.700
Ozone Action Day (Reduce VMT 1%)	0.023	0.025	0.230	0.022	0.024	0.220	0.007	0.007	0.070
Reductions by Source Category									
Area	0.148	0.370	1.651	0.154	0.367	2.667	0.061	0.136	1.254

Control Measure by Source Category	Sullivan, TN			Unicoi, TN			Washington, TN		
	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD	NOx TPD	VOC TPD	CO TPD
Area									
Open Burning Ban –residential garbage	0.076	0.092	1.100	0.022	0.026	0.031	0.063	0.077	0.890
Open Burning Ban -yard waste	0.003	0.020	0.108	0.001	0.006	0.031	0.003	0.017	0.091
Open Burning Ban - land clearing	0.199	0.735	9.183	0.023	0.085	1.060	0.139	0.515	2.300
Ozone Action Day (Reduce VMT 1%)	0.120	0.090	0.900	0.010	0.010	0.100	0.075	0.060	0.570
Reductions by Source Category									
Area	0.398	0.937	11.291	0.056	0.127	1.222	0.280	0.668	3.851

Figure 7-1a.
Comparison of NOx Emissions by Component for ATMOS Grid 3 for 2001 and the 2007 Baseline

Weekday Emissions for 18 June

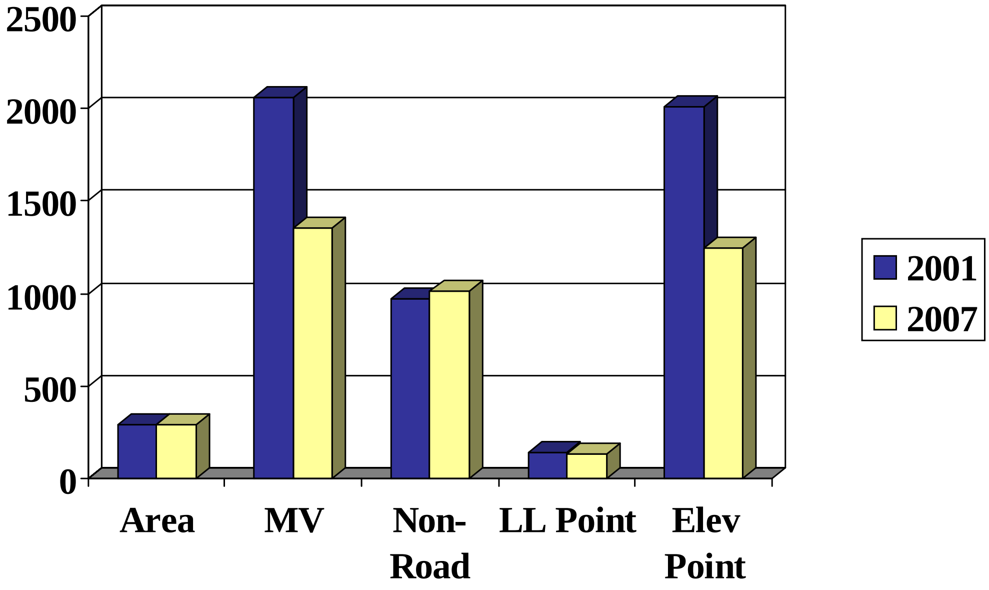


Figure 7-1b.
Comparison of VOC Emissions by Component for ATMOS Grid 3 for 2001 and the 2007 Baseline

Weekday Emissions for 18 June

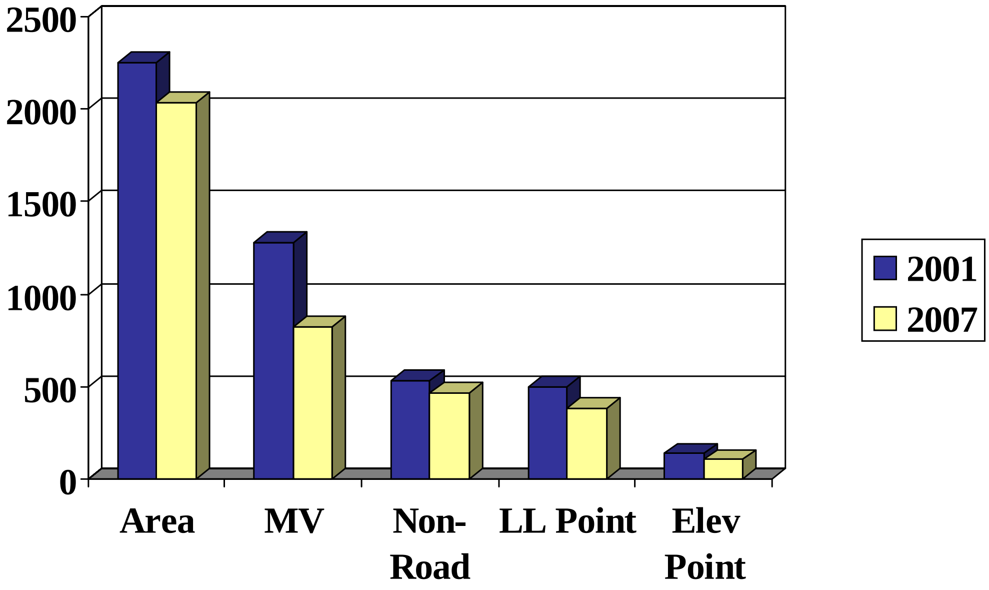


Figure 7-1c.
Comparison of CO Emissions by Component for ATMOS Grid 3 for 2001 and the 2007 Baseline

Weekday Emissions for 18 June

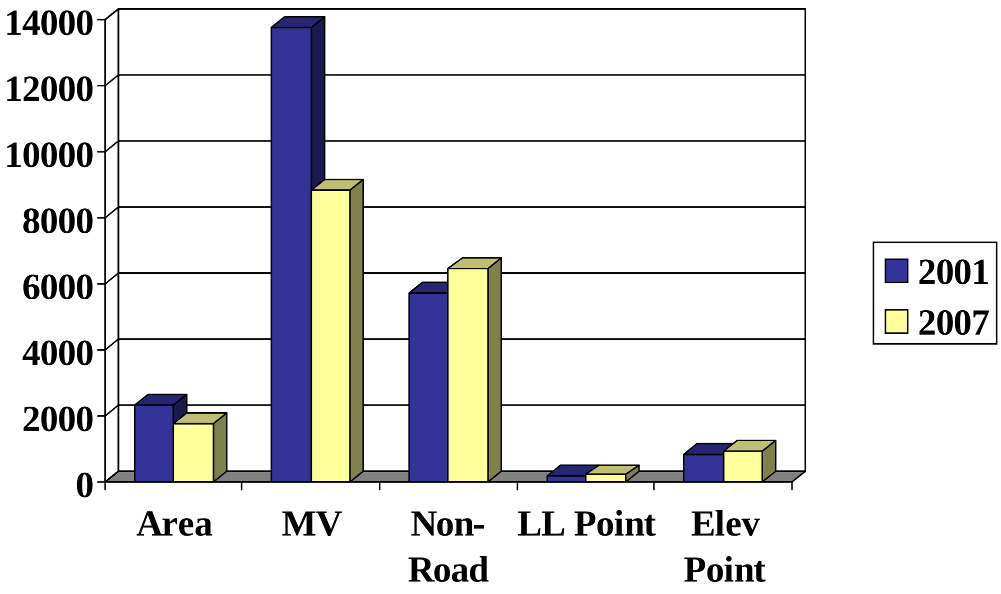


Figure 7-2.
Anthropogenic Emissions (tpd) for the Memphis EAC Area

Emissions for 18 June Episode Day

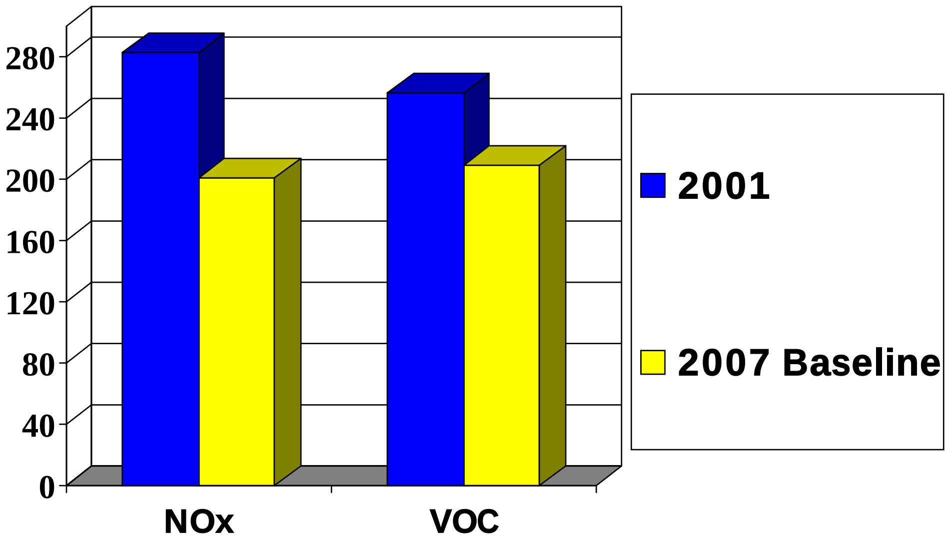


Figure 7-3.
Anthropogenic Emissions (tpd) for the Nashville EAC Area

Emissions for 18 June Episode Day

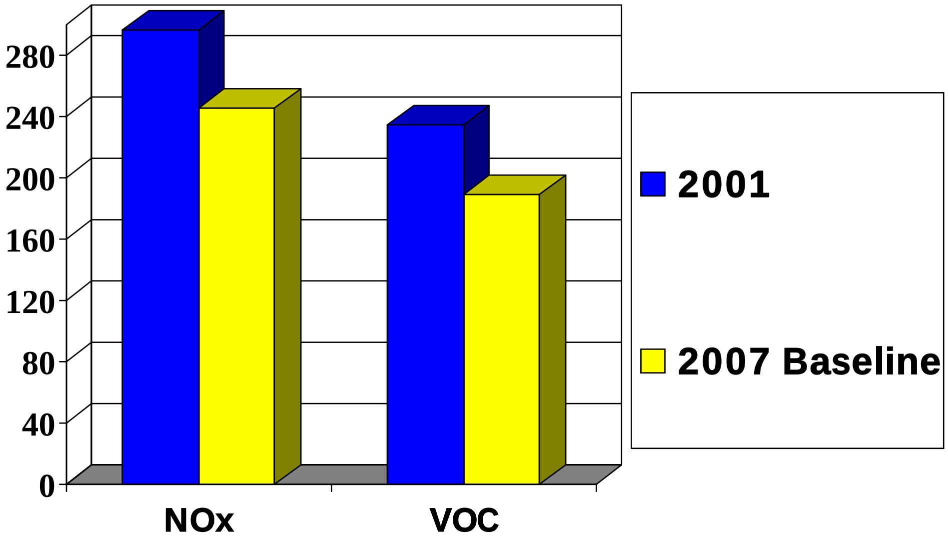


Figure 7-4.
Anthropogenic Emissions (tpd) for the Knoxville EAC Area

Emissions for 18 June Episode Day

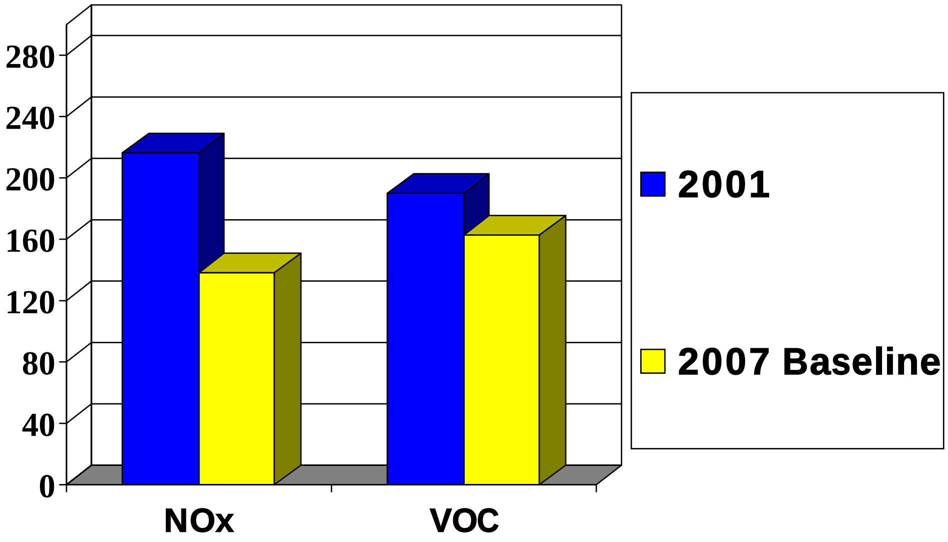


Figure 7-5.
Anthropogenic Emissions (tpd) for the Chattanooga EAC Area

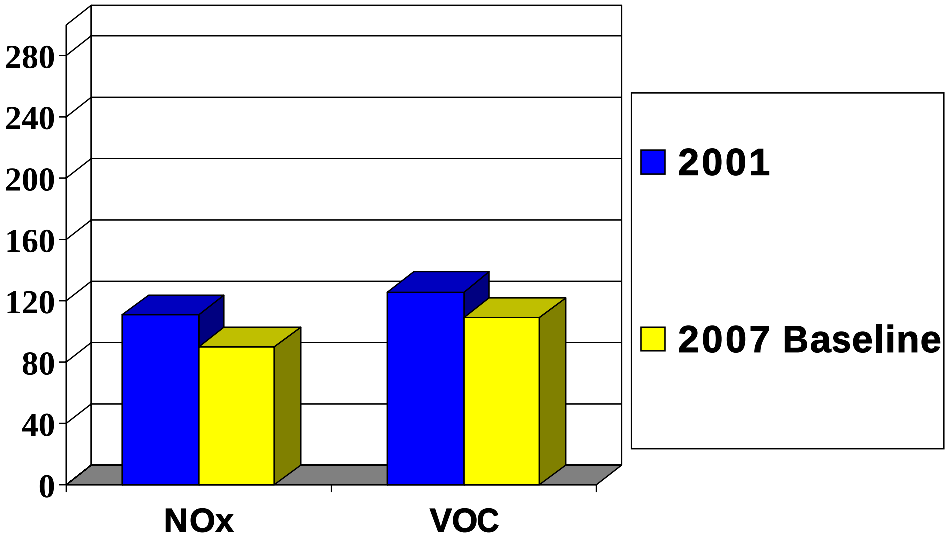


Figure 7-6.
Anthropogenic Emissions (tpd) for the Tri-Cities EAC Area

Emissions for 18 June Episode Day

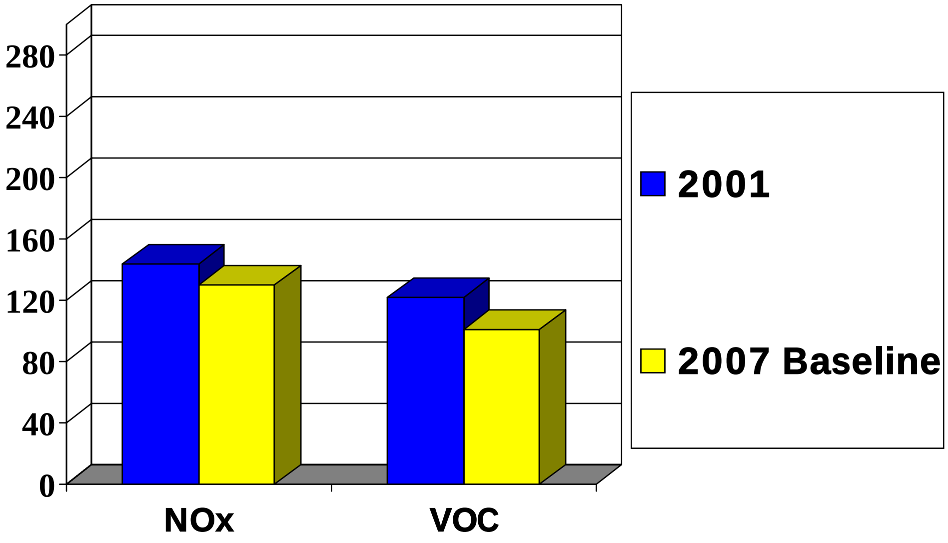


Figure 7-7.
Contribution from NOx and VOC Emissions to Total 8-hour Ozone Exceedance Exposure in the Memphis EAC Area

Aug/Sep (1999) and June (2001) Simulation Periods Combined: 2007 Baseline

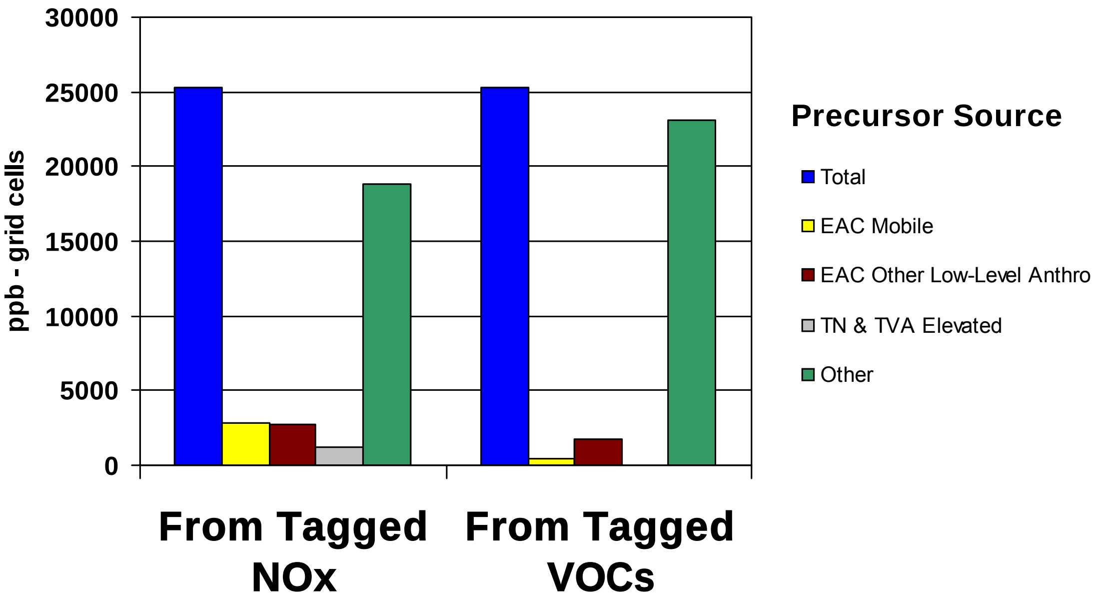


Figure 7-8.
Contribution from NOx and VOC Emissions to Total 8-hour Ozone Exceedance Exposure in the Nashville EAC Area

Aug/Sep (1999) and June (2001) Simulation Periods Combined: 2007 Baseline

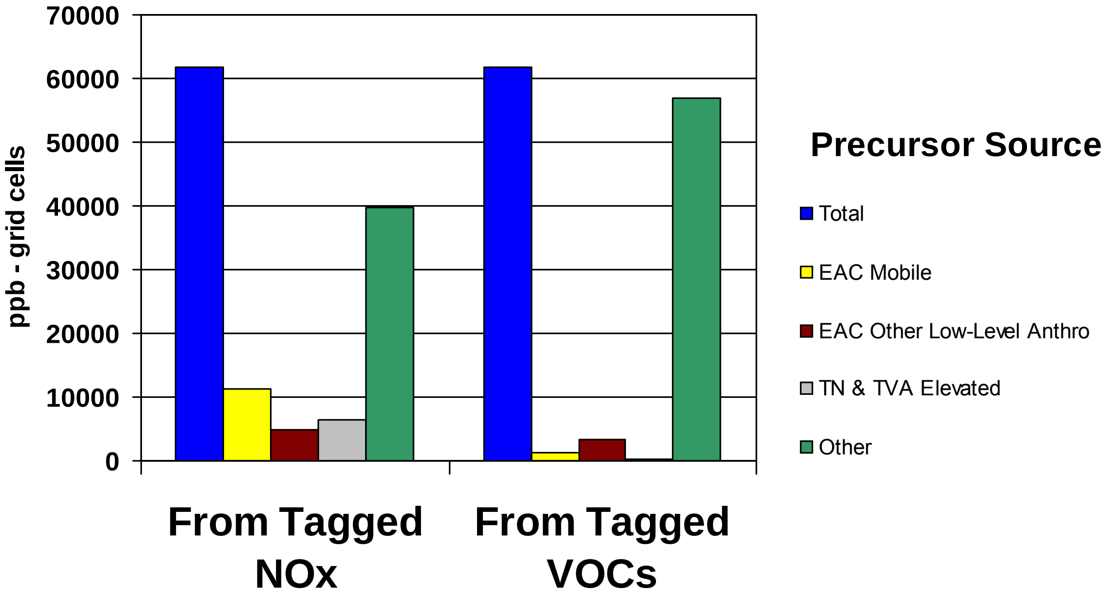


Figure 7-9.
Contribution from NOx and VOC Emissions in Shelby, Crittenden, and DeSoto Counties to Total 8-hour Ozone Exceedance Exposure in Shelby County, TN

Aug/Sep (1999) and June (2001) Simulation Periods Combined: 2007 Baseline

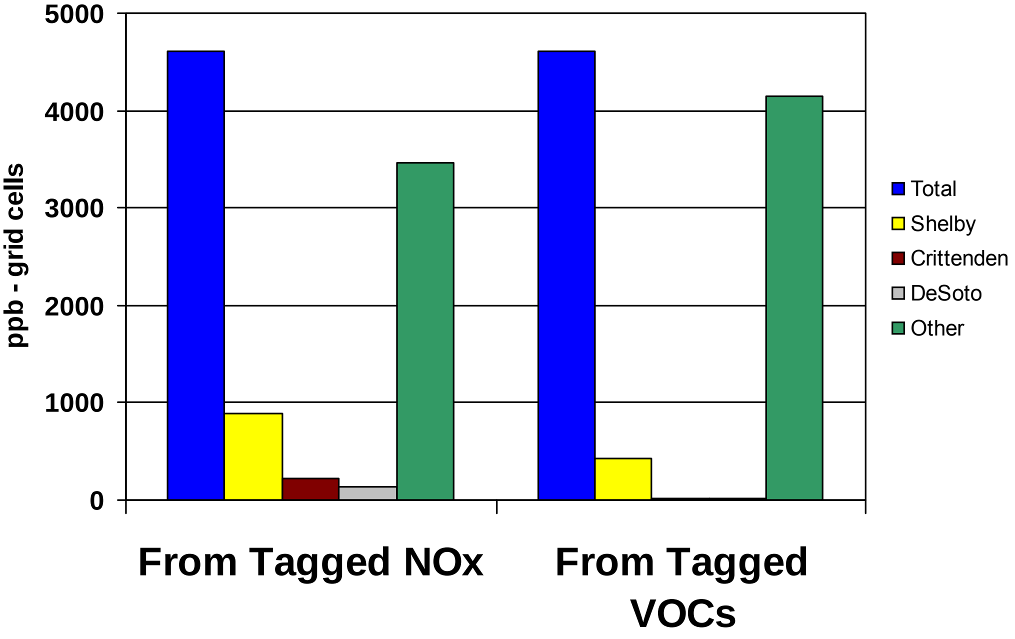


Figure 7-10.
Contribution from NOx and VOC Emissions in Shelby, Crittenden, and DeSoto Counties to Total 8-hour Ozone Exceedance Exposure in Crittenden County, AR

Aug/Sep (1999) and June (2001) Simulation Periods Combined: 2007 Baseline

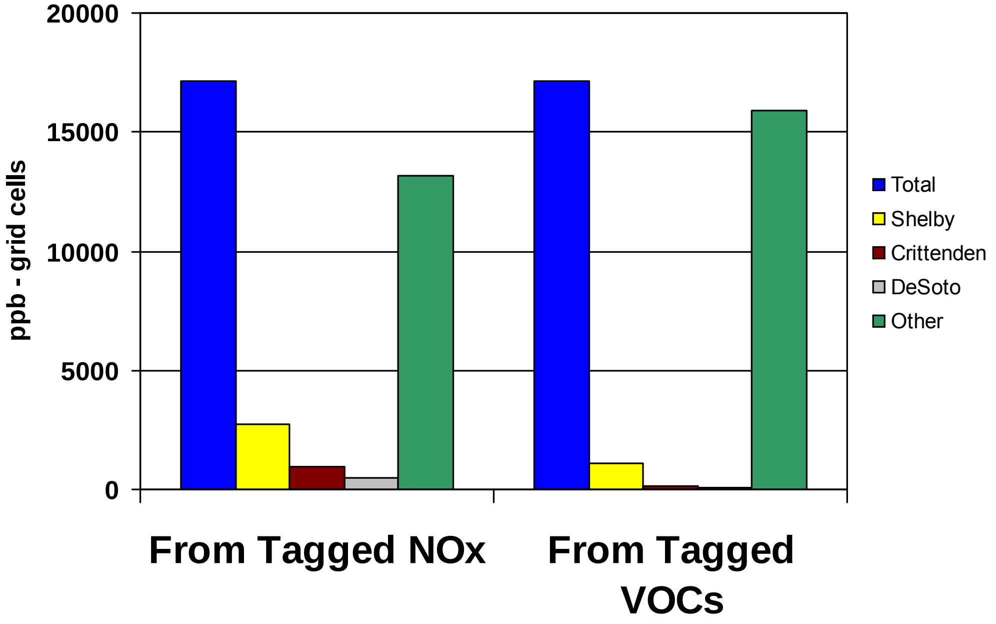


Figure 7-11.
Contribution from NOx and VOC Emissions in Atlanta, Birmingham, within Grid 3, and Outside Grid 3 to Total 8-hour Ozone Exceedance Exposure in the Chattanooga EAC Area

Aug/Sep (1999), June (2001), and July (2002) Simulation Periods Combined: 2007 Baseline

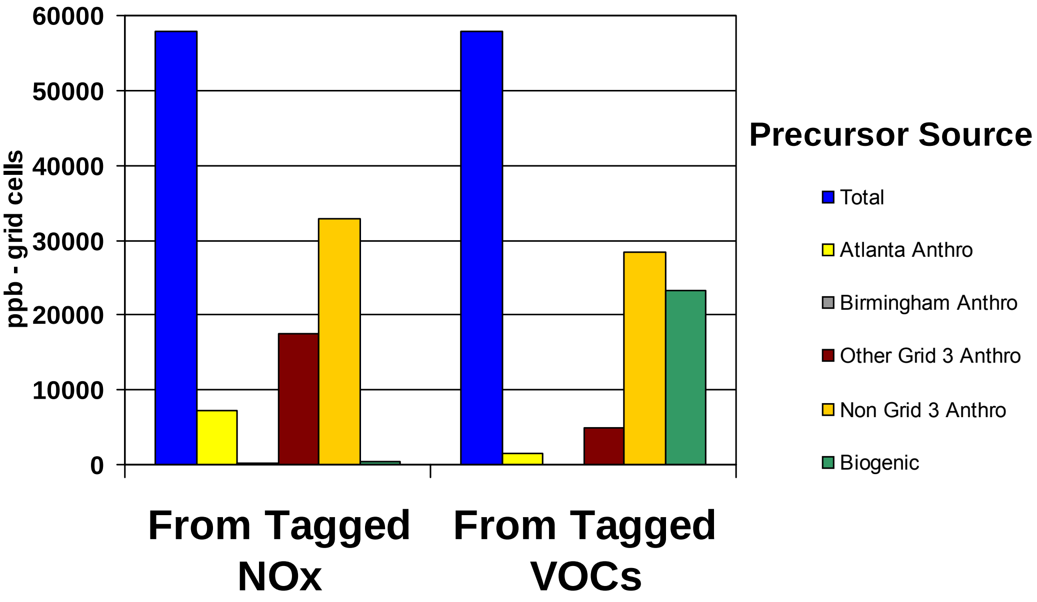


Figure 7-12.
Relative Contribution from Regional VOC and NOx Emissions to Simulated 8-hour Maximum Ozone Concentration at the Sequoyah Monitor (Chattanooga) for Three Different 8-Hour Periods

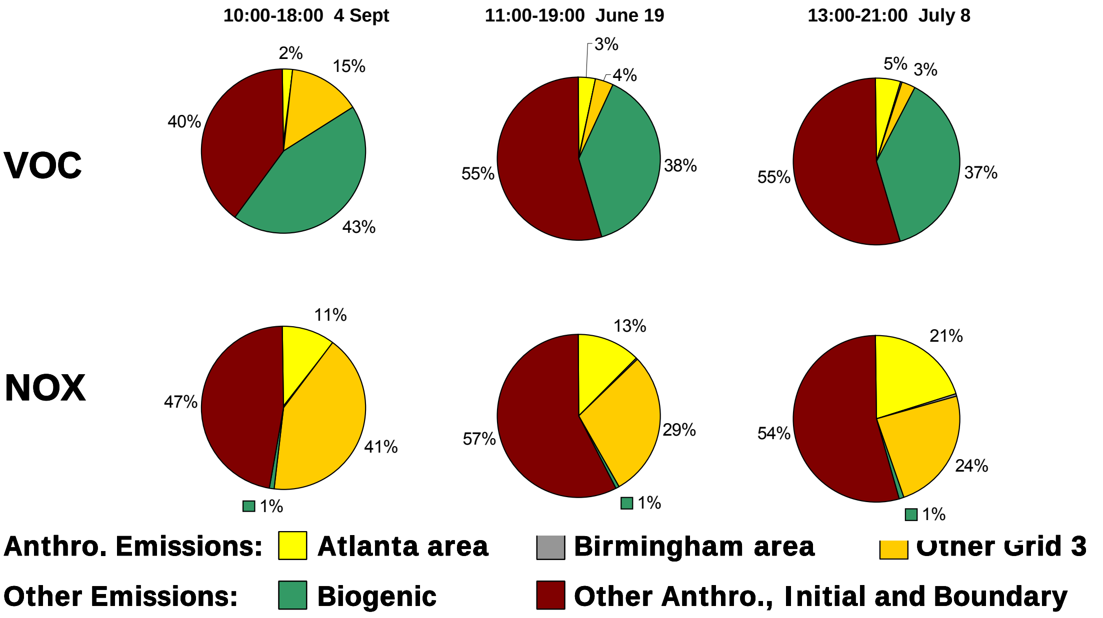


Figure 7-13.
Contribution from NOx and VOC Emissions in Atlanta, Birmingham, Within Grid 3, and Outside of Grid 3 to Total 8-hour Ozone Exceedance Exposure in the Knoxville EAC Area

Aug/Sep (1999), June (2001), and July (2002) Simulation Periods Combined: 2007 Baseline

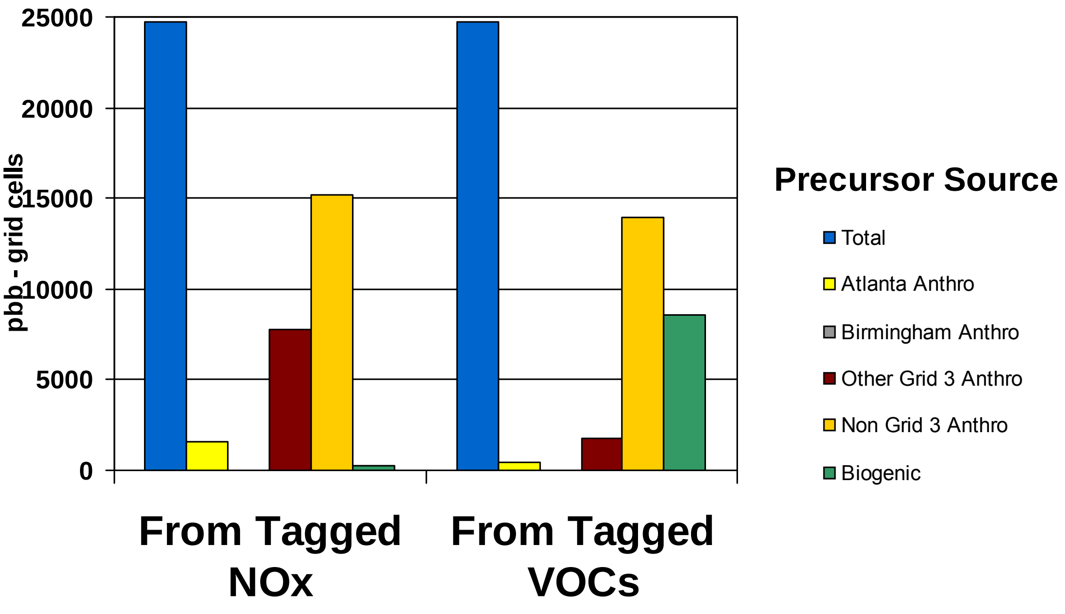


Figure 7-14a.
Total NOx Emissions (tpd) for the EAC Areas for the 2007 Baseline and "All Measures" Strategy Simulation (AS-2)

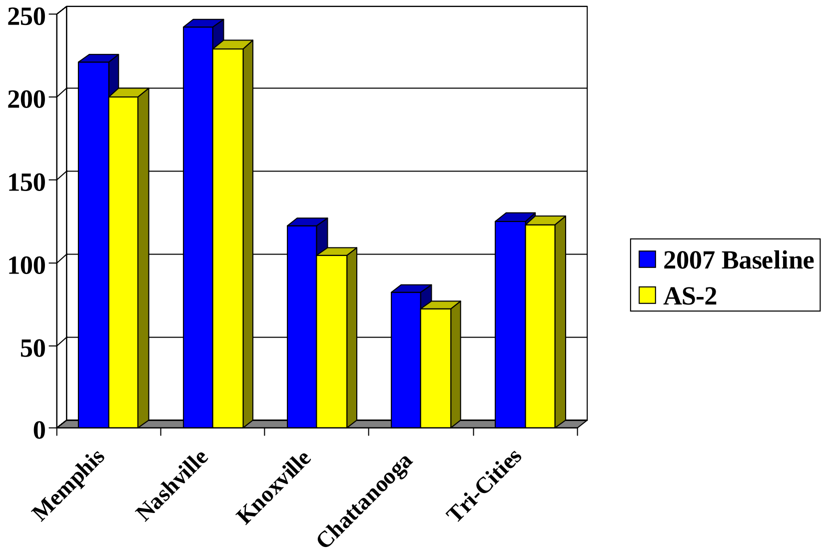
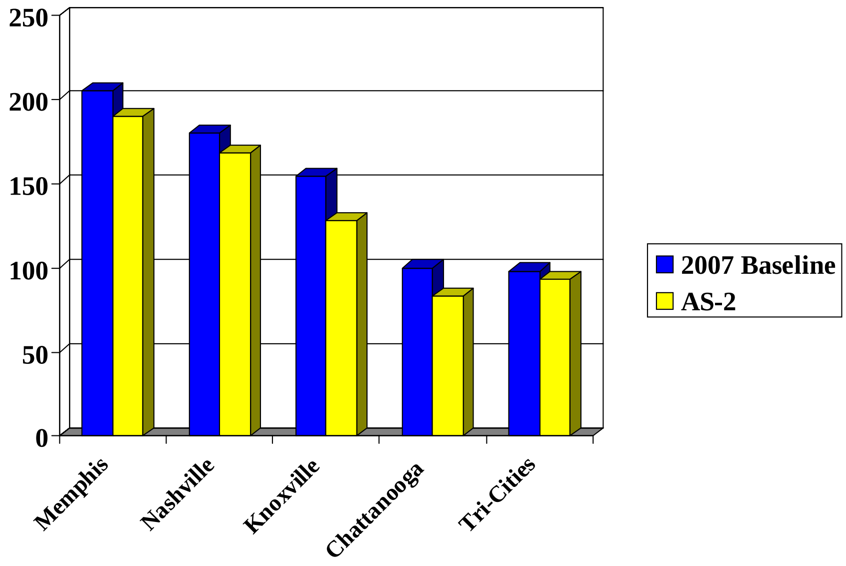


Figure 7-14b.
Total VOC Emissions (tpd) for the EAC Areas for the 2007 Baseline and "All Measures" Strategy Simulation (AS-2)



8. Attainment Demonstration

In this section we present results from the application of the draft EPA 8-hour ozone attainment demonstration procedures. These procedures are outlined in the draft guidance document on using models and other analyses to demonstrate future attainment of the proposed 8-hour ozone standard (EPA, 1999a). They were adapted for the ATMOS modeling domain and simulation periods and applied using the results from the attainment strategy simulation AS-4, as presented in the previous section.

Overview of the ATMOS 8-Hour Ozone Attainment Demonstration Procedures

The draft EPA guidance on 8-hour ozone modeling recommends that an attainment demonstration include three elements: (1) a modeled attainment test, (2) a screening test, and (3) a weight of evidence determination. A brief review of each component and a description of the procedures used for the ATMOS modeling analysis in each phase of the attainment demonstration are provided in this section.

The draft attainment demonstration procedures for 8-hour ozone differ from those for 1-hour ozone. A key difference is that the modeled attainment test is based on relative (rather than absolute) use of the modeling results. Thus, the test relies on the ability of the photochemical modeling system to simulate the change in ozone due to emissions reductions, but not necessarily its ability to simulate exact values for future-year ozone concentrations. Another difference is that the 8-hour attainment test is site-specific while the 1-hour test focuses on an urban-scale modeling domain. Other areas of the domain are considered in the 8-hour analysis as part of a screening test. The modeled attainment and screening tests comprise a part of the “weight of evidence” for the 8-hour ozone attainment demonstration, other factors are also considered as part of the assessment.

Modeled Attainment Test

The modeled attainment test is applied for each monitoring site, and the results for all sites within an area of interest are used to determine whether the test is passed for the area. For a monitoring site to pass the attainment test, the future-year estimated design value for that site must not exceed 84 ppb. Future-year estimated design values (EDVs) are calculated for each site using “current-year” design values and relative reduction factors (RRFs) derived from future-year and current -year modeling results. The current-year design value for a given site is the three-year average of the annual fourth highest measured 8-hour ozone concentration. The RRF is the ratio of the future- to current-year 8-hour simulated maximum ozone concentration in the vicinity of that monitoring site. The EDV is obtained by multiplying the current-year design value by the RRF. The area-wide EDV is the maximum of the site-specific EDVs over all sites in the area.

In applying the modeling attainment test for ATMOS, the attainment test procedures outlined in the draft EPA guidance document were adapted for the ATMOS modeling domain and simulation periods. Key implementation issues are discussed here.

The UAM-V modeling system was run for the three ATMOS simulation periods using current-year (2001) emissions. This ensured the effective and reasonable combination of the results in calculating the RRF and EDV parameters, despite the different base years. In this manner, all three episode periods were put on a consistent basis for use in the attainment test.

An important component of the attainment test is the calculation of a relative reduction factor (RRF) for each site and each simulation day. The RRF represents the ratio of the future-year daily maximum 8-hour ozone concentration to the corresponding base-year value. It is calculated for each site using simulated ozone concentrations within the vicinity of the site. EPA guidance recommends the use of a 15-km radius of influence for determining the maximum 8-hour ozone concentration within the vicinity of a site, and this was used for the ATMOS application. As an alternative to this, we also defined “vicinity” as within one grid cell of the grid cell in which the monitoring site is located. That is, the nine grid cells surrounding a monitoring site were included in the search for the maximum value. For the 4-km grid sites of interest, this resulted in a radius of influence of approximately 6 km.

This alternative radius of influence is smaller than that suggested in the EPA guidance document and it was used in this analysis to examine and quantify the effects of the assumptions inherent in this parameter. The use of a 15-km radius of influence results in an influence zone for many sites that encompasses, or nearly encompasses, other nearby sites that routinely exhibit very different concentration characteristics. The use of a more limited (4-km) radius of influence accommodates the geographic and meteorological variability and the observed concentration gradients. Use of a value smaller than the EPA default value ensures that the sites are considered independently from one another, and preserves the site-specific nature of the attainment-demonstration exercise. In general, we found that the results using a 9-cell radius of influence are in most cases not significantly different than those calculated using the larger radius of influence. Both results are presented in this report.

For ATMOS, the RRF and EDV values were calculated using the ADVISOR database, as presented in Section 7. The ADVISOR database allows the user to specify which simulation days to include in the calculation of the RRF. The user may select the day(s) directly or use one of several day selection options. These include: (1) each simulation day for which the simulated maximum 8-hour ozone value is greater than or equal to a user-specified value (which defaults to the EPA-recommended 70 ppb), (2) all observed 8-hour ozone exceedance days, and (3) all days for which the base-case simulation results are within a user-specified range of model performance. The estimated design value (EDV) for each site is then calculated by multiplying the RRF by the site-specific design value. In the ADVISOR database, there are several options the user may select for the design value. EPA recommends consideration of (1) the design value period, which spans the current year (in this case, 2000-2002), and (2) the period upon which designations are based (in this case, 2001-2003). EPA guidance recommends that the maximum of these two values be used, provided that the value is representative of the meteorological conditions that occur during a typical design value cycle.

For the results presented here, we include all days with simulated current-year 8-hour ozone concentrations greater than or equal to 70 ppb in the primary calculations, and we also consider alternate day selection options. We present results for both the 2000–2002 and 2001-2003 design values, and provide an assessment of design value representativeness.

Screening Test

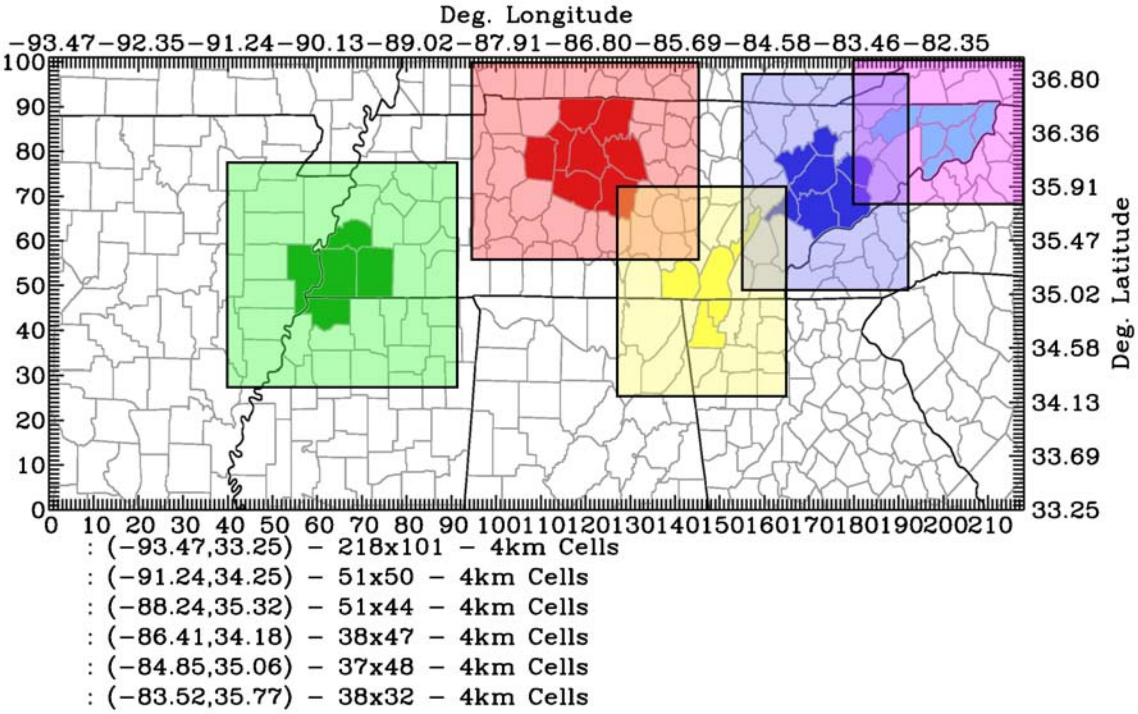
The screening test is intended as an accompaniment to the attainment test and is specifically applied to areas in the domain where the simulated maximum 8-hour ozone concentrations (for the base-case simulation) are consistently greater than any in the vicinity of a monitoring site.

EPA guidance defines “consistently” as 50 percent or more of the simulation days and “greater than” as more than 5 percent higher. Thus, the screening test is designed to be applied to an array of grid cells where the simulated maximum 8-hour ozone concentrations are more than 5 percent higher than any near a monitored location on 50 percent or more of the simulation days. The screening test procedures are otherwise identical to the attainment test procedures; the current-year design value for the unmonitored area is set equal to the maximum value at any site.

We applied the screening test in two ways. First, we considered Grid 3 in its entirety. Since these results do not apply to any one area, they are briefly presented here. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. In the first approach, there are several locations in the southeastern portion of the Grid 3 domain with concentrations that are more than 5 percent greater than the peak vales near any site, but this occurs on only two of the 20 simulation days. Using the 49-cell blocks, one block of cells in the southeastern portion of Grid 3 has simulated concentrations greater than any at any site peak on a total of two out of the 20 simulation days. Again, the "50 percent of days" criteria is not met.

Second, to focus more intensively on the five key areas of interest, we assumed that the extent of the search (for candidate screening test location) should be limited to the region surrounding the EAC area within which emissions from that area could influence the simulated higher ozone concentrations. This same philosophy is typically applied in selecting a photochemical modeling domain for an urban-scale modeling application. Rectangular subregions were specified for each of the EAC areas of interest (these are shown in Figure 8-1). Any screening test locations were labeled “pseudo sites”. Each pseudo site was assigned a design value equal to the maximum design value for any site in the subregion with which it was associated. The screening test was then applied. As noted earlier, from this point on it is the same as the attainment test (as described above). The results of the subregional screening tests for each area are presented later in this section.

Figure 8-1.
Subdomains Used for the Regional Application of the Screening Test for Design Values for ATMOS



Design Value Analysis

The design value is an important part of the modeled attainment test, in which future design values are estimated. For ATMOS, the modeled attainment test primarily uses, as its basis, the observation-based design value for the three-year period spanning the current model year. This value is expected to represent the current period in the same way the modeled simulation periods are expected to represent typical or frequently occurring meteorological conditions. Thus it is important that the base or current design value is representative of typical meteorological conditions. Given the form of the design value metric, however, year-to-year variations in meteorology and especially unusually persistent meteorological conditions during one or more of the years comprising a design value cycle can lead to a design value that is not representative of typical conditions.

As noted earlier in the report, the design value is defined for each monitoring site as the three-year average of the fourth highest 8-hour ozone concentration. This 8-hour ozone NAAQS (in its current form) requires the design value to be less than or equal to 84 parts per billion (ppb). In using the fourth highest ozone concentration and by averaging over a three-year period, the 8-hour ozone design value is formulated in part to accommodate year-to-year variations in meteorological conditions. However, recent variations in the design values for the several of the ATMOS EAC areas have indicated that the metric may not be stable when weather conditions (either ozone conducive or not) persist over the region for large portions of the ozone season. In developing “meteorologically adjusted” design values for each area, our objective was to create a metric similar to the 8-hour design value but less sensitive to yearly meteorological variation. This exercise relies on results of the Classification and Regression Tree (CART) analysis, as discussed in Section 1 of this document.

CART was used in the ATMOS episode selection analysis to classify all ozone season days for the years 1996-2002 according to meteorological and air quality parameters. While the category of a bin reflects the severity of ozone associated with the bin's meteorological conditions, the number of days in a bin represents the frequency with which those conditions occur. Since the bins are determined using a multi-year period, individual years may be normalized such that the different sets of meteorological conditions are represented no more or less than they are on average over all years in the period. This is the basis for our creation of meteorologically adjusted design values.

The methodology described here utilizes the original ATMOS CART analysis for years 1996-2002, and extends the period of consideration to 2003, by applying the same classification rules to 2003 data that were defined in the CART tree. Thus each day between 1996–2003, April to October inclusive, is classified into one of the CART bins. For the design value analysis, we treat the exceedance categories (Categories 3 and 4 bins) as a single category—this does not change the bin structure but broadens the number of days that are considered correctly classified. Finally, we determine design values for the key sites for each EAC area, following the steps outlined below:

Step 1. Determine "key" bins that represent sufficiently frequent conditions

- Key bins are represented in at least four of the eight years by at least one day whose maximum 8-hour ozone value at the site matches the bin category (call these, "site-correct" days).
- Key bins are represented by, on average, at least one day per year, of days whose area-wide maximum 8-hour ozone values match the bin category (call these, "area-correct" days).

Step 2. Determine the number of days to include from each bin.

- For "key" bins, use the rounded average of area-correct bin days per year.
- Include zero days from bins that do not meet the "key" bin requirements.

Step 3. For each year, eliminate non-representative days and excess days from over represented bins.

- Keep only site-correct days.
- For bins with excess days, eliminate days with lower values first.

Step 4. For each year, add days to underrepresented bins.

- Use the average value of site-correct days within that bin, for that year, if available.
- Otherwise, use the average value of site-correct days within that bin for the five-year span centered on that year, if values are available.
- Otherwise, use the average value of site-correct days within that bin for the full eight-year span.

Step 5. Use resulting fourth-highest values from these normalized years to define meteorologically-adjusted design values.

In the course of developing this procedure, we attempted multiple variations of the steps above. Both arbitrary and reasoned decisions led to the methodology presented here, so the remainder of this subsection provides a more detailed discussion of the steps above.

Step 1: Determining Key Bins

This and step 2 appear to have the greatest effect on resulting design values. Certain parameters are arbitrary and were ultimately determined by what led to the most reasonable results. These parameters are the number of years required to have a “site-correct” day, and the minimum average “area-correct” days per year. Since the classification variable from the original ATMOS CART analysis is actually an area-wide 8-hour ozone maximum, the frequency of “area-correct” days seems the most appropriate measure of the prevalence of a particular bin. Therefore the high-ozone bins represent met conditions leading to high ozone somewhere in the area, though not necessarily at the site. On the other hand, the “site-correct” requirement ensures that a high-ozone key bin has representative high values available for a minimum of years, with values for the other years filled in by substitution rules defined at a later step. We wanted the procedure to be inclusive of high ozone bins without resulting in an extreme amount of substitution.

Step 2: Determining Number of Days to Include from Key Bins

Again, we sought a balance between inclusion of high ozone bins for all years, and minimal substitution for the years where a high ozone bin may not appear, or may not appear as frequently as required. Step 2 plays an important role in moderating extremes, since it sets the threshold for the elimination and addition of data in Steps 3 and 4. We decided to use the average from the “area-correct” criteria in step 1, so that the importance attributed to a bin reflects its prevalence in CART as originally intended—representing the area rather than the site. Since the site value is less than the area maximum, use of the “area-correct” day average results in more high ozone bin days than use of a “site-correct” day average. We err on the side of including more high ozone days by rounding rather than truncating the average to an integer. Other ways to determine the day requirement, such as taking the median, may result in either a higher or lower value than the rounded average, so the choice of the rounded average is somewhat arbitrary.

Step 3: Eliminating Days

At this stage and beyond, we consider only days whose maximum 8-hour value at the site is consistent with the category of the bin in which it falls. For high ozone bins, this means we only include days where the high ozone predicted by CART occurs at the site itself.

If a bin has more days per year than the limit set in Step 2, the meteorological conditions are considered over-persistent, and the lowest days are eliminated from consideration until the bin has the desired number of days. By keeping the highest days first, we lean towards a worst-case-scenario. But the eliminated days may also have been among the highest for the year, so this step ultimately has the effect of potentially lowering the fourth highest value and suppressing the effect of over-persistent conditions.

Step 4: Adding Days

This step can increase the fourth highest value by adding high-ozone days that did not appear in the actual year. Thus a bin with fewer days than required is supplemented with days similar to those already in the bin for that year. Adding a day with the average ozone value expands the bin from the middle, preserving the position of the highest and lowest values within the bin, while reducing the lower days' ranking among all days in the year. When a bin is entirely absent from a particular year, the alternative substitution rules are meant to preserve some temporal changes in ozone levels, presumably due to emissions changes. If available, the value for substitution comes from the average over neighboring years, defined as those at most two years before or after the year requiring substitution; these neighboring years are the same whose values are averaged with the middle year in calculating design values. The period-wide average provides a value for substitution only if the five-year substitution rule cannot. Since we use only "site-correct" days for these averages, we guarantee that exceedance values fill open slots in high-ozone bins.

Additional Weight-of-Evidence Analysis

For areas with estimated future-year design values that are less than 90 ppb, additional weigh-of-evidence analyses may be presented to support or enlighten the attainment demonstration. Building directly on the modeling analysis, EPA guidance recommends incorporating key findings from model performance and information on episode representativeness into a weight of evidence analysis. The guidance also recommends the calculation of additional metrics based on modeled outputs that provide a slightly different perspective on the modeling results and specifically the expected ozone reductions. EPA guidance also recommends the examination of air quality and emissions trends, especially if they can be normalized for differences in meteorology. Other types of weight-of-evidence or corroborative analyses discussed in the EPA guidance include the use of observational models, uncertainty analysis, examination of design value representativeness, and use of alternative applications (for example, including/excluding days) in the attainment test calculations.

For ATMOS, we offer a variety of weight-of-evidence analyses that are designed to improve our understanding and interpretation of the modeled attainment test results, and to explore the effects of the various assumptions that are employed in the application of the photochemical model and the attainment test procedures. Our goal here is to make the best possible use of the modeling results and the observed data to assign a level of confidence to the outcome of the modeled attainment test. The weight-of-evidence analyses for each area are tailored to the observed data; the meteorological, geographical, and monitoring network considerations; and the modeling results for the area.

Attainment Demonstration for the Memphis EAC Area

The attainment demonstration analysis for the Memphis EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Memphis EAC area includes Shelby, Fayette, and Tipton Counties in Tennessee, Crittenden County in Arkansas, and DeSoto County in Mississippi. There are four monitoring sites in the Memphis EAC area, two in Shelby County (Edmund Orgill Park and Frayser), one in Crittenden County (Marion), and one in DeSoto County.

Modeled Attainment Test for Memphis

The modeled attainment test was applied for all sites in the Memphis EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used also both the 2000-2002 and the 2001-2003 design values for each site. Table 8-1 lists the observation-based design values (DV) and future-year 2007 estimated design values (EDV) for the AS-4 control-measures simulation for each site in the Memphis EAC area.

Table 8-1.
Observed and Estimated Design Values (ppb) for Sites in the Memphis EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000–2002 and 2001–2003 Design Values

Site	2000–2002			2001–2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Edmund Orgill Park	90	82	83	89	81	82
Frayser	87	82	82	84	79	79
Marion	94	88	88	92	86	86
DeSoto Co.	86	80	81	81	75	76

The maximum observation-based design value for the 2000–2002 period is 94 ppb, for the Marion monitoring site in Crittenden County, AR. The corresponding maximum future-year (2007) EDV for the area is also calculated for the Marion monitoring site. The future-year EDV for this site is 88 ppb using the 15-km radius of influence, and 88 ppb using the 9-cell radius of influence. The details of the calculations for the 15-km approach are provided in Table 8-2, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV. The EDVs for all other sites in the area (including the Edmund Orgill Park and Frayser sites in Shelby County, TN and the DeSoto County site in MS) are below 84 ppb. The values with the 15-km approach are 82 ppb for Edmund Orgill Park, 82 ppb for Frayser, and 80 ppb for DeSoto County. The values are the same for Frayser and one ppb higher for the other two sites for the 9-cell approach.

Table 8-2.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Marion, AR Site in the Memphis EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	90.5	87.1
9/1/99	78.2	78.2
9/2/99	104.9	99.5
9/3/99.	119.9	109.5
9/4/99	73.2	68.4
9/7/99	74.5	72.4
6/18/01	101.0	94.9
6/19/01	88.1	82.3
6/20/01	103.0	97.2
6/22/01	77.4	71.4
7/6/02	100.0	89.1
7/7/02	88.6	83.6
7/8/02	118.9	111.2
7/9/02	79.8	72.4
7/10/02	70.9	68.4
Average	91.3	85.7
EDV Calculations		
RRF		0.94
2000-2002 DV		94
2007 EDV (2002)		88
2001-2003 DV		92
2007 EDV (2003)		86

The design values for 2001-2003 are slightly lower than those for 2000-2002 at all sites, with a maximum value of 92 ppb for the Marion site. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 86 ppb (for the Marion site) and values of 81, 79, and 75 ppb, respectively, for the Edmund Orgill Park, Frayser, and DeSoto County sites.

Limiting or otherwise selecting the days based on observed exceedances or model performance does not change the resulting EDV for the Marion site. This is because model performance is acceptable for most days and all high ozone days.

Thus, the attainment test for the Memphis EAC area is nearly passed for the AS-4 2007 control measure scenario, with a range in maximum area-wide EDV of 86 to 88 ppb, depending upon the assumptions employed in the application of the attainment test. Of the four monitoring sites located in the area, the EDV is above 84 ppb for only one of the sites.

Regional Screening Test for Memphis

The screening test was applied for the Memphis-area subregion defined in Figure 8-1. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for four and six days, respectively, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analyses

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Memphis EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-3 summarizes the percent change in each of these metrics for the Memphis EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-3.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Memphis EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	59
Number of grid-cell hours > 84 ppb	48
Number of grid cells with 8-hour max > 84 ppb	46
Total 1-hour ozone > 84 ppb	54

All four of these metrics appear to provide similar information, that the amount of ozone in excess of the 8-hour ozone standard is reduced within the EAC area by about 50 percent. This is less than the value of 80 percent used in the EPA guidance as an example of a “large” value, but does indicate a significant reduction in the hourly and 8-hour ozone values from the current-year simulation.

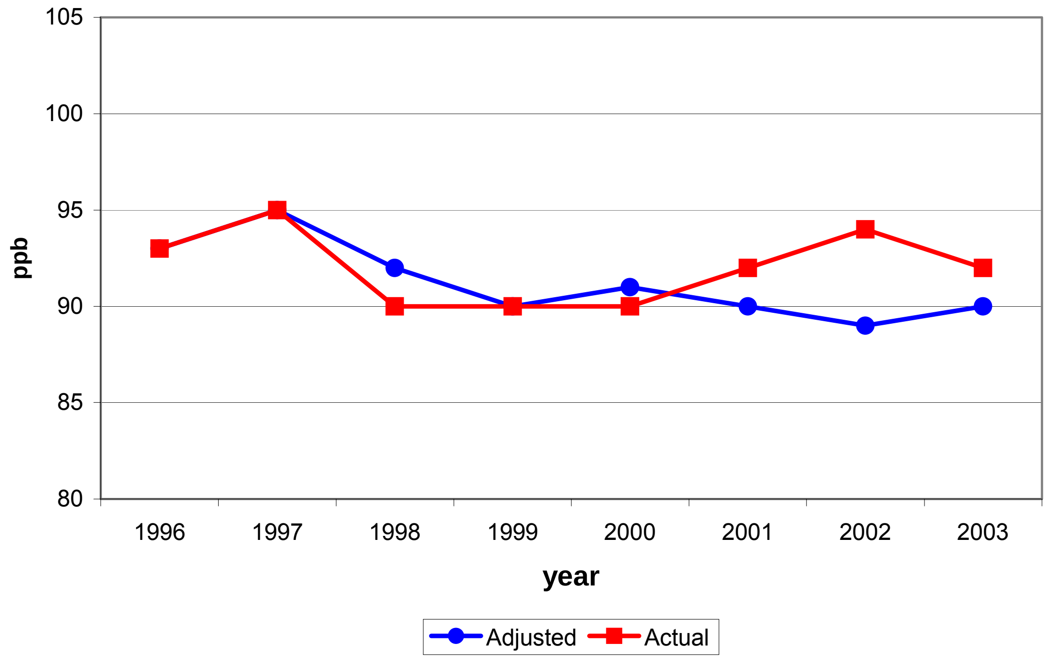
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Memphis area, based on the Marion site, are listed in Table 8-4 and plotted in Figure 8-2.

Table 8-4.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Marion

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• DVs	93	95	90	90	90	92	94	92
• 4th highest	96	91	85	95	91	92	100	84
Adjusted								
• - DVs	93	95	92	90	91	90	89	90
• - 4th highest	98	88	92	91	91	89	89	92

Figure 8-2.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Marion

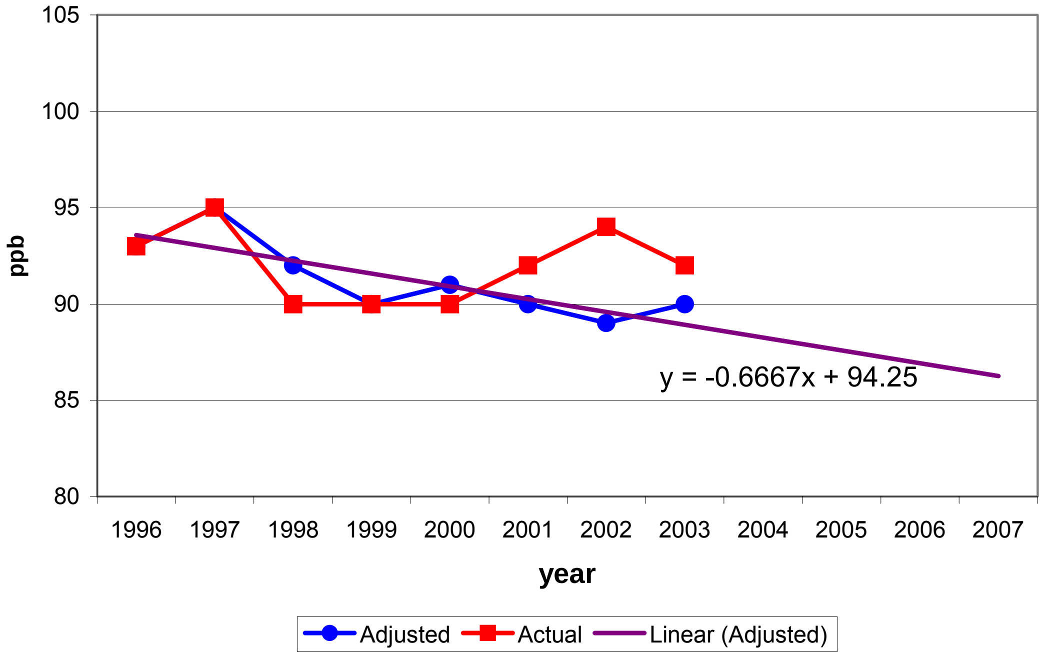


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 91 ppb, only one ppb lower than the average actual design values. But, as intended, the adjusted design values exhibit less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is much more stable than the observation-based design value. Using this methodology, the high design value for 2002 is attributable to more persistent than usual ozone conducive meteorological conditions. Unfortunately, this is the primary value used in the ATMOS modeling analysis as the basis of the modeled attainment. These results indicate that a more appropriate design value for application of the attainment test is approximately 90 ppb. Use of a value of 90 ppb in the attainment test results in a 2007 EDV of 84 ppb.

The observation that meteorologically-adjusted design values change more gradually and linearly than actual design values, invites one to extrapolate to future years. Figure 8-3 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 86 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint is likely to represent a high-end value. It is expected that the ATMOS modeling results, which take into account the expected future emissions reductions, using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-3.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically-Adjusted 8-Hour Ozone Trends for Marion



Summary Attainment Demonstration for Memphis

The attainment and screening tests and additional corroborative analyses indicate that the Memphis EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the results of the modeled attainment test significantly. There are no locations within a subdomain encompassing the Memphis EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 50 percent for each of the exposure-type metrics. Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation – that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values.

Three of the four monitoring sites in the Memphis area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. One site, the Marion site in Crittenden County, AR, has an EDV that is greater than the 84 ppb standard. The 2007 EDV for this site is 88 ppb if the 2000-2002 design value is used, 86 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. The 2000-2002 design value is the highest recorded in recent years. Based on the values for the other years as well as the indications from the meteorological adjustment, use of the 2000-2002 design value likely represents a worst case for Memphis for 2007.

To further support future attainment of the 8-hour ozone standard for the Memphis area, ADEQ is currently designing a scoping study and field program to examine the spatial representativeness and causes of high observed ozone concentrations at the Marion site. An improved understanding of the 8-hour ozone issues in Crittenden County will enable the more effective implementation of the planned attainment/maintenance strategies for the area.

Attainment Demonstration for the Nashville EAC Area

The attainment demonstration analysis for the Nashville EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Nashville EAC area includes Davidson, Rutherford, Sumner, Williamson, Wilson, Cheatham, Dickson, and Robertson Counties. There are eight monitoring sites in the Nashville EAC area.

Modeled Attainment Test for Nashville

The modeled attainment test was applied for all sites in the Nashville EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used also both the 2000-2002 and the 2001-2003 design values for each site. Table 8-5 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for each site in the Nashville EAC area.

Table 8-5.
Observed and Estimated Design Values (ppb) for Sites in the Nashville EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
E. Nashville Health Center	71	66	67	71	66	67
Percy Priest Dam	80	75	73	77	72	71
Rutherford Co.	84	77	76	80	73	72
Rockland Road.	88	81	82	86	79	80
Wright's Farm	87	82	80	82	77	76
Fairview	87	80	79	84	77	76
Lebanon	85	76	76	82	74	73
Dickson Co.	NA	NA	NA	NA	NA	NA

The maximum observation-based design value for the 2000-2002 period is 88 ppb, for the Rockland Road monitoring site. Two sites have values of 87 ppb. These are Cottontown Wrights Farm and Fairview. The corresponding maximum future-year (2007) EDV for the area is calculated for the Wright's Farm site if the 15-km radius of influence is used and for the Rockland Road site if the 9-cell radius of influence is used. In both cases, the value is 82 ppb. The details of the calculations for the Rockland Road site are provided in Table 8-6, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV. The EDVs for all other sites in the Nashville EAC area are at or below 80 ppb (well below 84 ppb).

Table 8-6.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Rockland Rd. Site in the Nashville EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	89.6	86.4
9/1/99	107.9	99.7
9/2/99	74.9	72.6
9/3/99.	91.8	86.6
9/4/99	131.3	122.7
9/5/99	84.7	80.3
9/6/99	86.7	82.3
9/7/99	76.9	74.4
9/8/99	88.9	85.8
6/18/01	89.7	82.0
6/19/01	99.5	89.0
6/20/01	116.0	109.9
6/21/01	75.0	69.9
6/22/01	76.9	70.5
7/6/02	72.2	68.4
7/7/02	74.8	71.3
7/8/02	85.1	78.3
7/9/02	94.7	90.4
7/10/02	112.7	84.6
Average	91.0	84.5
EDV Calculations		
RRF		0.93
2000-2002 DV		88
2007 EDV (2002)		81
2001-2003 DV		86
2007 EDV (2003)		79

The design values for 2001-2003 are lower than those for 2000-2002 at most sites, with a maximum value of 86 ppb for the Rockland Road site. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 79 ppb (for the Rockland Road site).

Using only observed exceedance days in the calculation results in an EDV of 83 ppb for the Rockland Road site (using the 2000-2002 DV and a 15-km radius of influence). Selecting only days with very good model performance for that site gives an EDV of 82 ppb (compared to 81 ppb with all other parameters kept the same). Thus, the calculation of the EDV is somewhat sensitive to the selection of days.

The attainment test for the Nashville EAC area is passed for the AS-4 2007 control-measure scenario, with a range in maximum area-wide EDV of 79 to 83 ppb, depending upon the assumptions employed in the application of the attainment test.

Regional Screening Test for Nashville

The screening test was applied for the Nashville-area subregion defined in Figure 8-3. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-

cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for three days using both approaches, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analysis

To support the finding of modeled attainment for the Nashville area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Nashville EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-7 summarizes the percent change in each of these metrics for the Nashville EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-7.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Nashville EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	70
Number of grid-cell hours > 84 ppb	55
Number of grid cells with 8-hour max > 84 ppb	60
Total 1-hour ozone > 84 ppb	63

All four of these metrics appear to provide similar information, that the amount of ozone in excess of the 8-hour ozone standard is reduced within the EAC area by about 60 percent. This is less than the value of 80 percent used in the EPA guidance as an example of a “large” value, but does indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

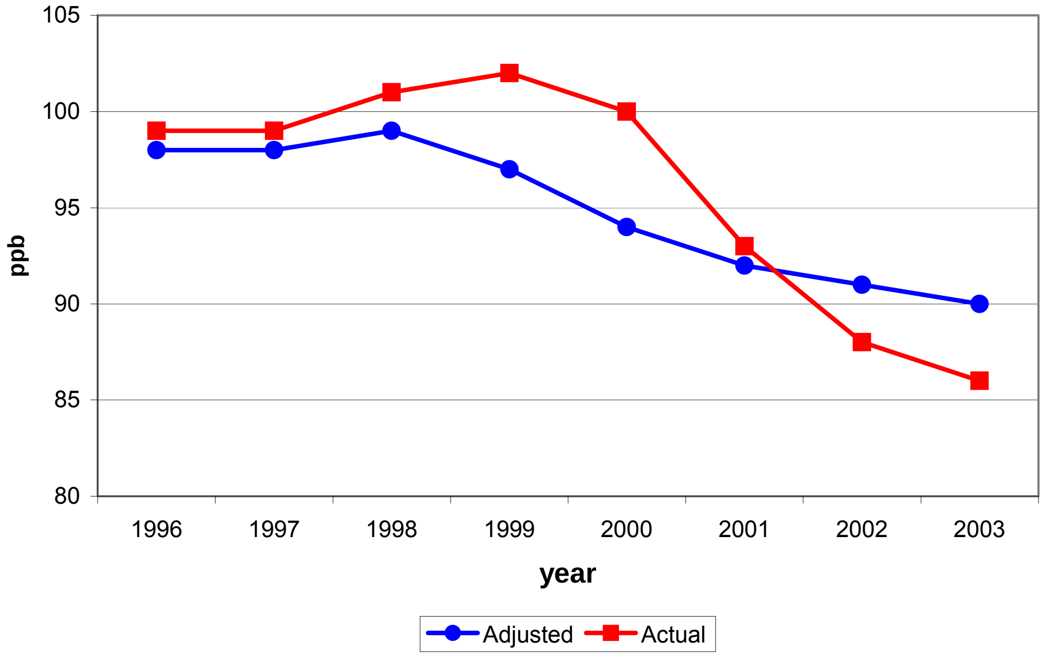
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Nashville area, based on the Rockland Road site, are listed in Table 8-8 and plotted in Figure 8-4.

Table 8-8.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Rockland Road

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	99	99	101	102	100	93	88	86
• - 4th highest	97	100	107	101	93	86	86	86
Adjusted								
• - DVs	98	98	99	97	94	92	91	90
• - 4th highest	95	101	101	91	92	94	87	90

Figure 8-4.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Rockland Road

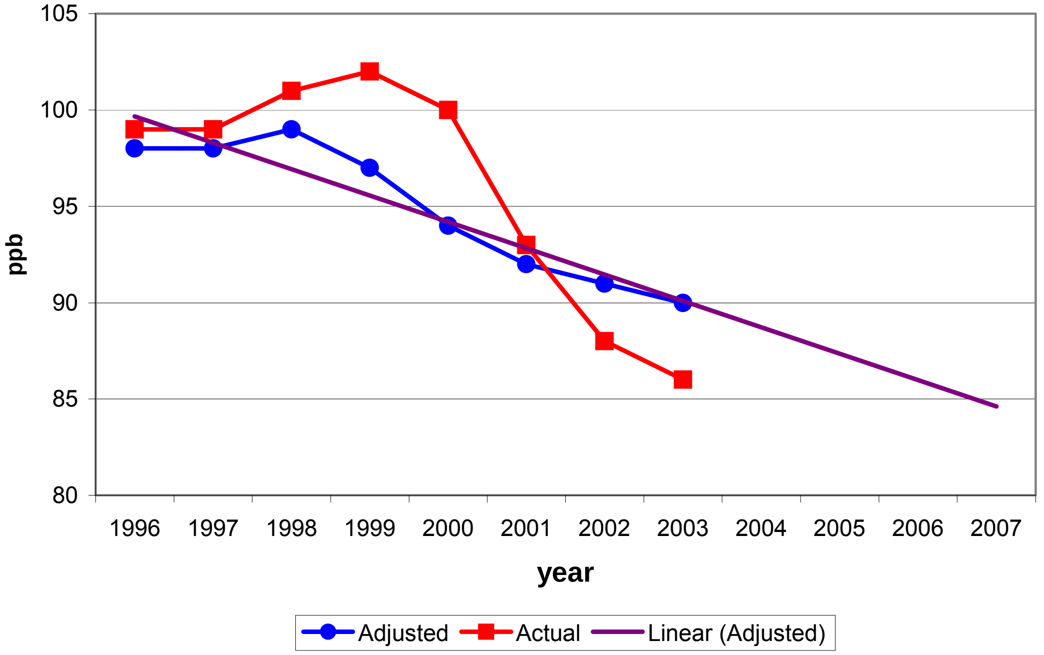


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 94 ppb, two ppb lower than the average actual design value of 96 ppb. But, as intended, the adjusted design values exhibit less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is more stable than the observation-based design value, although both show a clear tendency toward lower design values between 1998/1999 and 2003. The results also indicate that the design value for 2000-2002, as used in the modeled attainment may be low as a result of fewer days than normal with ozone-conducive meteorological conditions during 2002. These results suggest that a more appropriate design value for application of the attainment test is approximately 90 ppb. Use of a value of 90 ppb in the attainment test results in a 2007 EDV of 83 ppb, whereas use of a value of 91 ppb gives a result of 84 ppb for the EDV. In either case, the attainment test is still passed. This finding adds to the robustness of the analysis, in that even if the design value used for the attainment test was lower than might be expected under more typical meteorological conditions, the test would still be passed.

Figure 8-5 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 84 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst-case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-5.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Rockland Road



Summary Attainment Demonstration for Nashville

The attainment and screening tests and additional corroborative analyses indicate that the Nashville EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the outcome of the modeled attainment test. There are no locations within a subdomain encompassing the Nashville EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the

2007 AS-4 control measures simulation - approximately 60 percent for each of the exposure-type metrics. Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation – that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values.

All of the monitoring sites in the Nashville area have future-year estimated design values for 8-hour ozone that are less than 84 ppb. The areawide 2007 EDV for this site is 82 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 84 ppb if a meteorologically adjusted design value is used. Use of a meteorologically adjusted DV that is higher than observed supports a finding of modeled attainment.

Attainment Demonstration for the Knoxville EAC Area

The attainment demonstration analysis for the Knoxville EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Knoxville EAC area includes Anderson, Blount, Knox, Loudon, Sevier, Union, and Jefferson Counties. There are eight monitoring sites in the Knoxville EAC area. Four of these sites are located in the greater Knoxville area, while four others are located in the Great Smoky Mountains National Park.

Modeled Attainment Test for Knoxville

The modeled attainment test was applied for all sites in the Knoxville EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used both the 2000-2002 and the 2001-2003 design values for each site. Table 8-9 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for each site in the Knoxville EAC area.

Table 8-9.
Observed and Estimated Design Values (ppb) for Sites in the Knoxville EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
East Knoxville	92	85	84	88	81	81
Spring Hill	96	90	89	92	86	86
Jefferson Co.	95	87	86	91	83	83
Anderson Co.	92	83	85	87	79	80
Cove Mountain	96	86	86	92	83	82
Clingman's Dome	98	89	87	92	83	82
Cades Cove	79	70	70	76	68	68
Look Rock	94	84	84	93	83	84

The maximum observation-based design value for the 2000-2002 period is 98 ppb, for the Clingman's Dome monitoring site. Among the non-GSM sites, The Spring Hill site has the highest value of 96 ppb. The corresponding maximum future-year (2007) EDVs for these sites are 89 and 90 ppb, respectively, if the 15-km radius of influence is used, and 87 and 89 ppb, respectively, if the 9-cell radius of influence is used. The details of the calculations for the Spring Hill site are provided in Table 8-10, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV. The EDVs for four other sites are also above 84 ppb, these are East Knoxville (using the 15-km approach only), Jefferson Co., Anderson Co. (using the 9-cell approach only), and Cove Mountain. The EDVs for the remaining two GSM sites are at or below 84 ppb.

Table 8-10.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Spring Hill Site in the Knoxville EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	77.5	76.9
9/1/99	76.3	73.9
9/2/99	91.3	87.6
9/3/99.	89.4	89.9
9/4/99	92.1	85.9
9/6/99	70.6	66.7
9/7/99	84.9	79.6
9/8/99	89.5	86.5
6/18/01	81.6	81.9
6/19/01	102.0	89.8
6/20/01	111	99.3
6/21/01	92.7	85.5
7/6/02	82.4	76.0
7/7/02	98.4	90.1
7/8/02	73.7	70.0
7/9/02	110.5	98.8
7/10/02	80.5	74.8
Average	88.9	83.2
EDV Calculations		
RRF		0.94
2000-2002 DV		96
2007 EDV (2002)		90
2001-2003 DV		92
2007 EDV (2003)		86

The design values for 2001-2003 are lower than those for 2000-2002 for all sites, with a maximum value of 93 ppb for the Look Rock monitoring site. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 86 ppb, in this case for the Spring Hill site. Using the 2001-2003 values, the EDVs for all other sites in the Knoxville area are at or below 84 ppb.

Using only observed exceedance days in the calculation reduces the number of days available to the calculation but the resulting EDV is unchanged (using the 2000-2002 DV and a 15-km radius of influence). Selecting only days with very good model performance for that site gives an EDV of 91 ppb (compared to 90 ppb with all other parameters kept the same). Thus, the calculation of the EDV is somewhat sensitive to the selection of days.

The attainment test for the Knoxville EAC area is not passed for the AS-4 2007 control-measure scenario, with a range in maximum area-wide EDV of 86 to 90 ppb, depending upon the assumptions employed in the application of the attainment test.

Regional Screening Test for Knoxville

The screening test was applied for the Knoxville-area subregion defined in Figure 8-5. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for three days using the 15-km approach and for two days using the 9-cell approach, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analysis

To further examine the modeling results and the findings from the application of the modeled attainment test for the Knoxville area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Knoxville EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-11 summarizes the percent change in each of these metrics for the Knoxville EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-11.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Knoxville EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	85
Number of grid-cell hours > 84 ppb	59
Number of grid cells with 8-hour max > 84 ppb	66
Total 1-hour ozone > 84 ppb	76

The number of grid cells with hourly or 8-hour ozone concentrations greater than 84 ppb is reduced by about 60 percent. The amount of ozone greater than this value is reduced by an even greater percentage (about 80 percent). These metrics indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

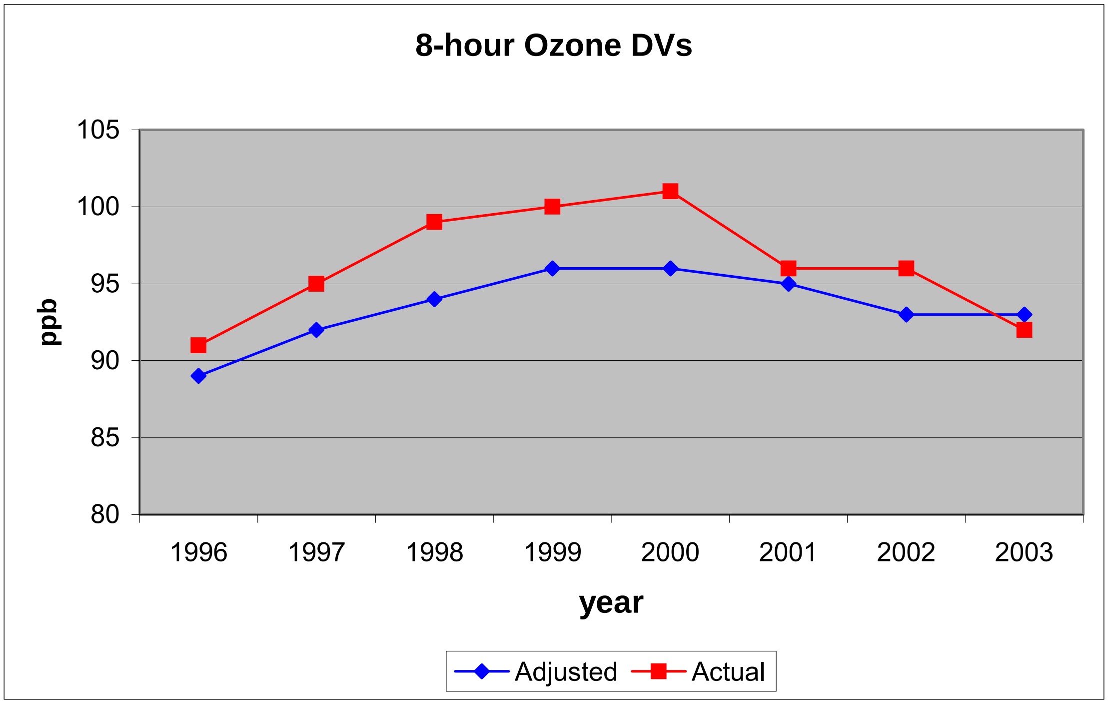
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Knoxville area, based on the Spring Hill site, are listed in Table 8-12 and plotted in Figure 8-6.

Table 8-12.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Spring Hill

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	91	95	99	100	101	96	96	92
• - 4th highest	98	96	95	99	100	90	98	90
Adjusted								
• - DVs	89	92	94	96	96	95	93	93
• - 4th highest	92	93	97	100	92	93	96	91

Figure 8-6.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Spring Hill

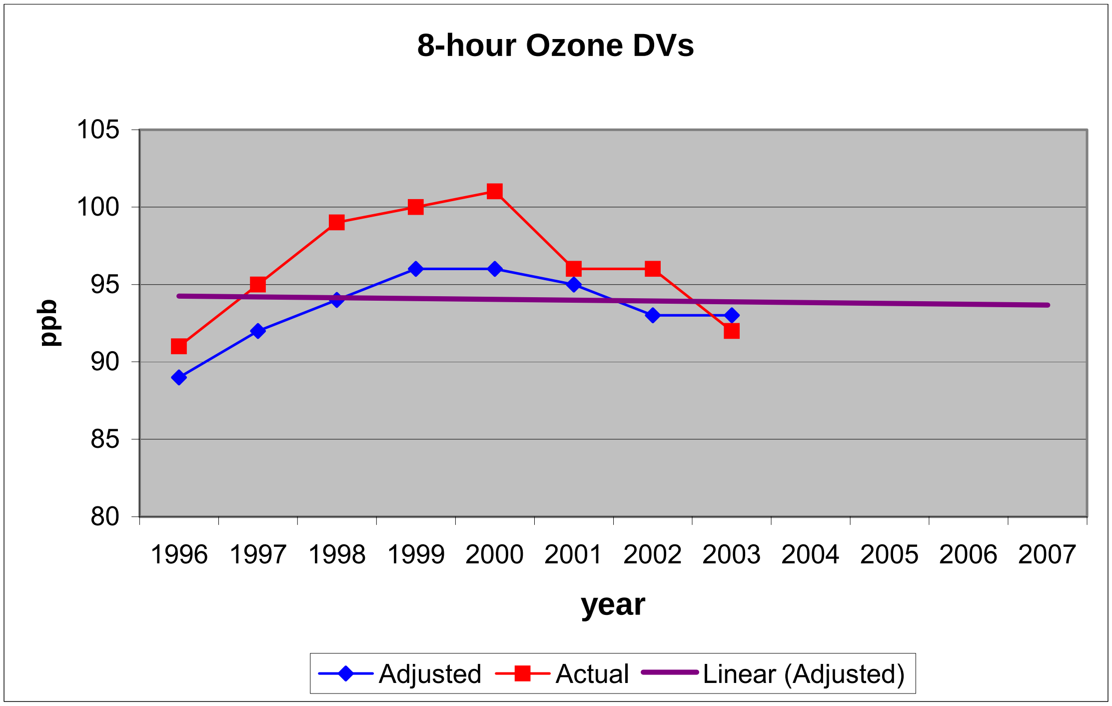


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 93 ppb, three ppb lower than the average actual design value of 96 ppb. As intended, the adjusted design values exhibit less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is more stable than the observation-based design value, although both show a clear tendency toward increasing DV from 1996 to 2000 and the reverse tendency between 2000 and 2003. The results also indicate that the design value for 2000-2002, as used in the modeled attainment, may be higher than expected for meteorologically typical design value period. The results suggest that a more appropriate design value for application of the attainment test is approximately 93 ppb. Use of a value of 93 ppb in the attainment test results in a 2007 EDV of 87 ppb, which brings the area closer to the passing the modeled attainment test. Nevertheless, this result suggests that additional emissions reductions will be needed to bring Knoxville into attainment by 2007.

Figure 8-7 below shows the trend in adjusted design values out to 2007. Linear extrapolation is not well suited to the changing design values, so we anchored the trend line at 1998 in this example. The 2007 extrapolated value is still greater than 90 ppb, as this assumes that the changes in emissions for 2003 to 2007 will follow the trends of 1998 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-7.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Spring Hill



Summary Attainment Demonstration for Knoxville

The modeled attainment test indicates that the Knoxville EAC area will likely not achieve attainment of the 8-hour ozone standard by 2007, unless additional controls to those included in the AS-4 control measure package are implemented. The modeling and attainment test results suggest a range in future-year estimated design values from 86 to 90 ppb. The higher value corresponds to the use of the 2000-2002 design value in the calculations, and the lower value corresponds to the use of the 2001-2003 DV. Although the EDV values are relatively high, the values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 60 to 80 percent for the various exposure metrics.

The difference in results using the different design values prompted an examination of the representativeness of the design value. A meteorologically adjusted design value for 2002 was calculated and use of this value gives a future EDV of 87 ppb. Thus, use of a meteorologically adjusted DV is consistent with the use of the 2001-2003 value.

The oxidant tagging results (as presented in Section 7 of this document) indicate that 8-hour ozone concentrations in the Knoxville area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, and other areas in northern Georgia) will contribute positively to lower ozone in the Knoxville region.

Attainment Demonstration for the Chattanooga EAC Area

The attainment demonstration analysis for the Chattanooga EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Chattanooga EAC area includes Hamilton, Marion and Meigs Counties in Tennessee, and Walker and Catoosa Counties in Georgia. There are three monitoring sites in the Chattanooga EAC area.

Modeled Attainment Test for Chattanooga

The modeled attainment test was applied for all sites in the Chattanooga EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used both the 2000-2002 and the 2001-2003 design values for each site. Table 8-13 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for each site in the Chattanooga EAC area.

Table 8-13.
Observed and Estimated Design Values (ppb) for Sites in the Chattanooga EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Sequoyah	93	85	85	87	79	80
Chattanooga VAAP	92	84	85	88	80	81
Meigs Co.	93	85	85	88	81	80

The maximum observation-based design value for the 2000-2002 period is 93 ppb, for both the Sequoyah and Meigs Co. monitoring sites. The value for the VAAP site is also very similar. The corresponding maximum future-year (2007) EDV for the area is 85 ppb (again both for the Sequoyah and Meigs Co. sites). The result is the same using both the 15-km radius of influence as well as the 9-cell radius of influence. The details of the calculations for the Sequoyah site are provided in Table 8-14, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV.

Table 8-14.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Sequoyah Site in the Chattanooga EAC Area

The concentrations and RRF Values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
8/31/99	95.4	89.0
9/1/99	83.0	76.7
9/2/99	97.2	90.0
9/3/99.	111.9	103.3
9/4/99	128.0	116.4
9/5/99	72.9	67.1
9/7/99	90.7	84.4
9/8/99	93.5	90.0
6/18/01	83.5	80.0
6/19/01	105.0	92.8
6/20/01	130.0	123.8
6/21/01	97.2	88.6
7/6/02	91.6	83.4
7/7/02	100.7	90.9
7/8/02	105.5	88.9
7/9/02	96.2	88.3
7/10/02	89.9	83.3
Average	98.4	90.4
EDV Calculations		
RRF		0.92
2000-2002 DV		93
2007 EDV (2002)		85
2001-2003 DV		87
2007 EDV (2003)		79

The design values for 2001-2003 are lower than those for 2000-2002 at all three sites, with a maximum value of 88 ppb for the VAAP and Meigs Co. sites. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 81 ppb (for the Meigs Co. site).

Using only observed exceedance days in the calculation results in an EDV of 84 ppb for the Sequoyah site (using the 2000-2002 DV and a 15-km radius of influence). Selecting only days with very good model performance does not change the EDV, since model performance is generally very good for the Chattanooga sites.

The attainment test for the Chattanooga EAC area is nearly passed for the AS-4 2007 control-measure scenario, with a maximum area-wide EDV of 85.

Regional Screening Test for Chattanooga

The screening test was applied for the Chattanooga-area subregion defined in Figure 8-7. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for four days using the 15-km approach and for 11 days using the 9-cell approach. This outcome resulted in a candidate screening test location for the Chattanooga area, located northeast of the Chattanooga urban area. Application of the attainment test procedures for this location using a design value of 93 ppb (the maximum for any site within the subregion) gives an EDV of 84 ppb, so the screening test is passed.

Additional Corroborative Analysis

To support a finding of attainment for the Chattanooga area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Chattanooga EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-15 summarizes the percent change in each of these metrics for the Chattanooga EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-15.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Chattanooga EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	75
Number of grid-cell hours > 84 ppb	60
Number of grid cells with 8-hour max > 84 ppb	64
Total 1-hour ozone > 84 ppb	70

The number of grid cells with hourly or 8-hour ozone concentrations greater than 84 ppb is reduced by about 60 percent. The amount of ozone greater than this value is reduced by an even greater percentage (about 70-75 percent). These metrics indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

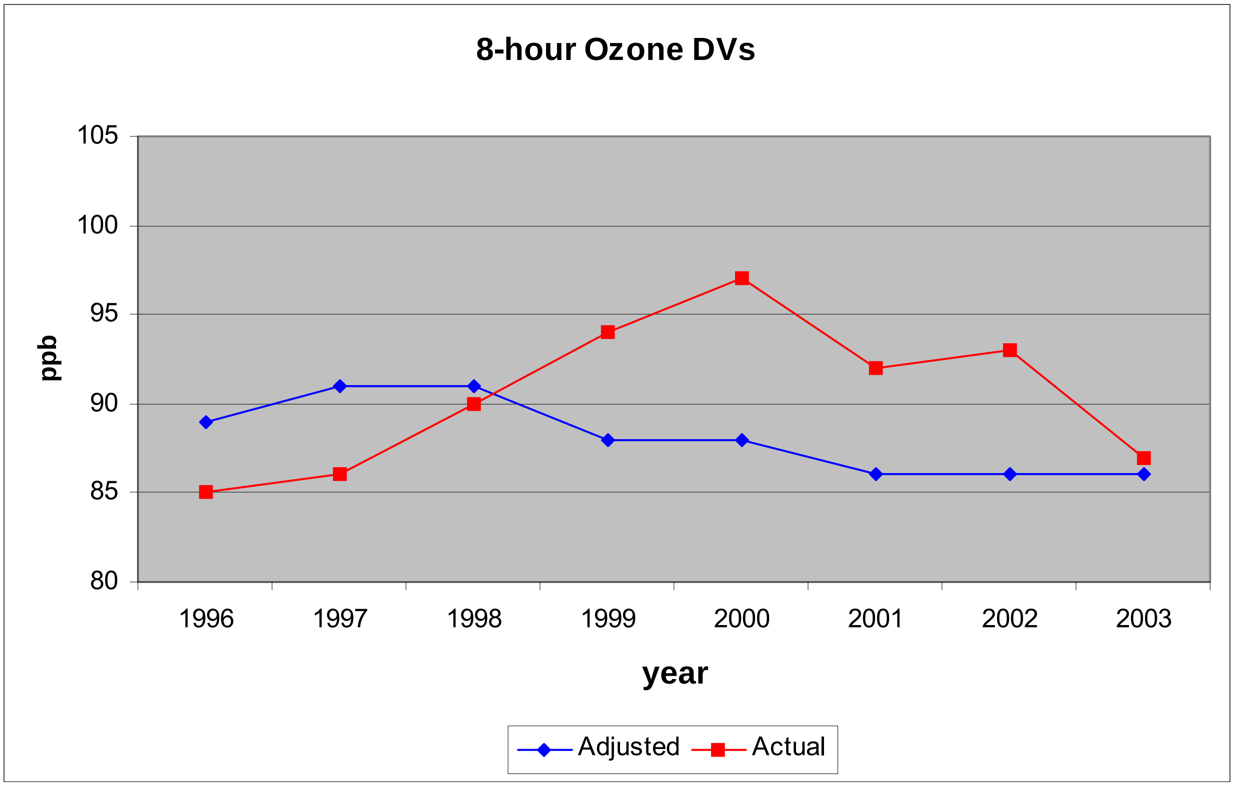
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Chattanooga area, based on the Sequoyah site, are listed in Table 8-16 and plotted in Figure 8-8.

Table 8-16.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Sequoyah

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	85	86	90	94	97	92	93	87
• - 4th highest	85	89	97	98	98	82	99	80
Adjusted								
• - DVs	89	91	91	88	88	86	86	86
• - 4th highest	98	89	88	87	89	82	89	89

Figure 8-8.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Sequoyah

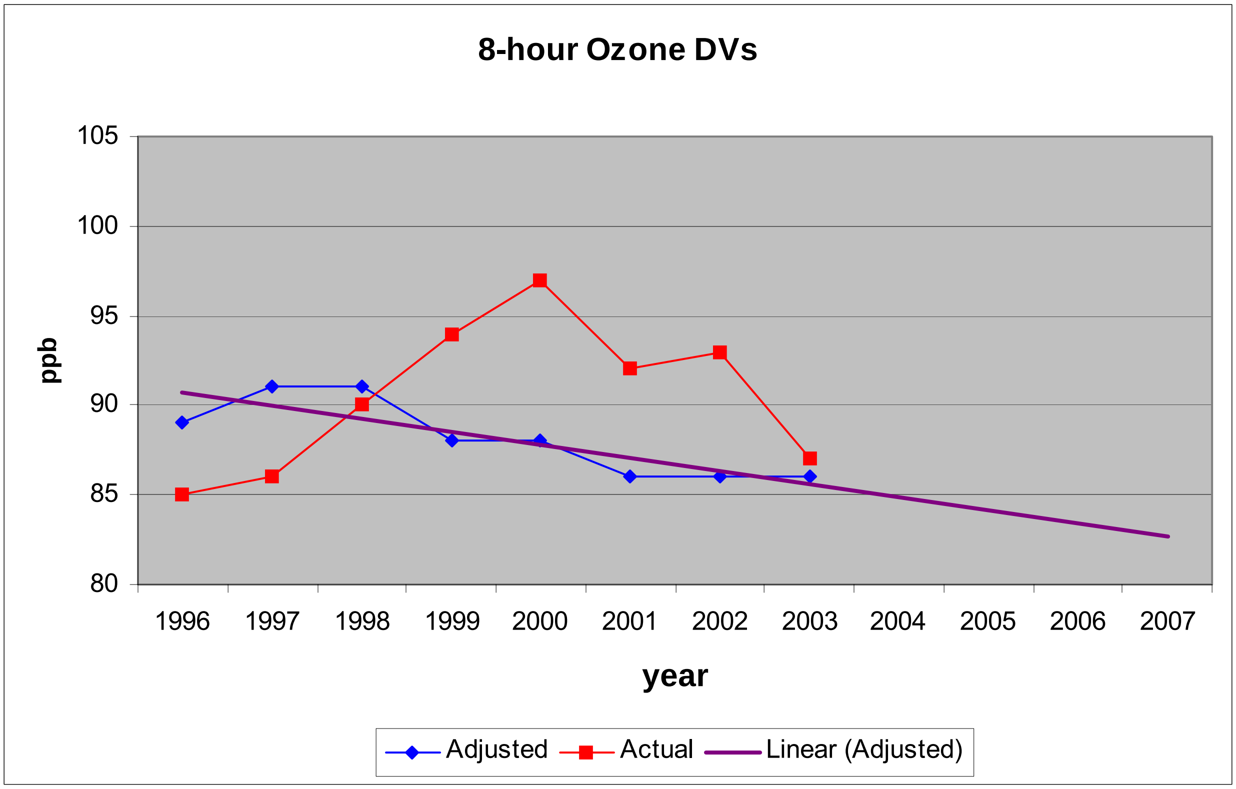


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 88 ppb, two ppb lower than the average actual design value of 90 ppb. The adjusted design values exhibit less variation between years.

The higher design value for 1999, 2000, and for 2002 resulted from a greater number of a certain type of ozone conducive meteorological conditions during those summers, coupled with the fact that this occurred for two or more of the years included in the DV cycle. Conditions associated with the four highest ozone days for 1998 and 2003 were more typical of frequently occurring conditions. The results suggest that the 2000-2002 DV of 93 ppb is representative of a period that had more frequent than usual ozone conducive conditions and that the 2001-2003 value (86 ppb) is a more representative DV. Use of a value of 86 ppb in the attainment test results in a 2007 EDV of 79 ppb. These results suggest that more weight should be given to the attainment test results using the 2001-2003 DV, than to the results using the 2000-2002 DV and support a finding of modeled attainment

Figure 8-9 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 83 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-9.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Sequoyah



Summary Attainment Demonstration for Chattanooga

The attainment and screening tests and additional corroborative analyses indicate that the Chattanooga EAC area will be in attainment of the 8-hour ozone standard by 2007. Good modeling results and good representation of typical 8-hour ozone conducive meteorological conditions by the simulation periods provide a sound basis for the application of the model-based tests. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the outcome of the modeled attainment test, but do suggest an even greater response for higher ozone days than when all days are considered. There is one location within a subdomain encompassing the Chattanooga EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. When the attainment test is applied for this location using the maximum design value for any site in the subregion, it is passed. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 60 to 75 percent for each of the exposure metrics. The amount of excess ozone is reduced by a somewhat greater percentage than the incidence (number of hours) of high ozone.

Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation—that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values. In addition, the oxidant tagging results (as presented in Section 7 of this document) indicate that 8-hour ozone concentrations in the Chattanooga area are influenced by emissions from the Atlanta area as well as other areas outside of the ATMOS fine grid. Thus, any regional ozone reductions that are not accounted for in the ATMOS modeling inventory (such as that from EACs being developed for Augusta, Macon, and other areas in northern Georgia) will contribute positively to lower ozone in the Chattanooga region.

All three of the monitoring sites in the Chattanooga area have future-year estimated design values for 8-hour ozone that are less than or equal to 85 ppb if the 2000-2002 design value is used and less than or equal to 81 ppb if the 2001-2003 design value is used. Analysis of the effects of meteorology on the design value provides an estimate of a meteorologically adjusted design value for both 2000-2002 and 2001-2003 that is equal to 86 ppb. Use of a meteorologically adjusted DV of 86 ppb is consistent with the outcome of the attainment test based on the use of the 2001-2003 DV and gives an EDV of 79 ppb. Meteorologically adjusted trends indicate a value of 83 ppb, assuming that the emissions changes between 2003 and 2007 will be, on average, the same as that for 1996-2003.

Regional- and national-scale modeling by the Georgia Department of Natural Resources, Environmental Protection Division (GEPD) and the U.S. EPA, gives even lower future-year EDVS for the Chattanooga area. The GEPD EDV for 2007 for Chattanooga is 81 ppb, while that for the Clear Skies Initiative is 79 ppb. These other studies use coarser grid resolution, but may be more specific in incorporating regional (e.g., for Atlanta) and national measures. Therefore, these results further support a finding of attainment.

Finally, it is important to note that the future-year emissions estimates for Chattanooga do not fully reflect the reduced number of permitted non-major industrial sources (approximately 12 percent) and the loss in manufacturing jobs (approximately 13 percent) that has occurred in the Chattanooga area during the past several years (1999-2002). Overall, these factors would tend to lower the future-year emissions and further support a finding of attainment.

Attainment Demonstration for the Tri-Cities EAC Area

The attainment demonstration analysis for the Tri-Cities EAC area includes the application of the modeled attainment test, the regional application of the screening test, and several additional analyses. A summary of the results and conclusions regarding future attainment are presented at the end of this section.

The Tri-Cities EAC area includes Carter, Hawkins, Sullivan, Unicoi, and Washington Counties. There are two monitoring sites in the Tri-Cities EAC area.

Modeled Attainment Test for Tri-Cities

The modeled attainment test was applied for all sites in the Tri-Cities EAC area, using all days with current-year simulated ozone concentrations greater than 70 ppb and using both the 15-km and 9-cell radii of influence to define maximum 8-hour ozone concentration in the vicinity of the site. In applying this test, we used both the 2000-2002 and the 2001-2003 design values for each site. Table 8-17 lists the observation-based design value (DV) and future-year 2007 estimated design values (EDV) for the two sites in the Tri-Cities EAC area.

Table 8-17.
Observed and Estimated Design Values (ppb) for Sites in the Tri-Cities EAC Area Calculated Using the 15-km and 9-cell Approaches and the 2000-2002 and 2001-2003 Design Values

Site	2000-2002			2001-2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Kingsport	92	84	84	86	79	78
Blountville	90	83	83	86	80	79

The maximum observation-based design value for the 2000-2002 period is 92 ppb, for the Kingsport monitoring site. The corresponding maximum future-year (2007) EDV for the area is 84 ppb, regardless of the approach used in defining the vicinity of the site. The details of the calculations for the Kingsport site are provided in Table 8-18, which gives the simulated current- and future-year concentrations for each day, along with the calculated RRF and the future-year EDV.

Table 8-18.
Simulated Current- and Future-year (AS-4) 8-Hour Ozone Concentrations (ppb) for the Kingsport Site in the Tri-Cities EAC Area

The concentrations and RRF values were calculated using the 15-km approach and the EDV was calculated using both the 2000–2002 and 2001–2003 design values

Simulation Date	Simulated Maximum 8-Hour Ozone (ppb)	
	CY2001	AS-4
9/1/99	73.1	66.2
9/2/99	74.3	66.2
9/3/99.	72.8	69.0
9/4/99	70.7	66.3
9/7/99	72.4	70.1
9/8/99	82.7	76.7
6/18/01	75.7	71.4
6/19/01	98.5	93.4
6/20/01	79.6	77.1
6/21/01	97.8	92.7
6/22/01	74.2	69.2
7/6/02	82.1	69.1
7/7/02	84.7	76.6
7/8/02	87.3	83.2
7/9/02	114.8	98.8
Average	82.7	76.4
EDV Calculations		
RRF		0.92
2000-2002 DV		92
2007 EDV (2002)		84
2001-2003 DV		86
2007 EDV (2003)		80

The design values for 2001-2003 are lower than those for 2000-2002, with a value of 86 ppb for both sites. Use of the 2001-2003 design value together with the 15-km radius of influence results in an area-wide maximum design value of 79 ppb for the Kingsport site and a value of 80 ppb for the Blountville (Sullivan Co.) site.

The attainment test for the Tri-Cities EAC area is passed for the AS-4 2007 control-measure scenario, with a value of 84 ppb for the maximum area-wide EDV.

Regional Screening Test for Tri-Cities

The screening test was applied for the Tri-Cities-area subregion defined in Figure 8-9. No screening test locations were found. We applied the test using both 49-cell blocks of cells and 9-cell blocks of cells, in keeping with the two approaches to the modeled attainment test. Locations with maximum concentrations more than 5 percent higher than any near a site were found for eight days using both approaches, and thus on fewer than 50 percent of the analysis days.

Additional Corroborative Analysis

To support the finding of modeled attainment for the Tri-Cities area, we conducted some additional analyses.

Model Output Diagnostics

Several additional metrics were used to quantify the amount of ozone reduction achieved within the Tri-Cities EAC areas for the 2007 AS-4 control-measures simulation. The first of these is 8-hour ozone exceedance exposure. This is a measure of the “excess” simulated 8-hour concentration that is greater than 85 ppb. The difference between the maximum simulated 8-hour ozone concentration and 85 ppb is calculated and summed for each grid cell and day within a specified grid or subregion and time period. The units are ppb, with grid-cell and day implied. Three other metrics are defined in the EPA guidance on 8-hour ozone modeling and include 1) number of grid cells hours with ozone greater than 84 ppb, 2) number of grid cells with 8-hour ozone concentrations greater than 84 ppb, and 3) sum of the excess concentrations greater than 84 ppb for the hourly ozone values. All of these metrics are considered in the relative sense, in this case relative to the corresponding current-year values.

Table 8-19 summarizes the percent change in each of these metrics for the Tri-Cities EAC area. These values were calculated using all days, with the exception of the two start-up days for each simulation period.

Table 8-19.
Percent Reduction in Selected 1-Hour and 8-Hour Ozone Metrics for the 2007 AS-4 Scenario, Relative to the Current-Year Simulation: Tri-Cities EAC Area

Metric	Percent Reduction Relative to the Current-Year UAM-V Simulation
8-hour ozone exceedance exposure	73
Number of grid-cell hours > 84 ppb	55
Number of grid cells with 8-hour max > 84 ppb	52
Total 1-hour ozone > 84 ppb	69

All four of these metrics appear to provide similar information, that the amount of ozone in excess of the 8-hour ozone standard is reduced within the EAC area by about 50-70 percent. This is less than the value of 80 percent used in the EPA guidance as an example of a “large” value, but does indicate a significant reduction in the simulated hourly and 8-hour ozone values from the current-year simulation.

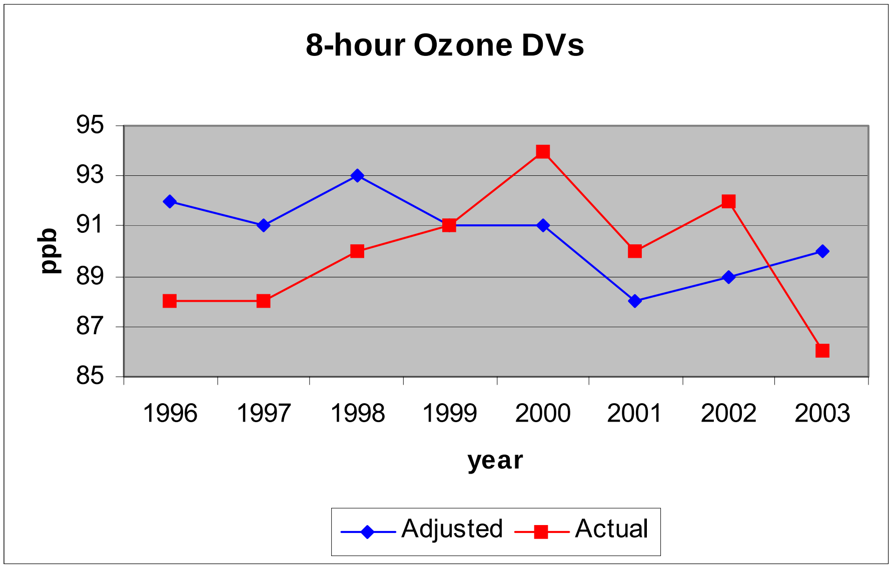
Design Value Analysis

Using the steps outlined earlier in this section, we created for each year a normalized, or meteorologically adjusted, year. The resulting design values for the Tri-Cities area, based on the Kingsport site, are listed in Table 8-20 and plotted in Figure 8-10. Since CART was not applied for the Tri-Cities area as part of the episode selection analysis, we used the meteorological regimes and the CART tree prepared for the Knoxville area as the basis for the adjustment. These area are nearby to each other and have similar geographical features.

Table 8-20.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Tri-Cities

Metric	1996	1997	1998	1999	2000	2001	2002	2003
Actual								
• - DVs	88	88	90	91	94	90	92	86
• - 4th highest	85	89	97	89	97	86	93	80
Adjusted								
• - DVs	92	91	93	91	91	88	89	90
• - 4th highest	92	90	97	88	89	87	93	90

Figure 8-10.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values for Kingsport

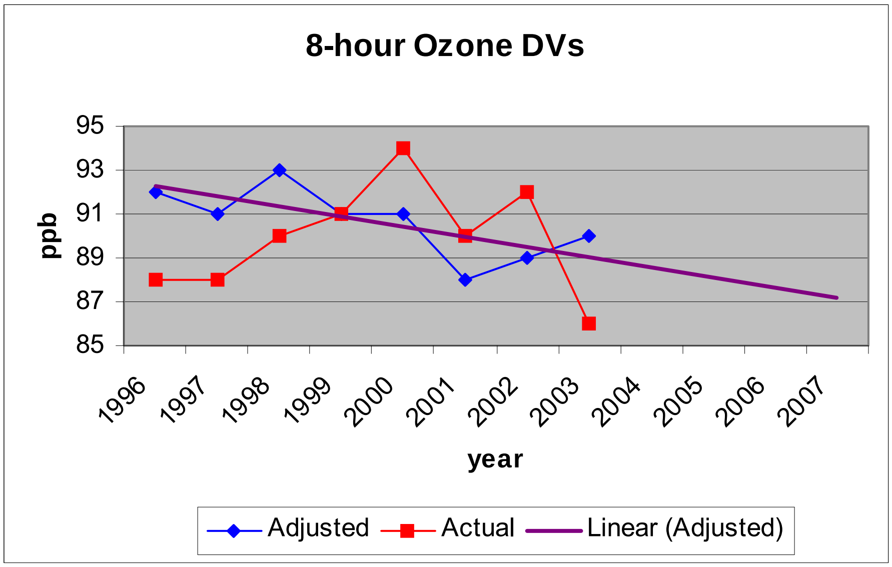


For 1996 and 1997, the adjusted design values are calculated using actual fourth-highest values for 1995 and 1994, since the CART analysis did not include those years. The average adjusted design value for the eight-year period is 90 ppb, one ppb higher than the average actual design value of 89 ppb. The adjusted design values exhibit somewhat less variation between years.

The results of this analysis indicate that a meteorologically adjusted design value is slightly more stable than the observation-based design value. The actual values show a clear tendency toward lower design values between 2000 and 2003, while the meteorologically adjusted values show a flatter tendency. The results also indicate that the design value for 2000-2002, as used in the modeled attainment test, may be unrepresentatively high as a result of more days than normal with ozone conducive meteorological conditions during the period and that for 2001-2003 may be unrepresentatively low for the opposite reasons. These results suggest that a more appropriate design value for application of the attainment test is 89 or 90 ppb. Use of a value of 89 ppb in the attainment test results in a 2007 EDV of 82 ppb, whereas use of a value of 90 ppb gives a result of 83 ppb for the EDV. In both cases, the attainment test is passed. This supports a finding of modeled attainment for the Tri-Cities area.

Figure 8-11 below shows the trend in adjusted design values out to 2007; the 2007 extrapolated value is 87 ppb. Note that these trends assume that the changes in emissions for 2003 to 2007 will follow the trends of 1996 to 2003. By not accounting for regional or local emissions reductions associated with planned future control measures, the endpoint may represent a worst case scenario. It is expected that the ATMOS modeling results using the meteorologically adjusted DV provide a better estimate of the future design value.

Figure 8-11.
Actual and Meteorologically-Adjusted 8-Hour Ozone Design Values and Meteorologically—Adjusted 8-Hour Ozone Trends for Kingsport



Summary Attainment Demonstration for the Tri-Cities Area

The attainment and screening tests and additional corroborative analyses indicate that the Tri-Cities EAC area will be in attainment of the 8-hour ozone standard by 2007. Variations in the selection of days or the radius of influence assumptions employed in the application of the attainment test do not alter the outcome of the modeled attainment test. There are no locations within a subdomain encompassing the Tri-Cities EAC area for which high ozone concentrations (greater than any near a monitor) are consistently simulated. The values of the simulated ozone exposure metrics indicate a significant reduction in 8-hour ozone for the 2007 AS-4 control measures simulation - approximately 50 percent for each of the exposure-type metrics. Estimates of modeling system noise also suggest that, relative to the 2007 baseline simulation, the simulated ozone reductions associated with the AS-4 control measures are meaningful within the context of the simulation – that is, the measures are expected to result in meaningful further ozone reductions by 2007, compared to the baseline values.

Both of the monitoring sites in the Tri-Cities area have future-year estimated design values for 8-hour ozone that are less than or equal to 84 ppb. The areawide 2007 EDV is 84 ppb if the 2000-2002 design value is used, 80 ppb if the 2001-2003 design value is used, and 82 ppb if a meteorologically adjusted design value is used.

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9. Maintenance Analysis for 2012

One of the requirements of the Early Action Compact is to evaluate maintenance of the 8-hour standard for 2012, five years beyond the attainment date of 2007. As such, a 2012 baseline emission inventory was developed for the ATMOS modeling episodes and 2012 baseline simulations were conducted. The development of the 2012 baseline emission inventory followed the same procedures as those used in developing the 2007 emission inventory. Specific details are presented by source category as follows:

Area Sources

- Applied BEA GSP projection factors to base emissions for all states except for the States of Louisiana (used BEA Employment projection factors) and Texas
- Applied energy adjustment factors for fuel combustion sources
- Applied VOC controls included in the Federal control measures, Title III MACT and Title I RACT assumptions
- Applied additional controls for residential wood combustion and Stage II VOC for gasoline service stations
- Eliminated all emissions due to the seasonal ban on open burning in 45 counties in Northern Georgia and 8 Counties in Alabama
- Kept the area source emissions for State of Texas at 2007 level (TCEQ 2007 Mid-Course Review Phase I)
- Applied the same percentage reductions for NO_x, VOC and CO emissions in the EAC counties reflecting area source control measures as specified in the final 2007 EAC attainment strategy (AS-4)

Point Sources

- Applied BEA GSP projection factors to base emissions for all states except for States of Louisiana (used BEA Employment projection factors) and Texas
- Applied energy adjustment factors for the non-EGU fuel combustion sources
- Applied NO_x SIP Call Phase I controls to the EGU and non-EGU sources located in the SIP Call-affected States
- Applied controls included in the CAA and MACT assumptions for non-EGU point sources
- Incorporated 2012 emissions estimates provided by TVA, and assumed that the combustion turbines (CTs) only operate on the three intermediate days of the episode for 4 hours per day (noon to 4pm)
- Incorporated day-specific 2012 emissions estimates provided by Southern Company
- Kept the emissions for the Entergy facilities (located in States of Arkansas, Louisiana and Mississippi) at the base level
- Kept the point source emissions for State of Texas at 2007 level (TCEQ 2007 Mid-Course Review Phase I)

- Kept the emissions at the 2007 levels for the gas compressor stations, Eastman Chemical Company and William Refining & Marketing LLC located in State of Tennessee, and the facilities currently under construction located in State of Mississippi
- Applied the same NO_x and VOC emissions reductions in the EAC counties reflecting to reflecting point source control measures as specified in the final 2007 EAC attainment strategy (AS-4)

Non-Road Mobile Sources

- Used EPA NONROAD2002a model with monthly maximum, minimum and average temperatures (calculated from the 1970-2000 30-year historical averages) by state, except for State of Texas and four counties in Arkansas
- Applied BEA GSP projection factors for emissions from aircraft, railroad and commercial marine vessels (NEI99V2 data) for all states except for States of Louisiana (used BEA Employment projection factors) and Texas
- Projected the 2000 non-road mobile source emissions for the four counties in Arkansas to 2012 level
- Kept the non-road mobile source emissions for State of Texas at 2007 level (TCEQ 2007 Mid-Course Review Phase I)
- Applied the same percentage reductions for NO_x, VOC and CO emissions for the EAC counties reflecting non-road control measures as specified in the final 2007 EAC attainment strategy (AS-4)

On-Road Mobile Sources

MOBILE6.2 with State-specific VMT Data

The mobile source emissions were estimated using MOBILE6.2 with 30-year historical average temperatures and absolute humidity data and state provided 2012 VMT data for Alabama, Arkansas, Georgia, Louisiana, Mississippi, South Carolina, North Carolina, Tennessee, and Texas.

MOBILE6.2 with FHWA VMT Data

The mobile source emissions for all other states in the ATMOS modeling domain were estimated using MOBILE6.2 with 30-year historical seasonal average temperatures and absolute humidity data, and 2012 FHWA VMT data.

The same percentage reductions were applied for NO_x, VOC and CO emissions for the EAC counties reflecting mobile source control measures as specified in the final 2007 EAC attainment strategy (AS-4).

Summary of Modeling Emission Inventories

The summaries of the 2012 baseline emissions are presented in Appendix B for each modeling episode as follows:

- Table B-34 through Table B-36 for the August/September 1999 episode.
- Table B-37 through Table B-39 for the June 2001 episode.
- Table B-40 through Table B-42 for the July 2002 episode.

The emission summaries are given by species (NO_x, VOC and CO) and by major source category. The low-level emissions include anthropogenic (area, non-road, on-road motor vehicle, and low-level point sources) and biogenic sources. The units are tons per day.

Figure 9-1 presents component emission totals for NOx, VOC, and CO for Grid 3 for a typical weekday (18 June 2001) comparing the current year 2001 emissions, the 2007 baseline emissions, and the 2012 baseline emissions. For Grid 3, the expected changes in emissions between 2001 and 2012 result in a 35 percent reduction in anthropogenic NOx emissions, an 18 percent reduction in anthropogenic VOC emissions, and a 20 percent reduction in CO emissions. Figures 7-2 through 7-6 present total emissions for each of the EAC areas for 2001, 2007, and 2012. These plots are presented using the same scale so that the totals can be compared between the EAC areas. The figures indicate that precursor NOx, VOC, and CO emissions in the ATMOS region and in the EAC areas are expected to decrease further in 2012 compared to 2007 as a result of vehicle fleet turnover and a number of new national rules affecting on-road and off-road engine and fuel requirements.

Modeling Results for 2012

The 2012 baseline simulation was conducted for all three of the ATMOS EAC modeling episodes. Table 9-1 presents a comparison of 1-hour and 8-hour metrics for the 2001 current year simulation and the 2012 baseline simulation. Compared to the metrics for the 2007 baseline simulation, the results for 2012 show substantial additional reductions in all of the metrics with reductions from the 2001 current year between 60 and 90 percent. Table 9-2 presents the maximum EDVs for 2012 for all of the EAC areas using both the 2000-2002 and 2001-2003 base year design values. The EDVs for 2012 are lower for all areas by 2 to 4 ppb compared to the 2007 baseline. The modeling results indicate that, despite the expected growth in population between 2007 and 2012, the expected emission reductions reflecting the local EAC measures and national measures provides for further improvement in ozone air quality and maintenance of the 8-hour standard in all of these areas.

Table 9-1a.
Comparison of the ATMOS Current Year (2001) and Future Year Baseline (2012) Simulation Results for All Non-startup Days

Grid/Area	8-hr Exceedance Exposure			# Grid-cells where max 8-hr > 84 ppb		
	2001	2012	% Reduction	2001	2012	% Reduction
Grid 3	4502274	805865	82	41602	9182	78
Memphis EAC	92093	25775	72	766	338	56
Nashville EAC	208109	35284	83	2079	513	75
Knoxville EAC	140359	9459	93	1358	215	84
Chattanooga EAC	204711	23307	88	1741	278	84
Tri-Cities EAC	60247	5635	91	411	124	70

Table 9-1b.
Comparison of the ATMOS Current Year (2001) and Future Year Baseline (2007) Simulation Results for All Non-startup Days

Grid/Area	# Grid Cell Hours where 1-Hr Concs > 84 ppb			1-Hr Exceedances Exposure for Concs > 84 ppb		
	2001	2012	% Reduction	2001	2012	% Reduction
Grid 3	388289	102063	74	3800105	835852	78
Memphis EAC	7514	3244	57	77821	27063	65
Nashville EAC	18777	5741	69	176247	40412	77
Knoxville EAC	11554	2663	77	111972	13555	88
Chattanooga EAC	14858	3109	79	154244	22420	85
Tri-Cities EAC	5015	1240	75	47512	6725	86

Table 9-2.
Maximum Observed and Estimated Design Values (EDVs) for the ATMOS EAC Areas for the 2012 Baseline Simulation

Site	2000–2002			2001–2003		
	Observed DV	EDV (15-km)	EDV (9-cell)	Observed DV	EDV (15-km)	EDV (9-cell)
Memphis EAC (Marion)	94	86	86	92	84	84
Nashville EAC (Rockland Rd.)	88	79	79	86	77	77
Knoxville EAC (Spring Hill)	96	86	86	92	83	82
Knoxville EAC (Clingman's Dome)	98	86	84	92	80	79
Chattanooga EAC (Sequoyah)	93	81	82	87	76	76
Tri-Cities EAC (Kingsport)	92	82	80	86	76	74

Figure 9-1a.
Comparison of NOx Emissions by Component for ATMOS Grid 3 for 2001, 2007, and 2012

Weekday Emissions for 18 June

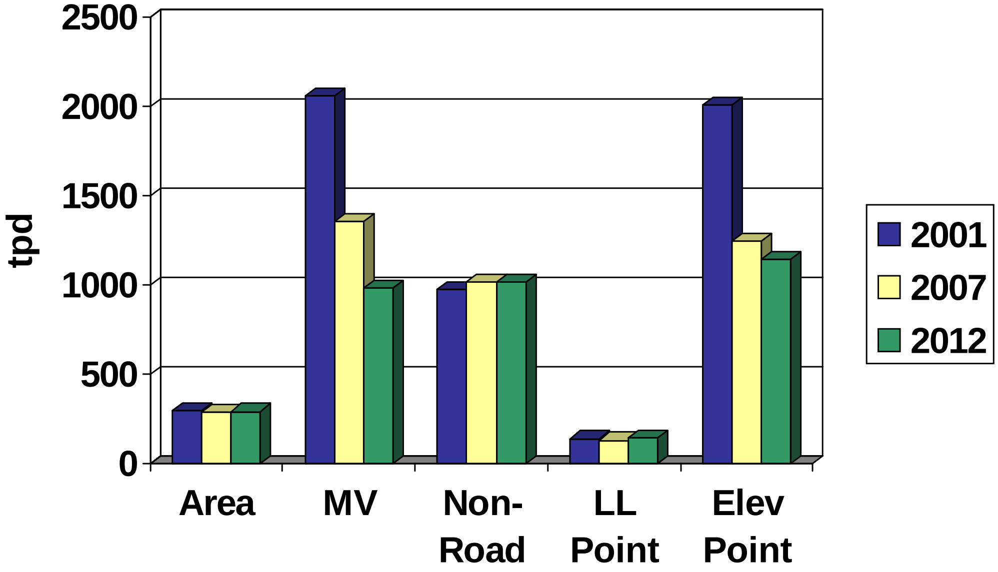


Figure 9-1b.
Comparison of VOC Emissions by Component for ATMOS Grid 3 for 2001, 2007, and 2012

Weekday Emissions for 18 June

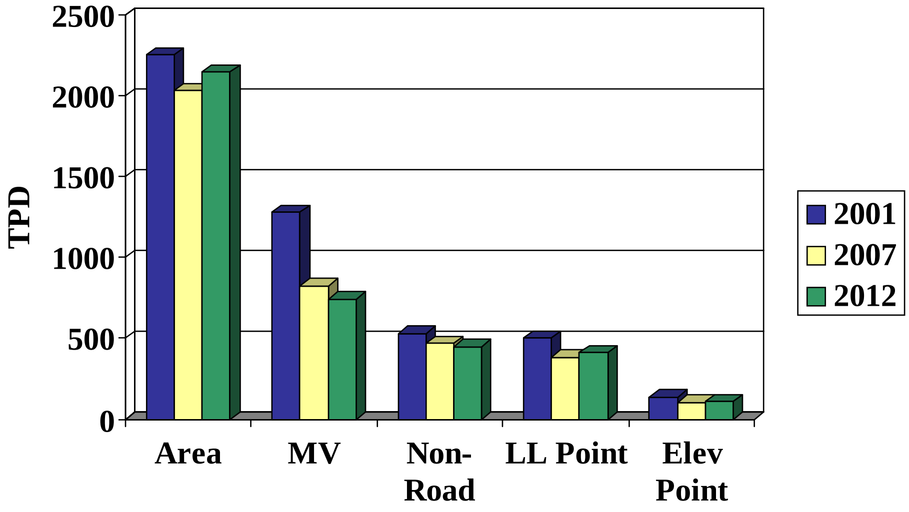


Figure 9-1c.
Comparison of CO Emissions by Component for ATMOS Grid 3 for 2001, 2007, and 2012

Weekday Emissions for 18 June

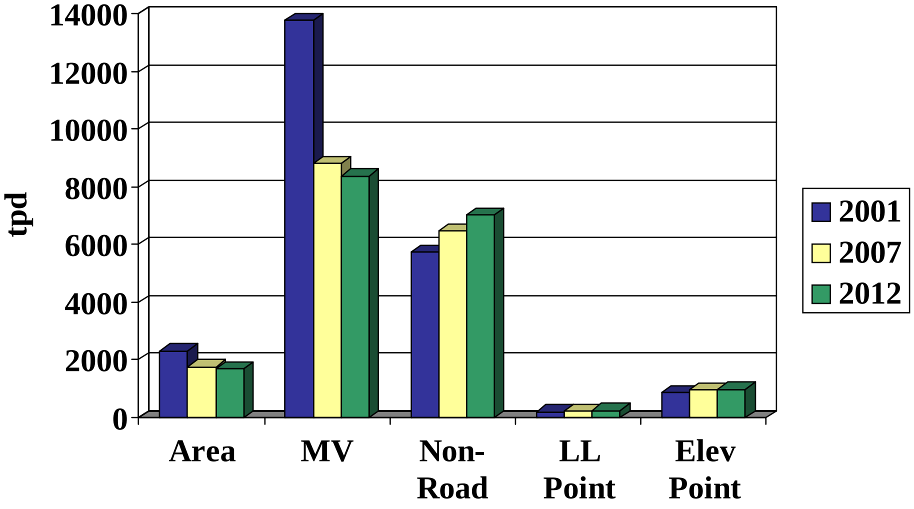


Figure 9-2.
Anthropogenic Emissions (tpd) for the Memphis EAC Area

Emissions for 18 June Episode Day

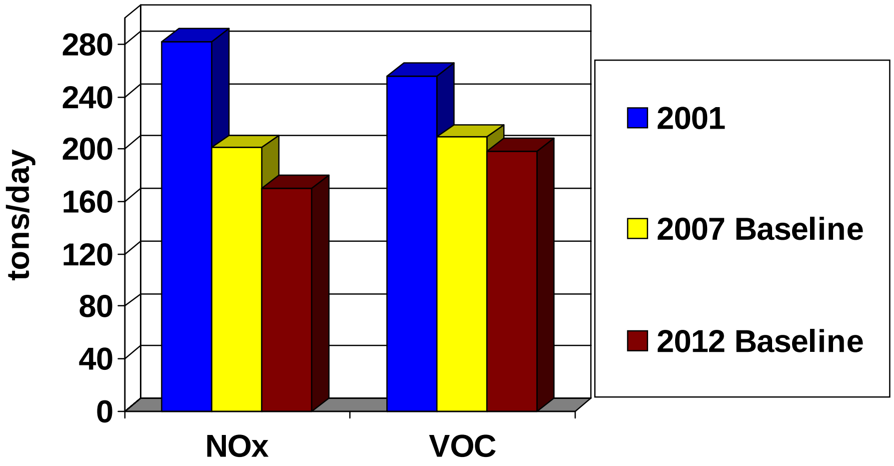


Figure 9-3.
Anthropogenic Emissions (tpd) for the Nashville EAC Area

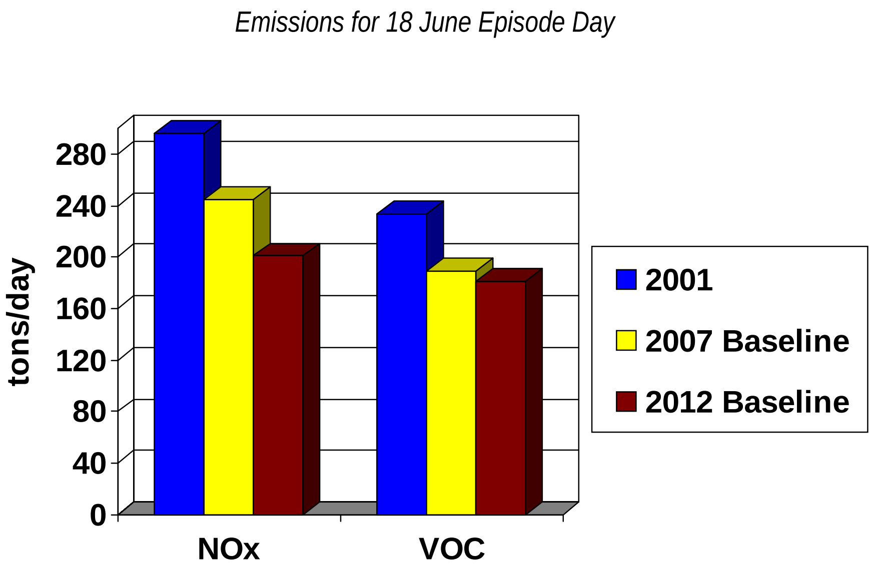


Figure 9-4.
Anthropogenic Emissions (tpd) for the Knoxville EAC Area

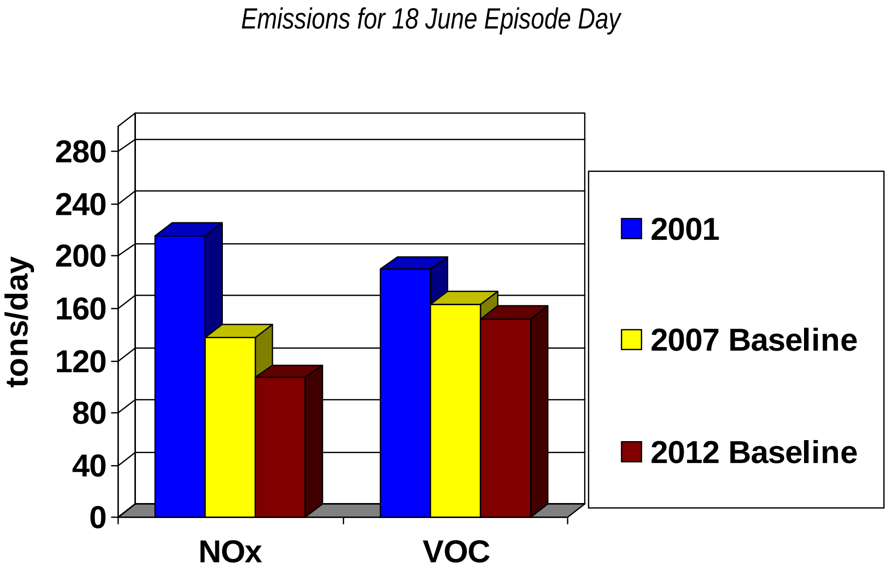


Figure 9-5.
Anthropogenic Emissions (tpd) for the Chattanooga EAC Area

Emissions for 18 June Episode Day

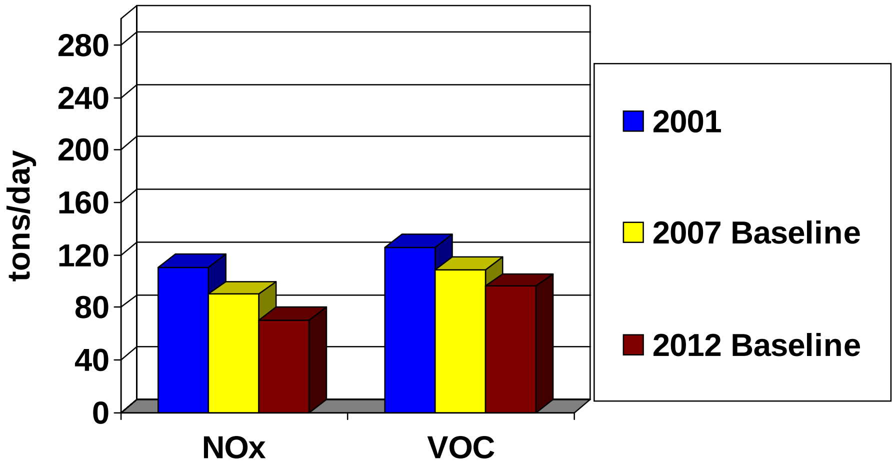
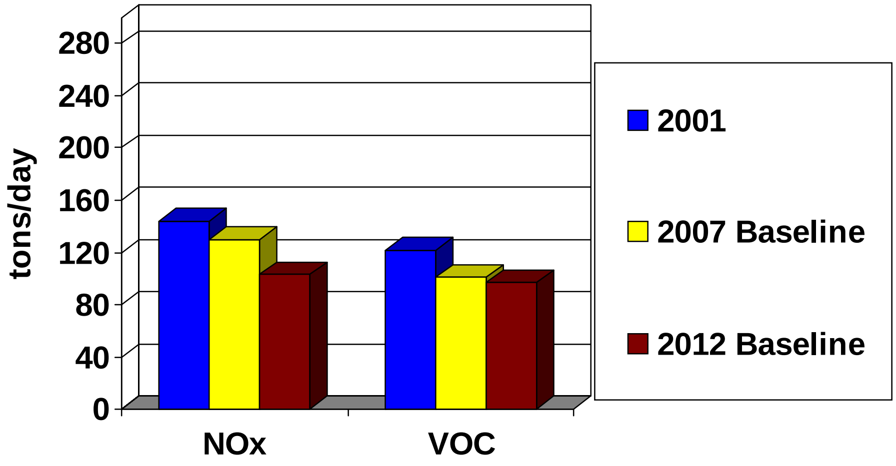


Figure 9-6.
Anthropogenic Emissions (tpd) for the Tri-Cities EAC Area

Emissions for 18 June Episode Day



10. Summary of Review Procedures Used

The review procedures employed as part of the ATMOS EAC modeling analysis included quality assurance of the modeling inputs and outputs by SAI and the ATMOS technical committee members (with the emphasis for the technical committee on the emissions inputs), and review and analysis of the simulation results by all study participants.

The quality assurance procedures for the modeling system inputs are described in Sections 3, 4, and 5 of this report. Procedures for quality assurance of the simulation results are described in Sections 6 and 7. The ADVISOR database was an important component of the quality assurance review and provided detailed and timely access to the simulation results (and emissions inputs) for all of the modeling analysis participants. In addition, the simulation results were presented to representatives from EPA, Regions 4 and 6 and members of the ATMOS Technical Committee and the general public at meetings held throughout the course of the study (approximately every two to three months).

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11. Data Access Procedures

The data, input, and output files for the modeling analysis are available in electronic format. Interested parties should contact the Tennessee Department of Environment and Conservation, Air Pollution Control Division for information on how to obtain these files. The modeling tools used for this study are all publicly available and can be obtained from EPA (BEIS, MOBILE), NCAR (MM5), or SAI (EPS2.5, UAM-V).

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