Appendix G

Conceptual Model for the AER

Ozone Conceptual Model
for the Austin Area

DRAFT

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EXECUTIVE SUMMARY

The Capital Area Planning Council (CAPCO) is currently preparing an Early Action Compact (EAC) for submission to the Texas Commission on Environmental Quality (TCEQ) and the United States Environmental Protection Agency (U.S. EPA). A crucial component of the EAC is photochemical modeling of one or more multi-day high ozone episodes to evaluate the effects of both local and regional emissions control strategies. The development of a conceptual model, which describes the local meteorological conditions and associated large-scale weather patterns experienced during periods of high ozone, is the first step in episode day selection. This report expands the latest conceptual model for Austin (completed in September 2002) by incorporating data collected during 2002 and 2003.

For the purposes of this report, high ozone days were defined as those days exhibiting a peak 8-hour average ozone concentration greater than 75 ppb. During the 1993 through 2003 period, one or more Austin monitoring stations measured 75 ppb or greater on 188 dates. The annual number of high ozone days ranged from a minimum of 6 during 1996 to 34 during 1999. High ozone concentrations peaked preferentially during the August through early October period. A minor secondary peak occurred during late May and June. Local meteorological measurements on high ozone days indicated an average daily maximum temperature of 92 ^{o}F and an average resultant mean wind speed of only 3.1 mph. Decoupling of the surface layer from the prevailing synoptic-scale circulation often resulted in rather variable morning wind directions. By late morning, mechanical mixing by convective thermals brought higher momentum air dominated by the large-scale flow to the surface, and afternoon winds typically blew from the northeast, east, or southeast.

A consistent synoptic-scale weather cycle was observed during a majority of the high ozone episodes in Central Texas. A multi-day high ozone episode typically began immediately after the passage of a frontal trough. These fronts often provided little difference in terms of temperature, but represent a transition zone between drier continental air to the north and tropical maritime air from the Gulf of Mexico to the south. A ridge of surface high pressure typically advanced southward into Texas behind the front. These high pressure systems are characterized by meteorological conditions highly favorable to the formation and accumulation of ground-level ozone, including light wind speeds, abundant sunshine, warm temperatures, and subsidence (sinking air) that inhibits vertical mixing and traps pollutants in a shallow layer near the surface.

The clockwise circulation around the surface ridge of high pressure, often centered over the Central Plains or Ohio/Mississippi River Valleys, generated northeasterly or easterly flow that transported continental air and haze into eastern Texas. This continental airmass was often characterized by reduced visibility, and likely contained elevated concentrations of ozone and its precursor compounds associated with both biogenic and anthropogenic emissions. High ozone levels were often monitored throughout eastern Texas during these periods. Peak 8-hour ozone concentrations at the San Marcos and Fayette County monitoring stations under these conditions averaged 80-85% of the observed Austin maximum, suggesting significant regional transport of background ozone into Central Texas. With background levels ranging from 65 ppb to 85 ppb on most high ozone days, even small contributions of ozone formed from local source emissions in the Austin area would result in an exceedance of the 8-hour NAAQS of 0.08 ppm.

As the surface ridge of high pressure over Texas weakened, southeasterly and southerly surface flow returned. This flow is initially associated with transport of continental air over the Gulf of Mexico and does not represent an immediate return to relatively clean maritime tropical inflow. With continued southerly winds, however, relatively clean air from the Gulf of Mexico improves horizontal dilution of ozone concentrations across the Austin Area. High ozone episodes sometimes end when a second frontal system enters Texas, bringing cooler temperatures and generating convection and shower activity.

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1.0 Introduction

The development of air quality plans involves a number of complex planning steps that include ambient air quality data analyses, emission inventory development, air quality modeling, and analysis of emissions control options. A crucial part of the process is photochemical modeling of one or more multi-day high ozone episodes to evaluate the effects of both local and regional emissions control strategies. Since photochemical modeling is costly and resource intensive, a limited number of days are selected. It is essential that the episode days (typically from three to ten) selected for photochemical modeling be representative of weather patterns most often associated with high ozone levels in the local area. As such, the development of a conceptual model of the weather patterns that are most often associated with high ozone levels is the first step in episode day selection. This report describes the development of the conceptual model.

1.1 Conceptual Model Definition

EPA has prepared draft guidance for the development of a conceptual model that defines the meteorological conditions associated with high ozone concentrations (EPA, 1999). A conceptual model of ozone formation should ideally summarize both the local meteorological conditions and associated large-scale weather patterns typically experienced during periods of elevated ozone. The supporting analysis should include a review of all available ambient air quality data, meteorological data, and previous photochemical modeling efforts. Based on the predominant weather features typically experienced in Texas during the ozone season, the TCEQ has interpreted the EPA guidance and offered additional suggestions for data analyses, as summarized in the following paragraph (TNRCC, 2000, 2001).

Ozone is formed by a complex series of chemical reactions involving photochemically active Volatile Organic Compounds (VOCs) and Oxides of Nitrogen (NO_x) in the presence of sunlight. In most highly developed urban areas, ambient concentrations of these precursor compounds are sufficient to produce ozone; however, favorable meteorological conditions are required before high ozone concentrations are measured. Meteorological conditions conducive to the formation and accumulation of ozone typically include light wind speeds, warm temperatures, clear skies, and a stable atmosphere that traps pollutants in a shallow layer close to the surface. When developing the ozone conceptual model, both local and synoptic (i.e., large-scale) data analyses should be performed to determine the influence of weather systems such as high pressure areas, frontal troughs, jet streams, thunderstorms, and hurricanes. Local surface meteorological conditions should be quantitatively described. Back-trajectories, which indicate movement of air parcels over time based on the three-dimensional wind field, can be used to explore the potential influence of regional transport. Days with exceptional events (such as large accidental emissions releases from industry or unusual mobile plumes due to a massive traffic jam) should be eliminated from the dataset. Together, these analyses should describe the typical large-scale weather regimes and associated local meteorological conditions that are conducive to the accumulation and formation of elevated ozone levels for a particular region.

1.2 Austin Air Quality

Austin is one of five areas that have received funding from the Legislature of the State of Texas to address ozone air quality issues through the Near Non-attainment Area Program. The Capitol Area Planning Council (CAPCO) coordinates air quality planning activities in the five-county Austin area. Austin is currently examining the effectiveness of local and regional emissions control strategies, assessing the magnitude of regional transport, and preparing technical information for participation in the Early Action Compact (EAC). The EAC is a voluntary U.S. EPA program available to areas that are in attainment of the 1-hour ozone standard but approach or monitor exceedances of the 8-hour standard. The EAC emphasizes local control in the development and implementation of emissions control strategies to achieve and maintain the 8-hour ozone standard.

The U.S. EPA's *Draft Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS* (1999) is the principal guidance document for areas submitting EACs. The guidance specifies four primary criteria for selecting meteorological episodes to model:

1. "Choose a mix of episodes which represent a variety of meteorological conditions which frequently correspond with 8-hour daily maxima > 84 ppb at different monitoring sites.
2. Model periods in which observed 8-hour daily maximum concentrations are close to the average 4th high 8-hour daily maximum concentrations.
3. Model periods for which extensive air quality and meteorological databases exist.
4. Model a sufficient number of days so that the modeled attainment test applied at each monitor violating the NAAQS is based on several days."

The guidance also indicates that tradeoffs among the four primary criteria may be necessary. In addition, the U.S. EPA's *Protocol for Early Action Compacts* (2003) specifies that "a 1999 or later episode reflective of a typical ozone season exceedance that meets the U.S. EPA's episode selection guidance to ensure that representative meteorological regimes are considered" must be included.

In 2001, Austin collaborated with San Antonio, Victoria, Corpus Christi, and the TCEQ to select a multi-day high ozone episode for photochemical modeling. The conceptual model was used to select the September 13-20, 1999 high ozone episode for development with the Comprehensive Air Quality Model with Extensions (CAMx) photochemical grid model. The September 13-20, 1999 modeling episode fulfills both the requirements of the U.S. EPA's *Draft Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS* (1999) and the U.S. EPA's *Protocol for Early Action Compacts* (2003) that require representation of meteorological regimes typical of ozone exceedances. The episode covers one synoptic cycle for ozone in Austin with two initialization days and six high ozone days. It includes weekend days such that control strategies can be evaluated with different emission characteristics. In accordance with the U.S. EPA's *Protocol for Early Action Compacts* (2003), CAPCO submitted documentation of the development of the September 13-20, 1999 Base Case to the TCEQ and the U.S. EPA in November 2003.

An area violates the 8-hour ozone NAAQS if the annual fourth highest 8-hour daily peak concentration, averaged over three consecutive years, exceeds 0.08 parts per million (ppm) at a given monitoring site. Figure 1-1 presents the annual 8-hour design values for Austin for the years 1988 through 2003. The value for a year is the average of the fourth highest concentration for that year and the two previous years (e.g., the 2003 design value is the average of the fourth highest over 2001, 2002, and 2003). Although the 8-hour design value of 84 ppb for 2001-2003 indicates compliance with the NAAQS, the long-term trend in design values suggests that Austin will remain on the cusp of attainment or nonattainment during the next several years.

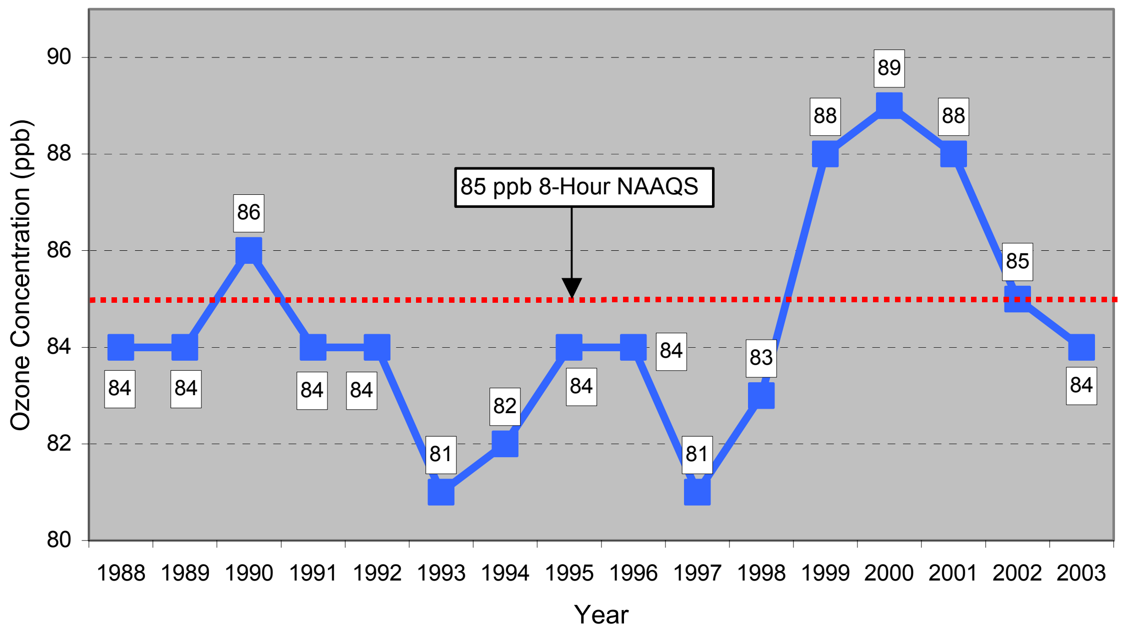

Figure 1-1. 8-Hour Ozone Design Values for the Austin Area 1988 - 2003

1.3 Report Organization

The following report is organized into seven additional sections. Section 2 contains a description of the air quality and meteorological datasets that were used to develop the conceptual model for Austin. Annual and seasonal trends of high ozone days are presented in Section 3. Section 4 documents the relationship between ozone and local surface meteorological variables such as temperature, wind speed, and wind direction. Regional transport of background ozone into the Austin area is discussed in Section 5. Section 6 summarizes the large-scale weather patterns and associated local meteorological conditions that occurred during representative multi-day high ozone episodes in Central Texas over the 1999 through 2003 period. Section 7 provides a description of the conceptual model for Austin. Existing and recommended episodes for photochemical modeling are discussed in Section 8. References are reported in Section 9.

2.0 Data

The development of the ozone conceptual model for the Austin Area was based primarily on ozone and meteorological data collected during the 1993 through 2003 period. These years were selected because: 1.) The conceptual model should be based on data collected during periods with emissions similar to current inventories; and 2.) These data are available from several sources, including the EPA AIRS Database. This section describes both the local and national datasets that were used to develop the ozone conceptual model. These datasets include ozone and meteorological data collected at the Austin, Fayette County, and San Marcos monitoring stations. Analyses of the prevailing large-scale weather patterns were based on surface weather maps, upper air charts, and infrared satellite images archived by the UNISYS weather. Regional transport was investigated via a back-trajectory model (HYSPLIT) developed by a joint effort between the National Oceanic and Atmospheric Administration and Australia's Bureau of Meteorology.

2.1 TCEQ CAMS Monitoring Data

Continuous Air Monitoring Stations (CAMS) collect ozone and meteorological data throughout Texas. Data collected at five Austin Area CAMS monitoring stations were utilized for the historical trend and data analyses presented in this paper. In addition, data collected at the San Marcos and Fayette County monitoring locations were used to estimate regional levels of background ozone. Table 2-1 presents a summary of identification and geographic data for each monitoring location. Figure 2-1 presents a map showing the locations of the CAMS monitoring stations. The CAMS 3 site, located at Murchison Middle School, collected continuous measurements during the 1993 through 2003 period. The CAMS 25 monitoring station, located at the intersection of Parmer Lane and Mopac, was active from 1993 until the site was dismantled in February 1997. The site was relocated to the Audubon monitoring station (CAMS 38), located about 18 miles northwest of downtown Austin, in March 1997. Both the Murchison and Audubon monitoring stations continue to collect ozone and meteorological data through the present period. Monitoring at the San Marcos and Fayette County stations began in 1998. Monitoring at the San Marcos station was discontinued in August 2002. In preparation for the 2003 ozone season, CAPCO installed two additional stations to improve the spatial coverage of the ozone monitoring network in the Austin area. The CAMS 613 station was installed in December 2002 in Pflugerville, or approximately 12 miles northeast of downtown Austin. The CAMS 614 station was installed in Dripping Springs, or approximately 20 miles west-southwest of downtown Austin. The Dripping Springs monitoring station is well-positioned to sample a portion of the downwind Austin urban ozone plume during periods of northeasterly or easterly flow. Data collected at the all CAMS locations are archived by TCEQ as hourly averages, and are available via the Internet through the EPA's Aerometric Information Retrieval System (AIRS) (http://www.epa.gov/airs).

Table 2-1. Description and Location of Ozone Monitoring Stations

Monitor Name	CAMS #	AIRS ID	Address	Active Years during 1993 - present
Audubon	38	48-453-0020	12200 Lime Creek Rd.	Mar. 1997 - present
Dripping Springs	614	48-209-0614	29400 Ranch Rd. 12	Mar. 2003 - present
Fayette County	601	48-149-0001	636 Roznov Rd.	Jul. 1998 - present
Murchison	3	48-453-0014	3724 North Hills Dr.	1993 - present
Parmer	25	48-453-0003	Parmer Lane at Mopac	1993 – Feb. 1997
Pflugerville	613	48-453-0613	2609 East Pecan St.	Dec. 2002 - present
San Marcos	62	48-055-0062	2041 Airport Dr.	Aug. 1998 – Aug. 2002

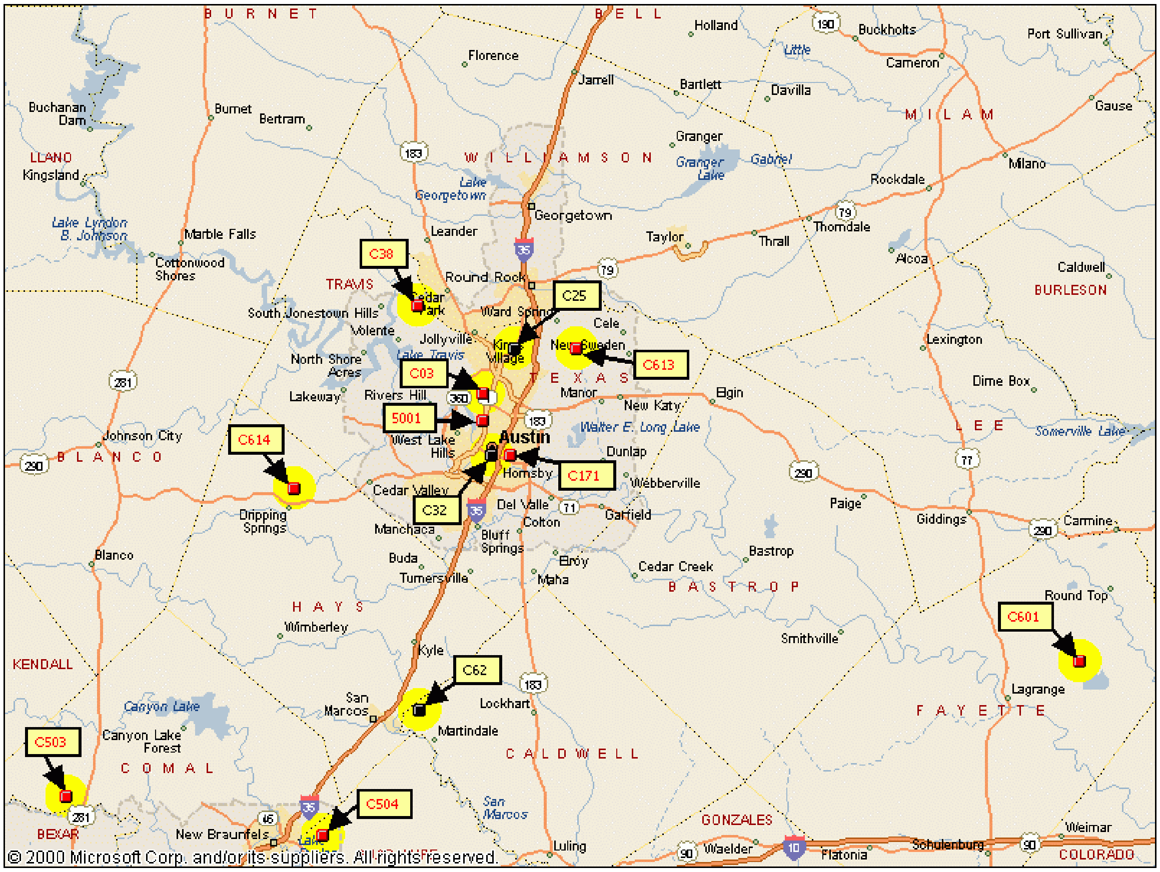

Figure 2-1. Location of Austin Area Monitors by CAMS #
(Active monitors labeled in red. Ozone is not monitored at C171 or 5001.)
Courtesy of TCEQ Website http://www.tceq.state.tx.us/updated/air/monops

2.2 National Weather Service Synoptic Analyses

The National Weather Surface provides both surface weather maps and upper-air charts for the continental U.S. on a near real-time basis. These maps summarize data analyses that incorporate meteorological observations at airports and automated observing platforms, rawinsondes, radar scans, and present weather conditions from monitoring sites across the U.S. Contours of temperature, dewpoint temperature, pressure, wind direction, and wind speed were used to investigate the locations of large-scale synoptic features such as frontal troughs, high pressure ridges, and jet streaks. All weather maps analyzed or discussed in this paper were obtained from the UNISYS Weather World Wide Web site (http://weather.unisys.com). The UNISYS archive of surface weather maps and upper-air charts is currently available for the 1997 through present period. Twice-daily visible, infrared, and water vapor imagery obtained from the NOAA GOES satellite are also available from the UNISYS website.

2.3 HYSPLIT Back-Trajectories

The Lagrangian trajectory model HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) was used to investigate the potential source regions of air entering the Austin Area. HYSPLIT was developed by a joint effort between the National Oceanic and Atmospheric Administration (NOAA) and Australia's Bureau of Meteorology, and can be run interactively on the World Wide Web (http://www.arl.noaa.gov/ready/hysplit4.html). HYSPLIT uses meteorological model forecast data from the National Centers for Environmental Prediction (NCEP) archived by Air Resources Laboratory (ARL). Most trajectories for the 1993 through 1996 period were calculated based on the three-dimensional wind field provided by the Nested Grid Model (NGM) model forecast. The NGM data are archived by ARL with a 2-hour time resolution and a 180-km spatial resolution. Trajectories for the 1997 through 2003 period were primarily calculated from the three-dimensional wind field provided by the Eta Data Assimilation System (EDAS). The EDAS data are archived by ARL with a 3-hour time interval over an 80-km grid.

3.0 Ozone Trends

This section presents a historical overview of ozone concentrations monitored in the Austin Area during the 1993 through 2003 period. Concurrent measurements were compared between sites to determine the locations that typically monitor maximum concentrations. In addition, annual, seasonal, and day of week trends of high ozone concentrations are presented.

3.1 Sensitivity to Monitoring Locations

Throughout the analyses presented in this report, the reader should keep in mind that data interpretations are inherently biased by the locations of the individual monitors within the Austin monitoring network. For example, based on the predominant southerly and southeasterly summertime wind flow patterns, past ozone monitoring stations in Austin have been installed to the north and northwest of the downtown area. These monitors should be well-positioned to sample a portion of the downwind ozone plume during the climatologically favored summertime flow, though the overall maximum ozone concentrations may not be captured. As shown in subsequent data analyses, high ozone is often associated with northeasterly or easterly flow as well. During these wind flow patterns, the existing monitoring networks have not been well-sited to sample the downwind urban plume, and the maximum ozone concentrations in the Austin Area could have been substantially different than the available data indicate. In preparations for the 2003 ozone season, monitors were installed at the Pflugerville and Dripping Springs locations. The Pflugerville monitor is well positioned to measure background ozone concentrations entering the Austin area during periods of northerly winds, and ozone concentrations within the downwind Austin plume during periods of southerly flow. The Dripping Springs monitor, located 20 miles to the west-southwest of downtown Austin, is well-sited to capture a portion of the Austin urban ozone plume during northeasterly or easterly flow.

3.2 Peak 8-Hour Ozone Concentrations

For the purposes of conceptual model development, high ozone days are defined as those days exhibiting a peak 8-hour concentration greater than 75 ppb. The threshold value of 75 ppb was selected because: 1) EPA guidance suggests 75 ppb as the lower threshold for an 8-hour averaging period for these analyses (EPA, 1999); and 2) a 75 ppb threshold provides a large enough dataset to allow robust statistics for the Austin Area. Table 3-1 presents the 188 dates when the peak 8-hour ozone concentration exceeded 75 ppb at one or more Austin Area monitoring stations during the 1993 through 2003 period.

Table 3-1. Days with Peak 8-Hour Ozone Concentration > 75 ppb at One or More Austin Monitoring Stations During 1993 through 2003**

Date (mm/dd/yy)	Maximum 8-Hour Ozone Concentration (ppb)	Station Measuring Maximum Concentration
06/02/93	77	Murchison
09/05/93	86	Murchison
09/07/93	80	Murchison
09/08/93	82	Parmer
09/09/93	85	Parmer
09/10/93	87	Murchison
09/29/93	82	Murchison
05/19/94	81	Murchison
05/20/94	80	Murchison/Parmer
05/22/94	76	Parmer
07/29/94	81	Parmer
08/11/94	79	Murchison
08/12/94	88	Parmer
08/13/94	80	Parmer
08/15/94	76	Murchison
08/16/94	88	Murchison
09/20/94	79	Murchison
09/21/94	89	Murchison
10/01/94	89	Murchison
03/18/95	80	Murchison
03/19/95	75	Murchison
04/13/95	82	Murchison
06/13/95	85	Murchison
06/14/95	89	Murchison
06/20/95	80	Murchison
06/21/95	98	Murchison
06/22/95	90	Murchison
06/24/95	77	Murchison
07/09/95	81	Murchison
07/10/95	90	Parmer
07/11/95	89	Parmer

Date (mm/dd/yy)	Maximum 8-Hour Ozone Concentration (ppb)	Station Measuring Maximum Concentration
07/12/95	76	Murchison
08/04/95	89	Murchison
08/20/95	79	Murchison
08/21/95	77	Murchison
08/24/95	79	Murchison
08/25/95	84	Murchison
08/26/95	83	Murchison
08/30/95	76	Parmer
09/01/95	81	Murchison
09/02/95	90	Murchison
09/03/95	91	Murchison
09/04/95	92	Parmer
09/08/95	85	Murchison
09/09/95	86	Murchison
09/11/95	88	Murchison
09/12/95	78	Parmer
09/25/95	83	Murchison
09/26/95	82	Murchison
09/29/95	76	Murchison
10/04/95	75	Parmer
10/10/95	81	Murchison
04/24/96	75	Murchison
06/09/96	83	Parmer
07/03/96	84	Murchison
07/04/96	85	Parmer
10/01/96	79	Murchison
10/02/96	81	Murchison
03/23/97	78	Audubon
04/16/97	80	Audubon
04/17/97	86	Audubon
04/29/97	77	Audubon
05/11/97	75	Audubon
06/02/97	87	Audubon
06/03/97	92	Audubon
06/04/97	81	Audubon
07/16/97	83	Audubon
07/17/97	80	Audubon
08/01/97	80	Audubon
08/02/97	85	Murchison
08/03/97	76	Murchison
08/04/97	83	Audubon
08/25/97	78	Audubon
08/26/97	97	Audubon
09/02/97	84	Audubon
09/06/97	79	Audubon
09/07/97	80	Audubon
09/11/97	80	Audubon
09/27/97	76	Murchison
09/29/97	86	Audubon

Date (mm/dd/yy)	Maximum 8-Hour Ozone Concentration (ppb)	Station Measuring Maximum Concentration
10/02/97	91	Audubon
04/05/98	76	Audubon
04/11/98	76	Audubon
05/08/98	86	Audubon
05/11/98	80	Audubon
06/15/98	87	Murchison
08/03/98	79	Murchison
08/28/98	85	Murchison
08/29/98	89	Murchison
08/30/98	92	Murchison
08/31/98	78	Murchison
09/01/98	79	Audubon
09/03/98	93	Murchison
09/04/98	95	Murchison
09/05/98	81	Audubon
10/10/98	76	Audubon
04/12/99	77	Audubon
05/07/99	81	Audubon
06/18/99	76	Audubon
08/03/99	82	Audubon
08/04/99	84	Audubon
08/05/99	103	Audubon
08/06/99	98	Audubon
08/07/99	90	Audubon
08/15/99	84	Audubon
08/16/99	96	Audubon
08/17/99	80	Audubon
08/20/99	93	Audubon
08/21/99	98	Audubon
08/28/99	79	Audubon
08/30/99	94	Audubon
08/31/99	94	Audubon
09/01/99	93	Audubon
09/02/99	89	Audubon
09/09/99	78	Audubon
09/10/99	76	Audubon
09/15/99	79	Audubon
09/16/99	86	Audubon
09/17/99	100	Audubon
09/18/99	99	Audubon
09/19/99	101	Audubon
09/20/99	88	Murchison
09/23/99	79	Audubon
09/24/99	89	Audubon
10/01/99	97	Audubon
10/05/99	79	Audubon
10/07/99	78	Audubon
10/10/99	80	Audubon
10/13/99	87	Audubon

Date (mm/dd/yy)	Maximum 8-Hour Ozone Concentration (ppb)	Station Measuring Maximum Concentration
10/14/99	87	Audubon
04/22/00	75	Audubon
04/26/00	85	Audubon
06/07/00	75	Audubon/Murchison
07/14/00	75	Murchison
07/24/00	86	Audubon
07/27/00	75	Audubon
08/01/00	85	Murchison
08/02/00	86	Audubon
08/12/00	76	Audubon/Murchison
08/13/00	88	Murchison
08/24/00	75	Murchison
08/31/00	80	Audubon
09/01/00	88	Audubon
09/02/00	89	Murchison
09/03/00	87	Audubon
09/04/00	79	Audubon/Murchison
09/05/00	97	Audubon
09/06/00	77	Audubon
09/07/00	79	Audubon
09/15/00	83	Audubon
09/16/00	81	Audubon
09/17/00	77	Audubon
09/18/00	100	Audubon
09/30/00	86	Audubon
04/28/01	81	Murchison
05/23/01	85	Audubon
05/24/01	77	Audubon
06/18/01	82	Audubon
06/25/01	81	Audubon
09/12/01	79	Murchison
09/27/01	75	Murchison
10/02/01	80	Audubon
05/20/02	75	Murchison
06/18/02	82	Murchison
06/23/02	92	Murchison
06/24/02	100	Murchison
06/25/02	75	Murchison
08/30/02	79	Murchison
09/11/02	76	Murchison
09/12/02	87	Murchison
09/13/02	96	Murchison
09/14/02	91	Murchison
09/27/02	75	Murchison
04/26/03	77	Murchison/Dripping Springs
05/16/03	81	Pflugerville
05/23/03	75	Audubon/Murchison
05/24/03	81	Pflugerville
05/28/03	83	Pflugerville

Date (mm/dd/yy)	Maximum 8-Hour Ozone Concentration (ppb)	Station Measuring Maximum Concentration
05/29/03	82	Pflugerville
05/30/03	96	Pflugerville
05/31/03	80	Pflugerville
06/07/03	81	Murchison
06/19/03	77	Pflugerville
06/20/03	78	Dripping Springs
09/06/03	85	Murchison
09/07/03	92	Murchison
09/08/03	86	Pflugerville
10/23/03	84	Audubon

**Due to averaging method, these values should not be used for determining compliance with the 8-Hour Ozone NAAQS.

3.2.1 Comparison of daily peak ozone concentrations between the Parmer and Murchison monitoring stations

During the 1993 through 1996 period, the Parmer and Murchison monitoring stations were in continuous operation. Figure 3-1 presents a scatterplot of the 8-hour daily peak ozone concentrations at each monitoring location when one or both stations measured a peak concentration greater than 75 ppb. A line with a one-to-one slope has been drawn across the scatterplot. Data points located above this line indicate that Murchison measured a higher peak concentration. Conversely, data points located below this line indicate that Parmer measured a higher peak concentration. Note that Murchison, located approximately 6 miles to the north of downtown Austin, measured higher levels on most days. The peak ozone concentration at Murchison was, on average, 5.4 percent greater than that measured at Parmer. A wind direction analysis revealed that most days characterized by relatively higher 8-hour ozone concentrations at Parmer exhibited south-southeasterly afternoon winds. Parmer, located approximately 12 miles north of downtown Austin, would be well-positioned to sample a portion of the downwind ozone plume on days characterized by this flow pattern. Murchison consistently measured relatively higher ozone concentrations on days characterized by northeasterly and easterly afternoon winds, and may have been better positioned to monitor a portion of the urban plume during these conditions. However, there may be additional or alternate contributing factors to the observed bias between these monitoring stations. For example, the Parmer site was located immediately adjacent to a major transportation artery and NO from newly emitted mobile vehicle exhaust likely reacted with some of the ozone in the immediate area. The reaction of NO with ozone would result in a temporary and highly localized decrease in ambient ozone concentrations at and near the monitoring station (Bryan Lambeth, TCEQ, personal communication).

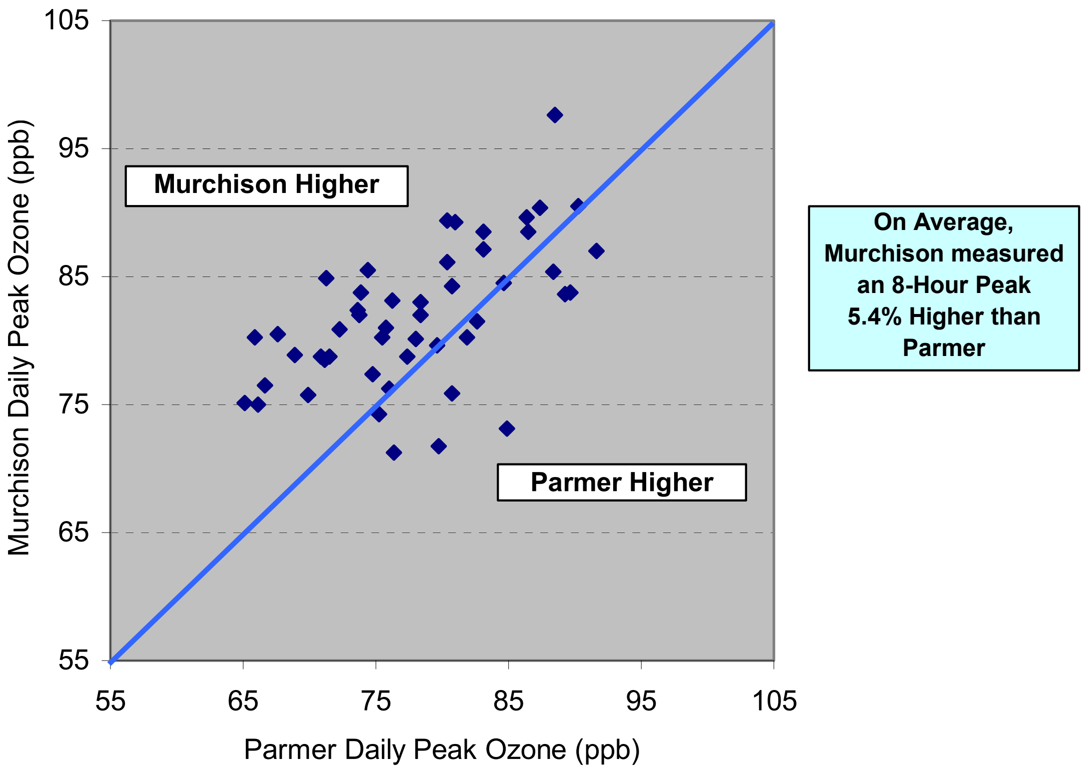

Figure 3-1. Daily Peak 8-Hour Ozone Concentrations at the Murchison and Parmer Stations on Days Characterized by an 8-Hour Peak > 75 ppb at One or Both Locations

3.2.2 Comparison of daily peak ozone concentrations between the Murchison and Audubon monitoring stations

Figure 3-2 presents a scatterplot of the 8-hour peak daily ozone concentrations at the Murchison and Audubon monitoring locations when one or both stations measured a peak concentration greater than 75 ppb during the 1997 through 2003 period. As in Figure 3-1, a line with a one-to-one slope has been drawn across the scatterplot. Data points located below this line indicate that Murchison measured a higher peak concentration. Conversely, data points located above this line indicate that Audubon measured a higher peak concentration. Audubon, on average, measured an 8-hour peak concentration 5.9 percent greater than that measured at Murchison. A wind direction analysis did not reveal an obvious bias, and higher concentrations were equally likely to be measured at Murchison on days characterized by northeasterly, easterly, and southeasterly afternoon winds. During southeasterly flow, Audubon was likely better positioned to capture a portion of the downwind ozone plume. In addition, the relatively greater distance between the downtown urban area (or the I-35 corridor) and the Audubon monitoring station would provide increased time for chemical reactions to occur within the urban plume, perhaps contributing to relatively higher ozone concentrations. However, the high bias at Audubon even during periods of easterly or northeasterly flow suggests there may be additional or alternate contributing factors to the observed bias between the two monitoring stations. Since the Murchison monitoring station is located relatively closer to the major transportation arteries in the region, NO from newly emitted mobile vehicle exhaust may have reacted with some of the ozone to produce a localized decrease in ozone concentrations at the Murchison monitoring station.

Interestingly, the bias decreases on days characterized by peak 8-hour ozone concentrations of 85 ppb or greater. Calm winds are often observed on these days, and the high ozone concentrations associated with the Austin plume are more likely to remain within the urban area.

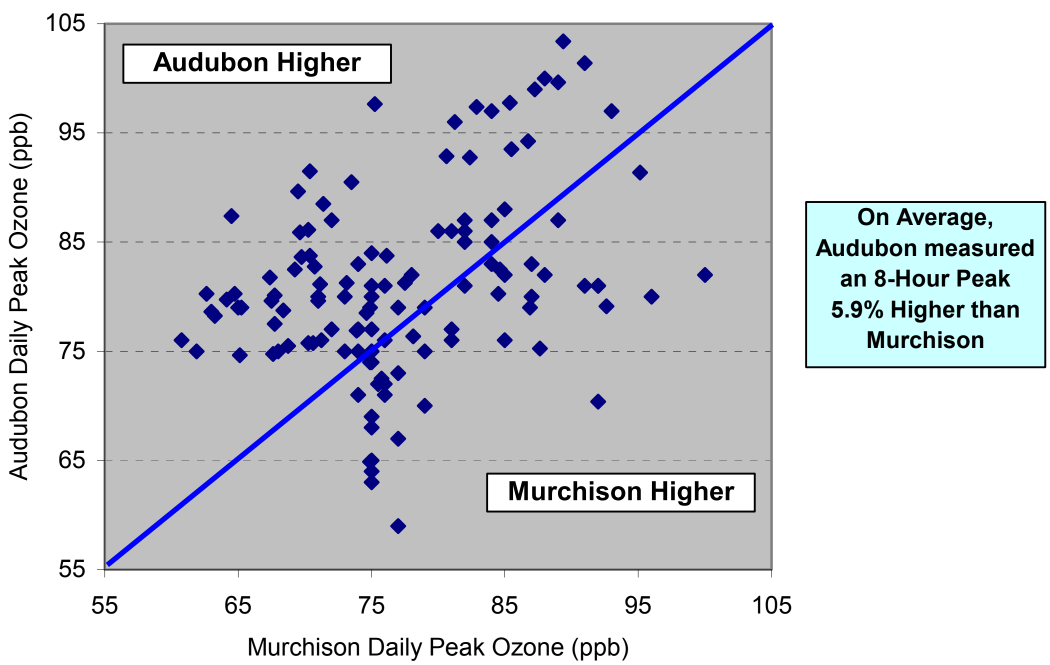

Figure 3-2. Daily Peak 8-Hour Ozone Concentrations at the Audubon and Murchison Stations on Days Characterized by an 8-Hour Peak > 75 ppb at One or Both Locations

3.3 Frequency of Occurrence by Year and Month

The number of days that one or more monitoring stations measured an 8-hour ozone concentration greater than 75 ppb is presented in Figure 3-3 for each year during the 1993 through 2003 period. The number of high ozone days varied from a minimum of 6 in 1996 to a maximum of 34 in 1999. The trend in annual high ozone days must be interpreted with caution since the locations and number of monitoring stations in the Austin monitoring network have changed over the period. Regardless, note the large number of high ozone days measured in 1995 and 1999. The year 1995 was characterized by a persistent large-scale stagnant weather pattern across the eastern and southeastern U.S, which produced atypically high ozone across much of the country.

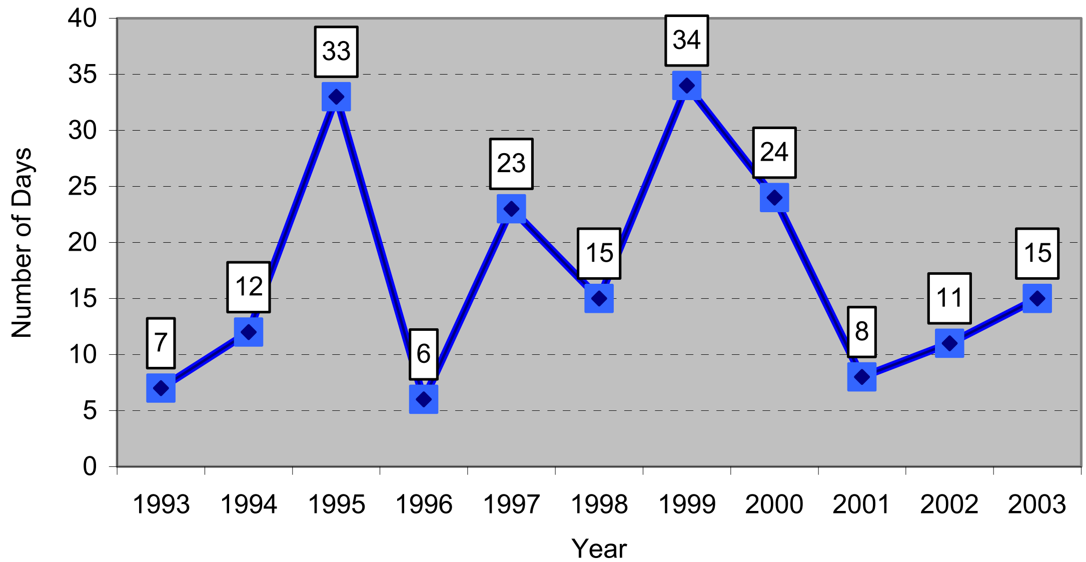

Figure 3-3. Annual Number of Days Characterized by a Peak 8-Hour Ozone Concentration > 75 ppb at One or More Austin Monitors 1993 - 2003

Figure 3-4 presents the frequency of occurrence of high ozone days by two-week segments. Peak 8-hour ozone concentrations occurred preferentially during the August through early October period, with an obvious peak in early September. Apparently, meteorological conditions conducive to ozone formation and/or accumulation in Central Texas occur with a relatively higher frequency during these months. A weak secondary peak is observed during the late May through June period. Figure 3-5 presents the maximum 8-hour ozone concentration measured during each two-week period. The highest magnitude concentrations also tended to occur during August through early October. Note, however, that relatively high 8-hour ozone values were measured throughout the ozone season, particularly during the early summer months.

3.4 Frequency of Occurrence by Day of the Week

Figure 3-6 presents the frequency of occurrence of all high ozone days during the 1993 through 2003 period by day of the week. The number of high ozone days varies from a minimum of 21 days on Sunday to a maximum of 31 days on Friday. The year-to-year frequency of occurrence by day of the week shows large variability and suggests that the day-to-day differences in number of ozone days presented in Figure 3-6 is likely due to normal variability associated with the small sample size.

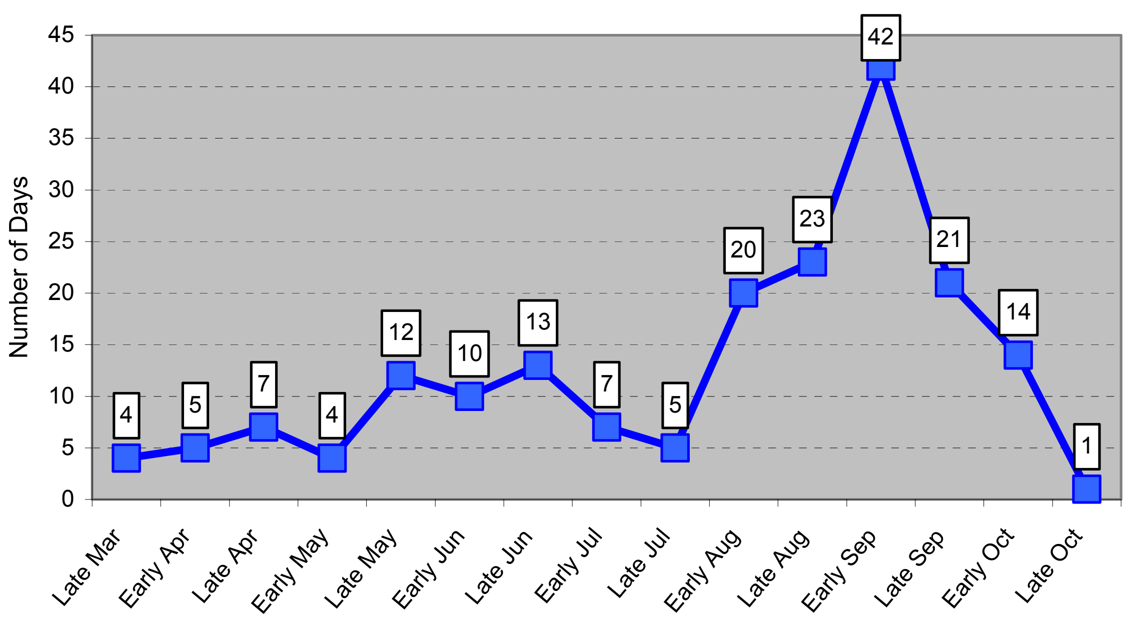

Figure 3-4. Number of Days By 2-Week Period Characterized by a Peak 8-Hour Ozone Concentration > 75 ppb at One or More Austin Monitors 1993 - 2003

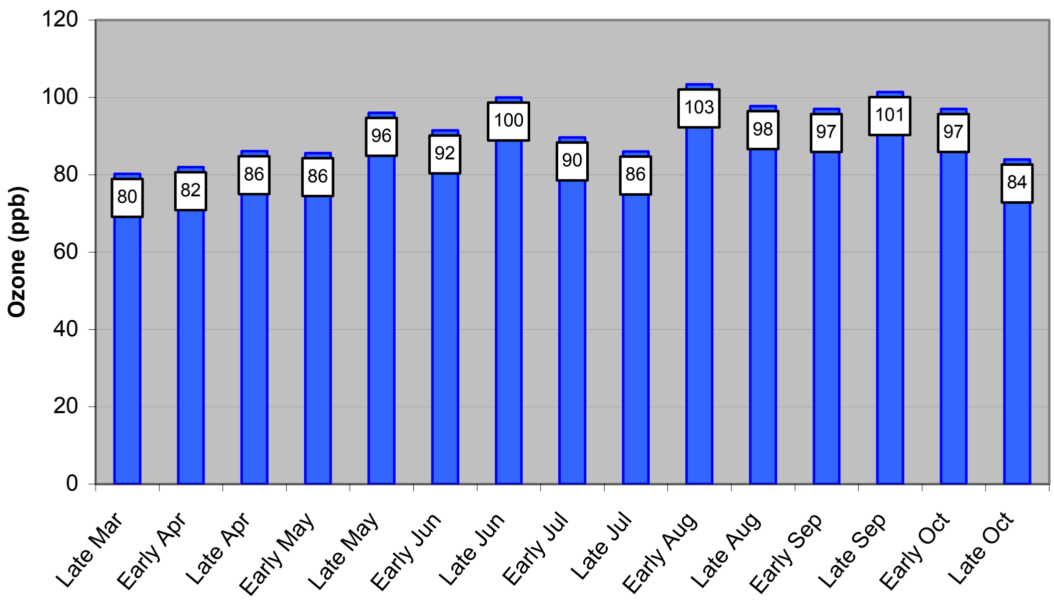

Figure 3-5. Maximum 8-Hour Ozone Concentration by 2-Week Period 1993 - 2003

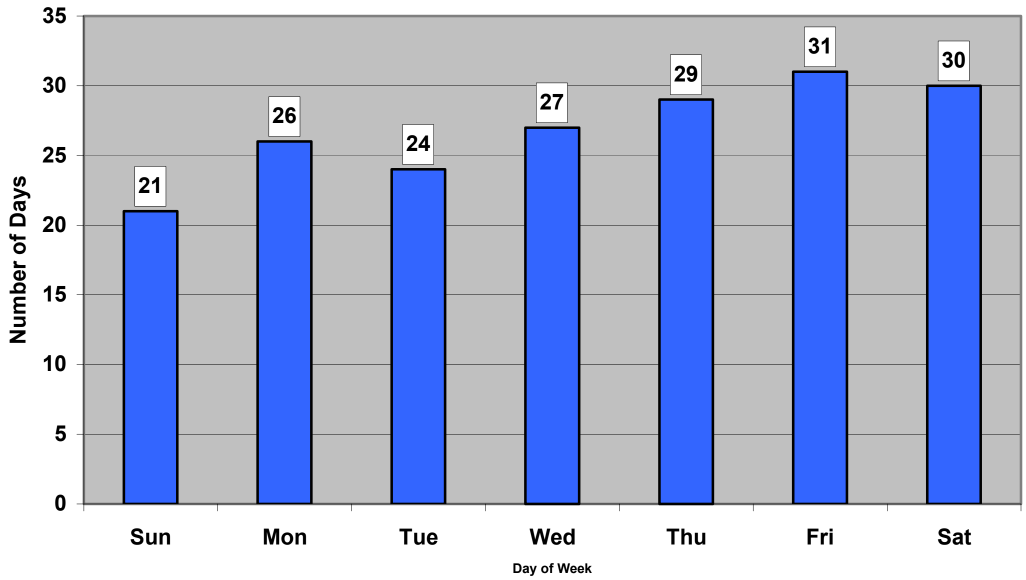

Figure 3-6. Number of Days by Day of Week Characterized by a Peak 8-Hour Ozone Concentration > 75 ppb at One or More Austin Monitors 1993 - 2003

4.0 Local Meteorological Conditions

Conditions conducive to the transport, formation, and accumulation of ozone are highly dependent on the prevailing large-scale weather patterns and the associated local meteorological conditions. Important local meteorological variables affecting ozone concentrations include solar radiation, clouds and precipitation, wind speed, wind direction, mixing height, and atmospheric stability. This section explores the relationship between daily peak 8-hour ozone concentrations in the Austin area and temperature, wind speed, and wind direction measured at the Murchison monitoring site. The data from the Murchison site were used in this analysis because this dataset provides a continuous record for the 1993 through 2003 period and is representative of conditions in the Austin area.

4.1 Temperature

Figure 4-1 presents a scatterplot of the daily peak 8-hour ozone concentration monitored in the Austin Area versus the daily peak temperature measured at Murchison. There is an obvious tendency to observe elevated ozone concentrations at higher temperatures; however, high daily peak temperatures are a necessary, but not sufficient, condition for high ozone. The average daily peak temperature on days with an 8-hour ozone concentration above 75 ppb was 92 ^{o}F, and 95% of high ozone days had a peak temperature greater than 79 ^{o}F. This relationship is not unexpected. Sunlight is necessary to drive the photochemical reactions leading to the formation of ozone, and warm temperatures are well-correlated with high levels of solar radiation. In addition, warmer temperatures are often associated with overall meteorological conditions conducive to the formation and accumulation of ozone. (For example, warm temperatures occur preferentially during summer weather patterns conducive to large-scale stagnation.)

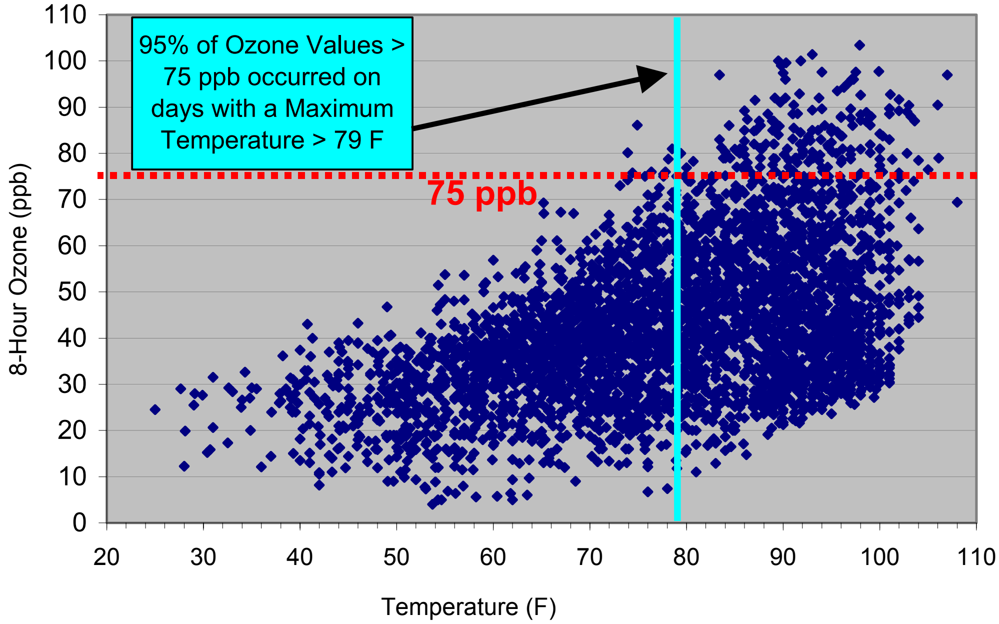

Figure 4-1. Daily Peak 8-Hour Ozone Vs. Daily Maximum Temperature 1993 - 2003

4.2 Wind Speed

A scatterplot showing the relationship between the daily peak 8-hour ozone concentrations versus the 6 a.m. through 2 p.m. resultant mean wind speed is shown in Figure 4-2. Elevated ozone concentrations occurred preferentially during periods of relatively light wind speeds. In fact, 95% of high ozone days occurred on days with wind speeds less than 6.4 mph. The average resultant mean wind speed on high ozone days was only 3.1 mph. These light wind speeds indicate conditions of limited horizontal ventilation and poor atmospheric dispersion, which are often associated with high atmospheric stabilities as well. As wind speed increases, improved horizontal ventilation and more efficient mixing throughout a deeper atmospheric boundary layer will favor relatively lower ozone concentrations. In addition, higher wind speeds are sometimes associated with other meteorological conditions (such as rain showers or colder surface temperatures associated with strong fronts or low pressure systems) that are not conducive to the formation and/or accumulation of ozone.

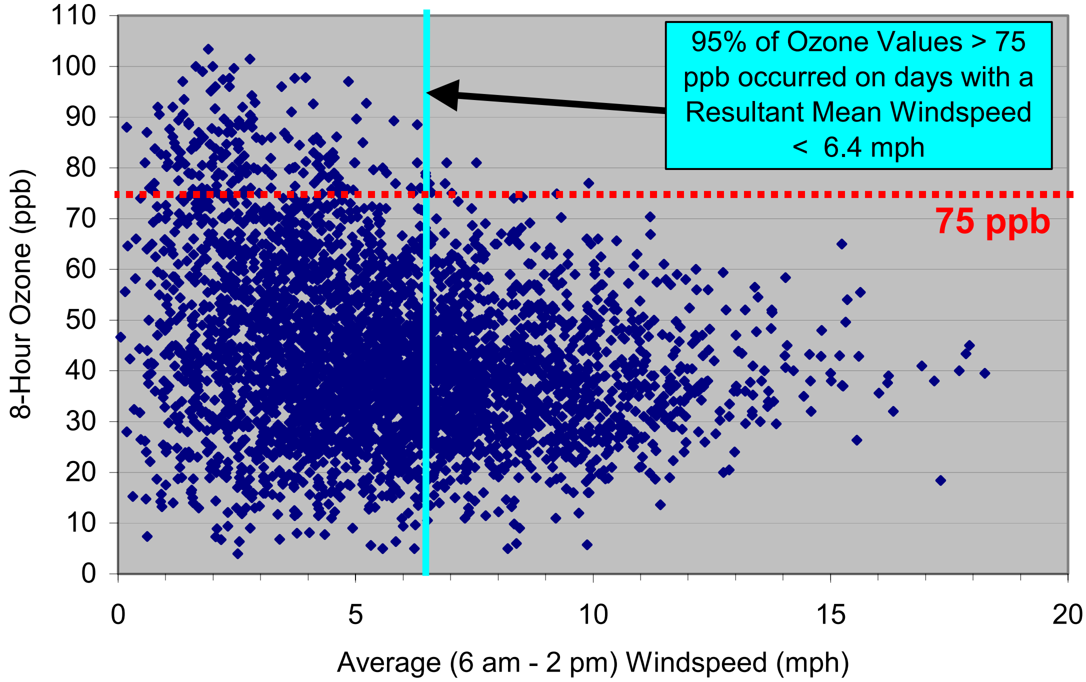

Figure 4-2. Daily Peak 8-Hour Ozone Vs. Resultant Mean 6 a.m. - 2 p.m. Wind Speed

4.3 Wind Direction

To help isolate the relationship between ozone levels and wind direction, wind directions were analyzed only on those days characterized by warm temperatures and light wind speeds. Diurnal circulation patterns were investigated by examining the daily morning and afternoon wind directions. The daily morning wind direction was defined as the resultant mean wind direction during the 6 a.m. through 8 a.m. period, while the daily afternoon wind direction was the resultant mean for the 12 p.m. through 2 p.m. period. Figure 4-3 presents the distribution frequency (as a percentage) of morning wind direction for all days and only days characterized by high ozone. Figure 4-4 presents a similar frequency distribution for the afternoon wind direction.

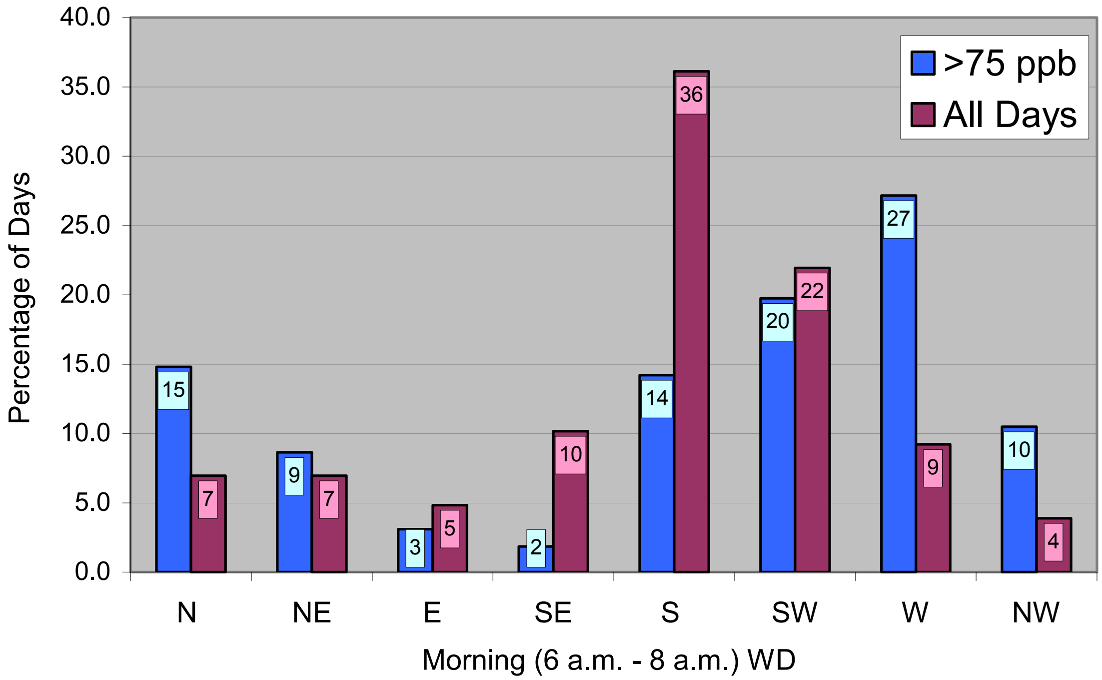

Figure 4-3. Percentage of Days by Morning Wind Direction Category [Peak Temperature > 79 F and 6 a.m. - 2 p.m. Wind Speed < 6.4 mph]

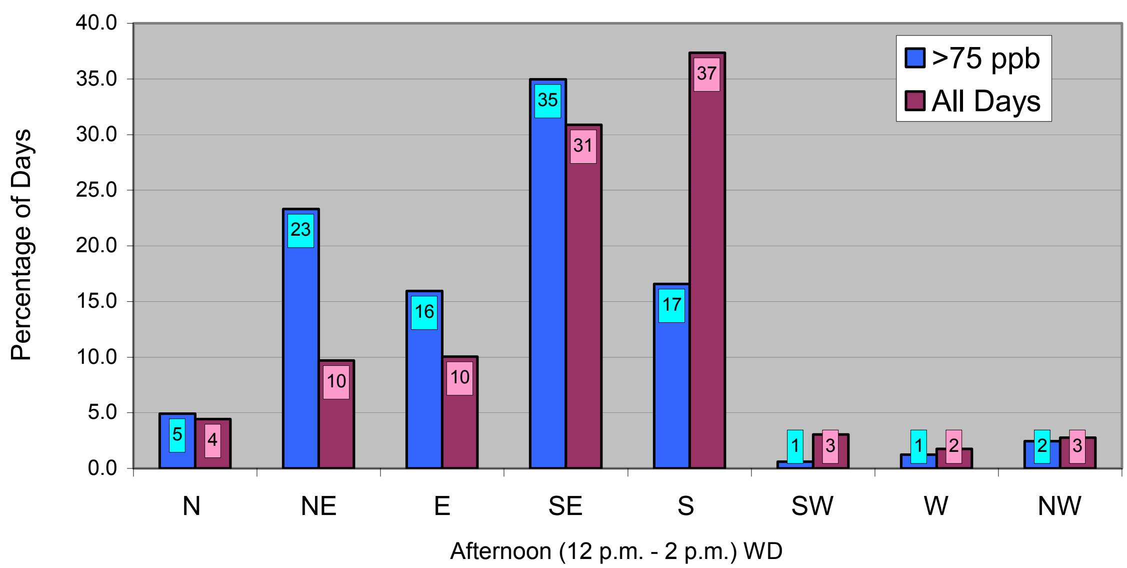

Figure 4-4. Percentage of Days by Afternoon Wind Direction Category [Peak Temperature > 79 F and 6 a.m. - 2 p.m. Wind Speed < 6.4 mph]

Figures 4-3 and 4-4 reveal that most days during the summer are characterized by light southerly or southwesterly flow during the morning hours, followed by somewhat stronger late morning and afternoon winds from the south and southeast. In contrast, morning winds on high ozone days show a range of directions from south/southwesterly through northeasterly. The frequency of occurrence of morning wind direction is preferentially from the west, northwest, and north on high ozone days compared to the climatological frequency of occurrence of these morning wind directions on all days. For example, note that the percentage of high ozone days characterized by morning westerly winds (27%) is far greater than the climatologically frequency of occurrence on all days (9%). Afternoon winds on high ozone days blow preferentially from the northeast, east, and southeast. Also note that although 14% of high ozone days are characterized by southerly morning winds and 17% of high ozone days are characterized by southerly afternoon winds, the relative frequency of occurrence of high ozone days is substantially lower compared to the climatological frequency of occurrence of southerly wind direction.

Morning winds from the west, northwest, and north, which occurred on 52% of high ozone days, are relatively rare on warm days in Texas. Further investigation revealed these days are often characterized by very light wind speeds. These light surface winds likely occur only during large-scale weather patterns that favor weak horizontal pressure gradients and high atmospheric stabilities. The observed morning southwesterly through northerly wind directions probably arise from weak and highly variable surface currents associated with downslope drainage along the eastern edge of the Balcones Escarpment. Regardless, these flows are localized and exist within a very shallow nocturnal boundary layer that is decoupled from the flow 50 to 100 meters above the surface. By late morning, turbulent mixing due to convective thermals breaks through the night-time radiation inversion, deepening the surface boundary layer. Higher momentum air dominated by the large-scale flow is mixed to the surface. The prevailing large-scale flow on high ozone days favors northeasterly to southeasterly afternoon winds, and is often associated with a surface ridge of high pressure that extends south or southwest into Texas. The observed morning and afternoon wind flow patterns may sometimes contribute to higher ozone levels by recirculating pollutants across the Austin Area as well. However, these wind flow patterns are more likely indicators of the prevailing large-scale weather conditions that favor highly stagnant atmospheric conditions often associated with high ozone levels.

It is interesting that high ozone is less likely on days characterized by either morning or afternoon winds from the south. Data analyses reveal that southerly flow is persistent and often occurs throughout the day during the summertime. This flow pattern would encourage more efficient horizontal ventilation across the region. Average wind speeds during this flow regime tend to be slighter higher, favoring a deeper mixed layer. In addition, the large-scale weather patterns that typically dominate Central Texas during periods of southerly winds may also be less conducive to the formation and/or accumulation of high ozone levels (e.g., by the introduction of relatively clean air from the Gulf of Mexico).

5.0 Regional Transport

Substantial transport of regional background ozone and precursor compounds undoubtedly contributes to elevated ozone levels in Austin during some episodes. Since the Fayette County and San Marcos monitoring stations are often upwind of Austin, data collected at these rural monitoring stations were used to estimate regional background levels entering the Austin Area on days characterized by high ozone concentrations. Figure 5-1 presents a scatterplot of the 8-hour daily peak Austin and San Marcos ozone concentrations when the peak concentration in Austin was greater than 75 ppb. A line with a one-to-one slope has been drawn across the scatterplot. Data points located above this line indicate that the Austin peak was higher than that measured at San Marcos. Conversely, data points located below this line indicate that the San Marcos daily peak was higher. Figure 5-2 presents the same data shown in Figure 5-1, but plots the San Marcos daily peak 8-hour concentration as a percentage of the Austin peak. Note that the San Marcos peak generally varied between 70% and 100% of the Austin maximum. On average, the San Marcos concentration was 86% of the Austin maximum on days characterized by an Austin peak of 75 ppb or greater.

Figures 5-3 and 5-4 present the analogous scatterplots for the Austin and Fayette County monitoring stations. Figure 5-4 shows that the peak 8-hour ozone concentration measured at the Fayette County monitoring station also ranged between 70% and 100% of the Austin peak. On average, the Fayette County concentration was 85% of the Austin maximum on days characterized by an Austin peak of 75 ppb or greater. Interesting, a wind direction analysis revealed that the range of peak ozone concentrations at the San Marcos and Fayette County monitoring stations were similar regardless if the stations were located upwind or downwind of the Austin Area. This implies that regional background levels are high throughout Central Texas on days characterized by high ozone concentrations in Austin. These data strongly suggest significant transport of ozone into the Austin Area on most high ozone days. With background levels ranging from 65 ppb to 85 ppb on high ozone days, even small contributions of ozone formed from local source emissions in the Austin area would result in an exceedance of the 8-hour NAAQS of 0.08 ppm.

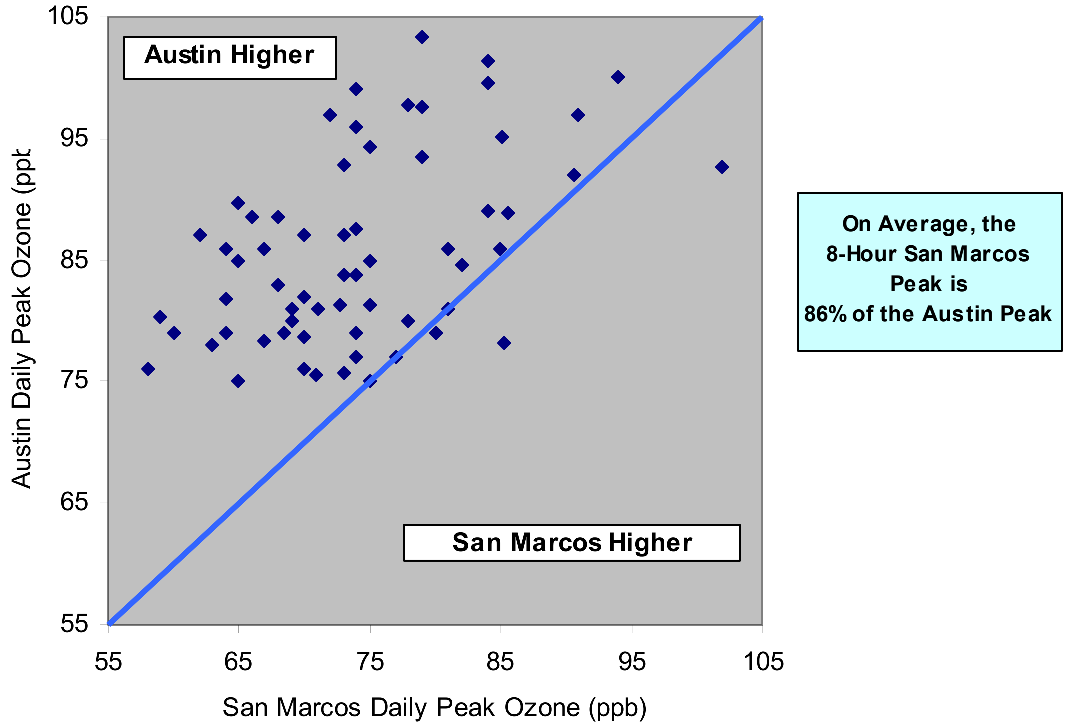

Figure 5-1. Austin and San Marcos Daily Peak 8-Hour Ozone Concentrations on Days Characterized by an Austin 8-Hour Peak > 75 ppb: 1998 - 2001

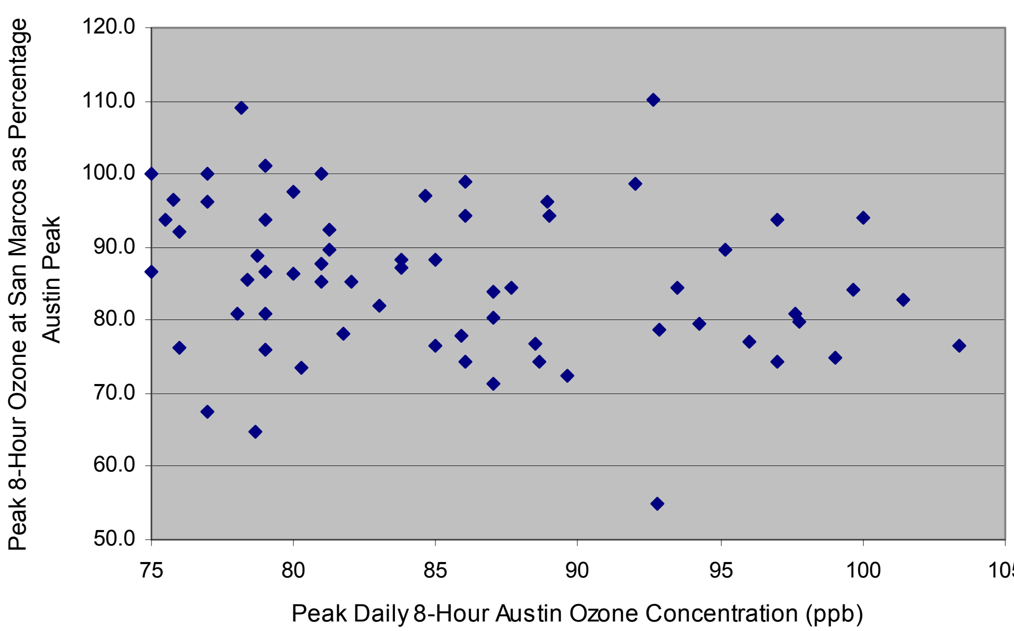

Figure 5-2. Peak Daily 8-Hour Ozone Concentration at San Marcos as a Percentage of Aus Area Maximum: 1998 - 2001

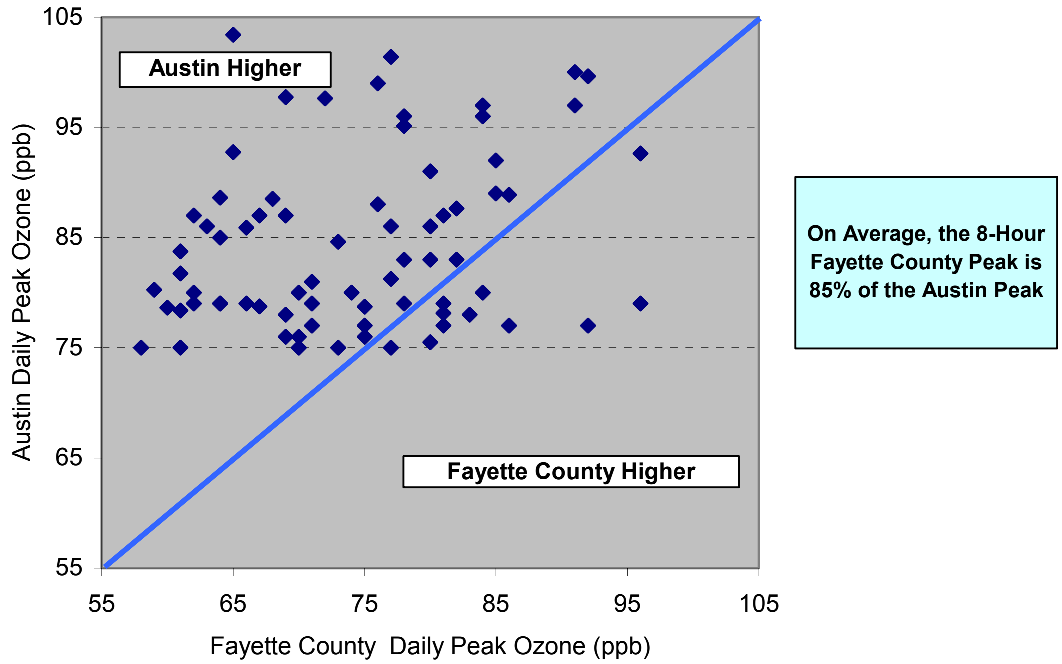

Figure 5-3. Austin and Fayette County Daily Peak 8-Hour Ozone Concentrations on Days Characterized by an Austin Area 8-Hour Peak > 75 ppb: 1998 - 2003

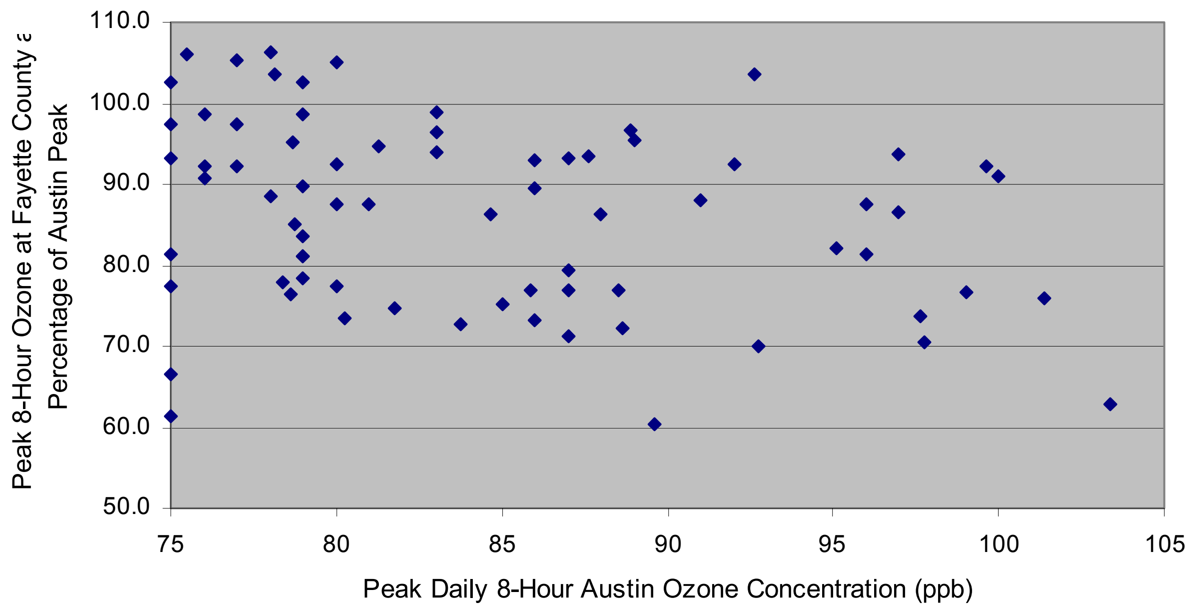

Figure 5-4. Peak Daily 8-Hour Ozone Concentration at Fayette County as a Percentage of Austin Maximum: 1998 - 2003

Potential long-range transport was further investigated by running 32-hour HYSPLIT back-trajectories for all days with 8-hour peak concentrations greater than 75 ppb. These trajectories can be used to indicate potential source regions of air entering Central Texas. When interpreting these trajectory results, the user should be aware of the time and space resolutions of the archived dataset. The relatively low spatial resolution probably captures the prevailing synoptic flow during weather patterns dominated by large-scale and slow-moving systems that are well-simulated by the meteorological models. The large-scale meteorological models have more trouble simulating local circulations, such as the land-sea breeze in coastal areas, and the archived datasets will poorly capture these events. In general, trajectories should not be interpreted as precise tracks of air parcels entering the Austin Area; however, patterns that emerge when analyzing a relatively large number of trajectories should provide a good indication of potential long-range transport due to the prevailing large-scale flow regime.

Figure 5-5 presents the 32-hour back-trajectories for 181 (of 188 total) high ozone days. (Meteorological data were unavailable for 7 of the 188 high ozone days). All trajectories were initiated at 4 p.m. local time from Mueller Airport at a height of 500 meters above the surface. This height was selected to approximate the middle of the mixed layer. Air flow into the Austin Area, as indicated by the back-trajectories, ranges from north-northeasterly through south-southwesterly. Trajectories from the west through north-northeast are rare. This is hardly surprising, since winds from these directions are also infrequent during the summer ozone season.

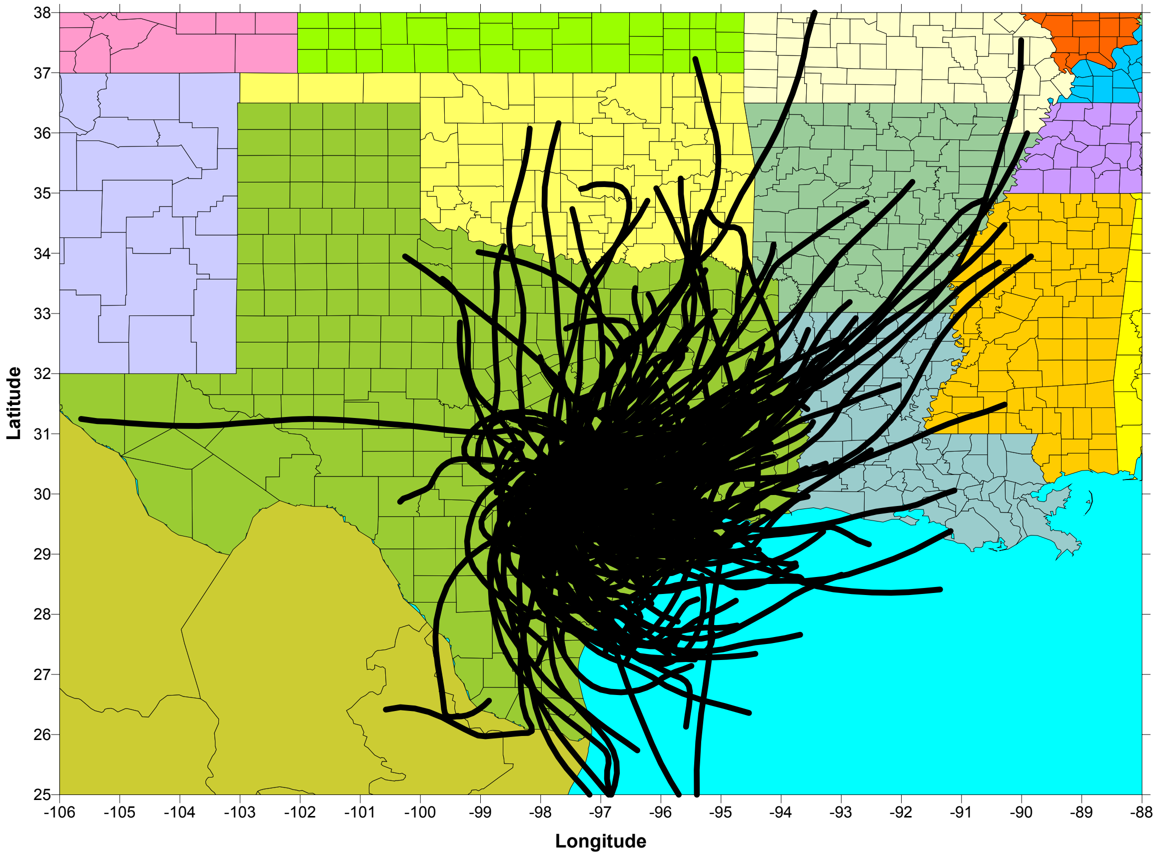

Figure 5-5. 32-Hour Back-Trajectories for All Days with a Peak 8-Hour Ozone Concentration > 75 ppb 1993 - 2003

Figures 5-6 through 5-8 display the trajectories, grouped by month. The spring months are dominated by transport from the east and southeast. Conversely, June and July are characterized by a relatively greater number of days with southerly transport. Data collected at Murchison indicate that winds with an easterly component occurred less frequently during June and July than in August and September. As noted previously in this report, the majority of high ozone days occurred during August, September, and early October. Again, note that the transport directions varied from north-northeasterly through south-southwesterly during these months.

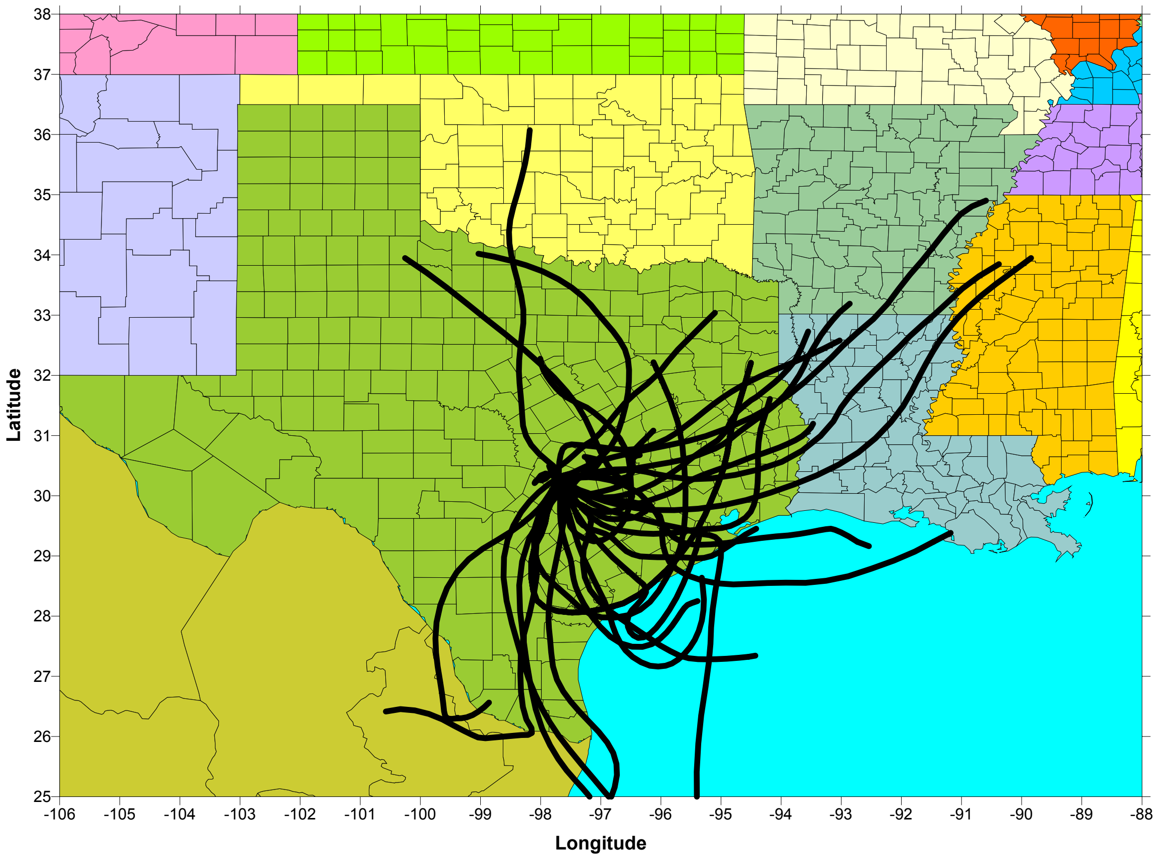

Figure 5-6. 32-Hour Back-Trajectories for March, April, and May on Days with a Peak 8-Hour Ozone Concentration > 75 ppb 1993 - 2003

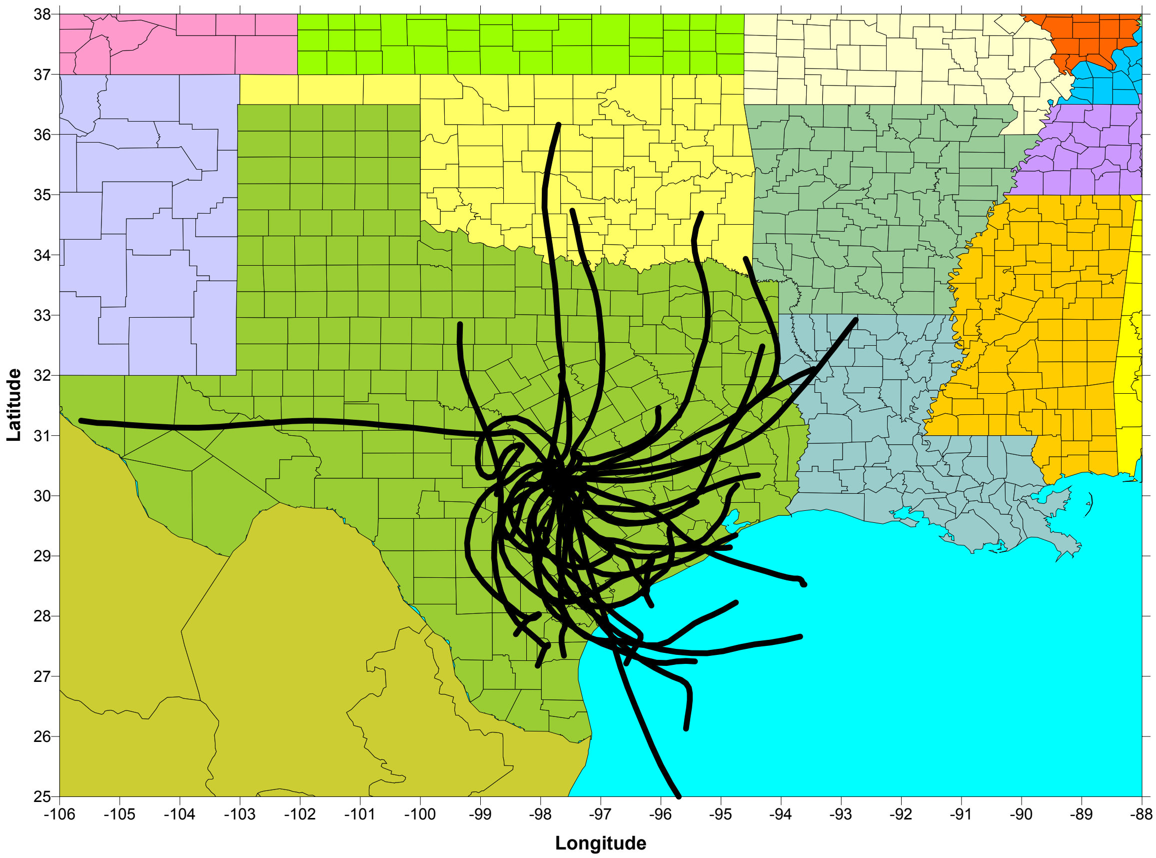

Figure 5-7. 32-Hour Back-Trajectories for June and July on Days with a Peak 8-Hour Ozone Concentration > 75 ppb 1993 – 2003

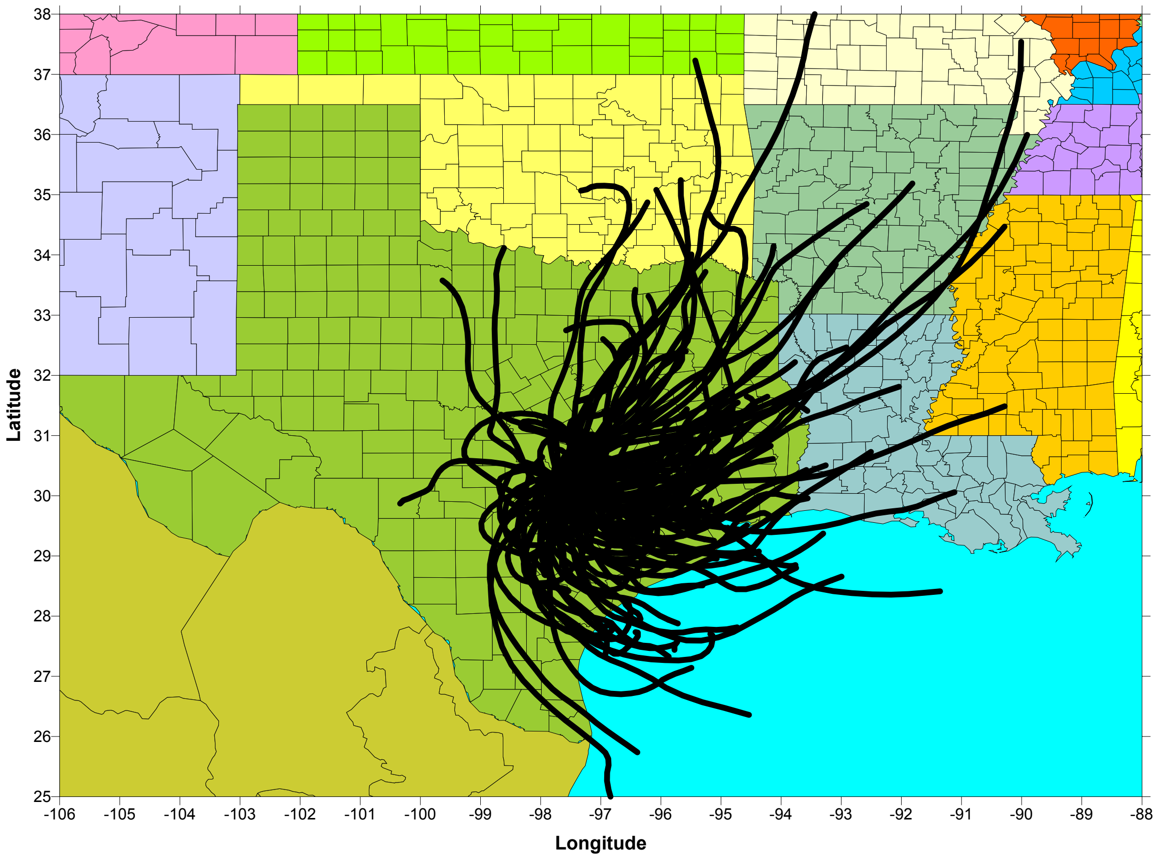

Figure 5-8. 32-Hour Back-Trajectories for August, September, and October on Days with a Peak 8-Hour Ozone Concentration > 75 ppb 1993 – 2003

Following TCEQ guidance, all trajectories were further analyzed to provide a statistical overview of the potential source regions of air entering the Austin Area. The HYSPLIT model provides an output ASCII text file that lists the hourly latitude/longitude locations for each hour during an individual trajectory. These data were used to compute the distance and direction from the origin (Mueller Airport) at each hour. This calculation was performed for all hourly locations for the entire family of trajectories presented in Figure 5-3. The hourly results were then divided into four distance classes: 1.) minimal transport (less than 50 miles); 2.) short-range transport (50 to 150 miles); 3.) medium-range transport (150 to 250 miles); and 4.) long-range transport (greater than 250 miles). The results were binned by direction to create a transport direction and distance matrix, as presented in Table 5-1. The final results were converted to a percent frequency of occurrence and are shown in Table 5-2.

Table 5-1. Hourly Trajectory Classification: Number of Hours in Each Zone

Direction	Local (< 50 mi.)	Short Range (50 - 150 mi.)	Medium Range (150 - 250 mi.)	Long Range (< 250 mi.)	Cumulative Total
N	89	119	122	71	373
NE	260	309	277	260	1097
E	340	350	549	332	1323
SE	376	395	539	341	1359
S	253	265	436	236	1060
SW	99	106	144	7	268
W	78	78	50	8	149
NW	59	71	72	17	163
TOTAL	1693	2189	1272	638	5792

Table 5-2. Hourly Trajectory Classification: Percentage of Hours in Each Zone

Direction	Local (< 50 mi.)	Short Range (50 - 150 mi.)	Medium Range (150 - 250 mi.)	Long Range (< 250 mi.)	Cumulative Total
N	2.1	2.1	1.2	1.1	6.4
NE	5.3	4.8	4.5	4.3	18.9
E	6.0	9.5	5.7	1.6	22.8
SE	6.8	9.3	5.9	1.5	23.5
S	4.6	7.5	4.1	2.1	18.3
SW	1.8	2.5	0.1	0.2	4.6
W	1.3	0.9	0.1	0.2	2.6
NW	1.2	1.2	0.3	0.1	2.8
TOTAL	29.2	37.8	22.0	11.0	100.0

As indicated graphically in Figure 5-5 the hourly trajectory locations are predominantly located to the northeast, east, southeast, and south of Austin. Approximately half (46.3%) of the hourly locations are found to the east and southeast. Note that almost 70% of the hourly locations are within 150 miles of the Austin Area. This indicates rather light wind speed conditions in the lower atmosphere, as expected during periods of regional stagnation.

The directional variability of the back-trajectories suggests that local emissions in the Austin Area are sufficient to generate significant ozone concentrations with transport from a wide range of source regions. As discussed in Section 6.0, longer-term back-trajectories (72-hour) suggest continental source regions located to the north, northeast, or east (e.g.., Central, MidWest, or Southeastern U.S.). These longer-term back-trajectories imply that many of the 32-hour back-trajectories shown in Figure 5-5 represent flow that recently originated over the continental U.S. This has important implications to understanding the large-scale weather patterns that are conducive to high ozone in Austin.

6.0 Synoptic-Scale Weather Patterns

Conditions conducive to the transport, formation, and accumulation of ozone are highly dependent on the prevailing large-scale weather patterns. For the discussions presented in this section, twice-daily surface weather maps, upper-air charts, and infrared satellite images were used to investigate the large-scale circulation features observed during multi-day high ozone episodes in the Austin Area. For the purposes of this review, a multi-day high ozone episode was defined as at least two consecutive days with daily peak 8-hour ozone concentrations greater than 75 ppb, with at least one day reaching 85 ppb. During the development of the original conceptual model for Austin, weather maps were reviewed for high ozone episodes that occurred during the 1997 through 1999 period. (The UNISYS archive of weather maps is not available for years prior to 1997.) The dates of all reviewed multi-day high ozone episodes that occurred during the 1999 through 2003 period are listed in Table 6-1. Detailed case studies of all episodes listed in Table 6-1 have not been prepared; however, eight multi-day ozone episodes were selected for presentation in this report. Given the historical preference for events to occur in August and September, emphasis was placed on high ozone episodes that occurred during these months. In addition, all recent high ozone episodes that occurred during the years 2002 and 2003 have been included.

A consistent large-scale weather pattern associated with multi-day high ozone episodes includes the migration of surface and/or upper level high pressure systems across eastern Texas. These high pressure systems are associated with meteorological conditions that favor the formation and accumulation of ground-level ozone. High pressure areas are characterized by light wind speeds, abundant sunshine, and warm temperatures. Relatively clear skies increase the amount of sunlight reaching the surface, providing the ultraviolet radiation necessary to drive the photochemical reactions leading to the formation of ozone. Warm temperatures enhance the rate of the reactions leading to ozone formation. Light wind speeds are associated with poor horizontal dispersion and limited vertical mixing in the boundary layer, allowing high concentrations of ozone to accumulate near the ground. The large-scale high pressure areas are also characterized by subsidence (sinking air) that inhibits vertical mixing and traps pollutants in a shallow layer near the surface. In addition, the large-scale clockwise flow around the high pressure systems results in substantial regional transport of continental air, which contains elevated levels of background ozone and its precursor compounds, into eastern Texas.

Table 6-1. High Ozone Episodes during the 1999 through 2003 Period (Refer to text for definition.)

Dates (mm/dd/yy)	Duration (Number of Days)	Daily Peak 8-Hour Ozone Concentrations (ppb)
8/03/99 – 8/07/99	5	82, 84, **103**, 98, 90
8/15/99 – 8/17/99	3	84, **96**, 80
8/20/99 – 8/21/99	2	93, **98**
8/30/99 – 9/02/99	4	**94**, **94**, 93, 89
9/15/99 – 9/20/99	6	79, 86, 100, 99, **101**, 88
9/23/99 – 9/24/99	2	79, **89**
10/13/99 – 10/14/99	2	87, 87
8/01/00 – 8/02/00	2	85, **86**
8/12/00 – 8/13/00	2	76, **88**
8/31/00 – 9/07/00	8	80, 88, 89, 87, 79, **97**, 77, 79
9/15/00 – 9/18/00	4	83, 81, 77, **100**
5/23/01 – 5/24/01	2	**85**, 77
6/23/02 – 6/25/02	3	92, **100**, 75
9/11/02 – 9/14/02	4	76, 87, **96**, 91
5/28/03 – 5/31/03	4	83, 82, **96**, 80
9/06/03 – 9/08/03	3	85, **92**, 86

6.1 Multi-Day High Ozone Episode Case Studies

August 3-7, 1999

High ozone concentrations were monitored across the eastern half of Texas during the August 3 – 7, 1999 period. Table 6-2 presents the maximum 8-hour concentrations for selected metropolitan areas. Daily peak 8-hour concentrations in Austin exceeded 80 ppb on each day of the episode. The August 5th concentration of 103 ppb is the highest ozone concentration measured in Austin during the 1993 through 2003 period. Extremely high ozone levels were measured in the Dallas/Ft. Worth and Houston/Galveston areas on the 4th, 5th, and 6th, with an overall maximum daily peak ozone concentration of 143 ppb measured on the 6th in Houston/Galveston.

Table 6-2. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during August 3, 1999 through August 7, 1999

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
8/03/99	81	94	44	97	98	65	89
8/04/99	83	78	55	127	106	70	91
8/05/99	103	84	80	135	120	100	120
8/06/99	97	91	83	113	143	80	97
8/07/99	89	87	56	104	94	74	98

Weather conditions throughout eastern Texas were characterized by warm (near-record) temperatures and high humidities. A large upper-level ridge that extended east-west from Northwest Mexico, through Texas, and across the Southern U.S. remained entrenched for much of the month. Southward dips of the jet-stream, located over the Ohio River Valley and Great Lakes regions, were associated with periodic weak and slow-moving surface fronts that advanced beneath the upper-level ridge. On August 1st, clouds and showers over the Texas Panhandle were associated with a surface center of low pressure. At upper levels, high pressure extended from Texas across the Southeastern U.S. In Central Texas, moderate southerly morning winds were followed by moderate southeasterly afternoon winds and peak ozone levels remained in the 30 ppb range. On the 2nd, wind speeds decreased to approximately 5 mph, and afternoon winds were characterized by a more easterly component. Maximum temperatures remained in the upper 90s as peak ozone concentrations in Austin increased rapidly to the low 60 ppb range. Daily peak ozone concentrations of 90 ppb and 88 ppb were measured in the Dallas/Fort Worth and Houston/Galveston areas, respectively. On August 3rd, the surface center of low pressure previously located over the Panhandle moved eastward to northern Texas and marked the western end of a near-stationary front that sagged across the northern Gulf coast. Spotty, strong convection was observed throughout the Desert Southwest and much of Texas. A large surface ridge of high pressure that covered much of the eastern U.S strengthened and moved southward behind the front. As shown in Figure 6-1, the 32-hour back-trajectory indicates transport into the Austin area from the east-northeast. The relatively short trajectory indicates relatively light wind speeds in the lower atmosphere, consistent with a daily average wind speed of approximately 4 mph at the Murchison monitoring station. Austin reported over an inch of rainfall at Bergstrom Airport on the 3rd associated with a squall line during the passage of the dissipating frontal trough. Despite the spotty convection and cloud cover across Central Texas, the 8-hour peak ozone concentration increased to 81 ppb at the Audubon monitoring station. In the Dallas/Fort Worth and Houston/Galveston areas, peak ozone concentrations climbed into the upper 90 ppb range.

Rainfall and convection continued across much of Texas on the 4th, though rainfall was more widespread across northern portions of the state. The 32-hour back-trajectory indicates eastward transport into the Austin area with very light wind speeds in the lower atmosphere. High pressure remained entrenched at upper levels over Texas. Observations of morning fog and haze suggest rather stagnant atmospheric conditions in the lower atmosphere. Peak daily 8-hour ozone concentrations of 83 ppb, 127 ppb, and 106 ppb were measured in the Austin, Dallas/Fort Worth, and Houston/Galveston areas, respectively. As on the 3rd, the daily peak 8-hour ozone concentration at the Fayette County monitoring station, located approximately 50 miles east-southeast of Austin, remained just above 60 ppb. These levels, which represent 75% of the Austin Area maximum ozone concentrations on the 3rd and 4th, suggest high regional background concentrations.

On the 5th, stagnant conditions dominated Central and South Texas as the surface ridge of high pressure pushed slowly southward and weakened ahead of a second advancing front. Haze and morning fog were reported, and maximum temperatures again approached 100 ^{o}F. The very short 32-hour back-trajectory and average surface wind speed less than 4 mph are consistent with very stagnant conditions in the lower atmosphere. The peak 8-hour ozone concentrations at the Murchison and Audubon monitoring stations increased to 89 ppb and 103 ppb, respectively. The daily peak at Audubon represents the highest ozone concentration measured in the Austin area during the 1993 through 2003 period. The daily peak concentration at the San Marcos monitoring station, located approximately 25 miles south-southwest of downtown Austin, was 79 ppb. Peak concentrations in the San Antonio, Dallas/Fort Worth, and Houston/Galveston areas were 100 ppb, 135 ppb, and 120 ppb, respectively.

On the 6th, a second cold front approached Central and southeast Texas as a weak trough of low pressure accompanied by widely scattered convection. The 32-hour back-trajectory indicates southeasterly flow into the Austin area. At the surface, light morning westerly winds were followed by moderate southeasterly afternoon winds. Morning fog and haze were again reported and maximum temperatures remained near 100 ^{o}F. With the continuing stagnant atmospheric conditions near the surface, a daily peak ozone concentration of 97 ppb was measured at the Audubon monitoring station. High ozone concentrations were measured at all monitoring stations in the Houston/Galveston area, and a peak concentration of 143 ppb was measured at the Bayland Park station in Houston.

On the 7th, onshore flow from the Gulf of Mexico returned to Texas and moderate morning winds from the south were followed by afternoon southeasterly winds in Central Texas. The surface ridge of high pressure that extended southwestward into Texas from south of the Great Lakes continued to weaken and move eastward; however, high pressure remained entrenched over Texas at upper levels and daytime high temperatures continued near 100 ^{o}F. Morning fog and haze were again reported as the daily peak ozone concentration in Austin reached 89 ppb. The peak daily concentrations in Dallas/Fort Worth and Houston/Galveston decreased from the previous day to 104 ppb and 94 ppb, respectively. With the continued advection of maritime air by southerly and southeasterly surface flow over Texas during the following days, peak ozone concentrations in Central and Southeast Texas decreased dramatically to the 40-50 ppb range by the 9th.

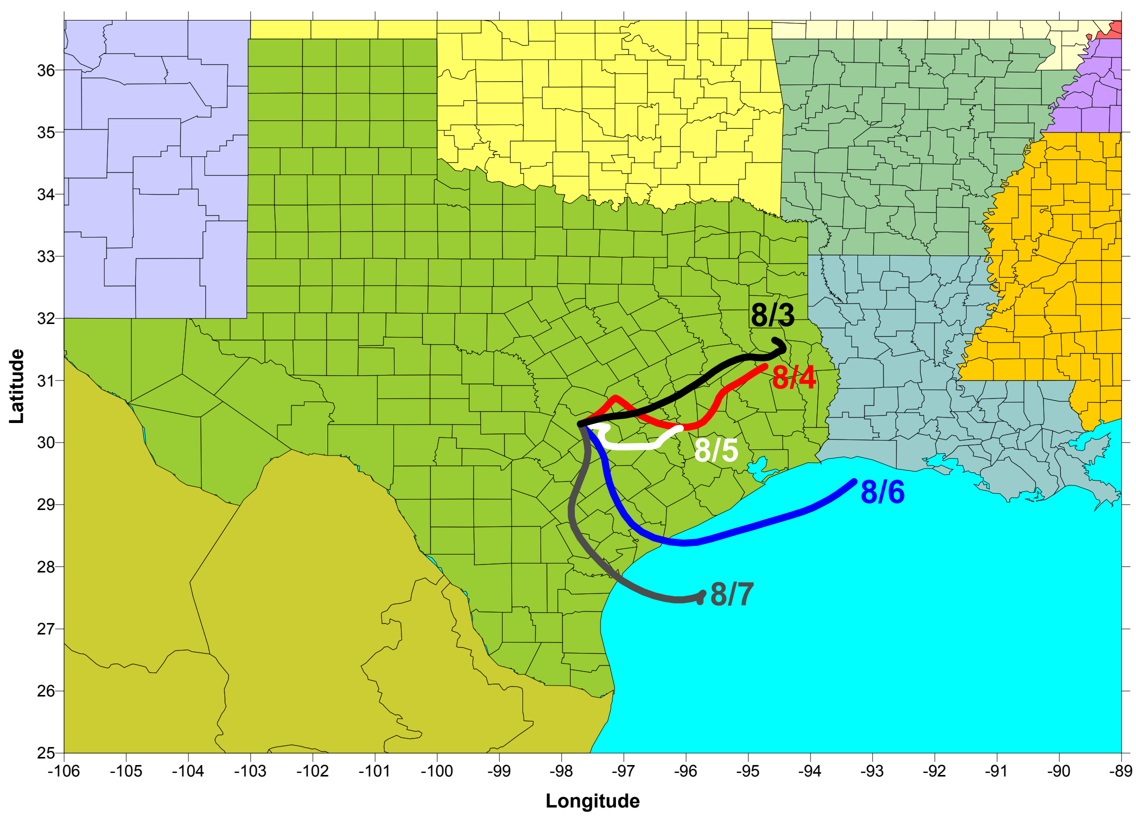

Figure 6-1. 32-Hour Back-Trajectories for August 3, 1999 through August 7, 1999

September 15-20, 1999

Table 6-3 presents the maximum 8-hour concentrations for selected metropolitan areas for the September 15-20, 1999 period. High ozone concentrations were monitored across eastern Texas. Maximum ozone concentrations of 85 ppb or greater were measured in Austin on five consecutive days. Peak ozone levels reached 99 ppb, 99 ppb, and 101 ppb on the 17th, 18th, and 19th, respectively. High ozone concentrations were measured in Houston/Galveston throughout the period, with an episode maximum of 124 ppb on the 20th.

Table 6-3. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during September 15, 1999 through September 20, 1999

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
9/15/99	78	70	82	80	97	82	85
9/16/99	85	89	81	78	104	85	82
9/17/99	99	69	86	99	111	76	86
9/18/99	99	101	89	99	98	96	91
9/19/99	101	100	88	96	120	91	97
9/20/99	87	79	99	92	124	86	110

Mid-September was characterized by warm temperatures and low humidities associated with a continental airmass. During September 12th through 14th, a vigorous low pressure system associated with a southward-moving cold front moved east and northeast through the U.S. northern plains and Great Lakes regions. The surface front passed through the Austin Area on September 13th, transporting cooler and drier air into Texas. Surface winds in Austin were northeasterly during this period, and daily maximum temperatures reached the low 90s. Daily peak 8-hour ozone concentrations ranged from 55 ppb to 65 ppb. By September 15th, the upper-level low pressure system lifted into eastern Canada, and zonal flow dominated most of the southern U.S. A second surge of cold air entered Central Texas as Hurricane Floyd moved north along the Eastern Coast. Overnight lows dropped into the 50s in Central Texas compared to the upper 60s prior to the frontal passage.

The subtropical jet settled east-west across northern Texas throughout the remainder of the period, and shower activity in the Dallas through the 17th was likely associated with a weak wave of low pressure propagating along the subtropical jet. A few isolated showers due to convergence along the dissipating surface trough occurred in Central and South Texas during this period as well; however, conditions in the Austin remained clear and rain-free. As shown in Figure 6-2, the 32-hour back-trajectories for the 15th and 16th indicated long-range northeasterly flow into the Austin area. The daily peak 8-hour ozone concentrations at the Fayette County and San Marcos monitoring stations ranged between 65 ppb and 70 ppb on the 15th and 16th, suggesting high regional background levels. Wind speeds at the Murchison monitoring station decreased from 6-7 mph on the 15th to 5-6 mph on the 16th. The rather stagnant atmospheric conditions, coupled with transport of continental haze into Central Texas, contributed to daily peak 8-hour concentrations in Austin of 78 ppb and 85 ppb on the 15th and 16th, respectively.

By the 18th, the strong surface ridge of high pressure centered over the Central Plains on the 15th had moved eastward to near Virginia. Clockwise flow around this ridge resulted in more southeasterly flow after the 16th. The 32-hour back-trajectories indicated easterly flow into the Austin area on the 17th and 18th, and the relatively short length of the trajectories is consistent with the observed wind speeds at the surface that averaged 4-5 mph. The surface ridge of high pressure over Texas was associated with weak pressure gradients and light wind speed conditions at the surface consistent with rather stagnant conditions in the lower atmosphere. Clear skies continued to dominate over Central Texas, and daily maximum temperatures increased to the mid-90s. The peak daily ozone concentrations in Austin increased markedly to 99 ppb on both the 17th and 18th at the Audubon monitoring station. Daily peak 8-hour ozone concentrations at the Fayette County and San Marcos monitoring stations ranged from 75 ppb to 85 ppb, suggesting continued regional transport of high ozone levels into the Austin area.

Consistent with the 32-hour back-trajectory, southerly flow returned to Texas on the 19th. Wind speeds remained quite low, however, and decreased to less than 3 mph. Tropical Storm Harvey formed in the central Gulf of Mexico and began to move northeasterly. This tropical circulation may have enhanced subsidence in Texas, though the impact of the system appears minimal. As on the 18th, fog and/or haze were reported on the 19th, likely associated with the transport of continental haze into Texas during the previous days exacerbated by extremely stagnant conditions in the lower atmosphere. A daily peak ozone concentration of 101 ppb was measured at the Audubon monitoring station, the second highest ozone concentration measured in Austin during the 1999 ozone season. Daily peak ozone levels in the 90 ppb range were measured in the San Antonio and Dallas/Fort Worth areas, while Houston/Galveston measured a maximum concentration of 120 ppb.

On the 19th and 20th, the surface ridge of high pressure, now located over the northeastern U.S., was rapidly weakening and moving to the northeast ahead of a second cold front. Very light wind speeds, observations of morning fog and haze, and a maximum temperature of 100 ^{o}F suggest conditions of continued atmospheric stagnation over Central Texas near the surface. While Houston/Galveston measured an episode maximum concentration of 124 ppb, the maximum ozone in Austin decreased to 87 ppb. Unlike previous days in Austin characterized by peak ozone at the Audubon monitoring station, the highest Austin concentration on the 20th was measured at the Murchison station. Given the very light easterly component to the wind direction throughout the day, the downwind urban ozone plume likely remained within and to the east of the downtown Austin area on the 20th. By the evening on the 20th, winds became gusty and southwesterly immediately ahead of a second frontal passage late on September 20th. This front brought strong northerly winds and much colder and drier air to all of Texas on the 21st. Peak ozone levels decreased dramatically to the 50-60 ppb and 60-70 ppb ranges in Central and coastal Texas, respectively.

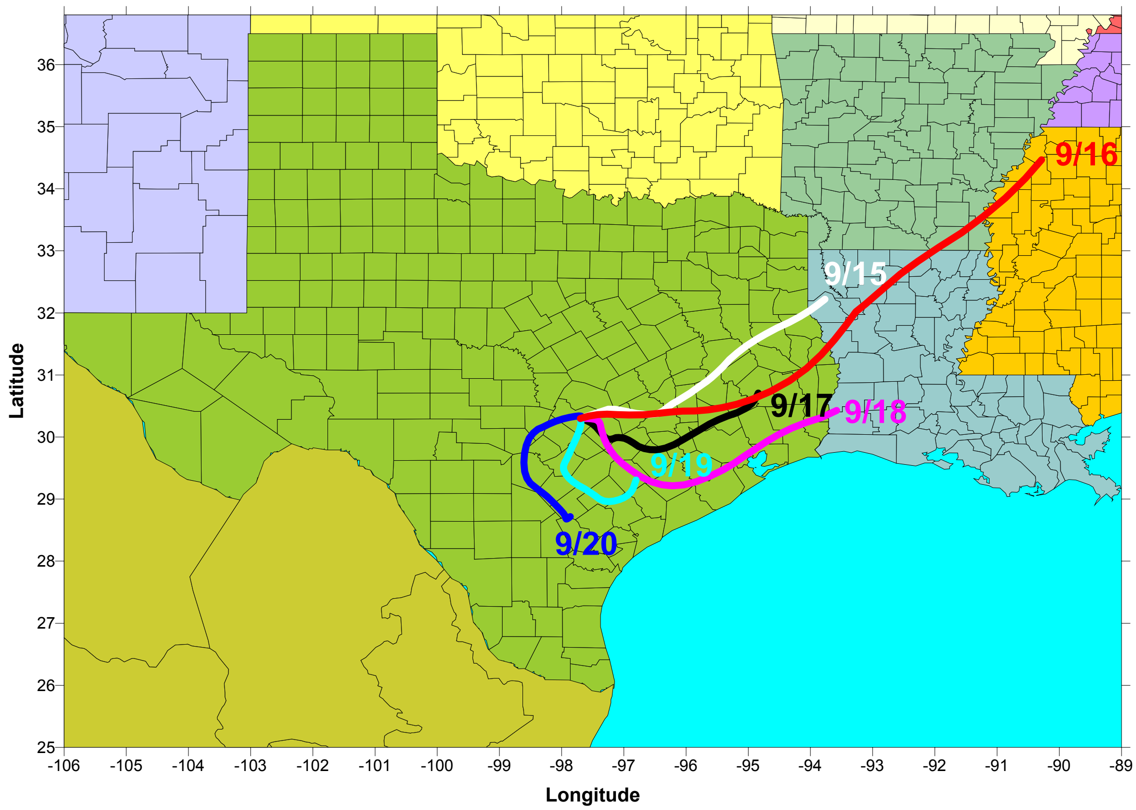

Figure 6-2. 32-Hour Back-Trajectories for September 15, 1999 through September 20, 1999

August 31 – September 7, 2000

Note: Although this episode demonstrates a number of characteristics that distinguish it from a typical multi-day high ozone event in Central Texas, it has been included as a case study because of its longevity and occurrence during the Texas Air Quality Study.

Table 6-4 presents the maximum 8-hour concentrations for selected metropolitan areas for the August 31 – September 7, 2000 period. High ozone concentrations were monitored across eastern Texas. Maximum ozone concentrations above 75 ppb were measured on 8 consecutive days in Austin, with an episode maximum of 97 ppb on the 5th. Maximum ozone concentrations of 120 ppb or greater were measured on three days (31st, 5th, and 6th) in the Houston/Galveston area.

Table 6-4. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during August 31, 2000 through September 7, 2000

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
8/31/00	80	105	65	89	130	69	95
9/1/00	88	96	61	99	102	76	103
9/2/00	89	86	61	106	95	83	103
9/3/00	87	75	52	97	93	69	96
9/4/00	79	97	67	104	90	71	96
9/5/00	97	80	76	97	120	87	70
9/6/00	77	85	84	82	123	80	77
9/7/00	79	46	67	84	62	79	60

The summer of 2000 was dominated by unusually hot and dry conditions throughout the Southern Plains. A persistently strong and broad ridge of high pressure remained entrenched over much of the region at upper levels. The subsidence associated with this ridge produced above normal temperatures and below normal rainfall throughout the period. In fact, virtually all of Texas was experiencing severe to extreme drought conditions according to the Palmer Drought Severity Index (Climate Prediction Center, 2000). The only exception was extreme eastern Texas (referred to as the "Piney Woods"), which was categorized with moderate drought. During the final few days of August and the first week of September, the high pressure ridge strengthened over Texas, further suppressing widespread convective activity and producing an unprecedented string of consecutive days with record heat. NWS stations throughout eastern Texas measured maximum daily temperatures in excess of 100 ^oF.

In Austin, the days preceding August 30th were characterized by consistent southerly winds at approximately 5 to 7 mph. Maximum temperatures reached 100 ^oF and widely scattered showers and thunderstorms covered parts of Central Texas. Daily peak ozone concentrations were limited to the mid-40 ppb range. Southerly winds persisted on the 30th, but daytime wind speeds decreased to approximately 4 to 5 mph. High pressure at the surface and upper levels enhanced subsidence over Texas, and stagnant atmospheric conditions contributed to a maximum temperature of 104 ^oF. Maximum ozone concentrations increased in Central and South Texas and a daily peak ozone concentration of 64 ppb was measured in Austin. Maximum ozone concentrations in Dallas and Houston were substantially higher at 85 ppb and 144 ppb, respectively. On the 31st, a record maximum temperature of 107 ^oF was measured in Austin. Light westerly late night and morning winds were followed by southerly winds in the afternoon. The 32-hour back-trajectory (Figure 6-3) suggests long-range southeasterly and southerly transport into Central Texas, and a maximum ozone concentration of 80 ppb was measured in Austin. In the Houston/Galveston area, a total of 16 monitoring stations measured maximum ozone concentration in excess of 85 ppb, with a maximum of 130 ppb measured at the Deer Park monitoring station.

As the upper level ridge continued to intensify over Texas, the unprecedented heat continued throughout the state. Record maximum temperatures of 107 ^oF, 107 ^oF, and 108 ^oF were measured in Austin on the 1st, 2nd, and 3rd, respectively. Precipitation was limited to a few strong afternoon and evening showers that developed in Central and Southeast Texas that provided no meaningful relief from the oppressive heat and drought. Winds at the surface remained light in Austin, and each day during the 1st through 3rd period was characterized by southwesterly morning winds and southeasterly or southerly afternoon and evening winds.

As shown in Figure 6-4, the 32-hour back-trajectories suggest long-range southerly transport on the 1st and 2nd. The short back-trajectory on the 3rd suggests stagnant conditions in the lower atmosphere. High ozone concentrations were measured throughout Central, Northern, and Southeastern Texas. In Austin, peak daily ozone concentration were 88 ppb, 89 ppb, and 87 ppb on the 1st, 2nd, and 3rd, respectively. Maximum ozone concentrations at the San Marcos monitoring station were 73 ppb and 74 ppb on the 2nd and 3rd, respectively, suggesting high regional ozone levels. (The San Marcos monitoring station was inoperable during the mid-August through September 1, 2000 period.)

The extreme heat across eastern Texas attained all-time record levels on both the 4th and the 5th. On September 4th, all-time maximum temperature records were either set or tied at Austin (110 ^{o}F), College Station (112 ^{o}F), Corpus Christi (107 ^{o}F), Galveston (101 ^{o}F, tied), Houston (109 ^{o}F), San Antonio (109 ^{o}F), and Victoria (110 ^{o}F). On the 5th, all-time maximum temperature records set the previous day were broken at Austin (112 ^{o}F), Corpus Christi (109 ^{o}F), Galveston (104 ^{o}F), San Antonio (111 ^{o}F), and Victoria (111 ^{o}F). Surface wind speeds in Central Texas remained light, however, afternoon winds blew with an easterly and northeasterly component on the 4th and 5th, respectively, rather than with a southerly component as observed during the 1st through 3rd. Average daytime wind speeds increased from approximately 4 mph during the first 3 days of the month to approximately 5-6 mph on the 4th and 5th. Westerly morning winds and easterly afternoon winds suggest that recirculation of air within Central Texas was likely on both days; in fact, the back-trajectory on the 4th indicates air movement through a 360 degree circle north of the city. The 32-hour back-trajectories for both the 4th and 5th are quite short, suggesting that wind speeds were light throughout the boundary layer.

The intense heat was associated with high ozone concentrations throughout Texas. On the 4th, the Austin, Dallas and Houston/Galveston areas measured maximum concentrations of 79 ppb, 104 ppb and 90 ppb, respectively. On the 5th, nine monitoring stations in the Houston/Galveston area measured maximum ozone concentration in excess of 85 ppb, with a maximum of 120 ppb measured at the Clute monitoring station in Brazoria County. The maximum ozone concentration measured in Austin was 97 ppb, the highest ozone concentration measured during the August 31st through September 7th episode.

During the 4th and 5th, the subtropical upper high centered over the Red River Valley had finally begun to weaken somewhat and shift westward. A large surface high pressure system, centered near the Great Lakes, had moved southward behind a Canadian cold front during the previous few days. This shallow dome of relatively cooler and drier air covered much of the eastern U.S. As the upper level high pressure ridge over the Red River Valley moved westward, the decaying frontal zone along the southwestern boundary of the surface high pressure system expanded southward across eastern and coastal Texas on the 5th and 6th. The clockwise flow around the strong surface ridge of high pressure produced long-range northeasterly and easterly transport on the 6th and 7th, respectively, as shown in Figure 6-4. The propagation of this system into Texas was accompanied by increased large-scale wind speeds late on the 6th. Daytime wind speeds in Austin increased from approximately 6 mph on the 5th to approximately 10 mph on the 6th. Skies remained clear throughout eastern Texas.

The advection of this slightly cooler and drier airmass into Texas, combined with weakening of the upper level ridge of high pressure, was associated with slightly lower maximum temperatures across Texas. Maximum temperatures in Austin on the 6th and 7th were 100 ^{o}F and 98 ^{o}F, respectively. Significant smoke and haze was reported along the Texas coast, likely due to transport from marsh fires in eastern Texas and Louisiana. For most urban areas in eastern Texas, both the overall maximum ozone concentration and the number of monitoring stations measuring maximum ozone levels greater than 85 ppb decreased. On the 6th, Austin measured a maximum ozone concentration of 77 ppb. In the Houston/Galveston area, six monitoring stations measured maximum concentrations over 85 ppb with a maximum of 123 ppb at the Croquet monitoring station. On the 7th, only Dallas, San Antonio, and Austin measured maximum ozone concentrations in excess of 75 ppb. An upper level trough of low pressure positioned over much of the southeastern U.S. during late August and early September retrograded westward into Texas. This system enhanced advection of moist unstable air from the Gulf of Mexico northward into the state, but cloudiness remained limited except in the far eastern Texas.

As the surface ridge of high pressure continued moving eastward on the 8th, the more typical flow of marine air from the Gulf of Mexico returned to Texas. Late morning and afternoon cloudiness increased significantly over the eastern half of Texas, although precipitation and rain showers remained limited. Maximum ozone levels in Austin decreased to the 50 ppb range on the 8th. Indeed, ozone levels decreased dramatically across eastern Texas and no monitoring stations measured 8-hour concentrations in excess of 65 ppb.

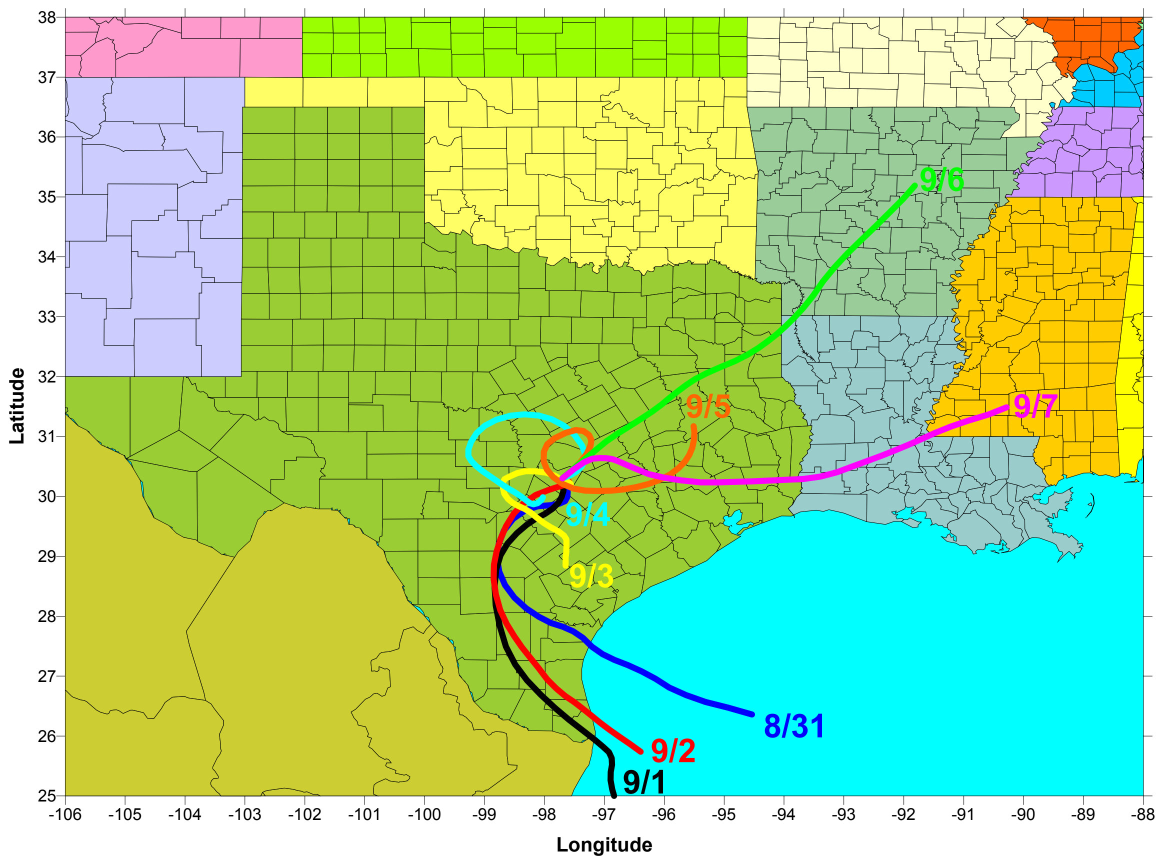

Figure 6-3. 32-Hour Back-Trajectories for August 31, 2000 through September 7, 2000

September 15-18, 2000

Table 6-5 presents the maximum 8-hour concentrations for selected metropolitan areas in eastern Texas for the September 15-18, 2000 period. Maximum ozone concentrations in Austin on the 15th, 16th, and 17th were 83 ppb, 81 ppb, and 77 ppb, respectively. On the 18th, a peak ozone concentration of 100 ppb was measured in Austin. Daily peak ozone concentrations in the Houston/Galveston area were comparable to those monitored in the Austin area with the exception of the 18th. On the 18th, a maximum ozone concentration of 128 ppb was measured in the Houston/Galveston area.

Table 6-5. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during September 16, 2000 through September 18, 2000

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
9/15/00	83	70	56	94	77	61	76
9/16/00	81	73	90	87	81	86	66
9/17/00	77	75	88	78	85	82	69
9/18/00	100	89	91	87	128	93	84

After the extremely dry and hot conditions associated with the continental airmass that plagued Texas during late August and early September, mid-September was characterized by a return flow of moisture from the Gulf of Mexico. Weak cool fronts brought much needed rainfall to parts of the state during the period; however, Texas remained beneath an upper level ridge of high pressure that extended westward across the Southwestern U.S. Maximum ozone concentrations in Austin during the 12th through 14th period remained in the 40 - 50 ppb range. Morning fog and mostly cloudy conditions were reported across much of the southern half of Texas on both the 13th and 14th. On the 14th, spotty showers produced 0.50 inch of rain at Austin Mabry, a trace of rain at Austin Bergstrom, and 1.24 inches in San Antonio. Although significant cloudiness remained over Central Texas on the 15th, light wind speeds and stagnant conditions contributed to a maximum temperature of 98 ^{o}F. A maximum ozone concentration of 83 ppb was measured in Austin. The 32-hour back-trajectory indicated northerly flow into the area, consistent with the observed northwesterly morning winds and northeasterly afternoon winds at the surface. With a maximum ozone concentration of 94 ppb, Dallas/Ft. Worth was the only metropolitan area in Texas to measure a higher ozone concentration than Austin on the 15th.

During the previous few days, a vigorous low pressure system associated with a southward-moving cold front had been moving east and northeast across the U.S. northern plains and Great Lakes regions. Strong northeasterly winds late on the 15th were associated with the passage of the surface cold front through Central Texas. The expansive high pressure system associated with the cold front covered much of the eastern U.S. and clear skies dominated most of the region during the 16th through 18th period. The only significant precipitation in the eastern two-thirds of the U.S. was associated with Tropical Storm Gordon, which moved northward from the eastern Gulf of Mexico into the Florida Panhandle on the 17th and continued moving up the east coast during the period.

The clockwise flow around the strong surface ridge of high pressure centered over the Southeastern U.S. produced long-range northeasterly transport on the 16th and 17th, as shown in Figure 6-4. At the surface, winds blew consistently from the northeast as well. Afternoon relative humidities fell into the 20-30% range as drier and cooler air was transported into the state. Maximum temperatures returned to more seasonable levels in the low 90s. Clear skies and low relative humidities resulted in enhanced nighttime radiational cooling; and record low temperatures of 50 ^{o}F and 48 ^{o}F were measured on the 17th and 18th, respectively. Average daytime wind speeds were quite strong on the 16th at approximately 12 mph, decreasing to approximately 8 mph on the 17th. Daily peak ozone concentrations in Austin on the 16th and 17th reached 77 ppb and 81 ppb, respectively. Interestingly, the maximum ozone concentrations in San Marcos were identical to those measured in the Austin area, suggesting that substantial levels of background ozone were entering the Austin area.

The upper level ridge over Texas on the 18th was associated with continued clear skies and relatively stagnant conditions across the eastern half of Texas on the 18th. The maximum temperature in Austin reached 93 ^{o}F and wind speeds decreased to less than 5 mph. Note the lighter wind speeds in the lower atmosphere are consistent with the relatively shorter 32-hour back-trajectory on the 18th. The stagnant atmospheric conditions, coupled with transport of continental air into Texas, contributed to high ozone concentrations throughout the state. Maximum ozone concentrations in Austin and San Marcos were 100 ppb and 94 ppb, respectively. Ozone concentrations in the Houston/Galveston area increased significantly. Thirteen monitoring stations in the Houston/Galveston area measured peak ozone concentrations greater than 85 ppb, with a maximum of 128 ppb at both the Aldine and Wayside monitoring stations.

On the 19th, the upper level ridge over Texas weakened ahead of a cold front that stalled across northern Texas. As the surface ridge of high pressure centered over the eastern U.S. also weakened and moved eastward, southeasterly winds returned to Texas. Temperatures remained warm and a maximum temperature of 96 ^{o}F was measured in Austin. Maximum ozone concentrations fell substantially on the 19th, with Austin and Houston maximums of 75 ppb and 88 ppb, respectively. By the 20th, the subtropical jet moved eastward over Texas, transporting upper-level moisture from the Pacific into the state and enhancing convective activity. Maximum ozone levels dropped dramatically across Texas as cloudiness and showers increased over the next few days.

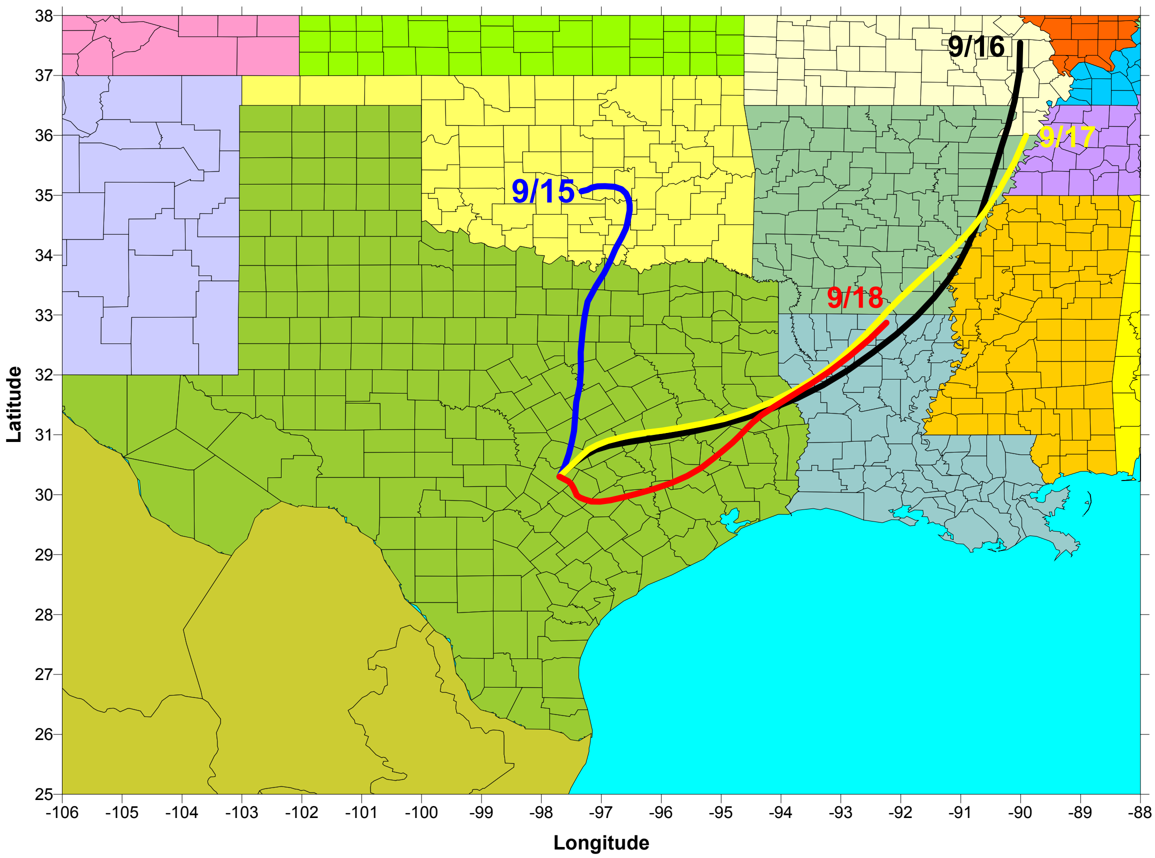

Figure 6-4. 32-Hour Back-Trajectories for September 15, 2000 through September 18, 2000

June 23-25, 2002

Table 6-6 presents the maximum 8-hour concentrations for selected metropolitan areas in eastern Texas for the June 23-25, 2002 period. Only Austin, Dallas, and San Antonio measured daily 8-hour peaks greater than 75 ppb on each day of the June 23 – June 25 period. The overall maximum concentration measured in eastern Texas was 122 ppb in Dallas on the 24th. Daily peak ozone concentrations in Austin were 92 ppb, 100 ppb, and 75 ppb on the 23rd, 24th, and 25th, respectively. Compared to the previous high ozone episodes discussed in this section, relatively lower 8-hour peaks were measured in the coastal metropolitan areas.

Table 6-6. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during June 23, 2002 through June 25, 2002

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
6/23/02	92	83	74	114	95	97	84
6/24/02	100	73	68	122	83	110	64
6/25/02	75	59	43	99	52	99	70

Early and mid-June was characterized by slightly above normal temperatures and dry conditions throughout most of Texas. On the 21st, the eastern U.S. enjoyed slightly cooler and drier air due to the southward intrusion of a large Canadian air mass during the previous days. A large surface ridge of high pressure associated with this air mass was centered over the Ohio River Valley, and extended from northeastern Texas to the northeastern U.S. Clouds and showers over much of the southeastern U.S. were associated with an upper level low pressure circulation over the Florida Panhandle. To the west, a high pressure ridge was centered over Texas and extended northward into the Great Plains. Maximum temperatures reached the mid-90s over Central Texas and ozone levels remained in the 40 ppb range.

On the 22nd, the upper level ridge over Texas began to weaken as the upper level low moved westward over Louisiana. In response to the tightening pressure gradient at upper levels over Texas, northerly winds at the

300 mb level increased to about 20 knots. Skies remained clear over most of the state. The surface ridge of high pressure centered over the Ohio River Valley extended southwestward into eastern Texas. The 32-hour back-trajectory (not shown) for the 22nd indicated long-range transport from the east-northeast, consistent with the clockwise circulation around the surface ridge of high pressure. Morning low temperatures in Central Texas dropped from the low 70s during the previous few days to the mid 60s on the 22nd and 23rd. Morning fog and haze was reported throughout much of Texas, suggesting stagnant atmospheric conditions near the surface. The daily peak 8-hour ozone concentrations increased throughout most of eastern Texas. In Austin, a maximum concentration of 72 ppb was measured at the Murchison monitoring station.

While most of Central and North Texas remained clear on the 23rd, high clouds over eastern and coastal Texas were associated with the upper level low now located over south central Louisiana. Although rain and showers associated with this system began to move into extreme eastern Texas, most of Texas remained dry. Upper level winds remained northerly over Central Texas as the upper ridge of high pressure previously centered over Texas amplified and retrograded westward over the southwestern U.S. The surface ridge of high pressure over the eastern U.S. weakened considerably, particularly in the southeastern U.S. under the influence of the upper level low pressure circulation. However, the 32-hour back-trajectory (Figure 6-5) shows continued long-range transport into Austin from the east, consistent with continued transport of continental air into the state. At the surface, the daily average wind speed in Austin decreased from about 4 mph on the 22nd to 3 mph on the 23rd. Daily peak 8-hour ozone concentrations greater than 85 ppb were measured in the Austin, Dallas, Houston, and San Antonio areas. In Dallas, thirteen of eighteen monitoring stations measured peak ozone concentrations equal to or greater than 85 ppb. A daily peak of 92 ppb was measured at the Murchison monitoring station in Austin. The daily average $PM_{2.5}$ concentration at the Audubon monitoring station increased from 11 ug/m^3 on the 22nd to 17 ug/m^3 on the 23rd.

By the 24th, the upper level low centered over northern Louisiana was associated with northerly winds near 30 knots over Central Texas. Most of Texas remained dry, although high clouds began to move into eastern portions of the state. Widely scattered afternoon showers and thunderstorms associated with the upper level low pressure circulation developed over eastern and coastal Texas. The increased cloudiness throughout coastal Texas decreased the amount of solar radiation reaching the surface, and likely played a role in the observed lower ozone concentrations in the coastal metropolitan areas. In Austin, the weak pressure gradients at the surface were associated with continued light wind speeds, and morning fog and haze were reported. In contrast to the coastal metropolitan areas, relatively higher peak 8-hour concentrations were measured in Central and North Texas compared to those observed on the previous day. Maximum concentrations in the Austin, Dallas, and San Antonio areas were 100 ppb, 122 ppb, and 110 ppb, respectively. $PM_{2.5}$ concentrations remained elevated, and a daily average of 19 ug/m^3 was measured at the Audubon monitoring station.

On the 25th, the upper level low moved westward into northeastern Texas. The surface ridge centered off the mid-Atlantic coast continued to weaken and moved eastward. At the surface, southerly flow into the southeastern U.S., including eastern Texas, transported tropical moisture inland. Widely scattered showers and thunderstorms formed along a line oriented from South Texas northward to the Dallas area. The 32-hour back-trajectory and wind observations in Austin indicated that southerly maritime flow had returned to the state; however, wind speeds remained light in Central Texas. Peak 8-hour ozone concentrations of 99 ppb were measured in both the Dallas and San Antonio areas. The peak ozone concentration in Austin dropped to 75 ppb. The daily average $PM_{2.5}$ concentration at the Audubon monitoring station dropped as well to 10 ug/m^3.

By the 26th, the upper level low across northeastern Texas had consolidated with a southward moving upper level tough. The trough was centered over eastern Texas and extended northward to the Great Lakes. The deep flow of moisture from the Gulf, combined with the atmospheric instability associated with the upper level trough, produced showers and thunderstorms throughout eastern and southern Texas. Over an inch of rain was measured at Austin Bergstrom as ozone concentrations dropped dramatically in Austin and across the state. The wet conditions would continue over the next ten days, resulting in record flooding over portions of Central and South Texas.

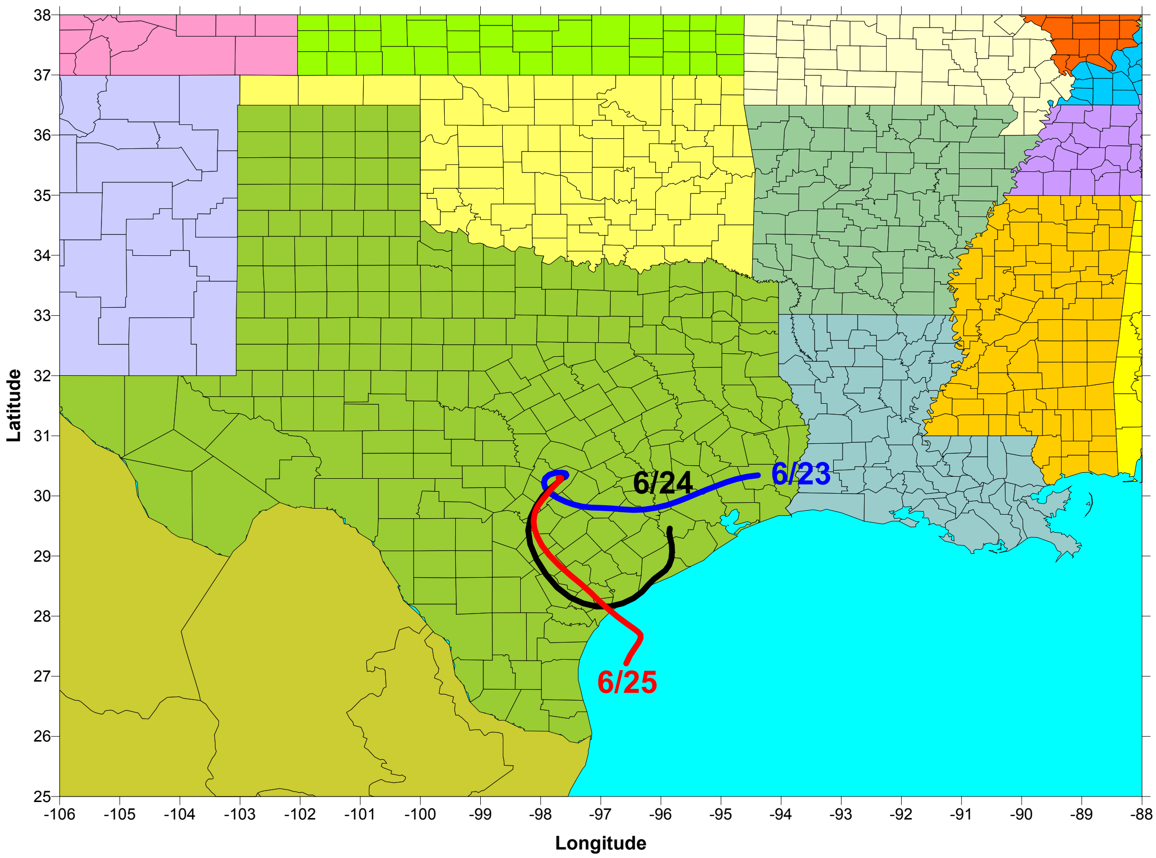

Figure 6-5. 32-Hour Back-Trajectories for June 23, 2002 through June 25, 2002

September 11-14, 2002

Table 6-7 presents the maximum 8-hour concentrations for selected metropolitan areas in eastern Texas for the September 11-14, 2002 period. Maximum ozone concentrations in Austin on the 12th, 13th, and 14th were 87 ppb, 96 ppb, and 91 ppb, respectively. Extremely high daily peak ozone concentrations were measured throughout eastern Texas during the period, with an episode maximum of 144 ppb measured in the Houston/Galveston area on the 13th.

Table 6-7. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during September 11, 2002 through September 14, 2002

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
9/11/02	76	95	69	105	96	75	91
9/12/02	87	95	100	85	121	111	82
9/13/02	96	92	96	101	144	104	90
9/14/02	91	121	75	99	121	92	92

Late August and early September were characterized by dry conditions and above normal temperatures. This weather pattern was brought to an abrupt end by the landfall of Tropical Storm Fay along the middle Texas coast on September 7th. Fay tracked westward across south central Texas on the 8th, spreading showers and thunderstorms across much of Central and South Texas. The four-day rainfall totals for the 6th through 9th period at Austin Bergstrom and Camp Mabry were 2.1 inches and 2.9 inches, respectively. The precipitation associated with this tropical system diminished late on the 9th as the remnants of Fay moved southwestward towards Mexico.

On the 10th, high pressure dominated Texas at upper levels. A weak cold front stretched northeastward from the Texas Panhandle to the Great Lakes. A large area of high pressure was centered over the Great Plains and moved westward as the front dipped southward into Texas. By the 11th, the surface ridge of high pressure extended southwestward into eastern Texas. As cloudiness decreased and dry conditions returned, the daily maximum temperatures in Austin increased from the mid-80s prior to the 10th to the mid-90s. Some high clouds extended into northeastern Texas in association with a large upper level low pressure system centered over Arizona. Morning fog and haze were reported across much of eastern Texas. The 32-hour back-trajectory (Figure 6-6) on the 11th showed northeasterly flow into Austin, consistent with the observed surface winds. Satellite photographs indicated that the clockwise circulation around the surface ridge of high pressure began to transport haze and possibly ozone into eastern Texas from the Ohio and Mississippi River Valleys. Throughout eastern Texas, maximum ozone concentrations increased from the 40 - 50 ppb range on the 10th to the 70 - 80 ppb range on the 11th. The daily peak ozone concentration in Austin was 76 ppb on the 11th. $PM_{2.5}$ concentrations increased throughout eastern Texas as well. In Austin, the $PM_{2.5}$ daily average concentration increased from 9.5 ug/m^3 on the 10th to 23.6 ug/m^3 on the 11th.

By the 12th, the hazy air mass originally over the Ohio and Mississippi River Valleys on the 10th now covered most of eastern Texas. The average daily wind speed in Austin decreased from 6 mph on the 11th to less than 3 mph on the 12th, consistent with the relatively short 32-hour back-trajectory. The stable atmospheric conditions, coupled with transport of continental air into Texas, contributed to high ozone and $PM_{2.5}$ concentrations throughout the state. The Corpus Christi, San Antonio, and Houston/Galveston areas each measured peak 8-hour ozone concentrations at or greater than 100 ppb. Austin measured a peak concentration of 87 ppb at the Murchison monitoring station. Given the large-scale wind flow from the north, the Audubon monitoring station was likely upwind of the Austin urban plume on this day. A maximum concentration of 80 ppb was measured at Audubon, suggesting substantial transport of ozone into the Austin area.

On the 13th, the upper level ridge migrated eastward toward the Southeastern U.S. while the surface high pressure system moved toward the Northeastern U.S. The weak pressure gradients at the surface were associated with very light wind speeds, and the hazy air stagnated across eastern Texas. Sixteen monitoring stations in the Houston/Galveston area and eleven monitoring stations in the Dallas area measured peak ozone concentrations greater than 85 ppb. An overall episode maximum concentration of 144 ppb was measured at the Polk Avenue monitoring station in Houston. The Austin episode maximum concentration of 96 ppb was measured at the Murchison monitoring station. The Fayette county and Audubon monitoring stations measured maximum concentrations of 84 ppb and 80 ppb, respectively. Although selection of an upwind location is difficult given the very light wind conditions, the high regional concentrations again suggest substantial transport of ozone into the Austin area. Significantly, the $PM_{2.5}$ measurements collected throughout eastern Texas on the 13th and 14th represent the highest daily average concentrations since monitoring began in 1999. In Austin, the daily average $PM_{2.5}$ concentration was 43.3 ug/m^3, indicating continued transport and/or formation of $PM_{2.5}$.

On the 14th, southerly return flow from the Gulf of Mexico returned to Texas; however, wind speeds remained light ahead of a weak front entering the Texas Panhandle. Showers and thunderstorms over western Texas occurred in association with a surface trough of low pressure moving ahead of the front. Skies over eastern Texas remained clear and maximum ozone concentrations remained high throughout eastern Texas. The continued light winds and sunny skies allowed local emissions to accumulate, adding to the haze and high ozone. In Austin, a peak concentration of 91 ppb was measured at Murchison. The peak concentrations at the Fayette County and Audubon stations were 80 ppb and 81 ppb, respectively. $PM_{2.5}$ concentrations remained elevated throughout eastern Texas, with Austin measuring a daily average concentration of 42.4 ug/m^3. On the 15th, ozone and $PM_{2.5}$ concentrations decreased dramatically as clouds and showers moved southward across eastern Texas as a second front pushed across the state.

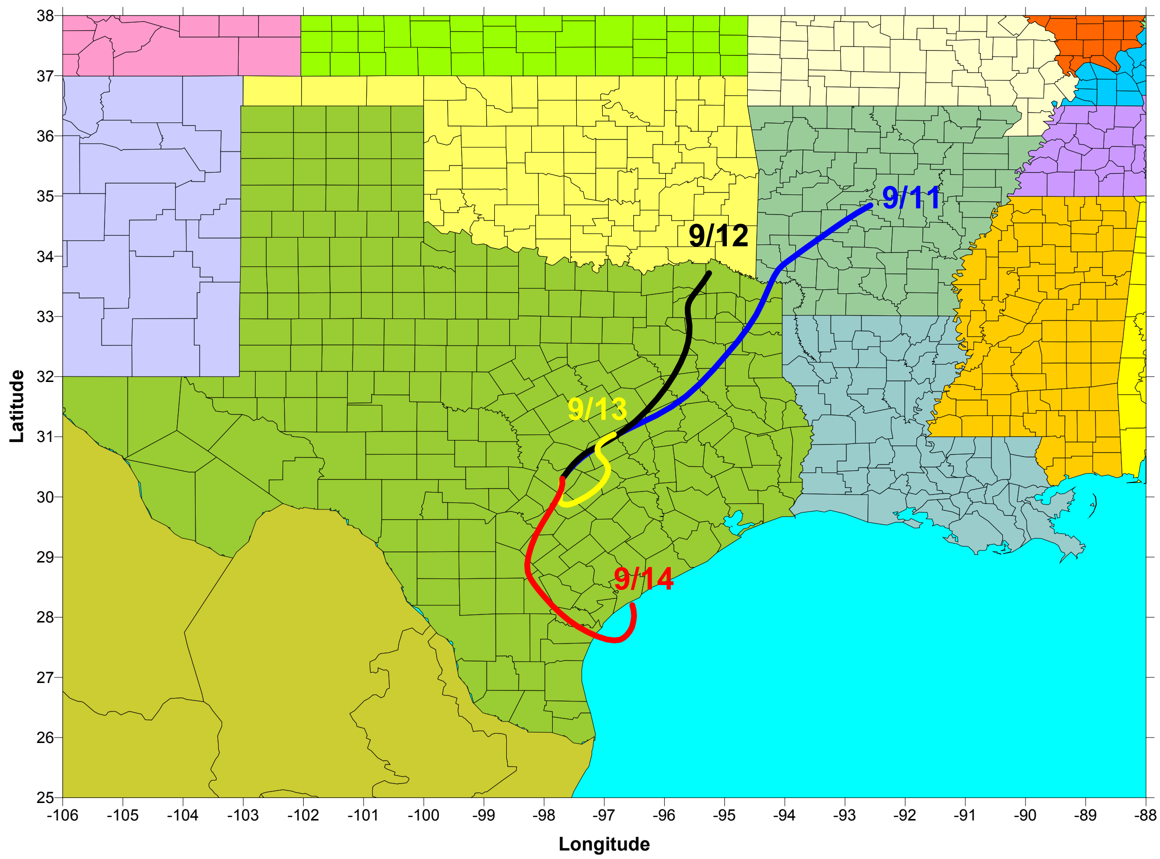

Figure 6-6. 32-Hour Back-Trajectories for September 11, 2002 through September 14, 2002

May 28-31, 2003

Table 6-8 presents the maximum 8-hour ozone concentrations for selected metropolitan areas in eastern Texas for the May 28-31, 2003 period. The peak daily concentrations in Austin on the 28th, 29th, and 30th and 31st were 83 ppb, 82 ppb, 96 ppb, and 80 ppb, respectively. The daily peak ozone concentration of 96 ppb on the 30th was the highest value measured during 2003 in Austin. Extremely high daily peak ozone concentrations were measured throughout eastern Texas during the period, with an episode maximum of 130 ppb measured in the Dallas/Fort Worth area on the 31st. Houston/Galveston measured a high of 126 ppb on the 29th.

Table 6-8. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during May 28, 2003 through May 31, 2003

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
5/28/03	83	89	84	96	99	96	82
5/29/03	82	114	78	89	126	95	90
5/30/03	96	84	69	82	94	87	87
5/31/03	80	71	78	130	99	89	97

May 2003 was characterized by summer-like conditions in Central and South Central Texas, with near-record heat and drought compared to climatological averages. Based on meteorological observations collected at Austin Bergstrom, May 2003 was the third warmest and driest on record. A cold front that passed through Central Texas on the 20th provided relief from the unusual heat and produced a few light showers over eastern Texas. High temperatures in Austin dropped from the mid-to-upper 90s to the low 80s as northerly winds brought much cooler and drier air into the state. Temperatures warmed back into the mid-90s ahead of a second frontal passage through Central Texas on the 26th. Three-quarters of an inch of precipitation was measured at Austin Mabry as the clouds and showers that accompanied the front passed over Austin. Daily peak temperatures in Austin again dropped into the mid-80s with low temperatures in the 60s.

As the cold front pushed offshore of the upper Texas coast on the 27th, heavy rains in south Texas were associated with the western portion of the frontal trough in combination with an upper level low located over northeastern Mexico. At upper levels over Texas, a high pressure ridge began to build southward as the upper level trough associated with the front moved eastward towards the Southeastern U.S. The clockwise circulation around a high pressure system centered over Oklahoma was associated with northeasterly winds over much of eastern Texas. Daily peak 8-hour ozone concentrations in Central Texas increased to into the 60 ppb range from the 50 ppb range on the 26th. The Dallas/Fort Worth and Houston/Galveston areas measured high ozone concentrations in the low 70 ppb range. $PM_{2.5}$ levels in Austin increased to approximately 15 ug/m^3 from 6-7 ug/m^3 on the 26th. With the exception of extreme South Texas, skies were clear throughout the state.

As the upper level low over northern Mexico began to move to the southwest on the 28th, high pressure continued to strengthen at the surface and upper levels over Texas. Northeasterly winds continued in the lower atmosphere over most of the state, and the 32-hour back-trajectory (Figure 6-7) indicates rather long range transport of air into the Austin area. The northerly and northeasterly winds continued to transport colder and drier continental air into Texas. Skies remained clear over most of Texas and early morning lows in

Austin dropped to the upper 50s with afternoon highs in the upper 80s. Average wind speeds decreased to approximately 5 mph compared to 9 mph on the 27th. Ozone levels increased dramatically to the 80 ppb to 90 ppb range in most metropolitan areas in eastern Texas. The highest Austin Area concentration of 83 ppb was measured at the Pflugerville monitoring location, which was upwind of the downtown area and was well-positioned to measure background ozone entering the Austin area on this day. The Fayette county monitoring peak of 78 ppb also suggest high regional background levels. The second highest Austin concentration of 77 ppb was measured at Murchison. Both Houston and Dallas measured concentrations in the upper 90s. $PM_{2.5}$ concentrations in Austin remained near 15 ug/m^3.

On the 29th, high pressure continued to dominate at the surface and upper levels over Texas, suppressing cloud formation and enhancing atmospheric subsidence throughout the state. Temperatures in Austin rose rapidly from morning lows in the upper 50s to afternoon highs in the upper 90s. Observations of fog and haze were reported but the average daily $PM_{2.5}$ levels remained relatively low at 12 ug/m^3. Wind speeds at the surface were light and variable throughout the day, consistent with stagnant conditions in the lower atmosphere. Note, however, that the 32-hour back-trajectory for the 29th, which includes the effects of winds throughout the lower portion of the atmosphere, indicates long-range transport into the Austin area from the north. Again, the peak Austin concentration of 82 ppb was measured at the Pflugerville monitoring station. The Fayette county monitoring station measured a peak 8-hour ozone concentration of 83 ppb, suggesting continued very high regional background levels of ozone. The second highest Austin daily peak 8-hour concentration was 77 ppb measured at Murchison. In the Houston/Galveston area, peak ozone concentrations above 100 ppb were measured at twelve of twenty-three monitoring stations with an episode maximum concentration of 126 ppb at Deer Park.

Strong high pressure at upper levels and the surface continued to suppress cloud cover over eastern Texas on May 30th. The high pressure system was likely associated with greatly enhanced atmospheric subsidence over Texas and, combined with ample sunshine, helped temperatures in the Austin area increase to 100 ^{o}F for the first time in 2003. In Central Texas, light morning winds from the northwest were followed by moderate afternoon winds from the south. Note that the 32-hour back-trajectory also indicates long-range transport of air into the Austin area from the south. Again, the maximum daily peak 8-hour ozone concentration was measured at the Pflugerville monitoring location, which was likely located downwind of the Austin area on this day given the southerly afternoon flow at the surface. A maximum 8-hour ozone concentration of 96 ppb was measured at Pflugerville, the highest concentration measured in Austin during 2003. Although there were no active rural ozone monitors located to the south of Austin to estimate the levels of regional transport, 8-hour ozone concentrations measured by the San Antonio urban monitors were in the 80 ppb to 90 ppb range. The daily peak concentrations at the Audubon, Dripping Springs, and Murchison monitoring stations were 83 ppb, 87 ppb, and 87 ppb, respectively. The Fayette County monitoring station measured a daily peak ozone concentration of 79 ppb.

On the 31st, the strong ridge of high pressure at upper levels began to weaken as a cold front approached Texas from the north. Although clouds and thunderstorms formed in western Texas, eastern Texas remained mostly clear. Warm temperatures continued and Austin measured a maximum temperature of 99 ^{o}F. $PM_{2.5}$ levels in Austin remained in the 11 to 12 ug/m^3 range. At the surface, southerly wind speeds increased to 5-7 mph. The 32-hour back-trajectory for the 31st indicates long-range transport from the south as well at relatively high wind speeds. Once again, the maximum 8-hour peak ozone concentration of 80 ppb was measured at the Pflugerville monitoring station. The daily peak concentrations at the remaining Austin monitoring stations were between 71 ppb and 74 ppb. Very high background levels continued as suggested by the Fayette County peak of 83 ppb. Maximum ozone levels in San Antonio, Dallas/Fort Worth and Houston/Galveston were 89 ppb, 130 ppb, and 99 ppb, respectively.

By June 1st, a weak frontal system increased cloudiness and showers over Central Texas. Maximum temperatures in Austin decreased slightly to the mid-90s. With a weak trough at upper levels, the atmosphere over Texas became less stable and ozone concentrations decreased throughout eastern Texas. Southerly surface flow continued to transport warm moist air from the Gulf of Mexico into the state. With continued southerly flow at the surface, ozone concentrations in Central and coastal Texas dropped into the 40 to 60 ppb range while ozone levels in Dallas remained above 85 ppb.

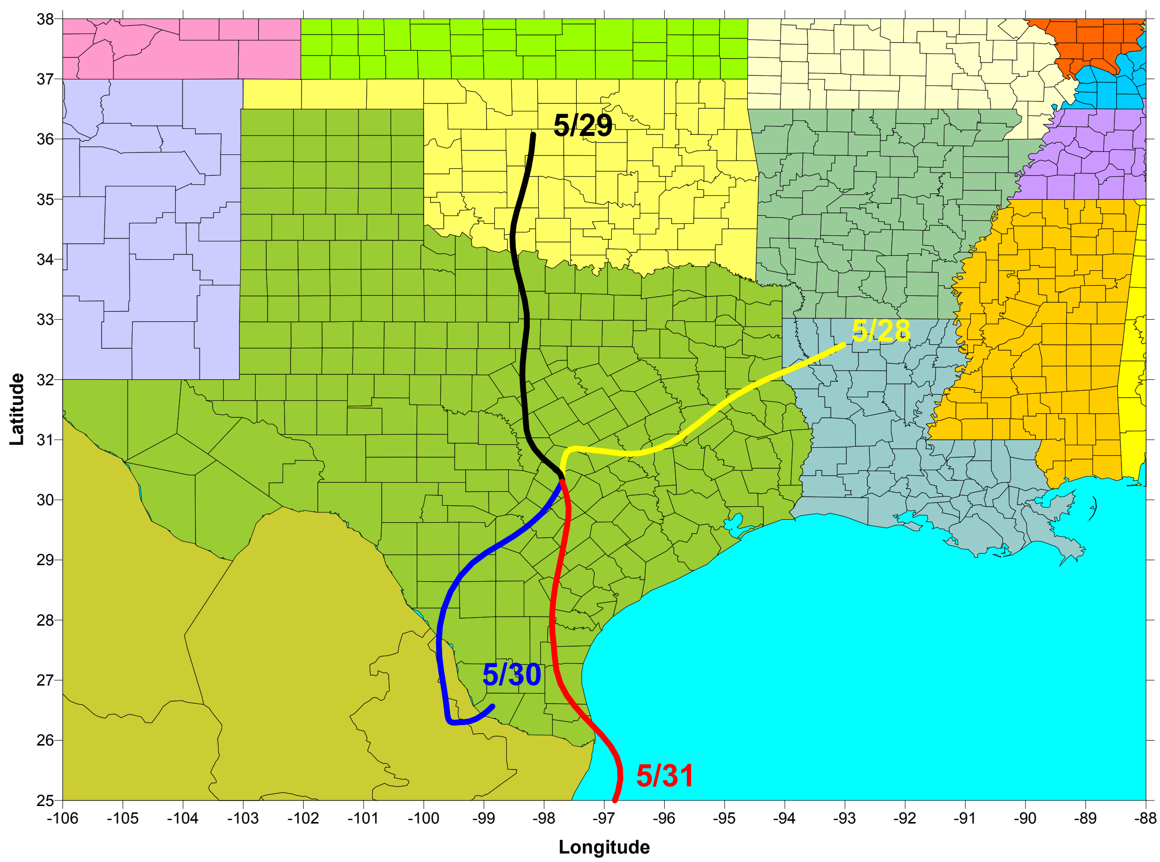

Figure 6-7. 32-Hour Back-Trajectories for May 28, 2003 through May 31, 2003

September 6-8, 2003

Table 6-9 presents the maximum 8-hour ozone concentrations for selected metropolitan areas in eastern Texas for the September 6-8, 2003 period. Maximum concentrations in Austin on the 6th, 7th, and 8th were 85 ppb, 92 ppb, and 86 ppb, respectively. Elevated daily peak ozone concentrations were also measured in the San Antonio and Corpus Christi/Victoria areas. Daily peak ozone concentrations above 100 ppb were measured in the Houston/Galveston throughout the period, with an episode maximum of 115 ppb on the 8th. Ozone levels in the northern Texas metropolitan areas were not particularly high, with an episode maximum of 91 ppb in Dallas/Fort Worth on the 7th.

Table 6-9. Daily Peak 8-Hour Ozone Concentrations in Eastern Texas during September 6, 2003 through September 8, 2003

Date	Austin	Beaumont/ Pt. Arthur	Corpus Christi/ Victoria	Dallas/ Ft. Worth	Houston/ Galveston/ Brazoria	San Antonio	Tyler/ Longview/ Marshall
9/06/03	85	66	77/77	81	102	91	72
9/07/03	92	79	90/95	91	109	90	78
9/08/03	86	69	64/84	82	115	80	52

September 2003 was characterized by cooler than normal temperatures in Texas compared to climatological averages as a series of cold fronts moved through the state. Most of Texas was characterized by above normal rainfall as well, although rainfall in Central Texas was slightly below normal. During the first days of September 2003, a weak front moved slowly south and dissipated along the Texas Gulf coast. On the 1st and 2nd, light precipitation was reported in Austin and by September 4th, the widespread showers and thunderstorms associated with the dissipating front were found over coastal Texas. As a second weak frontal system moved southward from northeast Texas on the 4th, clear skies in Central Texas enhanced radiational heating and a maximum temperature of 96 ^{o}F was recorded at Austin Bergstrom. Maximum ozone concentrations in Austin and San Antonio rose from the 30 to 40 ppb range during the previous days to the mid-60 ppb range. Daily average $PM_{2.5}$ concentrations remained well below 10 ug/m^{3}. On the 5th, most of eastern Texas was characterized by northeasterly winds associated with a southward moving high pressure system centered over the Great Lakes. An upper level trough extended southward into Texas and was associated with rain and thunderstorms over South Central and South Texas as skies cleared over most of northern Texas. Maximum 8-hour ozone concentrations in the Dallas, Houston, and Austin areas were 90 ppb, 73 ppb, and 62 ppb, respectively.

On the 6^{th}, most of Texas was characterized by clear skies and northeasterly winds as the surface ridge of high pressure centered near the Great Lakes moved eastward towards the Northeastern U.S. At upper levels, the trough lifted over Texas eastward towards the Southeastern U.S. The 32-hour back-trajectory for the 6^{th} (Figure 6-8) indicates northeasterly flow of air into the Austin region, consistent with the clockwise flow around the surface high pressure ridge. This surface ridge was likely associated with rather stagnant atmospheric conditions near the ground, and early morning fog was observed in Central Texas. Surface wind speeds in Central Texas decreased from 5-6 mph on the 5^{th} to 3-4 mph on the 6^{th}. Northeasterly winds continued to transport somewhat cooler and drier air into Texas, and early morning low temperatures in Central Texas dropped into the mid-60s from the mid-70s on previous days. Ozone concentrations increased throughout Texas as Austin and San Antonio measured daily maximum 8-hour concentrations of 85 ppb (Murchison) and 91 ppb, respectively. Daily peak 8-hour ozone concentrations at the Pflugerville and Fayette County monitoring stations were 76 ppb and 67 ppb, respectively. The Murchison $PM_{2.5}$ daily average concentration increased slightly from 12.6 ug/m^3 on the 5^{th} to 13.6 ug/m^3 on the 6^{th}. Daily peak ozone concentrations in the Houston/Galveston area reached 102 ppb.

The surface ridge of high pressure centered south of the Great Lakes continued to weaken on the 7^{th} as weak high pressure at upper levels enhanced atmospheric stability over Texas and mostly clear sky were reported over eastern portions of the state. In contrast, cloudiness and showers increased over the Texas Panhandle in association with an upper level disturbance that extended northward through Colorado and Wyoming. At the surface, eastern Texas was dominated by continued light northeasterly to easterly flow associated with the clockwise circulation around the surface ridge of high pressure. The relatively short 32-hour back-trajectory on the 7^{th} indicates light wind speeds throughout the lower atmosphere. Morning low temperatures in Central Texas remained in the lower 60s with highs in the mid-90s. A peak 8-hour ozone concentration of 92 ppb was measured at the Murchison monitoring stations in Austin, while Dallas/Fort Worth and Houston/Galveston measured maximum 8-hour concentrations of 91 ppb and 109 ppb, respectively. The Fayette County monitoring station recorded a maximum 8-hour ozone concentration of 77 ppb. This value is 84 percent of the Austin daily peak, suggesting substantial regional transport of background ozone into Central Texas.

As the surface ridge of high pressure centered to the northeast of the Great Lakes continued to weaken over Texas, southeasterly surface return flow from the Gulf of Mexico returned to Texas. In Central Texas, very light early morning winds from the south were followed by southeasterly afternoon winds. The 32-hour back-trajectory for the 8th shows the southerly inflow into the Austin area, and the relatively short length of the trajectory indicates continued light wind speeds in the lower atmosphere. In Central Texas, minimum temperatures remained in the low 60s while daytime high temperatures were limited to the low 90s. An Austin daily peak 8-hour ozone concentration of 86 ppb was measured at the Pflugerville monitoring station, which was likely downwind of downtown Austin on this day. Daily peak 8-hour concentrations at Audubon, Murchison, and Fayette County remained high as well at 83 ppb, 84 ppb, and 77 ppb respectively. Houston measured an episode maximum 8-hour concentration of 115 ppb. In Austin, the Murchison $PM_{2.5}$ daily average concentration increased from 13.4 ug/m^3 on the 7th to 18.1 ug/m^3 on the 8th.

As southeasterly flow continued at the surface across Texas on the 9th, tropical moisture from the Gulf of Mexico returned to the state. Maximum temperatures in Central Texas remained in the mid-90s. The daily peak ozone concentration in Austin dropped to 63 ppb, while Houston and Dallas measured maximum ozone concentrations of 87 ppb and 99 ppb, respectively. In Austin, the Murchison $PM_{2.5}$ daily average concentration decreased somewhat to 12.9 ug/m^3. By the 10th, an upper level disturbance moved over Texas from the northwest and brought showers and thunderstorms to eastern portions of the state, including the Austin area. Ozone levels dropped dramatically to the 20 to 40 ppb range.

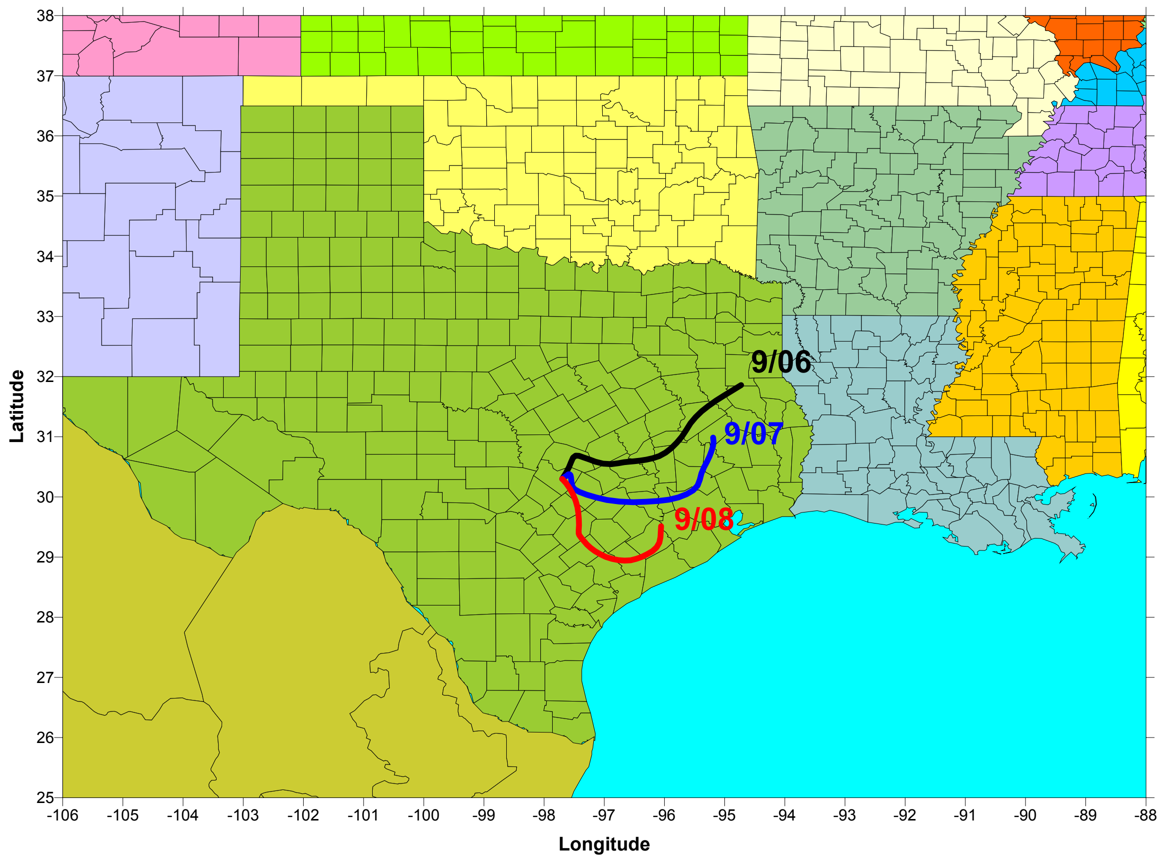

Figure 6-8. 32-Hour Back-Trajectories for September 6, 2003 through September 8, 2003

6.2 Multi-Day High Ozone Episode 32-Hour Back-Trajectories

A total of 22 multi-day high ozone episodes occurred during the months of August, September, and early October during the 1993 through 2003 period. If the generalized weather pattern summarized in the previous paragraph occurred consistently during high ozone episodes, the 32-hour back-trajectories from the initial days of these episodes should be dominated by northerly or easterly transport, while the 32-hour back-trajectories from the final days of the episodes would be more likely to exhibit southeasterly or southerly flow. Figure 6-9 presents the 32-hour back-trajectories on the first day of 20 of the 22 high ozone episodes. (Back-trajectories were not available on the first day for 2 of the 21 episodes.) As anticipated, these days are dominated by trajectories indicating transport from the north and east; however, exceptions do occur and two of the back-trajectories clearly indicate southeasterly to southwesterly transport into the Austin area. (These two trajectories represent episodes that began on August 1, 2000 and August 31, 2000.) Figure 6-10 presents the 32-hour back-trajectories for the final days of the 22 high ozone episodes. The number of days characterized by southerly back-trajectories is relatively greater compared to the first day back-trajectories shown in Figure 6-9; however, many episodes end with trajectories indicating continued easterly or northeasterly flow. The three high ozone episodes that occurred during the spring months (not shown) exhibited a similar pattern to the August through early October episodes. In contrast, three of the six June/July episodes (not shown) were dominated by southerly transport on both the initial and final days of the episodes. This suggests that the large-scale weather patterns during June and July differed from the generalized weather patterns experienced during the August through early October episodes; however, the frequency of occurrence of high ozone events during June/July is significantly lower.

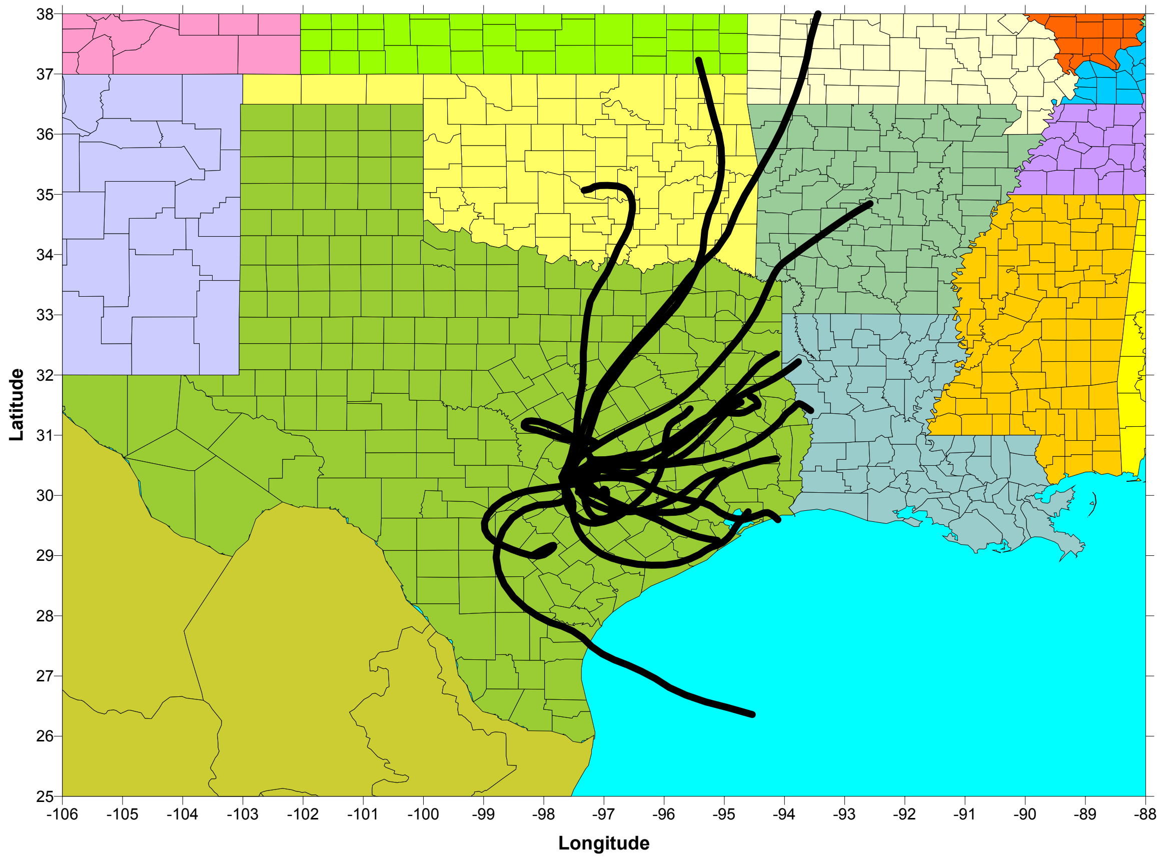

Figure 6-9. 32-Hour Back-Trajectories on the First Day of High Ozone Episodes that occurred during the August through early October period

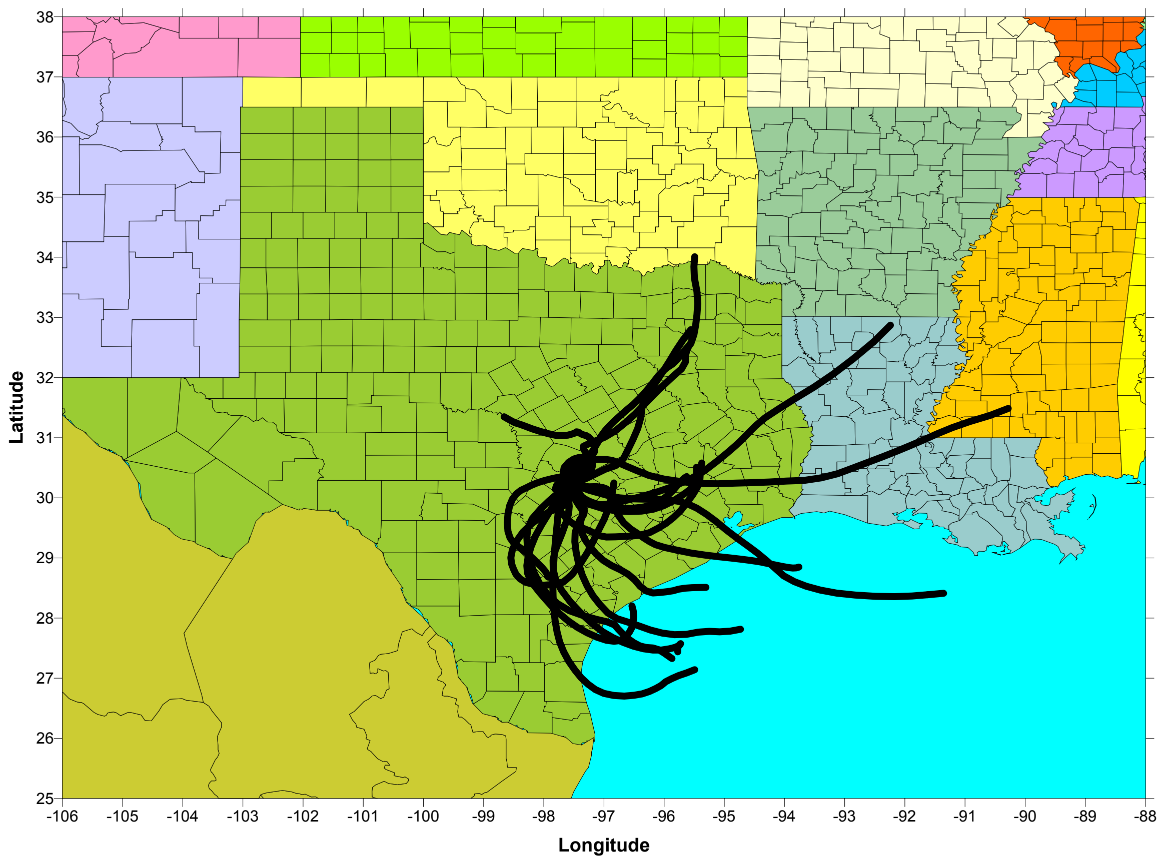

Figure 6-10. 32-Hour Back-Trajectories on the Last Day of High Ozone Episodes that occurred during the August through early October period

6.3 Long-range (72-Hour) Back-Trajectories on Days Characterized by Peak Ozone Concentrations > 85 ppb

Additional analysis was performed to investigate the synoptic-scale flow patterns that have been associated with the highest ozone levels in Austin, with an emphasis on the potential for regional transport from areas outside of Texas. Seventy-two hour back-trajectories were generated for all days characterized by a daily peak ozone concentration of 85 ppb or greater. Data collected by radar wind profilers in the Houston/Galveston area during the Texas Air Quality Study 2000 showed maximum afternoon mixing heights of 1-1.5 km. Observations of mixing height in Central Texas are limited; however, the mixing heights are likely as high or higher than those in coastal Texas. Since air at 1 km is potentially mixed to the surface on most summer days in Central Texas, a starting height of 1 km above the surface was used for the 72-hour back-trajectories rather than a starting height of 500 meters used for the previously presented 32-hour back-trajectories.

Again, the reader is cautioned against interpreting the HYSPLIT back-trajectories as precise paths of air parcels entering the Central Texas area, particularly given the 72-hour time period. As previously discussed, the trajectories are calculated from the three-dimensional wind field predicted by the archived gridded meteorological data with limited spatial and temporal resolution. In addition, the spatial and diurnal evolution of the planetary boundary layer will not be accurately represented and/or captured by the meteorological data. In particular, the nighttime mixed layer is often composed of multiple shallow layers as the near-surface layer becomes disconnected from the overlying large-scale synoptic flow. This nighttime mixed layer can be characterized by a rapid change of wind direction and speed with respect to height. The horizontal transport predicted by the HYSPLIT trajectory model can exhibit substantial errors if even small uncertainties exist in the vertical velocities within the lower atmosphere. In general, trajectories should not be interpreted as precise tracks of air parcels entering the Austin Area; however, patterns that emerge when analyzing a relatively large number of trajectories should provide a good indication of potential long-range transport due to the prevailing large-scale flow regime.

Figure 6-11 presents the 72-hour back trajectories for all days during the 1993 through 2003 period that were characterized by a daily peak 8-hour ozone concentrations of 85 ppb or greater in the Austin area. The figure includes back-trajectories for all high ozone days regardless of the month of occurrence. Note that the majority of trajectories indicate the clockwise flow of air into the state consistent with the large-scale circulation around a center or ridge of high pressure in the lower atmosphere. This is not unexpected as high pressure over Texas is generally a necessary condition for ozone to accumulate near the surface. Large-scale regions of high pressure near the surface are often associated with clear skies, light wind speeds, and stagnant atmospheric conditions conducive to the accumulation and formation of pollutants such as ozone.

Virtually all of the trajectories shown in Figure 6-11 indicate potential long-range transport of ozone and its precursors from the north, northeast, or east, with only a few trajectories indicating flow over the Gulf of Mexico. The tracks of these back-trajectories support the potential importance of regional transport during high ozone episodes in Texas; however, background concentrations can not be estimated in the absence of upwind monitoring data. In addition, the transport heights and ultimate source regions of the incoming air have not been considered.

A review of the surface weather maps for high ozone episodes characterized by one or more days with peak 8-hour concentrations greater than or equal to 85 ppb during the 1997 through 2003 period suggests a similar synoptic cycle regardless of the time of year of occurrence. Approximately 70 percent of the high ozone days (40 of the 55 days with peak 8-hour concentrations greater than or equal to 85 ppb) occurred during episodes that began with the passage of a cold front through Central Texas. The strongest fronts were accompanied by the transport of much colder air into the state, and daily peak ozone concentrations did not typically increase to 75 ppb or greater in Central Texas until several days after the passage of the front. In contrast, many of the cold fronts often represented little more than a transition zone between continental air to the north and maritime air to the south. Daytime high temperatures were often as warm or warmer following the passage of these weak fronts into Texas, and ozone levels often increased rapidly to 75 ppb or greater. Following the passages of all fronts, high pressure at the surface typically strengthened over Texas, and the large-scale clockwise flow shown in Figure 6-11 was associated with the continued transport of continental air into the state. Wind speeds at the surface were often relatively high after the frontal passages. As high pressure strengthened at the surface, daily average wind speeds decreased, and stagnant conditions prevailed in the lower atmosphere as high pressure continued over Texas. These meteorological conditions are quite conducive to the accumulation and formation of ozone and daily peak ozone concentrations increased dramatically.

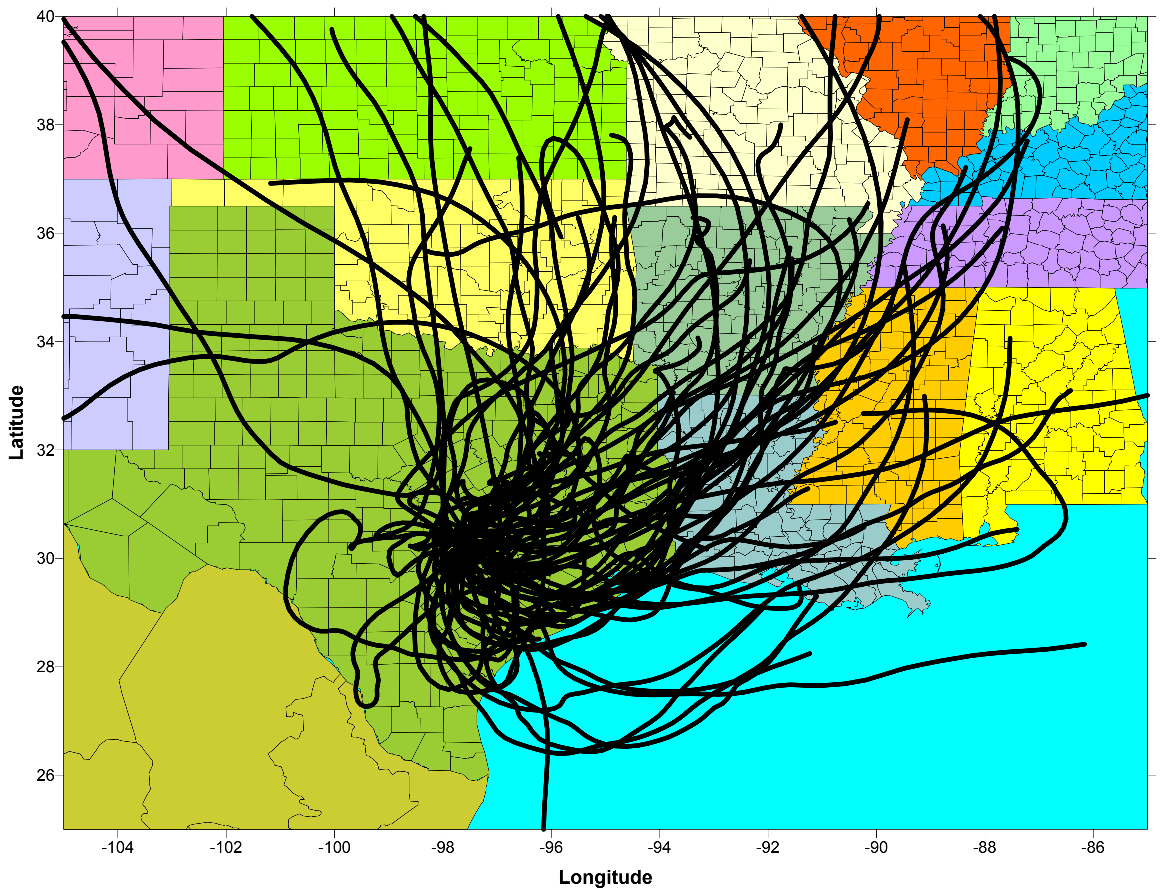

Figure 6-11. 72-Hour Back-Trajectories on all days during the 1993 through 2003 period characterized by a peak daily 8-hour ozone concentration of 85 ppb or greater

6.4 Generalized Synoptic-Scale Weather Patterns

The case studies and analyses presented in this section highlight a consistent synoptic-scale weather cycle that was observed during multi-day high ozone episodes in Central Texas. An upper level high pressure ridge is often (but not always) entrenched over Texas. This ridge suppresses vertical motion, and is often associated with clear skies, very warm temperatures, and light wind speeds at the surface. A southward dip in the jet stream over the eastern U.S. allows weak fronts to move southward from the Great Plains/Midwest regions. A multi-day high ozone episode in Central Texas typically begins immediately after the passage of a weak frontal trough. These fronts often provide little difference in terms of temperature, but represent a transition zone between drier continental air to the north and tropical maritime air associated with flow from the Gulf of Mexico to the south. As the surface ridge of high pressure strengthens and advances southward, northeasterly or easterly flow transports continental air into Texas. This continental airmass is often characterized by reduced visibility, and likely contains elevated concentrations of ozone and its precursor compounds associated with both biogenic and anthropogenic emissions. High ozone levels are often monitored throughout eastern Texas. As the surface ridge of high pressure weakens and/or moves eastward during the following days, southeasterly and southerly flow returns. This flow is initially associated with continued transport of continental air over the Gulf of Mexico and into Texas, and does not represent an immediate return to relatively clean maritime tropical inflow.

7.0 Ozone Conceptual Model for the Austin Area

The following discussion presents an idealized ozone conceptual model for the Austin Area. This model represents a description of the synoptic weather cycle that is typically observed during multi-day high ozone episodes. Only analyses of datasets discussed in this paper were considered: 1.) Ozone and meteorological measurements collected at the Austin, Fayette County, and San Marcos monitoring stations; 2.) Ozone concentrations measured at CAMS stations throughout eastern Texas; 3.) Meteorological observations from the National Weather Service stations at the Mueller and Bergstrom Airports; 4.) HYSPLIT back-trajectories; and 5.) Synoptic surface weather maps, upper-level charts, and infrared satellite images for the 1997 through 2003 period. In general, any given multi-day high ozone episode did not exhibit all phenomenon summarized below; however, the model is representative of the predominant local conditions and associated large-scale circulation features typically experienced during multi-day high ozone episodes in Central Texas, particularly during the August through early October period.

Prior to a typical high ozone episode, weak to moderate south/southeasterly flow from the Gulf of Mexico prevails. An upper-level ridge of high pressure enhances subsidence, suppressing vertical motion. The jet stream flows parallel to the Canada/U.S. border. Isolated afternoon convection and showers often occur along the coast in association with the sea breeze front or daytime convective heating. Peak ozone concentrations in Austin typically range from 40 ppb to 60 ppb. Skies are generally clear or partly cloudy and daily maximum temperatures reach the mid to upper 90s.

A consistent synoptic-scale weather cycle was observed during a majority of the high ozone episodes in Central Texas. An upper-level trough develops in the jet stream over the eastern U.S. This allows drier air to move southward from the Central U.S. and Midwest as cold fronts or surface troughs move ahead of a strengthening surface ridge of high pressure. An upper-level high pressure ridge is often (but not always) entrenched or strengthening over Texas. A multi-day high ozone episode typically began immediately after the passage of a frontal trough. The strongest fronts were accompanied by the transport of much colder air into Texas, and wind speeds at the surface were often relatively high after the frontal passage. The daily peak ozone concentrations did not typically increase to 75 ppb or greater in Central Texas until several days after the passage of the strongest fronts. In contrast, many of the cold fronts often provided little difference in terms of cooler temperatures, but represented a transition zone between continental air to the north and tropical maritime air from the Gulf of Mexico to the south. Daytime high temperatures were often as warm or warmer following the passage of these weak fronts into Texas, and ozone levels often increased rapidly to 75 ppb or greater.

The surface ridge of high pressure that typically advances southward into Texas behind the front is characterized by meteorological conditions highly favorable to the formation and accumulation of ground-level ozone, including light wind speeds, abundant sunshine, warm temperatures, and subsidence (sinking air) that inhibits vertical mixing and traps pollutants in a shallow layer near the surface. The clockwise circulation around the surface high pressure ridge, often centered over the Central Plains or Ohio/Mississippi River Valleys, generated northeasterly or easterly flow that transported continental air and haze into eastern Texas. This continental airmass was often characterized by reduced visibility, and likely contained elevated concentrations of ozone and its precursor compounds associated with both biogenic and anthropogenic emissions.

As high pressure strengthened at the surface, daily average wind speeds decreased, and stagnant conditions prevailed in the lower atmosphere over eastern Texas. Morning winds on high ozone days in Austin often exhibited a northerly or westerly component, likely associated with drainage along the Balcones Escarpment in a shallow surface layer that becomes decoupled from the prevailing synoptic-scale circulation. By mid-morning, mechanical mixing due to convective thermals deepens the mixed layer. Higher momentum air dominated by the larger-scale flow is mixed to the surface and afternoon winds typically blow with an easterly component. Daily maximum temperatures increased to the upper 90s in the slightly drier continental airmass. Extremely high ozone concentrations were often measured throughout eastern Texas. In Austin, peak ozone concentrations remained above 75 ppb for up to three consecutive days or more, sometimes reaching levels as high as 100 ppb. Substantial levels of background ozone are potentially transported into the Austin Area during these periods. In fact, the Fayette County and San

Marcos monitoring stations, which are often located upwind of Austin, typically measure peak ozone concentrations that are 80-85% of the observed Austin Area maximum. With background levels ranging from 65 ppb to 85 ppb on most high ozone days, even small contributions of ozone formed from local source emissions in the Austin area would result in an exceedance of the 8-hour NAAQS of 0.08 ppm.

As the surface ridge of high pressure over Texas weakened, southeasterly and southerly surface flow returned to eastern Texas. This flow is initially associated with transport of continental air over the Gulf of Mexico and does not represent an immediate return to relatively clean maritime tropical inflow. With continued southerly winds, however, warm, moist, tropical air from the Gulf of Mexico improves horizontal dilution of ozone concentrations across the Austin Area. Ozone levels decrease dramatically throughout the state. High ozone episodes sometimes end when a second frontal system enters Texas, bringing cooler temperatures and generating convection and shower activity.

8.0 Overview of Photochemical Modeling Activities in the Austin Area—WORK IN PROGRESS

Over the past six years, the Austin area has utilized its resources from the Texas Near Non-attainment Areas Program to develop photochemical models for air quality planning. Similar to the ozone non-attainment areas in Texas, the Austin area has struggled with achieving acceptable model performance. The area initially leveraged a regional photochemical model developed by the Texas Commission on Environmental Quality (TCEQ) for June 18-22, 1995 (The University of Texas at Austin, 2000). Several enhancements were made for photochemical modeling in the Austin area including modification of the modeling domain to a 32-km/16-km/4-km nested domain and incorporation of link data for Travis County on-road mobile source emissions, biogenic emission estimates from GLOBEIS2 and recent land cover surveys, and non-road mobile emissions estimates from the U.S. EPA's NONROAD Model. Evaluation of the model's performance indicated a strong under prediction tendency. Significant concern was expressed about the accuracy of modeled wind fields away from monitors and aloft, the inability of the Systems Application International Meteorological Model (SAIMM) to replicate small-scale land/sea breeze circulations along the Gulf Coast, and the sensitivity of model performance in Houston/Galveston to changes in the emissions inventory. Because of the model's relatively poor performance, the Austin area and the TCEQ decided not to use this modeling episode to evaluate regional and local emissions strategies.

Instead, in 2000, the area chose to modify the model-ready enhanced emissions inventory developed for the June 1995 episode and pursue modeling a July 7-12,1995 episode. ENVIRON initially developed the July episode for the San Antonio area with the Urban Airshed Model-IV (UAM-IV) in 1997 (ENVIRON International Corporation, 1997). The Alamo Area Council of Governments (AACOG), which coordinates air quality planning activities in San Antonio, requested that ENVIRON model this episode using CAMx (ENVIRON International Corporation, 1998). The TCEQ suggested that the Austin area update their existing June 1995 modeling emission inventory and leverage AACOG's CAMx model for their air quality planning activities.

The University of Texas at Austin (UT), under contract to CAPCO, modified the emissions for the June 1995 episode to obtain day-specific biogenic emissions, on-road mobile emissions, and NOx emissions from electric generating units for the July 7-12, 1995 episode (McDonald-Buller, 2000). The Regional Atmospheric Modeling System (RAMS, version 3a) simulations for OTAG were the basis of the meteorological data for July 7-12, 1995. The model's performance in the Central Texas grid during the July 7-12, 1995 episode was considerably better than during the June 18-23, 1995 episode. The TCEQ considered the performance of the model during the July 7-12, 1995 episode to be sufficient for initial air quality planning studies in both Austin and San Antonio.

8.1 July 7-12, 1995

The July 7-12, 1995 high ozone episode was selected for photochemical modeling prior to the development of the conceptual model described in this report. For the purpose of characterizing this episode within the context of the conceptual model, a description of the large-scale weather patterns and associated local meteorological conditions are provided below. This description is followed by a comparison of the July 7-12, 1995 high ozone episode to the conceptual model.

8.1.1 Meteorological Conditions during July 7-12, 1995

On July 7th, a stationary front extended northeastward from the Texas Panhandle to a surface center of low pressure located north of the Great Lakes. At upper levels, an eastward moving trough was located over the eastern U.S. and high pressure dominated over the western U.S. By July 8th, a surface ridge of high pressure centered south of the Great Lakes extended southwestward into Texas. As summarized in Table 8-1, calm winds were measured at the Murchison monitoring station on the 7th and 8th and daily peak temperatures reached the upper 90s. The 32-hour back-trajectories, shown in Figure 8-1 and initiated at a height of 500 meters above the surface, indicated southeasterly flow into the Austin area. The short trajectory length and direction is consistent with the observed afternoon surface winds. The 72-hour trajectories, shown in Figure 8-2 and initiated at a height of 1 km above the surface, also indicated southeasterly flow into the Austin area. Peak ozone concentrations in Austin were 44 ppb and 73 ppb on the 7th and 8th, respectively. Conditions in the lower atmosphere were likely rather stagnant given the very light wind speeds at the surface and warm temperatures.

By the 9th, high pressure strengthened at the surface and upper levels over Texas. Although the 32-hour back-trajectory for the 9th indicates southeasterly flow into the Austin area, the 72-hour back-trajectory shows northeasterly flow into Texas consistent with the clockwise flow around the surface ridge of high pressure. Winds at the surface remained essentially calm and a peak 8-hour ozone concentration of 81 ppb was measured in Austin. The stagnant atmospheric conditions continued on the 10th and the maximum daily temperature at Murchison increased to 101 F. Again, the rather short 32-hour trajectory indicates very light southeasterly flow into the Austin area; however, the 72-hour back-trajectory shows long-range northeasterly and easterly transport into Austin. The peak 8-hour ozone concentration increased to 90 ppb on the 10th, the highest ozone peak measured during the episode.

By the 11th, the surface ridge of high pressure over Texas began to move northeastward. The easterly transport indicated by the 72-hour back-trajectory is consistent with the clockwise circulation around the high pressure ridge. Note, however, that the 32-hour trajectory indicates light southerly winds, consistent with afternoon observations at the surface. Atmospheric conditions in the lower atmosphere remained stagnant, and maximum temperatures climbed to 102 F. The peak ozone concentration in Austin remained high at 89 ppb.

As the center of the high pressure associated with the surface ridge over Texas continued to move northeastward to New England on the 12th, southerly winds throughout the lower atmosphere returned to Texas. These southerly winds were likely associated with the clockwise circulation around the western periphery of the eastward moving surface ridge of high pressure. Atmospheric conditions remained stagnant, but the general surface flow likely began to transport relatively clean maritime air from the Gulf of Mexico into Texas. The peak ozone concentration in Austin decreased to 76 ppb. At both the surface and upper levels, high pressure remained entrenched over Texas on the 13th. Wind speeds remained very light and maximum temperatures exceeded 100 F. However, the continued southerly winds in the lower atmosphere likely advected maritime air into Texas and peak ozone concentrations decreased rapidly to the 40 ppb range by the 14th.

Table 8-1. Daily Peak Austin Area 8-Hour Ozone Concentrations and Local Meteorological Summary during July 7, 1995 through July 12, 1995

Date	Austin Peak 8-Hour Ozone (ppb)	Peak Temperature (F)	Resultant Mean 6 a.m. – 2 p.m. Wind Speed (mph)	Morning Wind Direction	Afternoon Wind Direction
7/07/95	44	97	1.6	W	S
7/08/95	73	99	1.4	W	SE
7/09/95	81	98	2.0	W	SE
7/10/95	90	101	2.2	W	SE
7/11/95	89	102	2.5	SW	S
7/12/95	76	102	1.6	W	SE

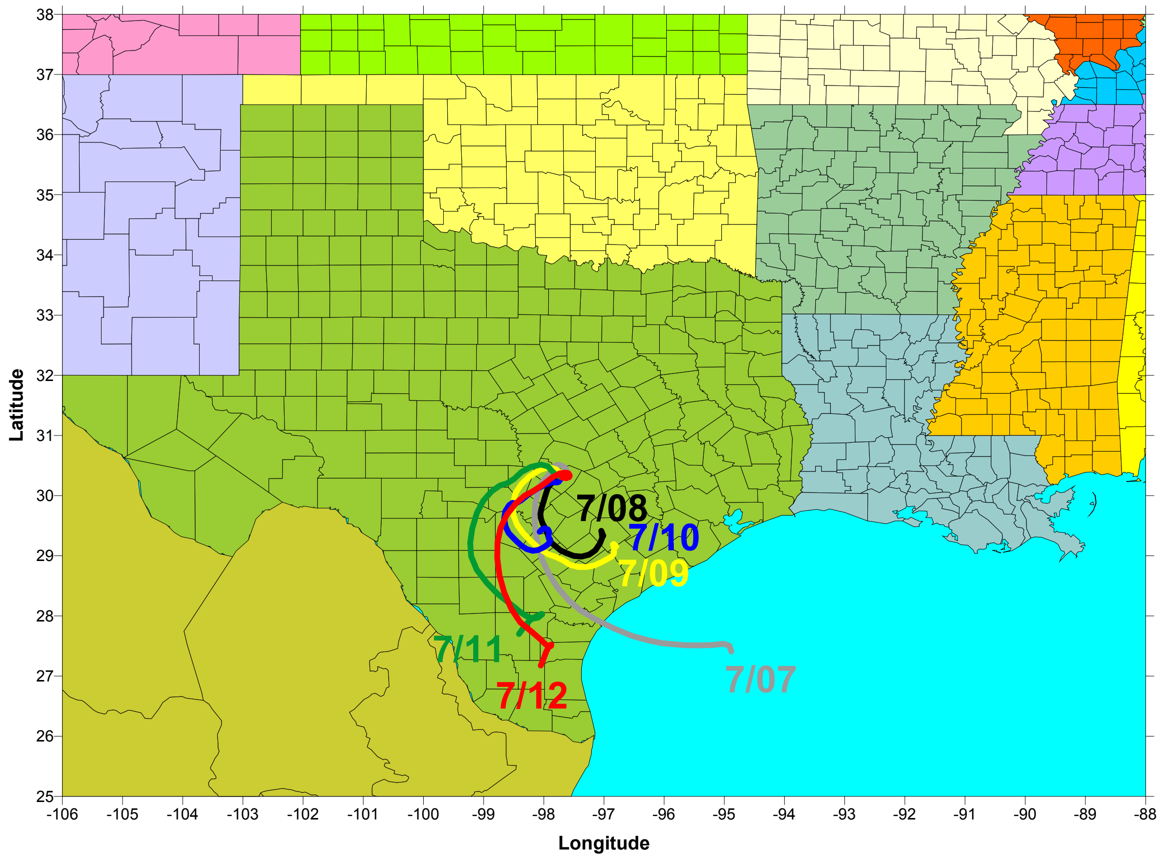

Figure 8-1. 32-Hour Back-Trajectories for July 7, 1995 through July 12, 1995. (Starting height is 500 meters above the ground surface.)

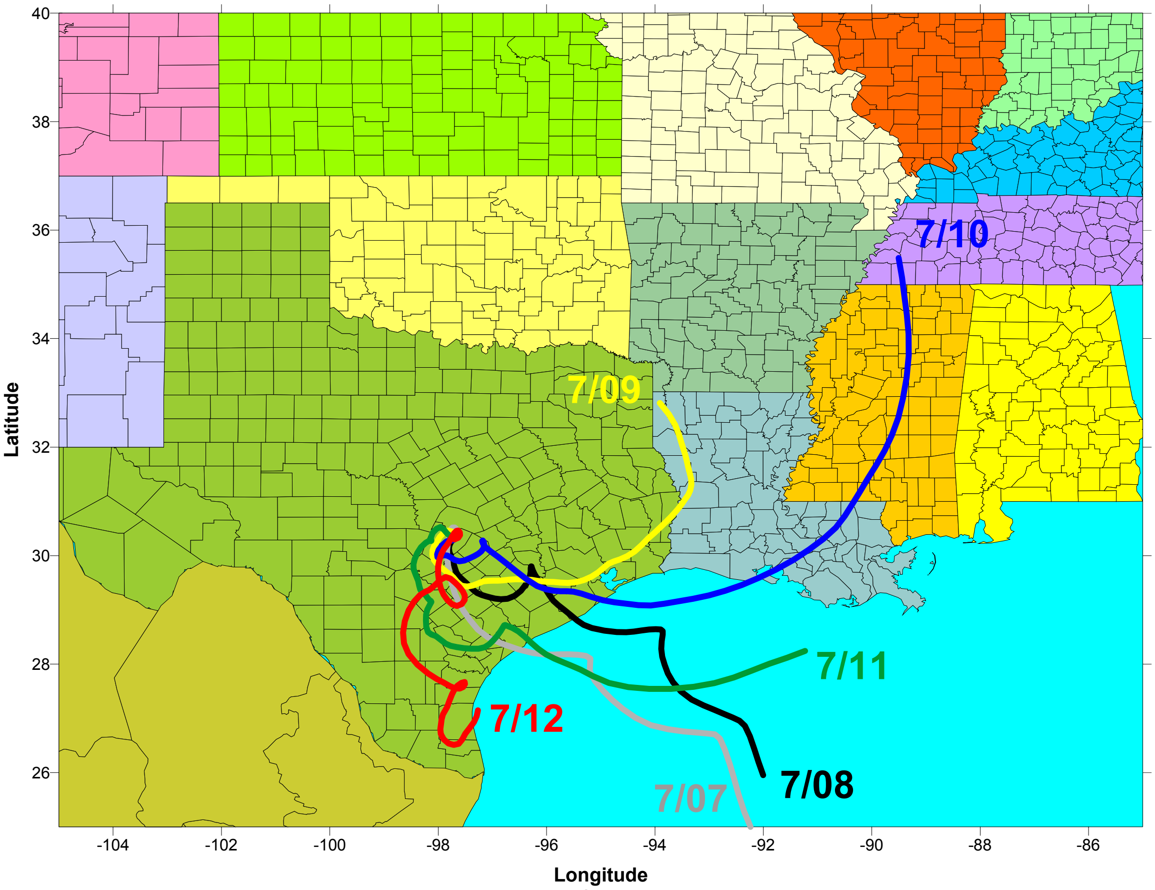

Figure 8-1. 72-Hour Back-Trajectories for July 7, 1995 through July 12, 1995. (Starting height is 1 km above the ground surface.)

8.1.2 Comparison of the July 7-12, 1995 Episode with the Conceptual Model

Based on the conceptual model, the historical frequency of occurrence of high ozone days in July is low. The year 1995 was characterized by a persistent large-scale stagnant weather pattern across the eastern and southeastern U.S., which was associated with atypically high ozone across much of the country. The local meteorological surface observations during the July 7-12, 1995 episode suggest conditions of extreme stagnation in the lower atmosphere compared to historical high ozone episodes in Austin. The daily peak temperatures are almost ten degrees warmer than the average for all high ozone days and the surface winds remained essentially calm. Typically, wind speeds are relatively higher during the initial days of a multi-day high ozone episode. The westerly component to the morning wind direction during the July 7-12, 1995 episode is often observed during historical high ozone episodes; however, afternoon winds tend to have a northerly and/or easterly component during the initial days, in contrast to the observed southerly component to the afternoon winds throughout the July episode.

The large-scale circulation features that were observed during the July 7-12, 1995 episode included strong high pressure over Texas at the surface and upper levels. These large-scale circulation features are commonly observed during historical multi-day high ozone episodes. Although the winds at the surface were southerly throughout the July episode, the long-range flow represented by the 72-hour back-trajectories indicates potential transport of continental air from the northeast and east into Texas on the 9^{th}, 10^{th}, and 11^{th}. The conceptual model suggests that regional transport of ozone into the Austin area is often significant during multi-day high ozone episodes. High ozone episodes often begin with 32-hour back-trajectories that indicate northerly or northeasterly transport of continental air into Texas following the passage of a cold front. As the episode continues, the back-trajectories indicate easterly flow, then southerly return flow from the Gulf of Mexico on the final days, likely in response to the eastward movement of the surface ridge of high pressure over Texas. This progression in the direction of 32-hour back-trajectories was not observed during the July 7-12, 1995 episode; however, the progression was noted to some extent by the 72-hour back-trajectories.

The strong high pressure at the surface and upper levels, combined with observed calm winds and very warm temperatures throughout the episode, suggest extremely stagnant atmospheric conditions. Although observations of mixing heights over Central Texas are unavailable, the stable atmospheric conditions likely limited vertical mixing and may have been associated with a relatively shallow near-surface mixed layer. However, any air mixed downward during the late morning and afternoon hours from heights near and above 1 km would be continental in origin given the clockwise flow demonstrated by the 72-hour back-trajectories. This suggests that continental air from outside of Texas may have been mixed to the surface from heights of 1 km; however, the impact of regional transport during this episode is difficult to quantify.

8.1.3 Conclusion

In summary, the observed calm winds, warm temperatures, and high pressure at the surface and upper levels over Texas during the July 7-12, 1995 period suggest conditions of regional stagnation that favor the accumulation and formation of ozone near the surface. These conditions are often observed on high ozone days in Texas; however, the large-scale weather pattern during the period does not conform to the conceptual model described in this report. A majority of multi-day high ozone episodes observed in Austin begin with the passage of a cold front through Texas. These multi-day episodes are typically characterized by initial 32-hour back-trajectories that indicate northerly and northeasterly transport of continental air into Texas, followed by easterly and southerly flow during subsequent episode days. The July 7-12, 1995 high ozone episode did not begin with the passage of a cold front through Texas, and the progression of long-range transport directions from northerly/northeasterly to southeasterly/southerly on subsequent days was not observed. The July 7-12, 1995 period was characterized by 32-hour back-trajectories and surface observations that indicated southerly winds near the surface throughout the episode. In addition, the conceptual model emphasizes the potential importance of regional transport of ozone and its precursor compounds into the Austin area. The importance of regional transport during the July 7-12, 1995 period is unclear.

8.2 Photochemical Modeling for Austin’s Early Action Compact

The ozone conceptual model for Austin was used as a basis for the selection of an additional high ozone episode for photochemical modeling in 2001. Austin collaborated with San Antonio, Victoria, Corpus Christi, and the TCEQ to develop a photochemical model for the September 13-20, 1999 period. The areas worked jointly for two years to improve this photochemical model, which is now being used for the Early Action Compacts for Austin and San Antonio.

As discussed in Section 6, the September 15-20, 1999 high ozone episode is an ideal example of the conceptual model developed in this report. For the purposes of review, a brief summary is presented here;

however the reader is referred to Section 6.0 of this report for a complete discussion of the large-scale weather patterns and associated local meteorological conditions that occurred during this multi-day high ozone event.

The September 15-20, 1999 high ozone episode occurred during the August through early October period, which is characterized by the greatest frequency of high ozone days in Austin based on historical data. High ozone levels were measured throughout eastern Texas on each day of the episode, and Austin measured peak 8-hour concentrations of 85 ppb or greater on five consecutive days. As for a majority of multi-day high ozone episodes, the episode began with the passage of a cold front on September 13th. The surface ridge of high pressure that moved southward behind the front was initially associated with long-range transport of continental air into Texas from the northeast and east. As high pressure continued to build over Texas, light wind speeds, warm temperatures, and clear skies prevailed over the state. Subsidence (sinking air) associated with the high pressure ridge likely inhibited vertical motions and depressed mixing heights, trapping pollutants in a shallow layer near the surface. Similar to most multi-day high ozone episodes reviewed in this report, the September 13-20, 1999 period was likely characterized by substantial levels of regional transport of ozone into the Austin area based on the prevailing wind directions and peak ozone measurements at rural monitoring stations. As the surface ridge of high pressure moved eastward after the 18th, the long-range trajectories indicated flow into the Austin area from the southeast and south on the final days of the episode. This progression of transport directions from northerly/northeasterly through southeasterly/southerly is often observed during multi-day high ozone events in Texas, and is associated with the clockwise flow around an eastward moving center or ridge of high pressure in the lower atmosphere.

8.3 Comparison of Modeled Episodes to EAC Guidance

The July 7-12, 1995 and the September 13-20, 1999 episodes are currently the only photochemical models available for air quality applications in Austin. In the following section, these episodes are compared to the

EPA guidance for demonstrations of the 8-hour NAAQS as outlined for areas submitting EACs. Recommendations for an additional episode are provided as well.

The U.S. EPA's *Draft Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS* (1999) is the principal guidance document for areas submitting EACs. The guidance specifies four primary criteria for selecting high ozone episodes for photochemical modeling:

1. "Choose a mix of episodes which represent a variety of meteorological conditions which frequently correspond with 8-hour daily maxima > 84 ppb at different monitoring sites.
2. Model periods in which observed 8-hour daily maximum concentrations are close to the average 4^{th} high 8-hour daily maximum concentrations.
3. Model periods for which extensive air quality and meteorological databases exist.
4. Model a sufficient number of days so that the modeled attainment test applied at each monitor violating the NAAQS is based on several days."

The guidance also indicates that tradeoffs among the four primary criteria may be necessary. In addition, the U.S. EPA's *Protocol for Early Action Compacts* (2003) specifies that "a 1999 or later episode reflective of a typical ozone season exceedance that meets the U.S. EPA's episode selection guidance to ensure that representative meteorological regimes are considered" must be included.

8.3.1 July 7-12, 1995 Episode

The characteristics of the July 7-12, 1995 episode are evaluated according to the four primary EAC criteria as follows:

1. The episode spans one synoptic cycle for ozone in the Austin area and is characterized by a subset of meteorological conditions that are frequently associated with 8-hour daily maxima greater than 84 ppb. There are two initialization days and four high ozone days.

2. As summarized in Table 8.1, the daily peak ozone concentrations at Murchison on the four episode days were 81 ppb, 90 ppb, 89 ppb and 76 ppb with an average of 84 ppb. These values compare favorably with the fourth highest concentrations shown in Table 8.2 that range from 75 ppb to 91 ppb with an average of 84.4 ppb. Monitoring at the Audubon monitoring location did not begin until 1997.
3. There are no extensive air quality and meteorological databases for the Austin area.
4. Based on the monitored values the attainment test could be applied for four days.

The July 7-12, 1995 episode meets the EPA guidance for demonstrations for the 8-hour ozone NAAQS.

Table 8.2. Fourth Highest Daily 8-Hour Ozone Concentrations and design values for the Murchison and Audubon Monitoring Sites for each year between 1997 and 2003.

	Murchison		Audubon	
	4th highest concentration (ppb)	Design Value (ppb)	4th highest concentration (ppb)	Design Value (ppb)
1997	75		87	
1998	88	83	81	89
1999	87	87	99	89
2000	88	84	88	88
2001	78	85	80	82
2002	91	84	81	80
2003	84		81	
Average	84.4	84.6	85.3	85.6

8.3.2 September 13-20, 1999 Episode

The Austin, San Antonio, Corpus Christi, and Victoria areas, along with the TCEQ, combined their resources for development of a new episode that focused specifically on conditions associated with high ozone in Central Texas and that was not leveraged from other areas, such as Houston and Dallas. The September 13-20, 1999 photochemical modeling episode fulfills both the requirements of the U.S. EPA draft guidance and the protocol for representation of meteorological regimes typical of ozone exceedances. The episode is an ideal example of the multi-day high ozone episodes described in the conceptual model. The characteristics of the episode are evaluated according to the four primary EAC criteria as follows:

1. The episode spans one synoptic cycle for ozone in the Austin area and is characterized by a variety of meteorological conditions that frequently correspond to 8-hour daily maxima greater than 84 ppb. There are two initialization days and five high ozone days in Austin, but six high ozone days in other metropolitan areas in eastern Texas. The episode includes two weekend days (September 18th and 19th), so control strategies can be evaluated on different days of the week. An important consideration in selecting this episode was that high ozone concentrations were observed throughout Central Texas, which had not necessarily been the case for previous photochemical modeling episodes.
2. The daily peak 8-hour ozone concentrations at Murchison on the six high ozone days were 68 ppb, 69 ppb, 89 ppb, 87 ppb, 91 ppb and 87 ppb with an average of 81.8 ppb. These values are comparable with the fourth highest concentrations shown in Table 8.2 that range from 76 ppb to 91 ppb with an average of 84.4 ppb. The daily peak 8-hour ozone concentrations at Audubon on the six high ozone days were 78 ppb, 85 ppb, 99 ppb, 99 ppb, 101 ppb and 75 ppb with an average of 89.5 ppb. These values compare favorably with the fourth highest concentrations shown in Table 8.2 that range from 80 ppb to 99 ppb with an average of 85.3 ppb.
3. There are no extensive air quality and meteorological databases for the Austin area.
4. Based on the monitored values, the attainment test could be applied for four days at the Murchison monitor and for six days at the Audubon monitor.

8.4 Additional Episodes for Photochemical Modeling

Criteria for selection of an additional episode for photochemical modeling were evaluated according to the following criteria:

a. EPA guidance for demonstrations for the 8-hour ozone NAAQS and EAC requirements must be met.

b. None of the previous episodes were developed for time periods that were consistent with the third EPA criteria, which requires the existence of extensive air quality and meteorological databases. If possible an additional episode should be developed based on extensive databases.

c. Occurrence after 1999.

d. The additional episode should be characterized by meteorological conditions that complement the conditions that occurred during the July 1995 and Sept 1999 episodes.

8.4.1 May 28-31, 2003

The characteristics of the May 28-31, 2003 episode are evaluated according to the four criteria as follows:

a. The May 28-31, 2003 episode meets the EPA guidance for demonstrations for the 8-hour ozone NAAQS.

   1. The episode spans one synoptic cycle for ozone in the Austin area and it covers a variety of meteorological conditions that frequently correspond to 8-hour daily maxima greater than 84 ppb. There are two initialization days, four episode days with one high ozone day in Austin.

   2. The daily peak 8-hour ozone concentrations at Murchison were 77 ppb, 77 ppb, 87 ppb and 74 ppb with an average of 78.8 ppb. The concentration for the high ozone days is lower than those from the fourth highest values shown in in Table 8.2 that range from 76 ppb to 91 ppb with an average of 84.4 ppb. The daily peak 8-hour ozone concentrations at Audubon were 67 ppb, 59 ppb, 83 ppb and 71 ppb with an average of 70.0 ppb. These concentrations are lower in comparison to the fourth highest values shown in Table 8.2, which range from 80 ppb to 99 ppb with an average of 85.3 ppb.

   3. There are no extensive air quality and meteorological databases for the Austin area.

   4.Based on the monitored values, the attainment test could be applied for four days at the Murchison monitor and for two days at the Audubon monitor

b. Extensive air quality and meteorological databases do not exist.

c. This is a recent episode that includes the period used to designate nonattainment areas.

d. This is a spring event that occurred during the historical secondary May/June peak in frequency of occurrence of high ozone days in Austin. The initial day 32-hour back-trajectories are more northerly and the final day back-trajectories are more southerly compared to those of the conceptual model; thus, this episode complements the existing episodes.

8.4.2 Sep 1-6, 2000

The characteristics of the September 1-6, 2000 episode are evaluated according to the four criteria as follows:

a. The September 1-6, 2003 episode meets the EPA guidance for demonstrations for the 8-hour ozone NAAQS.

1. The episode spans one synoptic cycle for ozone in the Austin area and includes a variety of meteorological conditions that frequently correspond to 8-hour daily maxima greater than 84 ppb. There are two initialization days, and five episode days with four high ozone days with peak concentrations greater than or equal to 85 ppb in Austin.

2. The daily peak 8-hour ozone concentrations at Murchison were 85 ppb, 89 ppb, 84 ppb, 79 ppb and 93 ppb with an average of 86.0 ppb. These compare favorably with the fourth highest values shown in Table 8.2 that range from 76 ppb to 91 ppb with an average of 84.4 ppb. The daily peak 8-hour ozone concentrations at Audubon were 88 ppb, 87 ppb, 87 ppb, 79 ppb and 97 ppb with an average of 87.6 ppb. These compare favorably with the fourth highest values shown in Table 8.2 that range from 80 ppb to 99 ppb with an average of 85.3 ppb.

3. Extensive air quality and meteorological databases do not exist for the Austin area, however this episode occurred during the TexAQS field study so there are extensive databases for the Houston area.

4. Based on the monitored values, the attainment test could be applied for five days at the Murchison monitor and for five days at the Audubon monitor

b. Extensive air quality and meteorological databases do not exist for the Austin area, however this episode occurred during the TexAQS field study so there are extensive databases for the Houston area.

c. This is a recent episode.

d. Record maximum temperatures were recorded in the Austin area and throughout Texas during this episode, indicating extreme conditions compared to climatological normals and suggesting atypical large-scale weather patterns.

8.5 Recommendation

The development of the September 1999 episode highlighted the necessity of having data on the meteorological conditions above the surface so that model performance could be improved and evaluated. Especially critical are measurements of the wind speed and direction throughout the lower atmosphere and the hourly heights of the mixed layer in Central Texas. In addition, developing the September 1999 episode indicated the need for monitors to measure the concentrations of both ozone and its precursor compounds that are transported into the Austin area. None of these parameters have been adequately monitored in the past; however, these parameters will be monitored during the TexAQS II study to be conducted during the 2005 and 2006 period.

Since none of the episodes that occurred during the 2000 through 2003 period provide a strong rationale for photochemical modeling, it is recommended that selection of an additional episode be delayed until data from the TexAQS II study are available. Choosing an episode from the TexAQS II study would provide an additional benefit if the Austin area does not meet its goal of attaining the standard in 2007 as it may be important to model time periods for which high ozone was measured during the 2005-2007 time period for the purpose of control strategy evaluation.

9.0 References

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TNRCC, 2001. Conceptual Model for Ozone Formation in the Houston-Galveston Area.

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