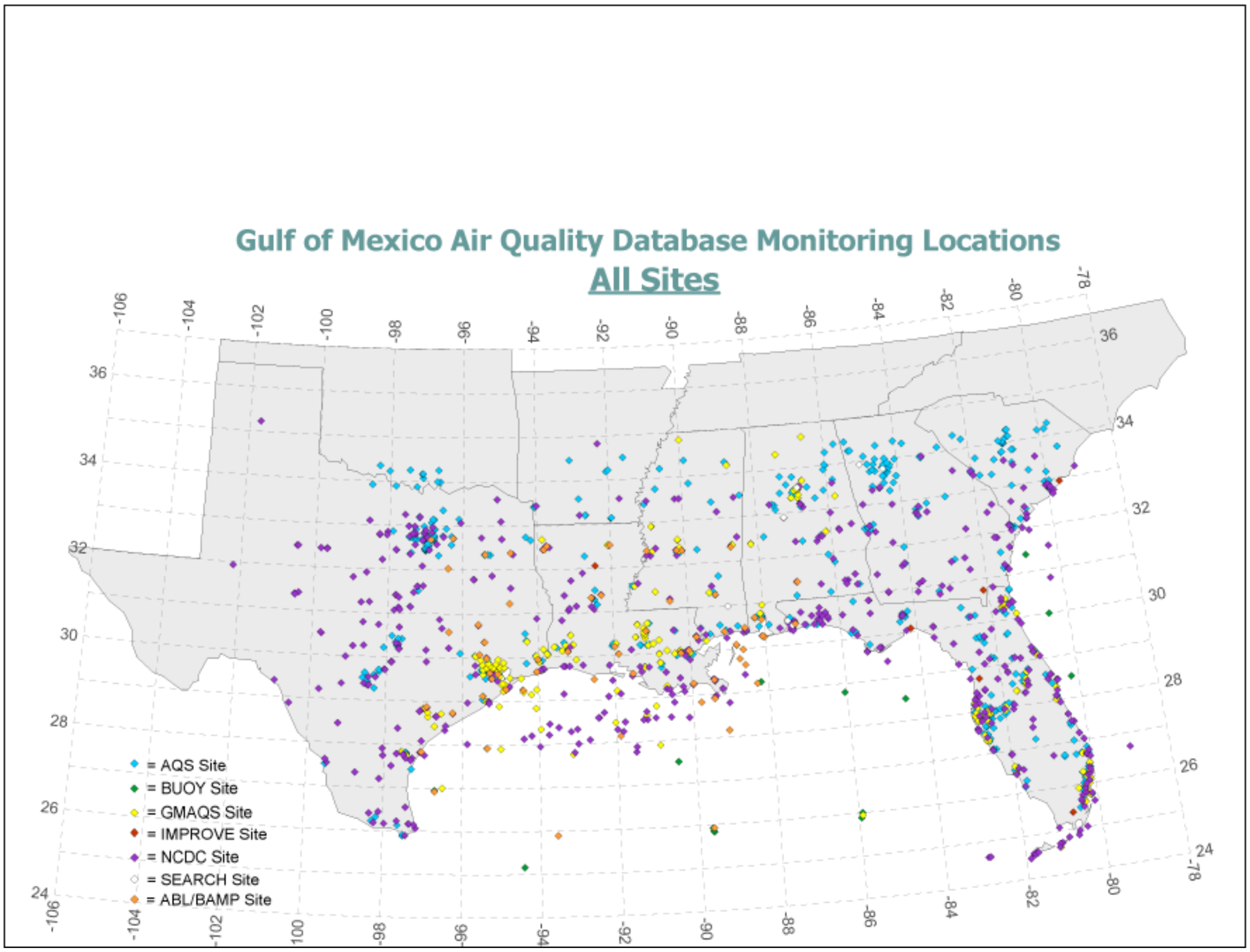
OCS Study
MMS 2009-057

Synthesis, Analysis, and Integration of Meteorological and Air Quality Data for the Gulf of Mexico Region

Volume III: Data Analysis



U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

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Synthesis, Analysis, and Integration of Meteorological and Air Quality Data for the Gulf of Mexico Region

Volume III: Data Analysis

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ABOUT THE COVER

The graphic on the cover depicts the locations of the air quality and meteorological monitoring sites that are included in the Gulf of Mexico Air Quality Database (GMAQDB) tool.

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1.0 INTRODUCTION

The Minerals Management Service (MMS), together with the oil and gas industry, have collected a variety of meteorological, air quality, and emission inventory data for the northern Gulf of Mexico (GOM) region. These data span the years 1988 to present, and have been used to support various air quality related data analysis and modeling activities. The focus of this data synthesis study was to assemble these data, as well as other data available from federal, state, and oil and gas industry studies and databases, into a coherent dataset, so that an integrated analysis of the data could be conducted. It is expected that this integrated dataset will provide the basis for an improved understanding of the relationships between meteorology, emissions, and air quality in the Gulf of Mexico region and support future regulatory data and modeling analyses related to ozone, fine particulate matter ($PM_{2.5}$) and regional haze.

The data synthesis study also included some basic analysis of the data, which was conducted in order to ensure the integrity and usability of the dataset. The analyses were also intended to provide new information about meteorological and air quality conditions in the GOM region, including the relationships between meteorology, emissions, and air quality revealed by the data. The specific goals of the data analysis task were to use the integrated dataset to 1) examine the relationships between meteorology, emissions, and air quality in the GOM region, 2) confirm and/or advance prior conceptual descriptions related to ozone, particulate matter, and regional-haze air quality issues along the Gulf Coast and in the Breton National Wilderness Area, 3) identify gaps in the data/knowledge bases, and 4) recommend future data analyses.

Two companion reports summarize the preparation and workings of the integrated dataset and associated database tool in the form of a User's Manual and Technical Reference Manual. This document presents the methods, results, and key findings from the data analysis tasks.

1.1. OVERVIEW OF THE STUDY REGION

The data synthesis study area is shown in Figure 1. It includes portions of several states as well as the Gulf of Mexico and Outer Continental Shelf (OCS) areas. The study area includes the Houston metropolitan area, the Tampa/St. Petersburg/Clearwater, Florida metropolitan area and several other moderate to small urban areas such as Baton Rouge and New Orleans in Louisiana; Gulfport, Mississippi; Mobile, Alabama; and Pensacola, Florida. The Houston, Baton Rouge, New Orleans, and Mobile areas along with Beaumont/Port Arthur, Texas, and Lake Charles, Louisiana are home to several industries including shipping, oil and gas production and refining, and chemical manufacturing. The offshore Western, Central, and Eastern OCS Planning Areas stretch west to east across more than 1,000 miles (about 1600 km) of the Gulf of Mexico from Brownsville, Texas to the Florida Keys and encompass an area that spans 200 miles (about 322 km) offshore of the coastal states. The Western Planning Area includes the offshore areas of Texas, starting 12 miles (20 km) offshore; the Central Planning Area includes offshore areas of Louisiana, Mississippi, and Alabama, starting 3 miles (5 km) offshore; and the Eastern Planning Area includes the area offshore of Florida, starting 12 miles (20 km) offshore.

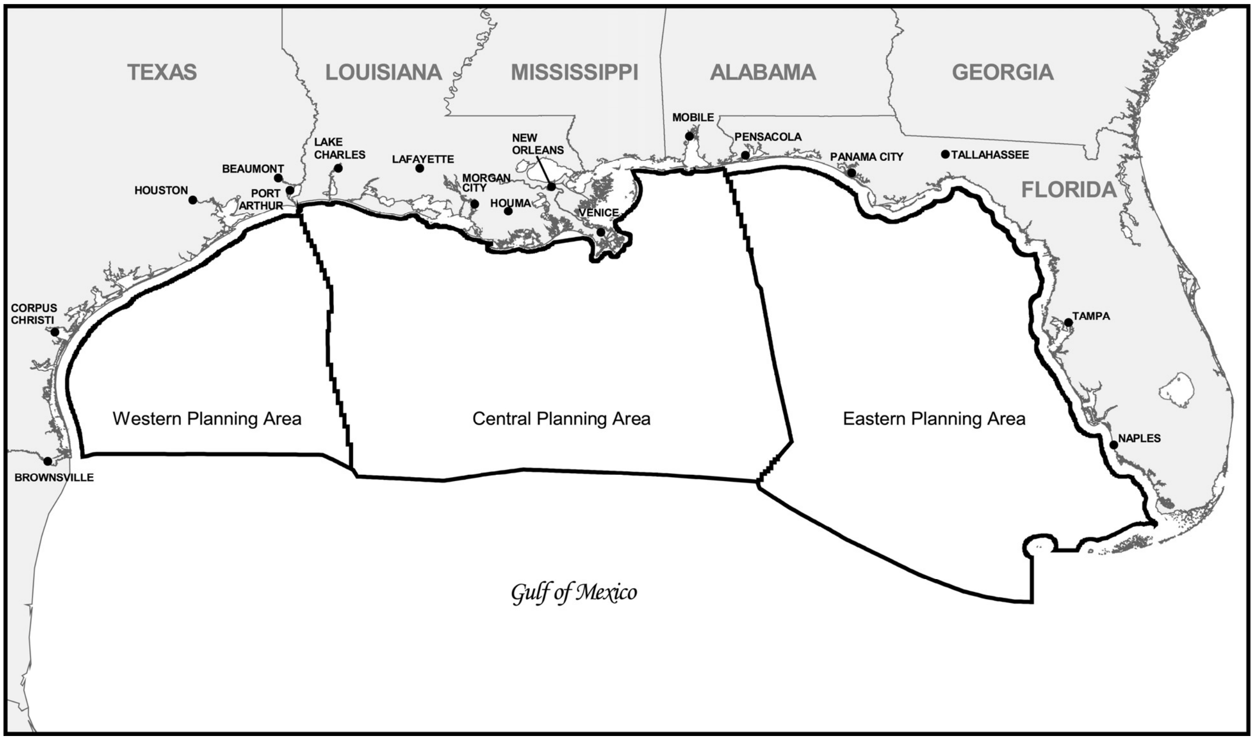
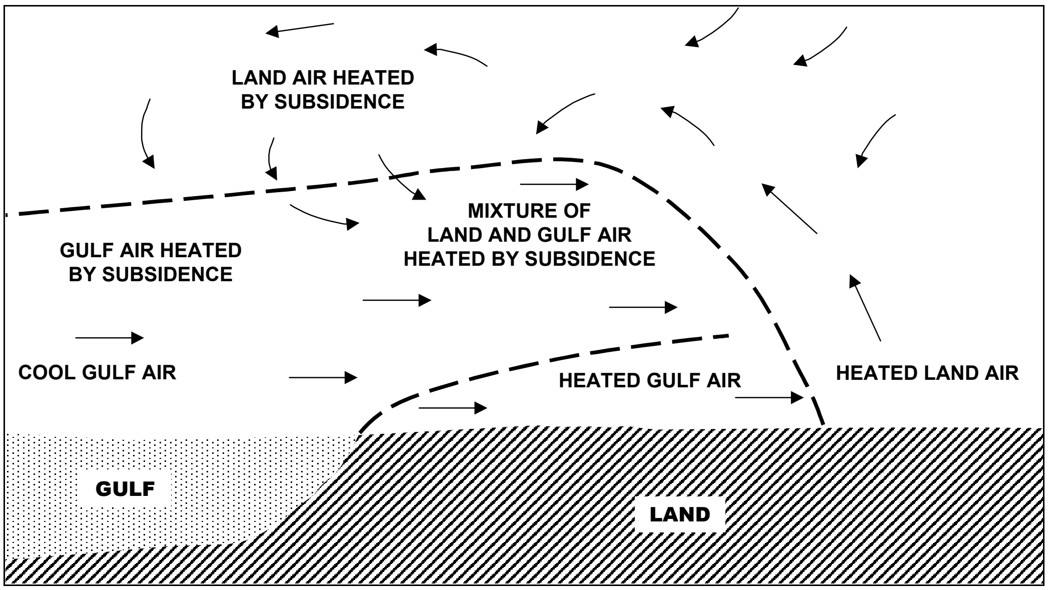


Figure 1. MMS data synthesis study area.

Geographically, the region is quite diverse. For this study we are most interested in the coastal areas, since they are most likely to be influence by emissions from offshore oil and gas activities in the GOM. Many of the coastal areas have geographic similarities with respect to proximity to the Gulf of Mexico, but have differences due to location, the contours of the coastline, and the presence of islands, bays, and inland waterways. Slightly inland from the coast, the New Orleans and Baton Rouge areas are influenced by the Mississippi River and associated wetlands/delta regions and Lake Ponchartrain. All of the areas also have different emissions sources and distributions.

The region is generally characterized by a warm, humid (subtropical) climate with moderate rainfall (on the order of 50 to 60 inches per year). The area is subject to hurricane activity. Researchers at Louisiana State University (LSU) (Muller, 1977; Hsu and Blanchard, 2000) have identified several types of regional scale meteorological conditions that prevail in the GOM region. Although these analyses were conducted specifically for Louisiana, it follows that there is a range of different weather conditions that affect the region. The influence of these weather systems is complicated by geography, resulting in differences in the local meteorological conditions along the Gulf Coast.

A meteorological feature that occurs along the coastal areas of Texas, Mississippi, Alabama, and Florida is the "gulf breeze." This meteorological circulation system develops in coastal areas as a result of differential heating of the land and water surfaces (due primarily to differences in specific heat, thermal conductivity, and reflectivity of these surfaces). During the daytime hours the air temperature above the land surface is typically higher than that over the water surface (land surfaces heat up faster than water). During the nighttime hours the air temperature above the water surface is typically higher than that over the land surface (the land surface cools faster than the water surface). These temperature differences set in motion a circulation system that tends to cause the air nearest the surface to move offshore during the nighttime hours and onshore during the daytime hours. Figure 2 illustrates the concept of a gulf-breeze circulation system during the daytime hours.



Source: Munn (1966)

Figure 2. Schematic diagram depicting a daytime gulf-breeze circulation system.

The development and characteristics of a gulf breeze can be influenced by many factors, such as prevailing regional-scale wind direction, temperature variations, and the shape of the coastline. A gulf breeze is generally characterized in terms of timing (time of onset), strength (associated wind speeds), and inland extent (distance inland over which its influence is apparent). The gulf breeze circulation is important to air quality because it provides a mechanism for the recirculation of pollutants. By this we mean that primary and precursor emissions and secondary pollutants may be carried offshore by the offshore-directed flow (either near the surface during the nighttime hours or as part of a daytime return flow aloft). Due to low vertical mixing (as a result of cooler temperatures) and relatively lower deposition rates over the water, pollutants may build up or pool over the water surface. With the onset of the gulf breeze, the pollutants may then be carried onshore. Hsu (1988) estimates that a well developed gulf breeze circulation (in this example, along the Texas gulf coast) may extend 20 km offshore and as much as 30 to 40 km inland. A detailed description and example of the gulf-breeze circulation system for the upper Texas coast is provided by Hsu (1988, pp. 140-147).

The gulf breeze is not expected to occur along much of the coast of Louisiana. The land/water boundary that represents the coastline of Louisiana is less well defined than that for the other states due to the numerous wetlands/bayous in the southern portion of the state. The wetland ecosystem mitigates the development of a sharp contrast in temperature between the land and water surfaces and, thus, the gulf breeze is less likely to develop here.

In summary, the GOM region is quite varied in terms of geography (primarily due to the shape and complexity of the coastline) and is characterized by a variety of regional and local meteorological conditions.

1.2. Emissions Characteristics of the GOM Region

Emissions influencing air quality in the GOM region originate from a variety of anthropogenic, biogenic, and geogenic sources located in both onshore and offshore areas of the region. The coastal areas of the GOM, in an arc from the southern tip of Texas to southern Florida, include the large urban area of Houston/Galveston, Texas; several mid-size urban areas including New Orleans and Baton Rouge in Louisiana, and Tampa/St. Petersburg/Clearwater in Florida; as well as a number of smaller cities (e.g. Brownsville, Beaumont/Port Arthur, Lake Charles, Gulfport, Biloxi, Mobile, Pensacola, Panama City, and Tallahassee). Currently, oil and gas development activities are only occurring offshore in coastal state waters of Texas, Louisiana, Mississippi, and Alabama, and in the Western and Central OCS Planning areas of the GOM, while commercial shipping, recreational boating, fishing, military, and other activities occur offshore throughout the Gulf of Mexico.

1.2.1. Onshore Emissions for the Coastal Areas of the GOM

The coastal onshore areas include population-based sources of oxides of nitrogen (NO_x), volatile organic compounds (VOC), sulfur dioxide (SO_2), carbon monoxide (CO) and fine particulate matter ($PM_{2.5}$) emissions from a variety of mobile, area, and non-road sources. Transportation-related sources make up a large percentage of the onshore emission inventory in the major metropolitan areas, at the coastal ports, and along the Interstate highway system (I-10, I-12, I-45, I-55, and I-59) and other transportation/freight movement highway and railway corridors that service the ports and cities. In addition, emissions from industrial point sources associated with the petroleum refining, petrochemical, and gas productions industries, located primarily in Texas and Louisiana, and from electric power generation and other industries situated across the coastal region, add to the daily mix of ozone and PM precursor emissions that influence the air quality of both the onshore and offshore areas of the GOM.

Figure 3a provides anthropogenic emissions totals for 2005 for the Houston, Beaumont/Port Arthur, Lake Charles, Baton Rouge, New Orleans, Gulfport, Mobile, Pensacola and Panama City areas combined for NO_x, VOC, SO_2, CO, and $PM_{2.5.}$ These totals were derived from EPA's latest 2005 National Emission Inventory (NEI) (version 1) (EPA, 2005). In addition to anthropogenic emissions, there are large-scale contributions of VOC emissions from biogenic sources including forests, wetlands, crops, and other vegetation in the coastal areas. The biogenic VOC emissions are much larger than the anthropogenic VOC emissions. In some areas, for example, nearly 80 percent of the total VOC emissions are from biogenic sources.

1.2.2. Offshore Emissions of the GOM Area

The offshore areas of the GOM contain a variety of anthropogenic oil and gas development related sources and other sources associated with commercial marine vessels, shipping, recreational boating, military, and fishing operations. There are also small contributions to VOC emissions from offshore biogenic and geogenic sources such as bacterial processes, mud volcanoes, and crude oil seeps. The oil and gas related sources include stationary platform sources associated with drilling, pumping and production, and non-stationary sources associated with exploration, pipe-laying, lightering, crew/supply boats and support helicopters. In 2005, prior to the hurricane season, there were over 3500 active platforms operating in the Western and Central OCS Planning Areas of the GOM. For a comparison with the coastal onshore emissions,

Figure 3b presents total NO_x, VOC, SO_2, CO, and $PM_{2.5}$ emissions for all offshore categories. These emissions are included in the most recent Gulfwide Emission Inventory (GWEI) for 2005. The GWEI covers the offshore planning areas shown in Figure 1. The offshore NO_x emissions are about 50 percent of the total emissions for the onshore areas depicted above. The offshore emissions of the other species are very small (less than 10 percent) compared to the onshore emission totals for these areas. Approximately one fourth of the offshore NO_x emissions are from stationary platform sources, and the remainder are from non-stationary sources.

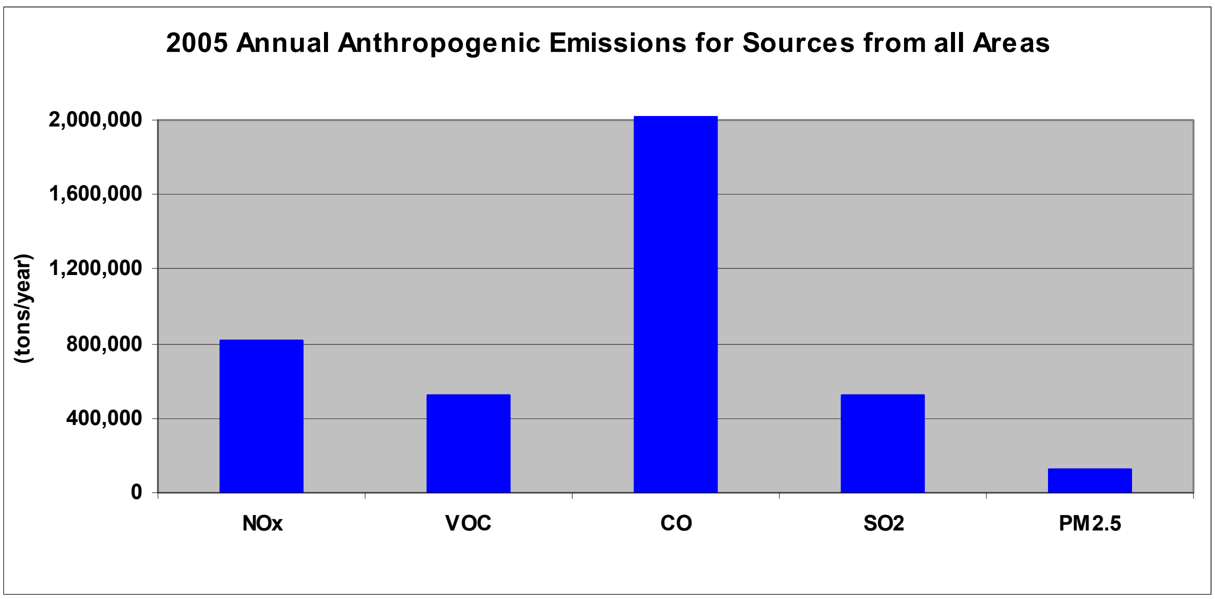


Figure 3a. Total anthropogenic emissions for the 2005 NEI for the coastal cities of the Gulf of Mexico region (Houston to Panama City).

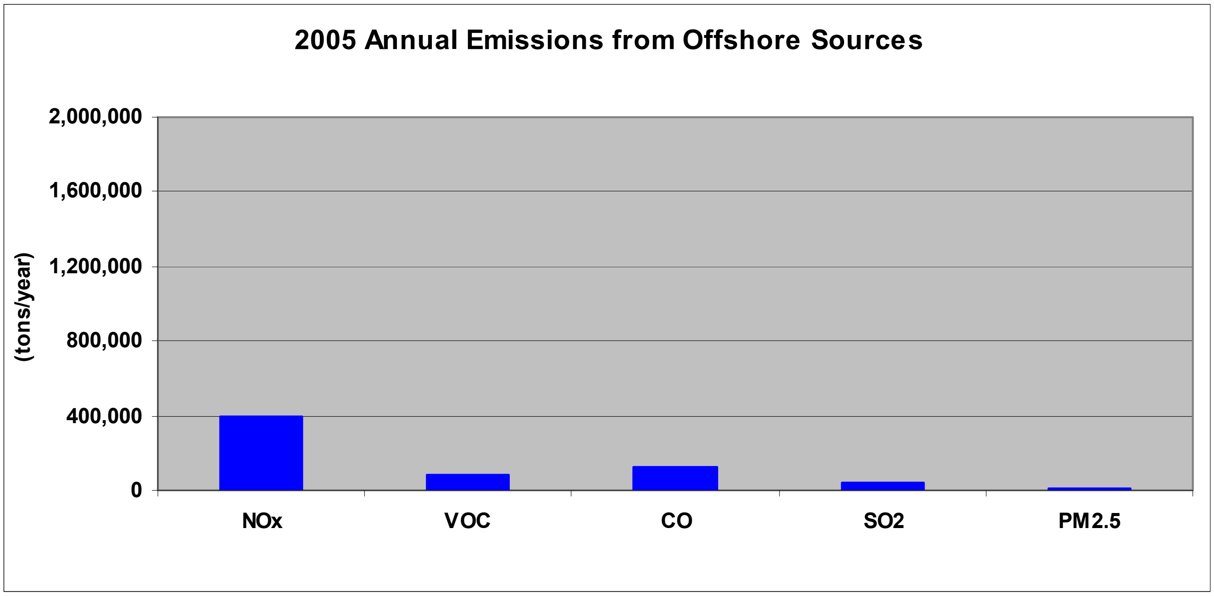


Figure 3b. Total emissions for the 2005 GWEI for the offshore areas of the Gulf of Mexico.

1.3. Current Air Quality Issues for the GOM Region

Geographical, meteorological and emissions characteristics affect the air quality of the GOM region and likely contribute to a variety of air quality issues. These issues affect the entire region but are especially pronounced in the coastal urban and industrial areas of Texas and Louisiana (Houston/Galveston, Beaumont/Port Arthur, Lake Charles, Baton Rouge). Ozone is an air quality concern for most (monitored) areas along the Gulf Coast. $PM_{2.5}$ concentrations tend to be relatively low along the Gulf Coast (e.g., compared to national standards), but some high values have been observed recently in the Houston area. Visibility (while generally good) is an important metric for the Class I areas (in the region).

1.3.1. 8-Hour Ozone

Ozone is a secondary pollutant that is not directly emitted into the atmosphere but instead is formed in the lower atmosphere by a series of reactions involving ultra violet (UV) radiation and precursor emissions of NO_x and VOC. NO_x consists of nitric oxide (NO) and nitrogen dioxide (NO_2), which are primarily emitted from anthropogenic sources. VOC consist of thousands of individual hydrocarbon and oxygenated hydrocarbon species emitted from anthropogenic, biogenic, and geogenic sources. Ozone formation in the troposphere is affected by local weather conditions: winds, temperature, solar radiation, and horizontal and vertical dispersion characteristics, which influence precursor concentrations, reaction rates, formation, transport, and deposition. Because the primary ozone-forming reaction is photochemically driven (i.e., by the sun), ozone concentrations typically peak during the daylight hours and then decrease after sunset.

Health effects studies have determined that exposure to ozone can reduce lung function and increase the incidence and severity of respiratory illnesses such as asthma. Repeated exposure to ozone may also damage vegetation and trees. To protect public health, the U.S. Environmental Protection Agency (EPA) established the first National Ambient Air Quality Standard (NAAQS) for ozone in 1971 and has since revised the level and form of the standard several times. The most recent revision occurred in March 2008 and set the 8-hour ozone standard to 75 parts per billion (ppb). To attain this standard, the three-year average of the annual fourth highest daily maximum 8-hour ozone concentration at all sites within a designated area must be less than 75 ppb. The three-year average or "design value" is calculated for each site and then the maximum value over all sites within an area determines the design value for the area. Initial compliance with the new standard is scheduled to be determined using data collected during the period 2006-2008.

To provide perspective on the current 8-hour ozone issues in the GOM region and recent trends, Table 1 lists the maximum 8-hour ozone design values (calculated as indicated above) for sites within selected counties and parishes of interest for the three consecutive three-year periods ending in 2005 through 2007.

Table 1

8-Hour Ozone Design Values (ppb) for the Three Consecutive Three-Year Periods Ending in 2005 through 2007 for Selected Areas Along the Gulf Coast. Compliance with the 8-Hour Ozone NAAQS Requires the Design Value to be Less than or Equal to 75 ppb.

Area (Counties/Parishes)	**2003-2005 8-Hour Ozone Design Value (ppb)**	**2004-2006 8-Hour Ozone Design Value (ppb)**	**2005-2007 8-Hour Ozone Design Value (ppb)**
Houston/Galveston (Harris and Galveston Counties, TX)	103	103	96
Beaumont/Port Arthur (Jefferson and Orange Counties, TX)	88	85	83
Lake Charles (Calcasieu Parish, LA)	83	82	81
Lafayette (Lafayette Parish, LA)	82	82	81
New Orleans (Jefferson, Orleans, St. Charles, and St. Bernard Parishes, LA)	84	82	83
Baton Rouge (East Baton Rouge, West Baton Rouge, Ascension, Iberville, and Livingston Parishes, LA)	96	91	89
Gulfport (Harrison County, MS)	83	83	83
Pascagoula (Jackson County, MS)	81	80	88
Mobile (Mobile and Baldwin Counties, AL)	77	78	78
Pensacola (Escambia and Santa Rosa Counties, FL)	83	83	82
Panama City (Bay County, FL)	81	78	77
Tampa (Hillsborough, Pasco, Pinellas, Polk, Manatee and Sarasota Counties, FL)	81	80	81

The calculated design values for the most recent periods are above the 8-hour standard for all areas. With the exception of Pascagoula, the design values either decrease with time or stay about the same for these most recent three-year periods.

1.3.2. $PM_{2.5}$

The recent emphasis on $PM_{2.5}$ as an air pollutant of concern is based primarily on epidemiological studies that have indicated a cause and effect relationship between exposure to fine particles and health effects, including respiratory and cardiovascular disease and premature mortality. Particulates are also a primary constituent of regional haze, which limits visibility and the attainment of visibility goals, and ultimately diminishes the natural beauty of the environment.

Fine particulates in the atmosphere consist of primary particles that are emitted directly from sources and secondary particles that form in the atmosphere through chemical and physical processes. Pollutants that contribute to the formation of secondary aerosols include SO_2, NO_x, and ammonia (NH_3). Natural sources of fine particulates and precursor pollutants include organic aerosols from vegetation, wind blown dust, sea salt, and forest fires. Anthropogenic contributors include numerous agricultural, mobile, and industrial sources. Meteorology plays an important role in particulate formation and transport and in determination of the ambient particulate concentration levels.

The U.S. EPA established new standards for fine particulate matter in 1997, and subsequently revised the 24-hour standard in 2006. Under these standards, fine particles are defined as those with a diameter of less than 2.5 microns; particles of this size are also referred to as $PM_{2.5}$. The annual $PM_{2.5}$ NAAQS requires the three-year average annual mean concentration to be less than 15 micrograms per cubic meter (μgm^{-3}). The daily $PM_{2.5}$ standard requires the three-year average of the 98^{th} percentile daily average concentration to be less than 35 μgm^{-3}. The averages or "design values" are calculated for each site and then the maximum value over all sites within an area is the design value for the area. Affected states were required to submit (by April 2008) a State Implementation Plan (SIP) demonstrating attainment of the annual $PM_{2.5}$ standard by April 2010.

Table 2 lists the annual and 24-hr $PM_{2.5}$ design values for selected areas of interest in the GOM region for the consecutive three-year periods ending in 2005 through 2007. "INC" indicates incomplete data for calculation of one or more of the design values.

Table 2a

Annual $PM_{2.5}$ Design Values (μgm^{-3}) for the Three Consecutive Three-Year Periods Ending in 2005 through 2007 for Selected Areas along the Gulf Coast. Compliance with the Annual $PM_{2.5}$ NAAQS Requires the Design Value to Be Less than or Equal to 15 μgm^{-3}.

Area (Counties/Parishes)	**2003-2005 Annual PM2.5 Design Value (μgm^{-3})**	**2004-2006 Annual PM2.5 Design Value (μgm^{-3})**	**2005-2007 Annual PM2.5 Design Value (μgm^{-3})**
Houston/Galveston (Harris and Galveston Counties, TX)	15.0	15.4	15.8
Beaumont/Port Arthur (Jefferson and Orange Counties, TX)	11.7	11.5	11.3
Lake Charles (Calcasieu Parish, LA)	11.2	11.1	10.9
Lafayette (Lafayette Parish, LA)	11.2	11.0	11.0
New Orleans (Jefferson, Orleans, St. Charles, and St. Bernard Parishes, LA)	11.4	11.7	11.4
Baton Rouge (East Baton Rouge, West Baton Rouge, Ascension, Iberville, and Livingston Parishes, LA)	13.2	13.6	13.7
Gulfport (Harrison County, MS)	12.3	12.3	12.0
Pascagoula (Jackson, MS)	12.2	12.1	11.8
Mobile (Mobile and Baldwin Counties, AL)	12.9	12.5	12.3
Pensacola (Escambia and Santa Rosa Counties, FL)	11.8	11.9	11.5
Panama City (Bay County, FL)	11.3	13.5	11.4
Tampa (Hillsborough, Pasco, Pinellas, Polk, Manatee and Sarasota Counties, FL)	11.0	10.8	10.4

Table 2b

24-Hour $PM_{2.5}$ Design Values (μgm^{-3}) for the Three Consecutive Three-Year Periods Ending in 2005 through 2007 for Selected Areas Along the Gulf Coast. Compliance with the 24-Hour $PM_{2.5}$ NAAQS Requires the Design Value to be Less than or Equal to 35 μgm^{-3}.

Area (Counties/Parishes)	**2003-2005 24-Hour $PM_{2.5}$ Design Value (μgm^{-3})**	**2004-2006 24-Hour $PM_{2.5}$ Design Value (μgm^{-3})**	**2005-2007 24-Hour $PM_{2.5}$ Design Value (μgm^{-3})**
Houston/Galveston (Harris and Galveston Counties, TX)	30	31	31
Beaumont/Port Arthur (Jefferson and Orange Counties, TX)	26	28	29
Lake Charles (Calcasieu Parish, LA)	27	27	26
Lafayette (Lafayette Parish, LA)	24	24	24
New Orleans (Jefferson, Orleans, St. Charles, and St. Bernard Parishes, LA)	26	28	27
Baton Rouge (East Baton Rouge, West Baton Rouge, Ascension, Iberville, and Livingston Parishes, LA)	29	31	29
Gulfport (Harrison County, MS)	INC	INC	29
Pascagoula (Jackson, MS)	INC	INC	27
Mobile (Mobile and Baldwin Counties, AL)	30	29	27
Pensacola (Escambia and Santa Rosa Counties, FL)	31	29	27
Panama City (Bay County, FL)	29	34	27
Tampa (Hillsborough, Pasco, Pinellas, Polk, Manatee and Sarasota Counties, FL)	24	24	24

The $PM_{2.5}$ annual design values are all below the standard, with the exception of Houston. The 24-hr design values are below the standard for all sites. For most sites, the design values either decrease with time or remain about the same for the three three-year periods. For Houston (both design values) and Beaumont/Port Arthur (24-hour design value) the values increase with time.

1.3.3. Visibility

Visibility impairment or light extinction can result from the scattering and/or absorption of light by particles in the atmosphere. Fine particles from both natural and anthropogenic sources (as described in the previous section), coarse particles, and, in coastal areas, sea salt can contribute to light extinction. High humidity conditions can also contribute to light extinction and reduced visibility. Visibility is sometimes expressed in terms of deciview units, which vary approximately in proportion to the human response to visibility change. Higher deciview (DV) values correspond to poorer visibility (and a lower visual range).

In 1999, the U.S. EPA promulgated regional haze regulations to prevent "any future, and remedy any existing, impairment of visibility" at 156 designated Class I areas (national parks greater than 6000 acres and wilderness areas greater than 5000 acres). The regional haze rule calls for states to establish "reasonable progress goals" for each Class I area to improve visibility on the 20% haziest days and to prevent visibility degradation on the 20% clearest days. The national goal is to return visibility to natural background levels by 2064. Using the period 2000 to 2004 as the baseline period, states are to evaluate progress in improving visibility by 2018 and every ten years thereafter. SIPs for the first phase of the regional haze regulation were due in December 2007. Several Regional Planning Organizations (RPOs) have been developing control strategies to guide states in meeting the regional haze goals.

There are three coastal Class I areas within the GOM region. These are the Breton National Wilderness Area (NWA) in Louisiana and St. Mark's NWA and Chassahowitzka NWA in Florida. Table 3 lists the average visibility (deciviews) for the 20 percent worst visibility days for each year for the period 2000-2004. Deciviews (DV) corresponding to the 2018 goal and estimated natural conditions (the 2064 goal) are also provided. Note that the data for Breton are incomplete for 2000.

Table 3

Average Visibility for 20% Worst Days Based on 2000 through 2004 Data for Class I Areas Along the Gulf Coast.

Class I Area	2000-2004 Average Visibility for 20% Worst Days (DV)	2018 Glidepath Goal (DV)	Estimated Natural Conditions (DV)
Breton NWA	26.0	22.80	12.30
St. Mark's NWA	26.31	22.88	11.64
Chassahowitzka NWA	25.54	22.21	11.29

Table 3 indicates that improvements in visibility are needed to achieve the 2018 and natural conditions goals for all three areas. As noted above, some measures to reduce regional haze and improve visibility at these and other Class I areas may be under consideration (or being implemented), based on the work conducted by the RPOs.

1.4. Overview of the Synthesis Data Analysis and Review of Prior Studies

In this study, a variety of data analyses were conducted in order to "mine" the integrated MMS dataset in a variety of ways and thus ensure the integrity and usability of the dataset. The analyses were also intended to provide information about the air quality and meteorology of the GOM region, including the relationships between meteorology, emissions, and air quality revealed by the data. The specific goals of the data analysis were to use the integrated dataset to 1) examine the relationships between meteorology, emissions, and air quality in the GOM region, 2) confirm and/or advance prior conceptual descriptions related to ozone, particulate, and regional-haze air quality issues along the Gulf Coast and in the Breton National Wilderness Area, 3) identify gaps in the data/knowledge bases, and 4) recommend future data analyses.

The analysis consisted of several data analysis subtasks:

Data Summaries: Statistical and graphical summaries were prepared to provide an overview of the meteorological, air quality, and emissions data and highlight key features/components of the integrated dataset. Several key questions related to this task are:

- What are the key meteorological characteristics of the Gulf of Mexico region and how do these vary throughout the year? Throughout the region?
- How well do the special study periods represent the important meteorological characteristics of the Gulf of Mexico region?
- Which of the onshore areas have air quality problems, and what are the pollutants of interest for each area?
- What are the general meteorological conditions that are associated with poor air quality along the Gulf Coast?
- What is the geographical extent of the region (both onshore and offshore) from which emissions influence air quality along the Gulf Coast?
- How are the emissions distributed geographically? Among the source categories? By pollutant? Onshore versus offshore?

CART Analysis for Coastal Ozone Non-Attainment Areas: Classification and Regression Tree (CART) analysis and other data analysis techniques were used to examine the relationships between onshore and offshore meteorological conditions and ozone air quality in coastal non-attainment areas. The CART technique is described in more detail in Section 4 of this report. Key questions include:

- What are the relationships between the offshore meteorological conditions, onshore meteorological conditions, and high ozone in selected onshore areas of interest?
- Does the incorporation of offshore data change our interpretation of the CART results and our understanding of the mechanisms driving ozone formation in the areas of interest?
- What are the different types of conditions leading to high ozone within each of the areas?
- Is onshore-directed flow associated with one or more of the high ozone regimes and what is the frequency of the regime(s)?

CART Analysis for the Breton NWA: CART analysis as well as other data analysis methods was used to probe the relationships between meteorology, $PM_{2.5}$, and visibility (regional haze) at the Breton NWA. Key questions include:

- What is the role of meteorology in determining pollutant concentration levels and distinguishing between hazy and clear days for the Breton area?

- What is the potential for offshore emissions to contribute to visibility degradation at the Breton Class I area?

Air Quality Trends Analysis: Meteorologically adjusted trends for ozone, $PM_{2.5}$, and visibility were developed based on meteorological typing provided by CART analysis. Key questions include:

- How have year-to-year variations in meteorology affected observed 8-hour ozone and $PM_{2.5}$ trends in the areas of interest and what are the meteorologically adjusted trends?
- Can we distinguish the effects of meteorology versus the effects of emissions changes on 8-hour ozone and $PM_{2.5}$ air quality trends?
- Do the meteorologically adjusted trends for each area support a finding of air quality improvement?
- How well do the onshore and offshore emissions changes explain the remaining trend in air quality?

Case Study Analyses: Meteorological modeling results for selected case studies (previously prepared using the MM5 dynamic mesoscale meteorological model), were compared with special studies meteorological data. Key questions include:

- Are the existing MM5 model results consistent with the available over-water measurements of wind speed, wind direction, and other parameters?
- What are the specific areas for improvement and are there techniques that could result in future improvements in MM5 or other meteorological model performance?

Over the past many years, numerous data collection, data analysis, and modeling studies have been conducted to examine air quality issues in the GOM region. These studies were reviewed and in some cases used to guide some aspects of the data analysis. Some of the more recent studies are summarized below.

Of particular interest were several data collection and data analysis studies sponsored by the MMS and, in one case, by the offshore oil operators.

- Hsu and Blanchard (2000) collected and analyzed air quality and meteorological data for two locations (Breton NWA and Dauphin Island) during the period 1997-1998. They found that higher SO_2 occurred at both locations under conditions of northerly winds, but that higher NO_2 occurred under a range of wind directions. A key finding from their analysis was that local influences are more important than synoptic conditions (we used this finding to guide our study and to really focus on the local conditions). The authors also present methods for estimating offshore mixing heights.
- Hsu and Blanchard (2005) further investigated visibility and mixing height over the northern GOM. They found that visibility is affected by sea spray and concluded that that fog is more frequent than haze in the Breton NWA area and other areas along the Gulf Coast. Poor visibility occurs under a variety of wind directions. The authors also developed/applied air-sea interaction formulae to

examine the relationship between visibility and mixing height and found that over-water mixing height may be important in determining visibility.

- MacDonald et al. (2004) present various analyses of the data from the 1998-2001 MMS Atmospheric Boundary Layer (ABL) study. Data from the September 2000-October 2001 Breton Area Monitoring Program (BAMP), sponsored by the offshore oil and gas developers (Shannon, 1999), were also integrated into the analysis. The monitoring components of both of these studies included the collection of offshore upper-air measurements, which were designed to observe the structure of the marine boundary layer. Seasonal variations in wind speed and wind direction were observed. Mixing heights over the water were estimated to be approximately 600 meters, on average. Based on calculated trajectories, the authors concluded that, under certain observed meteorological conditions, emissions from offshore sources are advected toward coastal areas and may contribute to air quality issues in these areas.

Several modeling studies have examined the question of contribution from offshore sources to onshore ozone air quality and these studies also provided important information for this analysis.

- The Gulf of Mexico Air Quality Study (GMAQS) (Haney et al., 1995) was a comprehensive data collection, data analysis and air quality modeling study sponsored by the MMS. This study advanced the understanding of the summertime meteorology and ozone air quality of the GOM region and the development and testing of procedures for using air quality modeling tools (emission inventory development and processing, meteorological modeling, photochemical modeling) to quantitatively estimate the contribution from offshore emissions sources to ozone concentrations in the coastal areas.
- The Gulf Coast Ozone Study (GCOS) (Douglas et al., 2001 and 2005) also included the analysis of meteorological and ozone data for the GOM region. The emphasis of this study was air quality modeling to support attainment/maintenance of the 8-hour ozone standard for areas along the eastern Gulf Coast (Baton Rouge, New Orleans, coastal Mississippi, Mobile, and Pensacola). Model-based ozone and precursor tagging was used to quantify the contributions from various source regions, source categories, and specific sources to 8-hour ozone concentrations along the coast. One finding of this study was that the contribution from offshore sources is small (on the order of 1 to 2 percent of the total 8-hour ozone exceedance exposure), but varies by area and by simulation period. In this study, offshore emissions for 1993 were used although the simulation periods ranged from 1996 to 2000.
- More recently, MMS-sponsored ozone modeling studies have been conducted using the 2000 and 2005 Gulfwide Emission Inventories (GWEI). The primary objective of these studies was to assess the impacts of offshore sources on onshore ozone concentrations in light of updates to the offshore emissions inventories and the new 8-hour ozone standard. For the eastern Gulf Coast and using the 2000 GWEI, Haney and Douglas (2005) found that that the onshore impacts from all offshore oil-related sources are less than 10 ppb. For the western

Gulf Coast, also using the 2000 GWEI, Yarwood et al. (2005) found that the average impacts are on the order of 2 to 3 ppb. A recently completed study of the eastern Gulf Coast using the new 2005 GWEI showed that, with the changes/updates in offshore NO_x and VOC emissions, more ozone is produced offshore compared to the 2000 GWEI, but the onshore impacts are also less than 10 ppb for the particular ozone episode period simulated (Haney et al., 2008).

Certain of the analyses for the current study include data for the Houston/Galveston and Beaumont/Port Arthur areas in Texas. Numerous recent studies have been conducted to address air quality issues in Southeast Texas. The Texas Air Quality Study (AQS), conducted in August and September 2000, provided some new evidence of high ozone aloft and possible underestimation of VOCs in the emission inventory for the Houston/Galveston and Beaumont/Port Arthur areas (TCEQ, 2005). Remote sensing is being used to further assess and characterize the deficiencies in the emission inventories. Modeling has also been used (e.g., Czader et al. (2008)) to determine the type of VOCs that have the greatest impacts on ozone formation in this area. With the exception of the work discussed above, the available literature does not address the impacts of offshore sources. Presumably this is because of the difficulty involved in accurately characterizing the onshore urban and industrial emissions and obtaining high quality modeling. Work in this area is ongoing.

1.5. DATASETS USED FOR THIS ANALYSIS

This analysis relied on data from the MMS Gulf of Mexico Air Quality Database (GMAQDB) tool, which was prepared as part of this data synthesis study and is summarized in Volumes I and II of this report. All of the data that appear in the remainder of this report are also included in the GMAQDB. The database consists of routine and special studies data from a variety of sources. The routine data are as follows:

- EPA Air Quality System (AQS) ozone, coarse particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), speciated particulate matter, sulfur dioxide (SO_2), and carbon monoxide (CO) for coastal Texas, Louisiana, Mississippi, Alabama and Florida (1992-2004, as available).
- Interagency Monitoring of Protected Visual Environments (IMPROVE) speciated PM and visibility data for the Breton NWA and other Class I areas (2000-2004, as available).
- SouthEastern Aerosol Research and CHaracterization (SEARCH) data for Mississippi, Alabama, and Florida (2000-2004).
- National Weather Service (NWS) surface and upper-air meteorological data for coastal Texas, Louisiana, Mississippi, Alabama, and Florida (1992-2004, as available).
- Meteorological buoy data for the Gulf of Mexico (1992-2004, as available).

The AQS ozone, SO_2 and CO data and the NWS and buoy meteorological data for the period 1992 through 2004 were included in the database. The AQS PM data, the IMPROVE PM and visibility data, and the SEARCH data for the period 2000-2004 were included. This is based on data availability for the AQS PM and IMPROVE data.

The special studies datasets include the following:

- MMS Gulf of Mexico Air Quality Study (GMAQS) data (1993).
- MMS Atmospheric Boundary Layer (ABL) data (1998-2001).
- Breton Area Monitoring Program (BAMP) (2000-2001).
- Emissions data for Gulf of Mexico (2000 and 2005 Gulfwide offshore emission inventories).

2.0 DATA SUMMARIES

The objective of the data summaries task was to provide an overview of the meteorological, air quality, and emissions data and highlight key features/components of the integrated dataset. Selected data summaries are presented in this section of the report. A more complete set of data summary charts (similar to those included in this section) are available in Excel format.

2.1. METEOROLOGICAL DATA SUMMARIES

One objective of the data analysis task was to summarize the key meteorological characteristics of the GOM region, and to examine how meteorological conditions vary throughout the region and throughout the year.

Historical surface and upper-air meteorological data for the period 1995 through 2004 were used to prepare the summaries. Surface meteorological data summaries were prepared for 13 different locations along the coast and four offshore locations. Upper-air meteorological data summaries were prepared for four locations. For the onshore surface measurement summaries, the areas include:

- Houston, Texas
- Galveston, Texas
- Beaumont/Port Arthur, Texas
- Lake Charles, Louisiana
- Lafayette, Louisiana
- New Orleans, Louisiana
- Boothville, Louisiana
- Baton Rouge, Louisiana
- Gulfport, Mississippi
- Mobile, Alabama
- Pensacola, Florida
- Panama City, Florida
- Tampa, Florida

For the offshore surface measurement summaries, the four buoys include:

- 42007
- 42035
- 42037
- 42040

The four upper-air sites are:

- Lake Charles, Louisiana

- Slidell, Louisiana
- Tallahassee, Florida
- Tampa, Florida

The locations are shown in Figure 4. The data summaries focus on routine monitoring sites with multi-year measurement periods. The surface and upper-air data were obtained from the NWS (NCDC, 2009) and the buoy data were obtained from the National Data Buoy Center (NDBC) (NDBC, 2009). As discussed later in this section the meteorological data sites were selected to represent the different regions of the Gulf Coast and for pairing with air quality monitoring sites. All of the data presented in this section are included in the GMAQDB. Detailed site information is also included in the GMAQDB.

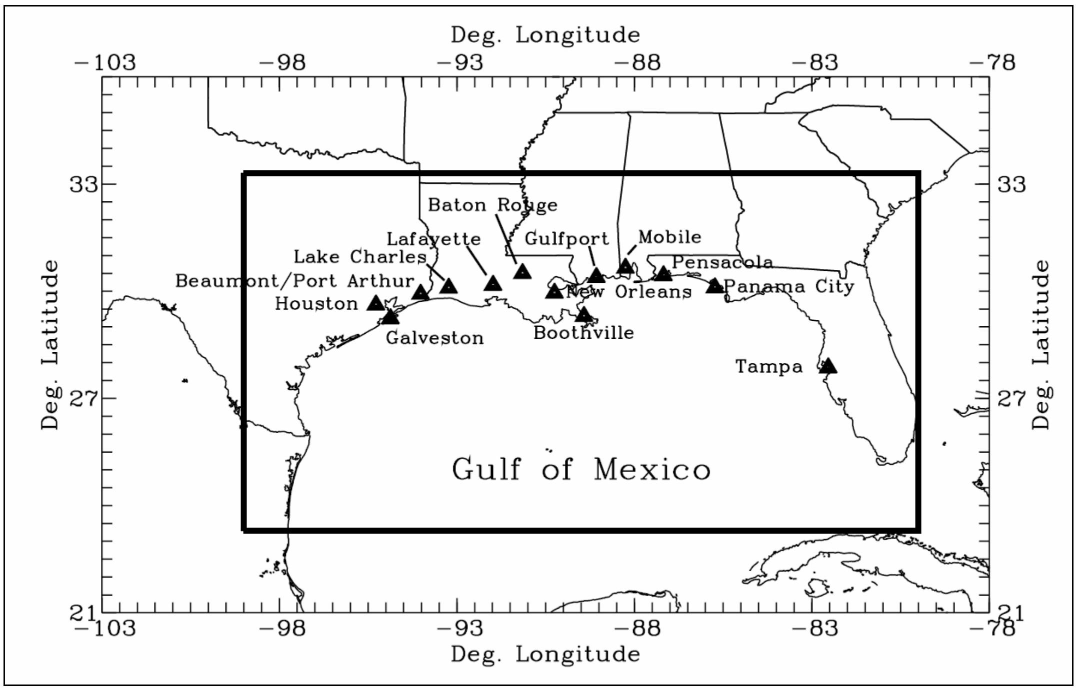


Figure 4a. Surface meteorological monitoring sites for the MMS synthesis data summaries.

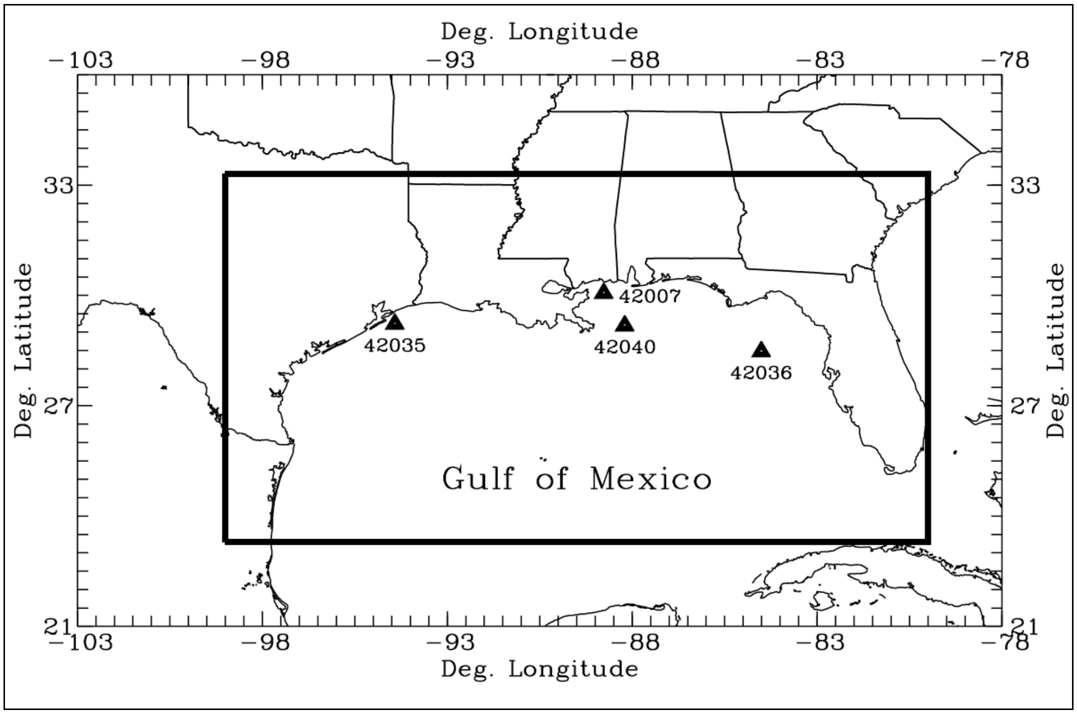


Figure 4b. Buoy meteorological monitoring sites for the MMS synthesis data summaries.

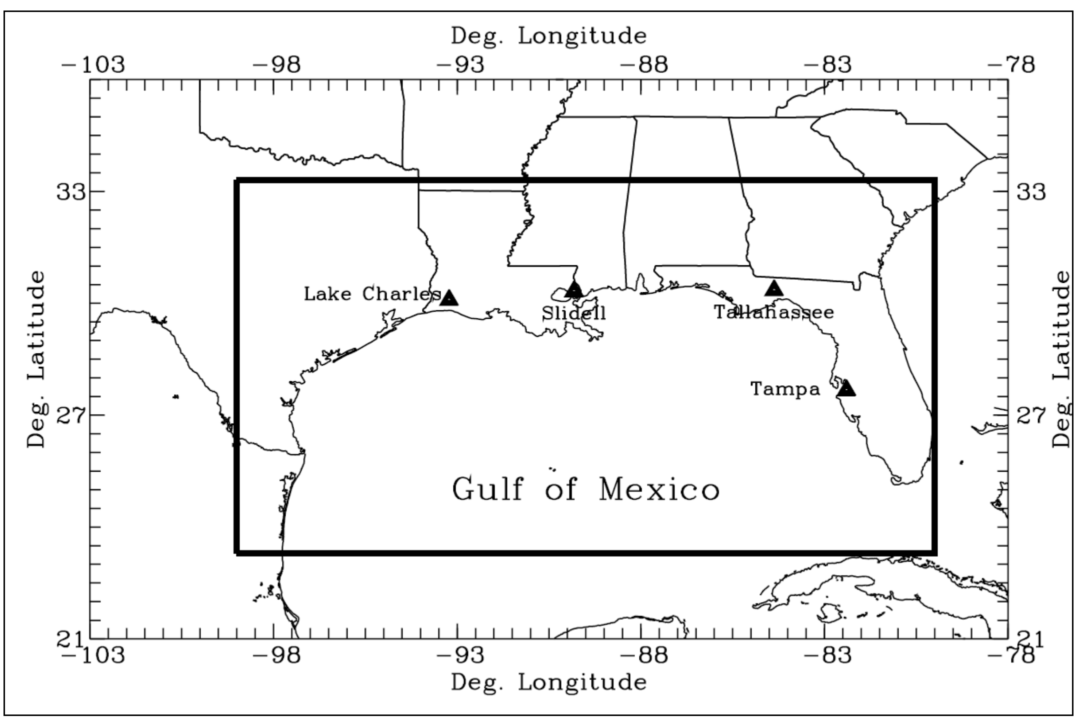


Figure 4c. Upper-air meteorological monitoring sites for the MMS synthesis data summaries.

2.1.1. Selected Surface Meteorological Metrics

In this section, plots illustrating the monthly and annual variations in selected meteorological parameters for the onshore surface monitoring sites of interest are presented and discussed. The surface-based parameters include:

- Minimum and maximum temperature (°C)
- Relative humidity at noon (%)
- Wind speed at 1000 and 1600 LST (ms^{-1})
- Wind direction at 1000 and 1600 LST (degrees)
- Precipitation amount (inches)
- Persistence index (unitless).

The "persistence index" is a derived parameter and is defined for each day as the average vector wind speed divided by the average scalar wind speed. A value close to one indicates a persistent wind direction during the daily averaging period. A lower value indicates some variation in wind direction during the period, such as is expected during a gulf breeze cycle. Simple calculations indicate that a classic gulf breeze circulation would have a persistence index in the range of 0.1 to 0.5. Throughout this report, the persistence index is used to identify possible gulf breeze conditions.

The NWS surface data typically represent temperature at three to five meters above the ground and winds at ten meters above the ground. The hours 1000 and 1600 LST were selected for these displays in order to sample different potions of the diurnal cycle. These two hours, respectively, typically represent key hours for photochemical production and pollutant transport (especially for ozone) and the initial and later (well established) phases of a gulf breeze.

Figures 5 through 8 present some example meteorological data summaries. These focus on four sites that span the Gulf Coast: Galveston, New Orleans, Pensacola, and Tampa. In each figure, the first four charts display month-to-month variations in selected parameters. The first chart (upper left-hand corner) presents the average (over all years) of the minimum (blue line) and maximum (red line) temperature (°C) for each month. The second chart (upper right hand corner) gives the average monthly precipitation. The third and fourth charts (in the middle of the page) display the average monthly wind speed and wind direction for 1000 and 1600 hours Local Standard Time (LST). The next two charts (bottom of the page) display annual variations for two key parameters - precipitation and the persistence index. Not all sites had complete data for the full period and thus some of the annual charts are for a subset of the full period. A full set of summary charts (for all sites listed above and additional meteorological parameters) is available in Excel format.

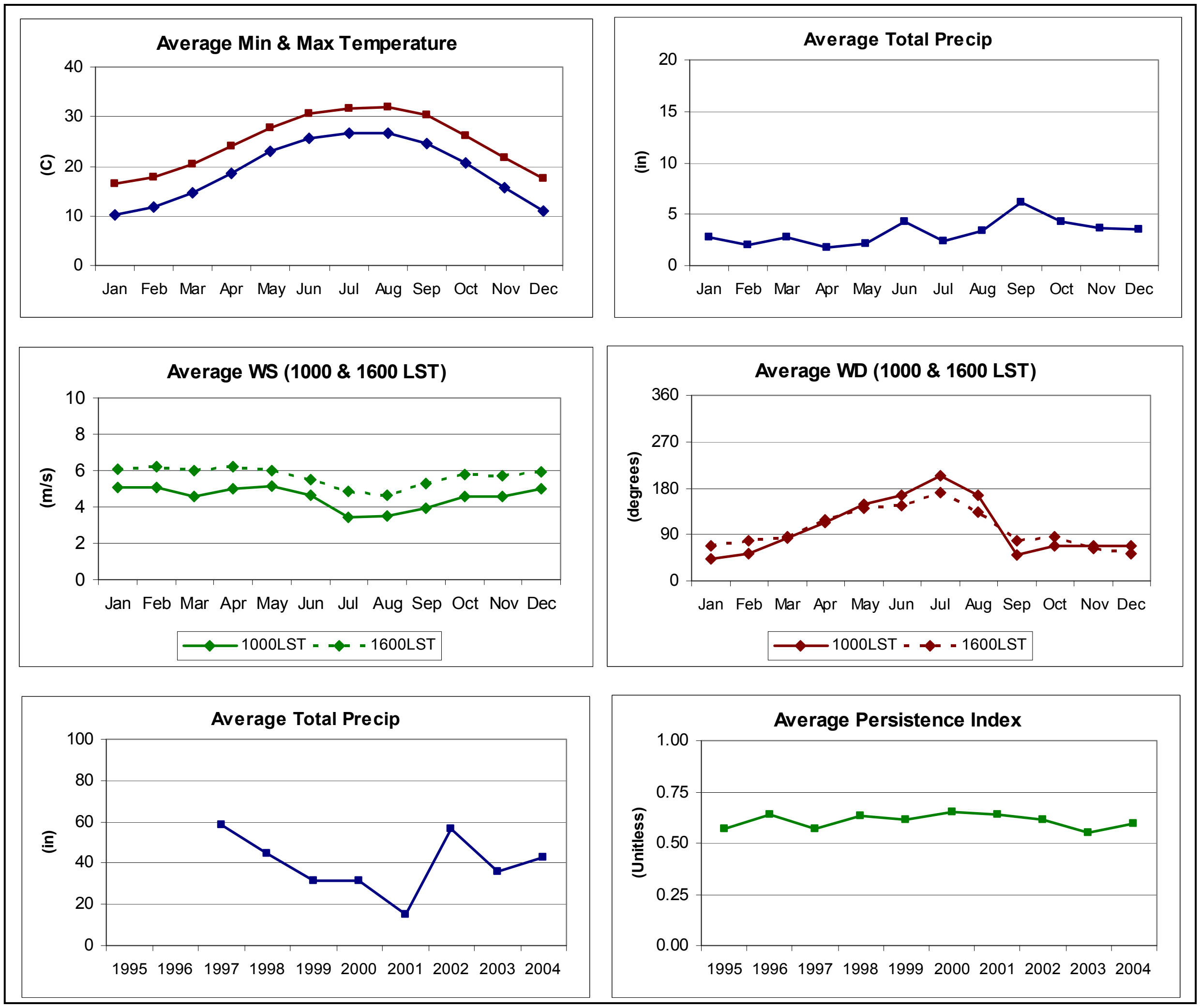


Figure 5. Surface meteorological data summary for Galveston (1995-2004).

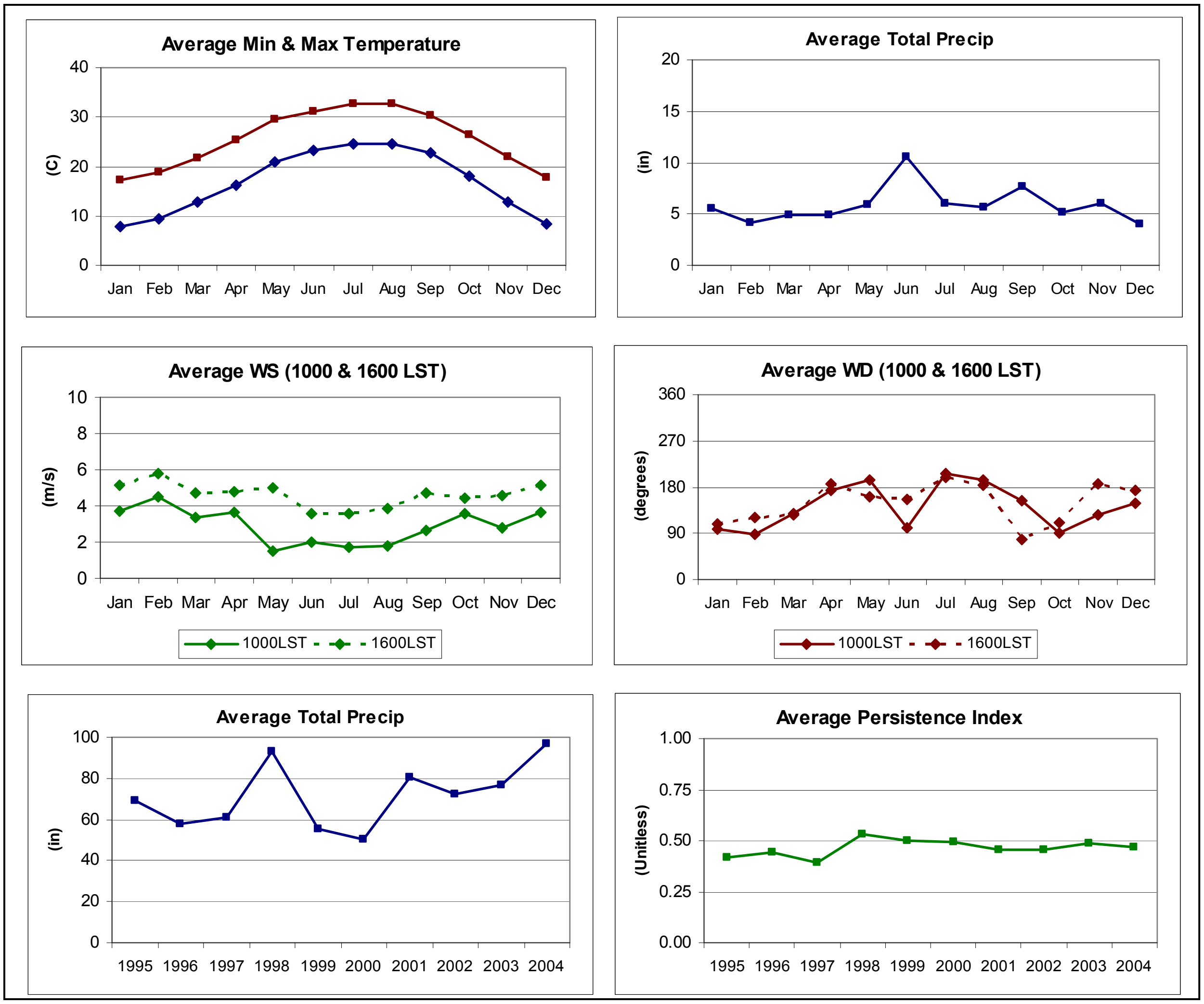


Figure 6. Surface meteorological data summary for New Orleans (1995-2004).

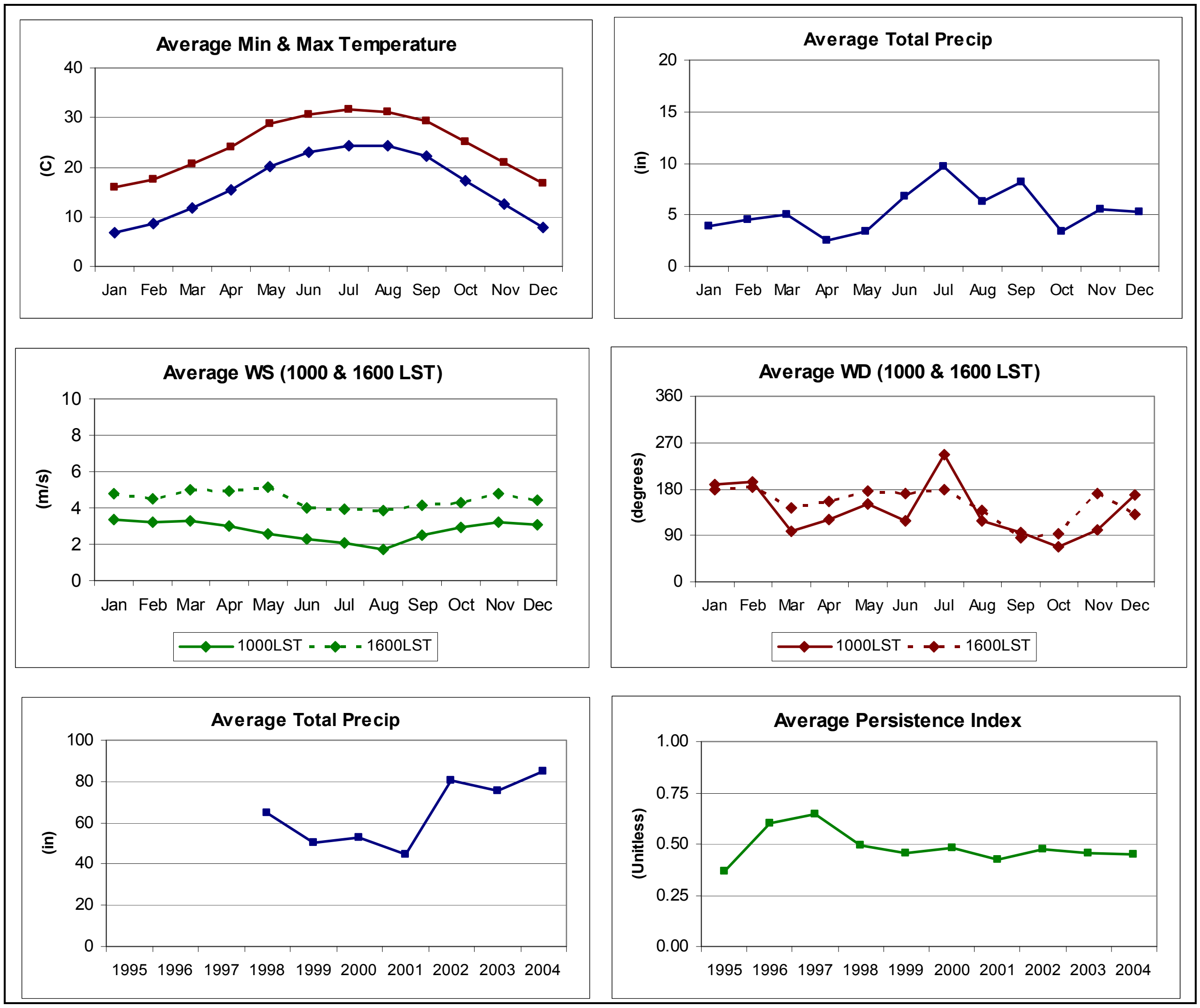


Figure 7. Surface meteorological data summary for Pensacola (1995-2004).

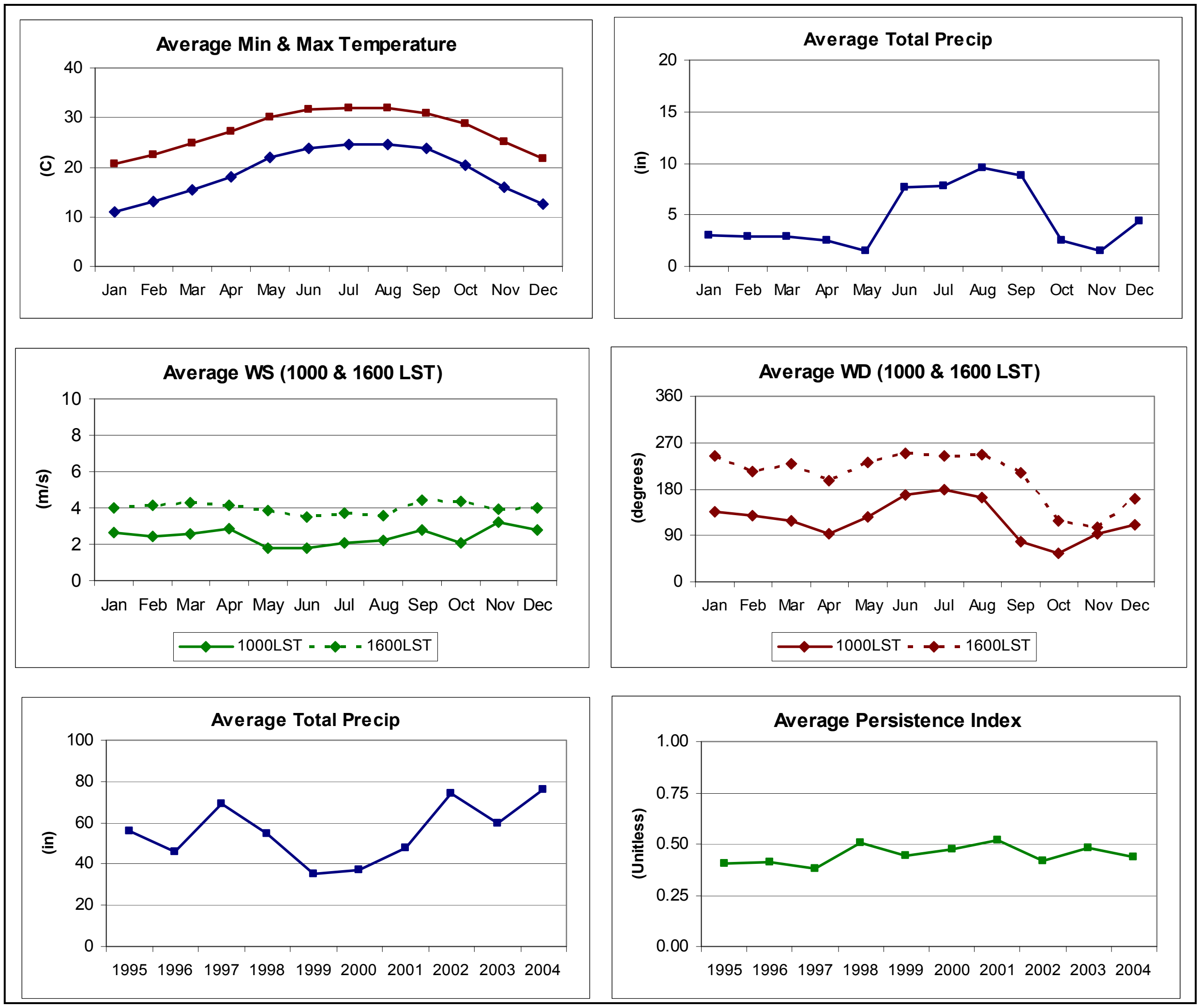


Figure 8. Surface meteorological data summary for Tampa (1995-2004).

There are both similarities and differences among the meteorological parameters for these four sites. Temperatures for all four sites exhibit the expected seasonal characteristics. Also, wind speeds are lower and precipitation amounts are higher during the summer months for all sites (compared to the winter months). Southerly winds (winds from the south) tend to appear and dominate during the summer months. Precipitation amounts and the month-to-month and annual variations are different among the sites. Note that there are a lot of missing data values for Galveston for 2001, and this results in a low annual total precipitation value. With a few exceptions, the average persistence index does not vary much from year to year, indicating that no years stand out as having a much greater frequency of gulf-breeze-conducive conditions compared to other years. Note that this index applied to New Orleans (as discussed earlier in this report) is likely not an indicator of gulf breeze conditions but simply an indicator of wind direction persistence.

2.1.2. Selected Buoy Meteorological Metrics

Buoy data include many of the same parameters as the onshore meteorological monitoring data. For this study, the following parameters were reviewed and summarized:

- Minimum and maximum temperature (°C)
- Sea surface temperature (°C)
- Relative humidity at noon (%)
- Wind speed at 1000 and 1600 LST (ms^{-1})
- Wind direction at 1000 and 1600 LST (degrees)
- Persistence index (unitless).

Figures 9 and 10 present some example buoy meteorological data summaries. A full set of summary charts is available in Excel format. Two sites were selected for this example. Buoy #42007 is located off the coast of Mississippi and buoy #42035 is located off the coast of southeast Texas (see Figure 4b). In each figure that follows, the first four charts display month-to-month variations in selected parameters. The first chart (upper left-hand corner) presents the average (over all years) of the sea surface temperature (°C) for each month. The second chart (upper right hand corner) gives the monthly average persistence index. The third and fourth charts (in the middle of the page) display the average monthly wind speed and wind direction for 1000 and 1600 LST. The next two charts (bottom of the page) display annual variations for two key parameters—sea surface temperature and the persistence index. Not all buoys have complete data for the full period, as indicated in the annual charts.

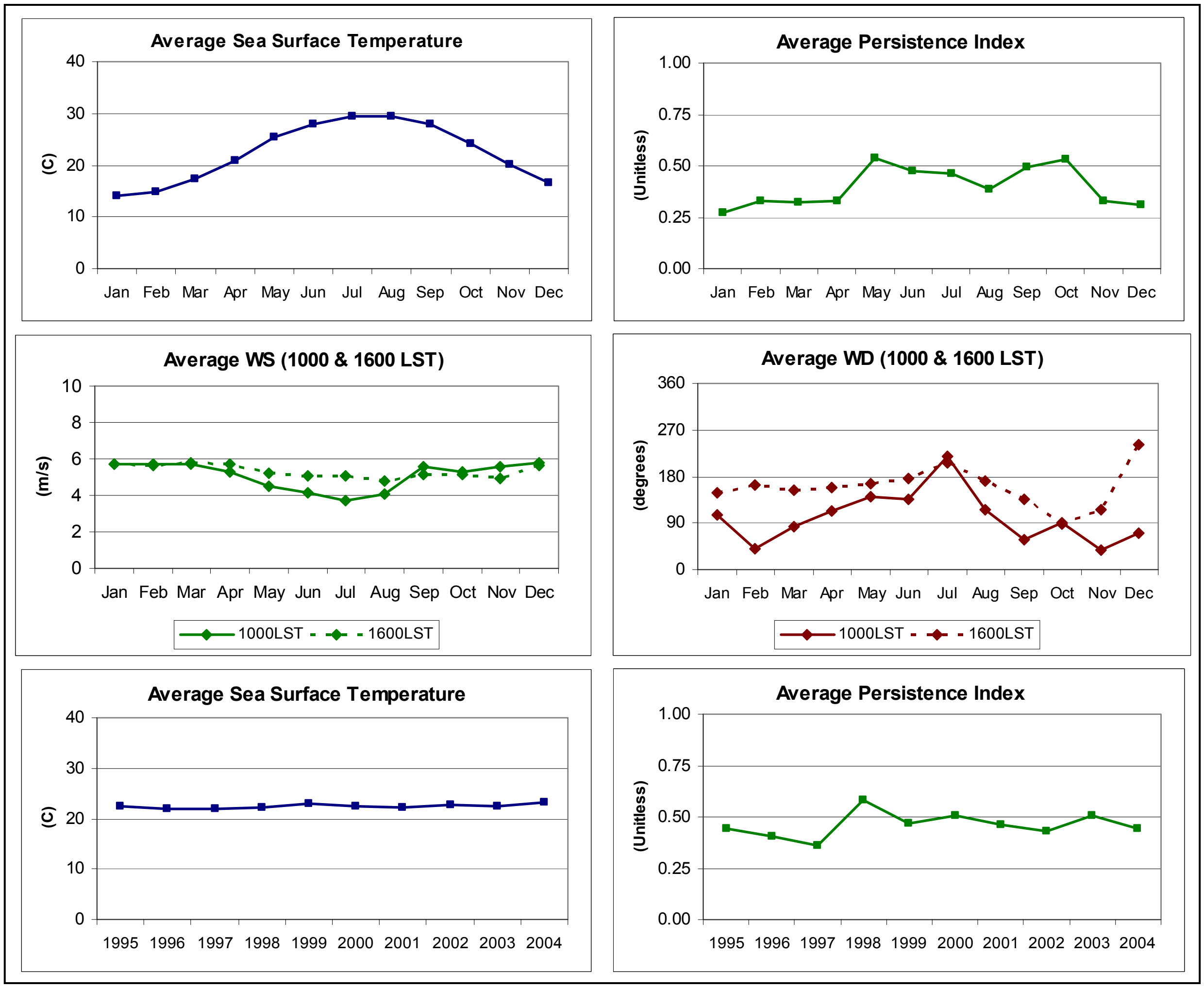


Figure 9. Surface meteorological data summary for Buoy #42007 (1995-2004).

Figure 10. Surface meteorological data summary for Buoy #42035 (1995-2004).

At the buoy sites, sea surface temperature exhibits the expected seasonal variations but does not vary much from year to year. Wind speeds are lower and daytime winds (on average) exhibit a southerly component during the summer months (compared to the remainder of the year). The average persistence index shows much more month-to-month variability than for the onshore locations, but still does not vary much from year to year and is similar for both sites. Considering only the ozone season months, the low persistence index indicates that gulf breeze conditions are most likely to occur in August for Buoy #42007 and in September for Buoy #42035.

2.1.3. Selected Upper-Air Meteorological Metrics

In this section, plots illustrating the monthly and annual variations in selected meteorological parameters for the upper-air monitoring sites of interest are presented and discussed. The parameters include:

- Temperature (°C)
- Dew-point temperature (°C)
- Wind speed (ms^{-1})
- Wind direction (degrees)
- Stability index (°C).

The upper-air measurements are taken twice daily at approximately 0600 and 1800 LST. For this analysis, we focused primarily on the 850 mb level, which is typically about 1500 meters (m) above sea level (asl), which along the Gulf Coast is close to 1500 m above ground level (agl). The “stability index” is defined as the difference in temperature between 900 mb (about 500 m) and the surface. The value of this parameter increases with increasing stability. Negative values (less than about -5°C) may indicate unstable (or very well mixed) conditions near the surface. Positive values indicate stable conditions (and limited mixing) near the surface.

Figures 11 through 14 present some example upper-air meteorological data summaries. These focus on four sites that span the Gulf coast: Lake Charles, Slidell, Tallahassee, and Tampa. The examples present (in order) the month-to-month variations in temperature, dew-point temperature, wind speed, wind direction, and stability index. The year-to-year variations aloft are much less than for the surface. A full set of summary charts is available in Excel format.

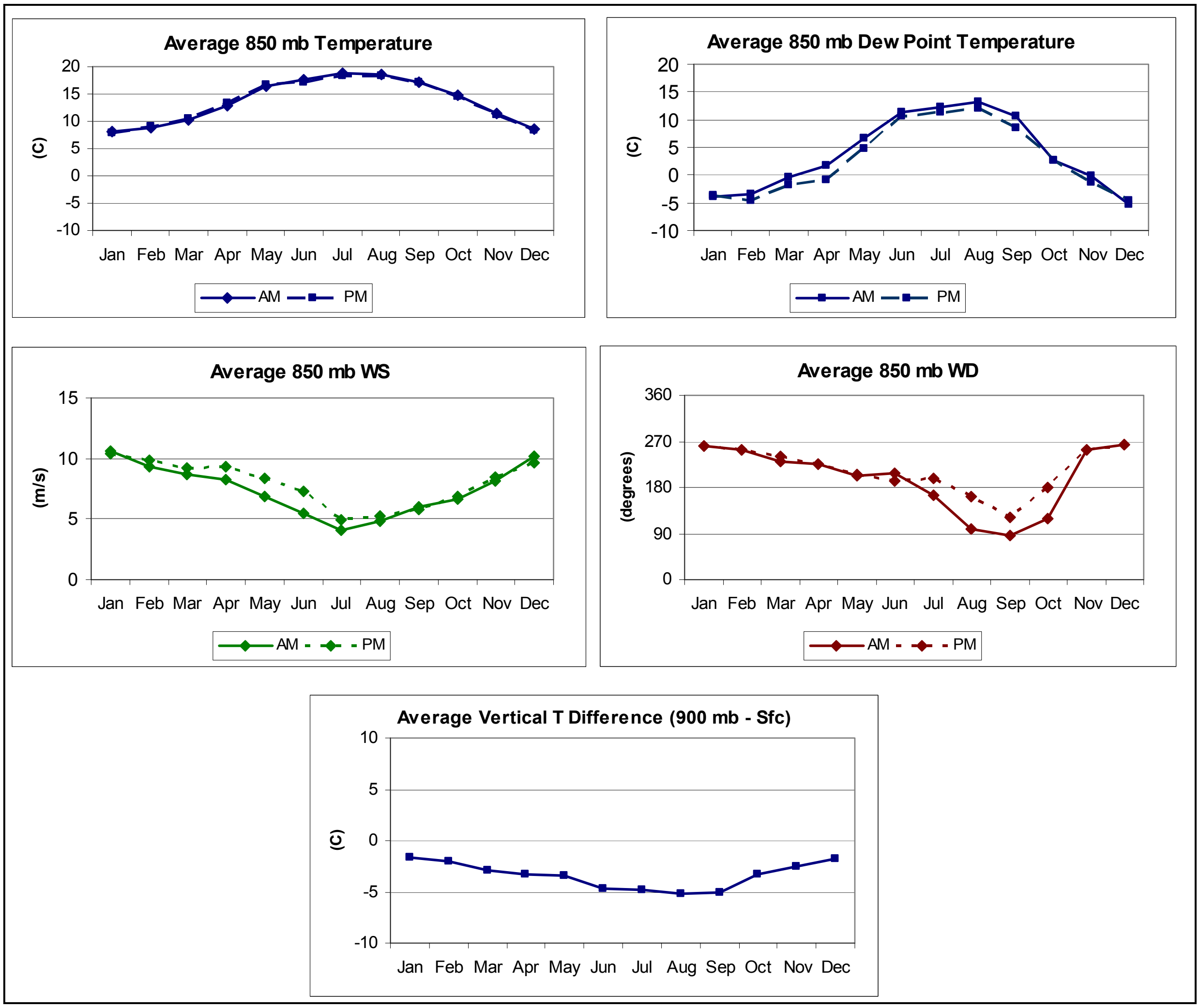


Figure 11. Upper-air meteorological data summary for Lake Charles, LA (1995-2004).

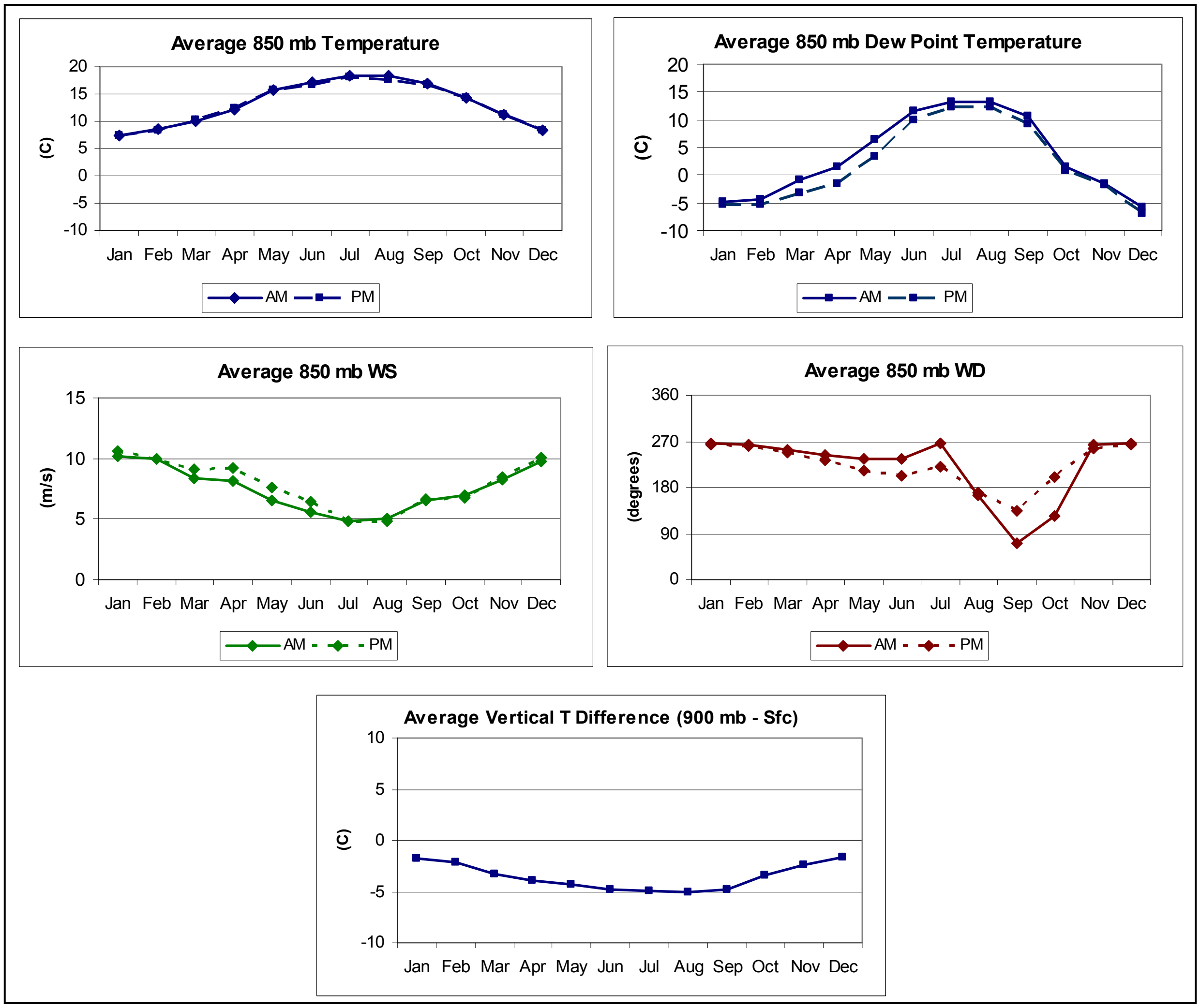


Figure 12. Upper-air meteorological data summary for Slidell, LA (1995-2004).

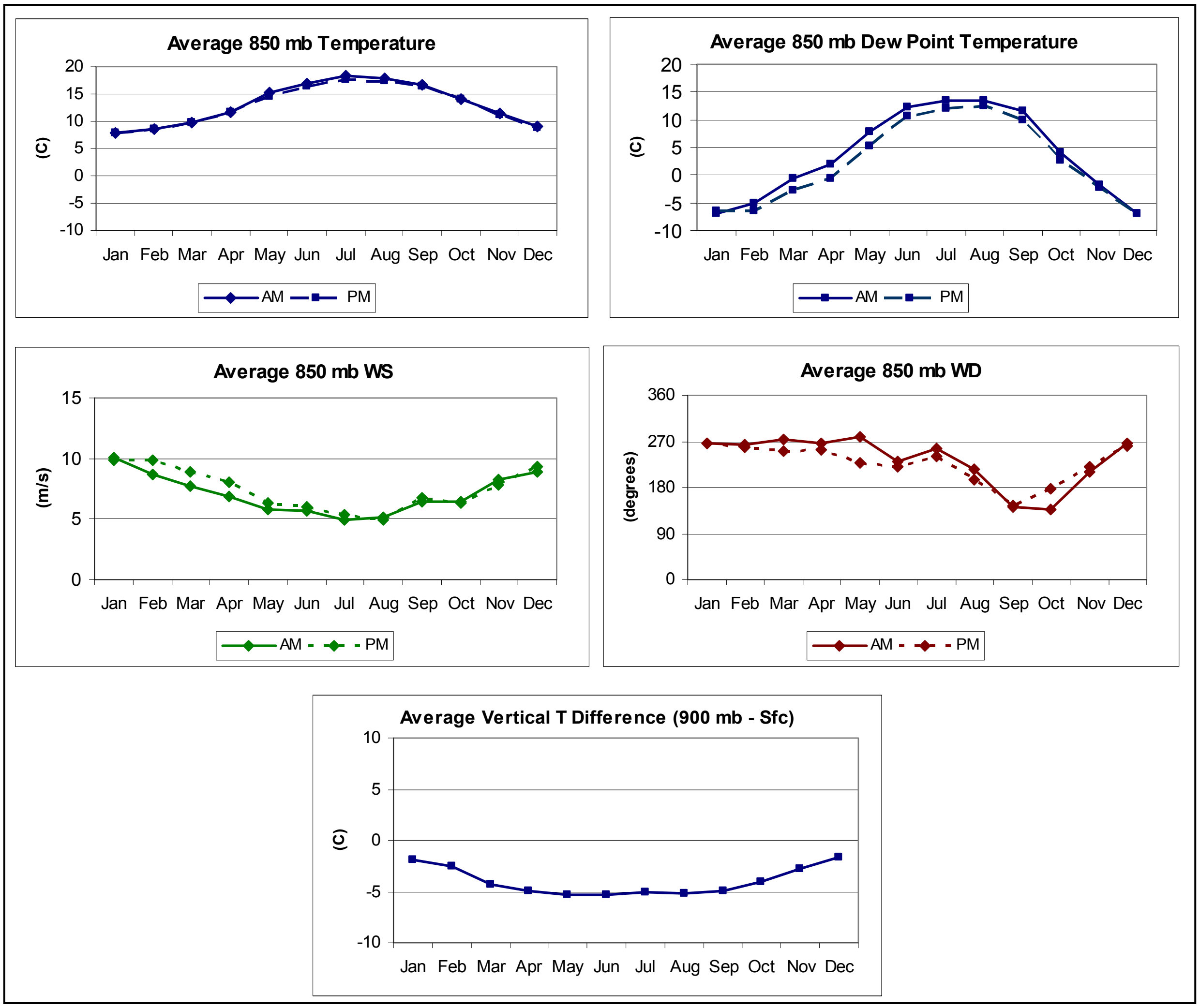


Figure 13. Upper-air meteorological data summary for Tallahassee, FL (1995-2004).

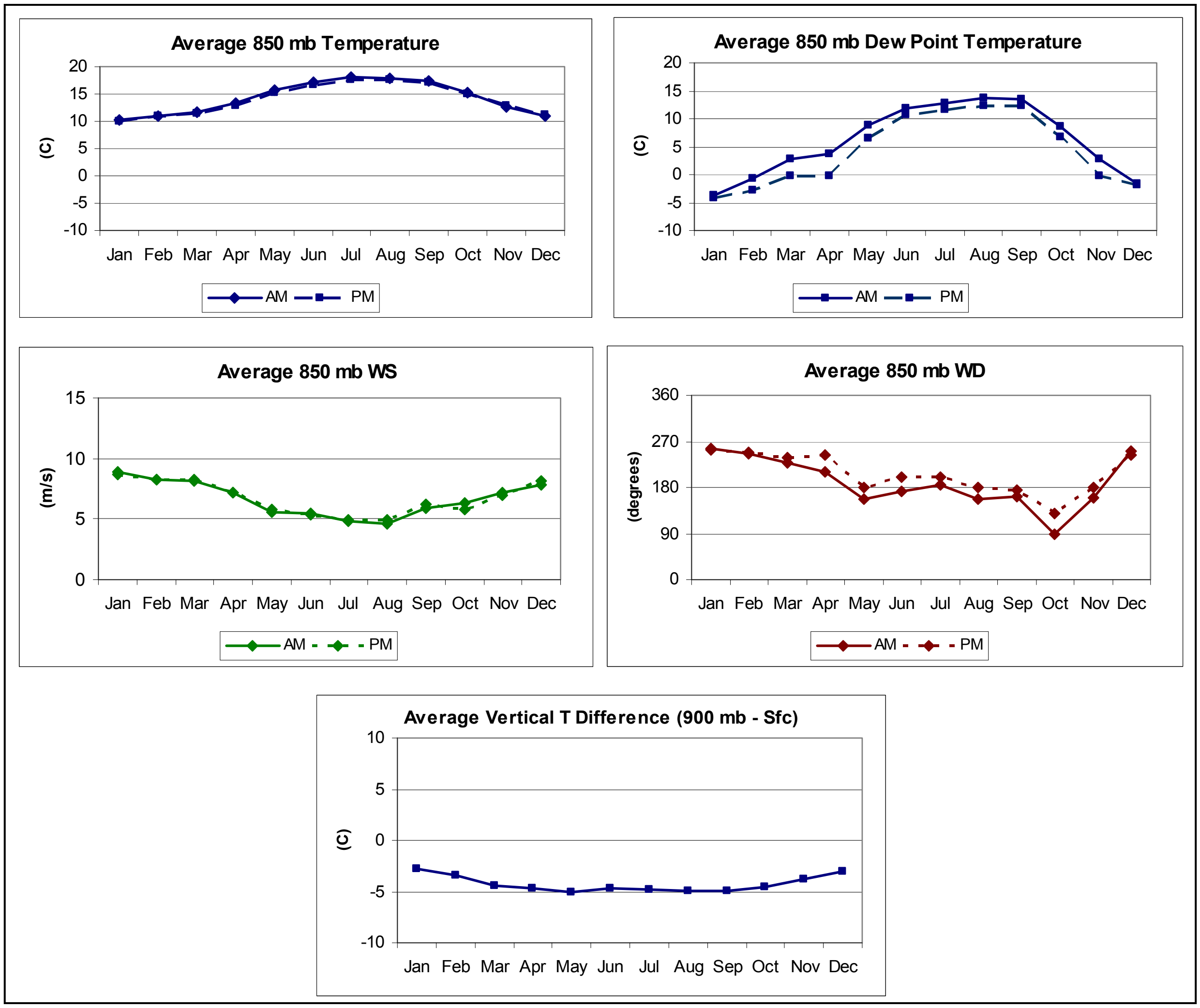


Figure 14. Upper-air meteorological data summary for Tampa, FL (1995-2004).

The upper-air data for all sites exhibit similar characteristics at the 850 mb level. Higher dew-point temperatures and less of a difference between the temperatures and the dew-point temperatures during the warmer months reflect the relatively humid conditions of the region. Wind speeds aloft are lowest during the summer months. Easterly and northerly winds aloft dominate the average 850 mb wind directions for July–October for Lake Charles, August through October for Slidell, September and October for Tallahassee, and October for Tampa (onset is later for each location, from west to eastward). For the remaining months, winds aloft are generally southwesterly for Lake Charles, westerly for Slidell and Tallahassee, and southwesterly to southerly for Tampa. For all locations, the stability index indicates greater stability during the winter months and less stability during the summer months and the values are very similar.

2.2. OZONE DATA SUMMARIES

Ozone is one of the key air quality issues affecting the coastal urban areas. As presented in Section 1, most of the urban and/or industrial areas along the coast are expected to be nonattainment areas relative to the current 8-hour ozone standard of 75 ppb. Compliance with the standard is to be determined using data collected during the period 2006-2008.

In this study, historical ozone data for the period 1995 through 2004 were examined for 14 different areas along the coast. These areas include:

- Houston, Texas
- Galveston, Texas
- Beaumont/Port Arthur, Texas
- Lake Charles, Louisiana
- Lafayette, Louisiana
- Morgan City, Louisiana
- New Orleans, Louisiana
- Baton Rouge, Louisiana
- Gulfport, Mississippi
- Pascagoula, Mississippi
- Mobile, Alabama
- Pensacola, Florida
- Panama City, Florida
- Tampa, Florida

The locations are shown in Figure 15. A representative ozone monitoring site from each of these areas was selected, based on calculated ozone design value and the length of the data record. Sites with average ozone concentrations near the design value for the area and longer data records were favored. In addition to the ozone data for these sites, surface and upper-air meteorological data from nearby sites were also examined with the goal of determining whether relationships between meteorology and ozone are readily apparent in the observed data. The ozone data were obtained from the EPA AQS database (USEPA, 2009a). All of the data presented in this section are included in the GMAQDB. Detailed site information is also included in the GMAQDB.

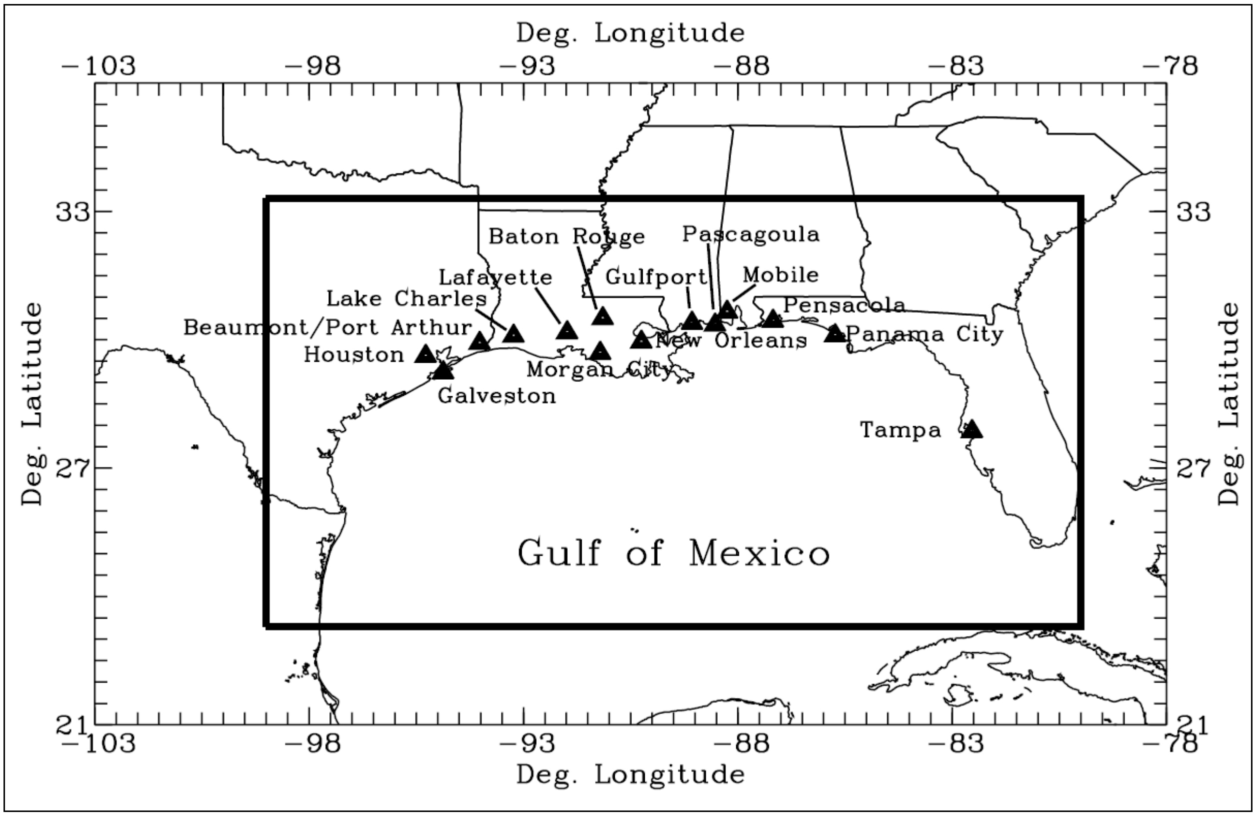


Figure 15. Ozone monitoring sites for MMS synthesis data summaries.

2.2.1. Selected Ozone Metrics

In this section, plots illustrating the monthly, diurnal, and annual variations in ozone concentration for the representative sites for each area of interest are presented and discussed. The metrics used to present the ozone data and derived information are as follows:

- Maximum and hourly (1-hour) ozone concentration.
- Daily maximum 8-hour average ozone concentration.
- Number of days on which the daily maximum 1-hour ozone concentration exceeds 125 ppb (the former 1-hour ozone NAAQS).
- Number of days on which the daily maximum 8-hour average ozone concentration exceeds 75 ppb (the current 8-hour ozone NAAQS).
- 8-hour ozone design value (the three-year average of the fourth highest ozone concentration per year).

Figures 16 through 29 summarize ozone air quality for the selected sites and metrics. The first chart (upper left-hand corner) presents the average (over all years) of the maximum 1-hour (gray bar) and 8-hour (blue bar) average ozone concentration (ppb) for each month. The second chart (upper right hand corner) gives the average (over all years) number of 1-hour (gray bar) and 8-hour (blue bar) ozone exceedances (of the former and current NAAQS) for each month. The third chart (middle of the page) displays the hourly average ozone concentration (ppb) by month for the ozone season months of May through September. The fourth chart (lower left-hand corner) gives the number of 8-hour ozone exceedances per year for each year with data (from the period 1995-2004). The final chart (lower right-hand corner) displays the 8-hour ozone design value for each three-year period with data (the end year of each three-year period is shown on the plot). The dashed, red line marks the 75 ppb NAAQS level. Not all sites have complete data for the full period and thus some of the annual charts are for a subset of the full period.

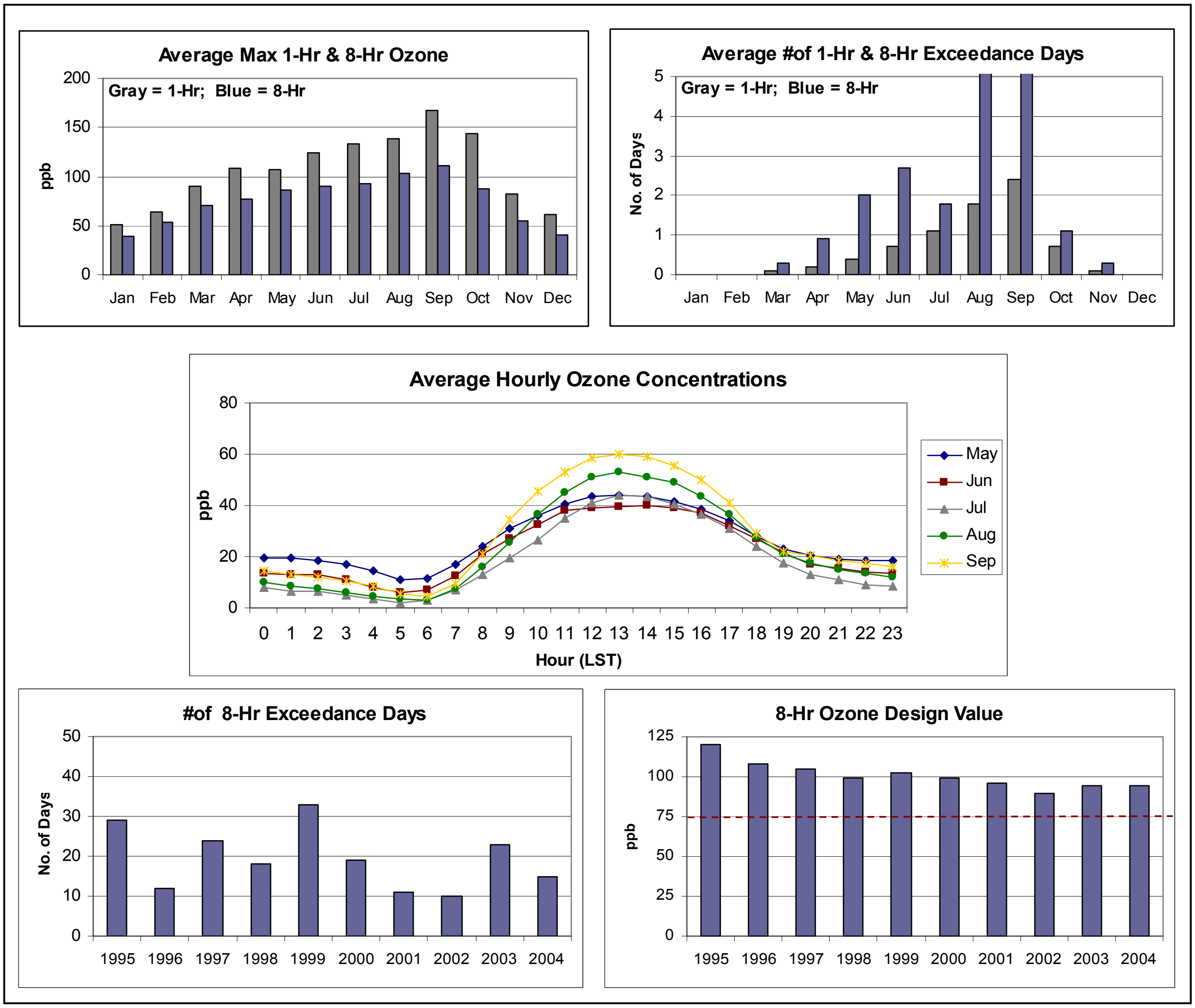
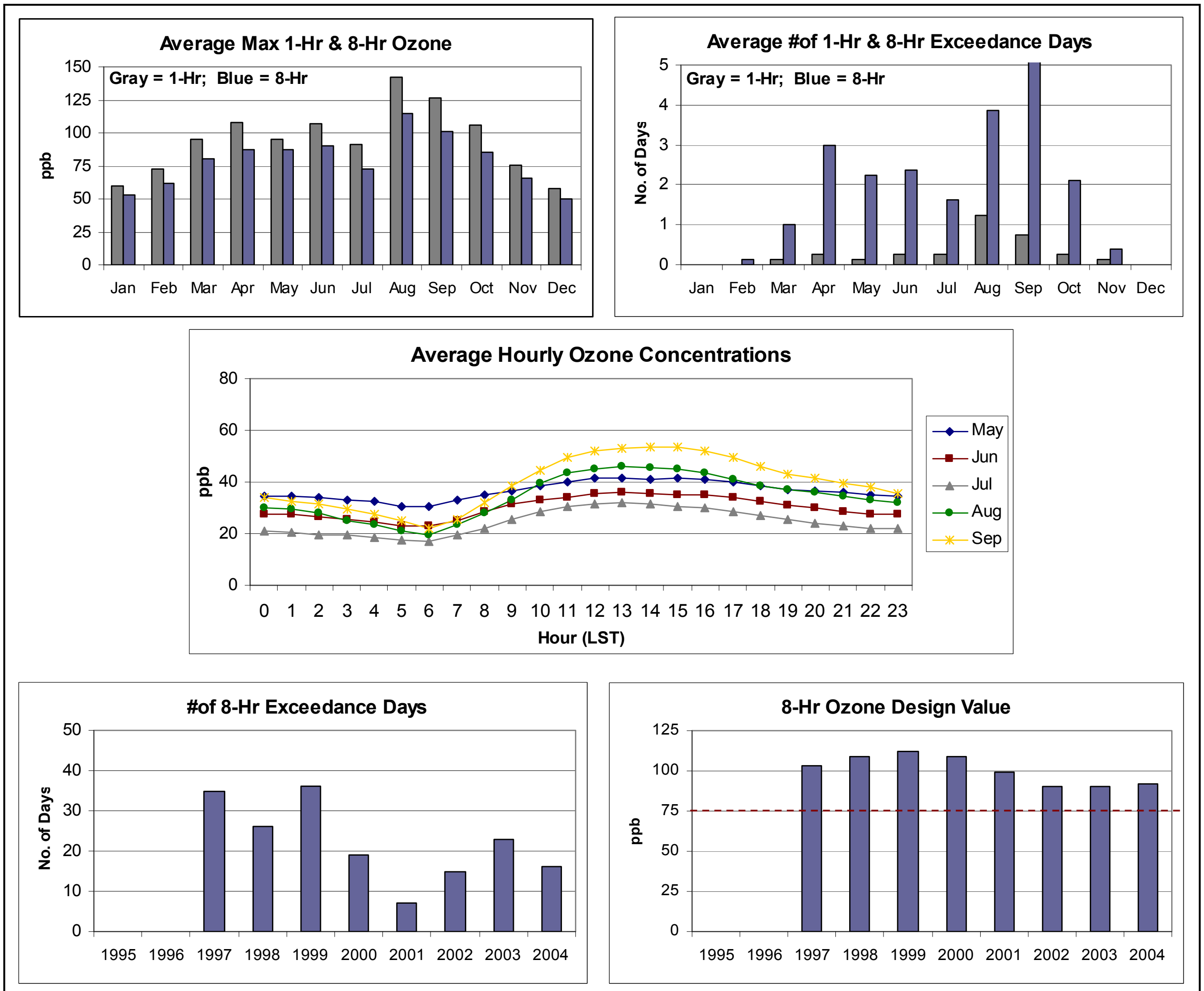


Figure 16. Ozone data summary for Houston area site (AQS # 482011035 (Clinton)).



** Data not available for 1995 and 1996.*

Figure 17. Ozone data summary for Galveston area site (AQS # 481670014).

Figure 18. Ozone data summary for Beaumont/Port Arthur area site (AQS # 482450011 (Port Arthur)).

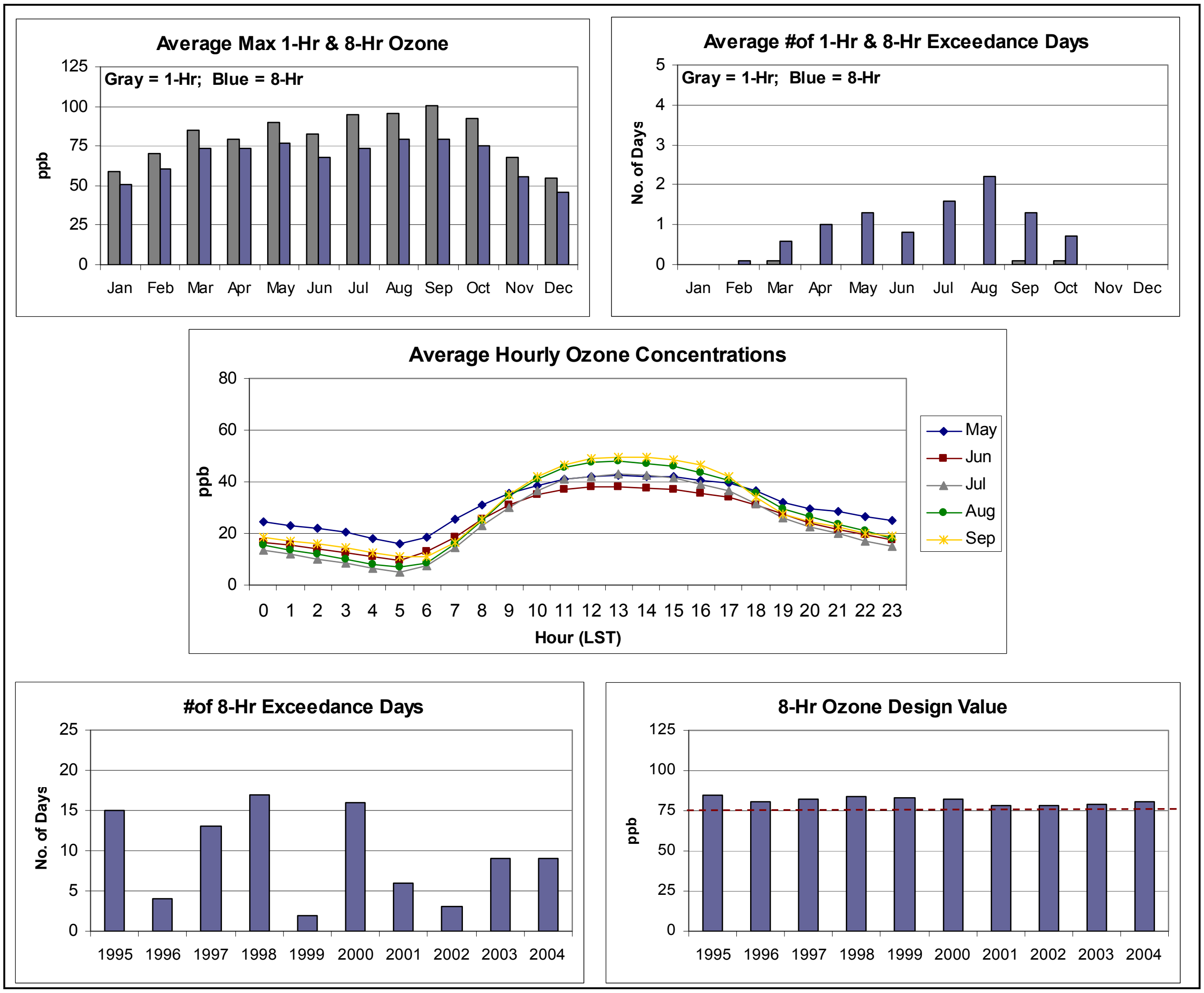


Figure 19. Ozone data summary for Lake Charles area site (AQS # 220190002 (Carlyss)).

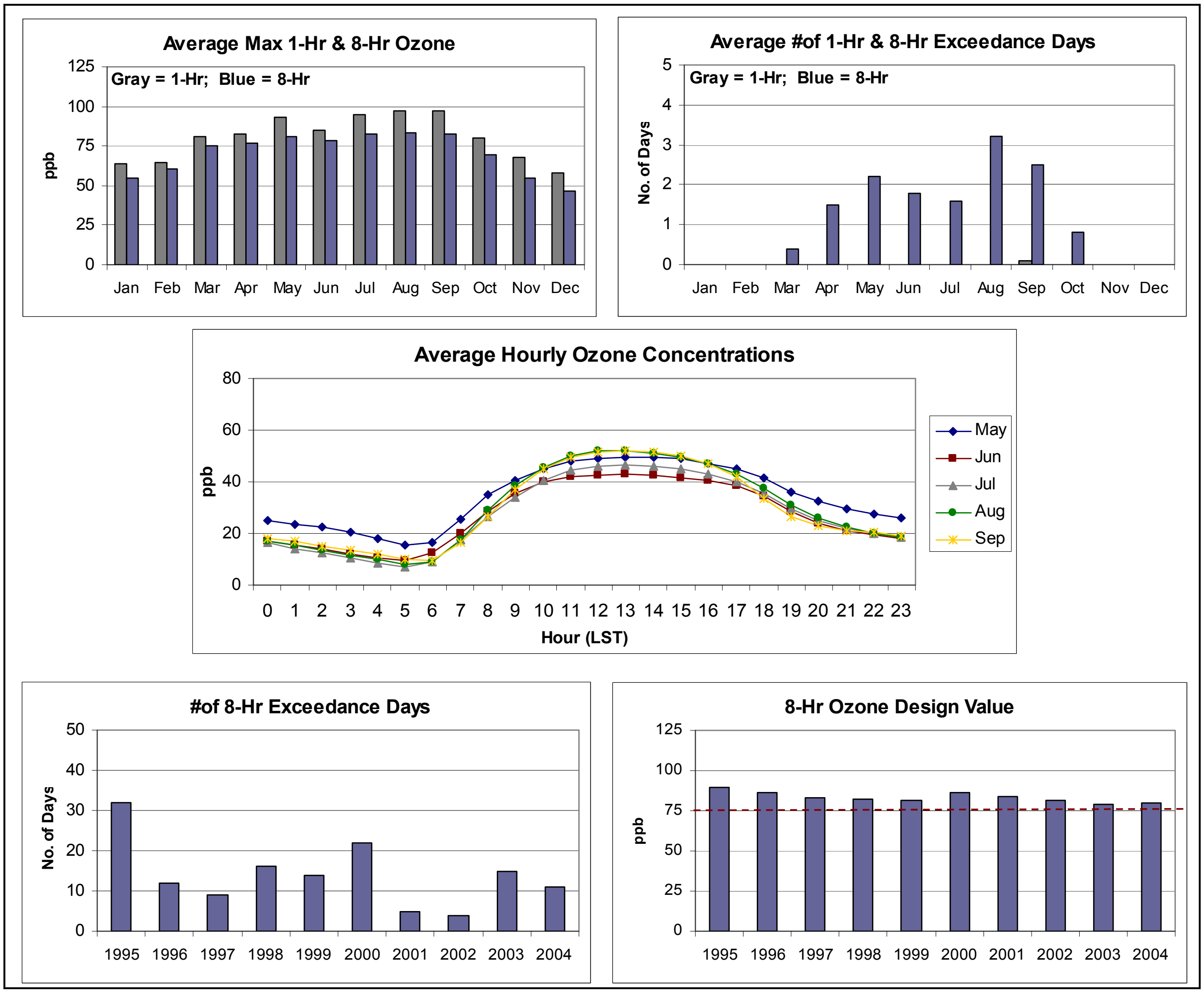


Figure 20. Ozone data summary for Lafayette area aite (AQS # 220550005).

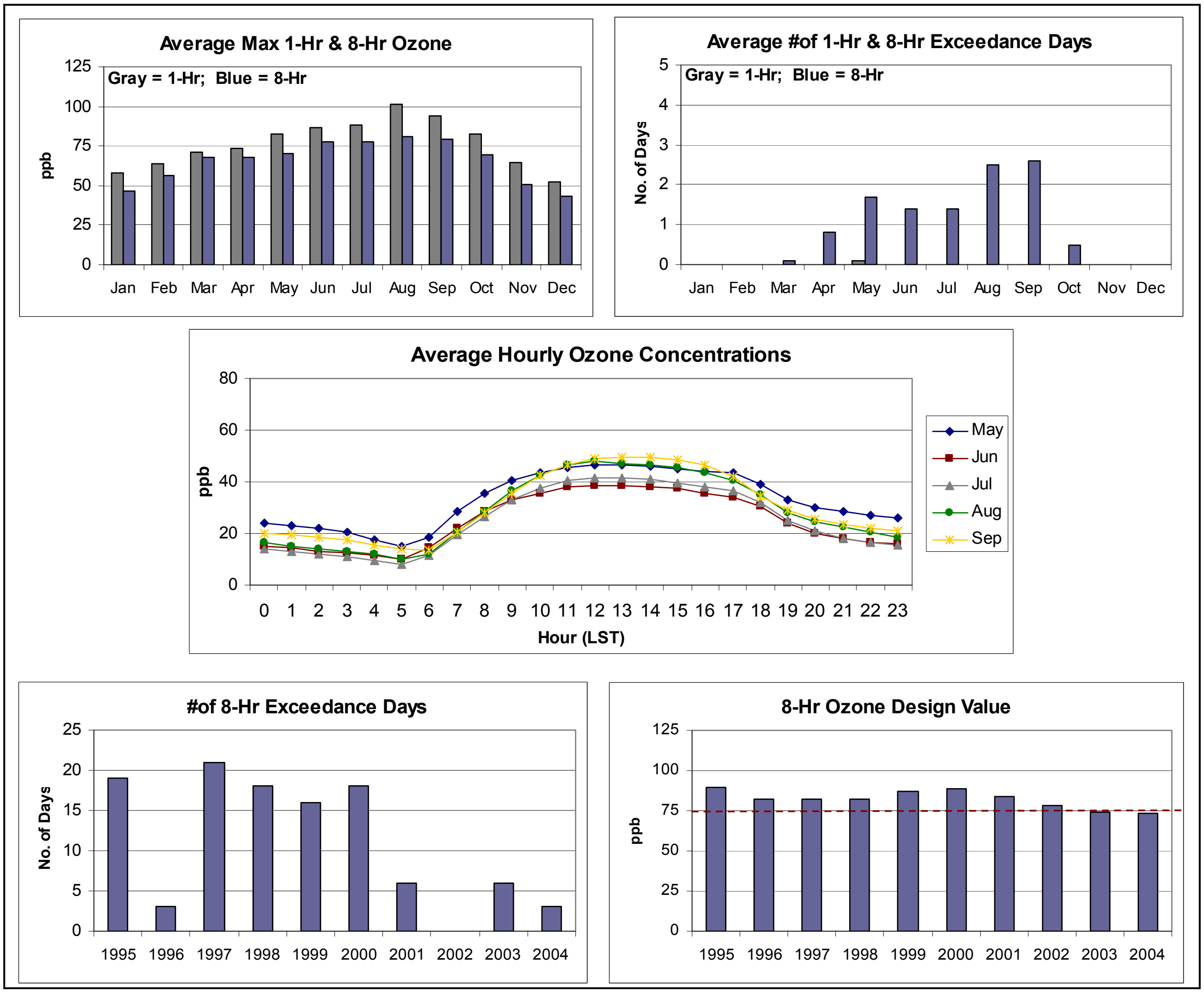


Figure 21. Ozone data summary for Morgan City area site (AQS # 221010003).

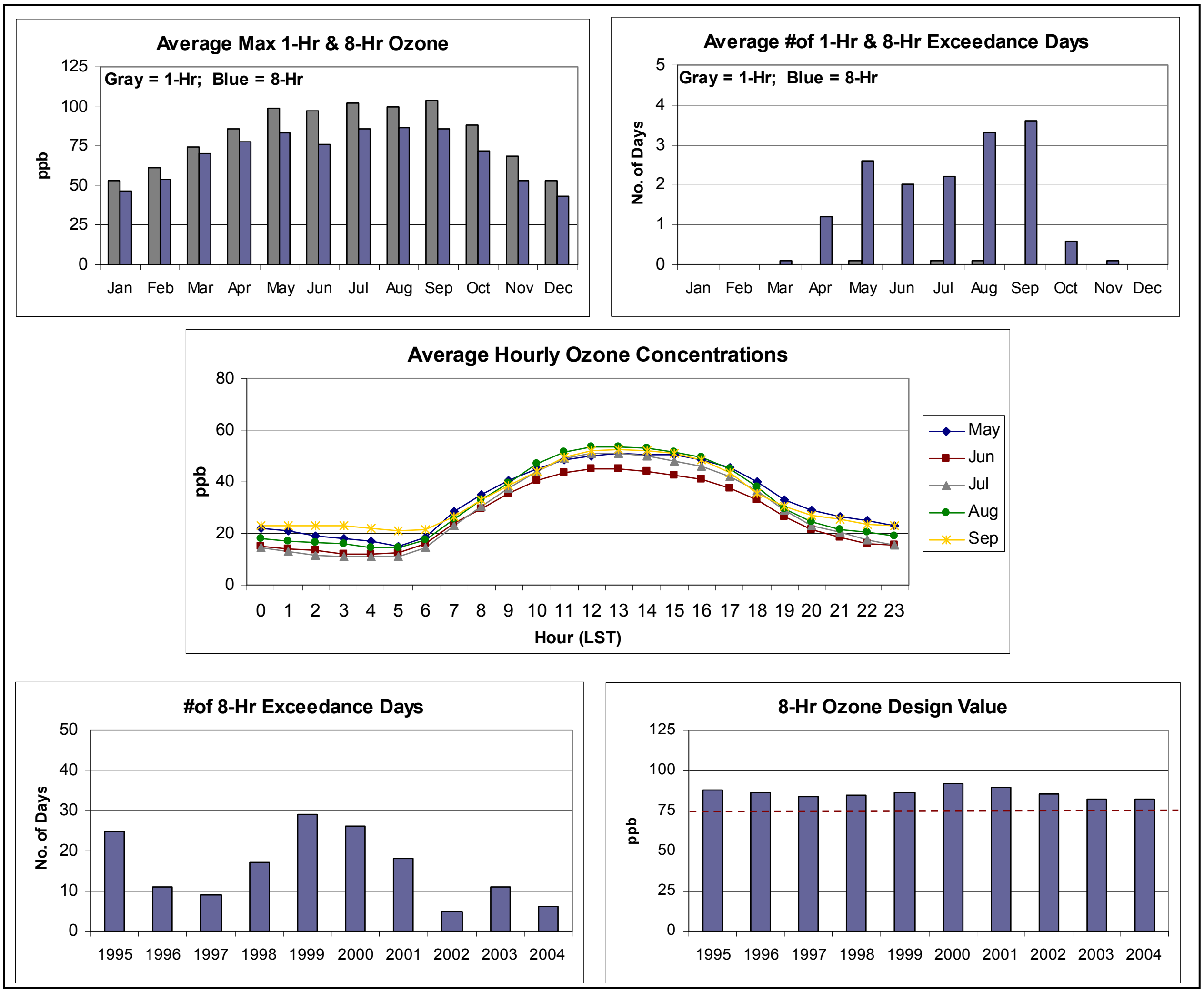


Figure 22. Ozone data summary for New Orleans area site (AQS # 220511001 (Kenner)).

Figure 23. Ozone data summary for Baton Rouge area site (AQS # 220330003 (LSU)).

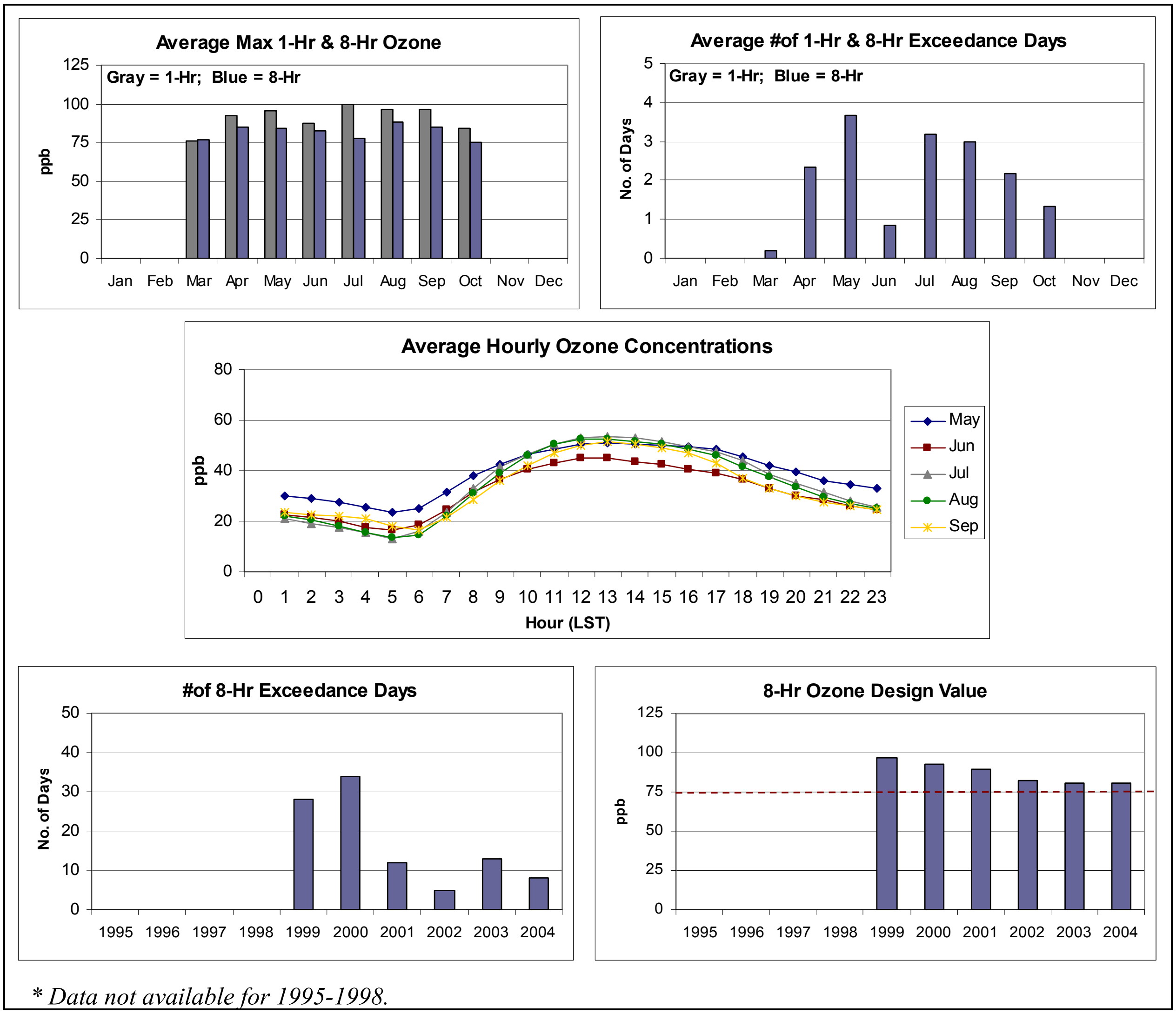


Figure 24. Ozone data summary for Gulfport area site (AQS # 280470008).

Figure 25. Ozone data summary for Pascagoula area site (AQS # 280590006).

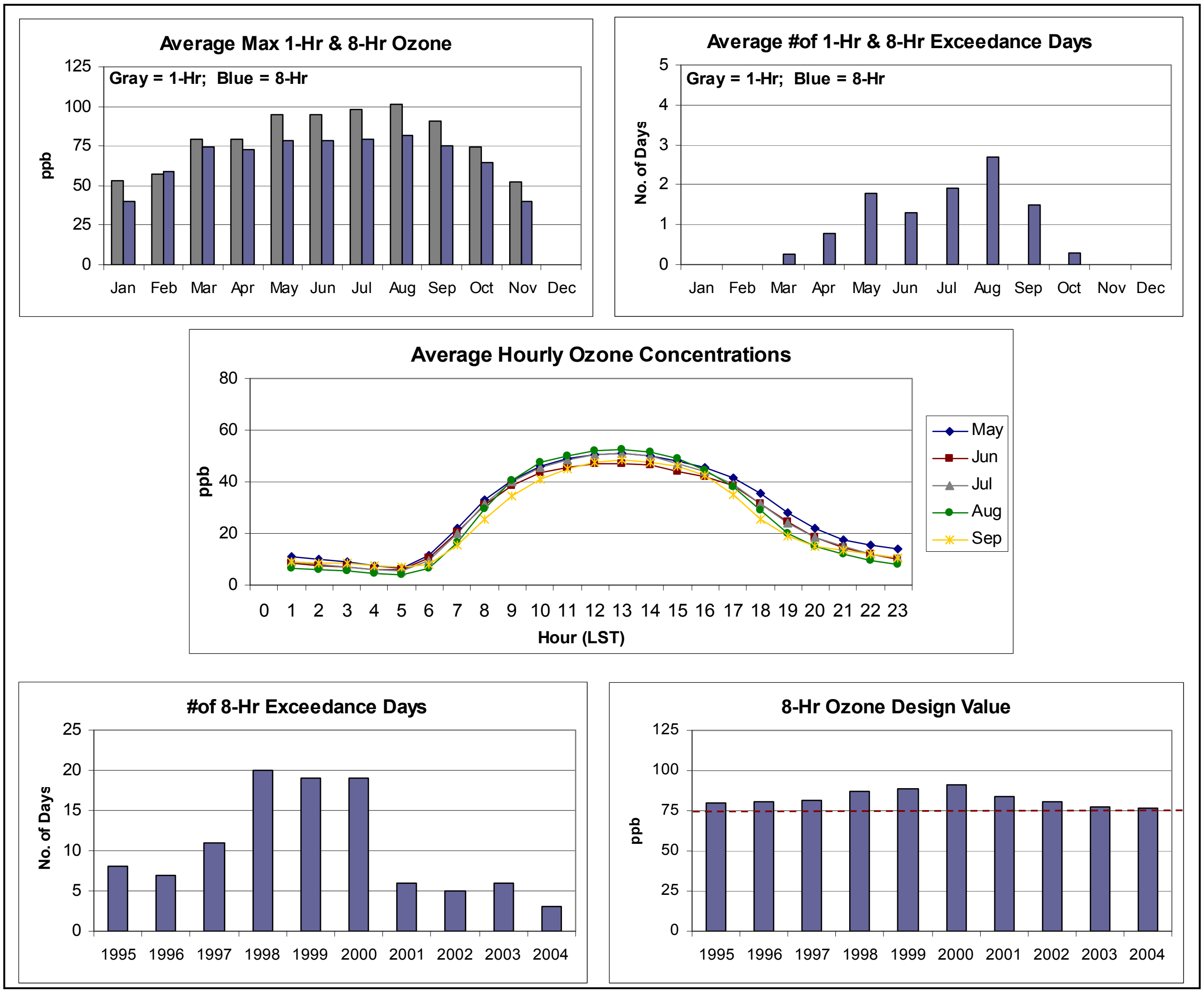


Figure 26. Ozone data summary for Mobile area site (AQS # 010970003 (Axis)).

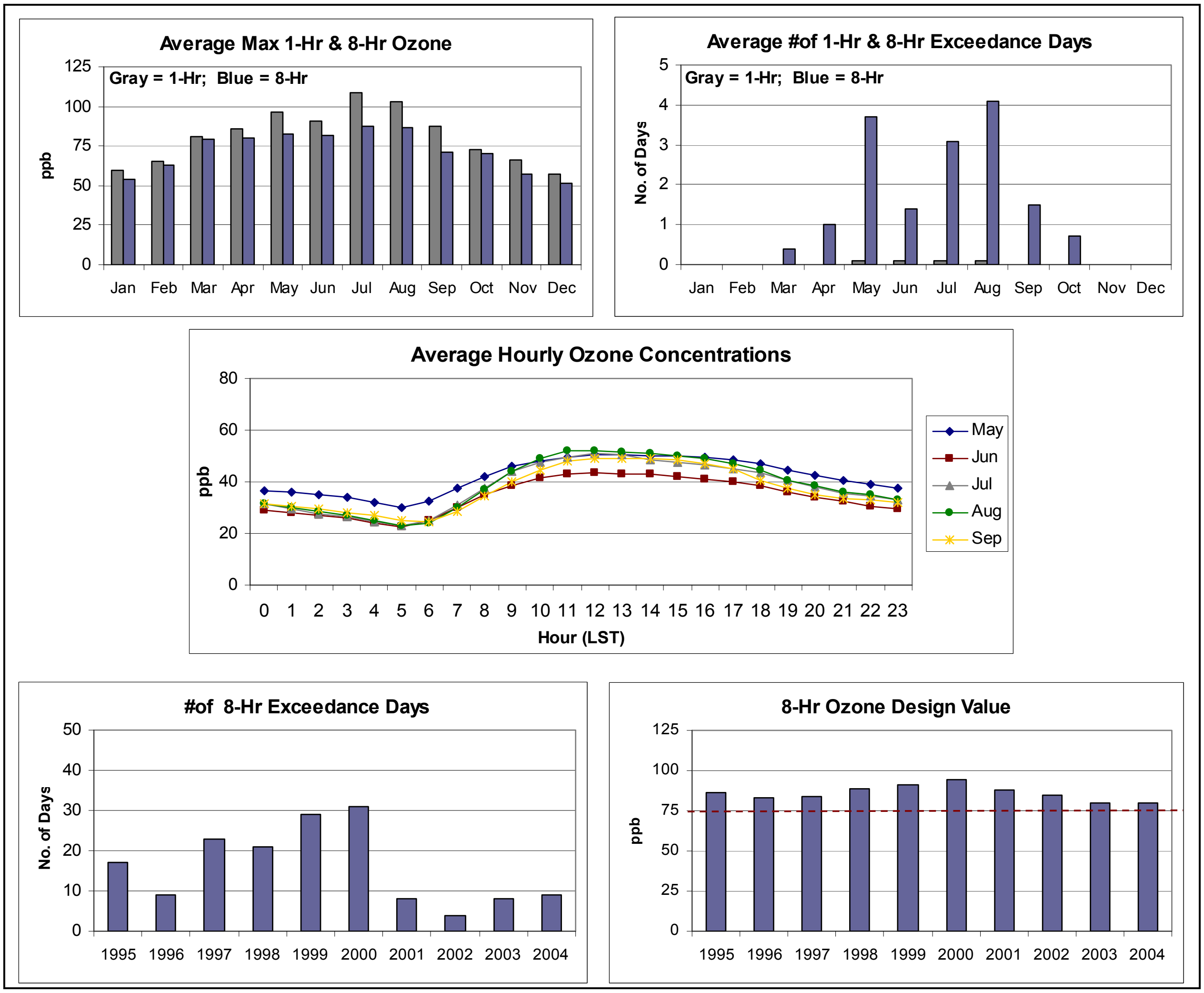


Figure 27. Ozone data summary for Pensacola area site (AQS # 120330018 (NAS)).

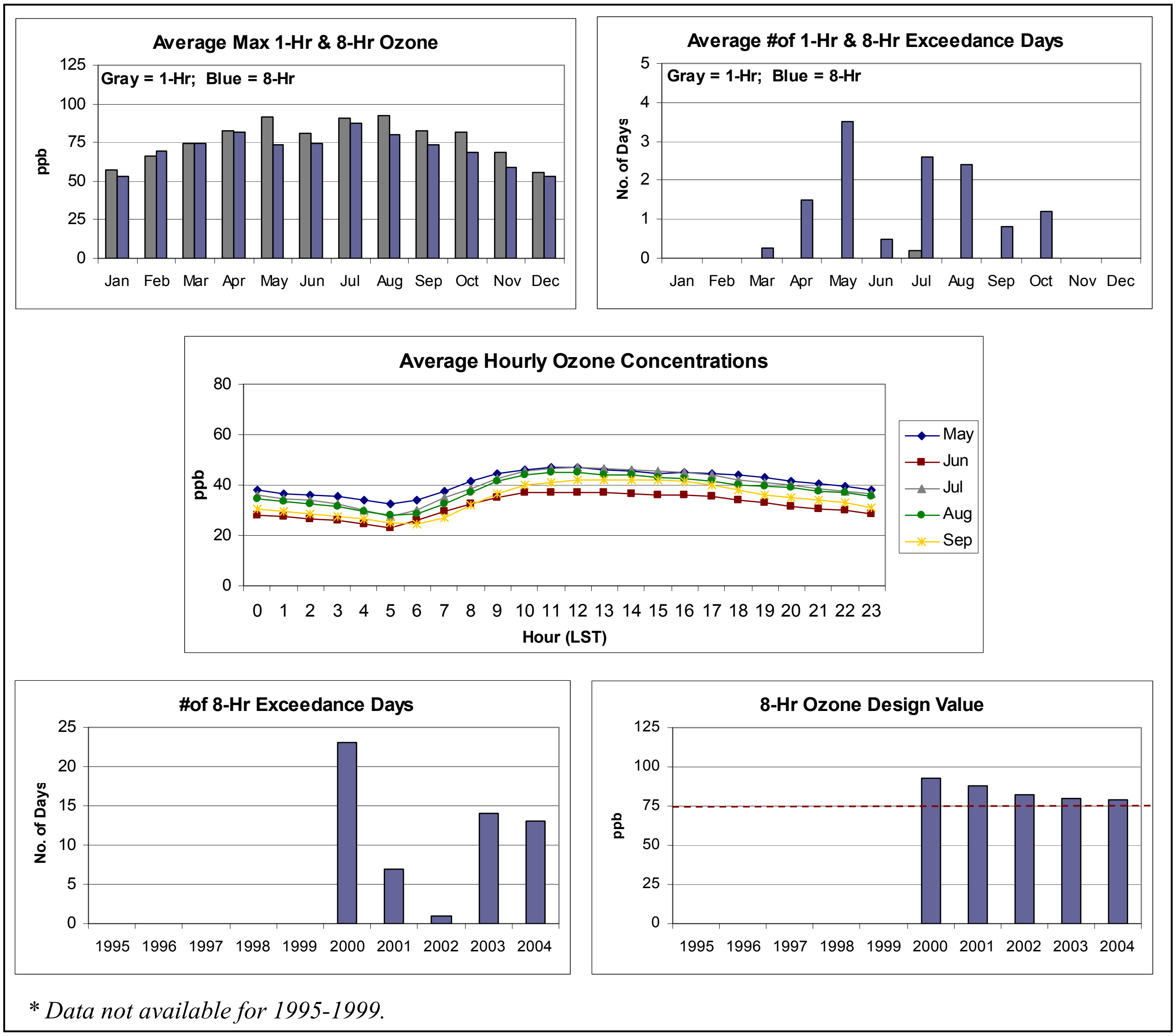


Figure 28. Ozone data summary for Panama City area site (AQS # 120050006).

Figure 29. Ozone data summary for Tampa area site (AQS # 120571065 (Gandy)).

These figures provide an overview of ozone along the Gulf Coast and highlight the severity of the ozone air quality issue for each area; the annual, monthly, and diurnal variations in ozone concentration for each area; and the key differences among the areas. To the extent possible, the same scales were used for each set of plots. However, the maximum value used to scale the first plot ("Average Max 1-Hr & 8-Hr Ozone") varies among the areas and is 200 ppb for Houston, 150 ppb for Galveston, Beaumont/Port Arthur and Baton Rouge and 125 ppb for the remainder of the areas. The higher values for Houston, Galveston, Beaumont/Port Arthur, and Baton Rouge reflect the higher ozone concentrations in those areas; and indicate that while all of the monitored areas experience high ozone, the severity of the ozone problem is correlated with the size of the urban area and the emissions.

In the western part of the region, the highest ozone concentrations tend to occur in August and September. For example, ozone concentrations and number of exceedance days are highest at the

Clinton site in Houston (Figure 16) in September and highest at the Galveston site (Figure 17) in August and September. Further eastward, the timing pattern of the ozone season changes. For example, high ozone/exceedance days occur in May, July and August in Gulfport (Figure 24), Pensacola (Figure 27) and several other areas. At the Tampa site (Figure 29) the peak month is May.

The average diurnal profiles also show some distinct differences that may be related to proximity to the coastline and the influence of the gulf breeze. For example, concentrations peak at about 1300 LST at the Baton Rouge (LSU) site and follow a classic diurnal profile. Baton Rouge is about 75 kilometers (km) (or 50 miles) from the coast and is also in an area where the gulf breeze is not expected to be prevalent (due to the lack of a well defined land-water boundary). For the coastal areas where a gulf breeze is expected (for example, Galveston (Figure 17) and Pensacola (Figure 27)) the average diurnal profile is much flatter and there is no distinct peak. Instead, moderately high ozone persists throughout the daytime hours and (in some cases) into the evening hours. Modeling studies (for example by Haney et al., 2004) have indicated that this prolonged period of moderate to high ozone is the result of photochemical production early in the day followed by the onshore transport of ozone from over the Gulf by the gulf breeze during the afternoon hours.

All of the selected areas have 8-hour ozone design values greater than the NAAQS for all or nearly all of the years included in this analysis. Without fully accounting for year-to-year differences in meteorology, a downward trend in the design values is apparent for most sites for the period 1999 (or 2000) to 2004. The design values for Houston (Figure 16) show a downward trend from 1995 to 2004. On the other hand, the design values for Lake Charles (Figure 19) show no tendency to either increase or decrease during that same period.

2.2.2. Combined Ozone and Meteorological Data Summaries

In the remainder of this section on ozone, the focus will be on the data for the period 2000-2004. This is done for ease of comparison with the $PM_{2.5}$ summaries (to follow) and other data analyses that will be presented later in this report.

Understanding the causes of high ozone concentrations along the Gulf Coast requires an understanding of the relationship between measured ozone concentration and meteorology. In this section, summary tables provide information about the meteorological conditions associated with different levels of ozone concentration at the various monitoring sites, and thus begin to explore this relationship. The observed ozone and meteorological data presented earlier were used to prepare the tables. Later in this report, additional data analysis techniques are used to examine the relative importance of the various meteorological parameters in determining ozone air quality and the specific combinations of parameters (conditions) that lead to high ozone at the monitoring sites.

To examine the variations in ozone versus meteorology, daily maximum 8-hour ozone was calculated for each area (as the maximum value over all sites within the area). Based on the value of daily maximum 8-hour ozone, each day was then placed into one of five concentration categories. These were defined using the ranges that EPA currently uses for ozone forecasting and calculating the daily, local air quality index and are: less than 60 ppb, 60 to 75 ppb, 75 to 95 ppb, 95 to 115 ppb and greater than or equal to 115 ppb. Then average values of a variety of meteorological parameters were calculated for all days within each of the ozone concentration categories. The highest category was not needed for all areas.

This analysis focuses on: Northwest Houston, Central Houston, Southeast Houston and Galveston, Beaumont/Port Arthur, Lake Charles, New Orleans, Baton Rouge, Gulfport, Mobile, and Pensacola. Houston was divided into three separate areas due to differences in the observed concentrations and more importantly the potential for differences in meteorology among these areas.

Meteorological data from the local surface monitoring site and the nearest upper-air monitoring site(s) were used to prepare the summary tables. For areas located between upper-air sites, multiple upper-air sites were considered.

The meteorological parameters include the following surface parameters: maximum and daily average temperature, relative humidity at noon, wind speed and direction for three three-hour daytime periods, persistence index, pressure, and rainfall amount.

The upper-air meteorological parameters include: 850 mb temperature, 900 mb to surface temperature difference (or stability index), change in geopotential height during the past 24 hours at 700 mb (an indicator of changing synoptic scale patterns), 850 mb wind speed and wind direction for the prior evening, morning, and evening soundings, a recirculation index (an indicator of upper-air wind persistence) and a cloud index.

Specific definitions for the data-derived parameters (or indexes) are as follows:

- **Persistence index:** 24-hour vector-averaged wind speed/24-hour scalar-averaged wind speed. This is an indicator of wind persistence. If the value is 1, this indicates that the vector-averaged and scalar-averaged wind speeds are the same, which further indicates that the wind was blowing from the same direction during the entire period. A value of 0 indicates that the wind was from one direction for half the time and from the opposite direction the other half of the time. Thus a low value indicates the potential for recirculation.
- **Recirculation index:** Recirculation index (value of 0 or 1) that is based on the difference between the average 850 mb wind direction for the prior day and the current day and/or the average 850 mb scalar wind speed for the current day. If the difference is within +/- 15 degrees of 180 degrees or if average scalar wind speed is < 3 ms^{-1} then the index is set to 1. Otherwise the value is 0.
- **Cloud index:** The cloud indicator parameter combines data from both 850 and 700 mb and was computed using data from the morning and evening soundings. The value is based on relative humidity at the 850 mb (rh850) and 700 mb (rh700) levels. Ranges from 1 to 3 are based on the empirical analysis of observed data and are defined as follows:
  - if (rh850 < 80% and rh700 < 65%) then cloud = 1;
  - if (rh850 >= 80% and rh700 < 65%) then cloud = 2;
  - if (rh850 < 80% and rh700 >= 65%) then cloud = 2;
  - if (rh850 >= 80% and rh700 >= 65%) then cloud = 3

In addition to the meteorological parameters, the average daily maximum 8-hour ozone concentration for each category is provided. Prior day average daily maximum 8-hour ozone concentrations for the area and potential upwind areas are also provided.

The combined ozone and meteorological summaries are given in Tables 4 through 13. Information for each area is presented in the order listed above (approximately west to east).

Table 4

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Northwest Houston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<60, 60-75,75-95 and 95-105 ppb.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	709	231	87	31
Ozone Parameters				
Ozone at Conroe (ppb)	42.7	66.5	84.0	107.0
Yesterday's Ozone Beaumont/Port Arthur (ppb)	44.3	60.9	72.0	73.5
Yesterday's Ozone at Houston/Galveston (ppb)	53.3	73.2	88.6	88.9
Surface Meteorological Parameters				
Max. surface temperature (°C)	29.6	30.9	31.8	31.6
Avg. surface temperature (°C)	25.3	25.7	26.0	26.0
Relative humidity at noon (%)	66	56	52	53
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.4	2.6	2.2	1.6
Surface wind speed at 1000 - 1300 LST (ms^{-1})	4.3	3.4	2.9	2.3
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.4	3.7	3.5	3.4
Surface wind direction 0700 - 1000 LST (degrees)	160	108	45	135
Surface wind direction 1000 - 1300 LST (degrees)	166	132	133	148
Surface wind direction 1300 - 1600 LST (degrees)	162	125	131	137
Persistence	0.8	0.8	0.7	0.8
Sea level pressure (mb)	1017	1018	1018	1018
Rainfall (inches)	0.3	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	16.4	16.1	16.3	16.1
Temperature PM 850 mb at Lake Charles (°C)	16.5	16.4	17.1	16.9
Stability at Lake Charles (°C)	-2.7	-1.0	-0.1	-1.4
Geopotential hgt difference 700 mb at Lake Charles (m)	-1.3	3.5	1.7	7.4
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.1	6.1	4.9	4.4
Wind speed AM 850 mb at Lake Charles (ms^{-1})	7.6	6.1	4.5	4.7
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.5	5.4	4.1	3.9
Wind dir. yesterday 850 mb at Lake Charles (degrees)	190	60	45	56
Wind dir. AM 850 mb at Lake Charles (degrees)	193	141	111	135
Wind dir. PM 850 mb at Lake Charles (degrees)	194	73	73	99
Recirculation index at Lake Charles	0.1	0.1	0.2	0.2

Table 5

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Central Houston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in Ozone Concentration for Categories 1 through 5 are as follows:
<60, 60-75,75-95,95-105 and ≥ 105 ppb.

	Category 1	Category 2	Category 3	Category 4	Category 5
No. of Days	689	170	129	62	17
Ozone Parameters					
Ozone at Houston (ppb)	38.3	66.9	85.5	103.8	126.5
Yesterday's Ozone at Houston/Galveston (ppb)	52.8	70.0	84.4	81.7	86.6
Yesterday's Ozone Beaumont/Port Arthur (ppb)	43.4	59.0	70.2	68.1	71.9
Surface Meteorological Parameters					
Max. surface temperature (°C)	29.5	30.3	32.1	31.9	32.6
Avg. surface temperature (°C)	25.2	25.0	26.7	26.2	26.7
Relative humidity at noon (%)	67	55	53	51	50
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.3	2.8	2.6	2.0	1.9
Surface wind speed at 1000 - 1300 LST (ms^{-1})	4.4	3.4	3.1	2.3	1.8
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.6	3.7	3.3	2.7	2.6
Surface wind dir. 0700 - 1000 LST (degrees)	164	47	14	45	45
Surface wind dir. 1000 - 1300 LST (degrees)	171	112	58	104	90
Surface wind dir. 1300 - 1600 LST (degrees)	167	114	97	103	117
Persistence	0.8	0.8	0.7	0.7	0.7
Sea level pressure (mb)	1017	1019	1017	1019	1016
Rainfall (inches)	0.3	0.1	0.0	0.0	0.0
Upper-Air Meteorological Parameters					
Temperature AM 850 mb at Lake Charles (°C)	16.4	15.7	16.6	16.0	16.2
Temperature PM 850 mb at Lake Charles (°C)	16.5	16.1	17.2	16.6	17.1
Stability at Lake Charles (°C)	-2.7	-0.8	-1.4	0.0	-0.8
Geopotential hgtdifference 700 mb at Lake Charles (m)	-0.1	0.6	0.5	3.8	-2.8
Wind speed yesterday 850 mb Lake Charles (ms^{-1})	6.2	6.0	5.4	5.1	6.1
Wind speed AM 850 mb at Lake Charles (ms^{-1})	7.8	5.7	4.8	4.6	4.6
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.5	5.2	5.0	4.3	4.7
Wind dir, yesterday 850 mb at Lake Charles (degrees)	186	38	38	31	11
Wind dir. AM 850 mb at Lake Charles (degrees)	193	139	73	38	90
Wind dir. PM 850 mb at Lake Charles (degrees)	193	49	55	39	48
Recirculation index at Lake Charles	0.1	0.2	0.2	0.2	0.1
Cloud index at Lake Charles	1.7	1.5	1.6	1.5	1.5

Table 6

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Southeastern Houston and Galveston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in Ozone Concentration for Categories 1 through 5 are as follows:
<60, 60-75,75-95,95-105 and ≥ 105 ppb.

	Category 1	Category 2	Category 3	Category 4	Category 5
No. of Days	734	181	116	29	10
Ozone Parameters					
Ozone at Galveston (ppb)	38.1	67.4	85.0	105.9	125.1
Yesterday's Ozone at Houston/Galveston (ppb)	53.8	74.8	81.8	79.3	101.7
Yesterday's Ozone Beaumont/Port Arthur (ppb)	44.1	63.9	68.6	64.9	77.9
Surface Meteorological Parameters					
Max. surface temperature (°C)	29.7	30.0	31.9	33.0	34.9
Avg. surface temperature (°C)	25.4	24.8	26.2	26.8	28.6
Relative humidity at noon (%)	66	56	52	51	47
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.2	2.9	2.3	1.9	2.4
Surface wind speed at 1000 - 1300 LST (ms^{-1})	4.3	3.6	2.7	2.2	2.1
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.5	3.8	3.2	2.3	1.8
Surface wind dir. 0700 - 1000 LST (degrees)	164	63	354	333	284
Surface wind dir. 1000 - 1300 LST (degrees)	169	87	76	315	323
Surface wind dir. 1300 - 1600 LST (degrees)	162	101	94	198	N/A
Persistence	0.8	0.8	0.7	0.6	0.5
Sea level pressure (mb)	1017	1019	1017	1017	1017
Rainfall (inches)	0.2	0.1	0.1	0.1	0.0
Upper-Air Meteorological Parameters					
Temperature AM 850 mb at Lake Charles (°C)	16.5	15.4	16.3	16.5	18.4
Temperature PM 850 mb at Lake Charles (°C)	16.6	15.8	16.7	17.3	19.9
Stability at Lake Charles (°C)	-2.7	-0.7	-0.6	-0.5	1.0
Geopotential hgt difference 700 mb at Lake Charles (m)	0.3	0.0	1.7	-1.6	-6.3
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.1	5.7	5.4	6.4	4.6
Wind speed AM 850 mb at Lake Charles (ms^{-1})	7.6	5.3	4.9	6.0	3.3
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.4	5.2	5.0	5.1	4.8
Wind dir. yesterday 850 mb at Lake Charles (degrees)	178	29	16	5	27
Wind dir. AM 850 mb at Lake Charles (degrees)	189	57	41	333	51
Wind dir. PM 850 mb at Lake Charles (degrees)	188	60	47	13	11
Recirculation index at Lake Charles	0.1	0.2	0.2	0.1	0.3
Cloud index at Lake Charles	1.7	1.6	1.5	1.6	1.9

Table 7

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Beaumont/Port Arthur.

Surface Meteorological Data are for Port Arthur SE TX Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as Follows:
<60, 60-75,75-95 and 95-105 ppb.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	726	208	122	14
Ozone Parameters				
Ozone at Beaumont/Port Arthur (ppb)	39.6	67.5	83.4	105.8
Yesterday's Ozone Beaumont/Port Arthur (ppb)	43.2	62.3	74.1	85.6
Yesterday's Ozone at Baton Rouge/New Orleans (ppb)	52.0	63.9	71.6	82.1
Yesterday's Ozone at Lake Charles (ppb)	41.1	54.9	63.4	66.9
Yesterday's Ozone at Houston/Galveston (ppb)	53.1	75.2	84.8	95.2
Surface Meteorological Parameters				
Max. surface temperature (°C)	29.3	30.5	31.7	35.8
Avg. surface temperature (°C)	24.9	24.6	25.3	28.4
Relative humidity at noon (%)	69	56	49	47
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.6	3.1	2.7	2.9
Surface wind speed at 1000 - 1300 LST (ms^{-1})	4.6	3.7	3.0	2.9
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.9	3.7	3.4	3.3
Surface wind direction 0700 - 1000 LST (degrees)	149	37	21	299
Surface wind direction 1000 - 1300 LST (degrees)	163	70	56	346
Surface wind direction 1300 - 1600 LST (degrees)	166	93	112	0
Persistence	0.8	0.7	0.7	0.6
Sea level pressure (mb)	1017	1018	1018	1015
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	16.4	15.8	16.0	19.1
Temperature PM 850 mb at Lake Charles (°C)	16.5	16.3	16.6	19.9
Stability at Lake Charles (°C)	-2.7	-0.9	-0.3	0.5
Geopotential hgt difference 700 mb at Lake Charles (m)	0.8	0.1	-1.4	-5.4
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.2	5.4	5.5	5.3
Wind speed AM 850 mb at Lake Charles (ms^{-1})	7.7	5.4	4.6	4.7
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.3	5.4	4.8	5.2
Wind dir. yesterday 850 mb at Lake Charles (degrees)	179	22	27	21
Wind dir. AM 850 mb at Lake Charles (degrees)	190	101	49	22
Wind dir. PM 850 mb at Lake Charles (degrees)	187	54	40	23
Recirculation index at Lake Charles	0.1	0.2	0.2	0.1
Cloud index at Lake Charles	1.7	1.6	1.4	1.8

Table 8

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Lake Charles.

Surface Meteorological Data are for Lake Charles Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<60, 60-75,75-95 and 95-105 ppb.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	836	170	49	15
Ozone Parameters				
Ozone at Lake Charles (ppb)	39.9	66.4	80.1	91.1
Yesterday's Ozone at Lake Charles (ppb)	42.0	60.8	69.3	72.7
Yesterday's Ozone at Baton Rouge (ppb)	52.3	70.6	79.4	88.0
Yesterday's Ozone Beaumont/Port Arthur (ppb)	45.2	68.3	80.1	78.9
Yesterday's Ozone at Houston/Galveston (ppb)	55.3	81.1	90.4	94.1
Surface Meteorological Parameters				
Max. surface temperature (°C)	29.4	30.9	32.0	32.3
Avg. surface temperature (°C)	24.6	24.8	25.2	25.7
Relative humidity at noon (%)	66	53	48	47
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.0	2.4	2.1	1.7
Surface wind speed at 1000 - 1300 LST (ms^{-1})	4.0	3.2	2.7	2.5
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.0	3.1	2.9	2.6
Surface wind direction 0700 - 1000 LST (degrees)	114	77	63	0
Surface wind direction 1000 - 1300 LST (degrees)	144	84	74	315
Surface wind direction 1300 - 1600 LST (degrees)	158	133	127	171
Persistence	0.8	0.7	0.7	0.7
Sea level pressure (mb)	1018	1019	1018	1018
Rainfall (inches)	0.2	0.0	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	16.3	15.9	16.6	17.3
Temperature PM 850 mb at Lake Charles (°C)	16.4	16.6	17.5	17.7
Stability at Lake Charles (°C)	-2.5	-0.6	0.4	0.9
Geopotential hgt difference 700 mb at Lake Charles (m)	0.2	2.3	-4.7	-0.4
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.2	5.4	5.3	4.2
Wind speed AM 850 mb at Lake Charles (ms^{-1})	7.4	5.3	3.9	3.7
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.3	5.2	4.1	4.3
Wind dir. yesterday 850 mb at Lake Charles (degrees)	176	35	23	21
Wind dir. AM 850 mb at Lake Charles (degrees)	188	143	55	207
Wind dir. PM 850 mb at Lake Charles (degrees)	180	67	51	72
Recirculation index at Lake Charles	0.1	0.2	0.2	0.1
Cloud index at Lake Charles	1.7	1.5	1.4	1.3

Table 9

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: New Orleans.

Surface Meteorological Data are for New Orleans International Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<60, 60-75,75-95 and 95-105 ppb.

	Category 1	Category 2	Category 3	Category 4
No. of Days	785	205	73	7
Ozone Parameters				
Ozone at New Orleans (ppb)	41.5	67.6	83.3	101.7
Yesterday's Ozone at New Orleans (ppb)	44.0	62.4	72.7	82.0
Yesterday's Ozone at Baton Rouge (ppb)	50.2	66.9	79.3	99.2
Yesterday's Ozone at Houston/Galveston/Beaumont/Port Arthur (ppb)	57.3	75.1	88.3	97.0
Yesterday's Ozone at MS coastal sites (ppb)	47.2	61.5	70.8	84.8
Surface Meteorological Parameters				
Max. surface temperature (°C)	29.5	30.0	31.1	34.2
Avg. surface temperature (°C)	25.3	25.1	25.9	28.5
Relative humidity at noon (%)	66	53	52	52
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.5	3.3	2.6	2.6
Surface wind speed at 1000 - 1300 LST (ms^{-1})	4.3	4.1	3.5	3.4
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.3	4.0	3.5	3.4
Surface wind direction 0700 - 1000 LST (degrees)	131	42	25	279
Surface wind direction 1000 - 1300 LST (degrees)	134	9	6	284
Surface wind direction 1300 - 1600 LST (degrees)	152	0	2	323
Persistence	0.8	0.7	0.7	0.7
Sea Level pressure (mb)	1018	1018	1018	1017
Rainfall (inches)	0.3	0.0	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	16.0	15.4	15.4	18.1
Temperature PM 850 mb at Slidell (°C)	16.0	15.1	15.7	18.3
Stability at Slidell (°C)	-1.7	0.8	1.5	1.0
Geopotential height difference 700 mb at Slidell (m)	-0.4	2.5	1.7	0.6
Wind speed yesterday 850 mb at Slidell (ms^{-1})	6.2	6.2	5.5	3.9
Wind speed AM 850 mb at Slidell (ms^{-1})	6.9	5.9	4.6	6.2
Wind speed PM 850 mb at Slidell (ms^{-1})	6.3	5.9	5.0	4.3
Wind direction yesterday 850 mb at Slidell (degrees)	216	12	4	22
Wind direction AM 850 mb at Slidell (degrees)	203	303	22	270
Wind direction PM 850 mb at Slidell (degrees)	232	31	7	351
Recirculation index at Slidell	0.1	0.1	0.2	0.3
Cloud index at Slidell	1.8	1.5	1.4	1.3

Table 10

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Baton Rouge.

Surface Meteorological Data are for Baton Rouge Ryan Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<60, 60-75,75-95 and 95-105 ppb.

	Category 1	Category 2	Category 3	Category 4
No. of Days	648	264	124	34
Ozone Parameters				
Ozone at Baton Rouge (ppb)	43.1	66.9	84.0	104.8
Yesterday's Ozone at Baton Rouge (ppb)	47.5	63.5	74.4	83.0
Yesterday's Ozone at New Orleans (ppb)	42.0	58.2	66.4	71.4
Yesterday's Ozone at Houston/Galveston/Beaumont/Port Arthur (ppb)	54.4	72.0	82.1	91.2
Surface Meteorological Parameters				
Max. surface temperature (°C)	29.2	30.6	31.1	33.8
Avg. surface temperature (°C)	24.0	24.2	24.5	26.9
Relative humidity at noon (%)	65	53	48	47
Surface wind speed at 0700 - 1000 LST (ms^{-1})	2.8	2.3	1.9	1.6
Surface wind speed at 1000 - 1300 LST (ms^{-1})	3.8	3.2	2.6	2.0
Surface wind speed at 1300 - 1600 LST (ms^{-1})	3.7	3.4	2.9	2.3
Surface wind direction 0700 - 1000 LST (degrees)	122	82	81	79
Surface wind direction 1000 - 1300 LST (degrees)	156	108	107	45
Surface wind direction 1300 - 1600 LST (degrees)	161	111	132	180
Persistence	0.8	0.8	0.7	0.6
Sea level pressure (mb)	1018	1018	1018	1017
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	16.0	15.4	15.4	18.1
Temperature PM 850 mb at Slidell (°C)	15.9	15.8	16.2	18.7
Stability at Slidell (°C)	-1.9	-0.1	1.3	1.0
Geopotential height difference 700 mb at Slidell (m)	-0.7	1.4	3.0	0.3
Wind speed yesterday 850 mb at Slidell (ms^{-1})	6.4	5.9	5.8	5.1
Wind speed AM 850 mb at Slidell (ms^{-1})	7.3	5.6	5.2	4.3
Wind speed PM 850 mb at Slidell (ms^{-1})	6.7	5.3	5.2	4.6
Wind direction yesterday 850 mb at Slidell (degrees)	222	21	16	23
Wind direction AM 850 mb at Slidell (degrees)	205	214	63	301
Wind direction PM 850 mb at Slidell (degrees)	231	27	38	0
Recirculation index at Slidell	0.1	0.2	0.2	0.1
Cloud index at Slidell	1.8	1.6	1.4	1.4

Table 11

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Gulfport.

Surface Meteorological Data are for Gulfport–Biloxi Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<60, 60-75,75-95 and 95-105 ppb.

	Category 1	Category 2	Category 3	Category 4
No. of Days	770	203	59	3
Ozone Parameters				
Ozone at Gulfport (ppb)	42.4	67.2	82.0	100.0
Yesterday's Ozone at Mobile (ppb)	44.4	63.4	72.5	87.3
Yesterday's Ozone at New Orleans (ppb)	44.5	64.0	70.7	92.0
Yesterday's Ozone at MS coastal sites (ppb)	47.3	64.2	71.3	86.6
Surface Meteorological Parameters				
Max. surface temperature (°C)	28.6	29.5	30.4	30.7
Avg. surface temperature (°C)	24.4	24.0	24.4	25.4
Relative humidity at noon (%)	66	52	49	49
Surface wind speed at 0700 - 1000 LST (ms^{-1})	6.2	5.5	5.4	5.3
Surface wind speed at 1000 - 1300 LST (ms^{-1})	7.0	5.0	4.6	6.2
Surface wind speed at 1300 - 1600 LST (ms^{-1})	6.3	5.5	4.5	4.8
Surface wind direction 0700 - 1000 LST (degrees)	52	17	4	0
Surface wind direction 1000 - 1300 LST (degrees)	144	103	128	207
Surface wind direction 1300 - 1600 LST (degrees)	168	176	180	180
Persistence	0.8	0.6	0.6	0.8
Sea level pressure (mb)	1018	1018	1018	1018
Rainfall (inches)	0.2	0.0	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	15.8	15.8	15.8	15.5
Temperature PM 850 mb at Slidell (°C)	15.9	16.1	16.7	16.3
Stability at Slidell (°C)	-1.5	1.0	1.8	1.7
Geopotential height difference 700 mb at Slidell (m)	-0.1	0.0	6.9	-7.8
Wind speed yesterday 850 mb at Slidell (ms^{-1})	7.1	5.5	4.8	5.1
Wind speed AM 850 mb at Slidell (ms^{-1})	7.8	5.6	5.6	6.5
Wind speed PM 850 mb at Slidell (ms^{-1})	7.1	5.3	5.2	5.8
Wind direction yesterday 850 mb at Slidell (degrees)	225	15	12	90
Wind direction AM 850 mb at Slidell (degrees)	207	253	270	90
Wind direction PM 850 mb at Slidell (degrees)	245	35	20	270
Recirculation index at Slidell	0.1	0.2	0.2	0.3
Cloud index at Slidell	1.8	1.5	1.3	1.0
Wind speed yesterday 850 mb at Jackson (ms^{-1})	7.1	5.5	4.8	5.1
Wind speed AM 850 mb at Jackson (ms^{-1})	7.8	5.6	5.6	6.5
Wind speed PM 850 mb at Jackson (ms^{-1})	7.1	5.3	5.2	5.8
Wind direction yesterday 850 mb at Jackson (degrees)	212	1	0	180
Wind direction AM 850 mb at Jackson (degrees)	232	280	309	225
Wind direction PM 850 mb at Jackson (degrees)	224	32	222	243
Cloud index at Jackson	1.8	1.5	1.4	1.0

Table 12

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Mobile.

Surface Meteorological Data are for Mobile Regional Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<60, 60-75,75-95 and 95-105 ppb.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	757	233	62	7
Ozone Parameters				
Ozone at Mobile (ppb)	41.0	67.0	82.3	100.6
Yesterday's Ozone at Mobile (ppb)	43.4	61.9	75.5	81.8
Yesterday's Ozone at Pascagoula (ppb)	43.0	58.8	70.9	76.0
Yesterday's Ozone at Pensacola (ppb)	44.3	61.9	74.5	86.3
Yesterday’s Ozone at Port Bienville/Gulfport (ppb)	45.8	61.7	71.6	73.0
Surface Meteorological Parameters				
Max. surface temperature (°C)	28.9	30.4	32.5	36.7
Avg. surface temperature (°C)	23.9	24.0	25.5	29.5
Relative humidity at noon (%)	62	47	41	40
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.2	2.7	2.4	2.8
Surface wind speed at 1000 - 1300 LST (ms^{-1})	3.9	3.3	2.8	2.9
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.2	3.6	2.9	2.9
Surface wind direction 0700 - 1000 LST (degrees)	94	27	352	323
Surface wind direction 1000 - 1300 LST (degrees)	153	37	0	323
Surface wind direction 1300 - 1600 LST (degrees)	172	202	280	270
Persistence	0.8	0.7	0.6	0.7
Sea level pressure (mb)	1019	1019	1018	1016
Rainfall (inches)	0.2	0.0	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	15.9	15.4	16.7	19.6
Temperature PM 850 mb at Slidell (°C)	15.9	15.9	17.1	20.5
Stability at Slidell (°C)	-1.6	0.7	1.6	1.0
Geopotential height difference 700 mb at Slidell (m)	0.7	1.8	-5.3	-10.3
Wind speed yesterday 850 mb at Slidell (ms^{-1})	6.3	5.8	4.9	5.7
Wind speed AM 850 mb at Slidell (ms^{-1})	7.0	5.5	4.7	2.9
Wind speed PM 850 mb at Slidell (ms^{-1})	6.3	5.6	5.0	3.2
Wind direction yesterday 850 mb at Slidell (degrees)	218	6	6	34
Wind direction AM 850 mb at Slidell (degrees)	204	245	247	0
Wind direction PM 850 mb at Slidell (degrees)	231	23	8	27
Cloud index at Slidell	1.8	1.5	1.4	1.3
Wind speed yesterday 850 mb at Jackson (ms^{-1})	7.1	5.9	4.9	4.8
Wind speed AM 850 mb at Jackson (ms^{-1})	7.9	6.0	5.6	3.3
Wind speed PM 850 mb at Jackson (ms^{-1})	7.1	5.7	5.0	4.9
Wind dir. yesterday 850 mb at Jackson (degrees)	207	351	339	0
Wind direction AM 850 mb at Jackson (degrees)	228	273	313	0
Wind direction PM 850 mb at Jackson (degrees)	213	322	292	243
Cloud index at Jackson	1.9	1.5	1.5	1.4

Table 13

Summary of Ozone and Meteorological Data by Ozone Concentration Category for 2000-2004: Pensacola.

Surface Meteorological Data are for Pensacola Regional Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows: <60, 60-75,75-95 and 95-105 ppb.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	777	221	64	5
Ozone Parameters				
Ozone at Pensacola (ppb)	42.1	67.4	83.2	102.5
Yesterday's Ozone at Pensacola (ppb)	44.5	62.2	74.7	79.9
Yesterday's Ozone at Mobile (ppb)	43.8	61.8	74.8	74.1
Yesterday's Ozone at MS coastal sites (ppb)	46.9	62.9	72.9	67.7
Surface Meteorological Parameters				
Max. surface temperature (°C)	28.6	29.2	31.8	33.3
Avg. surface temperature (°C)	24.4	23.9	26.0	27.5
Relative humidity at noon (%)	66	51	42	44.6
Surface wind speed at 0700 - 1000 LST (ms^{-1})	3.2	2.8	2.8	1.7
Surface wind speed at 1000 - 1300 LST (ms^{-1})	4.1	3.5	3.2	2.9
Surface wind speed at 1300 - 1600 LST (ms^{-1})	4.6	4.2	3.9	3.3
Surface wind direction 0700 - 1000 LST (degrees)	79	14	354	315
Surface wind direction 1000 - 1300 LST (degrees)	128	81	10	0
Surface wind direction 1300 - 1600 LST (degrees)	164	180	198	194
Persistence	0.8	0.6	0.6	0.6
Sea level pressure (mb)	1019	1019	1018	1018
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	16.0	15.3	16.3	18.3
Temperature PM 850 mb at Slidell (°C)	16.0	15.7	16.8	18.4
Stability at Slidell (°C)	-1.6	1.1	1.2	1.0
Geopotential height difference 700 mb at Slidell (m)	0.3	0.6	2.0	-8.5
Wind speed yesterday 850 mb at Slidell (ms^{-1})	6.3	5.8	4.4	5.1
Wind speed AM 850 mb at Slidell (ms^{-1})	7.0	5.5	4.6	4.0
Wind speed PM 850 mb at Slidell (ms^{-1})	6.3	5.7	4.8	3.9
Wind direction yesterday 850 mb at Slidell (degrees)	216	8	351	56
Wind direction AM 850 mb at Slidell (degrees)	204	265	219	72
Wind direction PM 850 mb at Slidell (degrees)	238	19	18	90
Cloud index at Slidell	1.8	1.5	1.3	1.4
Wind speed yesterday 850 mb at Tallahassee (ms^{-1})	5.9	5.7	5.3	5.0
Wind speed AM 850 mb at Tallahassee (ms^{-1})	6.6	5.8	4.8	6.0
Wind speed PM 850 mb at Tallahassee (ms^{-1})	6.2	4.9	4.8	7.2
Wind dir. yesterday 850 mb at Tallahassee (degrees)	220	334	342	346
Wind direction AM 850 mb at Tallahassee (degrees)	209	286	308	0
Wind direction PM 850 mb at Tallahassee (degrees)	241	350	348	346
Cloud index at Tallahassee	1.8	1.6	1.5	1.4
Wind speed yesterday 850 mb at Birmingham (ms^{-1})	6.7	5.8	5.4	5.0
Wind speed AM 850 mb at Birmingham (ms^{-1})	7.6	6.6	6.6	6.2
Wind speed PM 850 mb at Birmingham (ms^{-1})	6.7	5.4	5.5	3.9
Wind dir. yesterday 850 mb at Birmingham (degrees)	214	343	338	326
Wind direction AM 850 mb at Birmingham (degrees)	231	300	314	346
Wind direction PM 850 mb at Birmingham (degrees)	231	326	326	304

The categorical comparisons reveal some expected patterns. For most areas, there are clear relationships between ozone concentration and 1) prior day ozone concentrations, 2) temperature, 3) relative humidity, 4) wind speed, both near the surface and aloft, and 5) stability. Higher ozone concentrations are associated with higher prior day ozone concentrations (carryover), higher temperatures, lower relative humidity, lower wind speeds, and greater stability. For several areas, such as Galveston, Beaumont/Port Arthur, and Pensacola, higher ozone is associated with less persistent wind directions (a greater tendency for a gulf breeze). Overall, the data suggest that the relationship between ozone and meteorology is rather complex (and that no single meteorological parameter or group of parameters easily defines this relationship)

Hsu (personal communication, 2008) found that, for operational applications, 8-hr ozone concentration for sites in the northern GOM region can be related to surface relative humidity. Using the concentration and relative humidity values from Tables 4 through 13, Hsu found that the average ozone concentrations decrease exponentially with increasing relative humidity and that the coefficient of determination (R-squared) is 0.75, which means that 75 percent of the total variation of ozone among the categories can be explained by the average relative humidity for the categories. This result may be useful for operation applications.

2.3. $PM_{2.5}$ DATA SUMMARIES

In addition to ozone, fine particulate matter ($PM_{2.5}$) is also a pollutant of concern in the coastal and offshore areas of the GOM because of its effects on human health, deposition to land and waterways, and regional haze/visibility. As presented in Section 1, with the exception of Houston, all coastal sites are in compliance of the annual $PM_{2.5}$ standard, while all sites are in compliance with the 24-hr standard.

In this study, historical $PM_{2.5}$ data for the period 1998 through 2004 (2000 through 2004 for most areas) were examined, for 14 different areas along the coast. These areas include:

- Houston, Texas
- Galveston, Texas
- Beaumont/Port Arthur, Texas
- Lake Charles, Louisiana
- Lafayette, Louisiana
- Terrebonne Parish, Louisiana
- New Orleans, Louisiana
- Baton Rouge, Louisiana
- Gulfport, Mississippi
- Pascagoula, Mississippi
- Mobile, Alabama
- Pensacola, Florida
- Panama City, Florida
- Tampa, Florida.

The locations are shown in Figure 30.

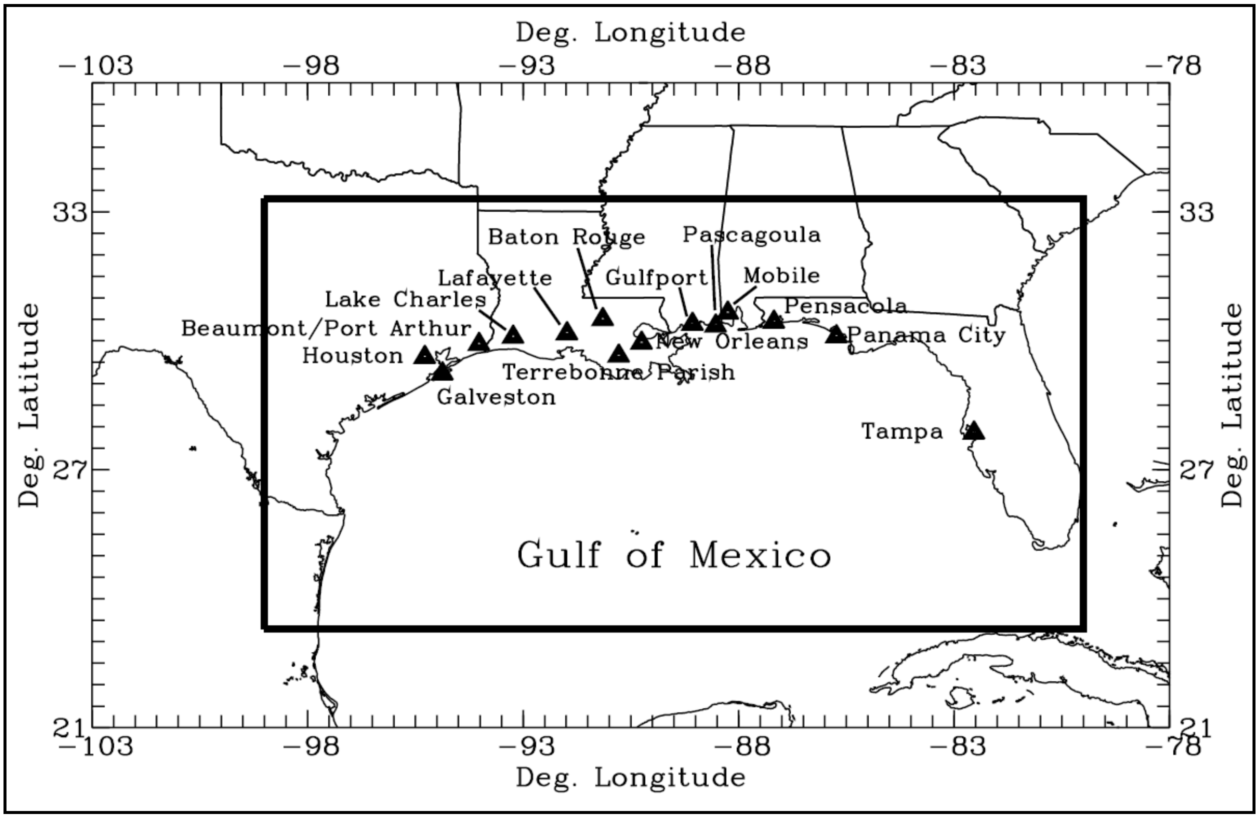


Figure 30. $PM_{2.5}$ monitoring sites for the MMS synthesis data summaries.

For areas with more than one $PM_{2.5}$ monitoring site, a representative monitoring site was selected, based on the calculated $PM_{2.5}$ design value and the length of the data record. Sites with average $PM_{2.5}$ concentrations near the design value for the area and longer data records were favored. In addition to the $PM_{2.5}$ data for these sites, surface and upper-air meteorological data from nearby sites were also examined with the goal of determining whether relationships between meteorology and $PM_{2.5}$ are readily apparent in the observed data. The $PM_{2.5}$ data were obtained from the EPA AQS database (USEPA, 2009a). All of the data presented in this section are included in the GMAQDB. Detailed site information is also included in the GMAQDB.

2.3.1. Selected $PM_{2.5}$ Metrics

In this section, plots illustrating the monthly, quarterly, and annual variations in total $PM_{2.5}$ concentration for the representative sites for each area of interest are presented and discussed. The metrics used to present the $PM_{2.5}$ data and derived information are as follows:

- Daily average (24-hour average) $PM_{2.5}$ concentration (μgm^{-3}) (and various monthly and quarterly averages based on this value).
- Number of days on which the daily average $PM_{2.5}$ concentration exceeds 15 μgm^{-3} (the annual NAAQS threshold).
- Number of days on which the daily average $PM_{2.5}$ concentration exceeds 35 μgm^{-3} (the 24-hour $PM_{2.5}$ NAAQS).

- Annual average $PM_{2.5}$ concentration (μgm^{-3}).
- 98th percentile 24-hour average $PM_{2.5}$ concentration (μgm^{-3}).
- Annual $PM_{2.5}$ design value (μgm^{-3}) (the three-year average annual mean concentration).
- 24-hr $PM_{2.5}$ design value (μgm^{-3}) (the three-year average of the 98th percentile daily average concentration).

Figures 31 through 44 summarize $PM_{2.5}$ air quality for the selected sites and metrics. The first chart (upper left-hand corner) presents the average (over all years) of both the daily average (gray bar) and maximum (red bar) $PM_{2.5}$ concentration for each month. The second chart (upper right hand corner) gives the average (over all years) of both the daily average (gray bar) and maximum (red bar) $PM_{2.5}$ concentration for each quarter. The third chart (left middle of the page) displays the annual average $PM_{2.5}$ concentration for each year between 1999-2004 with available data. The fourth chart (right middle of the page) gives the annual design value (the end year of each three-year period is shown on the plot). The dashed, red line marks the 15 μgm^{-3} NAAQS level. The next chart (lower left hand corner) displays the 98th percentile 24-hour $PM_{2.5}$ concentration for each year between 1999-2004 with available data. The final chart (lower right-hand corner) gives the 24-hour $PM_{2.5}$ design value (again, the end year of each three-year period is shown on the plot). The dashed, red line marks the 35 μgm^{-3} NAAQS level. $PM_{2.5}$ data collection for the selected sites began between 1998 and 2002. Thus, not all sites have complete data for the full period and some of the annual charts are for a subset of the full period. For these sites, the earlier design values may be based on one or two years of data, rather than the full three years of data. The annual $PM_{2.5}$ NAAQS requires the annual design value to be less than 15 μgm^{-3}. The daily $PM_{2.5}$ standard requires the 24-hour design value to be less than 35 μgm^{-3}.

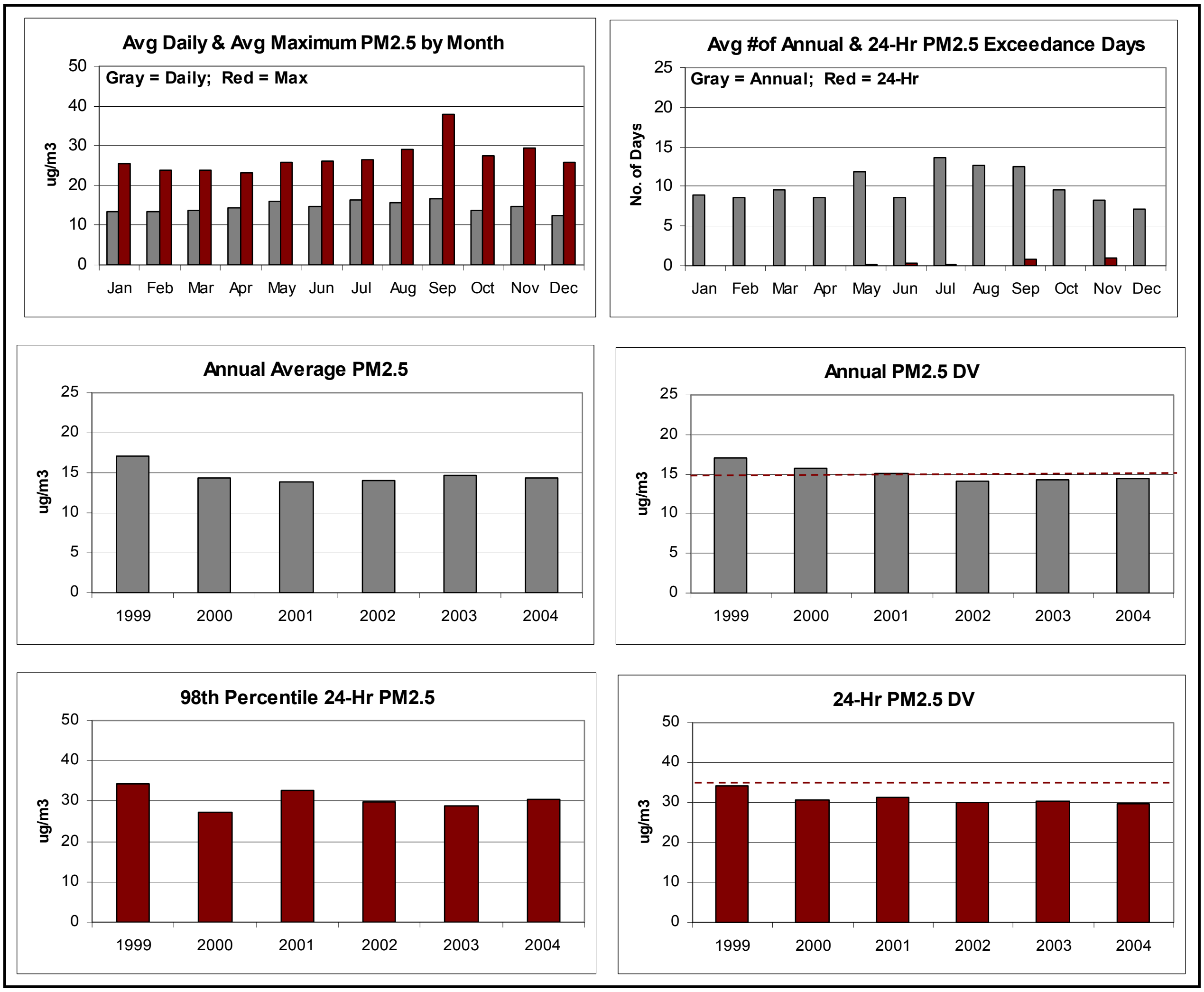
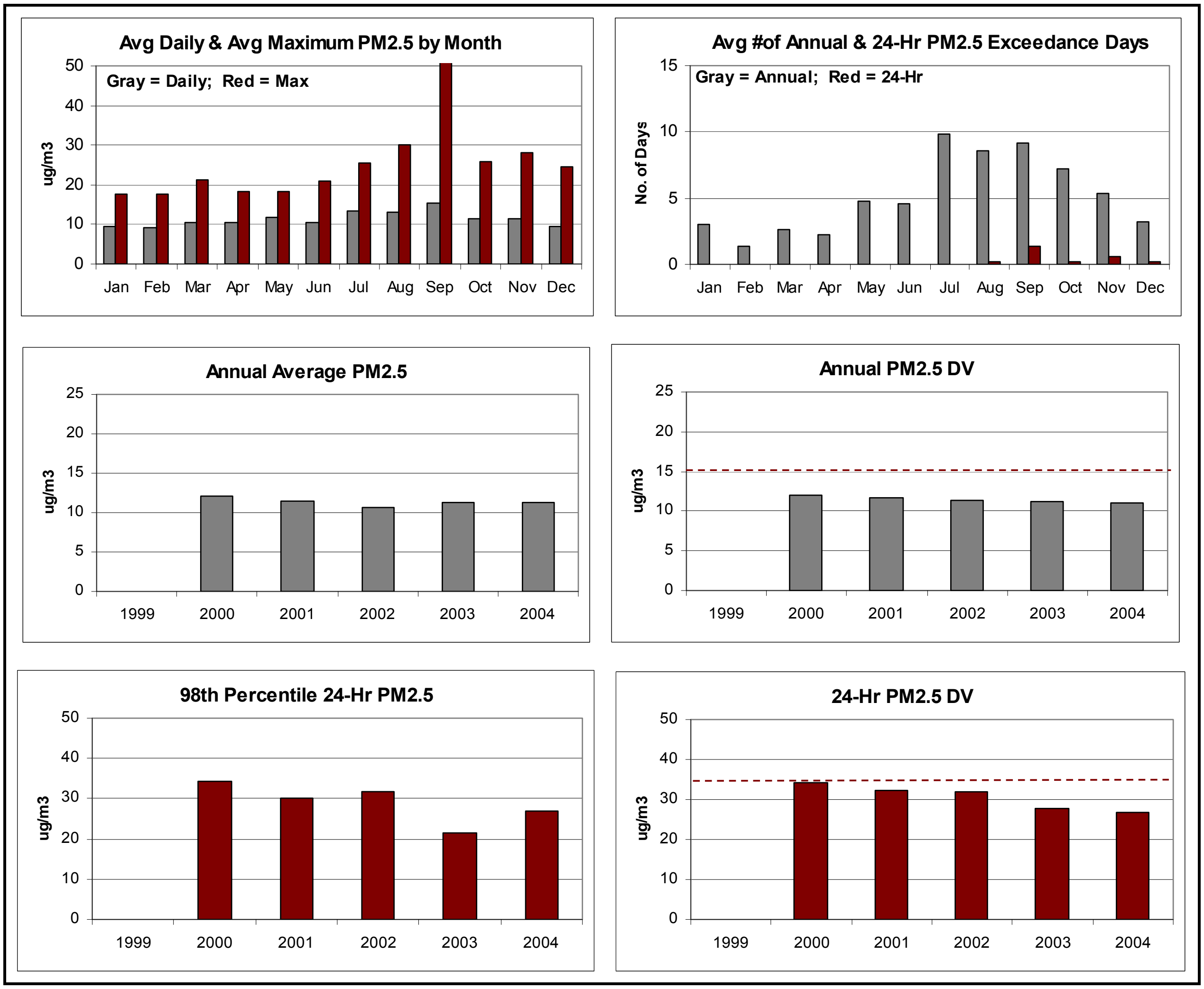


Figure 31. $PM_{2.5}$ data summary for Houston area site (AQS # 482011035 (Clinton)).

** Data not available for 1999.*

Figure 32. $PM_{2.5}$ data summary for Galveston area site (AQS # 481670014).



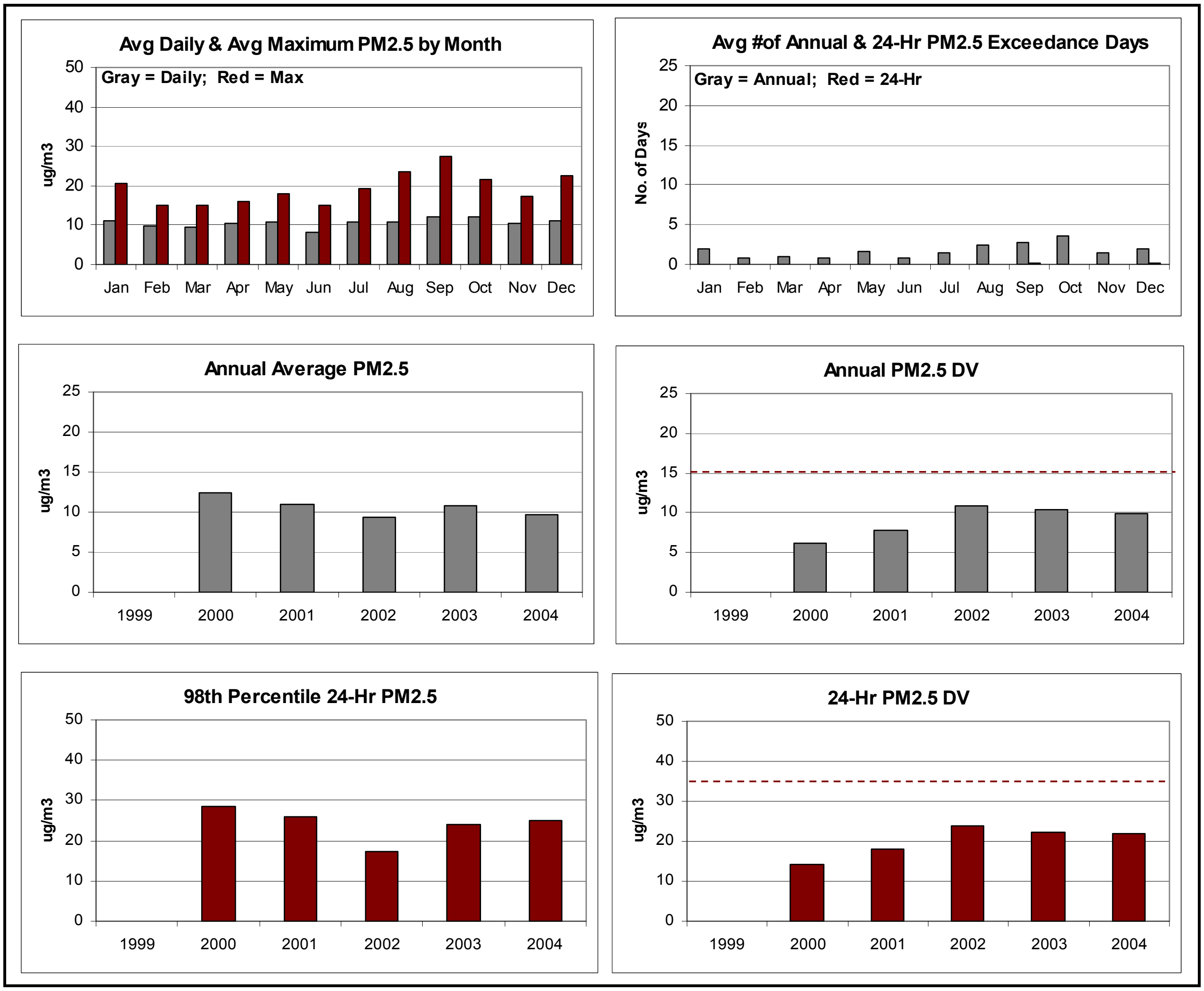
** Data not available for 1999.*

Figure 33. $PM_{2.5}$ data summary for Beaumont/Port Arthur area site (AQS # 482450021 (Port Arthur)).

Figure 34. $PM_{2.5}$ data summary for Lake Charles area site (AQS # 220190010 (Common)).

** Data not available for 1999.*

Figure 35. $PM_{2.5}$ data summary for Lafayette area site (AQS # 220550006).



** Data not available for 1999.*

Figure 36. $PM_{2.5}$ data summary for Terrebonne Parish site (AQS #221090001).

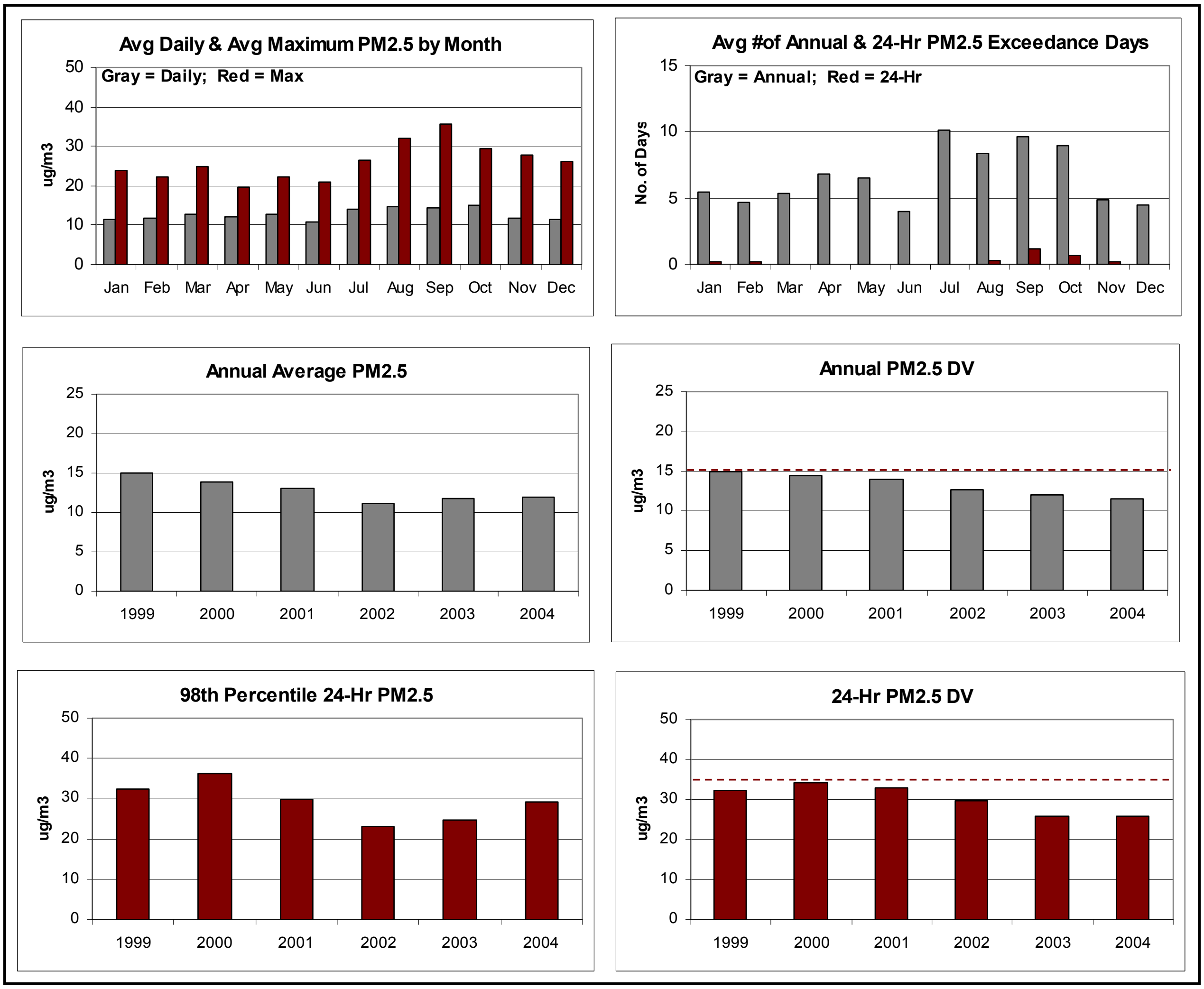


Figure 37. $PM_{2.5}$ data summary for New Orleans area site (AQS # 220710012 (Orleans)).

Figure 38. $PM_{2.5}$ data summary for Baton Rouge area site (AQS # 220330009 (Capitol)).

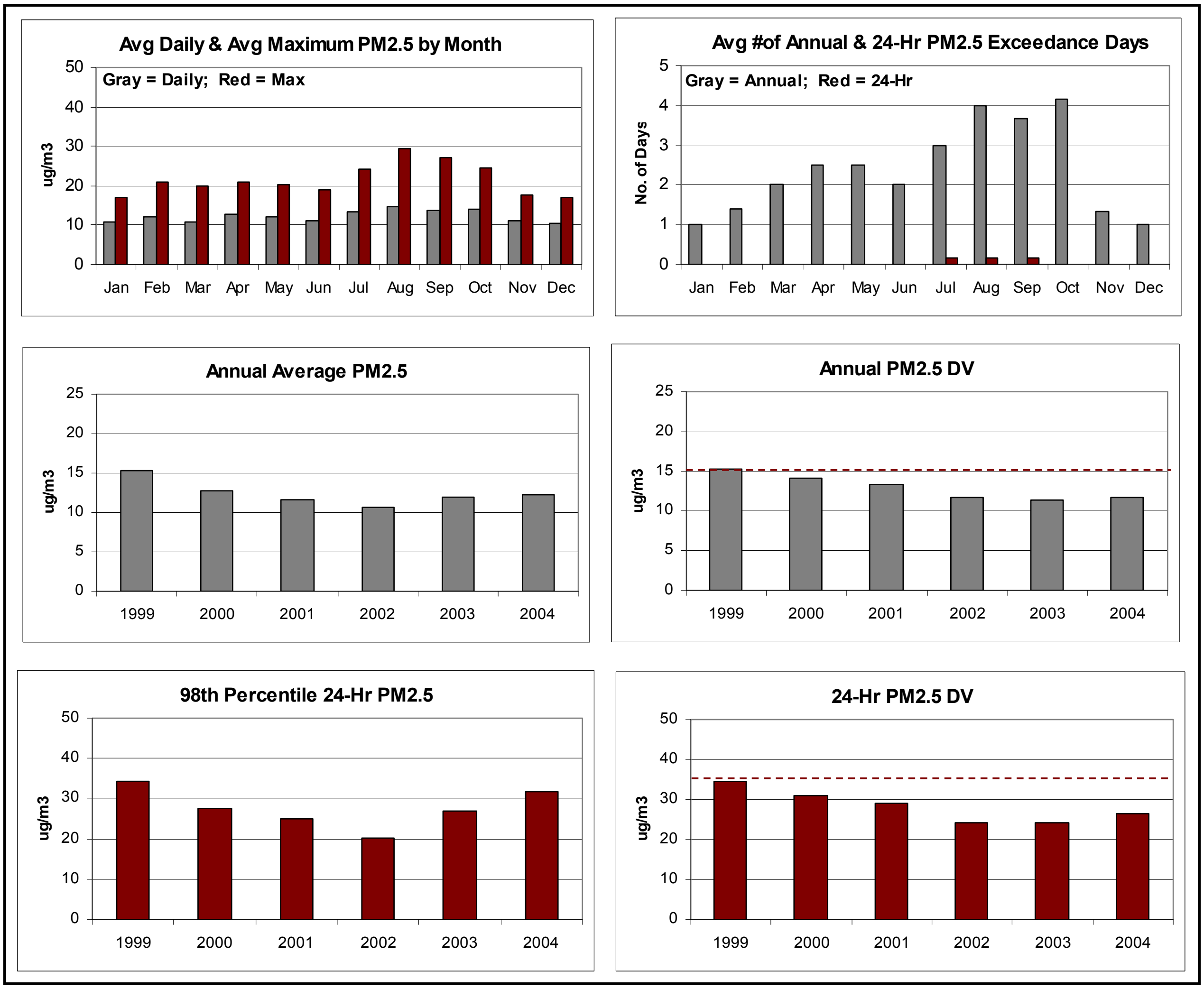


Figure 39. $PM_{2.5}$ data summary for Gulfport area site (AQS # 280470008).

Figure 40. $PM_{2.5}$ data summary for Pascagoula area site (AQS # 280590006).

Figure 41. $PM_{2.5}$ data summary for Mobile area site (AQS # 010970002 (Chickasaw)).

Figure 42. $PM_{2.5}$ data summary for Pensacola area site (AQS # 120330004 (Ellyson)).

** Data not available for 1999 and 2000.*

Figure 43. $PM_{2.5}$ data summary for Panama City area site (AQS # 120051004).

Figure 44. $PM_{2.5}$ data summary for Tampa area site (AQS # 120570030 (Morrison)).

These figures provide an overview of particulate concentrations along the Gulf Coast. For all areas, the average daily concentrations do not vary considerably from month to month. The average maximum concentrations are highest for most of the selected sites in July, August, and September, with some additional high values in October and May.

Annual average $PM_{2.5}$ concentrations for the selected sites are typically within the range of 10 to 15 μgm^{-3} during the 1999 to 2004 period, with a few values greater than 15. The corresponding annual design values are also typically less than 15 μgm^{-3}, with some higher values for Houston and Mobile during the early part of the period. Note that these higher values may reflect a shorter averaging period (i.e. less than three years of data).

Similarly, the 98th percentile 24-hour average $PM_{2.5}$ values for each year are less than 35 μgm^{-3} for all areas, with the exception of that for Mobile in 1999. Several areas, however, have 98th percentile concentrations greater than 30 μgm^{-3}, especially in 1999, 2000, and 2004. The design values reflect attainment of the 24-hr standard for most sites and design-value periods. Again, the higher values for the earlier periods may reflect a shorter averaging period.

Without fully accounting for year-to-year differences in meteorology, a downward trend in both the annual and 24-hour design values is apparent for most sites for the period 1999 (or 2000) to 2004. The data for Terrebonne Parish, however, show an increase during this period. Several of the sites along the eastern Gulf coast also show an increase in the 24-hour design value for one or more of the later averaging periods.

2.3.2. Combined $PM_{2.5}$ and Meteorological Data Summaries

In the remainder of this section on $PM_{2.5}$, summary tables provide information about the meteorological conditions associated with different levels of $PM_{2.5}$ concentration within selected areas. The observed $PM_{2.5}$ and meteorological data presented earlier were used to prepare the tables. Later in this report, additional data analysis techniques are used to examine the relative importance of the various meteorological parameters in determining $PM_{2.5}$ concentrations and the specific combinations of parameters (conditions) that lead to high $PM_{2.5}$ at the monitoring sites. The focus is on the period 2000-2004 and areas along the western Gulf Coast.

To examine the variations in $PM_{2.5}$ versus meteorology, the maximum 24-hour average $PM_{2.5}$ concentration was determined for each area (as the maximum value over all sites within the area). Based on the value of maximum 24-hour average $PM_{2.5}$, each day was then placed into one of four concentration categories. The concentration ranges for these categories are: less than 15 μgm^{-3}, 15 to 25 μgm^{-3}, 25 to 35 μgm^{-3} and greater than or equal 35 μgm^{-3}. Then average values of a variety of meteorological parameters were calculated for all days within each of the four $PM_{2.5}$ concentration categories. This analysis focuses on: Central Houston, Southeast Houston and Galveston, Beaumont/Port Arthur, Lake Charles, New Orleans and Baton Rouge.

Meteorological data from the local surface monitoring site and the nearest upper-air monitoring site(s) were used to prepare the summary tables.

The meteorological parameters include the following surface parameters: maximum and daily average temperature, relative humidity at noon, wind speed and direction for three three-hour daytime periods, persistence index, pressure, and rainfall amount.

The upper-air meteorological parameters include: 850 mb temperature, 900 mb to surface temperature difference (or stability index), change in geopotential height during the past 24 hours at 700 mb (an indicator of changing synoptic scale patterns), 850 mb wind speed and wind direction for the prior evening, morning, and evening soundings, recirculation index (an indicator of upper-air wind persistence) and cloud index.

In addition to the meteorological parameters, the average 24-hour $PM_{2.5}$ concentration for each category is provided. Prior day average 24-hour $PM_{2.5}$ concentrations for the area and potential upwind areas are also provided.

The combined $PM_{2.5}$ and meteorological summaries are given in Tables 14 through 19. Information for each area is presented in the order listed above (approximately west to east).

Table 14

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for 2000-2004: Central Houston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	1026	581	71	14
PM2.5 Parameters				
PM2.5 at Houston (µg/m^3)	10.8	18.4	28.5	43.7
Yesterday's PM2.5 at Houston (µg/m^3)	12.8	16.7	22.4	35.9
Yesterday's PM2.5 at Beaumont/Port Arthur (µg/m^3)	9.9	13.7	18.5	31.1
Surface Meteorological Parameters				
Max. surface temperature (°C)	24.7	27.2	28.2	30.5
Min. surface temperature (°C)	16.2	17.8	18.5	21.0
Average relative humidity (%)	75	75	75	75
Surface wind speed (ms^{-1})	3.8	3.0	2.6	2.1
Surface wind direction (degrees)	131	145	118	108
Persistence	0.8	0.8	0.8	0.7
Sea level pressure (mb)	1020	1020	1019	1020
Rainfall (inches)	0.2	0.1	0.0	0.1
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	13.0	14.1	14.6	16.3
Temperature PM 850 mb at Lake Charles (°C)	12.9	14.5	15.0	16.5
Stability at Lake Charles (°C)	-1.1	-0.4	0.3	-0.2
Geopotential hgt difference 700 mb at Lake Charles (m)	-0.9	1.8	1.5	3.2
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	10.1	8.7	8.1	6.5
Wind dir. yesterday 700 mb at Lake Charles (degrees)	250	287	295	0
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	7.8	6.6	6.2	5.8
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9	7	7	4
Wind speed PM 850 mb at Lake Charles (ms^{-1})	7.9	6.5	6.4	4.1
Wind dir. yesterday 850 mb at Lake Charles (degrees)	210	317	6	90
Wind dir. AM 850 mb at Lake Charles (degrees)	215	223	18	90
Wind dir. PM 850 mb at Lake Charles (degrees)	226	204	45	27
Recirculation index at Lake Charles	0.1	0.1	0.1	0.1
Cloud index at Lake Charles	1.7	1.6	1.4	1.5

Table 15

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for 2000-2004: Southeast Houston and Galveston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	661	193	26	8
PM2.5 Parameters				
PM2.5 at Galveston (µg/m^3)	9.7	18.6	29.0	43.5
Yesterday's PM2.5 at Houston/Galveston (µg/m^3)	13.3	17.4	23.9	34.3
Yesterday's PM2.5 at Beaumont/Port Arthur (µg/m^3)	10.1	14.5	21.3	28.1
Surface Meteorological Parameters				
Max. surface temperature (°C)	25.2	27.4	30.1	30.9
Min. surface temperature (°C)	16.5	17.9	20.5	21.2
Average relative humidity (%)	75	73	75	69
Surface wind speed (ms^{-1})	3.7	3.1	2.3	2.4
Surface wind direction (degrees)	134	144	121	135
Persistence	0.8	0.8	0.7	0.8
Sea Level pressure (mb)	1020	1020	1020	1017
Rainfall (inches)	0.2	0.1	0.1	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	13.1	14.1	15.7	16.8
Temperature PM 850 mb at Lake Charles (°C)	13.2	14.6	16.0	16.9
Stability at Lake Charles	-0.9	-0.4	-1.0	0.9
Geopotential hgt difference 700 mb at Lake Charles (m)	-1.5	2.7	-1.5	-1.4
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	9.9	8.9	6.9	7.6
Wind dir. yesterday 700 mb at Lake Charles (degrees)	254	299	0	342
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	7.6	6.2	6.2	7.0
Wind speed AM 850 mb at Lake Charles (ms^{-1})	8.6	6.6	6.0	5.8
Wind speed PM 850 mb at Lake Charles (ms^{-1})	7.9	6.4	4.7	6.1
Wind dir. yesterday 850 mb at Lake Charles (degrees)	220	358	60	18
Wind dir. AM 850 mb at Lake Charles (degrees)	214	252	56	63
Wind dir. PM 850 mb at Lake Charles (degrees)	211	0	63	45
Recirculation index at Lake Charles	0.1	0.1	0.2	0.0
Cloud index at Lake Charles	1.7	1.6	1.5	1.3

Table 16

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for 2000-2004: Beaumont/Port Arthur

Surface Meteorological Data are for Port Arthur SE TX Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	1263	288	40	14
PM2.5 Parameters				
PM2.5 at Beaumont/Port Arthur (μg/m^3)	9.3	18.3	28.6	47.3
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	10.2	15.7	20.4	30.5
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	13.3	18.4	22.2	31.4
Yesterday's PM2.5 at Baton Rouge/New Orleans (μg/m^3)	13.6	18.2	25.6	28.2
Surface Meteorological Parameters				
Max. surface temperature (°C)	24.5	27.9	29.9	30.7
Min. surface temperature (°C)	15.4	17.8	18.9	19.2
Average relative humidity (%)	78	76	72	77
Surface wind speed (ms^{-1})	3.9	3.0	2.7	2.3
Surface wind direction (degrees)	139	100	90	0
Persistence	0.8	0.8	0.7	0.7
Sea level pressure (mb)	1020	1019	1020	1017
Rainfall (inches)	0.2	0.1	0.0	0.1
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	13.0	14.8	14.7	15.8
Temperature PM 850 mb at Lake Charles (°C)	13.1	15.2	15.2	16.3
Stability at Lake Charles at Lake Charles (°C)	-0.9	-0.4	-0.7	1.2
Geopotential hgt difference 700 mb at Lake Charles (m)	0.0	0.5	-2.4	1.1
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	10.0	7.8	7.1	8.1
Wind dir. yesterday 700 mb at Lake Charles (degrees)	253	311	9	11
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	7.8	5.7	5.3	7.2
Wind speed AM 850 mb at Lake Charles (ms^{-1})	8.4	5.8	5.3	5.7
Wind speed PM 850 mb at Lake Charles (ms^{-1})	7.7	5.8	5.4	6.1
Wind dir. yesterday 850 mb at Lake Charles (degrees)	213	24	38	31
Wind dir. AM 850 mb at Lake Charles (degrees)	215	225	42	27
Wind dir. PM 850 mb at Lake Charles (degrees)	224	74	50	18
Recirculation index at Lake Charles	0.1	0.2	0.2	0.1
Cloud index at Lake Charles	1.7	1.6	1.5	1.4

Table 17

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for 2000-2004: Lake Charles.

Surface Meteorological Data are for Lake Charles Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	480	100	21	6
PM2.5 Parameters				
PM2.5 at Lake Charles ($\mu g/m^3$)	9.2	18.3	29.7	45.1
Yesterday's PM2.5 at Baton Rouge/New Orleans ($\mu g/m^3$)	12.8	18.2	26.5	26.1
Yesterday's PM2.5 at Houston/Galveston ($\mu g/m^3$)	13.3	17.0	21.7	33.7
Yesterday's PM2.5 at Beaumont/Port Arthur sites ($\mu g/m^3$)	10.0	14.1	21.1	27.3
Surface Meteorological Parameters				
Max. surface temperature (°C)	24.6	27.4	29.2	26.0
Min. surface temperature (°C)	15.1	16.2	16.4	12.0
Average relative humidity (%)	78	74	71	73
Surface wind speed (ms^{-1})	3.3	2.6	2.2	1.7
Surface wind direction (degrees)	131	91	90	135
Persistence	0.8	0.8	0.7	0.8
Sea Level pressure (mb)	1021	1021	1020	1023
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	13.1	14.2	14.8	13.3
Temperature PM 850 mb at Lake Charles (°C)	13.2	14.7	14.9	13.5
Stability at Lake Charles (°C)	-1.0	0.1	0.1	2.9
Geopotential hgt difference 700 mb at Lake Charles (m)	0.0	1.4	7.8	-3.3
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	10.3	7.6	8.9	4.7
Wind dir. yesterday 700 mb at Lake Charles (degrees)	254	309	21	270
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	7.9	5.5	6.1	4.5
Wind speed AM 850 mb at Lake Charles (ms^{-1})	8.5	5.6	6.0	3.6
Wind speed PM 850 mb at Lake Charles (ms^{-1})	7.7	5.9	5.9	5.5
Wind dir. yesterday 850 mb at Lake Charles (degrees)	226	32	27	18
Wind dir. AM 850 mb at Lake Charles (degrees)	219	270	0	225
Wind dir. PM 850 mb at Lake Charles (degrees)	218	63	61	225
Recirculation index at Lake Charles	0.1	0.1	0.1	0.3
Cloud index at Lake Charles	1.6	1.6	1.5	1.5

Table 18

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for 2000-2004: New Orleans.

Surface Meteorological Data are for New Orleans International Airport. The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	1285	438	70	19
PM2.5 Parameters				
PM2.5 at New Orleans (μg/m^3)	9.7	18.5	28.2	40.1
Yesterday's PM2.5 at New Orleans (μg/m^3)	10.9	16.4	23.0	30.2
Yesterday's PM2.5 at Baton Rouge (μg/m^3)	12.3	17.2	23.4	30.9
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur (μg/m^3)	13.8	16.9	21.0	30.5
Surface Meteorological Parameters				
Max. surface temperature (°C)	24.7	26.6	27.3	28.8
Min. surface temperature (°C)	16.4	17.1	17.5	18.5
Average relative humidity (%)	75	72	71	74
Surface wind speed (ms^{-1})	3.9	2.9	2.6	2.3
Surface wind direction (degrees)	122	80	45	56
Persistence	0.8	0.7	0.7	0.6
Sea level pressure (mb)	1020	1020	1020	1019
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	12.9	13.6	13.7	15.7
Temperature PM 850 mb at Slidell (°C)	12.8	13.9	14.8	15.5
Stability at Slidell (°C)	-0.2	1.3	2.0	2.8
Geopotential hgt difference 700 mb at Slidell (m)	-0.5	1.4	2.4	4.2
Wind speed yesterday 700 mb at Slidell (ms^{-1})	10.5	7.8	7.2	7.0
Wind dir. yesterday 700 mb at Slidell (degrees)	259	298	334	353
Wind speed yesterday 850 mb at Slidell (ms^{-1})	8.0	5.7	6.0	4.9
Wind speed AM 850 mb at Slidell (ms^{-1})	8.6	5.9	5.4	4.7
Wind speed PM 850 mb at Slidell (ms^{-1})	8.0	5.9	5.6	5.0
Wind dir. yesterday 850 mb at Slidell (degrees)	251	343	354	10
Wind dir. AM 850 mb at Slidell (degrees)	234	243	297	45
Wind dir. PM 850 mb at Slidell (degrees)	268	312	8	34
Recirculation index at Slidell	0.0	0.1	0.1	0.2
Cloud index	1.7	1.5	1.5	1.4

Table 19

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for 2000-2004: Baton Rouge.

Surface Meteorological Data are for Baton Rouge Ryan Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	1181	524	97	20
PM2.5 Parameters				
PM2.5 at Baton Rouge ($\mu g/m^3$)	10.4	18.7	28.5	41.0
Yesterday's PM2.5 at Baton Rouge ($\mu g/m^3$)	11.9	16.9	22.7	29.9
Yesterday's PM2.5 at New Orleans ($\mu g/m^3$)	10.7	15.7	21.8	28.3
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur ($\mu g/m^3$)	13.4	17.1	20.0	29.2
Surface Meteorological Parameters				
Max. surface temperature (°C)	24.6	26.5	28.4	27.1
Min. surface temperature (°C)	14.3	14.0	15.7	13.1
Average relative humidity (%)	75	73	72	71
Surface wind speed (ms^{-1})	2.9	2.2	1.7	1.4
Surface wind direction (degrees)	132	103	87	108
Persistence	0.8	0.8	0.7	0.8
Sea level pressure (mb)	1020	1020	1019	1020
Rainfall (inches)	0.2	0.1	0.1	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	12.9	13.4	14.4	14.2
Temperature PM 850 mb at Slidell (°C)	12.9	13.7	14.8	15.0
Stability at Slidell (°C)	-0.5	1.6	1.4	3.3
Geopotential hgt difference 700 mb at Slidell (m)	-1.4	3.3	-0.6	0.3
Wind speed yesterday 700 mb at Slidell (ms^{-1})	10.6	8.3	7.0	6.2
Wind dir. yesterday 700 mb at Slidell (degrees)	256	305	327	0
Wind speed yesterday 850 mb at Slidell (ms^{-1})	8.1	6.2	5.4	5.7
Wind speed AM 850 mb at Slidell (ms^{-1})	8.7	6.4	4.9	4.6
Wind speed PM 850 mb at Slidell (ms^{-1})	7.9	6.5	5.4	4.6
Wind dir. yesterday 850 mb at Slidell (degrees)	248	351	21	13
Wind dir. AM 850 mb at Slidell (degrees)	234	244	0	72
Wind dir. PM 850 mb at Slidell (degrees)	267	328	6	18
Recirculation at Slidell	0.0	0.1	0.2	0.1
Cloud index at Slidell	1.7	1.5	1.6	1.3

The categorical comparisons reveal that higher $PM_{2.5}$ concentrations are associated with higher prior day concentrations (carryover), lower wind speeds, and greater stability.

Hsu (2008) also found that, for operational applications, the average $PM_{2.5}$ concentrations present in Tables 14 through 19 are well correlated with surface wind speed. Using the average concentration and wind speed values from the tables, Hsu found that the average $PM_{2.5}$ concentrations increase exponentially with decreasing surface wind speed and that the coefficient of determination (R-squared) is 0.73, which means that 73 percent of the total variation of $PM_{2.5}$ among the categories can be explained by the average surface wind speed for the categories. It is interesting to note that, in general, when the average wind speed is greater that 4 ms^{-1} the average $PM_{2.5}$ concentration is less than 10 $\mu gm^{-3.}$ This information may be useful for operation applications.

Because high $PM_{2.5}$ concentrations can occur throughout the year, it follows that different meteorological factors may influence $PM_{2.5}$ during different times of the year. Tables 20-25 summarize this same information by quarter, for the four quarterly periods defined by January-March (Q1), April-June (Q2), July-September (Q3), and October-November (Q4). Recall that the earlier data summaries showed that, on average, the highest $PM_{2.5}$ concentrations tended to occur during Q3 and the lowest during Q2.

Table 20a

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for January–March, 2000-2004: Central Houston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	267	136	12	0
PM2.5 Parameters				
PM2.5 at Houston (μg/m^3)	10.6	18.2	27.2	N/A
Yesterday's PM2.5 at Houston (μg/m^3)	12.7	15.2	19.8	N/A
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	9.4	11.1	15.5	N/A
Surface Meteorological Parameters				
Max. surface temperature (°C)	18.9	20.1	18.8	N/A
Min. surface temperature (°C)	10.3	10.6	8.6	N/A
Average relative humidity (%)	73	78	80	N/A
Surface wind speed (ms^{-1})	4.5	3.2	2.5	N/A
Surface wind direction (degrees)	51	125	96	N/A
Persistence	0.8	0.8	0.8	N/A
Sea level pressure (mb)	1023	1022	1025	N/A
Rainfall (inches)	0.1	0.1	0.0	N/A
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	9.3	9.4	8.8	N/A
Temperature PM 850 mb at Lake Charles (°C)	8.9	9.8	8.2	N/A
Stability at Lake Charles (°C)	0.3	1.8	3.3	N/A
Geopotential hgt difference 700 mb at Lake Charles (m)	-3.1	6.0	1.7	N/A
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	13.8	12.9	10.1	N/A
Wind dir. yesterday 700 mb at Lake Charles (degrees)	261	274	281	N/A
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	9.6	8.4	4.9	N/A
Wind speed AM 850 mb at Lake Charles (ms^{-1})	10	9	7	N/A
Wind speed PM 850 mb at Lake Charles (ms^{-1})	9.6	8.4	5.6	N/A
Wind dir. yesterday 850 mb at Lake Charles (degrees)	244	278	315	N/A
Wind dir. AM 850 mb at Lake Charles (degrees)	257	266	288	N/A
Wind dir. PM 850 mb at Lake Charles (degrees)	259	255	225	N/A
Recirculation index at Lake Charles	0.0	0.0	0.1	N/A
Cloud index at Lake Charles	1.7	1.5	1.5	N/A

Table 20b

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for April - June, 2000-2004: Central Houston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	248	154	13	3
PM2.5 Parameters				
PM2.5 at Houston (μg/m^3)	11.5	18.2	28.3	41.8
Yesterday's PM2.5 at Houston (μg/m^3)	13.4	16.6	24.4	29.7
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	10.1	12.8	17.0	20.2
Surface Meteorological Parameters				
Max. surface temperature (°C)	28.4	29.7	31.2	32.8
Min. surface temperature (°C)	20.2	21.2	22.2	24.8
Average relative humidity (%)	77	76	78	75
Surface wind speed (ms^{-1})	3.7	3.4	3.9	2.4
Surface wind direction (degrees)	148	151	170	161
Persistence	0.8	0.8	0.9	0.6
Sea level pressure (mb)	1018	1017	1014	1020
Rainfall (inches)	0.3	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	15.0	15.9	17.8	19.5
Temperature PM 850 mb at Lake Charles (°C)	14.9	16.1	18.1	18.8
Stability at Lake Charles (°C)	-2.4	-2.3	-2.2	-3.4
Geopotential hgt difference 700 mb at Lake Charles (m)	2.2	-0.8	4.2	10.0
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	8.1	8.1	11.9	8.9
Wind dir. yesterday 700 mb at Lake Charles (degrees)	185	191	207	153
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.7	6.6	10.2	6.0
Wind speed AM 850 mb at Lake Charles (ms^{-1})	8.0	8.0	12.0	5.0
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.6	6.7	10.7	1.5
Wind dir. yesterday 850 mb at Lake Charles (degrees)	185	191	207	153
Wind dir. AM 850 mb at Lake Charles (degrees)	196	198	214	170
Wind dir. PM 850 mb at Lake Charles (degrees)	192	195	216	210
Recirculation index at Lake Charles	0.0	0.1	0.1	0.3
Cloud index at Lake Charles	1.6	1.5	1.3	1.7

Table 20c

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for July - September, 2000-2004: Central Houston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	219	187	31	7
PM2.5 Parameters				
PM2.5 at Houston ($\mu g/m^3$)	11.2	18.7	29.2	46.3
Yesterday's PM2.5 at Houston ($\mu g/m^3$)	13.4	18.0	22.9	38.6
Yesterday's PM2.5 at Beaumont/Port Arthur ($\mu g/m^3$)	10.7	16.0	20.6	34.9
Surface Meteorological Parameters				
Max. surface temperature (°C)	31.7	33.0	32.3	32.8
Min. surface temperature (°C)	23.3	23.6	23.1	23.3
Average relative humidity (%)	77	72	69	71
Surface wind speed (ms^{-1})	2.9	2.6	2.2	2.3
Surface wind direction (degrees)	156	155	74	117
Persistence	0.8	0.8	0.7	0.7
Sea level pressure (mb)	1017	1018	1017	1016
Rainfall (inches)	0.3	0.1	0.0	0.2
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	17.8	17.9	16.6	18.0
Temperature PM 850 mb at Lake Charles (°C)	18.1	18.2	17.4	18.8
Stability at Lake Charles (°C)	-2.6	-2.0	-1.3	-0.4
Geopotential hgt difference 700 mb at Lake Charles (m)	0.0	-0.5	-1.1	9.1
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	5.8	5.7	6.1	6.4
Wind dir. yesterday 700 mb at Lake Charles (degrees)	148	30	351	27
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	5.5	4.8	5.2	5.4
Wind speed AM 850 mb at Lake Charles (ms^{-1})	6	5	5	4
Wind speed PM 850 mb at Lake Charles (ms^{-1})	5.7	4.7	4.8	4.9
Wind dir. yesterday 850 mb at Lake Charles (degrees)	125	40	34	63
Wind dir. AM 850 mb at Lake Charles (degrees)	178	131	41	108
Wind dir. PM 850 mb at Lake Charles (degrees)	122	52	28	90
Recirculation index at Lake Charles	0.1	0.2	0.2	0.1
Cloud index at Lake Charles	1.8	1.7	1.5	1.3

Table 20d

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for October - December, 2000-2004: Central Houston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in Ozone Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm⁻³.

	Category 1	Category 2	Category 3	Category 4
No. of Days	292	103	15	4
PM2.5 Parameters				
PM2.5 at Houston (μg/m^3)	10.2	18.7	28.4	40.5
Yesterday's PM2.5 at Houston (μg/m^3)	11.7	16.2	21.6	36.1
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	9.6	13.7	18.6	33.4
Surface Meteorological Parameters				
Max. surface temperature (°C)	21.7	22.4	24.4	24.9
Min. surface temperature (°C)	13.0	11.9	13.6	13.9
Average relative humidity (%)	74	76	79	82
Surface wind speed (ms^{-1})	3.9	2.7	2.1	1.6
Surface wind direction (degrees)	54	100	110	72
Persistence	0.8	0.8	0.8	0.8
Sea level pressure (mb)	1022	1023	1024	1026
Rainfall (inches)	0.2	0.1	0.0	0.1
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	11.3	11.2	12.3	11.5
Temperature PM 850 mb at Lake Charles (°C)	11.2	11.6	13.0	10.6
Stability at Lake Charles (°C)	0.0	2.2	3.5	2.6
Geopotential hgt difference 700 mb at Lake Charles (m)	-2.0	4.0	4.4	-10.6
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	11.6	9.3	7.1	5.1
Wind dir. yesterday 700 mb at Lake Charles (degrees)	256	279	297	0
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	8.9	7.2	5.9	6.3
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9	6	6	4
Wind speed PM 850 mb at Lake Charles (ms^{-1})	8.9	6.7	7.0	4.0
Wind dir. yesterday 850 mb at Lake Charles (degrees)	234	326	353	45
Wind dir. AM 850 mb at Lake Charles (degrees)	247	255	333	0
Wind dir. PM 850 mb at Lake Charles (degrees)	269	217	180	0
Recirculation index at Lake Charles	0.0	0.1	0.1	0.0
Cloud index at Lake Charles	1.7	1.5	1.3	1.8

Table 21a

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for January–March, 2000-2004: Southeast Houston and Galveston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	169	43	4	0
PM2.5 Parameters				
PM2.5 at Galveston (µg/m^3)	9.8	18.7	28.8	N/A
Yesterday's PM2.5 at Houston/Galveston (µg/m^3)	13.3	15.4	18.3	N/A
Yesterday's PM2.5 at Beaumont/Port Arthur (µg/m^3)	9.7	10.7	16.7	N/A
Surface Meteorological Parameters				
Max. surface temperature (°C)	19.6	20.0	21.4	N/A
Min. surface temperature (°C)	10.9	10.4	11.7	N/A
Average relative humidity (%)	73	74	85	N/A
Surface wind speed (ms^{-1})	4.2	3.6	3.1	N/A
Surface wind direction (degrees)	95	125	108	N/A
Persistence	0.8	0.8	0.8	N/A
Sea level pressure (mb)	1023	1022	1024	N/A
Rainfall (inches)	0.1	0.1	0.0	N/A
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	9.2	9.3	10.8	N/A
Temperature PM 850 mb at Lake Charles (°C)	9.2	9.8	9.2	N/A
Stability at Lake Charles	0.6	1.7	-0.2	N/A
Geopotential hgt difference 700 mb at Lake Charles (m)	-3.3	-0.6	3.3	N/A
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	13.1	13.8	11.1	N/A
Wind dir. yesterday 700 mb at Lake Charles (degrees)	263	277	270	N/A
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	9.0	8.2	10.2	N/A
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9.6	8.7	10.5	N/A
Wind speed PM 850 mb at Lake Charles (ms^{-1})	9.5	8.9	5.3	N/A
Wind dir. yesterday 850 mb at Lake Charles (degrees)	253	290	225	N/A
Wind dir. AM 850 mb at Lake Charles (degrees)	253	277	270	N/A
Wind dir. PM 850 mb at Lake Charles (degrees)	244	273	207	N/A
Recirculation index at Lake Charles	0.0	0.0	0.0	N/A
Cloud index at Lake Charles	1.6	1.6	1.3	N/A

Table 21b

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for April - June, 2000-2004: Southeast Houston and Galveston.

Surface Meteorological Data are for Houston International Airport.
The Ranges PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	174	57	2	1
PM2.5 Parameters				
PM2.5 at Galveston ($\mu g/m^3$)	10.7	18.3	29.8	53.7
Yesterday's PM2.5 at Houston/Galveston ($\mu g/m^3$)	13.6	17.2	34.3	19.7
Yesterday's PM2.5 at Beaumont/Port Arthur ($\mu g/m^3$)	10.2	14.0	20.2	12.5
Surface Meteorological Parameters				
Max. surface temperature (°C)	29.0	29.8	31.9	27.8
Min. surface temperature (°C)	20.8	21.0	23.9	22.2
Average relative humidity (%)	76	76	80	86
Surface wind speed (ms^{-1})	3.6	3.5	2.9	3.2
Surface wind direction (degrees)	155	157	180	180
Persistence	0.8	0.9	0.8	1.0
Sea level pressure (mb)	1018	1017	1015	1017
Rainfall (inches)	0.3	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	15.5	15.5	17.9	16.8
Temperature PM 850 mb at Lake Charles (°C)	15.4	16.0	18.4	16.9
Stability at Lake Charles	-2.6	-1.6	-1.2	0.9
Geopotential hgt difference 700 mb at Lake Charles (m)	-1.6	6.4	-19.5	22.5
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	7.7	8.5	10.0	13.4
Wind dir. yesterday 700 mb at Lake Charles (degrees)	224	284	315	270
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.3	6.5	10.8	13.9
Wind speed AM 850 mb at Lake Charles (ms^{-1})	8.3	7.8	7.4	14.4
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.7	7.1	5.1	10.8
Wind dir. yesterday 850 mb at Lake Charles (degrees)	181	207	180	180
Wind dir. AM 850 mb at Lake Charles (degrees)	191	194	N/A	180
Wind dir. PM 850 mb at Lake Charles (degrees)	185	177	315	180
Recirculation index at Lake Charles	0.1	0.1	0.5	0.0
Cloud index at Lake Charles	1.6	1.5	1.5	1.0

Table 21c

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for July - September, 2000-2004: Southeast Houston and Galveston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	137	62	16	6
PM2.5 Parameters				
PM2.5 at Galveston ($\mu g/m^3$)	9.9	18.7	28.2	42.8
Yesterday's PM2.5 at Houston/Galveston ($\mu g/m^3$)	14.3	19.7	21.6	36.4
Yesterday's PM2.5 at Beaumont/Port Arthur ($\mu g/m^3$)	11.2	16.5	20.2	30.0
Surface Meteorological Parameters				
Max. surface temperature (°C)	31.9	33.5	33.3	32.4
Min. surface temperature (°C)	23.1	23.6	23.5	22.1
Average relative humidity (%)	76	71	70	65
Surface wind speed (ms^{-1})	3.0	2.6	2.1	2.5
Surface wind direction (degrees)	154	160	135	135
Persistence	0.8	0.8	0.6	0.8
Sea level pressure (mb)	1017	1018	1018	1015
Rainfall (inches)	0.2	0.1	0.1	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	17.7	17.9	17.5	17.2
Temperature PM 850 mb at Lake Charles (°C)	18.1	18.2	18.1	18.2
Stability at Lake Charles	-2.6	-1.9	-1.8	0.7
Geopotential hgt difference 700 mb at Lake Charles (m)	-0.9	-2.3	1.6	-2.9
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	6.0	5.7	6.0	6.7
Wind dir. yesterday 700 mb at Lake Charles (degrees)	127	30	45	18
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	5.6	4.4	4.8	6.2
Wind speed AM 850 mb at Lake Charles (ms^{-1})	6.5	4.3	4.7	4.1
Wind speed PM 850 mb at Lake Charles (ms^{-1})	5.7	4.4	4.7	5.5
Wind dir. yesterday 850 mb at Lake Charles (degrees)	117	33	45	18
Wind dir. AM 850 mb at Lake Charles (degrees)	170	202	67	63
Wind dir. PM 850 mb at Lake Charles (degrees)	124	41	66	45
Recirculation index at Lake Charles	0.1	0.3	0.2	0.0
Cloud index at Lake Charles	1.8	1.7	1.5	1.2

Table 21d

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for October - December, 2000-2004: Southeast Houston and Galveston.

Surface Meteorological Data are for Houston International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	181	31	4	1
PM2.5 Parameters				
PM2.5 at Galveston (μg/m^3)	8.6	18.8	32.1	38.0
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	12.0	15.8	36.0	36.3
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	9.5	14.6	29.1	34.4
Surface Meteorological Parameters				
Max. surface temperature (°C)	21.7	21.3	25.1	25.0
Min. surface temperature (°C)	12.6	11.0	15.6	14.4
Average relative humidity (%)	74	73	83	78
Surface wind speed (ms^{-1})	3.8	2.5	2.1	1.1
Surface wind direction (degrees)	81	78	72	90
Persistence	0.8	0.8	0.8	0.6
Sea level pressure (mb)	1022	1026	1026	1025
Rainfall (inches)	0.2	0.1	0.1	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	11.1	10.7	12.3	10.6
Temperature PM 850 mb at Lake Charles (°C)	11.3	11.0	11.1	10.3
Stability at Lake Charles	0.4	2.1	1.2	3.3
Geopotential hgt difference 700 mb at Lake Charles (m)	-0.3	10.2	-8.3	-17.5
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	11.7	9.4	4.8	7.7
Wind dir. yesterday 700 mb at Lake Charles (degrees)	264	283	45	270
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	9.0	6.9	6.8	5.1
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9.3	5.9	5.7	5.7
Wind speed PM 850 mb at Lake Charles (ms^{-1})	9.1	5.6	4.1	5.1
Wind dir. yesterday 850 mb at Lake Charles (degrees)	249	27	90	0
Wind dir. AM 850 mb at Lake Charles (degrees)	245	312	45	0
Wind dir. PM 850 mb at Lake Charles (degrees)	250	27	45	0
Recirculation index at Lake Charles	0.0	0.1	0.0	0.0
Cloud index at Lake Charles	1.6	1.3	1.8	2.0

Table 22a

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for January–March, 2000-2004: Beaumont/Port Arthur

Surface Meteorological Data are for Port Arthur SE TX Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	325	38	3	0
PM2.5 Parameters				
PM2.5 at Beaumont/Port Arthur (µg/m^3)	9.2	18.4	28.4	N/A
Yesterday's PM2.5 at Beaumont/Port Arthur (µg/m^3)	13.0	18.1	12.4	N/A
Yesterday's PM2.5 at Houston/Galveston (µg/m^3)	9.9	13.5	11.2	N/A
Yesterday's PM2.5 at Baton Rouge/New Orleans (µg/m^3)	13.7	17.2	17.6	N/A
Surface Meteorological Parameters				
Max. surface temperature (°C)	18.3	18.6	15.7	N/A
Min. surface temperature (°C)	9.0	8.8	0.0	N/A
Average relative humidity (%)	76	80	57	N/A
Surface wind speed (ms^{-1})	4.5	3.1	3.0	N/A
Surface wind direction (degrees)	81	86	297	N/A
Persistence	0.8	0.8	0.9	N/A
Sea level pressure (mb)	1023	1022	1028	N/A
Rainfall (inches)	0.1	0.0	0.0	N/A
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	9.1	9.0	0.2	N/A
Temperature PM 850 mb at Lake Charles (°C)	8.9	9.3	4.5	N/A
Stability at Lake Charles at Lake Charles (°C)	0.7	2.2	1.0	N/A
Geopotential hgt difference 700 mb at Lake Charles (m)	-0.3	2.0	-1.5	N/A
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	13.9	11.2	13.0	N/A
Wind dir. yesterday 700 mb at Lake Charles (degrees)	262	274	297	N/A
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	9.6	6.4	8.9	N/A
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9.6	6.8	12.2	N/A
Wind speed PM 850 mb at Lake Charles (ms^{-1})	9.4	7.1	10.3	N/A
Wind dir. yesterday 850 mb at Lake Charles (degrees)	249	293	333	N/A
Wind dir. AM 850 mb at Lake Charles (degrees)	263	270	333	N/A
Wind dir. PM 850 mb at Lake Charles (degrees)	255	260	333	N/A
Recirculation index at Lake Charles	0.0	0.1	0.0	N/A
Cloud index at Lake Charles	1.6	1.6	1.0	N/A

Table 22b

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for April - June, 2000-2004: Beaumont/Port Arthur

Surface Meteorological Data are for Port Arthur SE TX Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	315	63	3	0
PM2.5 Parameters				
PM2.5 at Beaumont/Port Arthur (μg/m^3)	9.8	18.0	28.6	N/A
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	10.7	14.8	21.0	N/A
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	14.4	18.5	25.5	N/A
Yesterday's PM2.5 at Baton Rouge/New Orleans (μg/m^3)	13.1	15.6	18.0	N/A
Surface Meteorological Parameters				
Max. surface temperature (°C)	28.4	29.9	32.4	N/A
Min. surface temperature (°C)	19.8	20.7	22.0	N/A
Average relative humidity (%)	80	77	80	N/A
Surface wind speed (ms^{-1})	4.1	3.6	1.7	N/A
Surface wind direction (degrees)	165	162	207	N/A
Persistence	0.8	0.8	0.6	N/A
Sea level pressure (mb)	1017	1017	1020	N/A
Rainfall (inches)	0.2	0.0	0.3	N/A
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	15.3	15.8	18.1	N/A
Temperature PM 850 mb at Lake Charles (°C)	15.2	16.5	17.7	N/A
Stability at Lake Charles at Lake Charles (°C)	-2.4	-2.1	-3.0	N/A
Geopotential hgt difference 700 mb at Lake Charles (m)	1.6	-2.2	-0.2	N/A
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	8.2	8.9	6.6	N/A
Wind dir. yesterday 700 mb at Lake Charles (degrees)	235	295	333	N/A
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.9	7.1	2.9	N/A
Wind speed AM 850 mb at Lake Charles (ms^{-1})	8.6	7.9	3.1	N/A
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.9	6.8	3.3	N/A
Wind dir. yesterday 850 mb at Lake Charles (degrees)	184	121	90	N/A
Wind dir. AM 850 mb at Lake Charles (degrees)	185	200	180	N/A
Wind dir. PM 850 mb at Lake Charles (degrees)	185	135	45	N/A
Recirculation index at Lake Charles	0.0	0.1	0.3	N/A
Cloud index at Lake Charles	1.6	1.5	1.3	N/A

Table 22c

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for July–September, 2000-2004: Beaumont/Port Arthur

Surface Meteorological Data are for Port Arthur SE TX Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as Follows: <15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	270	121	20	9
PM2.5 Parameters				
PM2.5 at Beaumont/Port Arthur (μg/m^3)	9.6	18.8	28.5	50.3
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	10.9	17.1	20.0	34.6
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	14.0	19.6	21.8	36.1
Yesterday's PM2.5 at Baton Rouge/New Orleans (μg/m^3)	13.9	19.2	23.0	31.1
Surface Meteorological Parameters				
Max. surface temperature (°C)	31.8	32.5	33.7	34.3
Min. surface temperature (°C)	23.0	22.4	22.8	23.1
Average relative humidity (%)	80	74	71	76
Surface wind speed (ms^{-1})	2.9	2.6	2.5	2.5
Surface wind direction (degrees)	163	78	297	346
Persistence	0.8	0.7	0.6	0.7
Sea level pressure (mb)	1017	1017	1017	1014
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	17.8	17.5	17.5	18.3
Temperature PM 850 mb at Lake Charles (°C)	18.1	17.9	18.2	18.7
Stability at Lake Charles at Lake Charles (°C)	-2.5	-2.0	-1.2	-0.2
Geopotential hgt difference 700 mb at Lake Charles (m)	0.2	-1.2	-2.7	5.9
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	5.6	6.1	7.0	6.3
Wind dir. yesterday 700 mb at Lake Charles (degrees)	127	41	20	37
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	5.2	4.9	5.3	5.4
Wind speed AM 850 mb at Lake Charles (ms^{-1})	6.0	4.6	4.5	3.8
Wind speed PM 850 mb at Lake Charles (ms^{-1})	5.3	4.7	5.0	5.1
Wind dir. yesterday 850 mb at Lake Charles (degrees)	127	41	20	37
Wind dir. AM 850 mb at Lake Charles (degrees)	178	90	41	72
Wind dir. PM 850 mb at Lake Charles (degrees)	118	57	29	56
Recirculation index at Lake Charles	0.1	0.2	0.2	0.2
Cloud index at Lake Charles	1.8	1.8	1.6	1.4

Table 22d

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for October - December, 2000-2004: Beaumont/Port Arthur

Surface Meteorological Data are for Port Arthur SE TX Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	353	66	14	5
PM2.5 Parameters				
PM2.5 at Beaumont/Port Arthur (μg/m^3)	8.5	17.8	28.8	41.9
Yesterday's PM2.5 at Beaumont/Port Arthur (μg/m^3)	9.6	15.6	23.2	22.4
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	12.1	16.3	24.3	23.1
Yesterday's PM2.5 at Baton Rouge/New Orleans (μg/m^3)	13.7	19.5	32.6	23.1
Surface Meteorological Parameters				
Max. surface temperature (°C)	21.2	22.9	26.8	24.3
Min. surface temperature (°C)	11.4	12.0	16.7	12.0
Average relative humidity (%)	77	79	76	79
Surface wind speed (ms^{-1})	4.0	3.2	3.3	2.0
Surface wind direction (degrees)	69	75	96	90
Persistence	0.8	0.8	0.8	0.7
Sea level pressure (mb)	1022	1023	1024	1021
Rainfall (inches)	0.2	0.1	0.0	0.2
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	11.0	12.4	13.0	12.0
Temperature PM 850 mb at Lake Charles (°C)	11.1	12.8	12.7	11.9
Stability at Lake Charles at Lake Charles (°C)	0.4	2.3	0.1	3.5
Geopotential hgt difference 700 mb at Lake Charles (m)	-1.3	5.4	-2.5	-6.6
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	11.5	7.6	6.0	11.5
Wind dir. yesterday 700 mb at Lake Charles (degrees)	259	275	180	333
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	8.9	5.5	5.1	10.4
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9.0	5.4	5.4	8.9
Wind speed PM 850 mb at Lake Charles (ms^{-1})	8.8	6.3	5.3	7.8
Wind dir. yesterday 850 mb at Lake Charles (degrees)	240	342	82	0
Wind dir. AM 850 mb at Lake Charles (degrees)	247	242	72	297
Wind dir. PM 850 mb at Lake Charles (degrees)	259	166	124	297
Recirculation index at Lake Charles	0.0	0.2	0.1	0.0
Cloud index at Lake Charles	1.6	1.5	1.5	1.4

Table 23a

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for January–March, 2000-2004: Lake Charles.

Surface Meteorological Data are for Lake Charles Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	129	19	3	1
PM2.5 Parameters				
PM2.5 at Lake Charles (μg/m^3)	9.0	17.9	26.8	47.0
Yesterday's PM2.5 at Baton Rouge/New Orleans (μg/m^3)	13.3	17.6	18.7	14.9
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	12.6	16.9	20.9	N/A
Yesterday's PM2.5 at Beaumont/Port Arthur sites (μg/m^3)	9.3	12.3	23.9	N/A
Surface Meteorological Parameters				
Max. surface temperature (°C)	18.6	18.7	17.8	20.0
Min. surface temperature (°C)	8.7	8.3	2.2	2.2
Average relative humidity (%)	75	77	75	74
Surface wind speed (ms^{-1})	3.9	3.3	2.2	2.1
Surface wind direction (degrees)	102	73	90	270
Persistence	0.9	0.8	0.8	0.8
Sea Level pressure (mb)	1024	1024	1025	1027
Rainfall (inches)	0.1	0.0	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	9.1	9.1	5.6	7.2
Temperature PM 850 mb at Lake Charles (°C)	9.1	9.5	4.0	10.4
Stability at Lake Charles (°C)	0.3	2.0	5.0	4.0
Geopotential hgt difference 700 mb at Lake Charles (m)	-0.6	1.6	7.3	-15.5
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	14.2	10.2	15.7	7.2
Wind dir. yesterday 700 mb at Lake Charles (degrees)	261	278	315	270
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	9.9	6.3	10.6	3.6
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9.7	7.4	11.3	6.7
Wind speed PM 850 mb at Lake Charles (ms^{-1})	9.4	7.5	9.0	7.7
Wind dir. yesterday 850 mb at Lake Charles (degrees)	250	297	0	0
Wind dir. AM 850 mb at Lake Charles (degrees)	260	279	315	270
Wind dir. PM 850 mb at Lake Charles (degrees)	247	284	N/A	270
Recirculation index at Lake Charles	0.0	0.1	0.0	0.0
Cloud index at Lake Charles	1.6	1.6	1.0	2.0

Table 23b

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for April–June, 2000-2004: Lake Charles.

Surface Meteorological Data are for Lake Charles Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	129	20	1	0
PM2.5 Parameters				
PM2.5 at Lake Charles ($\mu g/m^3$)	9.7	18.3	30.6	N/A
Yesterday's PM2.5 at Baton Rouge/New Orleans ($\mu g/m^3$)	12.6	15.3	22.2	N/A
Yesterday's PM2.5 at Houston/Galveston ($\mu g/m^3$)	14.8	17.5	18.0	N/A
Yesterday's PM2.5 at Beaumont/Port Arthur sites ($\mu g/m^3$)	10.8	15.1	15.8	N/A
Surface Meteorological Parameters				**N/A**
Max. surface temperature (°C)	28.3	30.1	30.6	N/A
Min. surface temperature (°C)	19.5	19.0	15.6	N/A
Average relative humidity (%)	80	74	64	N/A
Surface wind speed (ms^{-1})	3.3	2.5	1.8	N/A
Surface wind direction (degrees)	155	165	180	N/A
Persistence	0.8	0.8	0.3	N/A
Sea Level pressure (mb)	1018	1018	1017	N/A
Rainfall (inches)	0.2	0.0	0.0	N/A
Upper-Air Meteorological Parameters				**N/A**
Temperature AM 850 mb at Lake Charles (°C)	15.4	15.2	16.0	N/A
Temperature PM 850 mb at Lake Charles (°C)	15.4	16.2	15.0	N/A
Stability at Lake Charles (°C)	-2.6	-0.6	0.2	N/A
Geopotential hgt difference 700 mb at Lake Charles (m)	-0.1	2.1	-8.5	N/A
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	8.1	8.2	11.3	N/A
Wind dir. yesterday 700 mb at Lake Charles (degrees)	226	311	0	N/A
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	6.7	6.4	6.1	N/A
Wind speed AM 850 mb at Lake Charles (ms^{-1})	8.5	5.9	3.6	N/A
Wind speed PM 850 mb at Lake Charles (ms^{-1})	6.8	6.3	6.1	N/A
Wind dir. yesterday 850 mb at Lake Charles (degrees)	184	14	0	N/A
Wind dir. AM 850 mb at Lake Charles (degrees)	191	214	270	N/A
Wind dir. PM 850 mb at Lake Charles (degrees)	193	90	0	N/A
Recirculation index at Lake Charles	0.1	0.2	0.0	N/A
Cloud index at Lake Charles	1.6	1.5	1.0	N/A

Table 23c

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for July–September, 2000-2004: Lake Charles.

Surface Meteorological Data are for Lake Charles Airport.

The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	103	37	12	2
PM2.5 Parameters				
PM2.5 at Lake Charles (μg/m^3)	9.5	19.0	30.3	39.1
Yesterday's PM2.5 at Baton Rouge/New Orleans (μg/m^3)	13.1	19.6	27.9	25.9
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	14.2	18.2	22.0	45.5
Yesterday's PM2.5 at Beaumont/Port Arthur sites (μg/m^3)	10.9	15.2	22.1	34.1
Surface Meteorological Parameters				
Max. surface temperature (°C)	31.5	32.5	34.0	32.5
Min. surface temperature (°C)	23.1	21.3	22.4	21.4
Average relative humidity (%)	80	71	69	74
Surface wind speed (ms^{-1})	2.4	2.1	2.3	1.1
Surface wind direction (degrees)	142	75	72	N/A
Persistence	0.7	0.7	0.7	0.8
Sea Level pressure (mb)	1018	1018	1016	1016
Rainfall (inches)	0.3	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	17.8	17.5	18.2	16.9
Temperature PM 850 mb at Lake Charles (°C)	18.0	17.9	18.6	17.2
Stability at Lake Charles (°C)	-2.7	-1.3	-1.2	-0.4
Geopotential hgt difference 700 mb at Lake Charles (m)	-2.6	-3.8	2.6	7.3
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	5.9	5.9	8.2	3.6
Wind dir. yesterday 700 mb at Lake Charles (degrees)	315	54	45	N/A
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	5.3	4.9	5.6	4.1
Wind speed AM 850 mb at Lake Charles (ms^{-1})	6.5	4.6	4.7	3.1
Wind speed PM 850 mb at Lake Charles (ms^{-1})	5.7	4.9	6.0	1.3
Wind dir. yesterday 850 mb at Lake Charles (degrees)	68	47	36	0
Wind dir. AM 850 mb at Lake Charles (degrees)	181	56	90	0
Wind dir. PM 850 mb at Lake Charles (degrees)	118	56	69	315
Recirculation index at Lake Charles	0.1	0.2	0.2	0.5
Cloud index at Lake Charles	1.9	1.6	1.6	1.5

Table 23d

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for October–December, 2000-2004: Lake Charles.

Surface Meteorological Data are for Lake Charles Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	119	24	5	3
PM2.5 Parameters				
PM2.5 at Lake Charles (μg/m^3)	8.5	17.7	29.9	48.4
Yesterday's PM2.5 at Baton Rouge/New Orleans (μg/m^3)	12.5	19.1	27.2	30.0
Yesterday's PM2.5 at Houston/Galveston (μg/m^3)	11.4	14.5	22.3	25.8
Yesterday's PM2.5 at Beaumont/Port Arthur sites (μg/m^3)	9.2	13.1	18.7	20.6
Surface Meteorological Parameters				
Max. surface temperature (°C)	21.0	24.3	24.2	23.7
Min. surface temperature (°C)	10.5	12.3	10.8	9.1
Average relative humidity (%)	76	78	74	72
Surface wind speed (ms^{-1})	3.3	2.8	1.8	2.0
Surface wind direction (degrees)	94	75	90	117
Persistence	0.8	0.9	0.7	0.8
Sea Level pressure (mb)	1022	1024	1028	1025
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Lake Charles (°C)	11.0	12.4	10.8	12.9
Temperature PM 850 mb at Lake Charles (°C)	11.1	12.7	10.5	12.1
Stability at Lake Charles (°C)	0.9	1.3	1.1	4.8
Geopotential hgt difference 700 mb at Lake Charles (m)	2.8	8.9	22.7	-6.3
Wind speed yesterday 700 mb at Lake Charles (ms^{-1})	12.1	7.6	7.4	4.6
Wind dir. yesterday 700 mb at Lake Charles (degrees)	265	266	0	270
Wind speed yesterday 850 mb at Lake Charles (ms^{-1})	9.4	5.1	5.5	5.1
Wind speed AM 850 mb at Lake Charles (ms^{-1})	9.1	5.7	7.0	2.9
Wind speed PM 850 mb at Lake Charles (ms^{-1})	8.4	5.7	4.3	7.5
Wind dir. yesterday 850 mb at Lake Charles (degrees)	256	90	27	90
Wind dir. AM 850 mb at Lake Charles (degrees)	256	225	0	180
Wind dir. PM 850 mb at Lake Charles (degrees)	259	153	56	180
Recirculation index at Lake Charles	0.1	0.1	0.0	0.3
Cloud index at Lake Charles	1.5	1.6	1.4	1.3

Table 24a

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for January–March, 2000-2004: New Orleans.

Surface Meteorological Data are for New Orleans International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	330	106	9	3
PM2.5 Parameters				
PM2.5 at New Orleans (μg/m^3)	9.8	18.3	28.7	38.1
Yesterday's PM2.5 at New Orleans (μg/m^3)	11.0	15.5	21.9	25.4
Yesterday's PM2.5 at Baton Rouge (μg/m^3)	12.2	16.3	20.8	25.3
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur (μg/m^3)	13.2	16.2	19.2	14.6
Surface Meteorological Parameters				
Max. surface temperature (°C)	18.7	19.2	18.3	20.0
Min. surface temperature (°C)	9.9	9.0	4.8	10.2
Average relative humidity (%)	73	73	69	82
Surface wind speed (ms^{-1})	4.4	3.0	2.6	2.0
Surface wind direction (degrees)	42	73	63	90
Persistence	0.8	0.8	0.8	0.5
Sea level pressure (mb)	1023	1024	1024	1027
Rainfall (inches)	0.1	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	9.0	8.9	6.1	9.6
Temperature PM 850 mb at Slidell (°C)	8.8	9.1	9.0	8.0
Stability at Slidell (°C)	1.3	3.1	5.8	1.6
Geopotential hgt difference 700 mb at Slidell (m)	-0.6	2.8	15.7	-22.5
Wind speed yesterday 700 mb at Slidell (ms^{-1})	15.0	11.6	13.6	10.8
Wind dir. yesterday 700 mb at Slidell (degrees)	263	276	292	270
Wind speed yesterday 850 mb at Slidell (ms^{-1})	10.1	6.5	8.8	8.2
Wind speed AM 850 mb at Slidell (ms^{-1})	10.5	7.2	8.8	5.9
Wind speed PM 850 mb at Slidell (ms^{-1})	9.8	7.6	7.8	6.7
Wind dir. yesterday 850 mb at Slidell (degrees)	263	302	326	0
Wind dir. AM 850 mb at Slidell (degrees)	264	272	326	225
Wind dir. PM 850 mb at Slidell (degrees)	274	269	315	N/A
Recirculation index at Slidell	0.0	0.0	0.0	0.0
Cloud index	1.6	1.5	1.2	1.5

Table 24b

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for April - May, 2000-2004: New Orleans.

Surface Meteorological Data are for New Orleans International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	331	116	0	0
PM2.5 Parameters				
PM2.5 at New Orleans (μg/m^3)	9.9	17.9	N/A	N/A
Yesterday's PM2.5 at New Orleans (μg/m^3)	10.9	15.2	N/A	N/A
Yesterday's PM2.5 at Baton Rouge (μg/m^3)	12.0	15.5	N/A	N/A
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur (μg/m^3)	14.6	16.4	N/A	N/A
Surface Meteorological Parameters				
Max. surface temperature (°C)	28.7	29.2	N/A	N/A
Min. surface temperature (°C)	20.5	19.7	N/A	N/A
Average relative humidity (%)	75	70	N/A	N/A
Surface wind speed (ms^{-1})	3.8	3.3	N/A	N/A
Surface wind direction (degrees)	162	157	N/A	N/A
Persistence	0.8	0.7	N/A	N/A
Sea level pressure (mb)	1018	1019	N/A	N/A
Rainfall (inches)	0.3	0.1	N/A	N/A
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	14.8	14.6	N/A	N/A
Temperature PM 850 mb at Slidell (°C)	14.7	15.1	N/A	N/A
Stability at Slidell (°C)	-1.6	0.7	N/A	N/A
Geopotential hgt difference 700 mb at Slidell (m)	-0.2	4.2	N/A	N/A
Wind speed yesterday 700 mb at Slidell (ms^{-1})	8.1	8.0	N/A	N/A
Wind dir. yesterday 700 mb at Slidell (degrees)	245	295	N/A	N/A
Wind speed yesterday 850 mb at Slidell (ms^{-1})	6.9	6.0	N/A	N/A
Wind speed AM 850 mb at Slidell (ms^{-1})	8.2	6.8	N/A	N/A
Wind speed PM 850 mb at Slidell (ms^{-1})	6.9	6.0	N/A	N/A
Wind dir. yesterday 850 mb at Slidell (degrees)	221	321	N/A	N/A
Wind dir. AM 850 mb at Slidell (degrees)	206	217	N/A	N/A
Wind dir. PM 850 mb at Slidell (degrees)	231	223	N/A	N/A
Recirculation index at Slidell	0.0	0.1	N/A	N/A
Cloud index	1.7	1.4	N/A	N/A

Table 24c

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for June - September, 2000-2004: New Orleans.

Surface Meteorological Data are for New Orleans International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	288	129	34	9
PM2.5 Parameters				
PM2.5 at New Orleans ($\mu g/m^3$)	9.9	19.1	27.7	40.1
Yesterday's PM2.5 at New Orleans ($\mu g/m^3$)	11.5	17.4	23.0	28.7
Yesterday's PM2.5 at Baton Rouge ($\mu g/m^3$)	12.7	18.0	22.7	32.5
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur ($\mu g/m^3$)	15.3	18.4	20.2	40.7
Surface Meteorological Parameters				
Max. surface temperature (°C)	31.1	32.2	32.9	33.6
Min. surface temperature (°C)	23.9	23.6	24.0	24.4
Average relative humidity (%)	78	71	68	69
Surface wind speed (ms^{-1})	3.0	2.8	2.9	2.9
Surface wind direction (degrees)	144	8	18	297
Persistence	0.7	0.7	0.7	0.6
Sea level pressure (mb)	1018	1017	1017	1014
Rainfall (inches)	0.3	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	17.4	17.2	17.4	18.2
Temperature PM 850 mb at Slidell (°C)	17.6	17.8	18.1	18.6
Stability at Slidell (°C)	-2.1	-0.7	0.1	1.0
Geopotential hgt difference 700 mb at Slidell (m)	0.4	-2.4	0.0	4.8
Wind speed yesterday 700 mb at Slidell (ms^{-1})	6.0	5.3	5.2	9.0
Wind dir. yesterday 700 mb at Slidell (degrees)	287	5	21	346
Wind speed yesterday 850 mb at Slidell (ms^{-1})	5.7	5.0	5.1	5.2
Wind speed AM 850 mb at Slidell (ms^{-1})	5.8	4.3	4.0	4.2
Wind speed PM 850 mb at Slidell (ms^{-1})	5.7	4.9	4.7	5.1
Wind dir. yesterday 850 mb at Slidell (degrees)	104	26	9	353
Wind dir. AM 850 mb at Slidell (degrees)	205	117	270	14
Wind dir. PM 850 mb at Slidell (degrees)	337	38	27	0
Recirculation index at Slidell	0.1	0.2	0.2	0.2
Cloud index	2.0	1.7	1.6	1.8

Table 24d

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for October - December, 2000-2004: New Orleans.

Surface Meteorological Data are for New Orleans International Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	336	87	27	7
PM2.5 Parameters				
PM2.5 at New Orleans ($\mu g/m^3$)	9.4	18.8	28.7	41.0
Yesterday's PM2.5 at New Orleans ($\mu g/m^3$)	10.3	17.5	23.4	33.5
Yesterday's PM2.5 at Baton Rouge ($\mu g/m^3$)	12.3	19.4	25.1	30.4
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur ($\mu g/m^3$)	12.3	16.3	22.7	22.0
Surface Meteorological Parameters				
Max. surface temperature (°C)	21.1	23.9	23.4	26.3
Min. surface temperature (°C)	12.3	14.1	13.5	14.6
Average relative humidity (%)	73	75	75	76
Surface wind speed (ms^{-1})	4.1	2.5	2.3	1.8
Surface wind direction (degrees)	68	59	52	76
Persistence	0.8	0.8	0.8	0.7
Sea level pressure (mb)	1022	1023	1023	1023
Rainfall (inches)	0.2	0.0	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	10.9	12.7	11.4	13.5
Temperature PM 850 mb at Slidell (°C)	10.8	12.7	12.4	13.6
Stability at Slidell (°C)	1.2	3.0	3.2	6.4
Geopotential hgt difference 700 mb at Slidell (m)	-1.6	1.6	2.1	9.4
Wind speed yesterday 700 mb at Slidell (ms^{-1})	12.3	6.8	8.1	4.0
Wind dir. yesterday 700 mb at Slidell (degrees)	262	274	293	14
Wind speed yesterday 850 mb at Slidell (ms^{-1})	9.1	5.5	6.4	4.1
Wind speed AM 850 mb at Slidell (ms^{-1})	9.6	5.5	6.0	5.1
Wind speed PM 850 mb at Slidell (ms^{-1})	9.2	5.4	6.0	4.3
Wind dir. yesterday 850 mb at Slidell (degrees)	269	355	336	56
Wind dir. AM 850 mb at Slidell (degrees)	253	231	117	117
Wind dir. PM 850 mb at Slidell (degrees)	281	304	315	104
Recirculation index at Slidell	0.0	0.1	0.1	0.3
Cloud index	1.6	1.5	1.4	1.0

Table 25a

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for January–March 2000-2004: Baton Rouge.

Surface Meteorological Data are for Baton Rouge Ryan Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	306	126	14	1
PM2.5 Parameters				
PM2.5 at Baton Rouge (μg/m^3)	10.4	18.9	29.3	37.4
Yesterday's PM2.5 at Baton Rouge (μg/m^3)	12.0	16.2	19.8	31.9
Yesterday's PM2.5 at New Orleans (μg/m^3)	11.0	15.1	19.6	31.7
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur (μg/m^3)	12.9	16.6	16.0	21.0
Surface Meteorological Parameters				
Max. surface temperature (°C)	18.4	20.0	19.8	17.8
Min. surface temperature (°C)	7.7	6.6	7.2	1.7
Average relative humidity (%)	71	72	73	45
Surface wind speed (ms^{-1})	3.3	2.5	2.1	0.7
Surface wind direction (degrees)	84	126	135	180
Persistence	0.8	0.8	0.8	0.5
Sea level pressure (mb)	1023	1023	1024	1030
Rainfall (inches)	0.2	0.0	0.1	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	8.9	9.0	8.2	3.6
Temperature PM 850 mb at Slidell (°C)	8.7	9.4	8.8	4.6
Stability at Slidell (°C)	0.9	3.7	3.8	6.0
Geopotential hgt difference 700 mb at Slidell (m)	-3.1	7.8	-1.0	N/A
Wind speed yesterday 700 mb at Slidell (ms^{-1})	15.2	12.2	10.7	N/A
Wind dir. yesterday 700 mb at Slidell (degrees)	262	278	278	N/A
Wind speed yesterday 850 mb at Slidell (ms^{-1})	10.3	7.0	7.0	N/A
Wind speed AM 850 mb at Slidell (ms^{-1})	10.5	8.0	6.6	6.7
Wind speed PM 850 mb at Slidell (ms^{-1})	9.9	8.0	6.5	8.2
Wind dir. yesterday 850 mb at Slidell (degrees)	264	293	333	N/A
Wind dir. AM 850 mb at Slidell (degrees)	263	273	270	0
Wind dir. PM 850 mb at Slidell (degrees)	279	261	259	0
Recirculation at Slidell	0.0	0.0	0.0	0.0
Cloud index at Slidell	1.5	1.4	1.8	1.0

Table 25b

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for April–June, 2000-2004: Baton Rouge.

Surface Meteorological Data are for Baton Rouge Ryan Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	324	125	6	0
PM2.5 Parameters				
PM2.5 at Baton Rouge (μg/m^3)	10.7	17.9	27.6	N/A
Yesterday's PM2.5 at Baton Rouge (μg/m^3)	11.7	15.8	16.0	N/A
Yesterday's PM2.5 at New Orleans (μg/m^3)	10.7	15.0	16.1	N/A
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur (μg/m^3)	14.4	16.6	17.6	N/A
Surface Meteorological Parameters				
Max. surface temperature (°C)	28.9	29.2	28.2	N/A
Min. surface temperature (°C)	18.6	16.9	15.6	N/A
Average relative humidity (%)	76	71	65	N/A
Surface wind speed (ms^{-1})	3.0	2.6	2.5	N/A
Surface wind direction (degrees)	154	140	90	N/A
Persistence	0.8	0.8	0.8	N/A
Sea level pressure (mb)	1018	1018	1019	N/A
Rainfall (inches)	0.2	0.0	0.1	N/A
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	15.0	14.3	14.6	N/A
Temperature PM 850 mb at Slidell (°C)	14.8	14.8	14.7	N/A
Stability at Slidell (°C)	-1.6	0.5	1.1	N/A
Geopotential hgt difference 700 mb at Slidell (m)	-0.6	4.8	3.4	N/A
Wind speed yesterday 700 mb at Slidell (ms^{-1})	6.9	6.3	4.8	N/A
Wind dir. yesterday 700 mb at Slidell (degrees)	244	301	315	N/A
Wind speed yesterday 850 mb at Slidell (ms^{-1})	6.9	6.3	4.8	N/A
Wind speed AM 850 mb at Slidell (ms^{-1})	8.3	6.9	5.1	N/A
Wind speed PM 850 mb at Slidell (ms^{-1})	6.9	6.2	5.2	N/A
Wind dir. yesterday 850 mb at Slidell (degrees)	244	301	315	N/A
Wind dir. AM 850 mb at Slidell (degrees)	230	225	N/A	N/A
Wind dir. PM 850 mb at Slidell (degrees)	223	336	342	N/A
Recirculation at Slidell	0.0	0.1	0.3	N/A
Cloud index at Slidell	1.7	1.5	1.0	N/A

Table 25c

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for July - September, 2000-2004: Baton Rouge.

Surface Meteorological Data are for Baton Rouge Ryan Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	**Category 2**	**Category 3**	**Category 4**
No. of Days	254	157	41	8
PM2.5 Parameters				
PM2.5 at Baton Rouge ($\mu g/m^3$)	10.3	18.9	28.6	40.6
Yesterday's PM2.5 at Baton Rouge ($\mu g/m^3$)	12.1	17.8	22.8	31.0
Yesterday's PM2.5 at New Orleans ($\mu g/m^3$)	11.1	16.7	23.0	25.2
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur ($\mu g/m^3$)	14.7	18.5	20.8	42.6
Surface Meteorological Parameters				
Max. surface temperature (°C)	31.3	32.5	33.4	33.5
Min. surface temperature (°C)	22.1	21.4	21.6	21.6
Average relative humidity (%)	80	74	69	69
Surface wind speed (ms^{-1})	2.2	1.9	1.7	1.5
Surface wind direction (degrees)	152	53	50	90
Persistence	0.7	0.7	0.7	0.8
Sea level pressure (mb)	1018	1017	1016	1015
Rainfall (inches)	0.2	0.1	0.0	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	17.3	17.6	17.3	17.0
Temperature PM 850 mb at Slidell (°C)	17.6	17.8	18.0	17.6
Stability at Slidell (°C)	-2.1	-0.8	0.1	0.0
Geopotential hgt difference 700 mb at Slidell (m)	0.9	-2.3	-2.1	8.6
Wind speed yesterday 700 mb at Slidell (ms^{-1})	5.7	5.5	7.0	7.5
Wind dir. yesterday 700 mb at Slidell (degrees)	258	16	29	18
Wind speed yesterday 850 mb at Slidell (ms^{-1})	5.5	5.3	5.4	6.4
Wind speed AM 850 mb at Slidell (ms^{-1})	5.7	4.8	4.5	4.0
Wind speed PM 850 mb at Slidell (ms^{-1})	5.4	5.5	5.3	4.4
Wind dir. yesterday 850 mb at Slidell (degrees)	232	36	27	0
Wind dir. AM 850 mb at Slidell (degrees)	209	115	9	45
Wind dir. PM 850 mb at Slidell (degrees)	285	43	29	0
Recirculation at Slidell	0.1	0.2	0.2	0.3
Cloud index at Slidell	2.0	1.7	1.7	1.6

Table 25d

Summary of PM2.5 and Meteorological Data by PM2.5 Concentration Category for October - December, 2000-2004: Baton Rouge.

Surface Meteorological Data are for Baton Rouge Ryan Airport.
The Ranges in PM2.5 Concentration for Categories 1 through 4 are as follows:
<15, 15-25, 25-35 and ≥ 35 μgm^{-3}.

	Category 1	Category 2	Category 3	Category 4
No. of Days	297	116	36	11
PM2.5 Parameters				
PM2.5 at Baton Rouge ($\mu g/m^3$)	10.2	18.9	28.1	41.6
Yesterday's PM2.5 at Baton Rouge ($\mu g/m^3$)	11.8	17.7	24.7	28.9
Yesterday's PM2.5 at New Orleans ($\mu g/m^3$)	9.9	15.6	22.2	30.3
Yesterday's PM2.5 at Houston/Galveston/Beaumont/Port Arthur ($\mu g/m^3$)	11.7	16.3	21.0	20.2
Surface Meteorological Parameters				
Max. surface temperature (°C)	20.4	22.7	26.2	23.4
Min. surface temperature (°C)	9.8	9.1	12.4	7.9
Average relative humidity (%)	75	73	76	74
Surface wind speed (ms^{-1})	3.0	1.8	1.3	1.5
Surface wind direction (degrees)	84	86	84	111
Persistence	0.8	0.8	0.7	0.8
Sea level pressure (mb)	1022	1023	1022	1023
Rainfall (inches)	0.2	0.0	0.1	0.0
Upper-Air Meteorological Parameters				
Temperature AM 850 mb at Slidell (°C)	10.9	11.7	13.3	11.0
Temperature PM 850 mb at Slidell (°C)	10.9	11.9	13.1	11.2
Stability at Slidell (°C)	0.7	3.8	2.0	6.0
Geopotential hgt difference 700 mb at Slidell (m)	-2.6	4.2	0.7	-7.9
Wind speed yesterday 700 mb at Slidell (ms^{-1})	9.3	6.6	4.9	5.2
Wind dir. yesterday 700 mb at Slidell (degrees)	257	290	284	346
Wind speed yesterday 850 mb at Slidell (ms^{-1})	9.3	6.6	4.9	5.2
Wind speed AM 850 mb at Slidell (ms^{-1})	9.9	6.4	4.8	6.0
Wind speed PM 850 mb at Slidell (ms^{-1})	9.4	6.6	5.3	5.0
Wind dir. yesterday 850 mb at Slidell (degrees)	260	339	45	34
Wind dir. AM 850 mb at Slidell (degrees)	251	262	111	153
Wind dir. PM 850 mb at Slidell (degrees)	283	286	333	166
Recirculation at Slidell	0.0	0.1	0.3	0.0
Cloud index at Slidell	1.6	1.4	1.4	1.2

The information contained in Tables 20-25 indicates that, in general, higher prior day concentrations (carryover), lower wind speeds, and greater stability characterize high $PM_{2.5}$ for most areas and quarters. These factors were also found to be important on an annual basis. Depending on the area and the time of year, other meteorological factors are correlated with high $PM_{2.5}$.

2.4. VISIBILITY CALCULATIONS

In this study, visibility was examined for three Class I areas along the coast. These areas are:

- Breton National Wilderness Area (NWA), Louisiana
- St. Mark's NWA, Florida
- Chassahowitzka NWA, Florida.

The areas represented by the monitoring sites are shown in Figure 45.

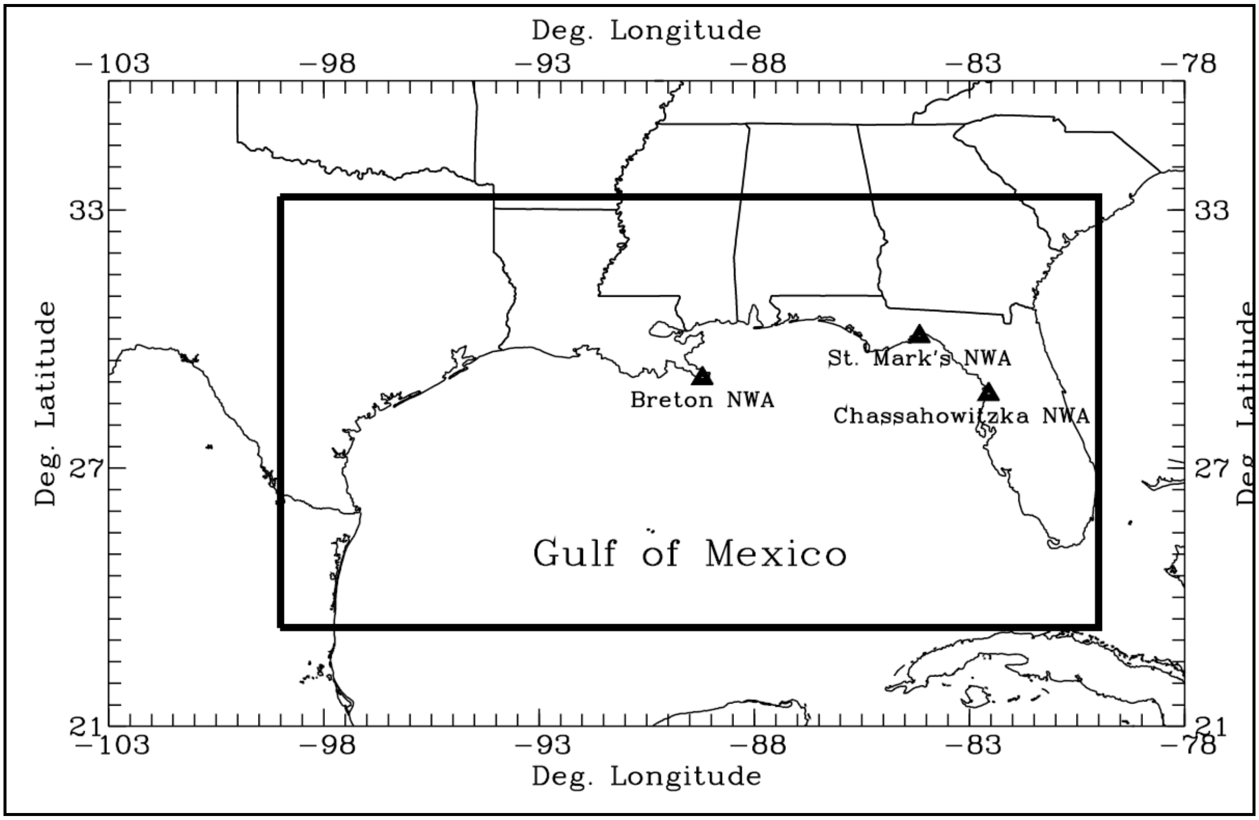


Figure 45. IMPROVE monitoring sites for the MMS synthesis data summaries.

IMPROVE network monitors were located in all three of these areas and the data indicate that some improvement in visibility will be needed for all three areas to achieve the 2018 and beyond regional haze goals. The regional haze rule calls for states to establish "reasonable progress goals" for each Class I area to improve visibility on the 20 percent haziest (worst) days and to prevent visibility degradation on the 20 percent clearest (best) days, with the ultimate goal of returning to natural visibility conditions by 2064. The visibility data were obtained from the VIEWS database (CIRA, 2009). All of the data presented in this section are included in the GMAQDB. Detailed site information is also included in the GMAQDB.

2.4.1. Selected Visibility Metrics

In this section, plots illustrating annual variations in extinction coefficient and visibility (in deciviews) for the 20 percent best (clearest) and worst (haziest) days for each year comprising the period 2000-2004 are presented and discussed.

An estimate of the daily extinction coefficient (Bext) is calculated using the current IMPROVE algorithm (IMPROVE, 2006)). Details are presented in the latest EPA guidance document on the use of models and other analyses for demonstrating attainment of the regional haze goals (USEPA, 2007). Specifically, Bext is calculated as follows:

Bext = 2.2 x f(RH) x [Small Sulfate] + 4.8 x f(RH) x [Large Sulfate]

+ 2.4 x f(RH) x [Small Nitrate] + 4.8 x f(RH) x [Large Nitrate]

+ 2.8 x f(RH) x [Small Organic Mass] + 4.8 x f(RH) x [Large Organic Mass]

+ 10 x [Elemental Carbon]

+ 1 x [Fine Soil]

+ 1.7 x f(rh) x [Sea Salt]

+ 0.6 x [Coarse Mass]

+ Rayleigh Scattering (site specific)

In this equation, f(rh) is a relative humidity adjustment factor. Monthly values of f(rh) are used and they differ for small and large particles and sea salt. The brackets represent concentrations of each constituent. The last term involving NO_2 concentration was not included here due to lack of NO_2 data. In applying this algorithm, sulfate, nitrate, and organic mass are apportioned into small and large size fractions using empirical formulae. The units for Bext are Mm^{-1}.

Deciviews are defined as the natural logarithm of the ratio of extinction coefficient to Rayleigh scattering (USEPA, 2007) as follows:

Deciview = 10 ln(Bext/10)

For the data summaries presented in this section, pre-calculated values of Bext by species were obtained from the IMPROVE dataset and used to prepare the summary charts.

Figures 46 through 48 summarize visibility for the three Class I areas. The first chart presents average Bext by species for the 20 percent best days for each year. The second chart presents average Bext by species for the 20 percent worst days for each year. The third chart gives the average deciview index for the 20 percent best and worst days for each year. The abbreviations used in the first two charts are defined as follows: SO_4 (sulfate mass), NO_3 (nitrate mass), OMC (organic carbon mass), SS (sea salt), and PMC (coarse particulate mass). Extinction coefficient attributable to each component is presented. Note that the scale is different for best and worst Bext, in order to show the relative contributions from each component.

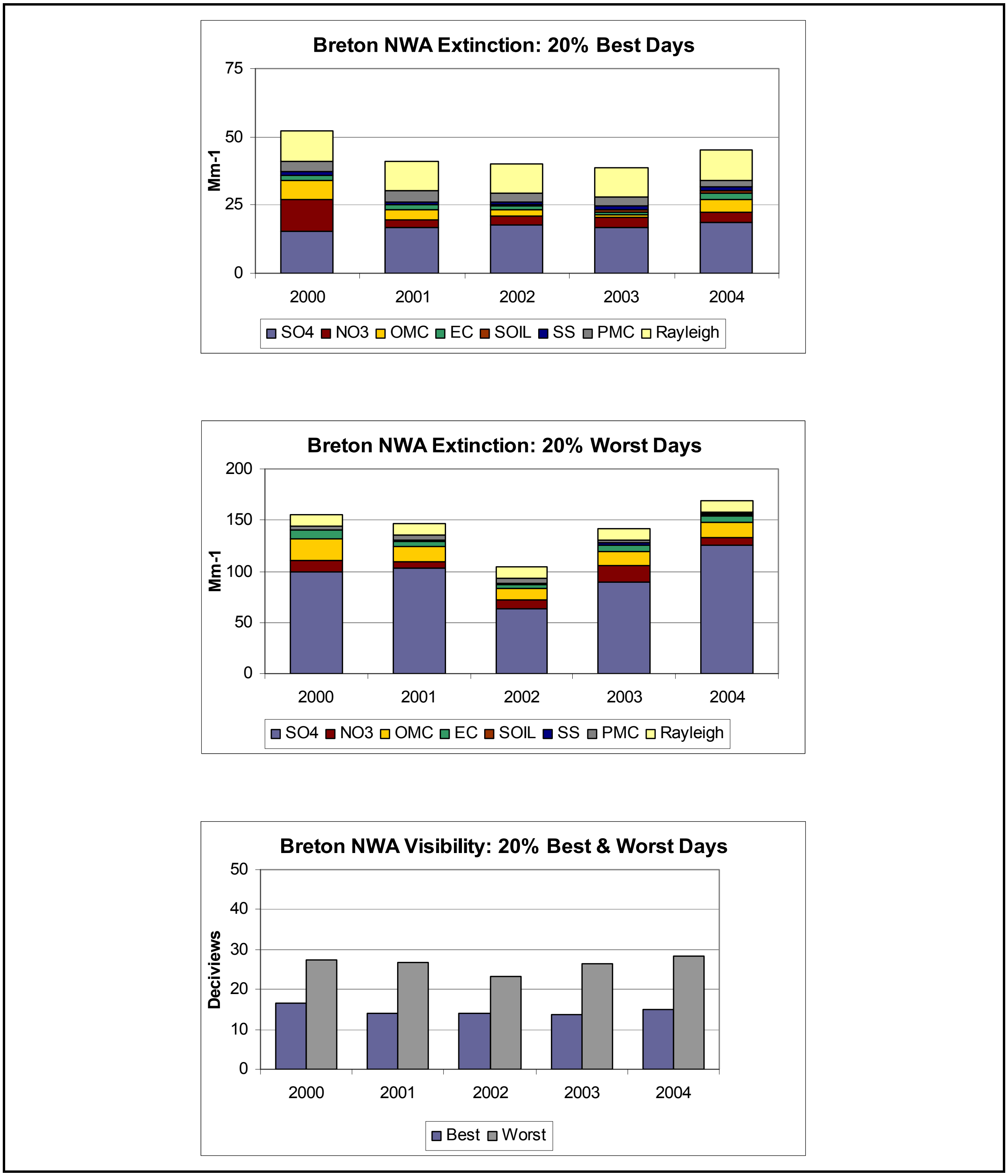


Figure 46. Visibility data summary for Breton NWA (2000-2004).

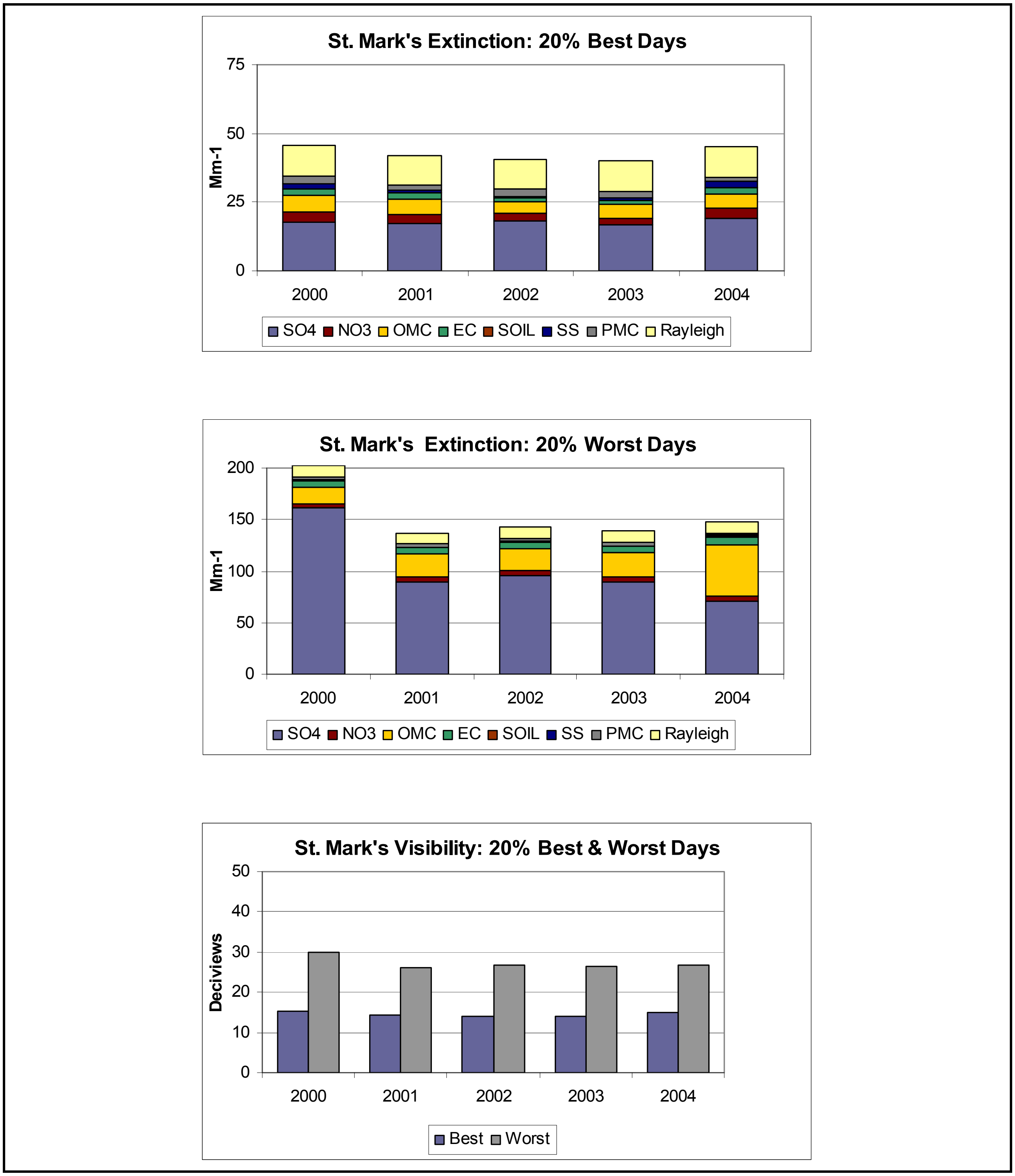


Figure 47. Visibility data summary for St. Mark's NWA (2000-2004).

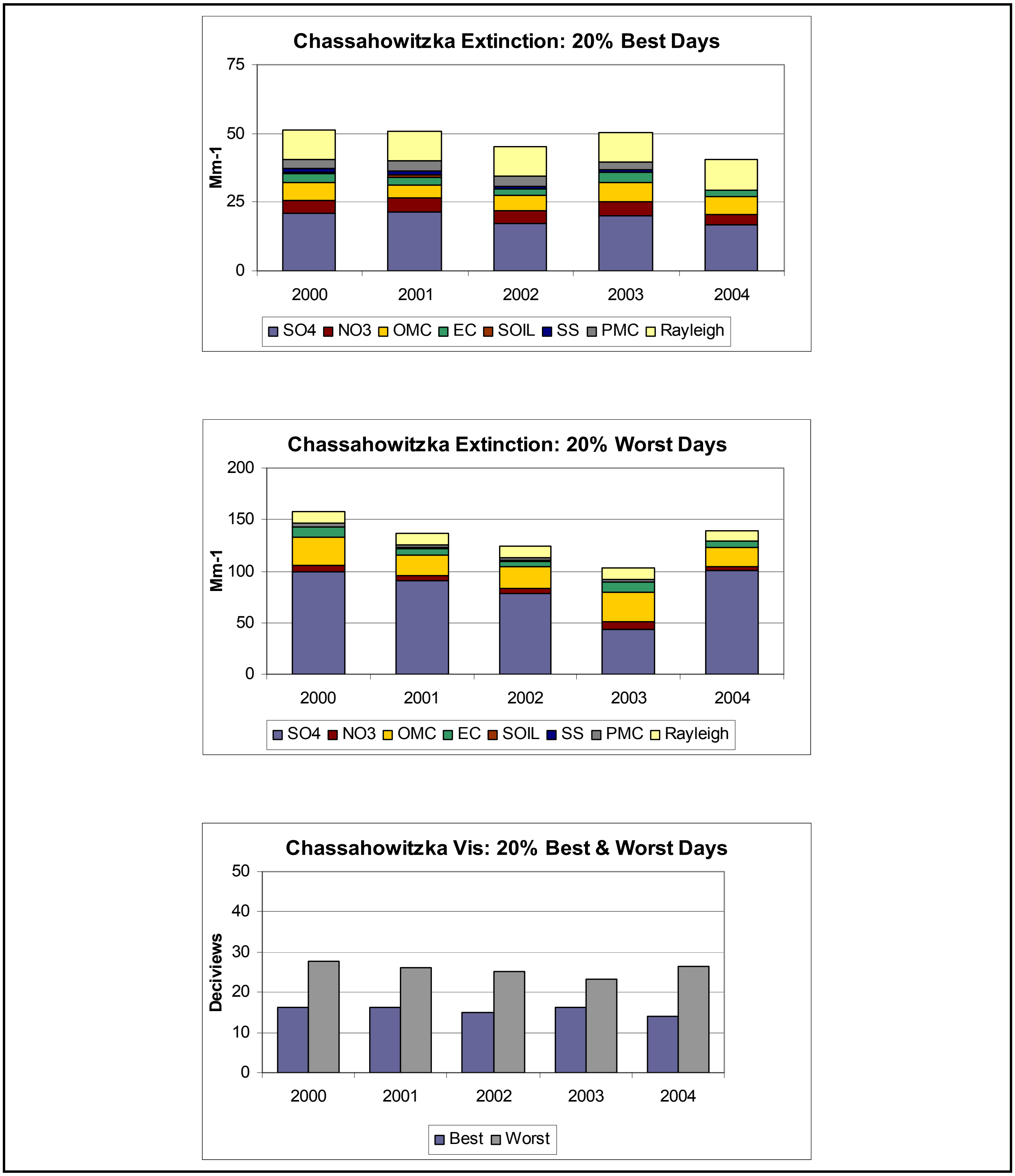


Figure 48. Visibility data summary for Chassahowitzka NWA (2000-2004).

For all three areas, the visibility metrics vary from year to year and there is no clear trend in visibility during the baseline period.

2.4.2. Combined Visibility and Meteorological Data Summaries

In the remainder of this section on visibility, summary tables provide information about the meteorological conditions associated with different levels of extinction coefficient within the Class I areas. The focus is on the period 2000-2004.

Average values of a variety of meteorological parameters were calculated for five ranges of extinction coefficient, that are defined by the 20, 50, 80, and 95 percentile values of calculated extinction coefficient for each site. Specifically, the ranges for each category are <20, 20-50, 50-80, 80-95, and ≥95 percentiles values. For the summary tables the ranges are rounded to the nearest 5 Mm^{-1}.

Meteorological data from the nearest surface monitoring site and the nearest upper-air monitoring site(s) were used to prepare the summary tables. For areas located between upper-air sites, multiple upper-air sites were considered.

The meteorological parameters include the following surface parameters: maximum and daily average temperature, relative humidity at noon, wind speed and direction for three three-hour daytime periods, persistence index, pressure, and rainfall amount.

The upper-air meteorological parameters include: 850 mb temperature, 900 mb to surface temperature difference (or stability index), change in geopotential hgt during the past 24 hours at 700 mb (an indicator of changing synoptic scale patterns), 850 mb wind speed and wind direction for the prior evening, morning, and evening soundings, recirculation index (an indicator of upper-air wind persistence) and cloud index.

In addition to the meteorological parameters, the average extinction coefficient for each category is provided. Prior day 24-hour average $PM_{2.5}$ concentrations for potential upwind areas are also provided.

The combined visibility and meteorological summaries are given in Tables 26 through 28. Information for each area is presented in the order listed above (west to east).

Table 26

Summary of Extinction Coefficient and Meteorological Data by Extinction Category for 2000-2004: Breton NWA.

Surface Meteorological Data are for Boothville, LA.
The Ranges in Extinction Coefficient for Categories 1 through 5 are as follows:
<50, 50-70, 70-105, 105-135 and ≥ 135 Mm^{-1}.

	Category 1	Category 2	Category 3	Category 4	Category 5
No. of Days	74	83	88	50	16
Visibility-Related Parameters					
Extinction Coefficient at Breton (Mm^{-1})	40.8	59.6	84.5	122.5	180.3
Yesterday's PM2.5 at New Orleans/Baton Rouge ($\mu g/m^3$)	9.8	12.3	13.9	17.4	23.5
Yesterday's PM2.5 at Gulfport ($\mu g/m^3$)	7.8	10.0	11.0	15.3	19.9
Yesterday's PM2.5 at Pensacola ($\mu g/m^3$)	9.5	11.4	13.7	17.5	20.4
Surface Meteorological Parameters					
Max. surface temperature (°C)	21.0	23.4	24.5	25.2	23.9
Min. surface temperature (°C)	15.3	17.1	18.0	18.4	16.0
Avg. relative humidity (%)	74	79	84	82	84
Avg. vector surface wind speed (ms^{-1})	3.2	3.0	2.7	2.6	2.0
Avg. surface wind direction (degrees)	45	73	124	112	31
Persistence	0.8	0.8	0.8	0.8	0.8
Sea level pressure (mb)	1022	1020	1019	1019	1019
Rainfall (inches)	0.2	0.1	0.2	0.0	0.0
Upper-Air Meteorological Parameters					
Temperature AM 850 mb at Slidell (°C)	11.0	12.4	13.5	13.3	12.1
Temperature PM 850 mb at Slidell (°C)	11.6	12.4	13.8	13.6	12.5
Stability at Slidell (°C)	0.5	-0.3	0.2	-0.2	1.3
Geopotential hgt difference 700 mb at Slidell (m)	7.2	3.7	-1.1	0.7	-4.3
Wind speed yesterday 700 mb at Slidell (ms^{-1})	12.2	11.5	10.1	8.3	6.8
Wind dir. yesterday 700 mb at Slidell (degrees)	276	264	262	306	306
Wind speed yesterday 850 mb at Slidell (ms^{-1})	9.1	7.8	7.0	6.6	5.9
Wind speed AM 850 mb at Slidell (ms^{-1})	8.8	8.7	7.6	6.6	6.0
Wind speed PM 850 mb at Slidell (ms^{-1})	6.6	7.7	7.8	6.6	6.9
Wind dir. yesterday 850 mb at Slidell (degrees)	315	251	270	304	297
Wind dir. AM 850 mb at Slidell (degrees)	281	239	225	261	239
Wind dir. PM 850 mb at Slidell (degrees)	309	276	257	284	342
Recirculation index at Slidell	0.1	0.0	0.0	0.1	0.1
Cloud index at Slidell	1.6	1.7	1.8	1.6	1.7

Table 27

Summary of Extinction Coefficient and Meteorological Data by Extinction Category for 2000-2004: St. Mark's NWA.

Surface Meteorological Data are for Tallahassee, FL.
The Ranges in Extinction Coefficient for Categories 1 through 5 are as Follows:
<40, 40-70, 70-100, 100-140 and ≥ 140 Mm^{-1}.

	Category 1	Category 2	Category 3	Category 4	Category 5
No. of Days	81	94	108	56	21
Visibility-Related Parameters					
Extinction Coefficient at St. Marks (Mm^{-1})	40.5	59.9	84.3	117.0	165.8
Yesterday's PM2.5 at Orlando (μg/m^3)	9.3	8.5	10.6	11.6	13.7
Yesterday's PM2.5 at Pensacola (μg/m^3)	9.1	11.2	14.0	16.9	21.8
Surface Meteorological Parameters					
Max. surface temperature (°C)	22.8	26.1	25.4	27.3	27.4
Min. surface temperature (°C)	11.4	13.8	12.8	14.2	15.5
Avg. relative humidity (%)	65	72	72	73	78
Avg. vector surface wind speed (ms^{-1})	2.4	1.9	1.8	1.5	1.4
Avg. surface wind direction (degrees)	42	86	128	135	90
Persistence	0.8	0.7	0.8	0.7	0.7
Sea level pressure (mb)	1022	1020	1020	1020	1022
Rainfall (inches)	0.2	0.2	0.1	0.0	0.1
Upper-Air Meteorological Parameters					
Temperature AM 850 mb at Tallahassee (°C)	10.9	13.2	12.5	13.5	14.1
Temperature PM 850 mb at Tallahassee (°C)	11.2	13.5	12.6	13.6	14.1
Stability at Tallahassee (°C)	-0.3	-0.2	0.2	0.5	1.1
Geopotential hgt difference 700 mb at Tallahassee (m)	0.1	6.3	-1.4	2.7	4.7
Wind speed yesterday 700 mb at Tallahassee (ms^{-1})	13.5	9.8	9.9	8.2	7.5
Wind dir. yesterday 700 mb at Tallahassee (degrees)	266	264	261	267	309
Wind speed yesterday 850 mb at Tallahassee (ms^{-1})	10.1	7.3	7.4	5.8	5.6
Wind speed AM 850 mb at Tallahassee (ms^{-1})	9.8	7.9	7.5	6.2	5.0
Wind speed PM 850 mb at Tallahassee (ms^{-1})	7.7	6.9	6.5	5.9	5.5
Wind dir. yesterday 850 mb at Tallahassee (degrees)	283	278	273	285	331
Wind dir. AM 850 mb at Tallahassee (degrees)	286	229	244	251	270
Wind dir. PM 850 mb at Tallahassee (degrees)	324	291	259	239	63
Recirculation index at Tallahassee	0.0	0.1	0.0	0.1	0.1
Cloud index at Tallahassee	1.6	1.7	1.7	1.6	1.6

Table 28

Summary of Extinction Coefficient and Meteorological Data by Extinction Category for 2000-2004: Chassahowitzka.

Surface Meteorological Data are for Brooksville, FL.
The Ranges in Extinction Coefficient for Categories 1 through 5 are as Follows:
<60, 60-85, 85-115, 115-165 and ≥ 165 Mm^{-1}.

	Category 1	**Category 2**	**Category 3**	**Category 4**	**Category 5**
No. of Days	73	95	89	49	17
Visibility-Related Parameters					
Extinction Coefficient at Chassahowitzka (Mm^{-1})	50.0	71.7	97.5	133.5	190.3
Yesterday's PM2.5 at Tampa (μg/m^3)	10.1	11.0	13.7	14.7	22.6
Yesterday's PM2.5 at Orlando (μg/m^3)	8.4	10.5	11.7	13.0	18.2
Surface Meteorological Parameters					
Max. surface temperature (°C)	24.5	27.5	27.8	27.7	30.9
Min. surface temperature (°C)	13.0	15.0	14.5	14.9	17.2
Avg. relative humidity (%)	71	76	78	80	80
Avg. vector surface wind speed (ms^{-1})	3.0	2.2	1.4	1.7	1.1
Avg. surface wind direction (degrees)	18	333	279	17	300
Persistence	0.9	0.8	0.7	0.7	0.6
Sea level pressure (mb)	1021	1020	1020	1021	1018
Rainfall (inches)	0.1	0.1	0.1	0.2	0.0
Upper-Air Meteorological Parameters					
Temperature AM 850 mb at Tampa (°C)	12.4	13.6	14.4	14.3	15.8
Temperature PM 850 mb at Tampa (°C)	12.8	13.9	14.6	14.1	16.3
Stability at Tampa (°C)	-1.9	-1.4	-0.4	-0.7	-1.0
Geopotential hgt difference 700 mb at Tampa (m)	2.1	-0.8	-0.3	5.2	-1.9
Wind speed yesterday 700 mb at Tampa (ms^{-1})	10.2	8.1	7.2	7.7	5.3
Wind dir. yesterday 700 mb at Tampa (degrees)	274	268	254	285	304
Wind speed yesterday 850 mb at Tampa (ms^{-1})	9.0	7.2	6.1	5.4	4.4
Wind speed AM 850 mb at Tampa (ms^{-1})	8.6	7.4	6.3	5.3	3.5
Wind speed PM 850 mb at Tampa (ms^{-1})	7.6	7.3	6.4	5.7	3.7
Wind dir. yesterday 850 mb at Tampa (degrees)	243	143	125	0	81
Wind dir. AM 850 mb at Tampa (degrees)	294	222	222	209	297
Wind dir. PM 850 mb at Tampa (degrees)	127	200	132	45	124
Recirculation index at Tampa	0.0	0.1	0.1	0.2	0.1
Cloud index at Tampa	1.8	1.7	1.7	1.8	1.4

Higher extinction coefficients (poorer visibility) are associated with higher prior day regional $PM_{2.5}$ concentrations, higher relative humidity, and lower wind speeds. Surface wind direction and persistence also vary among the categories. Again, the data suggest that the relationship between extinction coefficient and meteorology is not easily defined by a few key parameters.

For operational applications, Hsu (personal communication, 2008) found that the best indicator of visibility is the average prior day $PM_{2.5}$ concentrations using the potential upwind sites presented for each area in Tables 25 through 27. Extinction coefficient increases with increasing prior day $PM_{2.5}$ concentration, and the R-squared value is 0.94. This information combined with the prior relationships established between $PM_{2.5}$ and wind speed may prove useful for operation applications.

Hsu and Blanchard (2005) suggest that most hazy days in the Breton area are due to high relative humidity rather than high particulate concentrations. Figures 49 through 51 summarize the characteristics of the worst visibility days for Breton, St. Marks and Chassahowitzka, respectively, in terms of $PM_{2.5}$ concentrations and relative humidity. First $PM_{2.5}$ concentrations for all days with measured data were classified as very high, high, moderate or low. The levels corresponding to these categories are site-specific and are based on the 97, 90 and 70 percentile values from the observed data (i.e. if the concentration for a given day is greater than or equal to the 97th percentile value over all days, the days is classified as a very high $PM_{2.5}$ day, etc.). Next the relative humidity values (based on relative humidity at noon) for these same days were also classified as very high (greater than or equal to 95 percent), high (85-95 percent), moderate (75-85 percent), low-moderate (60-75 percent) or low (less than 60 percent). The distribution of the 20 percent worst visibility days was then examined relative to these categories.

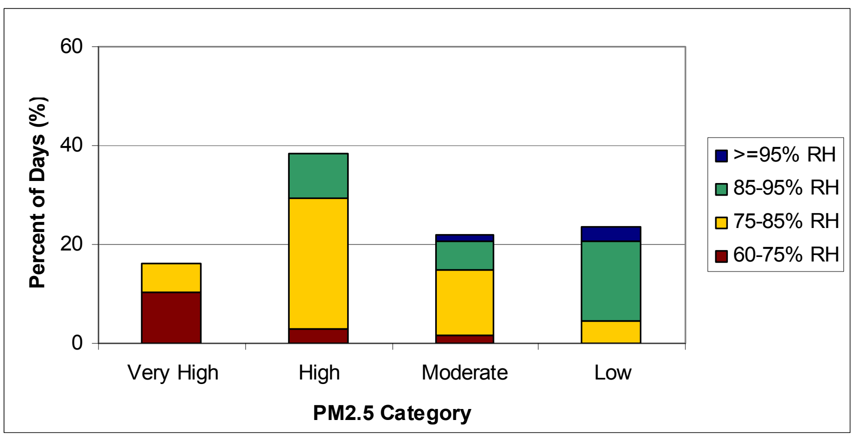


Figure 49. Distribution of 20% worst visibility days among $PM_{2.5}$ and relative humidity categories: Breton NWA (2000-2004).

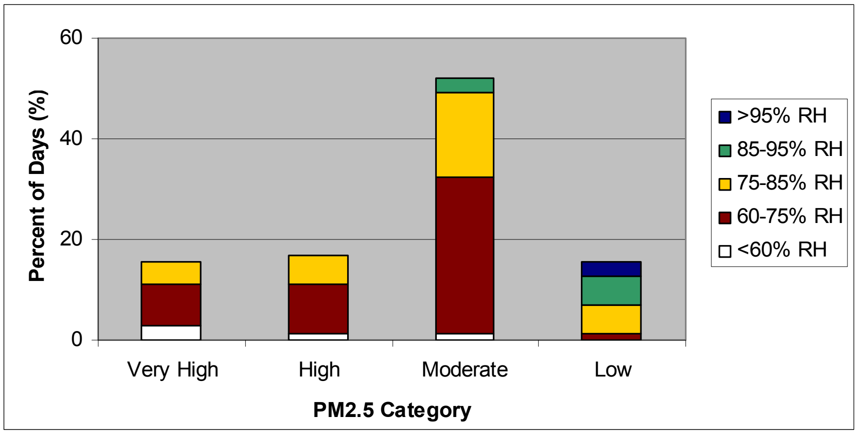


Figure 50. Distribution of 20% worst visibility days among $PM_{2.5}$ and relative humidity categories: St. Mark's NWA (2000-2004).

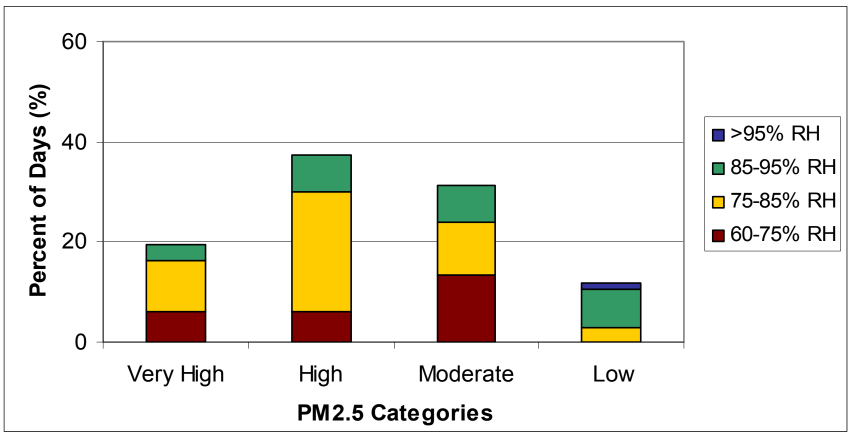


Figure 51. Distribution of 20% worst visibility days among $PM_{2.5}$ and relative humidity categories: Chassahowitzka NWA (2000-2004).

For all three areas, the worst visibility days occur under a variety of conditions. The predominant conditions include very high $PM_{2.5}$ and low to moderate relative humidity, high to moderate $PM_{2.5}$ and relative humidity, and low $PM_{2.5}$ and high relative humidity. These results indicate that the situation may be more complex than indicated by Hsu and Blanchard (2005) in that various combinations of particulate concentrations and humidity can lead to poor visibility.

2.5. Emissions Data Summaries

For this study, ozone and PM precursor emissions inventories from both offshore and onshore sources were acquired, examined and used to infer the effects on observed air quality conditions and trends. For the offshore sources, emissions were obtained for 2000 and 2005 from the MMS-sponsored Gulfwide Emission Inventory development studies (ERG, 2004 and 2007). For these inventories, emissions are provided for a variety of oil and gas development related sources (e.g., platforms, exploration vessels, crew and supply boats, etc.) as well as non oil and gas sources, such as commercial marine and fishing vessels. Emission estimates have been developed for the following criteria pollutant species: (NO_x, VOC, CO, SO_2, PM_{10} and $PM_{2.5}$, as well as greenhouse gas species: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Table 29 presents a summary of emissions for NO_x, VOC, CO, SO_2, and $PM_{2.5}$ for 2000 and 2005 for oil-and-gas-related (platform and non-platform) and other offshore sources operating in the Gulf of Mexico. Emissions data for these pollutants for 2000 and 2005 are included in the GMAQDB tool that was developed for this study.

Although attempts were made to prepare a consistent emission inventory for 2005 based on quarterly equipment counts and activity levels, it should be noted that the 2005 offshore emissions were affected in the fourth quarter by Hurricanes Katrina and Rita, which resulted in damage and shut-downs of a number of platforms and overall reduced platform, exploration, and supporting vessel activity. Thus, the 2005 emissions do not reflect typical annual activity conditions for the Gulf of Mexico.

Table 29

Offshore Emissions for the Gulf of Mexico for 2000 and 2005.

Source	NOx		VOC		CO		SO_2		PM	
	2000	2005	2000	2005	2000	2005	2000	2005	2000	2005
Platform	78,049	82,581	59,536	51,241	92,144	89,813	3,472	1,961	783	743
Non-Platform Oil/ Gas Production	94,375	199,979	3,400	5,257	17,228	27,597	15,963	27,520	2,423	3,812
Other Offshore	30,925	110,402	22,074	24,434	3,931	4,885	7,325	11,078	804	1,530
Total	203,349	392,962	85,010	80,932	113,303	122,295	26,760	40,559	4,010	6,085

In addition to the offshore emissions, information for onshore sources in the coastal states was acquired from EPA's National Emission Inventory (NEI) for 1999 and 2005. This information is currently not included in the GMAQDB tool but has been used to assess and compare the magnitude of the onshore coastal emissions with the offshore totals and to analyze changes in onshore emissions over time. To provide the spatial distribution of the offshore emissions as well as comparisons with the onshore emissions, Figure 52 presents an emission density plot of total low-level (those sources without substantial stack heights or resulting plume-rise) NO_x and VOC emissions, respectively, for both the onshore areas and offshore areas of the Western, Central, and portions of the Eastern Planning Areas. The figures, derived from a recent ozone modeling analysis conducted for MMS (Haney et al., 2008), show 1999 onshore emissions with 2005 offshore emissions. The oil and gas related sources are located in the Western and Central Planning Areas and emissions from certain of the source categories are distributed across these planning areas. That accounts for the underlying blue shading for these areas versus the white background for the Eastern Planning Area. In addition to the oil-and-gas-related sources, the figure shows emissions in the Eastern Planning Area associated with the major commercial shipping lanes. Similarly, Figure 53 presents NO_x and VOC emissions for "elevated" point sources, which have significant stack heights or plume rise. These plots show the locations of various offshore platform facilities as well as major power plant or other industrial sources located onshore.

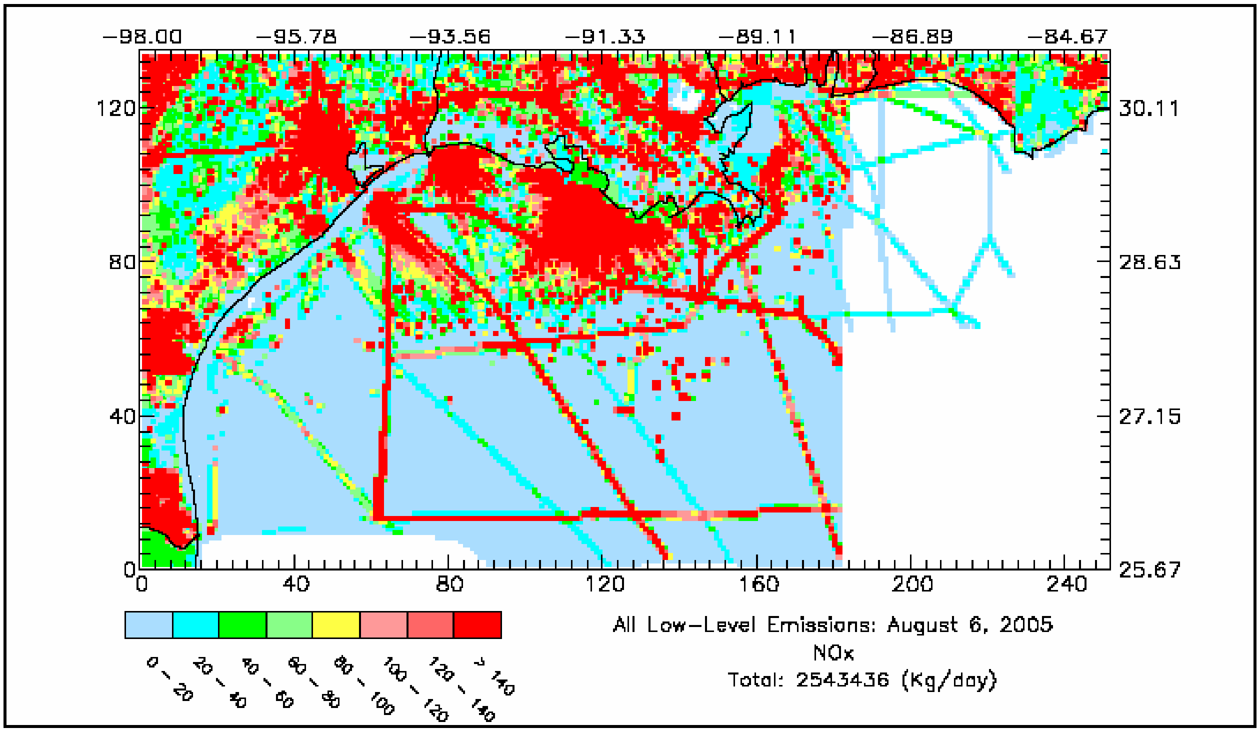


Figure 52a. Total daily low-level NOx emissions for 1999 (onshore) and 2005 (offshore).

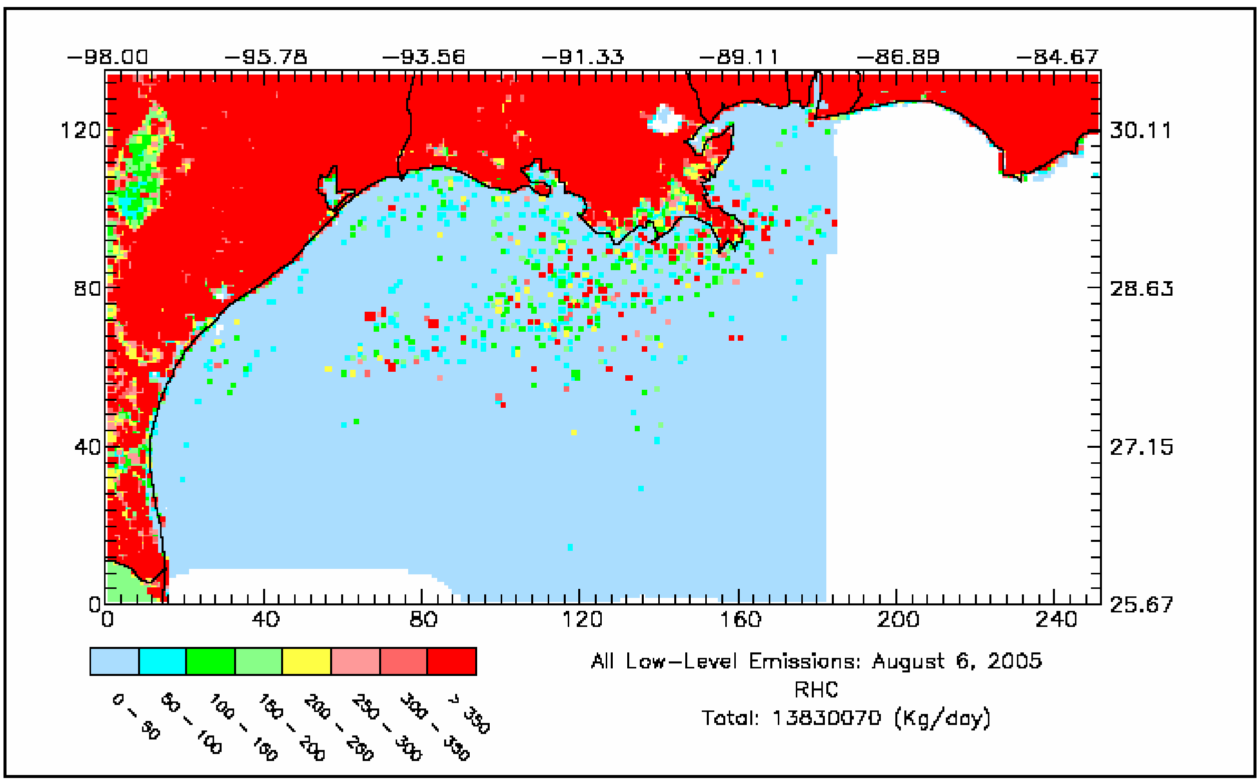


Figure 52b. Total daily low-level VOC emissions for 1999 (onshore) and 2005 (offshore).

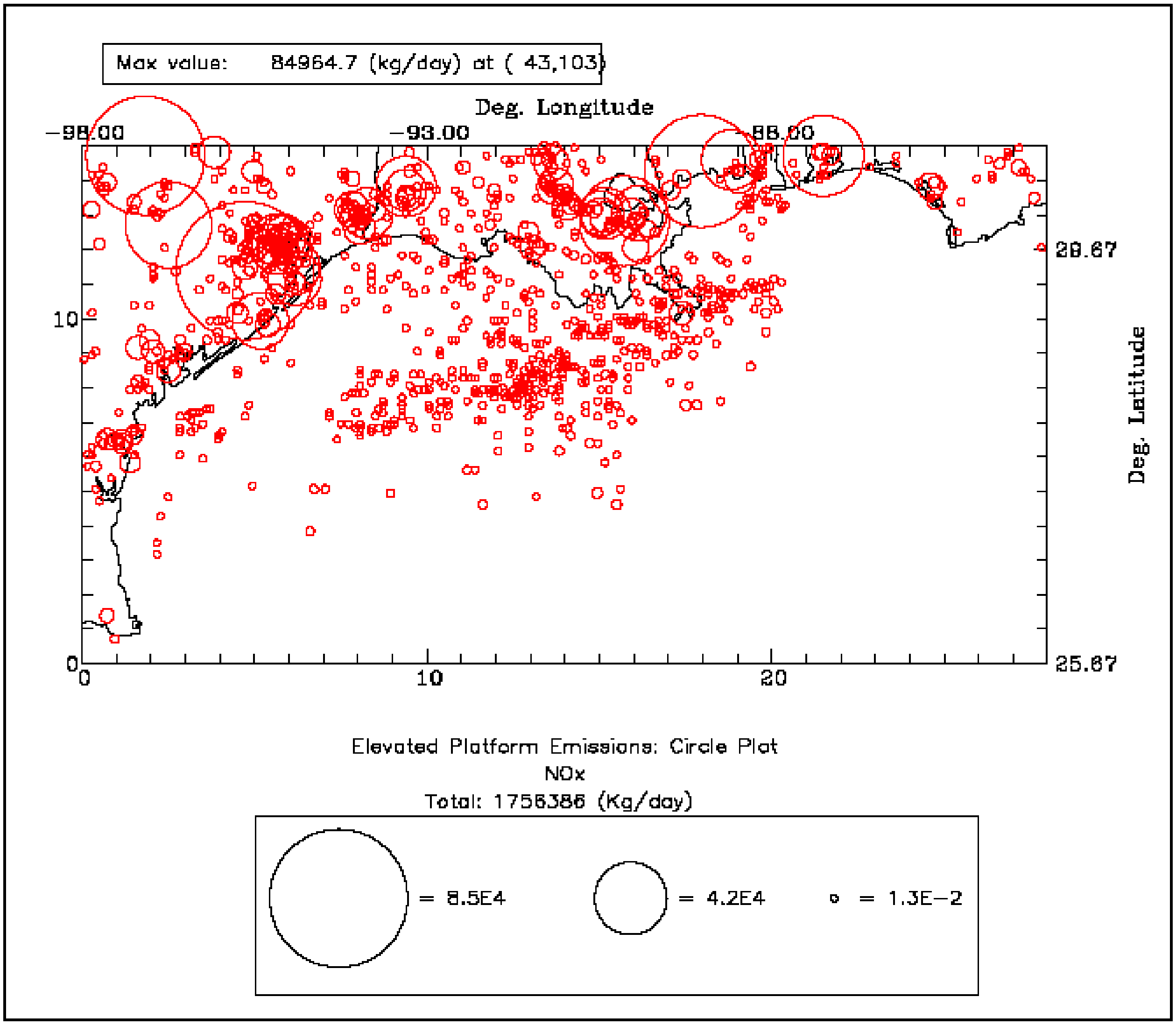


Figure 53a. Total daily elevated NOx emissions for 1999 (onshore) and 2005 (offshore).

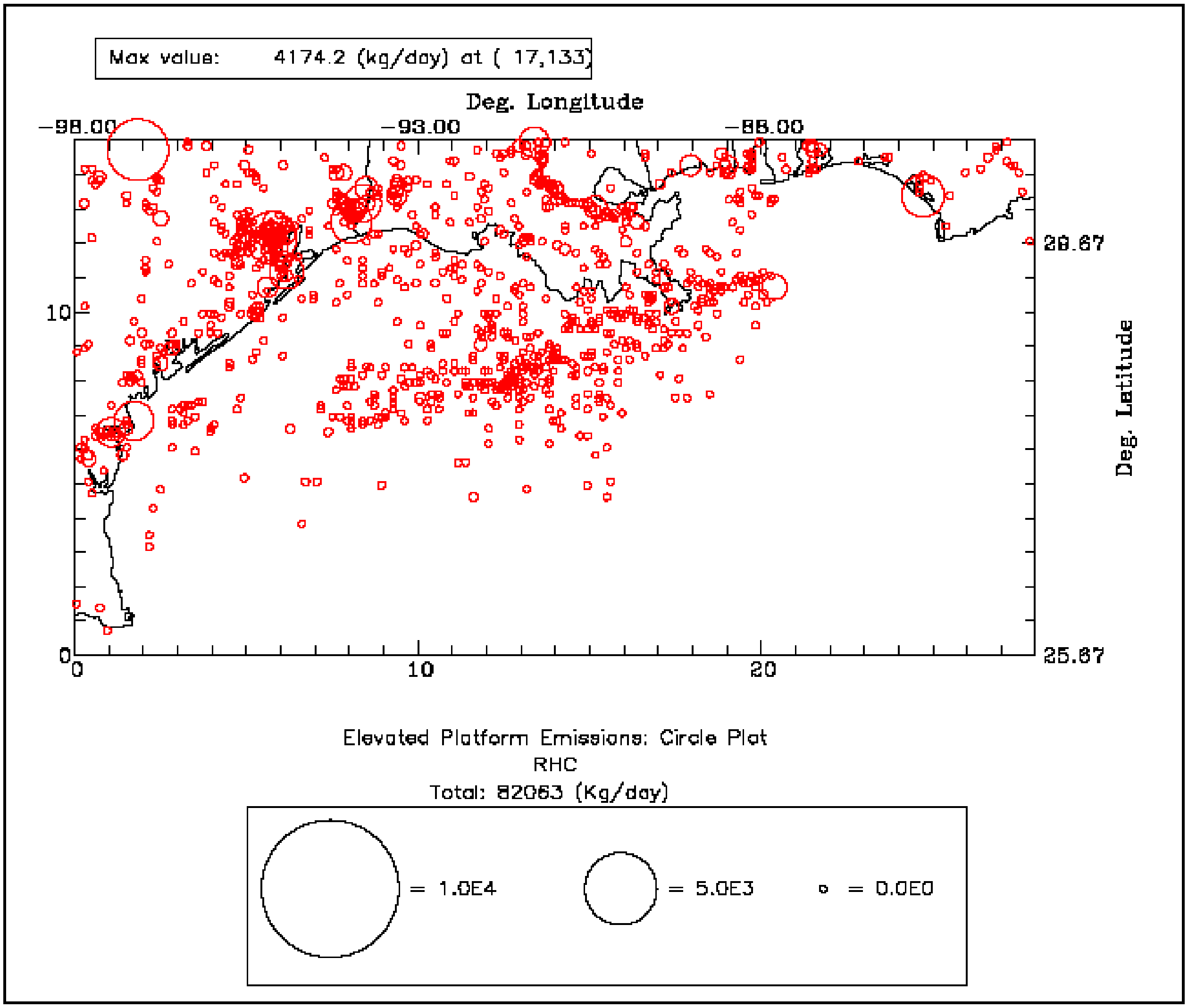


Figure 53b. Total daily elevated VOC emissions for 1999 (onshore) and 2005 (offshore).

3.0 ANALYSIS OF WIND DATA ALONG THE GULF COAST

One objective of this data analysis was to use available data to examine whether offshore emissions from oil and gas exploration and operations have the potential to contribute to air quality issues along the Gulf Coast. This requires the combined analysis of wind data and air quality measurements. Combined summaries of wind and pollutant concentration data for a variety of coastal areas are presented in this section of the report. An analysis of the effects of the gulf breeze on air quality is also presented. All of the data presented in this section are included in the GMAQDB.

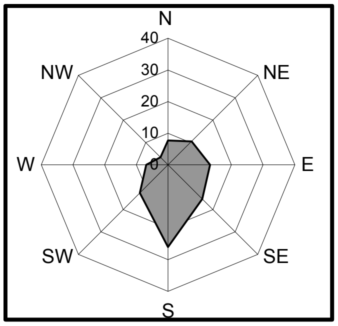
3.1. OZONE SEASON WIND DISTRIBUTIONS

Figures 54 through 63 present information about wind direction frequency, and the observed relationship between wind speed, wind direction and ozone concentration. The data used to prepare the diagrams cover the period April through October, 2000-2004. This analysis samples several areas along the Gulf Coast including Northwest Houston, Central Houston, Southeast Houston and Galveston, Beaumont/Port Arthur, Lake Charles, Baton Rouge, New Orleans, Gulfport, Mobile and Pensacola. These are the same areas included in the combined meteorological and ozone summaries presented in Section 2.2.2. For each area, the wind distribution/ozone summary consists of two parts. In the first part, surface wind data are used as the basis of the diagram. Specifically, the average surface winds for 1000-1300 LST, which is a key time period for daytime ozone formation, are depicted. In the second part, upper-air wind data for 850 mb and the morning (0600 LST) sounding are used as the basis of the diagram. The 850 mb pressure level (approximately 1500 m asl) was selected for this display to represent upper-level winds and possible transport conditions. The data for the morning sounding were selected because the winds at this time have the potential to influence ozone formation during the critical daytime hours. Previous analyses (e.g. Douglas et al., 2001) have also found winds for these times and the 850 mb level to be important to ozone formation. Wind data from the local surface and nearest upper-air meteorological monitoring sites were used.

Each display consists of a table that summarizes the frequency of occurrence of calm winds and winds from eight principal wind directions. Calm winds are defined as winds with zero wind speeds, but this category may also include periods with non-zero wind speeds with values up to the threshold of the sensor (typically 0.2-0.4 ms^{-1}). Each wind direction represents the 45 degree sector centered on the direction (e.g., N winds range from 337.5 to 22.5 degrees, NE winds range from 22.5 to 67.5 degrees), where the wind direction is the direction from which the winds blow. This information is then graphically displayed in a radar diagram, such that each ring moving outward from the center represents a ten percent increase in the frequency of occurrence of the wind from a given direction. Finally, the wind information is combined with ozone data in the wind/ozone relationship diagram. For each wind speed and wind direction combination, the 80^{th} percentile value of 8-hour ozone concentration over all days meeting the wind criteria (as defined along the x- and y-axes) is presented. The colors correspond to the concentration ranges used by EPA for 8-hour ozone forecasting as follows: Green (< 60 ppb), Yellow (60-75 ppb), Orange (75-95 ppb), Red (≥ 95 ppb).

The displays for each area are presented in the order listed above (approximately west to east).

WD	%
Calm	4
N	8
NE	11
E	13
SE	15
S	26
SW	13
W	7
NW	3



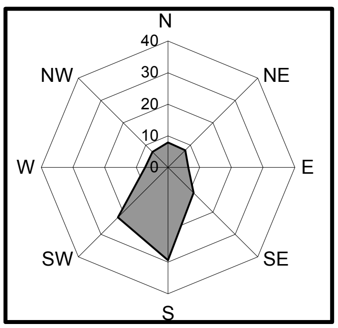
Calm: 4%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	81							
1-2	63	71	89	89	69	86	64	84
2-3	67	68	77	88	65	69	65	59
3-4	64	68	75	79	63	56	76	64
4-5	56	60	71	67	68	57	62	67
5-6	51	61	68	64	52	44	63	53
6-7	50	53	65	53	52	59	71	38
7-8	52	52	23	53	51	35		
8-9	48				58			
9-10	56	40						
>=10	28							

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 54a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Northwest Houston.

WD	%
Calm	1
N	8
NE	8
E	6
SE	11
S	29
SW	22
W	7
NW	7



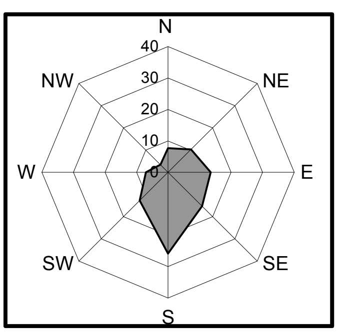
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	69							
1-2	81	73	82	69	64	64	85	77
2-3	72	78	89	75	65	57	84	77
3-4	83	83	76	70	64	57	49	73
4-5	67	67	80	79	75	52	59	76
5-6	70	62	79	85	73	64	45	81
6-7	73	72	66	78	57	55	89	88
7-8	77	64	78	90	59	52	61	58
8-9	79	70	74	56	55	49	53	63
9-10	49	56	65	64	60	58	60	58
>=10	65	61	63	62	51	55	63	67

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 54b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Northwest Houston/Lake Charles.

WD	%
Calm	4
N	8
NE	10
E	14
SE	15
S	26
SW	13
W	7
NW	3



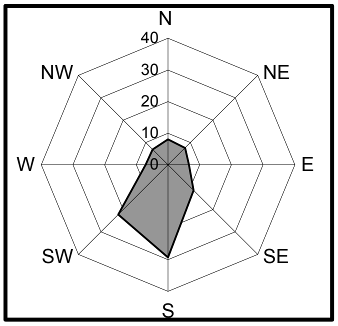
Calm: 4%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	102							
1-2	80	99	109	102	68	70	98	88
2-3	90	88	108	89	54	74	81	64
3-4	78	84	93	69	50	50	91	89
4-5	66	76	80	62	55	68	67	87
5-6	52	64	78	59	42	43	84	64
6-7	50	55	59	43	44	51	66	37
7-8	53	55	22	48	44	28		
8-9	48				51			
9-10	55	40						
>=10	28							

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 55a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Central Houston.

WD	%
Calm	1
N	8
NE	8
E	7
SE	11
S	29
SW	22
W	7
NW	7



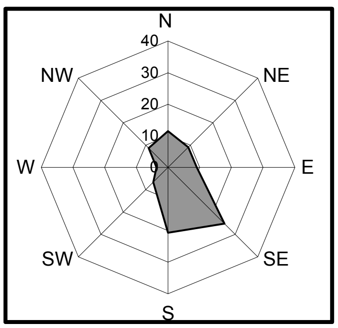
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	86							
1-2	94	94	94	103	84	80	91	94
2-3	90	95	93	86	69	59	96	91
3-4	105	118	84	89	61	59	70	83
4-5	84	94	93	89	64	48	61	98
5-6	96	71	105	79	61	50	40	82
6-7	90	94	70	81	41	45	97	98
7-8	91	72	91	66	49	43	77	58
8-9	103	90	68	50	40	39	52	68
9-10	60	54	90	56	47	53	62	71
>=10	74	65	64	72	42	46	65	94

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 55b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Central Houston/Lake Charles.

WD	%
Calm	6
N	11
NE	9
E	9
SE	25
S	21
SW	7
W	4
NW	9



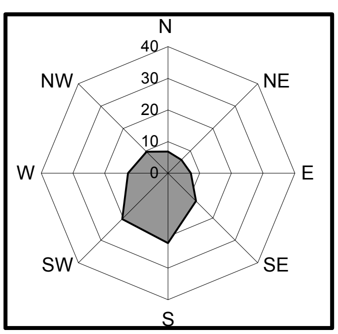
Calm: 6%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	68							
1-2	66	72	60	70	71	72	65	63
2-3	78	62	76	72	54	64	67	63
3-4	71	64	66	63	59	68	61	67
4-5	60	63	65	57	56	57	55	69
5-6	50	59	66	59	49	51	53	58
6-7	52	60	64	61	33		0	50
7-8	49	42	46	54	34	0	0	54
8-9	38		46	57	34			43
9-10				50				
>=10			43	46				47

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 56a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Galveston.

WD	%
Calm	3
N	7
NE	6
E	7
SE	12
S	22
SW	20
W	13
NW	10



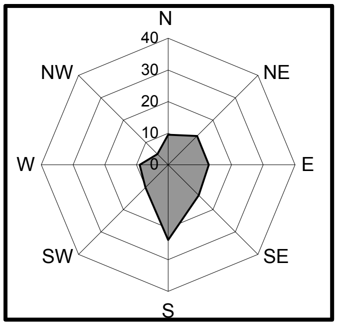
Calm: 3%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	72							
1-2	81	75	50	68	66	53	63	72
2-3	79	62	71	72	70	63	73	71
3-4	61	69	75	72	63	69	68	75
4-5	70	71	60	64	64	59	58	70
5-6	65	81	70	64	42	55	57	68
6-7	66	68	68	59	51	52	58	62
7-8	53	53	66	47	56	53	67	66
8-9	65	70	73	58	56	49	45	57
9-10	55	64	68	59	54	43	44	67
>=10	59	53	47	60	49	49	57	59

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 56b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Galveston/Lake Charles.

WD	%
Calm	3
N	10
NE	13
E	13
SE	14
S	24
SW	10
W	9
NW	5



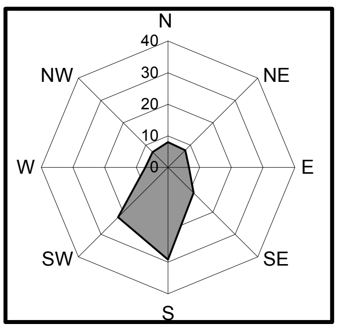
Calm: 3%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	82							
1-2	91	71	78	75	57	62	83	75
2-3	88	88	79	72	57	59	69	78
3-4	70	79	75	64	60	55	74	78
4-5	68	70	72	68	43	45	77	68
5-6	54	64	61	62	43	52	61	67
6-7	55	57	73	64	42	26	57	48
7-8	52	47	68	54	48	33	32	56
8-9	51	43	32	52	48			
9-10	52			41	35			
>=10				67	39			36

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 57a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Beaumont/Port Arthur.

WD	%
Calm	1
N	8
NE	8
E	7
SE	11
S	29
SW	22
W	7
NW	7



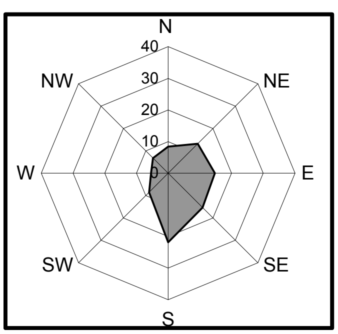
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	56							
1-2	84	79	72	76	67	74	88	88
2-3	77	84	85	79	72	60	84	71
3-4	87	88	82	77	64	58	71	84
4-5	86	78	75	69	53	57	53	80
5-6	71	70	73	74	64	55	48	70
6-7	73	81	70	80	52	48	77	77
7-8	89	69	83	64	51	43	66	63
8-9	77	77	75	44	45	48	49	63
9-10	49	58	82	57	47	53	57	56
>=10	73	62	58	64	45	46	65	77

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 57b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Beaumont/Port Arthur/Lake Charles.

WD	%
Calm	6
N	8
NE	13
E	15
SE	15
S	22
SW	9
W	5
NW	7



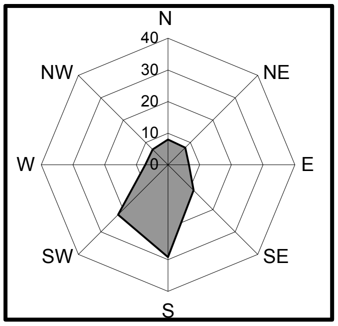
Calm: 6%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	67							
1-2	58	60	65	66	66	80	59	67
2-3	66	68	61	70	45	46	68	61
3-4	62	62	66	69	48	53	77	72
4-5	60	64	66	53	42	44	62	58
5-6	58	57	63	62	44	39		
6-7	52	54	49	55	46			
7-8	52	53	41	50	43			32
8-9	42	47	49	62	47			
9-10		38		59	43			
>=10								26

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 58a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Lake Charles.

WD	%
Calm	1
N	8
NE	8
E	7
SE	11
S	29
SW	22
W	7
NW	7



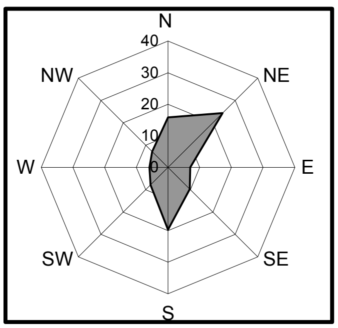
Calm: 1%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	57							
1-2	85	67	59	68	58	70	83	78
2-3	62	66	68	70	69	53	78	76
3-4	81	69	79	75	58	57	63	79
4-5	59	53	67	64	62	62	48	66
5-6	62	62	68	62	60	54	42	72
6-7	62	66	72	73	41	43	73	66
7-8	69	61	66	65	52	43	53	57
8-9	71	62	73	48	43	39	49	56
9-10	41	52	66	54	44	49	55	46
>=10	60	56	53	55	42	42	56	63

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 58b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Lake Charles/Lake Charles.

WD	%
Calm	3
N	16
NE	24
E	7
SE	10
S	20
SW	8
W	6
NW	7



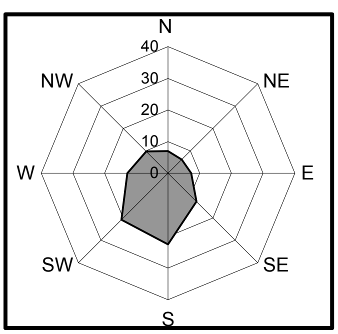
Calm: 3%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	60							
1-2	72	78	53	67	80	53	58	56
2-3	74	79	56	42	55	52	82	63
3-4	69	72	42	49	52	58	63	82
4-5	69	70	70	56	53	54	73	72
5-6	62	69	53	61	46	44	67	80
6-7	58	63	51	58	46	48	60	50
7-8	54	56		40	46	31	24	55
8-9	45			64	44		68	51
9-10	47				50			
>=10		27			48			

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 59a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: New Orleans.

WD	%
Calm	1
N	7
NE	6
E	7
SE	13
S	22
SW	21
W	13
NW	10



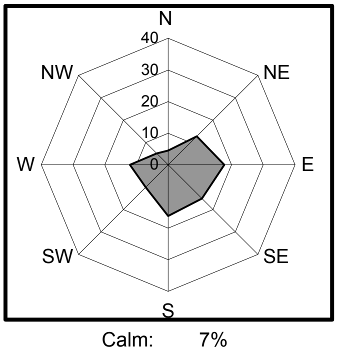
Calm: 1%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	71							
1-2	86	71	53	69	63	54	62	73
2-3	81	58	67	79	58	65	71	75
3-4	64	75	75	78	61	73	77	75
4-5	71	75	67	59	58	54	59	72
5-6	71	75	77	66	46	58	71	72
6-7	75	75	68	63	52	51	57	64
7-8	64	63	69	51	53	47	58	74
8-9	75	77	60	53	49	41	49	59
9-10	71	74	66	56	53	39	63	74
>=10	59	62	54	61	45	46	64	70

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 59b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: New Orleans/Slidell.

WD	%
Calm	7
N	5
NE	13
E	18
SE	15
S	16
SW	10
W	12
NW	5

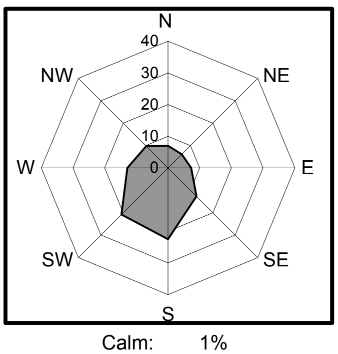


WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	87							
1-2	64	92	95	88	82	68	72	83
2-3	74	70	70	74	62	69	71	60
3-4	61	70	76	69	61	59	75	65
4-5	78	66	69	75	60	52	73	66
5-6	49	60	62	58	49	68	70	57
6-7		36	61	54	54	50		
7-8			73	57	50	46		24
8-9					46	54		
9-10					30			
>=10				34				

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 60a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Baton Rouge.

WD	%
Calm	1
N	7
NE	6
E	7
SE	13
S	22
SW	21
W	13
NW	10

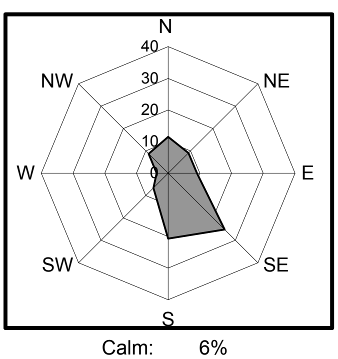


WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	75							
1-2	99	73	64	72	84	68	75	90
2-3	87	69	86	85	66	73	76	97
3-4	81	75	85	85	68	70	78	93
4-5	81	67	67	76	69	70	71	78
5-6	78	73	77	81	51	62	67	83
6-7	84	77	84	68	61	58	63	68
7-8	64	63	73	63	63	52	64	85
8-9	76	78	66	82	57	48	48	73
9-10	77	69	69	69	58	44	61	80
>=10	63	64	47	78	51	49	64	75

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 60b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Baton Rouge/Slidell.

WD	%
Calm	6
N	11
NE	9
E	9
SE	25
S	21
SW	7
W	4
NW	9

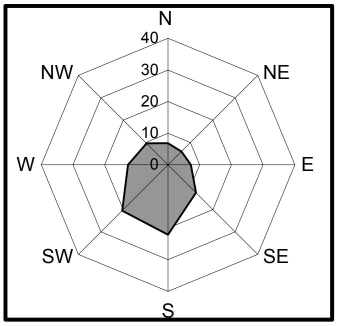


WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	68							
1-2	66	72	60	70	71	72	65	63
2-3	78	62	76	72	54	64	67	63
3-4	71	64	66	63	59	68	61	67
4-5	60	63	65	57	56	57	55	69
5-6	50	59	66	59	49	51	53	58
6-7	52	60	64	61	33		0	50
7-8	49	42	46	54	34	0	0	54
8-9	38		46	57	34			43
9-10				50				
>=10			43	46				47

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 61a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Gulfport.

WD	%
Calm	3
N	7
NE	6
E	7
SE	12
S	22
SW	20
W	13
NW	10



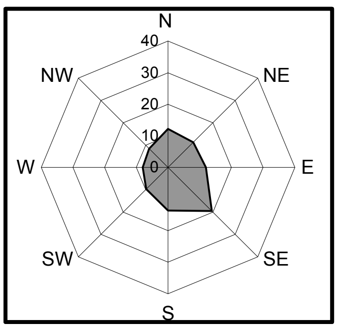
Calm: 3%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	72							
1-2	81	75	50	68	66	53	63	72
2-3	79	62	71	72	70	63	73	71
3-4	61	69	75	72	63	69	68	75
4-5	70	71	60	64	64	59	58	70
5-6	65	81	70	64	42	55	57	68
6-7	66	68	68	59	51	52	58	62
7-8	53	53	66	47	56	53	67	66
8-9	65	70	73	58	56	49	45	57
9-10	55	64	68	59	54	43	44	67
>=10	59	53	47	60	49	49	57	59

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 61b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Gulfport/Slidell.

WD	%
Calm	5
N	12
NE	11
E	12
SE	20
S	14
SW	10
W	8
NW	8



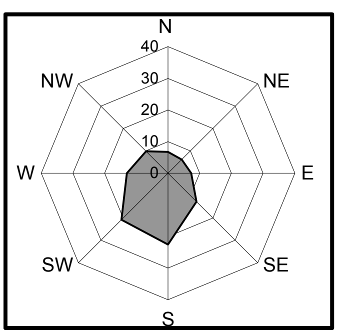
Calm: 5%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	71							
1-2	66	75	70	66	52	68	75	68
2-3	77	75	63	51	63	48	59	73
3-4	75	62	67	61	52	65	74	73
4-5	68	64	59	64	53	50	60	65
5-6	63	56	47	58	46	49	53	67
6-7	51	65	47	54	46	42	59	47
7-8	44	54		58	39	39	42	52
8-9	48		36	60	27			
9-10	49				34	32		
>=10				65	34			

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 62a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Mobile.

WD	%
Calm	1
N	7
NE	6
E	7
SE	13
S	23
SW	21
W	13
NW	10



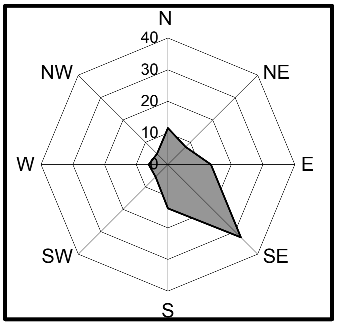
Calm: 1%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	70							
1-2	81	74	52	67	68	57	63	75
2-3	72	67	65	74	72	64	82	76
3-4	54	63	89	69	63	72	68	75
4-5	74	70	65	62	63	63	64	72
5-6	66	68	70	67	43	56	67	72
6-7	68	60	65	62	49	49	63	67
7-8	60	64	61	65	60	47	67	74
8-9	68	65	63	52	57	54	41	63
9-10	75	63	66	59	52	43	56	59
>=10	60	54	50	64	47	44	61	62

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 62b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Mobile/Slidell.

WD	%
Calm	4
N	12
NE	8
E	14
SE	33
S	14
SW	5
W	6
NW	5



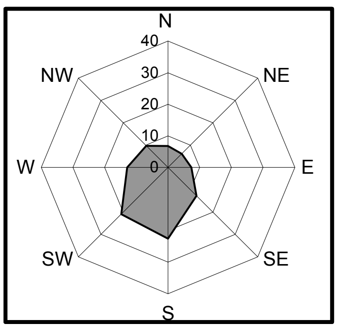
Calm: 4%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	65							
1-2	75	83	71	65	65	53	52	68
2-3	78	71	64	71	64	55	69	71
3-4	80	67	64	63	50	58	70	71
4-5	68	54	56	61	57	52	59	84
5-6	60	51	54	59	54	55	59	70
6-7	47		51	55	48	37	54	59
7-8	42		53	55	32	38	60	56
8-9			48	70	35	74		46
9-10				59	40			49
>=10					43	57		

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 63a. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on surface wind data for 1000-1300 LST for 2000-2004: Pensacola.

WD	%
Calm	1
N	7
NE	6
E	7
SE	13
S	23
SW	21
W	13
NW	10



Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	69							
1-2	70	69	56	71	65	55	61	73
2-3	72	68	64	76	74	64	69	72
3-4	62	61	92	65	65	65	56	78
4-5	68	74	69	59	60	61	66	70
5-6	72	75	74	73	50	56	62	70
6-7	67	59	65	59	55	48	69	68
7-8	58	58	60	59	62	50	66	76
8-9	70	65	65	54	59	58	45	61
9-10	82	57	71	61	54	46	51	63
>=10	60	61	44	64	48	48	61	61

80th percentile of daily maximum 8-hour ozone concentration (ppb) for days meeting the wind speed and direction criteria

Figure 63b. Wind direction frequency diagram and ozone concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Pensacola/Slidell.

The wind frequency diagrams indicate that both the midday surface winds and the morning upper-air winds frequently have a southerly component. There are a wide range of patterns among the different locations, but one general finding is that higher ozone concentrations tend to occur under conditions of low surface wind speeds and westerly to southeasterly winds aloft. The lowest concentrations tend occur with southerly or southwesterly winds, although this varies slightly from area to area.

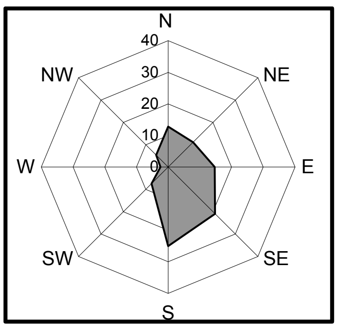
3.2. ANNUAL WIND DISTRIBUTIONS AND $PM_{2.5}$

Figures 64 through 69 present information about wind direction frequency, and the observed relationship between wind speed, wind direction and $PM_{2.5}$ concentration. The data used to prepare the diagrams cover the period 2000-2004. This analysis samples several areas along the gulf coast including Central Houston, Southeast Houston and Galveston, Beaumont/Port Arthur, Lake Charles, Baton Rouge and New Orleans. These are the same areas included in the combined meteorological and $PM_{2.5}$ summaries presented in Section 2.3.2. For $PM_{2.5,}$ daily (24-hour) average surface winds are depicted in the first part diagram (a) and upper-air winds for 850 mb and the morning (0600 LST) sounding are used in the second part of the diagram (b). The wind data are from the local surface and nearest upper-air meteorological monitoring site.

For each wind speed and wind direction combination in the wind/$PM_{2.5}$ relationship diagram, the 80th percentile value of the daily (24-hour average) $PM_{2.5}$ concentration over all days meeting the wind criteria is presented. The colors correspond to the following concentration range: Green (< 15 μgm^{-3}), Yellow (15-25 μgm^{-3}), Orange (25-35 μgm^{-3}), Red (≥ 35 μgm^{-3}).

The displays for each area are presented in the order listed above (approximately west to east).

WD	%
Calm	0
N	13
NE	11
E	15
SE	21
S	25
SW	7
W	2
NW	5



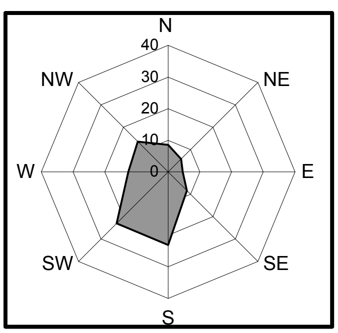
Calm: 0%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	25							
1-2	24	28	25	21	18	23	17	20
2-3	19	20	22	19	19	20	22	20
3-4	17	16	21	16	17	21	16	17
4-5	14	15	18	16	17	13	9	15
5-6	13	14	15	16	22	15	13	10
6-7	11	14	16	17	18		8	9
7-8	9	19	8					8
8-9							6	
9-10	7							
>=10								

80th percentile of daily average PM2.5 concentration (μg/m^3) for days meeting the wind speed and direction criteria

Figure 64a. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on surface wind data for 2000-2004: Central Houston.

WD	%
Calm	1
N	9
NE	6
E	5
SE	8
S	23
SW	23
W	13
NW	14



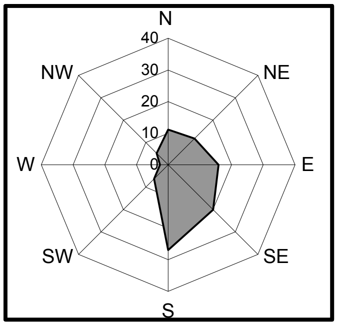
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	21							
1-2	22	17	32	17	18	20	16	18
2-3	22	23	18	22	19	18	19	20
3-4	18	27	20	23	18	19	20	20
4-5	19	23	21	21	18	18	17	20
5-6	24	16	21	18	16	19	20	17
6-7	26	22	17	21	16	15	22	21
7-8	20	17	18	15	16	17	17	22
8-9	21	23	15	15	16	16	16	16
9-10	14	19	28	15	16	16	18	19
>=10	15	16	16	17	17	17	15	18

80th percentile of daily average PM2.5 concentration (μg/m^3) for days meeting the wind speed and direction criteria

Figure 64b. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Central Houston/Lake Charles.

WD	%
Calm	0
N	11
NE	12
E	16
SE	20
S	27
SW	6
W	3
NW	5



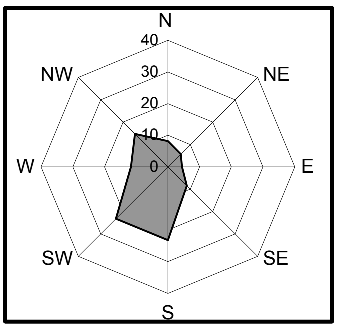
Calm: 0%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	18							
1-2	24	25	19	21	17	23	9	12
2-3	19	18	21	17	17	23	20	14
3-4	14	15	16	14	15	17	14	16
4-5	13	14	12	16	15	9	5	12
5-6	11	13	11	14	15	8	11	13
6-7	10	12	13		14		7	11
7-8	12	16						5
8-9							6	
9-10								
>=10								

80th percentile of daily average PM2.5 concentration ($\mu g/m^3$) for days meeting the wind speed and direction criteria

Figure 65a. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on surface wind data for 2000-2004: Galveston.

WD	%
Calm	1
N	8
NE	6
E	4
SE	8
S	23
SW	23
W	12
NW	15



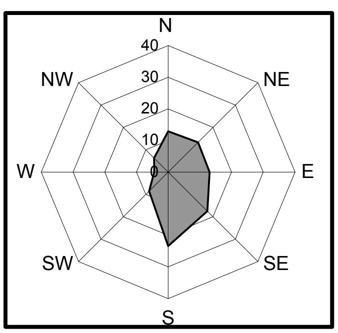
Calm: 1%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	16							
1-2	14	12	31	19	11	20	13	17
2-3	21	25	14	19	15	18	17	19
3-4	20	30	19	18	16	15	18	17
4-5	16	20	26	17	15	21	16	16
5-6	19	13	16	21	12	15	17	18
6-7	20	21	14	19	16	13	18	21
7-8	20	27	13	14	12	15	16	19
8-9	22	17	22	10	13	9	15	14
9-10	9	14	26	11	13	16	10	13
>=10	12	16	13	14	14	15	13	14

80th percentile of daily average PM2.5 concentration ($\mu g/m^3$) for days meeting the wind speed and direction criteria

Figure 65b. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Galveston/Lake Charles.

WD	%
Calm	1
N	13
NE	13
E	13
SE	17
S	23
SW	9
W	4
NW	6



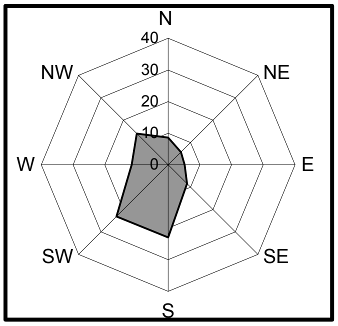
Calm: 1%

WS (m/s) \ WD →	N	NE	E	SE	S	SW	W	NW
<1	17							
1-2	24	19	20	15	19	18	20	14
2-3	21	19	19	15	15	18	17	15
3-4	15	16	17	14	12	16	16	9
4-5	13	14	16	13	12	11	9	8
5-6	10	11	14	11	12	10	8	9
6-7	9	13	14	12	13		4	9
7-8	8	14	10	13	14	8	6	4
8-9	12			13	12			
9-10			7					
>=10								

80th percentile of daily average PM2.5 concentration ($\mu g/m^3$) for days meeting the wind speed and direction criteria

Figure 66a. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on surface wind data for 2000-2004: Beaumont/Port Arthur.

WD	%
Calm	1
N	9
NE	6
E	5
SE	8
S	23
SW	23
W	12
NW	14



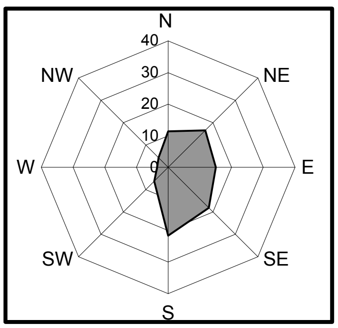
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	15							
1-2	17	21	20	16	14	21	13	25
2-3	22	22	16	19	18	15	21	15
3-4	18	25	18	19	17	14	16	17
4-5	18	19	18	18	19	18	14	19
5-6	21	14	21	15	12	15	15	12
6-7	23	18	17	19	15	12	17	14
7-8	14	15	14	14	12	16	13	15
8-9	14	16	14	14	11	14	11	10
9-10	10	20	29	10	12	13	13	14
>=10	11	15	15	16	12	13	12	11

80th percentile of daily average PM2.5 concentration (μg/m^3) for days meeting the wind speed and direction criteria

Figure 66b. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Beaumont Port Arthur/Lake Charles.

WD	%
Calm	3
N	11
NE	17
E	15
SE	18
S	22
SW	6
W	3
NW	4



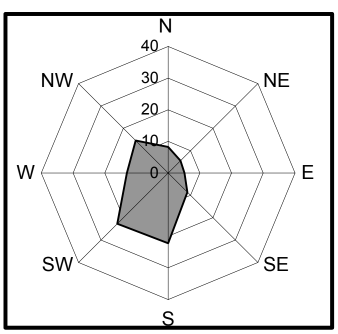
Calm: 3%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	22							
1-2	20	22	20	18	13	16	15	23
2-3	19	13	20	17	13	18	15	12
3-4	18	16	15	14	11	10	16	10
4-5	11	14	13	13	12	12	5	9
5-6	9	9	9	12	12	6		9
6-7	6	15	23	8	9			
7-8	5			10	10			
8-9								
9-10								
>=10								

80th percentile of daily average PM2.5 concentration (μg/m^3) for days meeting the wind speed and direction criteria

Figure 67a. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on surface wind data for 2000-2004: Lake Charles.

WD	%
Calm	0
N	8
NE	5
E	5
SE	9
S	22
SW	23
W	13
NW	15



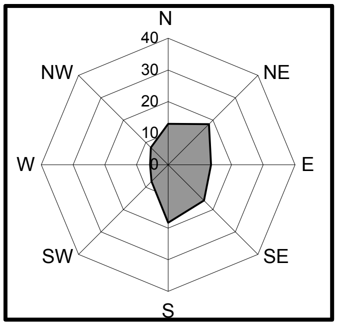
Calm: 0%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	10							
1-2	17	12	17	16	8	22	17	11
2-3	15	18	14	20	17	12	25	19
3-4	20	18	18	21	17	18	20	18
4-5	17	18	19	22	14	16	13	19
5-6	18	20	14	26	11	14	12	16
6-7	23	21		21	14	12	14	21
7-8	28	14		15	12	12	13	15
8-9	17	16	26	15	12	11	10	11
9-10	6	15	29	8	13	15	13	12
>=10	9	11	16	19	11	11	11	12

80th percentile of daily average PM2.5 concentration (μg/m^3) for days meeting the wind speed and direction criteria

Figure 67b. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Lake Charles/Lake Charles.

WD	%
Calm	0
N	13
NE	18
E	14
SE	16
S	18
SW	7
W	6
NW	8



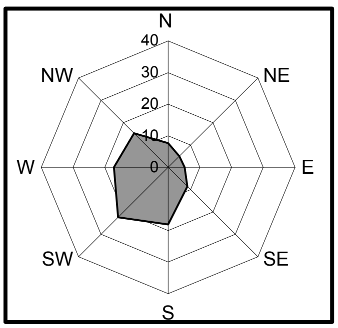
Calm: 0%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	19							
1-2	25	28	21	22	15	14	18	21
2-3	21	22	20	17	16	17	22	17
3-4	21	19	17	16	13	15	19	19
4-5	15	16	14	15	11	16	24	15
5-6	13	13	12	11	15	13	12	11
6-7	10	11	12	11	11	7	11	9
7-8	8	12		13	13	7	7	10
8-9	7					7	5	6
9-10	6	2		5				
>=10	9							

80th percentile of daily average PM2.5 concentration ($\mu g/m^3$) for days meeting the wind speed and direction criteria

Figure 68a. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on surface wind data for 2000-2004: New Orleans.

WD	%
Calm	1
N	8
NE	5
E	5
SE	9
S	18
SW	22
W	17
NW	15



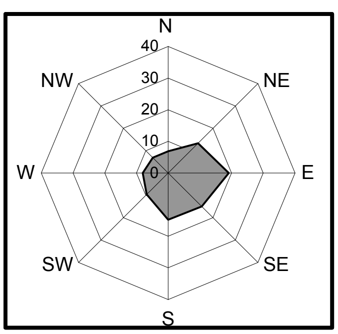
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	20							
1-2	30	23	19	22	20	16	18	18
2-3	21	18	24	19	16	18	23	24
3-4	17	23	23	19	19	19	15	18
4-5	21	20	17	20	17	16	18	19
5-6	18	19	24	20	16	15	17	18
6-7	17	24	23	19	14	15	19	20
7-8	18	14	23	14	14	16	18	18
8-9	20	21	16	23	13	16	12	15
9-10	18	23	12	16	14	16	15	19
>=10	14	19	13	15	12	12	12	13

80th percentile of daily average PM2.5 concentration ($\mu g/m^3$) for days meeting the wind speed and direction criteria

Figure 68b. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on wpper-air wind data for 0600 LST for 2000-2004: New Orleans/Slidell.

WD	%
Calm	6
N	7
NE	13
E	19
SE	15
S	15
SW	10
W	8
NW	7



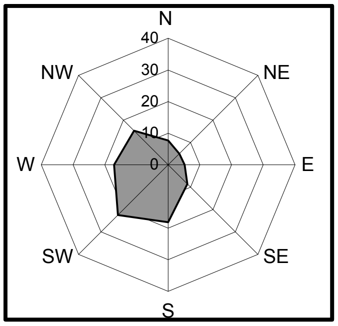
Calm: 6%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	26							
1-2	22	19	21	22	18	20	20	21
2-3	17	18	20	18	17	15	19	15
3-4	12	14	17	18	15	15	17	13
4-5	11	14	14	13	12	14	10	12
5-6	11	8	16	9	12	14	6	17
6-7				15	13	5	13	
7-8					11	8		
8-9				4				
9-10								
>=10								

80th percentile of daily average PM2.5 concentration ($\mu g/m^3$) for days meeting the wind speed and direction criteria

Figure 69a. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on surface wind data for 2000-2004: Baton Rouge.

WD	%
Calm	1
N	8
NE	5
E	5
SE	9
S	18
SW	22
W	17
NW	15



WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	18							
1-2	35	22	24	24	21	18	20	21
2-3	21	20	25	22	20	23	26	25
3-4	24	24	27	18	20	20	17	21
4-5	21	27	22	19	18	16	18	22
5-6	19	23	26	21	16	16	18	19
6-7	17	29	22	20	15	15	20	19
7-8	17	15	25	17	17	17	18	20
8-9	19	20	24	24	13	16	16	16
9-10	20	30	13	20	16	15	16	19
>=10	15	16	17	18	13	14	14	15

80th percentile of daily average PM2.5 concentration ($\mu g/m^3$) for days meeting the wind speed and direction criteria

Figure 69b. Wind direction frequency diagram and $PM_{2.5}$ concentration/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Baton Rouge/Slidell.

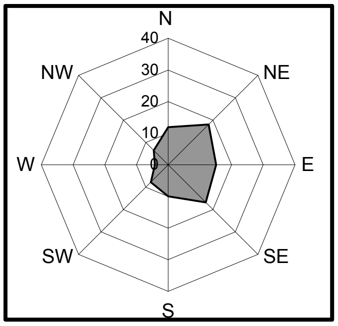
For most sites, higher $PM_{2.5}$ concentrations occur under conditions of low surface wind speeds and northerly to easterly winds aloft.

3.3. Annual Wind Distributions and Visibility

Figures 70 through 72 present information about wind direction frequency, and the observed relationship between wind speed, wind direction and extinction coefficient for the Breton, St. Marks, and Chassahowitzka NWAs. The data used to prepare the diagrams cover the period 2000-2004, as available. These are the same Class I areas included in the combined meteorological and $PM_{2.5}$ summaries presented in Section 2.4.2. Daily (24-hour) average surface winds are depicted in the first part of the diagram (a) and upper-air winds for 850 mb and the morning (0600 LST) sounding are used in the second part of the diagram (b). Again, the wind data are from the local surface meteorological monitoring site and the nearest upper-air monitoring site.

For each wind speed and wind direction combination in the wind/visibility relationship diagram, the average value of the daily extinction coefficient over all days meeting the wind criteria is presented. In this case, the colors designate whether the value shown falls approximately within the <20, 20-50, 50-80 and ≥80 percentile ranges of extinction coefficient for all days. Green is therefore representative of the "best" visibility days and red is representative of the "worst" visibility days. The percentile ranges for each site are only approximate, however, because a consistent formatting was used for all three areas with break points at 60, 90 and 120 Mm^{-1}. This allows us to compare the charts for the three areas.

WD	%
Calm	10
N	12
NE	18
E	15
SE	17
S	10
SW	8
W	4
NW	6



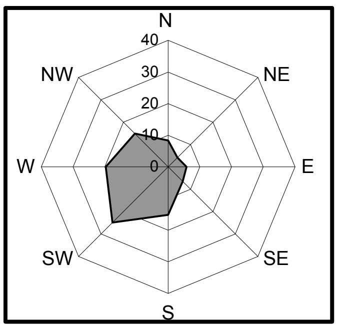
Calm: 10%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	93							
1-2	104	102	93	65	66	87	83	62
2-3	112	70	81	65	70	74	106	80
3-4	80	67	88	76	92	82	73	52
4-5	63	60	69	73	80	98	67	51
5-6	62	51	56	104	104	64		57
6-7	32	57		96	108		51	75
7-8		74			55	88		
8-9								
9-10								
>=10								

Average of daily average extinction coefficient (Mm-1) for days meeting the wind speed and direction criteria

Figure 70a. Wind direction frequency diagram and extinction coefficient/wind relationship diagram based on surface wind data for 2000-2004: Breton NWA.

WD	%
Calm	1
N	8
NE	4
E	6
SE	6
S	15
SW	25
W	20
NW	15



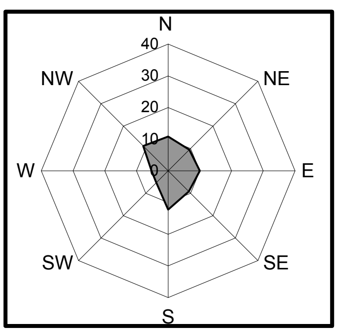
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	110							
1-2	89	100			54	50	124	
2-3	83	84	64	60	87	90	109	116
3-4	93	143	82	74	58	92	81	103
4-5	109	112	107	91	87	95	101	87
5-6	81	40	66	40	48	83	60	78
6-7	48			35	71	76	77	86
7-8	40		67		82	101	85	60
8-9	76		90	128	51	88	85	105
9-10	81		53	79	115	91	49	64
>=10	42		57	122	78	82	56	54

Average of daily average extinction coefficient (Mm-1) for days meeting the wind speed and direction criteria

Figure 70b. Wind direction frequency diagram and extinction coefficient/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Breton NWA/Slidell.

WD	%
Calm	27
N	11
NE	9
E	10
SE	9
S	12
SW	5
W	5
NW	11



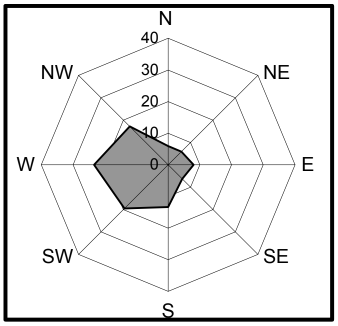
Calm: 27%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	85							
1-2	77	96	69	91	87	66	71	91
2-3	74	65	92	76	93	72	109	61
3-4	47	55	64		80	87	45	64
4-5	40	75	48	100	68	56		49
5-6								
6-7				62				40
7-8								
8-9								
9-10								
>=10								

Average of daily average extinction coefficient (Mm-1) for days meeting the wind speed and direction criteria

Figure 71a. Wind direction frequency diagram and extinction coefficient/wind relationship diagram based on surface wind data for 2000-2004: St. Mark's NWA.

WD	%
Calm	1
N	6
NE	6
E	8
SE	6
S	13
SW	20
W	23
NW	17



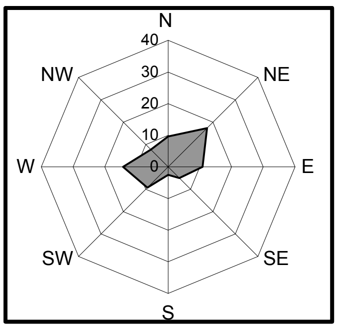
Calm: 1%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	55							
1-2	112	175	78	69	96	111	91	
2-3	151	63	60	101	67	124	58	48
3-4	55	48	78	84	89	78	108	93
4-5	115	77	141	52	96	90	84	79
5-6	205	115	73	61	108	84	96	78
6-7		52	69	52	73	96	80	78
7-8	68	90	43	44	71	127	79	78
8-9	119	173			74	57	82	80
9-10	41	48			92	68	58	74
>=10	58	45	59	74	84	70	59	55

Average of daily average extinction coefficient (Mm-1) for days meeting the wind speed and direction criteria

Figure 71b. Wind direction frequency diagram and extinction coefficient/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: St. Mark's NWA/Tallahassee.

WD	%
Calm	24
N	10
NE	17
E	11
SE	5
S	2
SW	9
W	14
NW	8



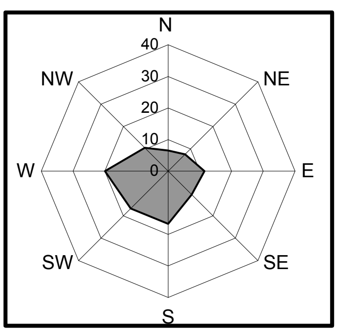
Calm: 24%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	109							
1-2	108	104	85	99	85	88	105	76
2-3	57	85	72	84	73	106	96	81
3-4	74	77	61	82	92	72	72	58
4-5	57	60	67	66		99	35	
5-6	43	70					48	
6-7								
7-8							44	
8-9								
9-10								
>=10								

Average of daily average extinction coefficient (Mm-1) for days meeting the wind speed and direction criteria

Figure 72a. Wind direction frequency diagram and extinction coefficient/wind relationship diagram based on surface wind data for 2000-2004: Chassahowitzka NWA.

WD	%
Calm	0
N	7
NE	8
E	11
SE	10
S	17
SW	17
W	20
NW	10



Calm: 0%

WD → WS (m/s)	N	NE	E	SE	S	SW	W	NW
<1	203							
1-2	168	40	109		133	51	127	211
2-3	120	101	95	86	111	106	110	107
3-4	91	74	93	105	102	117	91	66
4-5	75	118	65	79	95	93	100	138
5-6	76	70	131	73	86	82	147	86
6-7	58	129	79	70	87	99	89	79
7-8	69	117	71	68	75	88	80	
8-9	62	118	47	79	90	88	106	
9-10			88	55		65	75	104
>=10	82	79	72		74	80	66	72

Average of daily average extinction coefficient (Mm-1) for days meeting the wind speed and direction criteria

Figure 72b. Wind direction frequency diagram and extinction coefficient/wind relationship diagram based on upper-air wind data for 0600 LST for 2000-2004: Chassahowitzka NWA/Tampa.

For all three areas, higher extinction coefficients occur under a range of wind speeds and wind directions. Recall that poor visibility conditions for these areas (as discussed in Section 2.4) can be attributed to high $PM_{2.5}$ and/or high relative humidity. Days with onshore directed flow are likely to also have higher humidity. Given the shape of the coastline, onshore flow ranges from easterly to southwesterly for Breton, southeasterly to southerly for St. Mark's, and southwesterly to westerly for Chassahowitzka. Indeed, some of the higher extinction days occur under these conditions. Currently, most offshore emissions sources are adjacent to Texas and Louisiana (refer to Figures 52 and 53). Thus, among the Class I areas, Breton is most likely to be affected by emissions from offshore sources. The high extinction coefficients under conditions of onshore flow are potentially the combined result of high humidity and particulate matter formed from emissions from offshore sources. More detailed analysis of the data and air quality modeling is needed to further examine this hypothesis.

3.4. FREQUENCY AND CHARACTERISTICS OF THE GULF BREEZE AND RELATIONSHIP TO POLLUTANT CONCENTRATIONS

In this section we use the persistence index together with measured pollutant concentrations to examine the frequency of the gulf breeze and its relationship to pollutant concentrations for selected coastal locations. As a review, the persistence index is defined as the ratio of the 24-hour average vector wind speed and the 24-hour average scalar wind speed. It is an indicator of wind persistence. If the value is 1, this indicates that the vector and scalar wind speeds are the same, which further indicates that the wind was blowing from the same direction during the entire period. For example, a value of 0 indicates that the wind direction was from one direction for half the time and from the opposite direction the other half of the time. Thus a low value indicates the potential for recirculation. This parameter is by no means a measure of a true gulf breeze since wind reversals can occur under a variety of conditions. However, along the coast, the gulf breeze is an important driver of diurnal wind reversals.

For this analysis, potential gulf-breeze days are defined as those with a persistence index less than 0.5. Focusing first on ozone, the ozone season is defined as April through October. Based on this definition, the number of potential gulf breeze days for ozone season months for the years 2000-2004 was calculated for the following areas: Houston, Galveston, Beaumont/Port Arthur, Lake Charles, New Orleans, Baton Rouge, Gulfport, Mobile and Pensacola. The percentage of ozone season days with a possible gulf breeze is about 10 percent for Houston, Galveston, Beaumont/Port Arthur and Lake Charles; 14 percent for New Orleans and Baton Rouge; 15 percent for Mobile; and 18 percent for Gulfport and Pensacola. For New Orleans and Baton Rouge the index is more likely just an indication of variable diurnal wind directions and is not necessarily a gulf breeze. It is possible that the changing wind directions in New Orleans could represent a lake breeze (from Lake Ponchartrain).

To discern the relationship between the gulf breeze and 8-hour ozone, the hypothesis that maximum 8-hour ozone is, on average, higher for days with a gulf breeze than for days without was tested. Here the maximum 8-hour ozone is taken over all sites within a given area. Again, Houston is divided into three separate areas due to differences in the observed concentrations and more importantly the potential for differences in meteorology among these areas. Figure 73 compares the average concentrations for the gulf-breeze and non-gulf-breeze days.

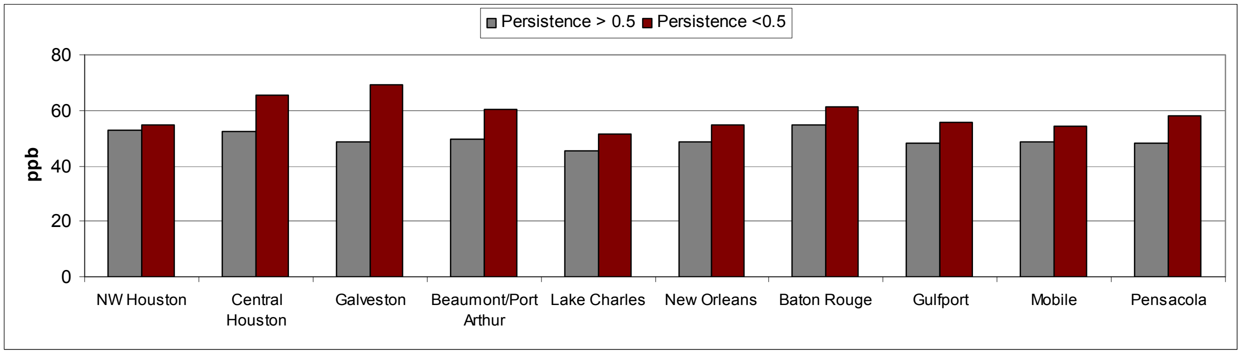


Figure 73. Comparison of average daily maximum 8-hour ozone concentration for non-gulf-breeze and gulf-breeze days for the 2000-2004 ozone seasons.

For all areas, the average 8-hour ozone concentration for days with a persistence index less than 0.5 and thus a possible gulf breeze recirculation is higher than for days persistent wind directions. The difference ranges from about 2 ppb for Northwest Houston to 20 ppb for Galveston. On average, considering all locations, days with a possible gulf breeze have a maximum 8-hour ozone value about 9 ppb greater than days without a gulf breeze recirculation.

Similar summaries are provided for the full annual periods and $PM_{2.5}$. The number of potential gulf breeze days for all months for the years 2000-2004 was calculated for the following areas: Houston, Galveston, Beaumont/Port Arthur, Lake Charles, New Orleans and Baton Rouge. The percentage of days with a possible gulf breeze is about 9 percent for Houston, Galveston and Lake Charles; 11 percent for Beaumont/Port Arthur and Baton Rouge; and 14 percent for New Orleans. Again, for New Orleans and Baton Rouge the index is more likely just an indication of changing wind directions and is not necessarily a gulf breeze.

To detect a relationship between the gulf breeze and $PM_{2.5}$ concentration, the hypothesis that 24-hour average $PM_{2.5}$ is, on average, higher for days with a gulf breeze than for days without was tested. Here the maximum value over all sites within a given area is used. Figure 74 compares the average concentrations for the gulf-breeze and non-gulf-breeze days.

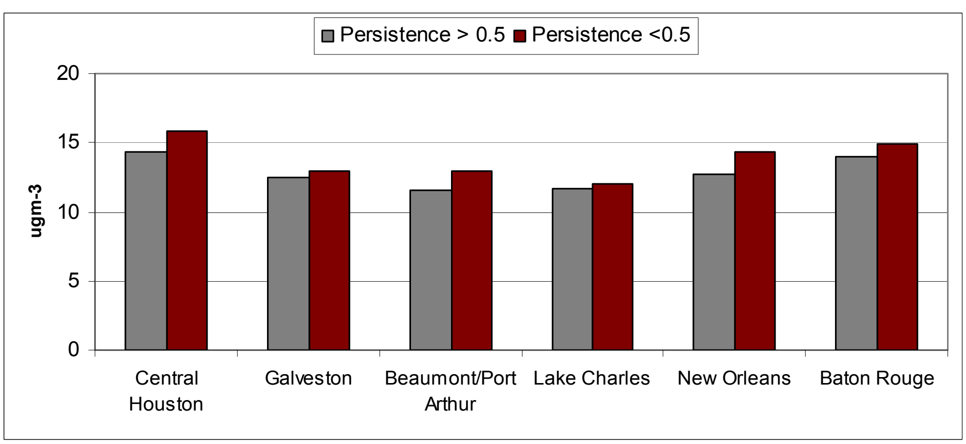


Figure 74. Comparison of average daily $PM_{2.5}$ concentration for non-gulf-breeze and gulf-breeze days for 2000-2004.

For all areas, the average $PM_{2.5}$ concentration for days with a persistence index less than 0.5 and thus a possible gulf breeze recirculation is higher than for days with more persistent wind directions. The difference ranges from about 0.3 μgm^{-3} for Lake Charles, to 1.5 μgm^{-3} for Central Houston and Galveston, to 1.6 μgm^{-3} for New Orleans. On average, considering all locations, days with a possible gulf breeze have a maximum $PM_{2.5}$ value about 1 μgm^{-3} greater than days without a possible gulf breeze recirculation.

Finally, summaries are provided for the full annual periods and extinction coefficient for the three Class I areas. The percentage of days with a possible gulf breeze is about 9 percent for Breton, 14 percent for St. Mark's and 15 percent for Chassahowitzka.

Figure 75 compares the average concentrations for the gulf-breeze and non-gulf-breeze days.

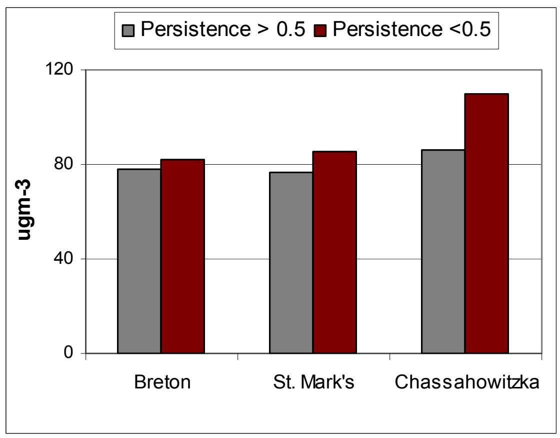


Figure 75. Comparison of average daily extinction coefficient for non-gulf-breeze and gulf-breeze days for 2000-2004.

For all three areas, the average extinction value for days with with a persistence index less than 0.5 and thus a possible gulf breeze recirculation is higher than for days with more persistent wind directions. The differences are 3.7 for Breton, 8.6 for St. Mark's, and 24 Mm^{-1} for Chassahowitzka. The average difference 12.1 Mm^{-1}.

This analysis clearly indicates that recirculation leads to higher pollutant concentrations and poorer visibility in all areas. For those areas where this recirculation is due to the presence of a gulf breeze, it follows that the gulf breeze circulation contributes to air quality issues along the Gulf Coast.

4.0 CART ANALYSIS FOR SELECTED COASTAL OZONE NONATTAINMENT AREAS

The Classification and Regression Tree (CART) analysis technique was used to examine the relationships between onshore and offshore meteorological conditions and ozone air quality in coastal non-attainment areas. The focus of this analysis was 8-hour ozone. CART was specifically applied for Houston, Galveston, Beaumont-Port Arthur, Lake Charles, Baton Rouge, and New Orleans. In addition, CART analyses conducted as part of the GCOS were updated and included in this analysis.

The objective of this analysis was to explore the relationships between the offshore meteorological conditions, onshore meteorological conditions, and high ozone in each of the areas of interest. Also of interest is the role of wind direction (and specifically onshore-directed flow) in determining high ozone regimes. All of the data presented in this section are included in the GMAQDB.

4.1. OVERVIEW OF CART

Classification and Regression Tree (CART) analysis (Brieman et al., 1984; Steinberg and Colla, 1997) is a statistical technique that can be used to “mine” and extract information from complex datasets. For air quality related analyses, the CART technique is used to segregate days with different values of an air quality parameter (the classification parameter) into different groups or bins and to provide information about the groupings. The input dataset is assumed to consist of a classification parameter (in this case pollutant concentration or another air quality related value) and a series of independent parameters that may be related to the classification parameter (typically a variety of meteorological input parameters). CART accomplishes the task of segregating the dataset through the development of a binary decision tree. At each split, the days are divided according to the value for one of the input parameters, in a way that best separates days with different values of a classification parameter. The end of a branch, called a bin, corresponds to a subset of days with predominantly one value for the classification parameter, characterized by input parameter ranges defined along the path to that bin.

Each value of the classification parameter may be represented by more than one bin, allowing for the possibility that different combinations of the independent parameters can be associated with a single value of the classification parameter (i.e., that different sets of meteorological conditions can lead, for example, to high ozone or high $PM_{2.5}$ events). CART assumes that there is a relationship between the independent parameters and the classification parameter, and that this relationship can be extracted from the data.

The CART classification “tree” provides information about the specific parameters and values that are used by CART to distinguish one type of air quality day from another (and, thus, which parameters are the most important determinants of poor air quality).

By segregating the data values into the classification bins, CART also provides information on the frequency of occurrence of the conditions associated with each bin. The likely recurrence rate for a particular type of day and the associated prevailing conditions are obtained. A simple example of a CART classification tree diagram is given in Figure 76. In this example, 365 days are grouped into four classification bins that correspond to different ranges of 8-hour ozone concentration. In the diagram, the difference colors represent the different classification categories. The bins are distinguished by three independent input parameters: temperature, wind speed and wind direction. In this example, Bin #3 includes 15 days that are classified as belonging to the highest 8-hour ozone category (with concentrations greater than or equal to 95 ppb). Days with temperatures greater than 30°C and northerly winds are placed in this bin. Bins 1, 2 and 4 are comprised of days with different 8-hour ozone concentrations and different meteorological characteristics.

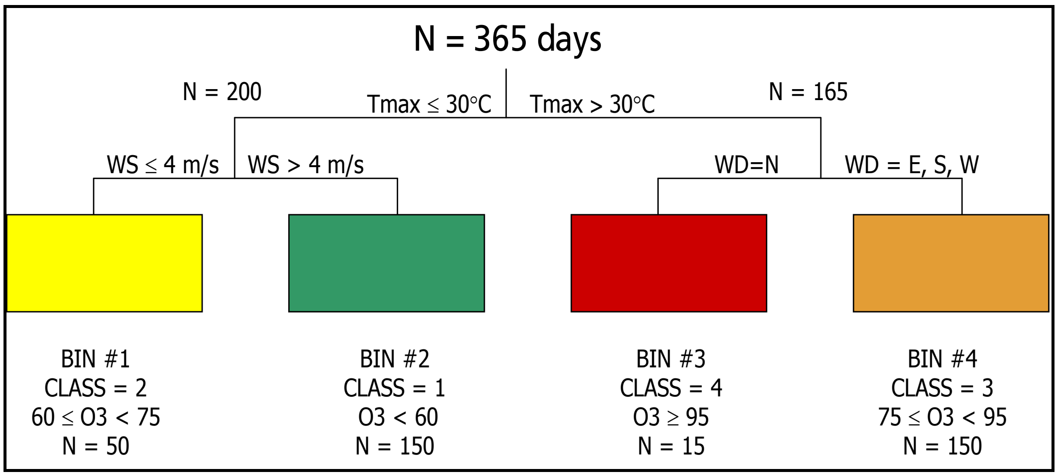


Figure 76. Simple CART classification tree diagram, with splits on temperature (Tmax), wind speed (WS) and wind direction (WD).

Note that this is a very simple example of a CART tree. For this study, most trees have approximately 25 to 35 bins and include multiple bins for each classification category.

CART also provides information about classification accuracy which can be used to assess the completeness and quality of the input parameters and the overall quality of the classification results. Misclassification can occur due to a number of reasons including monitoring network limitations, length (completeness) of the analysis period, use of discrete classification categories, and data errors or missing data. Throughout the remainder of this report, the term "classification accuracy" refers to the percentage of days that were assigned to the correct classes (that is, correctly placed into bins with ranges corresponding to their observed values).

In summary, the CART classification tree and the parameter and values used to divide the data into bins provide insight into the causal relationships between the independent parameters and the classification parameter, as well as the relative importance of the various independent parameters. In the case of air quality, this translates to the relationships between meteorology and air quality related values, and the key parameters and combinations of parameters that lead to poor air quality.

4.2. CART APPLICATION PROCEDURES

For ozone, CART was applied for the periods 1996-2004 and 2000-2004. Details of the CART application for ozone are presented in this section. In addition to assembling an input dataset consisting of relevant air quality and meteorological parameters, the user must also define the classification categories, specify the "costs" associated with the misclassification of days into bins corresponding to a different category than indicated by the observed data, and select an approximate number of bins to be included in the classification tree.

4.2.1. Identification of CART Input Parameters

A first step in the application of CART is the identification of the input parameters. The following list includes available meteorological and air quality parameters that are expected to influence ozone along the Gulf Coast. The starting point for the list of input parameters was the CART analysis conducted as part of GCOS (Douglas et al., 2001). Additional parameters were added based on data availability, and input from MMS staff and Science Review Group (SRG) members.

Surface Meteorological Parameters

Surface meteorological parameters were used to characterize the local meteorological conditions. The surface meteorological inputs for CART are listed below.

- **Temperature**
  - Daily maximum temperature (ºC)
  - Daily average temperature (ºC)
- **Relative Humidity**
  - Relative humidity at noon (%)
- **Wind**
  - 3-hour average vector wind direction bin; value of 1 through 5, indicating the wind direction corresponding to the 3-hour vector average wind direction for the periods 0700-1000, 1000-1300 and 1300-1600 LST. Bin definitions (in degrees) are: [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively.
  - 3-hour average scalar wind speed (ms^{-1}) for the periods 0700-1000, 1000-1300 and 1300-1600 LST
  - Persistence index (24-hour average vector wind speed/24-hour average scalar wind speed). This is an indicator of wind persistence, and a possible indicator of a gulf breeze. If the value is 1, this indicates that the vector and scalar wind speeds are the same, which further indicates that the wind is from the same direction during the entire period. A value of 0 indicates that the wind direction is from one direction for half the time and from the opposite direction the other half of the time. Thus a low value indicates the potential for recirculation.
- **Pressure**
  - Daily maximum sea level pressure (mb)

- **Precipitation**
  - 24-hour total precipitation (in)

Upper-Air Meteorological Parameters

Upper-air meteorological parameters were used to characterize the regional-scale meteorological conditions. The upper-air parameters are as follows:

- **Temperature**

  900 mb

  - 900 mb to surface temperature gradient, defined here as the difference between the temperature at 900 mb and the surface using the morning (0600 LST) temperature sounding data (ºC)

  850 mb

  - Upper-air 850 mb temperature corresponding to the morning (0600 LST) sounding on the current day (ºC)
  - Upper-air 850 mb temperature corresponding to the evening (1800 LST) sounding on the current day (ºC)

- **Wind**

  850 mb

  The following two upper-air wind variables were computed using data from the prior day's evening sounding, and the current day's morning and evening soundings for 850 mb (for a total of six input variables for each upper-air monitoring site):

  - Wind speed (ms^{-1})
  - Wind direction bin; value of 1 through 5, indicating the wind direction: (in degrees) [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively

- **Recirculation**

  850 mb

  - Recirculation index (value of 0 or 1) that is based on the difference between the average wind direction yesterday and today and/or scalar wind speed. If the difference is within +/- 15 degrees of 180 degrees or if average scalar wind speed is < 3 ms^{-1} then the index is set to 1. Otherwise the value is 0.

- **Geopotential Height**

  700 mb

  - Difference in the daily average geopotential height above sea level of the 700 mb surface (m) using height for the current day minus height for the prior day. Note that geopotential height differs from height above mean sea level in that it accounts for the variation of the effects of gravity with altitude and latitude. This parameter is an indicator of changing pressure patterns aloft.

- **Clouds**

  700/850 mb

  The cloud indicator variable combines data from both the 700 and 850 mb and was computed using data from the morning and evening soundings.

  - Cloud index. Value based on relative humidity at the 850 mb (rh850) and 700 mb (rh700) levels. Ranges from 1 to 3 are based on the empirical analysis of observed data and are defined as follows:

    if (rh850 < 80% and rh700 < 65%) then cloud = 1;

    if (rh850 >= 80% and rh700 < 65%) then cloud = 2;

    if (rh850 < 80% and rh700 >= 65%) then cloud = 2;

    if (rh850 >= 80% and rh700 >= 65%) then cloud = 3

Buoy Meteorological Parameters

For selected areas, buoy data were used to characterize the offshore meteorological conditions. These are also surface-based meteorological parameters as listed below.

- **Sea Surface Temperature**
  - Daily average sea-surface temperature (ºC)
- **Wind**
  - 3-hour average vector wind direction bin; value of 1 through 5, indicating the wind direction corresponding to the 24-hour vector average wind direction for the periods 0700-1000, 1000-1300 and 1300-1600 LST
  - 3-hour average scalar wind speed (ms^{-1}) for the periods 0700-1000, 1000-1300 and 1300-1600 LST
  - Persistence index (24-hour average vector wind speed/24-hour average scalar wind speed). This is an indicator of wind persistence and a possible indicator of a gulf breeze.

Air Quality Parameters

In addition to the meteorological input parameters, ozone concentrations for prior days as well as for the region were also used in the CART analysis.

- **Daily Maximum 8-Hour Ozone**
  - *Classification parameter for the application of CART for ozone.* Assigned a value of 1 through 5, such that each value corresponds to a different range of 8-hour ozone concentration. The concentration ranges are: less than 60 ppb, 60 to 75 ppb, 75 to 95 ppb, 95 to 115 ppb and greater than or equal to 115 ppb.

These are the same concentration ranges that EPA uses for ozone air quality forecasting. The highest category was not needed for all areas.

- **Regional Ozone Indicator Variables**
  - Prior-day daily maximum 8-hour ozone concentration for one or more nearby and thus potentially upwind sites (ppb). The specific sites and number of potential upwind sites is different for each CART region.

The input parameter lists were refined several times during the course of the CART application. The refinements were primarily guided by the CART results and were applied consistently for all of the areas of interest. Buoy data were not applicable for all regions, as discussed later in this section.

4.2.2. Quality Assurance Steps

Following each application, the results were assessed using statistical measures of the goodness of the classification, and then checked for physical reasonableness, as follows:

- The list of input parameters was checked for completeness.
- The CART input parameters were checked to ensure that they were specified reasonably (per the CART user's guide (Steinberg and Colla, 1997) and as intended.
- The values used to determine the branching of the CART output classification trees were checked to ensure that the values are reasonable and consistent with the input data.
- A matrix representing the statistical goodness of the classification (or classification accuracy) is created by CART, and the elements of this matrix were examined to ensure a minimum number of misclassifications. Classification accuracy refers to the percentage of days that were assigned to the correct classes (that is, correctly placed into bins with ranges corresponding to their observed values).
- Splits in the decision tree were checked to ensure that the parameters and values used to develop the classification tree are physically meaningful (i.e., consistent with basic conceptual models of ozone formation and transport).
- Splits in the decision tree were checked to ensure that CART made decisions (segregating the days) based on values of the input variables that are distinguishable in the data.
- The overall structure of the classification tree and number of classification bins were checked to ensure that the pathways to the different classification bins are distinct and that the bins provide a reasonable segregation of the days based on the daily extinction coefficient values.
- Final bins in the decision tree were checked for uniqueness, such that different bins represent different meteorological characteristics.

- One or more bins representing each classification category were selected and the decision pathways leading to those bins were explicitly checked for physical reasonableness.

4.2.3. Assessment of CART Results

The CART results were displayed in a variety of ways, both as part of the quality assurance and to aid the analysis of the results.

CART trees with approximately 25-35 bins were selected to optimize classification accuracy and physical reasonableness. The majority of the high ozone days, however, were grouped into one to four key bins.

Tabular summaries of classification accuracy were prepared and classification accuracy, by category and overall, were calculated. Overall classification accuracy ranged from approximately 76 to 87 percent without the buoy data and from 78 to 87 percent with the buoy data.

The relative importance of the various input parameters to the CART classification tree was examined and plotted for each site.

4.3. CART Results

Presentation of the CART analysis results for 8-hour ozone is divided into three parts: exploratory analyses, pathways to high ozone, and summary of findings. Throughout the discussion of the results, the term "classification accuracy" refers to the percentage of days that were assigned to the correct classes (that is, correctly placed into bins with ranges corresponding to their observed values).

4.3.1. Exploratory Analyses

The application of CART for each site included several exploratory analyses that were designed to test and refine the methodologies and input parameters. Specifically, sensitivity tests examined: 1) a longer (1996-2004) versus shorter (2000-2004) data period, 2) alternative category definitions (based on the newest ozone standard), 3) additional meteorological input parameters including a ventilation factor, a precipitation parameter, and several parameters based on buoy data, and 4) use of only meteorological input parameters (versus both meteorological and air quality parameters).

Key findings from the sensitivity testing include:

- Using fewer years of data does not significantly reduce the complexity of the CART classification tree. Classification accuracy, however, is better with the shorter period (by about 2 to 8 percentage points for most areas). Use of a shorter period may avoid changes in emissions that are expected to have occurred over the longer time period and this would tend to increase classification accuracy. For consistency with the $PM_{2.5}$ and visibility analyses (which only have data for the shorter period), the final CART analysis for ozone used data for 2000-2004.

- During the course of this study, EPA modified the 8-hour ozone standard and changed the concentration ranges used to characterize air quality. The standard was lowered from 85 ppb to 75 ppb, based on the 8-hour ozone design value, and the concentration ranges corresponding to good, moderate, unhealthy etc. were modified accordingly. The CART analyses used these concentration ranges to define the ozone categories. The original categories include <65, 65-85, 85-105, 105-125 and ≥125 ppb. The revised categories are <60, 60-75, 75-95, 95-115 and ≥115 ppb. CART found it more difficult to correctly classify the days into the ranges defined by the new categories. In particular, misclassification of the lower ozone days was greater using the new categories. This indicates that the conditions (primarily the meteorological conditions) associated with the lower ranges of ozone concentrations are not as distinct as with the prior categories. However, in keeping with the new standard, the new categories were used for the final CART analysis.
- Two additional meteorological parameters were also tested. These include a ventilation factor (based on wind speed and estimated mixing height) and total precipitation. Neither of these two parameters improved classification, nor were they found to be important by CART. While the ventilation factor is potentially very important in the characterization of ozone air quality, it is difficult to accurately estimate mixing height for the areas of interest primarily due to lack of upper-air data. This parameter was not retained. For consistency with the $PM_{2.5}$ and visibility analyses, the precipitation parameter was kept.
- Buoy data were also added to the Houston, Beaumont/Port Arthur and Lake Charles CART analyses. Data from Buoy #42035 (located off the coast of Southeast Texas) were used to calculate several new meteorological input parameters including sea surface temperature and temperature, wind speed, wind direction, and persistence for the offshore area. The results were mixed, and CART classification were slightly improved for Northwest Houston, Central Houston, and Lake Charles, unchanged for Southeast Houston/Galveston and slightly degraded for Beaumont/Port Arthur. In all cases, however, CART did use the buoy data to construct the classification tree and thus these data potentially an important source of information. Because of the mixed results, the final CART trees did not include the buoy data. Nevertheless, a key finding of this analysis is that that for some areas buoy data may provide information about the mechanisms leading to onshore ozone.
- The meteorological data only CART runs indicate that the selected meteorological data are good indicators of ozone concentration. The reduction in classification accuracy compared to the full CART run (which includes both meteorological and prior-day ozone data) is one to five percent. Classification accuracy ranges from 72 to 86 percent for the meteorological data only runs and from 76 to 89 percent for the full CART analyses.

For the final set of CART trees, classification accuracy is provided in Table 30 and (as noted above) ranges from approximately 76 to 89 percent.

Table 30

Summary of CART Classification Accuracy for All Areas for the MMS Synthesis 8-Hour Ozone Applications.

CART Area	Accuracy (%)
Northwest Houston	77
Central Houston	76
Southeast Houston/Galveston	79
Beaumont/Port Arthur	84
Lake Charles	86
New Orleans	87
Baton Rouge	80
Gulfport	89
Mobile	88
Pensacola	88

Our goal for this study was 80 percent classification accuracy for ozone and this goal was met or nearly met for all sites. This goal was selected based on prior applications and diagnostic testing. Houston was the most challenging area, presumably due to the complexity of the meteorology and emissions in that area.

4.3.2. Pathways to High Ozone

As noted earlier, the CART classification technique can provide information about the relative importance of the various independent parameters in distinguishing days with different ozone air quality characteristics as well as the combinations of parameters that lead to high ozone. This information has been extracted from the CART analysis results for ozone and is discussed in the remainder of this section.

Important Classification Parameters

Certain of the input parameters are used more frequently in the construction of the classification trees and an analysis of the important parameters provides some insight into the factors that influence air quality, and how these differ among the monitoring sites and for ozone, $PM_{2.5}$ and visibility.

Parameter importance is calculated by CART based on the number of times each parameter is used, either as a split parameter or as a surrogate parameter, to construct the final classification tree. Split parameters are those that explicitly define the branches of the CART tree, and thus separate the days. Surrogate parameters represent the next best splits, and are used in the case of missing data. For example, the 850 mb temperature might be a surrogate for the 900 mb to surface temperature difference since both are indicators of stability. Several surrogates are identified for each split.

Parameter importance is assigned a value ranging from 0 to 100, based on the use of the parameter in defining the CART tree. Specifically, the importance indicates the improvement in classification accuracy that results from using the best split parameter compared to the best surrogate split parameter. The importance values are normalized such that the most important parameter has a value of 100. The values are only meaningful in a relative sense and within the context of the CART analysis. We use parameter importance in this analysis to identify those parameters that are statistically relevant to the classification and assume that these same parameters are also physically relevant to 8-hour ozone concentrations. That is, we assume that the parameters that are most important in determining the structure of the CART tree are also most important in determining ozone air quality.

Parameter importance for each area is displayed in Figure 77. Note that in each plot, the relative importance assigned to the prior-day regional 8-hour concentration is an average of the relative importance of prior-day ozone for all neighboring and potential upwind areas used as input to the CART analysis. Because of the averaging, not all charts have a maximum value of 100. In addition, the relative importance assigned to several of the surface and upper-air meteorology categories is the maximum over the parameters that comprise the grouping (e.g., the morning and evening 850 mb temperatures comprise the upper-air temperature group). The category abbreviations are defined as follows and represent one or more of the CART input parameters:

YO3_Local = Yesterday's maximum 8-hour ozone concentration for the area of interest

YO3_Regional = Yesterday's ozone concentration for neighboring and upwind areas (average for the group)

TMAX = Daily maximum temperature

TAVG = Daily average temperature

RH = Relative humidity

WS (Sfc) = Surface wind speed (maximum for the surface wind speed parameter group)

WD (Sfc) = Surface wind direction (maximum for the surface wind speed parameter group)

PERSIST = Persistence or gulf-breeze index

SLP = Sea level pressure

RAIN = Total rainfall

CLOUD = Cloud cover index

DZ700 = Daily change in geopotential height at the 700 mb level

DT900 = 900 mb to surface temperature difference

T850 = 850 mb temperature (maximum for the upper-air temperature parameter group)

WS (Upper) = Wind speed aloft (maximum for the upper-air wind speed parameter group)

WD (Upper) = Wind direction aloft (maximum over the upper-air wind speed parameter group)

RECIRC = Recirculation index

In this and subsequent plots of parameter importance, red is used for air quality parameters, blue is used for surface meteorological parameters, and green is used for upper-air parameters.

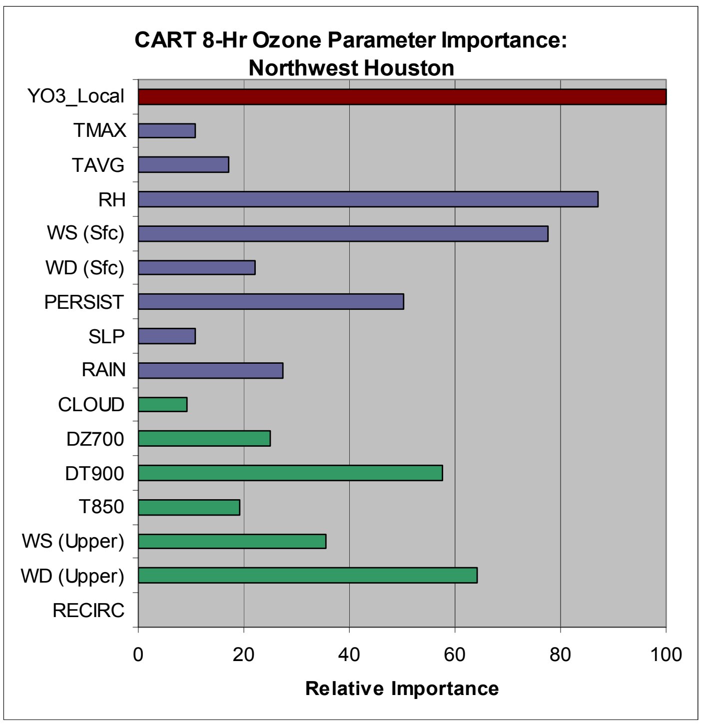


Figure 77a. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Northwest Houston.

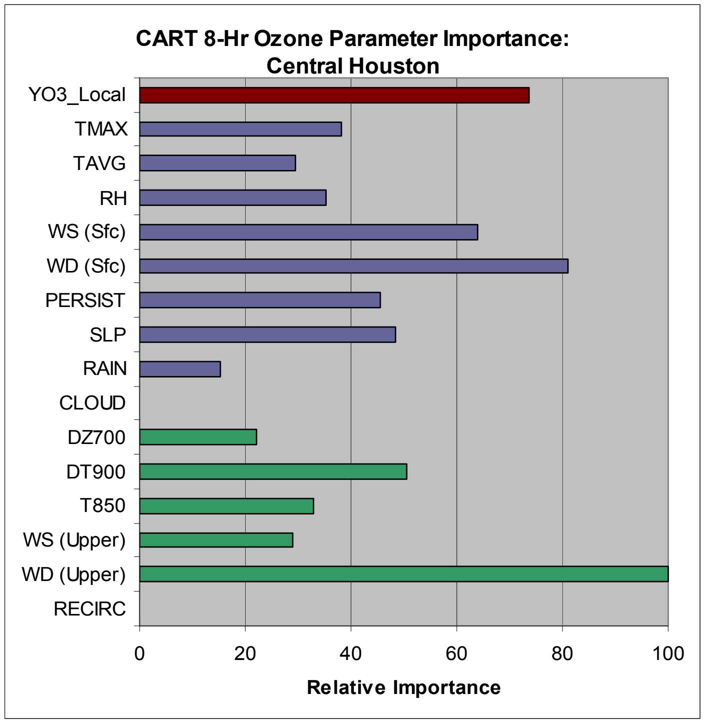


Figure 77b. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Central Houston.

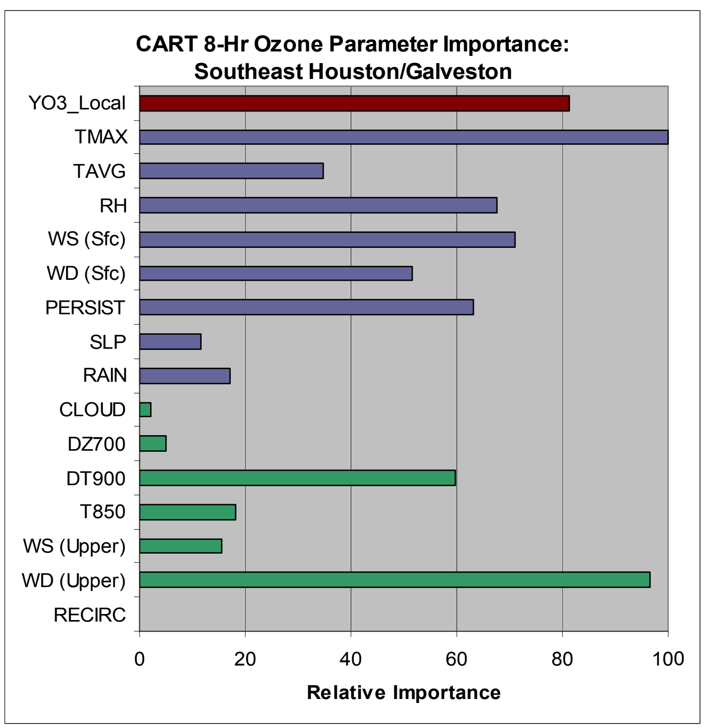


Figure 77c. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Southeast Houston/ Galveston.

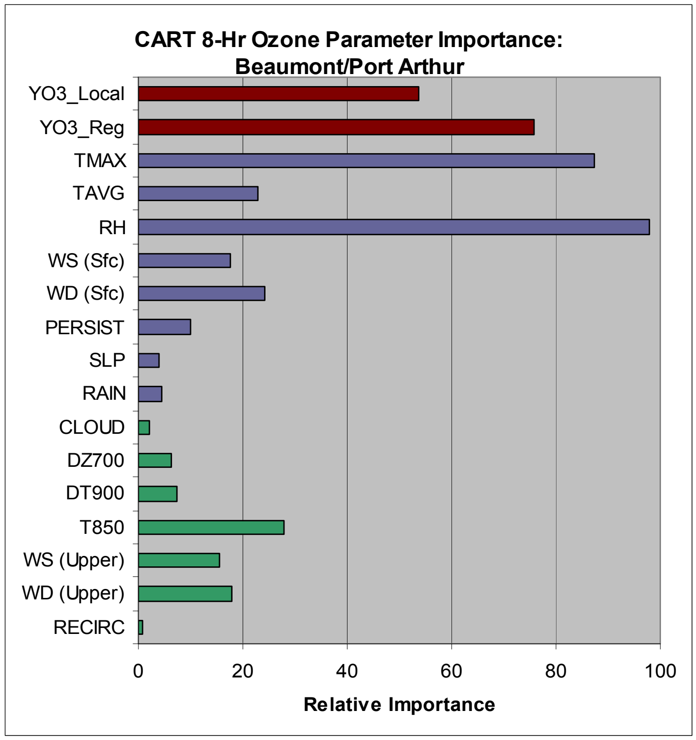


Figure 77d. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Beaumont/Port Arthur.

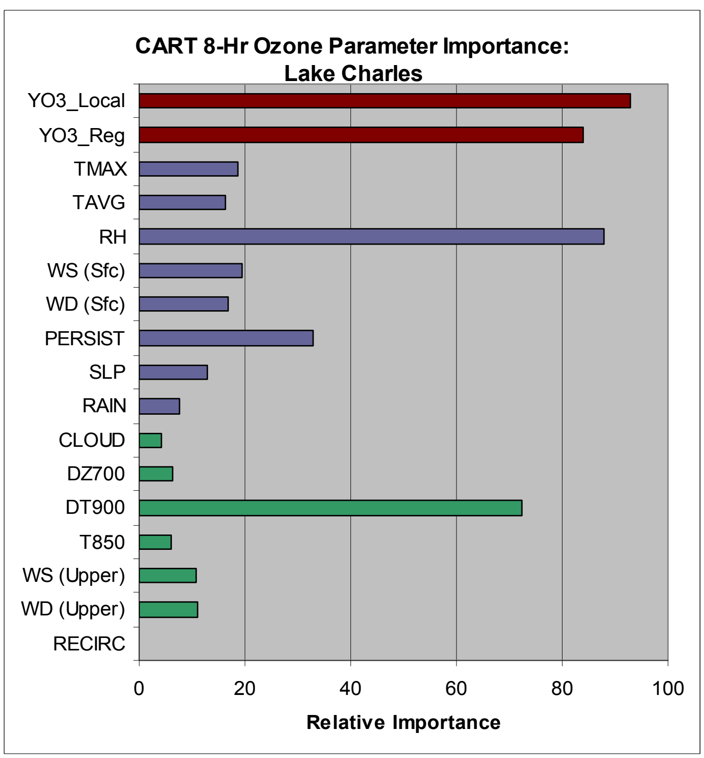


Figure 77e. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Lake Charles.

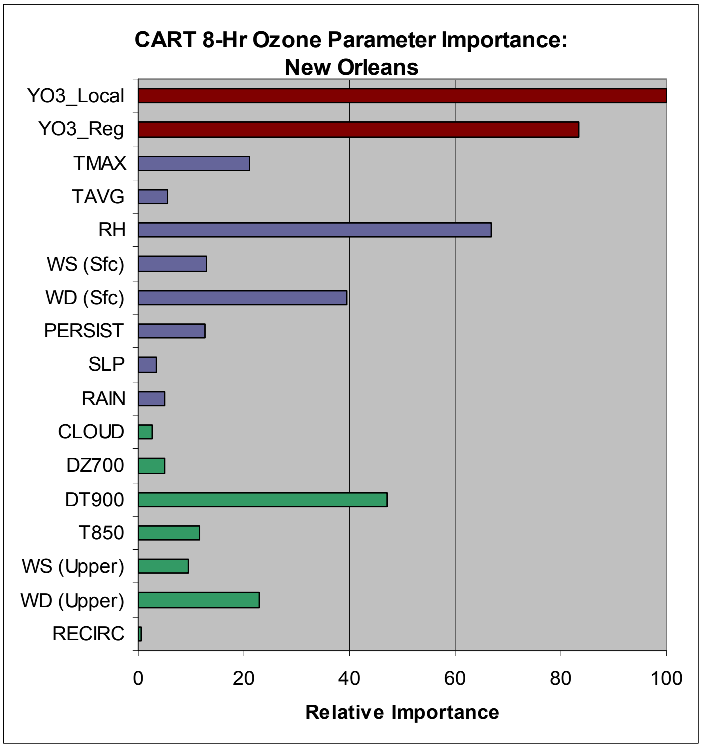


Figure 77f. Average parameter importance for the MMS synthesis 8-Hour ozone CART analysis: New Orleans.

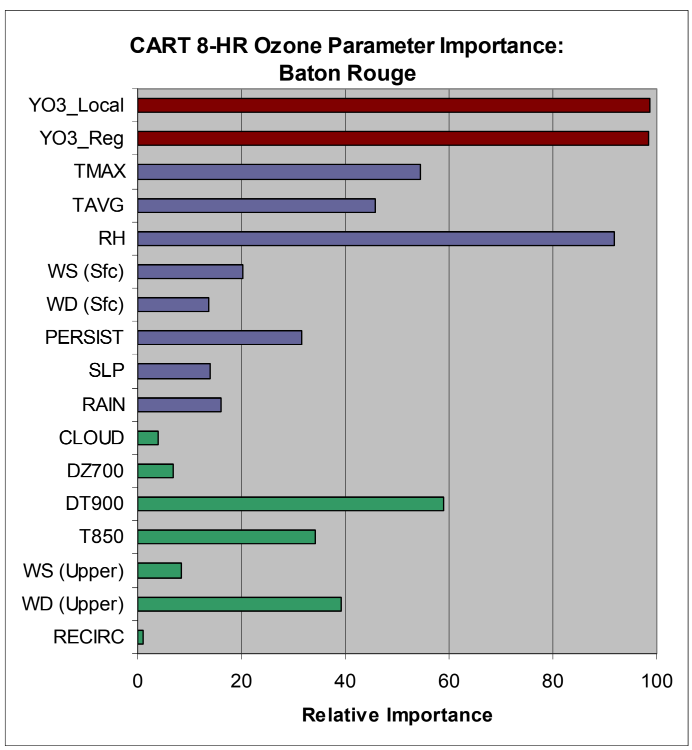


Figure 77g. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Baton Rouge

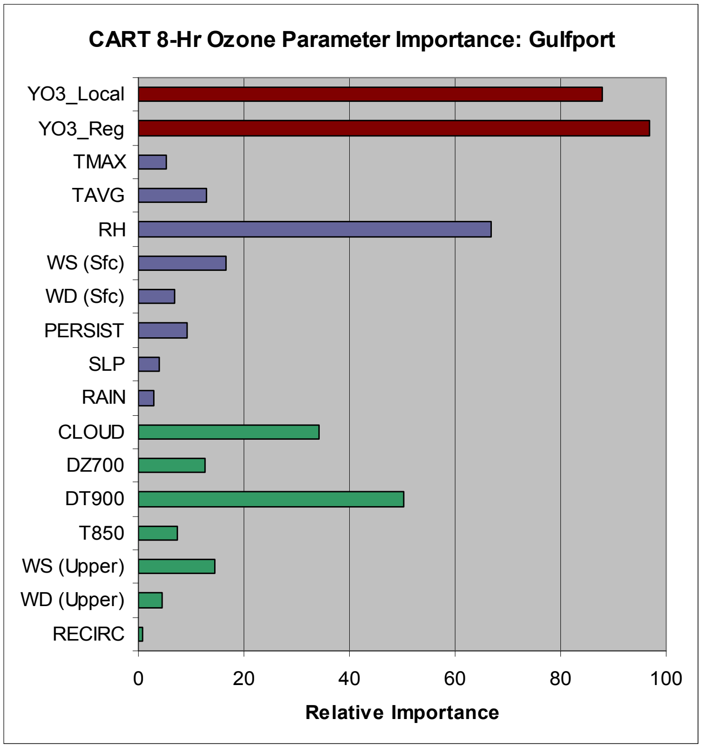


Figure 77h. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Gulfport.

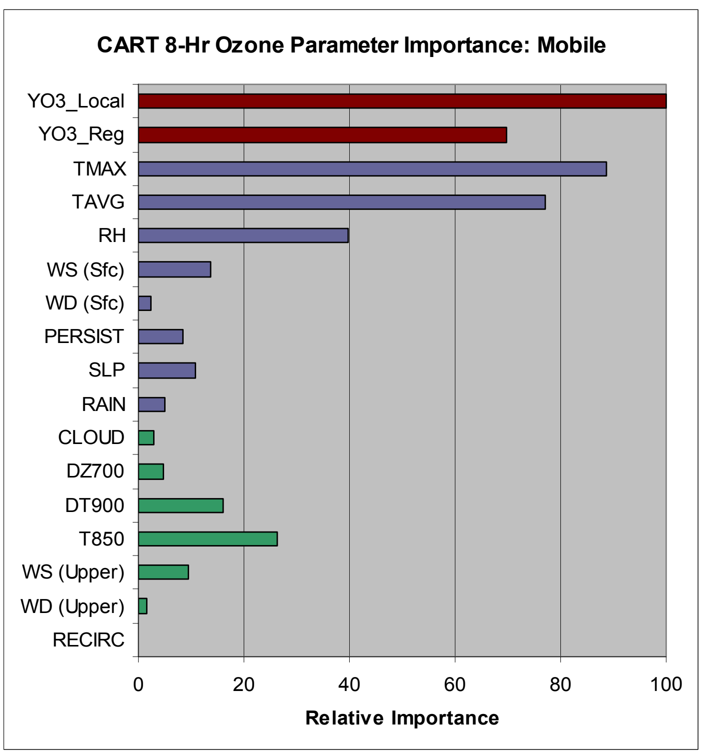


Figure 77i. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Mobile.

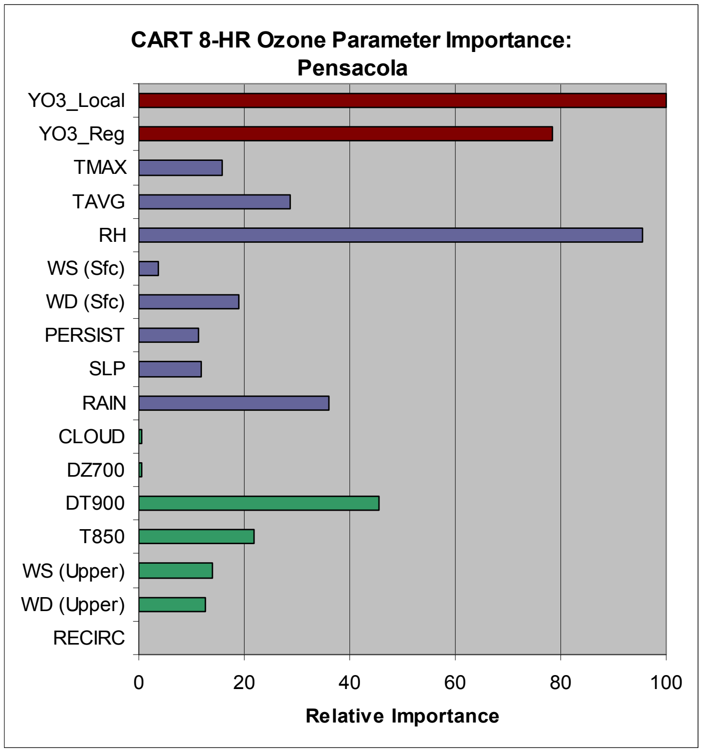


Figure 77j. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Pensacola.

Parameter importance varies considerably among the different areas, suggesting that the different combinations of prior day air quality and meteorological parameters lead to high ozone in each area. For all areas, prior day ozone concentrations are an important factor in determining the ozone category for the current day ozone. The CART results indicate that both carryover (local parameter) and transport (regional parameters) play an important role in determining ozone concentration. Relative humidity (which may be an indicator of cloud cover buildup during the summer months) is also important for all areas. Stability also tends to be among the more important parameters. Surface wind speed is more important in the Houston area than elsewhere in the region, and this suggests that ozone events in the Houston area are more likely to be driven by local emissions and the complex interactions between surface winds and emissions. Upper-air winds are moderately to very important for New Orleans, Baton Rouge and the Houston area.

To summarize the results for the Gulf Coast region, average parameter importance for all areas is displayed in Figure 78.

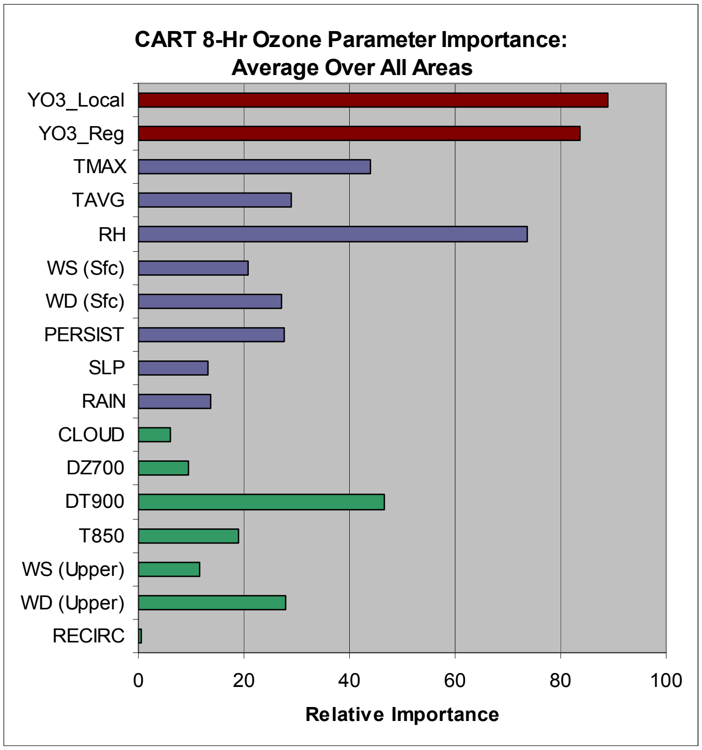


Figure 78. Average parameter importance for the MMS synthesis 8-hour ozone CART analysis: Average over all areas.

On average, the most important parameters include: prior day maximum 8-hour ozone concentration in the area of interest, prior day maximum 8-hour ozone concentration in potential upwind areas, relative humidity, stability, temperature and upper-level wind direction. Of secondary importance are surface wind speed and direction and persistence.

Characteristics of High Ozone (Categories and Bins)

In the previous section, we identified certain parameters that are important to the classification of days with respect to 8-hour ozone concentration and concluded that these parameters have the potential to influence air quality at the monitoring sites. However, understanding the causes of high ozone concentrations also requires an understanding of the relationship between the parameters and the air quality metrics, as well as the specific combinations of parameters (conditions) that lead to impaired air quality. In this section, we further explore those relationships using the CART input data and results.

Categorical Comparisons

Tables 4 through 13, presented in Section 2 of this report, examined the variations in ozone versus meteorology. The meteorological parameters listed in these tables are the same as the CART input parameters for ozone. The ozone concentration categories are the same as those used for the CART analysis. Referring back to those tables, a brief summary of the characteristics and categorical variations in selected parameters associated with high ozone in each area is provided. Emphasis is on those parameters that are most different between low and high ozone days.

For Northwest Houston (refer to Table 4), high ozone is associated with:

- Moderate to high ozone on previous day (local and potential upwind areas),
- Low relative humidity,
- Low wind speeds near the surface and aloft,
- Southeasterly winds near the surface and aloft,
- No precipitation,
- Increasing height (pressure) aloft, and
- Some recirculation aloft.

For Central Houston (refer to Table 5), high ozone is associated with:

- Moderate to high ozone on previous day (local and potentially upwind areas),
- Low relative humidity,
- Low wind speeds near the surface and moderate winds aloft,
- Easterly wind components near the surface and northeasterly to easterly winds aloft,
- No precipitation, and
- Stable conditions.

For Southeast Houston/Galveston (refer to Table 6), high ozone is associated with:

- High ozone on previous day (in the Houston/Galveston area) and moderate ozone in the region,
- High temperatures near the surface and aloft,
- Low relative humidity,
- Low wind speeds near the surface and aloft,
- Northwesterly winds near the surface and northerly to northeasterly winds aloft,
- Possible gulf breeze,
- No precipitation,
- Decreasing height (pressure) aloft, and
- Stable conditions.

For Beaumont/Port Arthur (refer to Table 7), high ozone is associated with:

- High ozone on previous day (local and potentially upwind areas, excepting Lake Charles),
- High temperatures near the surface and aloft,

- Low relative humidity,
- Low wind speeds near the surface and moderate winds aloft,
- Northwesterly to northerly winds near the surface and northeasterly winds aloft,
- Possible gulf breeze,
- No precipitation,
- Decreasing height (pressure) aloft, and
- Stable conditions.

For Lake Charles (refer to Table 8), high ozone is associated with:

- Moderate ozone on previous day (local) with higher ozone throughout the region,
- Low relative humidity,
- Low wind speeds near the surface and aloft,
- Northerly backing to southerly surface winds, and southwesterly to northeasterly winds aloft,
- No precipitation, and
- Stable conditions.

For New Orleans (refer to Table 9), high ozone is associated with:

- High ozone on previous day (local and potentially upwind sites) with very high ozone in the Baton Rouge and Houston/Galveston areas,
- High temperatures near the surface and aloft,
- Low relative humidity (but only relative to Category 1),
- Low to moderate wind speeds near the surface and aloft,
- Northwesterly winds near the surface and westerly to northwesterly winds aloft,
- No precipitation,
- Somewhat stable conditions, and
- Recirculation aloft.

For Baton Rouge (refer to Table 10), high ozone is associated with:

- High ozone on previous day (local) and moderate to high ozone at potentially upwind sites,
- High temperatures near the surface and aloft,
- Low relative humidity,
- Very low wind speeds near the surface and low to moderate wind speeds aloft,

- Northeasterly veering to southerly winds near the surface and northerly wind components aloft,
- Recirculation near the surface,
- No precipitation, and
- Somewhat stable conditions.

For Gulfport (refer to Table 11), high ozone is associated with:

- High ozone on previous day (local and potentially upwind sites),
- Low relative humidity,
- Low to moderate wind speeds near the surface and moderate wind speeds aloft,
- Northerly backing to southerly winds near the surface with easterly then westerly winds aloft near the coast and southwesterly winds aloft further inland,
- No precipitation, and
- Stable conditions.

For Mobile (refer to Table 12), high ozone is associated with:

- High ozone on previous day (local) and moderate to high ozone at potentially upwind sites,
- High temperatures near the surface and aloft,
- Very low relative humidity,
- Low wind speeds near the surface and aloft,
- Westerly to northwesterly winds near the surface and northerly to northeasterly winds aloft,
- No precipitation,
- Decreasing height (pressure) aloft, and
- Stable conditions.

For Pensacola (refer to Table 13), high ozone is associated with:

- Moderate on previous day (local and potentially upwind sites),
- High temperatures near the surface and aloft,
- Low relative humidity,
- Low wind speeds near the surface and moderate winds aloft,
- Northwesterly veering to southerly winds near the surface and northerly wind components aloft,
- Possible gulf breeze,

- No precipitation, and
- Stable conditions.

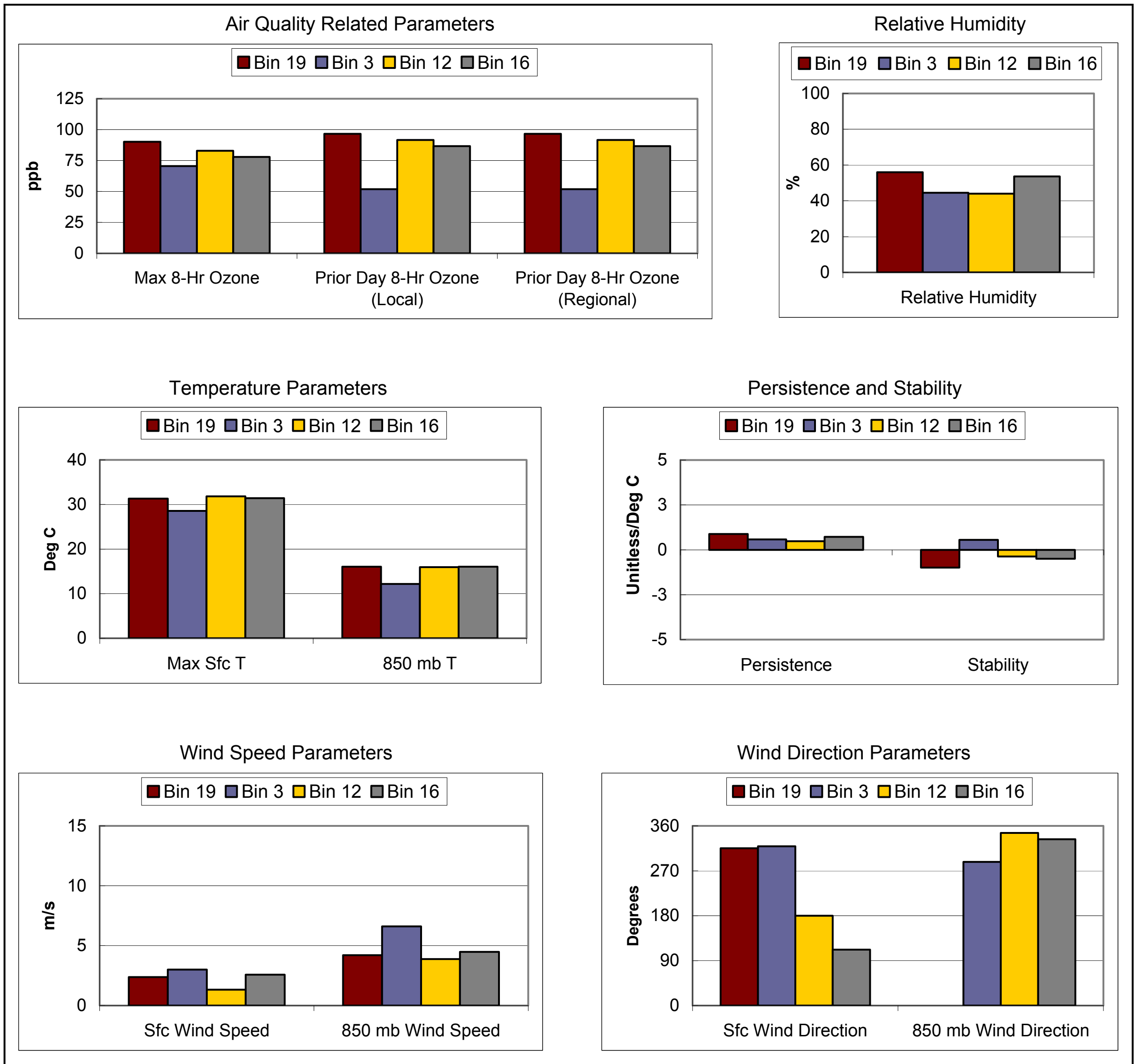
There are numerous similarities among the areas, especially with regard to relative humidity, wind speed, precipitation and stability. For many areas, higher ozone concentrations are associated with low relative humidity, low wind speeds (both near the surface and aloft), little or no precipitation and greater stability (compared to lower ozone days). The differences tend to be associated with wind direction (wind directions on high ozone days vary by area), prior day ozone (this ranges from moderate to high, on average), changing pressure patterns aloft, and the recirculation and persistence indexes. This suggests that there are certain prevailing conditions that are conducive to ozone formation across the Gulf Coast region, but that for each area different combinations of regional meteorology, local meteorology, and carryover and/or transport of ozone comprise an ozone episode.

Several of the areas have predominantly southerly winds or southerly wind components on the high ozone days. These are Northwest Houston (southeasterly winds), Lake Charles, Baton Rouge, Gulfport and Pensacola. Of these Lake Charles, Gulfport and Pensacola are truly coastal and based on wind direction alone are the most likely to be influenced by offshore emissions. This finding however is mitigated by the fact that most of the emissions sources are located off the coast of Louisiana and Texas and thus not directly offshore from Gulfport and Pensacola. There are sources offshore of Lake Charles. Under conditions of southeasterly flow, high ozone in Northwest Houston is likely due to transport of ozone and precursor emissions from Central and Southeast Houston. Similarly, under conditions of southerly flow, high ozone in Baton Rouge is likely influenced by emissions from sources along the industrial corridor between Baton Rouge and New Orleans, as well as sources in New Orleans and possibly offshore areas.

Analysis of Key Bins

Each value of the classification parameter may be represented by more than one bin, allowing for the possibility that different combinations of the independent parameters can be associated with a single value of the classification parameter (i.e., that different sets of meteorological conditions can lead to high ozone). CART assumes that there is a relationship between the independent parameters and the classification parameter, and that this relationship can be extracted from the data.

Greater insight is gained by considering the characteristics of the key bins that represent the high ozone days for each area. Key bins were defined as those containing at least five days and the greatest number of correctly classified days. Four key high-ozone bins corresponding to the highest and second highest ozone categories for each area were identified and the characteristics of those bins were examined and compared. Figure 79 displays and compares selected parameters for the key high ozone bins for each area. The parameters are grouped as follows: air quality related parameters, relative humidity, temperature parameters, stability and persistence parameters, wind speed parameters and wind direction parameters. The bin category and number of days in each bin is also given. As a reminder, the concentration categories are defined as follows: Category 1 (< 60 ppb), Category 2(60 to 75 ppb), Category 3(75 to 95 ppb), Category 4 (95 to 115 ppb) and Category 5 (≥ 115 ppb). Category 5 was not needed for most areas.



Bin 19 = Category 4 (18 Days); Bin 3 = Category 4 (8 Days); Bin 12 = Category 4 (7 Days); Bin 16 = Category 3 (31 Days)

Figure 79a. Average values of selected parameters by bin for the key high ozone bins: Northwest Houston.

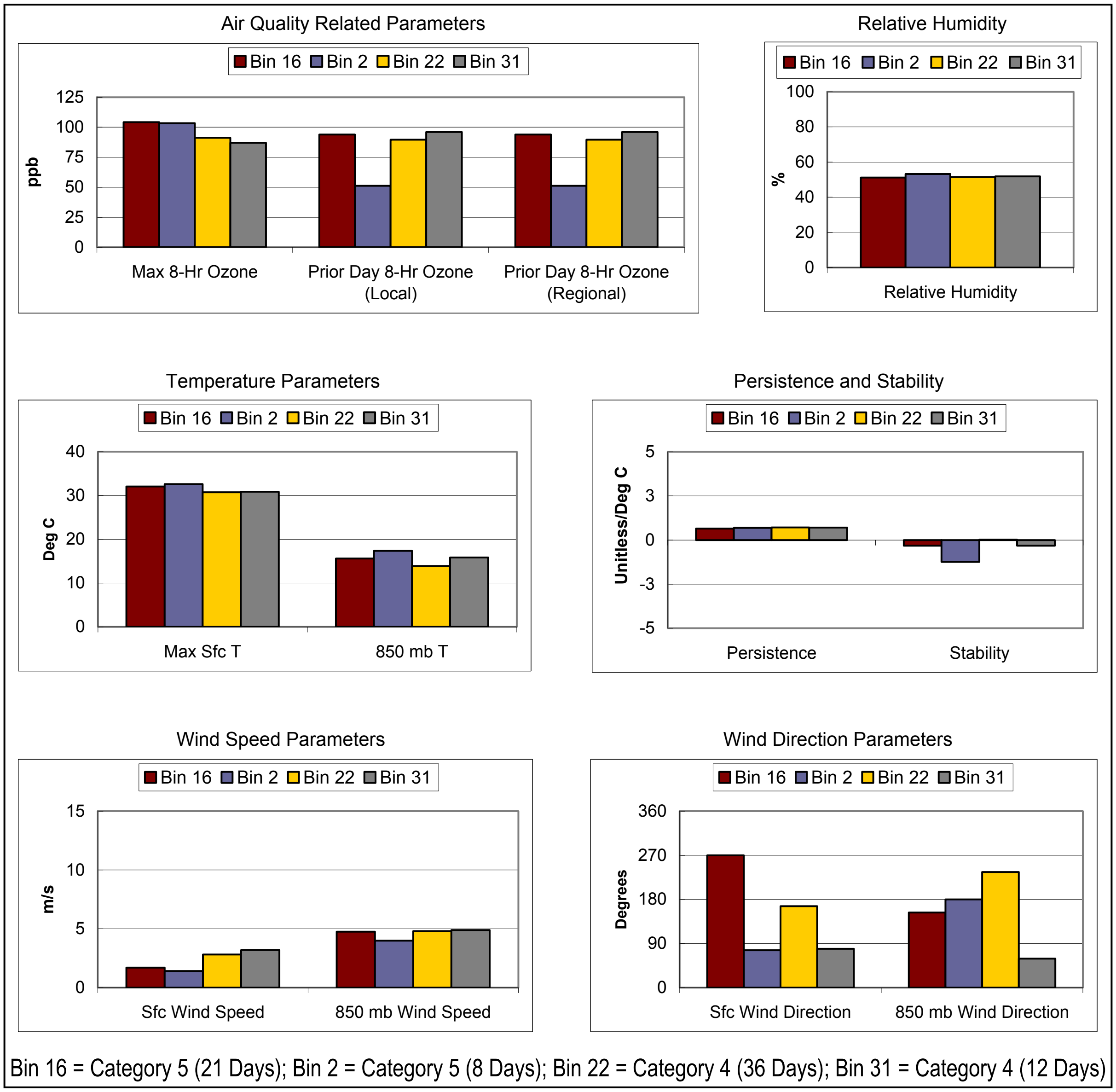
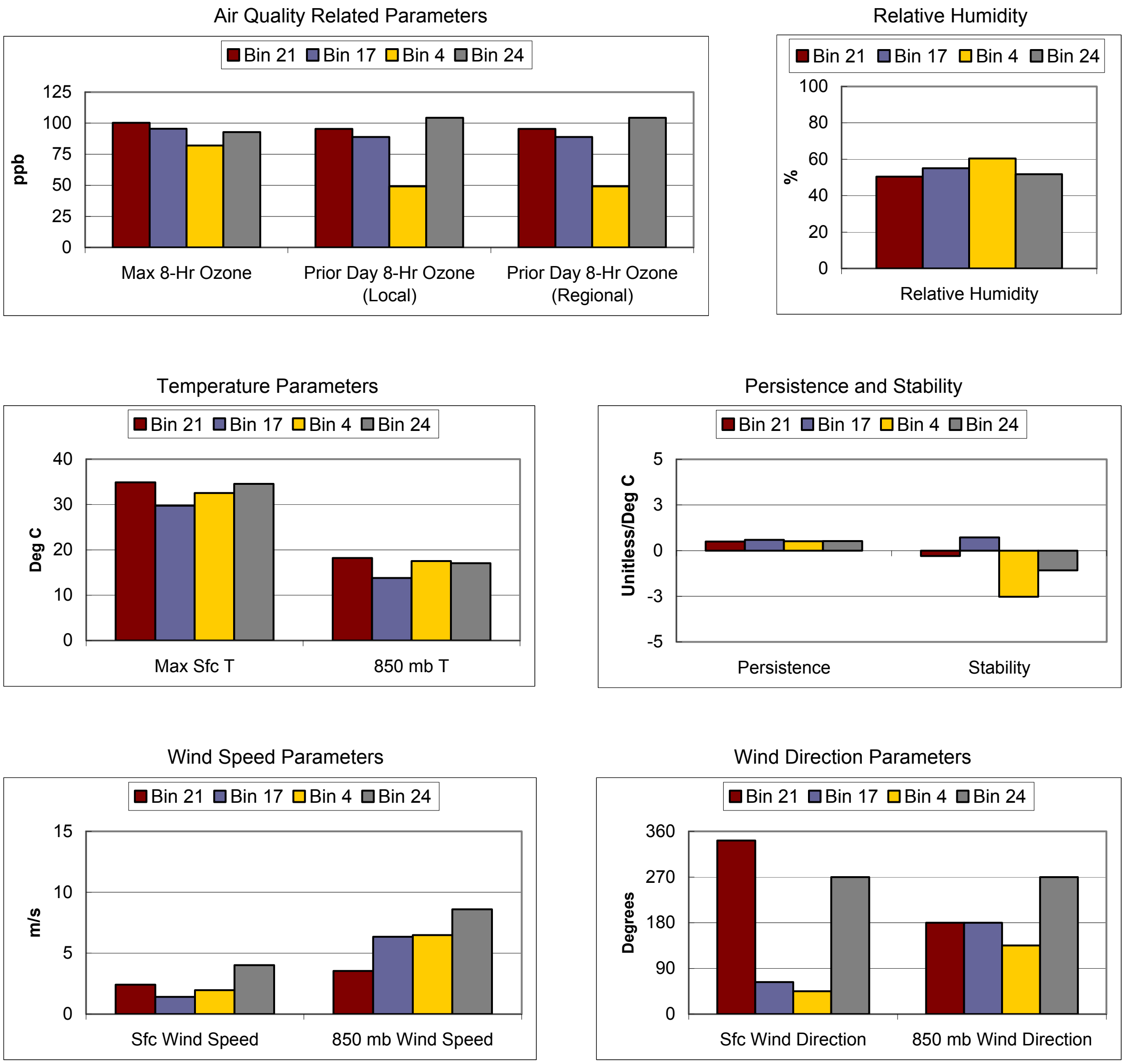
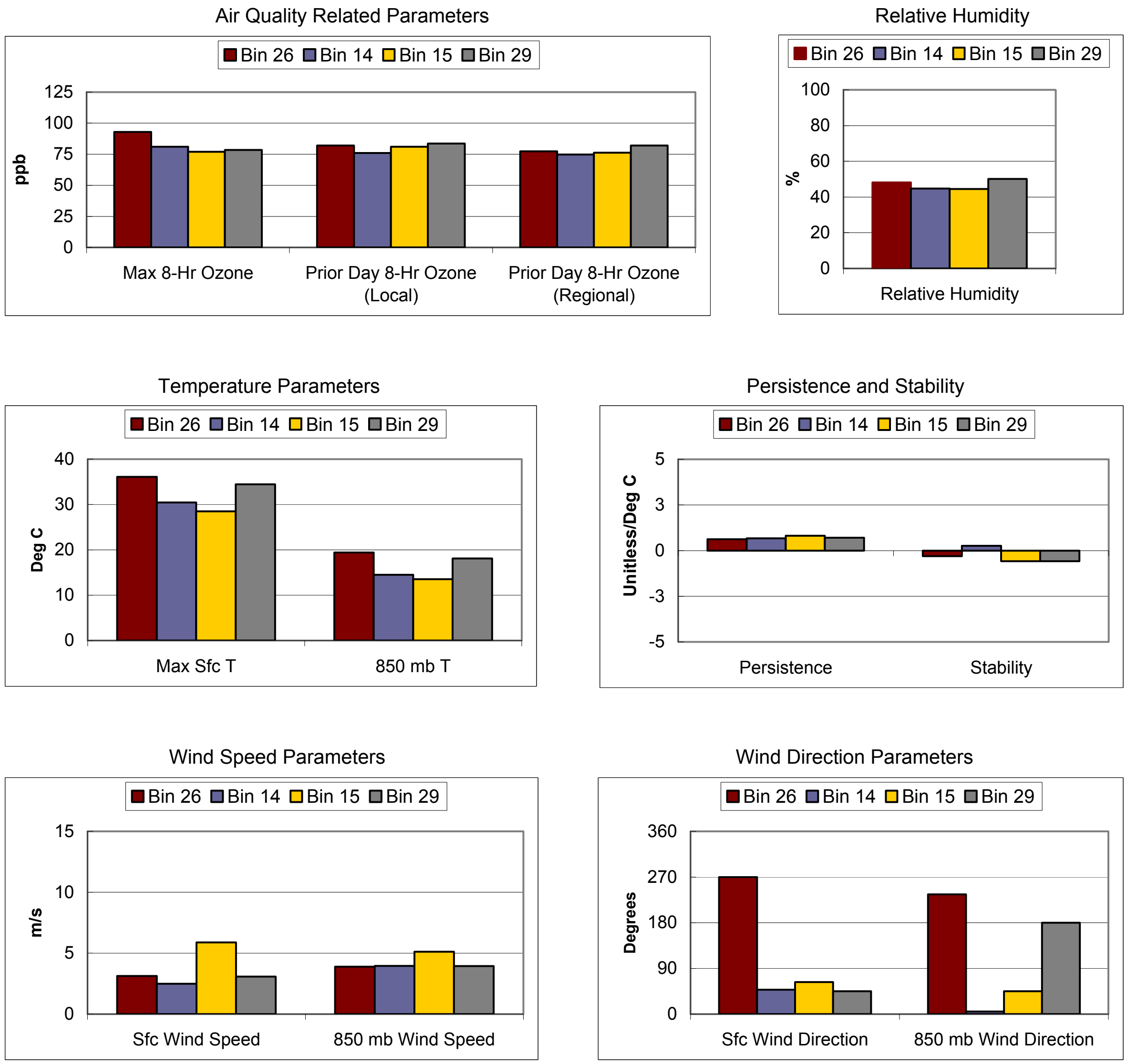


Figure 79b. Average values of selected parameters by bin for the key high ozone bins: Central Houston.



Bin 21 = Category 5 (20 Days); Bin 17 = Category 4 (10 Days); Bin 4 = Category 4 (9 Days); Bin 24 = Category 4 (5 Days)

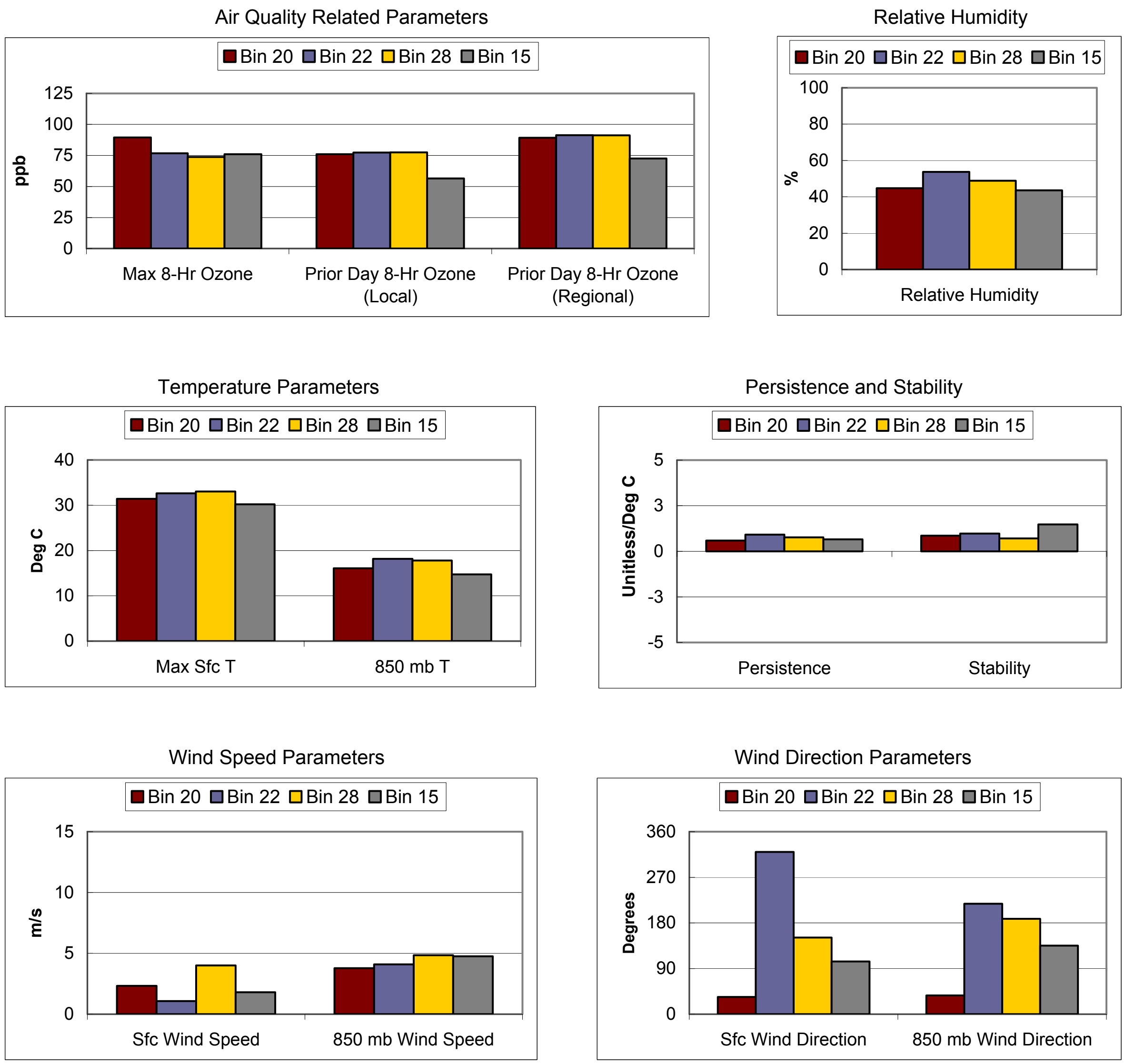
Figure 79c. Average values of selected parameters by bin for the key high zone bins: Southeast Houston/Galveston.



Bin 26 = Category 4 (25 Days); Bin 14 = Category 3 (52 Days); Bin 15 = Category 3 (10 Days);

Bin 29 = Category 3 (10 Days)

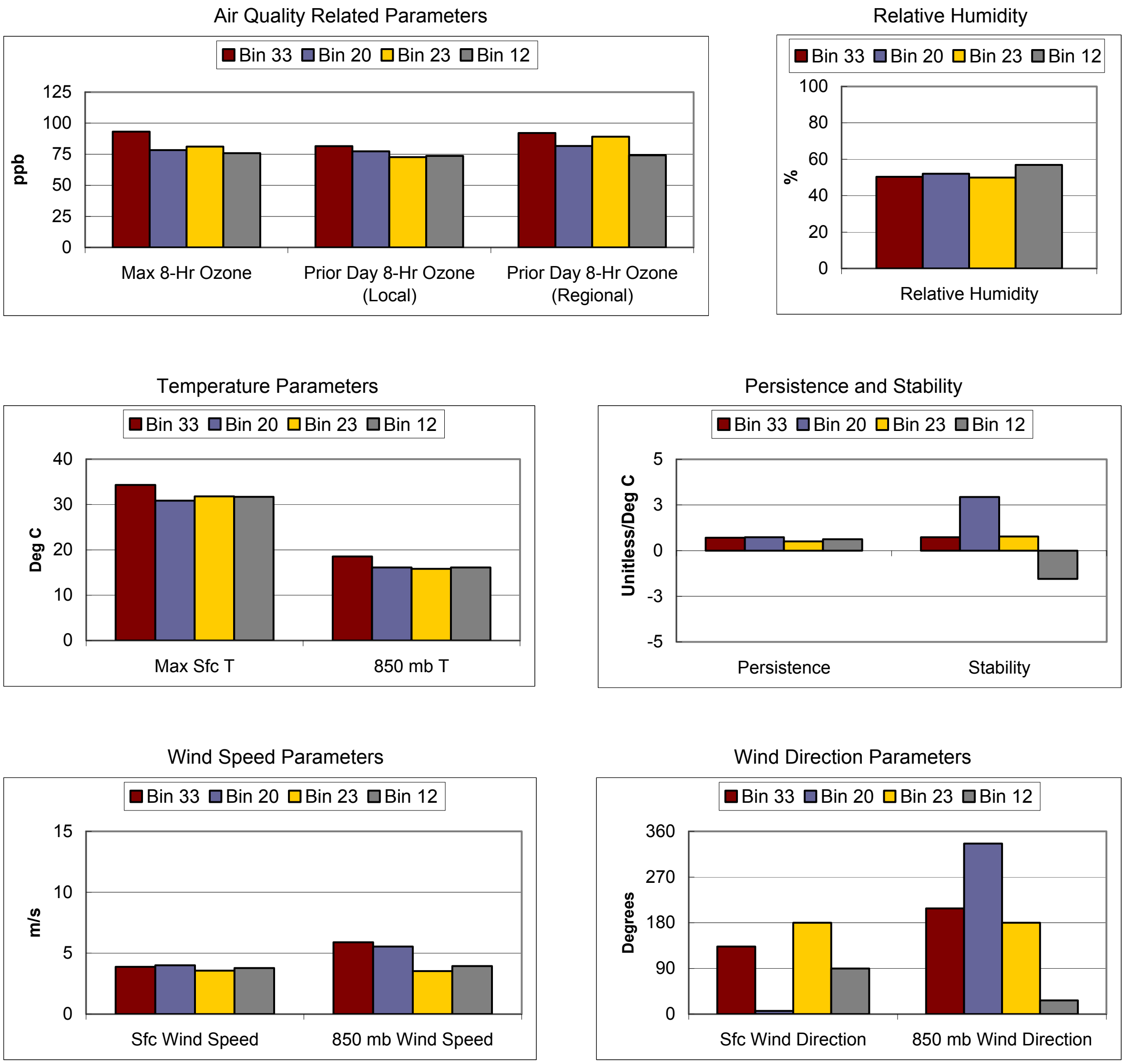
Figure 79d. Average values of selected parameters by bin for the key high ozone bins: Beaumont/Port Arthur.



Bin 20 = Category 4 (11 Days); Bin 22 = Category 4 (8 Days); Bin 28 = Category 3 (18 Days);

Bin 15 = Category 3 (14 Days)

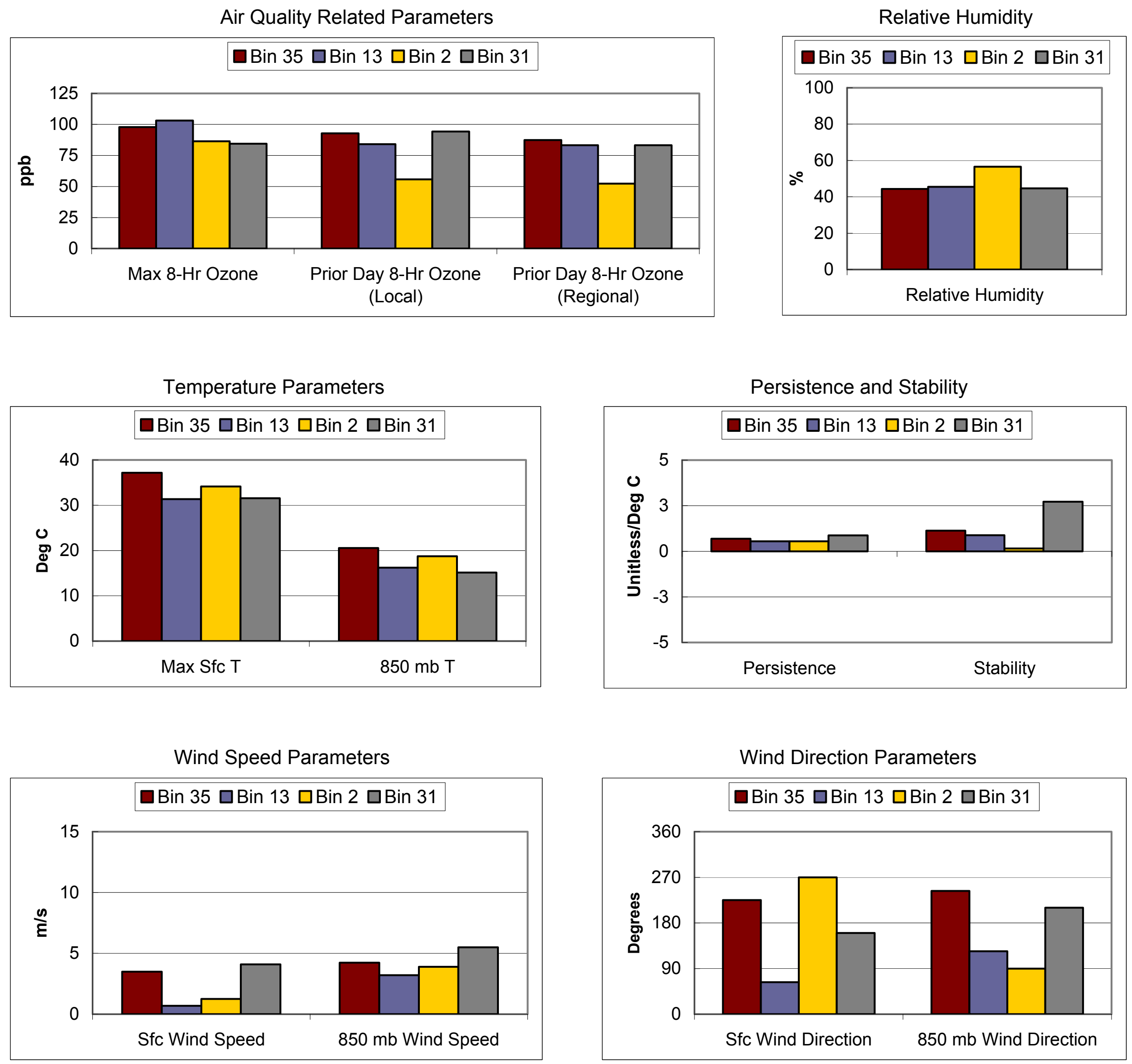
Figure 79e. Average values of selected parameters by bin for the key high ozone bins: Lake Charles.



Bin 33 = Category 4 (8 Days); Bin 20 = Category 3 (23 Days); Bin 23 = Category 3 (17 Days);

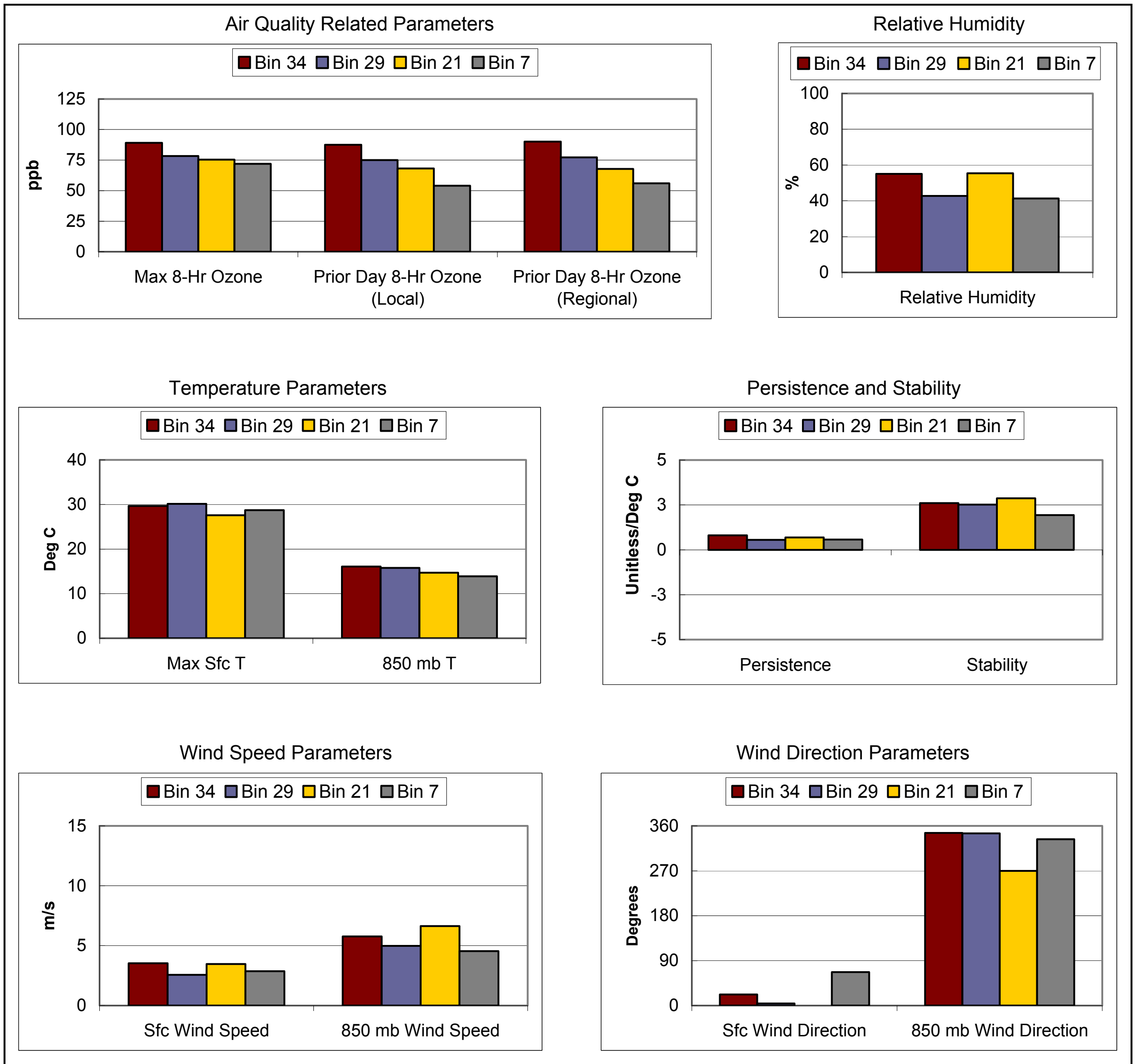
Bin 12 = Category 3 (10 Days)

Figure 79f. Average values of selected parameters by bin for the key high ozone bins: New Orleans.



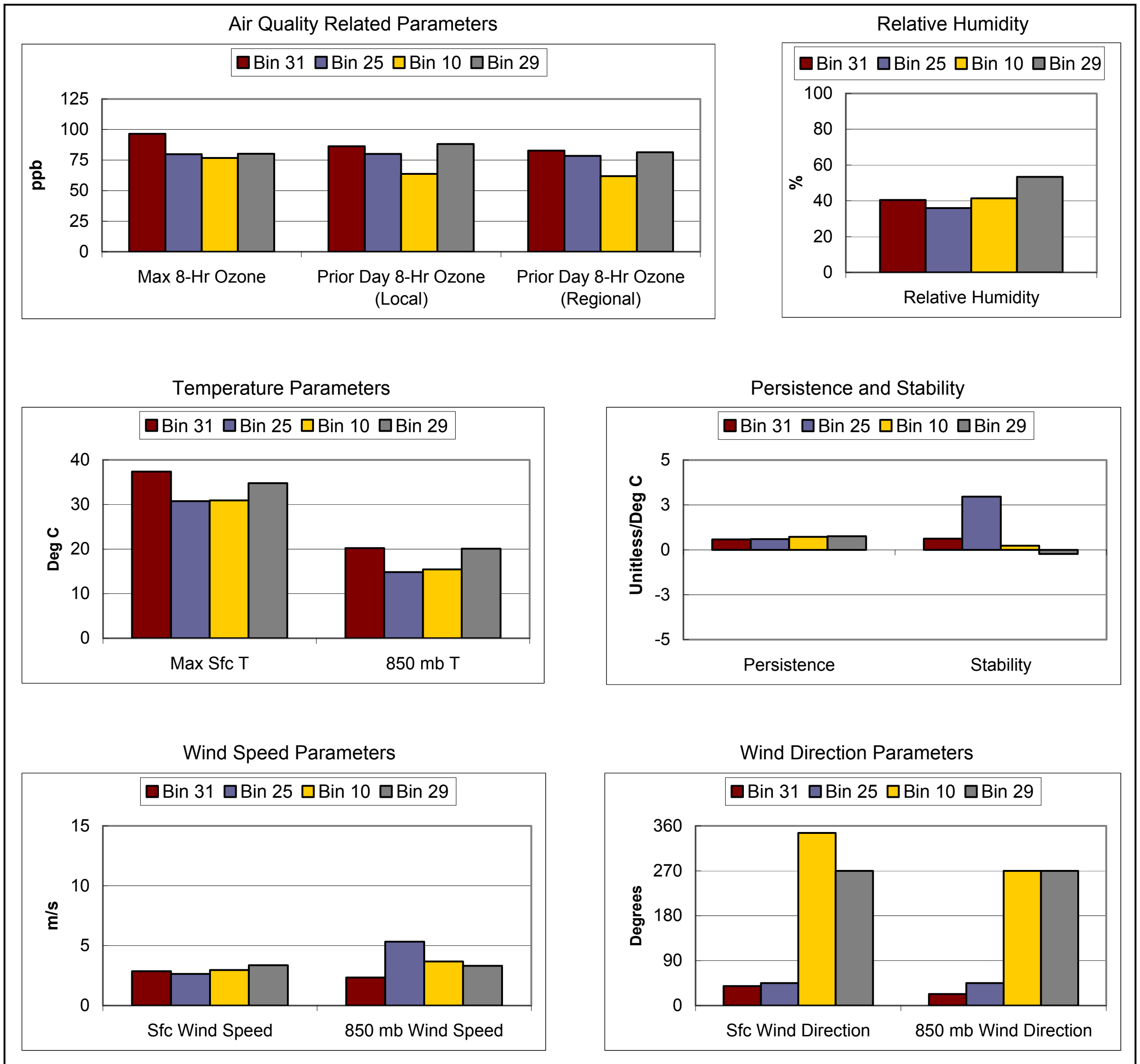
Bin 35 = Category 4 (18 Days); Bin 13 = Category 4 (14 Days); Bin 2 = Category 4 (9 Days); Bin 31 = Category 3 (17 Days)

Figure 79g. Average values of selected parameters by bin for the key high ozone bins: Baton Rouge.



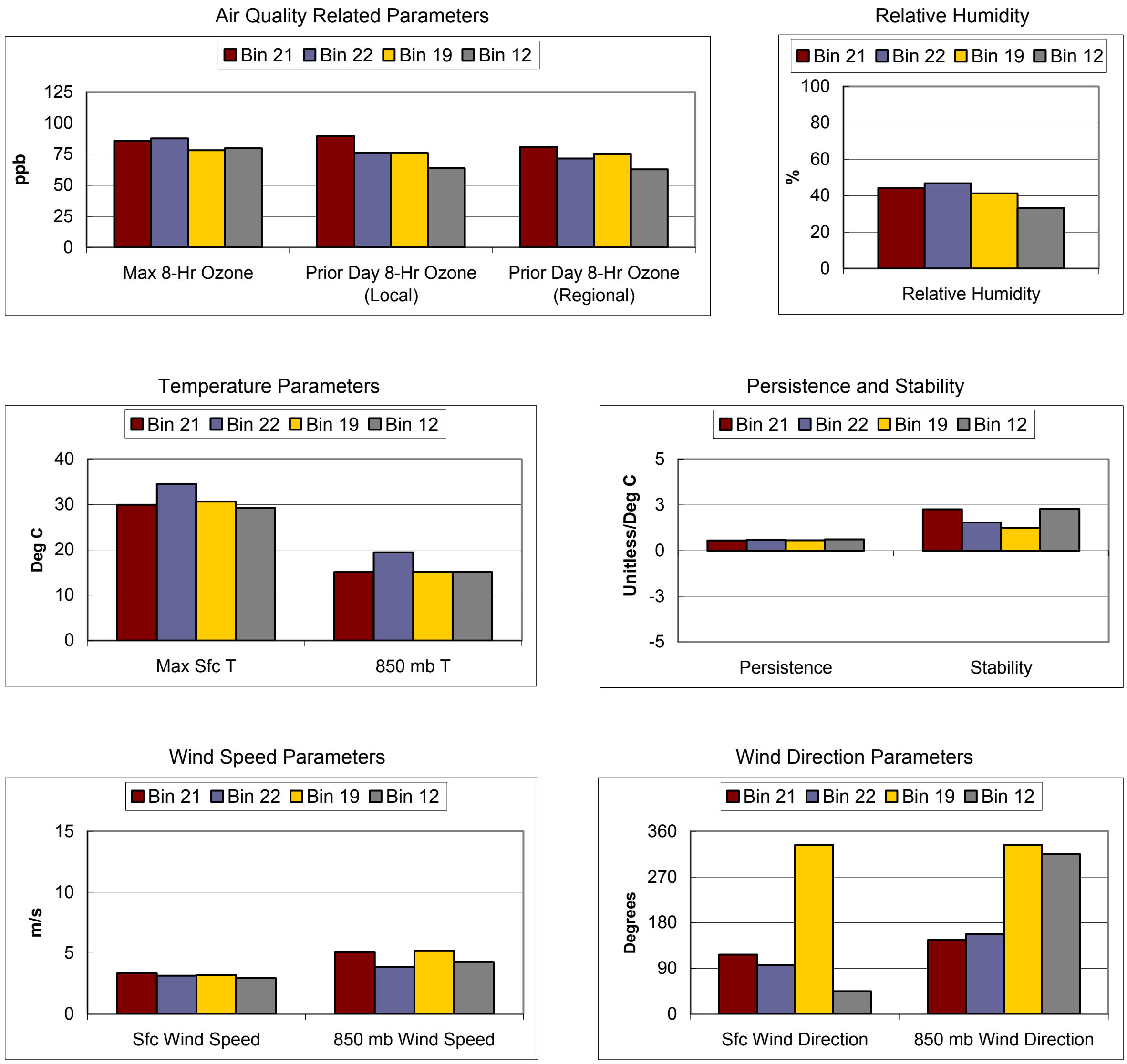
Bin 34 = Category 4 (5 Days); Bin 29 = Category 3 (30 Days); Bin 21 = Category 3 (15 Days); Bin 7 = Category 3 (9 Days)

Figure 79h. Average values of selected parameters by bin for the key high ozone bins: Gulfport.



Bins 31 = Category 4 (9 Days); Bin 25 = Category 3 (29 Days); Bin 10 = Category 3 (22Days); Bin 29 = Category 3 (8 Days)

Figure 79i. Average values of selected parameters by bin for the key high ozone bins: Mobile.



Bins 21 = Category 4 (9 Days); Bin 22 = Category 4 (8 Days); Bin 19 = Category 3 (32 Days);

Bin 12 = Category 3 (12 Days)

Figure 79j. Average values of selected parameters by bin for the key high ozone bins: Pensacola.

While there are many similarities in the conditions that describe the key bins, there are also some important differences (that relate directly to source-receptor relationships and potentially to control strategy effectiveness). For discussion purposes, we examine the results for the Central Houston, New Orleans and Pensacola areas.

For Houston (Figure 79b), two Category 5 and two Category 4 bins are presented. The Category 5 bins (Bins 16 and 2) are comprised of days with slightly higher temperatures, lower surface wind speeds and slightly lower upper air wind speeds than the Category 4 bins (Bins 22 and 31). Comparing the two Category 5 bins, days in Bin 16 are characterized by much higher prior day ozone concentrations (locally and regionally) than days in Bin 2. Days within Bin 2 are slightly warmer and have lower wind speeds (compared to Bin 16). The average wind directions are also quite different. For Bin 16 winds are, on average, westerly near the surface and south-southeasterly aloft. For Bin 2, winds are easterly near the surface and southerly aloft. The key Category 4 bins have many similar characteristics when compared to one another, but again, the wind directions are quite different. For Bin 22 winds are, on average, southerly near the surface and southwesterly aloft. For Bin 31, winds are easterly near the surface and northeasterly aloft. In summary, higher temperature and lower wind speeds distinguish the Category 5 bins. Within each category, there are different set of conditions that lead to high ozone. One of the key distinguishing factors between the high ozone bins in each category is wind direction.

The overall ozone concentrations for New Orleans are lower than for Houston. Figure 79f compares the characteristics of one Category 4 and three Category 3 bins. The Category 4 bin (Bin 33) is distinguished by higher prior day ozone concentrations and higher temperatures than the Category 3 bins. Days within this bin also have, on average, southerly wind components. Bin 23 (one of the Category 3 bins) has many of the same characteristics as Bin 33, but lower 850 mb wind speeds. This suggests that subtle differences in meteorology and prior day ozone can mean the difference between exceedance days and non-exceedance days. It may also suggest that regional transport of ozone (with the higher 850 mb wind speeds) is a factor in determining the ozone level. Bins 20 and 12 are both characterized by northerly wind components, but differ from each other with respect to stability and 850 mb wind speed.

For Pensacola (Figure 79j), two Category 4 and two Category 3 bins are presented. Comparing the two Category 4 bins, days in Bin 21 are characterized by higher prior day ozone concentrations (locally and regionally) and greater stability than days in Bin 22. Days within Bin 22 are warmer and slightly more humid. The average wind directions are similar for the two bins. While the Category 4 bins are characterized by easterly wind components, the Category 3 bins have northerly wind components. Days placed in Bin 19 are characterized by higher prior day ozone concentrations and higher humidity than days in Bin 12. Days in Bin 12 are more stable. In summary, wind directions clearly distinguish the Category 4 bins from the Category 3 bins. Otherwise, the results indicate that different combinations of local parameters can result in high ozone concentrations.

4.3.3. Summary of Findings

The CART analysis, together with the selected air quality and meteorological input parameters, correctly classifies, on average, approximately 83 percent of the ozone season days for 2000-2004 according to daily maximum 8-hour ozone concentration. CART classification accuracy for the ten study areas ranges from approximately 76 to 89 percent. When only meteorological data are used as input to the CART analysis, classification accuracy is one to five percent lower. This indicates that the selected meteorological data are reasonably good indicators of ozone concentration for areas along the Gulf Coast.

Exploratory analyses revealed that 1) using a reduced dataset (2000-2004 compared to 1996-2004) does not significantly reduce the complexity of the CART classification tree, but does improve classification accuracy, 2) classification categories defined based on the new EPA 8-hour ozone are less well suited to classification by CART than those associated with the prior standard (especially for the lower ozone categories), and 3) for some areas buoy data may provide information about the mechanisms leading to onshore ozone.

The CART classification technique can provide information about the relative importance of the various independent parameters in distinguishing days with different ozone air quality characteristics. Parameter importance varies considerably among the different areas, suggesting that the different combinations of prior day air quality and meteorological parameters lead to high ozone in each area. On average, the most important parameters include: prior day maximum 8-hour ozone concentration in the area of interest, prior-day maximum 8-hour ozone concentration in upwind areas, relative humidity, stability, temperature and upper-level wind direction. Of secondary importance are surface wind speed and direction and persistence.

Analysis of the variations in the input parameters across defined ozone concentration categories reveals that there are numerous similarities among the areas and that high ozone days are characterized by low relative humidity, low wind speed, little or no precipitation and stable conditions, compared to lower ozone days. For some parameters variations across the ozone concentration categories are different for the different areas of interest. These parameters include wind direction, prior-day ozone, change in geopotential height, and the recirculation and persistence indexes. For example (as discussed earlier) high ozone days for Central Houston are characterized (on average) by easterly wind components near the surface and northeasterly to easterly winds aloft while high ozone days for Beaumont/Port Arthur are characterized by northwesterly to northerly winds near the surface and northeasterly winds aloft. Also, low persistence (indicating a possible gulf breeze) is characteristic of high ozone days for Galveston but not for Northwest or Central Houston. This suggests that there are certain prevailing conditions that are conducive to ozone formation across the Gulf Coast region, but that, for each area, different combinations of regional meteorology, local meteorology, and carryover and/or transport of ozone comprise an ozone episode.

Several of the areas have predominantly southerly winds or southerly wind components on the high ozone days. Of these, Lake Charles, Gulfport and Pensacola are truly coastal and based on wind direction alone are the most likely to be influenced by offshore emissions. This finding however is mitigated by the fact that most of the emissions sources are located off the coast of Louisiana and Texas and thus not directly offshore from Gulfport and Pensacola.

High ozone days for each area are divided among several CART bins, and this indicates that different combinations of the input parameters can lead to high ozone in each area (i.e., that there are multiple pathways to high ozone). Analysis of the key high ozone bins (bin containing the most number of high ozone days) reveals that one of the key distinguishing factors among the high ozone bins is wind direction. For example (as discussed earlier), the two high ozone bins for Central Houston are characterized, on average, by westerly near the surface and south-southeasterly aloft (Bin 16) versus easterly winds near the surface and southerly winds aloft (Bin 2). Differences in the prior-day regional ozone concentrations among the bins suggests that regional transport can be a factor in determining the ozone level, but that it is not always a dominant factor. Local conditions can also be important and different combinations of local parameters can result in high ozone concentrations. For several of the areas, subtle differences in meteorology and prior-day ozone can mean the difference between exceedance days and non-exceedance days. This finding has implications for air quality forecasting and attainment strategy development.

5.0 CART ANALYSIS FOR PM2.5 FOR SELECTED COASTAL AREAS

The Classification and Regression Tree (CART) analysis technique was also used to examine the relationships between onshore and offshore meteorological conditions and particulate matter (specifically $PM_{2.5}$) in selected coastal urban areas. For $PM_{2.5}$, CART was applied for Houston, Galveston, Beaumont/Port Arthur, Lake Charles, Baton Rouge and New Orleans.

The objective of this analysis was to explore the relationships between offshore meteorological conditions, onshore meteorological conditions and $PM_{2.5}$ concentrations in each of the areas of interest. As for the ozone analysis, the role of wind direction (and specifically onshore-directed flow) in determining high $PM_{2.5}$ regimes is of particular interest. All of the data presented in this section are included in the GMAQDB.

5.1. CART Application Procedures

For $PM_{2.5}$, CART was applied for the period 2000-2004. Details of the CART application for $PM_{2.5}$ are presented in this section.

5.1.1. Identification of CART Input Parameters

The input parameters include available meteorological and air quality parameters that are expected to influence $PM_{2.5}$ along the Gulf Coast. The starting point for the list of input parameters was the CART analysis conducted for VISTAS (Douglas et al., 2006), which focused on $PM_{2.5}$ and visibility. The meteorological parameters are designed to reflect the 24-hour averaging period used for $PM_{2.5}$ measurements and are therefore different, in some respects, from the input parameters used for the ozone analysis. Buoy data were used for sensitivity testing only. Additional input parameters for the CART $PM_{2.5}$ application were tested based on data availability, and input from MMS staff and SRG members.

Surface Meteorological Parameters

Surface meteorological parameters were used to characterize the local meteorological conditions. The surface meteorological inputs for CART are listed below.

- **Temperature**
  - Daily maximum temperature (ºC)
  - Daily minimum temperature (ºC)
- **Relative Humidity**
  - Daily average relative humidity (%)
- **Wind**
  - 24-hour average vector wind direction bin; value of 1 through 5, indicating the wind direction corresponding to the 24-hour vector average wind direction. Bin definitions (in degrees) are: [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively.
  - 24-hour average scalar wind speed (ms^{-1})

- Persistence index (24-hour average vector wind speed/24-hour average scalar wind speed)

- **Pressure**
  - 24-hour average sea level pressure (mb)
- **Precipitation**
  - 24-hour total precipitation (in)

Upper-Air Meteorological Parameters

Upper-air meteorological parameters were used to characterize the regional-scale meteorological conditions. The upper-air parameters are as follows:

- **Temperature**

  900 mb

  - 900 mb to surface temperature gradient, defined here as the difference between the temperature at 900 mb and the surface using the morning temperature sounding data (ºC)

  850 mb

  - Upper-air 850 mb temperature corresponding to the morning sounding on the current day (ºC)
  - Upper-air 850 mb temperature corresponding to the evening sounding on the current day (ºC)

- **Wind**

  700 mb

  The following two upper-air wind variables were computed using data from the prior day's evening sounding for 700 mb:

  - Wind speed (ms^{-1})
  - Wind direction bin; value of 1 through 5, indicating the wind direction: (in degrees) [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively

  850 mb

  The following two upper-air wind variables were computed using data from the prior day's evening sounding, and the current day's morning and evening soundings for 850 mb:

  - Wind speed (ms^{-1})
  - Wind direction bin; value of 1 through 5, indicating the wind direction: (in degrees) [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively

- **Recirculation**

  850 mb

  - Recirculation index (value of 0 or 1) that is based on the difference between the wind direction yesterday and today and/or scalar wind speed.

- **Geopotential Height**

  700 mb

  - Difference in the daily average geopotential height above sea level of the 700 mb surface (m) using height for the current day minus height for the prior day.

- **Clouds**

  700/850 mb

  - Cloud index. Value based on relative humidity at the 850 mb (rh850) and 700 mb (rh700) levels. Ranges from 1 to 3 and is defined as follows:

    if (rh850 < 80% and rh700 < 65%) then cloud = 1;

    if (rh850 >= 80% and rh700 < 65%) then cloud = 2;

    if (rh850 < 80% and rh700 >= 65%) then cloud = 2;

    if (rh850 >= 80% and rh700 >= 65%) then cloud = 3

Buoy Meteorological Parameters

For selected areas, buoy data were used to characterize the offshore meteorological conditions. These are also surface-based meteorological parameters as listed below.

- **Sea Surface Temperature**

  - Daily average sea-surface temperature (ºC)

- **Wind**

  - 24-hour average vector wind direction bin; value of 1 through 5, indicating the wind direction as defined above
  - 24-hour average scalar wind speed (ms^{-1})
  - Persistence index (24-hour average vector wind speed/24-hour average scalar wind speed).

Air Quality Parameters

In addition to the meteorological input parameters, $PM_{2.5}$ concentrations for prior days as well as for the region were also used in the CART analysis.

- **PM2.5**

  - *Classification parameter for the application of CART for $PM_{2.5}$.* Assigned a value of 1 through 4, such that each value corresponds to a different range of 24-hour average $PM_{2.5}$ concentration. The concentration ranges are: less than

15 μgm^{-3}, 15 to 25 μgm^{-3}, 25 to 35 μgm^{-3} and greater than or equal 35 μgm^{-3}. All of the $PM_{2.5}$ data used for this analysis are Federal Reference Method (FRM) data.

- **Regional Ozone Indicator Variables**
  - Prior-day 24-hour average $PM_{2.5}$ ozone concentration for one or more nearby and thus potentially upwind sites (μgm^{-3}). The specific sites and number of potential upwind sites is different for each CART region.

The input parameter lists were refined several times during the course of the CART application. The refinements were primarily guided by the CART results and were applied consistently for all of the areas of interest.

5.1.2. Quality Assurance Steps

Following each application, the results were assessed using statistical measures of the goodness of the classification, and then checked for physical reasonableness. The procedures are the same as those used for the ozone analysis (refer to Section 4.2.2).

5.1.3. Assessment of CART Results

The CART results were displayed in a variety of ways, both as part of the quality assurance and to aid the analysis of the results.

CART trees with approximately 30-35 bins were selected to optimize classification accuracy and physical reasonableness. The majority of the high $PM_{2.5}$ days, however, were grouped into one to four key bins.

Tabular summaries of classification accuracy were prepared and classification accuracy by category and overall were calculated. Overall classification accuracy ranged from approximately 73 to 89 percent.

The relative importance of the various input parameters to the CART classification tree was examined and plotted for each site.

5.2. CART RESULTS

Presentation of the CART analysis results for $PM_{2.5}$ is divided into three parts: exploratory analyses, pathways to high $PM_{2.5}$ and summary of findings. Throughout the discussion of the results, the term "classification accuracy" refers to the percentage of days that were assigned to the correct classes (that is, correctly placed into bins with ranges corresponding to their observed values).

5.2.1. Exploratory Analyses

The application of CART for each site included several exploratory analyses that were designed to test and refine the methodologies and input parameters. Specifically, sensitivity tests examined: 1) alternative category definitions (fixed versus percentile based categories), 2) additional meteorological input parameters including buoy data, and 3) use of only meteorological input parameters (versus both meteorological and air quality parameters).

Key findings from the sensitivity testing include:

- The initial CART application for $PM_{2.5}$ used percentile-based category definitions. To align the results with the current EPA $PM_{2.5}$ standards, the categories were redefined as follows: <15, 15-25, 25-35, and ≥35 μgm^{-3}. The breakpoints follow the EPA recommended classification ranges for $PM_{2.5}$ air quality forecasting (EPA, 2009b) with an additional intermediate break point at 25 μgm^{-3} and are well suited to the CART analyses for these areas and were used in the final CART trees for $PM_{2.5}$.
- Several variations of the prior-day/upwind air quality parameters and several additional meteorological parameters were tested. Specifically, the $PM_{2.5}$ based parameters were revised to account for the temporal resolution of the $PM_{2.5}$ data (not all sites have daily data). Since the wind speed parameter is a 24-hour daily average, the vector wind speed was replaced with scalar wind speed. Contrary to the ozone analyses, buoy data did little to improve the $PM_{2.5}$ analysis for Houston, Beaumont/Port Arthur and Lake Charles CART analyses.
- The meteorological data only CART runs indicate that the selected meteorological data are incomplete indicators of $PM_{2.5}$ concentration. The reduction in classification accuracy compared to the full CART run (which includes both meteorological and prior-day ozone data) is two percent for Lake Charles and five to eight percent for all other areas. Classification accuracy ranges from 67 to 87 percent for the meteorological data only runs and from 73 to 89 percent for the full CART analyses. The reduction in accuracy for the meteorological data only runs is greater for $PM_{2.5}$ than for ozone.

For the final set of CART trees, classification accuracy is provided in Table 31 and (as noted above) ranges from approximately 73 to 89 percent. Our goal for this study was 70 percent classification accuracy for $PM_{2.5}$ and this goal was met for all areas. This goal was selected based on prior applications and diagnostic testing (e.g., Douglas et al., 2006).

Table 31

Summary of CART Classification Accuracy
for All Areas for the MMS Synthesis PM2.5 Applications.

CART Area	Accuracy (%)
Central Houston	73
Southeast Houston/Galveston	81
Beaumont/Port Arthur	83
Lake Charles	89
New Orleans	80
Baton Rouge	77

5.2.2. Pathways to High PM2.5

Information about the relative importance of the various independent parameters in distinguishing days with different $PM_{2.5}$ air quality characteristics as well as the combinations of parameters that lead to high $PM_{2.5}$ is presented in the remainder of this section.

Important Classification Parameters

Parameter importance is calculated by CART based on the number of times each parameter is used, either as a split parameter or as a surrogate parameter, to construct the final classification tree. Split parameters are those that explicitly define the branches of the CART tree, and thus separate the days. Surrogate parameters represent the next best splits, and are used in the case of missing data. Parameter importance is assigned a value ranging from 0 to 100, based on the use of the parameter in defining the CART tree. Specifically, the importance indicates the improvement in classification accuracy that results from using the best split parameter compared to the best surrogate split parameter. The importance values are normalized such that the most important parameter has a value of 100. In this analysis, we assume that the parameters that are most important in determining the structure of the CART tree are also most important in determining $PM_{2.5}$ concentrations.

Parameter importance for each area is displayed in Figure 80. Note that in each plot, the relative importance assigned to the prior-day regional $PM_{2.5}$ concentration is an average of the relative importance of prior-day $PM_{2.5}$ for all neighboring and potential upwind areas used as input to the CART analysis. In addition, the relative importance assigned to several of the surface and upper-air meteorology categories is the maximum over the parameters that comprise the grouping. The category abbreviations are defined as follows and represent one or more of the CART input parameters:

YPM_Local = Yesterday's 24-hour $PM_{2.5}$ concentration for the area of interest

YPM_Reg = Yesterday's $PM_{2.5}$ concentration for neighboring and upwind areas (average for the group)

TMAX = Daily maximum temperature

TMIN = Daily minimum temperature

RH = Relative humidity

WS (Sfc) = Surface wind speed (maximum for the surface wind speed parameter group)

WD (Sfc) = Surface wind direction (maximum for the surface wind speed parameter group)

PERSIST = Persistence or gulf-breeze index

SLP = Sea level pressure

PRECIP = Total rainfall (same as the RAIN parameter used in the ozone analyses)

CLOUD = Cloud cover index

DZ700 = Change in geopotential height at the 700 mb level

DT900 = 900 mb to surface temperature difference

T850 = 850 mb temperature (maximum for the upper-air temperature parameter group)

WS (Upper) = Wind speed aloft (maximum for the upper-air wind speed parameter group)

WD (Upper) = Wind direction aloft (maximum over the upper-air wind speed parameter group)

In this and subsequent plots of parameter importance, red is used for air quality parameters, blue is used for surface meteorological parameters and green is used for upper-air parameters.

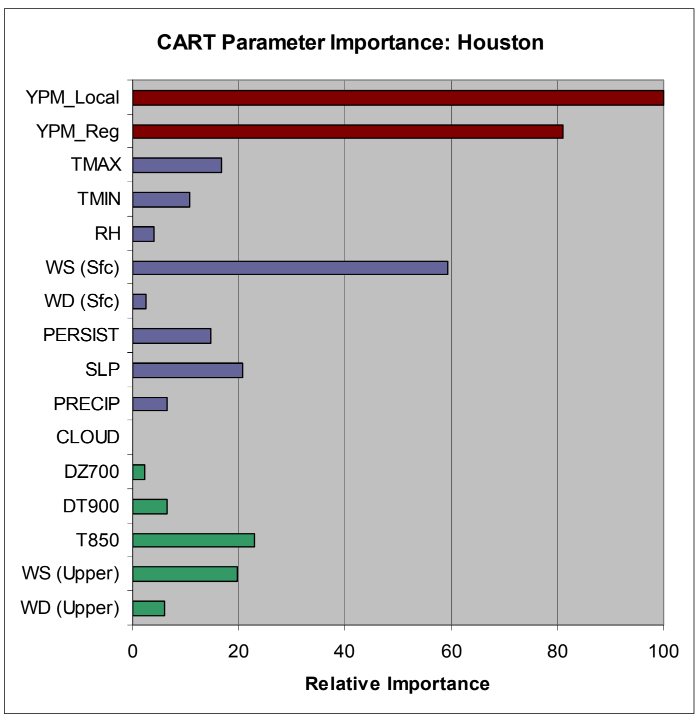


Figure 80a. Average parameter importance for the MMS synthesis $PM_{2.5}$ CART analysis: Houston.

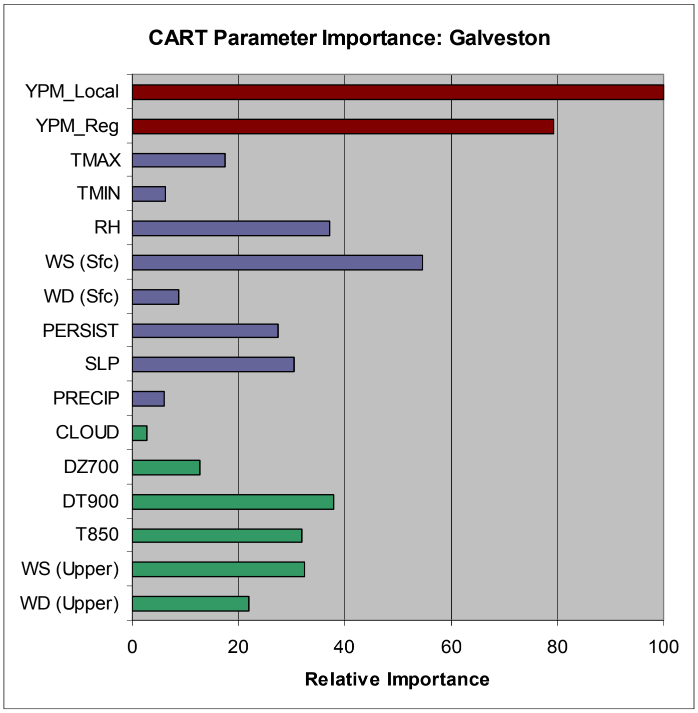


Figure 80b. Average parameter importance for the MMS synthesis $PM_{2.5}$ CART analysis: Southeast Houston/Galveston.

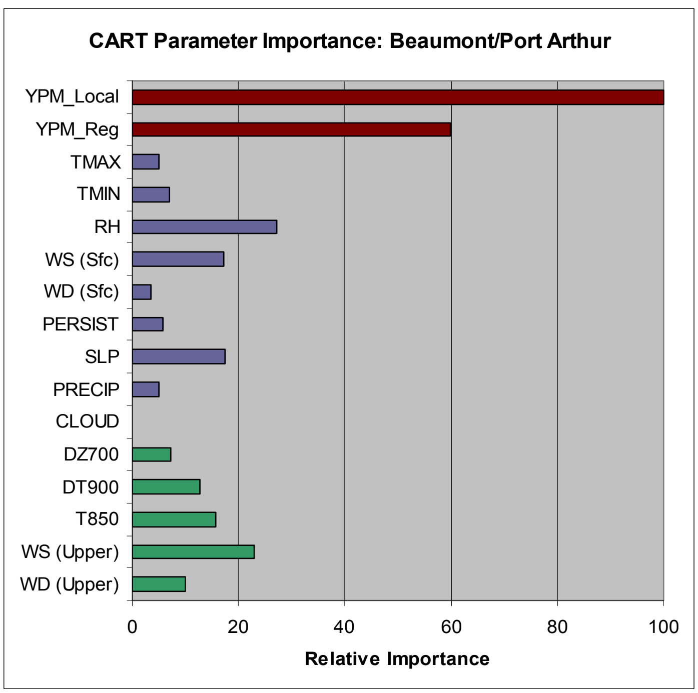


Figure 80c. Average parameter importance for the MMS synthesis $PM_{2.5}$ CART analysis: Beaumont/Port Arthur.

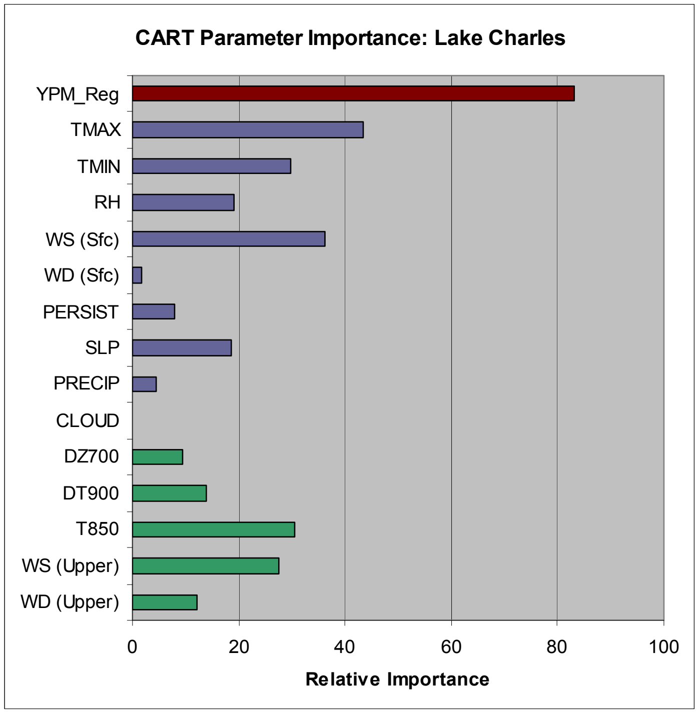


Figure 80d. Average parameter importance for the MMS synthesis $PM_{2.5}$ CART analysis: Lake Charles.

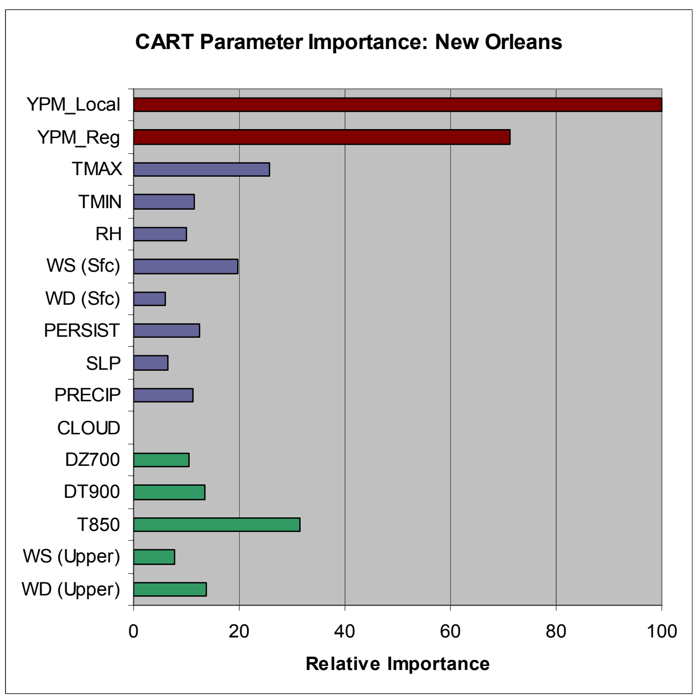


Figure 80e. Average parameter importance for the MMS synthesis $PM_{2.5}$ CART analysis: New Orleans.

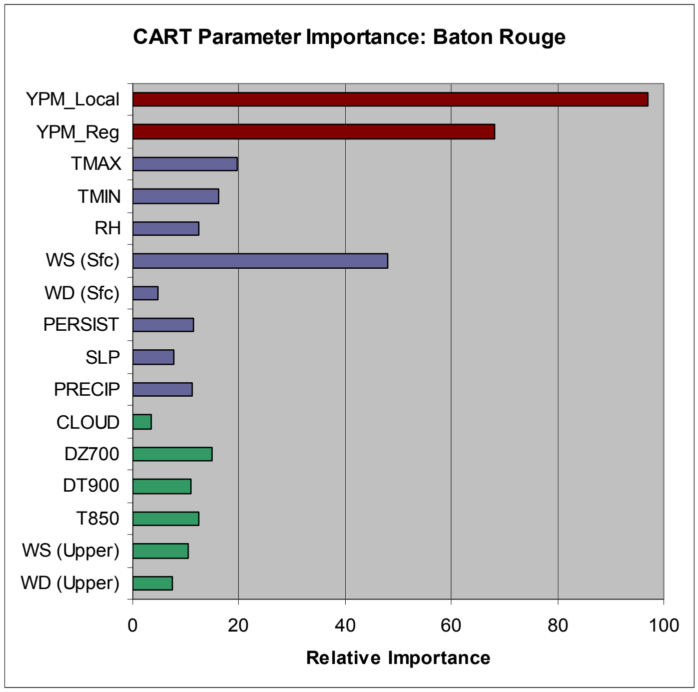


Figure 80f. Average parameter importance for the MMS synthesis $PM_{2.5}$ CART analysis: Baton Rouge

Parameter importance varies among the different areas, suggesting that the different combinations of prior day air quality and meteorological parameters lead to high $PM_{2.5}$ concentrations in each area. For all areas, however, prior day $PM_{2.5}$ concentrations are an important factor in determining the $PM_{2.5}$ category and this suggests that carryover (local parameter) and transport (regional parameters) play an important role in determining $PM_{2.5}$ concentration. Surface wind speed is among the more important of the meteorological parameters for Houston, Galveston, Lake Charles, and Baton Rouge. Upper-air wind speed and 850 mb temperature tend to be the most important of the upper-air meteorological parameters.

Average parameter importance for $PM_{2.5}$ classification for all areas is displayed in Figure 81.

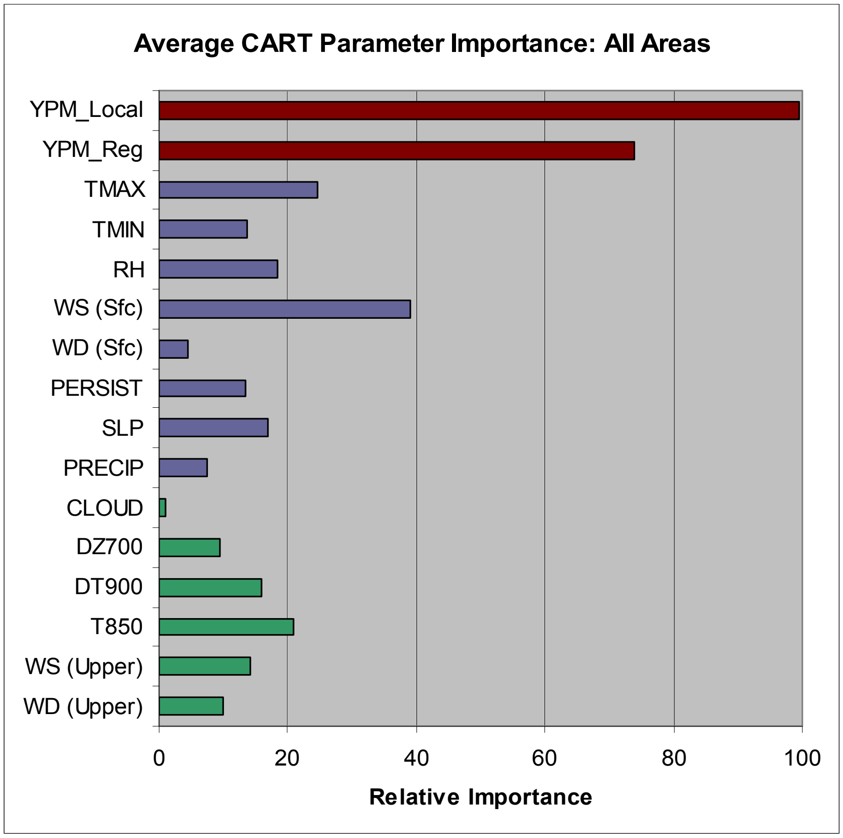


Figure 81. Average parameter importance for the MMS synthesis $PM_{2.5}$ CART analysis: Average over all areas.

On average, the most important parameters include: prior day $PM_{2.5}$ concentration in the area of interest, prior day $PM_{2.5}$ concentration in potential upwind areas, surface wind speed, maximum surface temperature, and 850 mb temperature. Of secondary importance are relative humidity, sea level pressure, stability and upper-air wind speed. These results suggest that while certain meteorological factors may contribute to high $PM_{2.5}$ concentrations, the regional-scale buildup and transport of $PM_{2.5}$ is of primary importance.

Characteristics of High PM2.5 (Categories and Bins)

Understanding the causes of high $PM_{2.5}$ concentrations also requires an understanding of the relationship between the parameters and the air quality metrics, as well as the specific combinations of parameters (conditions) that lead to impaired air quality. In this section, we further explore those relationships using the CART input data and results.

Categorical Comparisons

Tables 14 through 25, presented in Section 2 of this report, examined the variations in $PM_{2.5}$ versus meteorology, on both an annual and quarterly basis. The meteorological parameters listed in these tables are the same as the CART input parameters for $PM_{2.5}$ and the concentration categories are the same as those used for the CART analysis. Referring back to those tables, a brief summary of the characteristics and categorical variations in selected parameters associated with high $PM_{2.5}$ in each area is provided. Emphasis is on those parameters that are most different between low and high $PM_{2.5}$ days.

From the annual summary (Table 14), high $PM_{2.5}$ in the Houston area is (on average) associated with:

- Moderate to high $PM_{2.5}$ on previous day (local and regional),
- High temperatures, and
- Low wind speeds near the surface and aloft.

The quarterly summaries (Table 20) show that these and other conditions vary by quarter. High $PM_{2.5}$ days are distributed among the second, third and fourth quarters. High $PM_{2.5}$ on the prior day is less pronounced during the second quarter, compared to the other two quarters. High $PM_{2.5}$ days during the third quarter are characterized by low wind speeds and easterly to southeasterly wind directions, while high $PM_{2.5}$ days during the fourth quarter are characterized by very low wind speeds and northerly wind directions.

From the annual summary for Southeast Houston/Galveston (Table 15), high $PM_{2.5}$ is (on average) associated with:

- Moderate to high $PM_{2.5}$ on previous day (local and potential upwind areas),
- High temperatures,
- Low(er) relative humidity,
- Low wind speeds near the surface and moderate wind speeds aloft,
- Southeasterly winds near the surface and northeasterly winds aloft, and
- Stable conditions.

The quarterly summaries (Table 21) show that these and other conditions vary by quarter. High $PM_{2.5}$ days are distributed among the second, third and fourth quarters. As for central Houston, high $PM_{2.5}$ on the prior day is less pronounced during the second quarter, compared to the other two quarters. Wind direction variations among the categories also vary by quarter. High $PM_{2.5}$ days during the second quarter are characterized by southerly winds. High $PM_{2.5}$ days during the third quarter are characterized by southeasterly winds near the surface and northeasterly winds aloft (as in the annual average). High $PM_{2.5}$ days during the fourth quarter are characterized by easterly winds near the surface and northerly winds aloft.

From the annual summary for Beaumont/Port Arthur (Table 16), high $PM_{2.5}$ is (on average) associated with:

- Moderate $PM_{2.5}$ on previous day (local and potential upwind areas),
- High temperatures,
- Low wind speeds near the surface,
- Northeasterly wind directions, and

- Stable conditions.

The quarterly summaries (Table 22) show that these and other conditions vary by quarter. High $PM_{2.5}$ days are distributed among the third and fourth quarters. High $PM_{2.5}$ on the prior day is less pronounced during the fourth quarter (the current day $PM_{2.5}$ values are lower as well). Low surface wind speeds and stability are more defining characteristics for the fourth quarter days. This indicates that high $PM_{2.5}$ events during the fourth quarter may be more local in nature than those during the third quarter.

From the annual summary for Lake Charles (Table 17), high $PM_{2.5}$ is (on average) associated with:

- Moderate $PM_{2.5}$ on previous day (local and potentially upwind areas),
- Low(er) relative humidity,
- Very low wind speeds near the surface and low to moderate wind speeds aloft,
- No precipitation, and
- Stable conditions.

The quarterly summaries (Table 23) show that conditions vary by quarter. High $PM_{2.5}$ days are distributed among the first, third and fourth quarters, with some of the highest values occurring during the cooler months.

From the annual summary for New Orleans (Table 18), high $PM_{2.5}$ is (on average) associated with:

- Moderate $PM_{2.5}$ on previous day (local and potential upwind areas),
- High(er) temperatures,
- Low wind speeds near the surface,
- Northeasterly wind directions, and
- Stable conditions.

The quarterly summaries (Table 24) show that these and other conditions vary by quarter. High $PM_{2.5}$ days are distributed among the first, third and fourth quarters. High $PM_{2.5}$ days during the first quarter of the year have (on average) lower temperature and higher relative humidity, compared to high $PM_{2.5}$ days in the remaining quarters. Very low surface wind speeds also characterize these winter/early spring high $PM_{2.5}$ days. Wind directions and their variations among the categories vary by quarter.

From the annual summary (Table 19), high $PM_{2.5}$ in the Baton Rouge area is (on average) associated with:

- Moderate $PM_{2.5}$ on previous day (local and potential upwind areas),
- Low wind speeds near the surface and moderate wind speeds aloft.

- Northeasterly winds aloft, and
- Stable conditions.

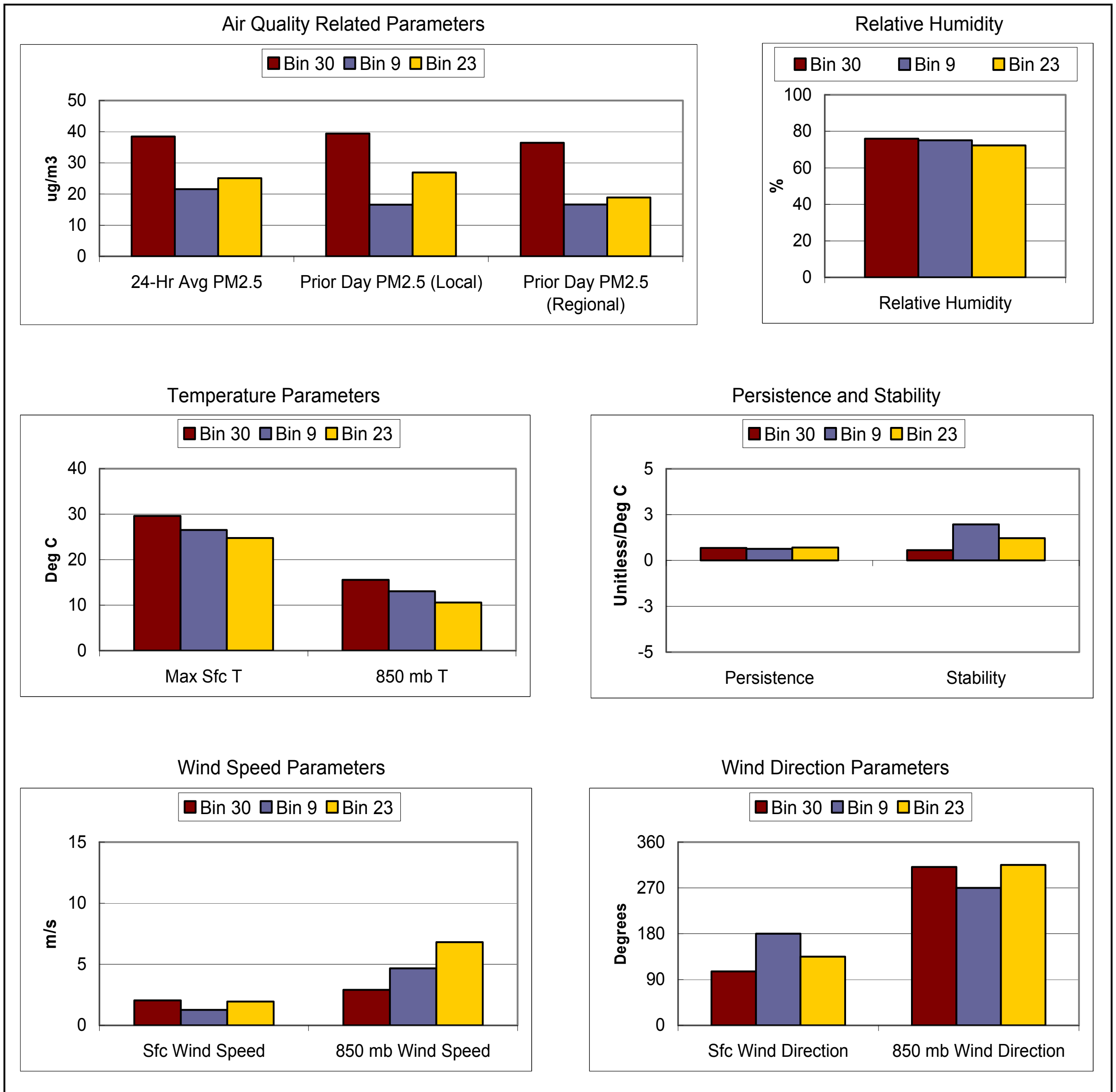
The quarterly summaries (Table 25) show that these and other conditions vary by quarter. High $PM_{2.5}$ days are distributed among the first, third and fourth quarters of the year. High $PM_{2.5}$ days during the first and fourth quarters are characterized by low temperatures, low wind speeds and very stable conditions. High $PM_{2.5}$ days during the third quarter are characterized by high temperatures, low humidity, low wind speeds and stable conditions. Wind directions and their variations among the categories vary by quarter.

The above summary provides only a brief overview how meteorological conditions vary across the $PM_{2.5}$ categories. Clearly there is much more information that can be extracted from these summary tables for each of the areas. On an annual basis, there are some similarities among the areas, especially with regard to the build up of $PM_{2.5}$ concentrations, wind speed, and stability. As in the case of ozone, key differences among the areas tend to be associated with wind direction. The quarterly summaries indicate that different mechanisms lead to high $PM_{2.5}$ concentrations during different times of the year. The summary parameters indicate that the regional build up of $PM_{2.5}$ is an important mechanism during the warmer months and that local factors such as low temperatures, low wind speeds and stability are important during the colder months. For most of the areas, the meteorological conditions that typically occur during April-June are least conducive to $PM_{2.5}$.

Analysis of Key Bins

Each $PM_{2.5}$ category may be represented in the CART tree by more than one bin, allowing for the possibility that different combinations of the independent parameters can be associated with a single value of the classification parameter (i.e., that, as indicated in the previous section, different sets of meteorological conditions can lead to high $PM_{2.5}$).

In this section we further explore the characteristics of the key bins that represent the high $PM_{2.5}$ days for each area. Key bins were defined as those containing at least five days and the greatest number of correctly classified days. Three key high- $PM_{2.5}$ bins corresponding to the highest and second highest $PM_{2.5}$ categories for each area were identified and the characteristics of those bins were examined and compared. Figure 82 displays and compares selected parameters for the key high $PM_{2.5}$ bins for each area. The parameters are grouped as follows: air quality related parameters, relative humidity, temperature parameters, stability and persistence parameters, wind speed parameters and wind direction parameters. The bin category and number of days in each bin is also given. As a reminder, the concentration categories are defined as follows: Category 1 (< 15 μgm^{-3}), Category 2 (15 to 25 μgm^{-3}), Category 3 (25 to 35 μgm^{-3}), and Category 4 (≥ 35 μgm^{-3}).



Bin 30 = Category 4 (13 Days); Bin 9 = Category 3 (21 Days); Bin 23 = Category 3 (20 Days)

Figure 82a. Average values of selected parameters by bin for the key high $PM_{2.5}$ Bins: Houston.

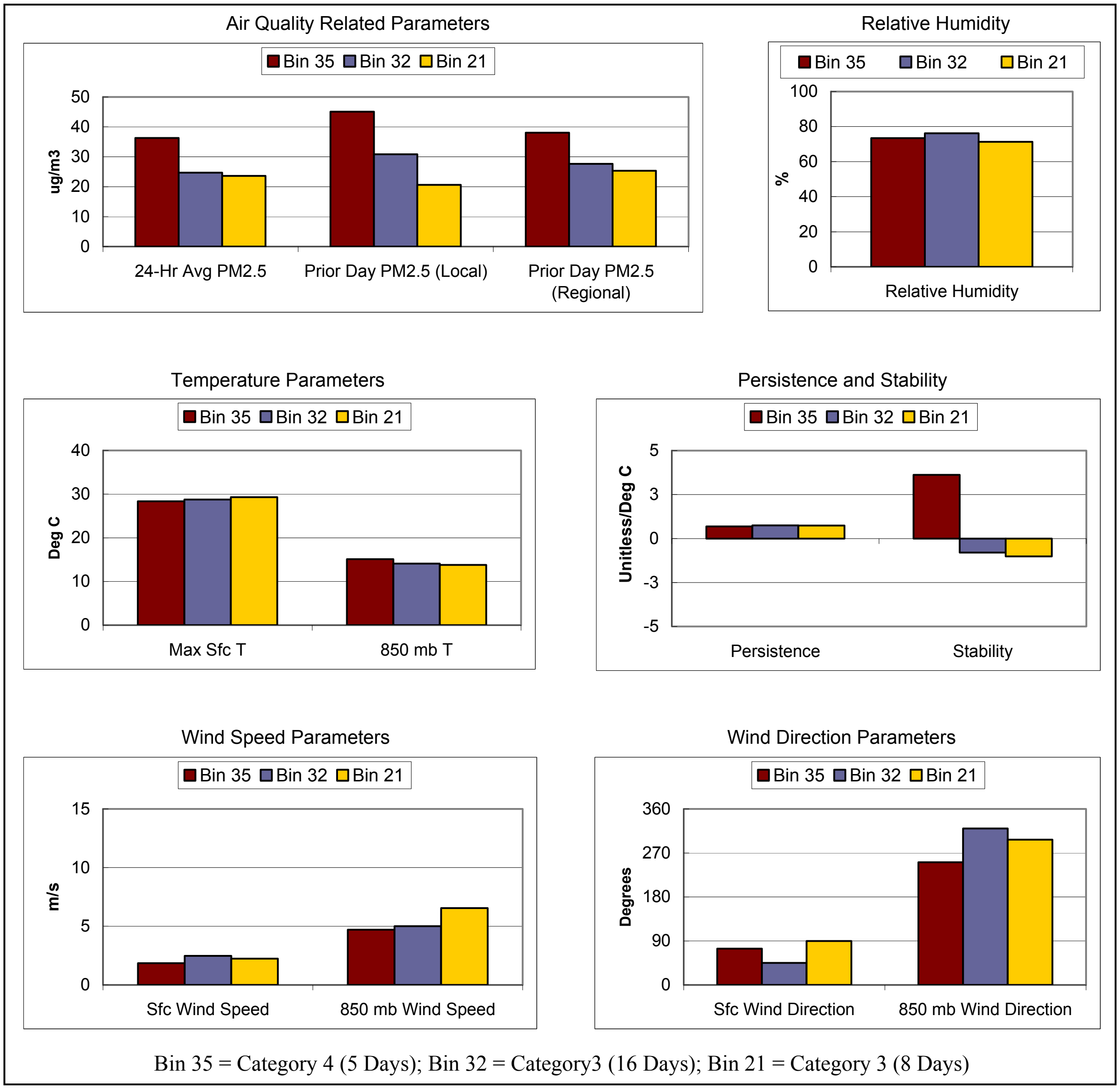


Figure 82b. Average values of selected parameters by bin for the key high $PM_{2.5}$ bins: Southeast Houston/Galveston.

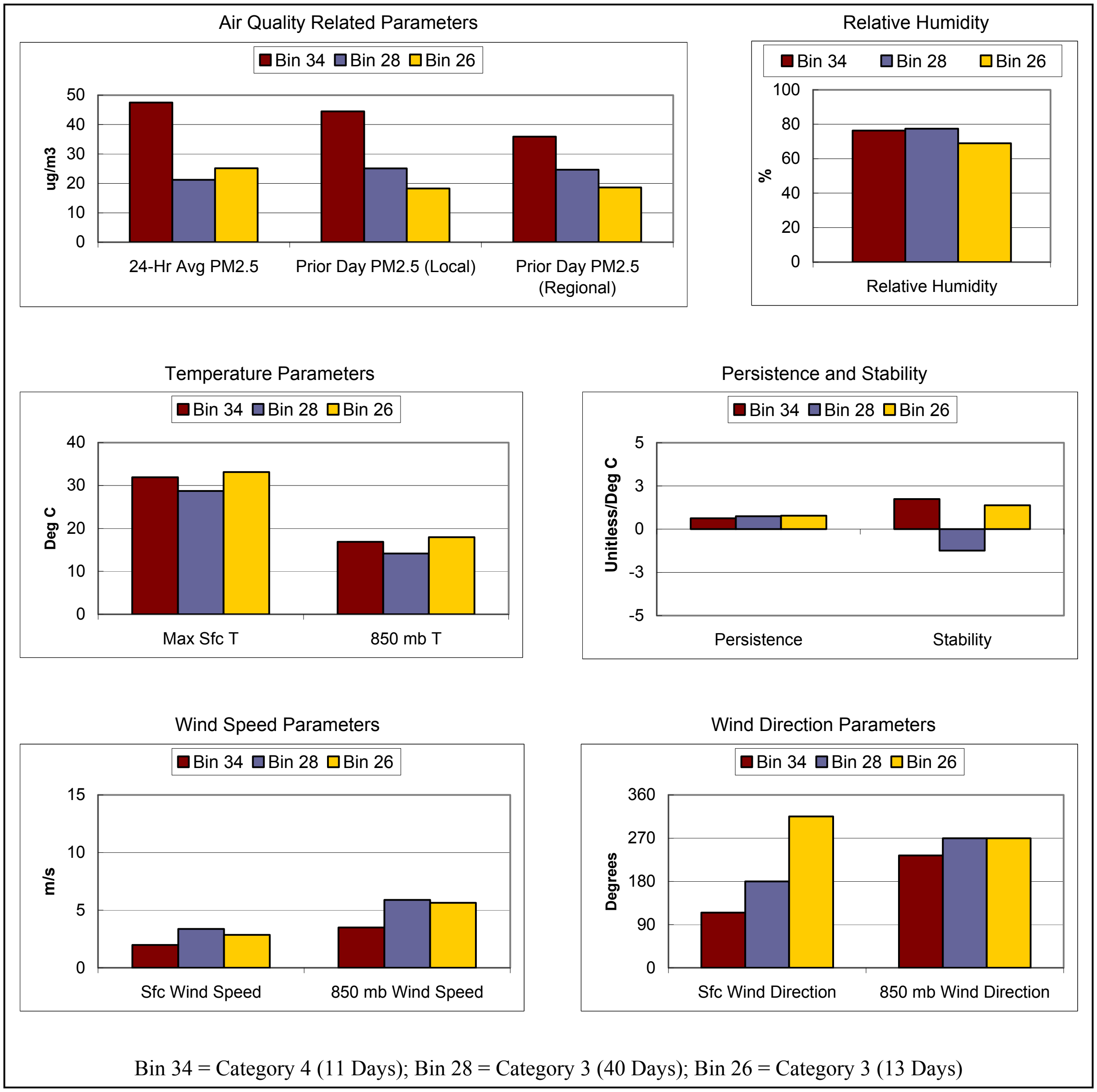


Figure 82c. Average values of selected parameters by bin for the key high $PM_{2.5}$ bins: Beaumont/Port Arthur.

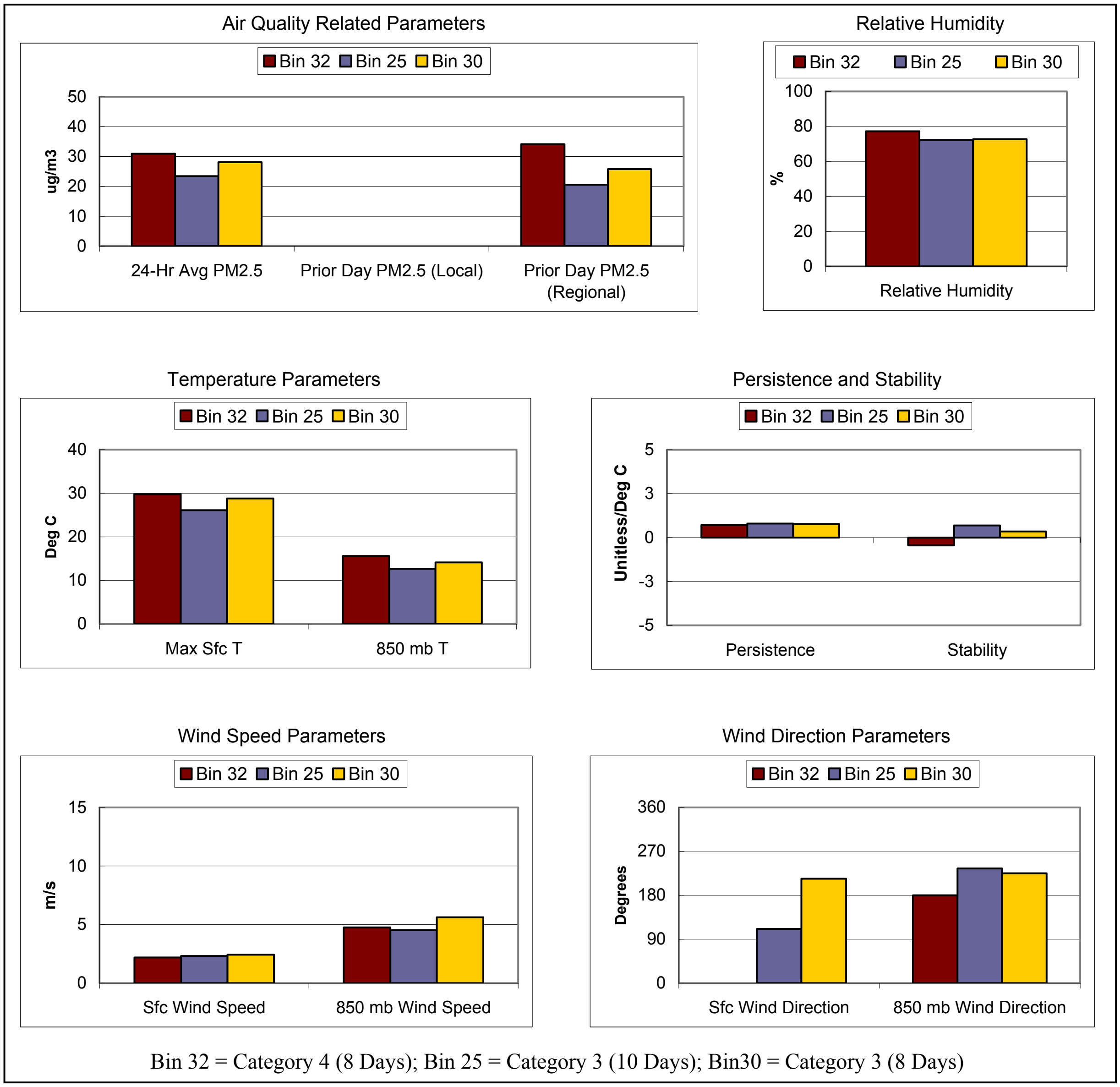


Figure 82d. Average values of selected parameters by bin for the key high $PM_{2.5}$ bins: Lake Charles.

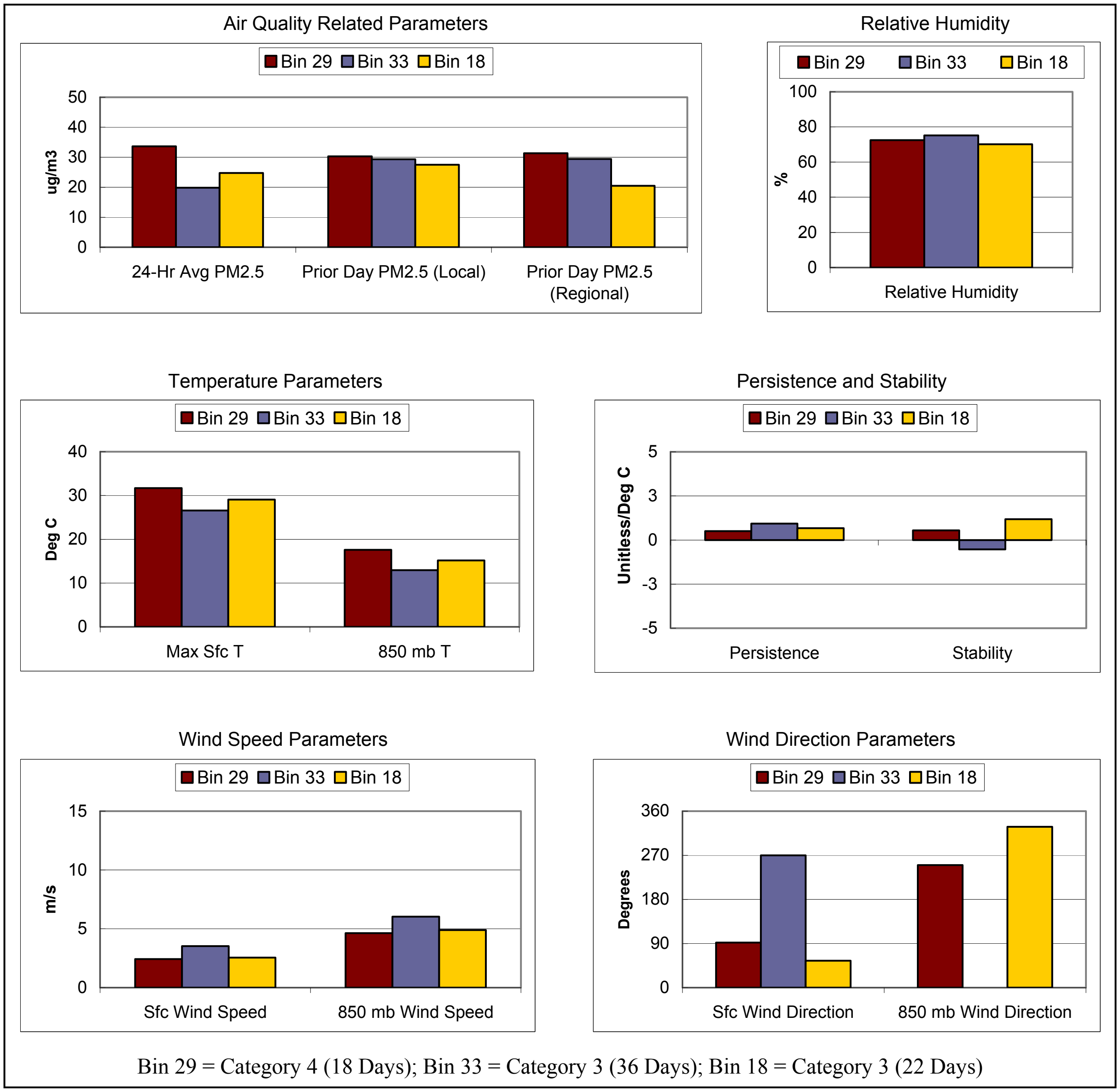
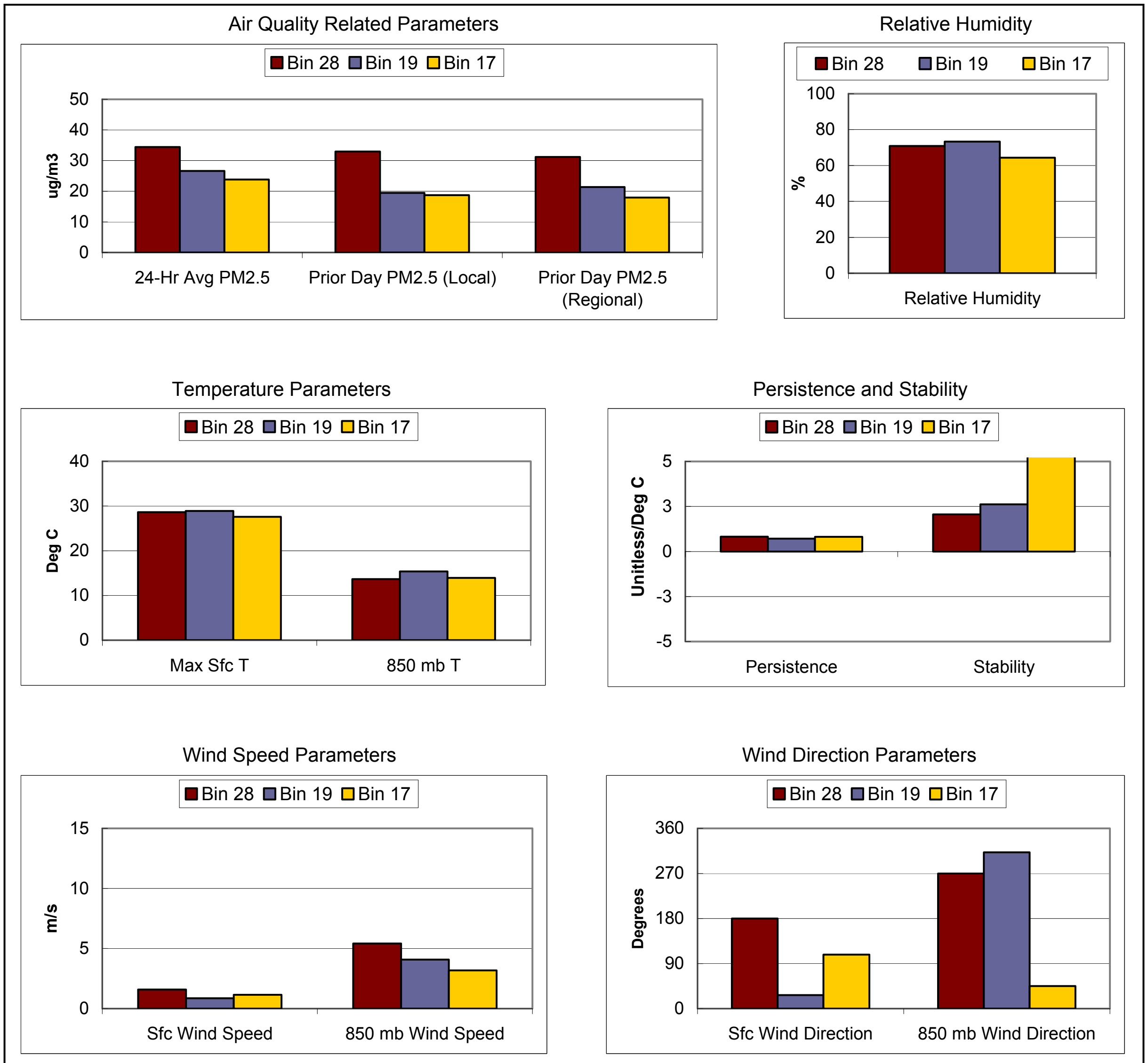


Figure 82e. Average values of selected parameters by bin for the key high $PM_{2.5}$ bins: New Orleans.



Bin 28 = Category 4 (31 Days); Bin 19 = Category 4 (16 Days); Bin 17 = Category 3 (14 Days)

Figure 82f. Average values of selected parameters by bin for the key high $PM_{2.5}$ bins: Baton Rouge.

For each area, there are both similarities and differences in the conditions that describe the key bins. For discussion purposes, we examine the results for the Houston and New Orleans areas.

For Houston, Figure 82a summarizes one Category 4 bin and two Category 3 bins. The concentration differences between the two categories are also reflected in the prior day concentrations. The Category 4 bin is also characterized by slightly higher temperatures and humidity, less stable conditions and lower 850 mb wind speeds than the Category 3 bins. A comparison of the two Category 2 bins shows that Bin 9 has higher temperatures, higher humidity, greater stability, and lower wind speeds. Bin 23 has higher prior day $PM_{2.5}$

concentrations (local and regional). Clearly, different combinations of parameters can result in high $PM_{2.5}$ concentrations.

For New Orleans, Figure 82e summarizes one Category 4 and two Category 3 bins. Bins 29 (Category 4) and 18 (Category 3) have similar characteristics. Higher temperatures and higher prior-day regional $PM_{2.5}$ concentrations distinguish Bin 29. This indicates that the regional component of $PM_{2.5}$ is potentially an important factor in the highest $PM_{2.5}$ days. However, Bin 33 has similar prior-day characteristics to Bin 29, and yet lower current-day $PM_{2.5}$ values. Days within Bin 33, on average, have higher humidity, lower temperatures, greater persistence, less stability, higher wind speeds, westerly (versus easterly) surface winds and northerly (versus westerly) 850 mb winds. This indicates that local and regional meteorological conditions also influence $PM_{2.5}$ levels in this area.

5.2.3. Summary of Findings

The CART analysis for $PM_{2.5}$, together with the selected air quality and meteorological input parameters, correctly classifies, on average, approximately 81 percent of the days for 2000-2004 according to 24-hour average $PM_{2.5}$ concentration. CART classification accuracy for the six study areas ranges from approximately 73 to 89 percent. When only meteorological data are used as input to the CART analysis, classification accuracy is lower by two percent for the Lake Charles area and five to eight percent for all other areas. This indicates that the selected meteorological data are incomplete indicators of $PM_{2.5}$ concentration for areas along the Gulf Coast. In the context of the CART analyses, prior-day air quality data are more important for $PM_{2.5}$ than for ozone.

Exploratory analyses revealed that 1) the defined classification ranges (based on the ranges used by EPA for air quality forecasting) for are well suited to the CART analyses for the selected areas and 2) buoy data do little to improve the $PM_{2.5}$ analyses for Houston, Beaumont/Port Arthur and Lake Charles.

The importance of the various input parameters in distinguishing days with different $PM_{2.5}$ concentrations varies among the different areas, suggesting that the different combinations of prior day air quality and meteorological parameters lead to high $PM_{2.5}$ concentrations in each area. For all areas, prior-day $PM_{2.5}$ concentrations are an important factor in determining the $PM_{2.5}$ category and this suggests that carryover and transport play an important role in determining $PM_{2.5}$ concentration. On average, the most important parameters include: prior-day $PM_{2.5}$ concentration in the area of interest, prior-day $PM_{2.5}$ concentration in upwind areas, surface wind speed, surface temperature and 850 mb temperature. Of secondary importance are relative humidity, sea-level pressure, stability and upper-air wind speed.

Analysis of the variations in the input parameters across defined $PM_{2.5}$ concentration categories reveals that, on an annual basis, high $PM_{2.5}$ concentrations occur in connection with a regional build up of $PM_{2.5}$ concentrations, low wind speed and stability. This is the case for all areas. Wind directions and the variation in wind direction across the $PM_{2.5}$ categories are different for each area. Quarterly summaries indicate that different mechanisms lead to high $PM_{2.5}$ concentrations during different times of the year. Specifically, the regional build up of $PM_{2.5}$ is an important mechanism during the warmer months while local factors such as low temperatures, low wind speeds and stability are important during the colder months. For most of the areas, the meteorological conditions that typically occur during April-June are least conducive to $PM_{2.5}$.

High $PM_{2.5}$ days for each area are divided among several bins. Analysis of the key high $PM_{2.5}$ bins (containing the most number of high $PM_{2.5}$ days) reveals that for all areas there are some differences in the conditions that describe the key bins. As noted earlier, the CART trees suggest that the regional-scale buildup and transport of $PM_{2.5}$ is of primary importance in distinguishing low $PM_{2.5}$ days from high $PM_{2.5}$ days. However, differences in this parameter among the high $PM_{2.5}$ bins indicate that local and regional meteorological conditions also influence $PM_{2.5}$ levels. Different combinations of the input parameters can lead to high $PM_{2.5}$ in each area.

6.0 CART ANALYSIS FOR VISIBILITY FOR THE BRETON NWA AND OTHER CLASS I AREAS

The CART analysis technique was also used to examine the relationships between observed meteorological parameters and visibility in selected coastal Class I areas. For visibility, CART was applied for the Breton, St. Mark's and Chassahowitzka NWAs.

The objective of this analysis was to explore the relationships between offshore meteorological conditions, onshore meteorological conditions and visibility in each of the areas of interest. Again, the role of wind direction (and specifically onshore-directed flow) in determining visibility regimes is of interest. All of the data presented in this section are included in the GMAQDB.

6.1. CART APPLICATION PROCEDURES

For visibility, CART was applied for the period 2000-2004, although missing data for Breton for much of 2000 limited the Breton analysis to December 2000-2004. A shorter period was also used for some exploratory analysis, as discussed in Section 6.2. Details of the CART application for visibility are presented in this section.

6.1.1. Identification of CART Input Parameters

The input parameters include available meteorological and air quality parameters that are expected to influence $PM_{2.5}$ and visibility along the Gulf Coast. The starting point for the list of input parameters was the CART analysis conducted for VISTAS (Douglas et al., 2006), which focused on $PM_{2.5}$ and visibility. The meteorological parameters are designed to reflect the 24-hour averaging period used for $PM_{2.5}$ measurements and visibility calculations. There are some slight differences compared to the parameters used for the $PM_{2.5}$ analysis. Buoy data were only used for sensitivity testing for the Breton area.

Surface Meteorological Parameters

Surface meteorological parameters were used to characterize the local meteorological conditions. The surface meteorological inputs for CART are listed below.

- **Temperature**
  - Daily maximum temperature (ºC)
  - Daily minimum temperature (ºC)
- **Relative Humidity**
  - Daily average relative humidity (%)
- **Wind**
  - 24-hour average vector wind direction bin; value of 1 through 5, indicating the wind direction corresponding to the 24-hour vector average wind direction. Bin definitions (in degrees) are: [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively.
  - 24-hour average vector wind speed (ms^{-1})

- Persistence index (24-hour average vector wind speed/24-hour average scalar wind speed)

- **Pressure**
  - 24-hour average sea level pressure (mb)
- **Precipitation**
  - 24-hour total precipitation (in)
  - Number of hours of measurable precipitation

Upper-Air Meteorological Parameters

Upper-air meteorological parameters are used to characterize the regional-scale meteorological conditions. The upper-air parameters are as follows:

- **Temperature**

  900 mb

  - 900 mb to surface temperature gradient, defined here as the difference between the temperature at 900 mb and the surface using the morning temperature sounding data (ºC)

  850 mb

  - Upper-air 850 mb temperature corresponding to the morning sounding on the current day (ºC)
  - Upper-air 850 mb temperature corresponding to the evening sounding on the current day (ºC)

- **Wind**

  700 mb

  The following two upper-air wind variables were computed using data from the prior day's evening sounding for 700 mb:

  - Wind speed (ms^{-1})
  - Wind direction bin; value of 1 through 5, indicating the wind direction: (in degrees) [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively

  850 mb

  The following two upper-air wind variables were computed using data from yesterday's evening sounding, and the current day's morning and evening soundings for 850 mb:

  - Wind speed (ms^{-1})
  - Wind direction bin; value of 1 through 5, indicating the wind direction: (in degrees) [315, 45), [45, 135), [135, 225), [225, 315), or calm, respectively

- **Recirculation**

  850 mb

  - Recirculation index (value of 0 or 1) that is based on the difference between the wind direction yesterday and today and/or scalar wind speed.

- **Geopotential Height**

  700 mb

  - Difference in the daily average geopotential height above sea level of the 700 mb surface (m) using height for the current day minus height for the prior day.

- **Clouds**

  700/850 mb

  - Cloud index. Value based on relative humidity at the 850 mb (rh850) and 700 mb (rh700) levels. Ranges from 1 to 3 and is defined as follows:

    if (rh850 < 80% and rh700 < 65%) then cloud = 1;

    if (rh850 >= 80% and rh700 < 65%) then cloud = 2;

    if (rh850 < 80% and rh700 >= 65%) then cloud = 2;

    if (rh850 >= 80% and rh700 >= 65%) then cloud = 3

Buoy Meteorological Parameters

For selected areas, buoy data were used to characterize the offshore meteorological conditions. These are also surface-based meteorological parameters as listed below.

- **Sea Surface Temperature**
  - Daily average sea-surface temperature (ºC)
- **Wind**
  - 24-hour average vector wind direction bin; value of 1 through 5, indicating the wind direction as defined above
  - 24-hour average scalar wind speed (ms^{-1})
  - Persistence index (24-hour average vector wind speed/24-hour average scalar wind speed).

Air Quality Parameters

In addition to the meteorological input parameters, $PM_{2.5}$ concentrations for prior days as well as for the region were also used in the CART analysis.

- **Extinction Coefficient**
  - *Classification parameter for the application of CART for visibility.* Assigned a value of 1 through 5, such that each value corresponds to a different range of

extinction coefficient. These correspond to the ranges defined by the 20, 50, 80, and 95 percentile values of calculated extinction coefficient for each site.

- **Regional $PM_{2.5}$ Indicator Variables**
  - Prior-day 24-hour average $PM_{2.5}$ concentration for one or more nearby and thus potentially upwind sites (μgm^{-3}). The specific sites and number of potential upwind sites is different for each CART application.

The input parameter lists were refined during the course of the CART application. The refinements were primarily guided by the CART results and were applied consistently for all of the areas of interest. The list above represents the final list of parameters.

6.1.2. Quality Assurance Steps

Following each application, the results were assessed using statistical measures of the goodness of the classification, and then checked for physical reasonableness. The procedures are the same as those used for the ozone analysis (refer to Section 4.2.2).

6.1.3. Assessment of CART Results

The CART results were displayed in a variety of ways, both as part of the quality assurance and to aid the analysis of the results.

CART trees with approximately 30-35 bins were selected to optimize classification accuracy and physical reasonableness. The majority of the days with high extinction coefficients, however, were grouped into one to four key bins.

Tabular summaries of classification accuracy were prepared and classification accuracy by category and overall were calculated. Overall classification accuracy is 68 percent for St. Mark's, 73 percent for Breton, and 74 percent for Chassahowitzka.

The relative importance of the various input parameters to the CART classification tree was examined and plotted for each site.

6.2. CART RESULTS

Presentation of the CART analysis results for visibility is divided into three parts: exploratory analyses, pathways to poor visibility, and summary of findings. Throughout the discussion of the results, the term "classification accuracy" refers to the percentage of days that were assigned to the correct classes (that is, correctly placed into bins with ranges corresponding to their observed values).

6.2.1. Exploratory Analyses

The application of CART included some exploratory analyses that were designed to examine the sensitivity of the CART results to a range of input parameters. Most of the tests were designed to examine the use of special-studies data to better characterize the relationships between meteorological parameters and visibility. These were focused on the Breton NWA. Specifically, sensitivity tests examined: 1) use of routine buoy data, and 2) use of special studies data for

Breton Island platform (BIP) from the BAMP/ABL data collection studies. The latter tests examined the effects of surface versus upper-air data, wind versus temperature information, and temporal and vertical resolution of the upper-air data on the CART analyses. The tests involving special studies data were limited to the period of data availability for BAMP, which is October 2000-September 2001 (and further limited by missing data at Breton during much of 2000). Thus the analysis period is effectively December 2000-September 2001. The upper-air data have high temporal (hourly) and vertical resolution. A total of 16 tests were completed. For comparison purposes, the CART analyses using routine data only were rerun for the shorter time period. Key findings from the sensitivity testing include:

- The CART classification tree for the limited period is much simpler than that that for the full period (11 bins versus 33 bins). This indicates that fewer combinations of meteorological parameters and extinction coefficient were identified for the shorter period. Classification accuracy, however, is comparable.
- Offshore surface data for BIP improved the ability of CART to correctly identify and classify the days according to visibility, but routine buoy data (Buoys #42007 and #42040) did not have the same result.
- Upper-air data for BIP improved the classification. The improvement was primarily due to the wind data. Increasing the temporal and vertical resolution of the data also improved the classification. For the test that supported the most comprehensive use of the special-studies data, classification accuracy was increased from 75 to 84 percent (compared to the baseline). These results suggest that additional, local upper-air wind data may be needed to fully characterize air quality mechanisms at Breton and along the Gulf Coast.

One additional set of sensitivity simulations, using only meteorological input parameters (rather than a combination of meteorological and air quality parameters) was run for all three areas. The meteorological data only CART runs indicate that the selected meteorological data are not always very good indicators of visibility. The reduction in classification accuracy compared to the full CART run (which includes both meteorological and prior-day ozone data) is two to ten percent. Classification accuracy is about 65 percent for all three of the meteorological data only runs and ranges from 68 to 74 percent for the full CART analyses.

For the final set of CART trees, classification accuracy is provided in Table 32. Our goal for the visibility analysis was 70 percent classification accuracy and this was met or nearly met for all three areas. This goal was selected based on prior applications and diagnostic testing (e.g., Douglas et al., 2006).

Table 32

Summary of CART Classification Accuracy
for All Areas for the MMS Synthesis Visibility Applications.

CART Area	Accuracy (%)
Breton	73
St. Mark's	68
Chassahowitzka	74

The classification for extinction coefficient is lower than for ozone and $PM_{2.5}$. This indicates that the relationships between the input parameters and the classification parameter are less well defined for extinction coefficient. This is possibly due to 1) the complex role of moisture in determining light extinction—affecting both particle formation and the contribution of sulfate and nitrate particle species to light extinction.

6.2.2. Pathways to Poor Visibility

As noted earlier, the CART results can provide information about the relative importance of the various independent parameters in distinguishing days with different air quality characteristics as well as the combinations of parameters that lead to high extinction coefficients (poor visibility). This information has been extracted from the CART analysis results and is discussed in the remainder of this section.

Important Classification Parameters

Certain of the input parameters are used more frequently in the construction of the classification trees and an analysis of the important parameters provides some insight into the factors that influence visibility and how these differ among the monitoring sites.

As noted earlier, parameter importance is calculated by CART based on the number of times each parameter is used to construct the final classification tree. Parameter importance is assigned a value ranging from 0 to 100, based on the use of the parameter in defining the CART tree. The importance values are normalized such that the most important parameter has a value of 100. The values are only meaningful in a relative sense and within the context of the CART analysis. We use parameter importance in this analysis to identify those parameters that are statistically relevant to the classification and assume that these same parameters are also physically relevant. That is, we assume that the parameters that are most important in determining the structure of the CART tree are also most important in determining visibility.

Parameter importance for each area is displayed in Figure 83. Note that the temporal resolution of the IMPROVE data is every three days, so there is no prior day extinction coefficient information for the sites of interest. However, prior day $PM_{2.5}$ concentrations for surrounding sites were used to develop the CART trees. In the relative importance plots, the value assigned to the prior-day regional $PM_{2.5}$ concentration is an average of the relative importance of prior-day $PM_{2.5}$ for all neighboring and potential upwind areas used as input to the CART analysis. In addition, the relative importance assigned to several of the surface and upper-air meteorology categories is the maximum over the parameters that comprise the grouping. The category abbreviations are defined as follows and represent one or more of the CART input parameters:

YFM_Regional = Yesterday's $PM_{2.5}$ concentration for neighboring and upwind areas (average for the group)

TMAX = Daily maximum temperature

TMIN = Daily minimum temperature

RH = Relative humidity

WS (Sfc) = Surface wind speed

WD (Sfc) = Surface wind direction

PERSIST = Persistence or gulf-breeze index

SLP = Sea level pressure

RAIN = Total rainfall

CLOUD = Cloud cover index

DZ700 = Change in geopotential height at the 700 mb level

DT900 = 900 mb to surface temperature difference

T850 = 850 mb temperature (maximum for the upper-air temperature parameter group)

WS (Upper) = Wind speed aloft (maximum for the upper-air wind speed parameter group)

WD (Upper) = Wind direction aloft (maximum over the upper-air wind speed parameter group)

In this and subsequent plots of parameter importance, red is used for air quality parameters, blue is used for surface meteorological parameters, and green is used for upper-air parameters.

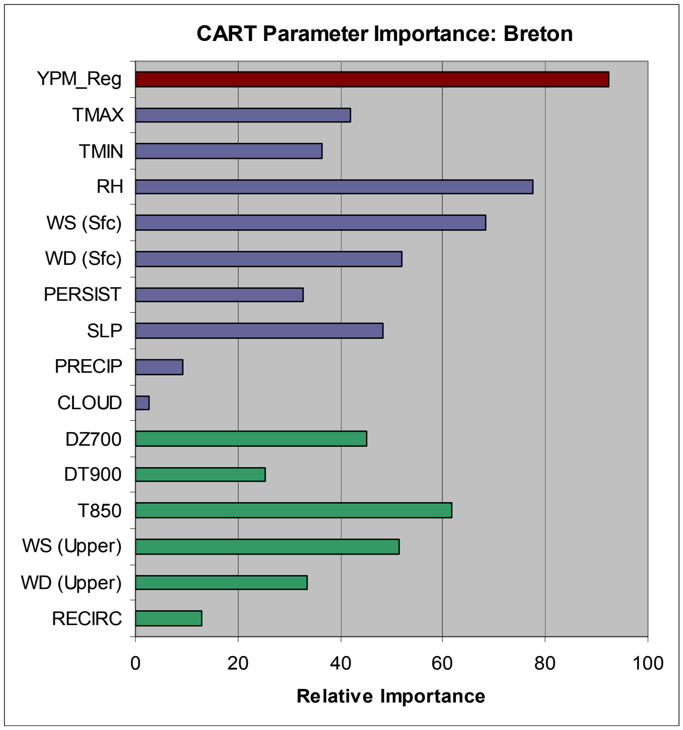


Figure 83a. Average parameter importance for the MMS synthesis visibility CART analysis: Breton NWA.

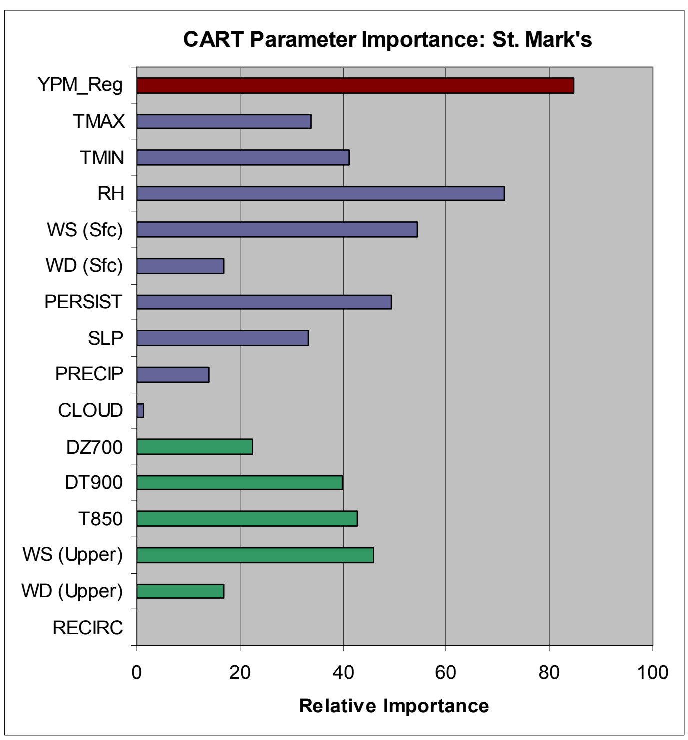


Figure 83b. Average parameter importance for the MMS synthesis visibility CART analysis: St. Mark's NWA.

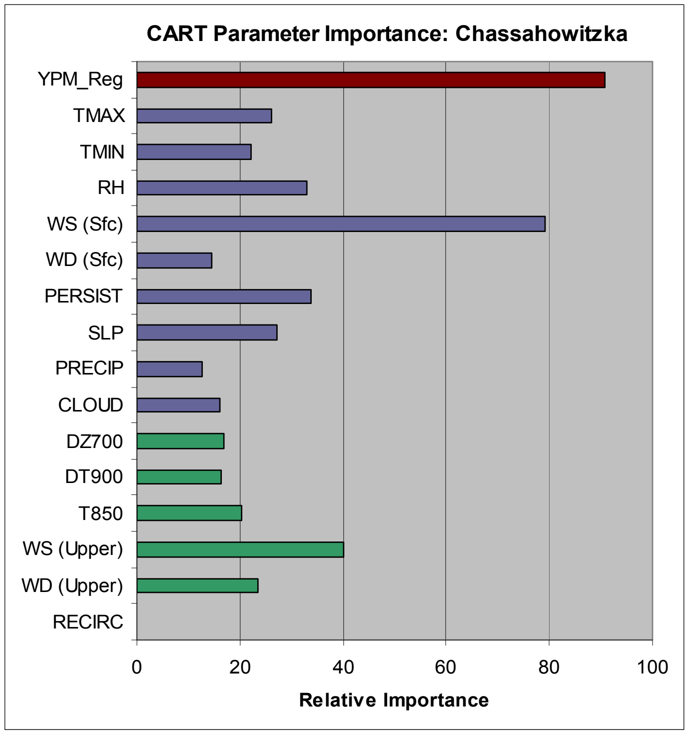


Figure 83c. Average parameter importance for the MMS synthesis visibility CART analysis: Chassahowitzka NWA.

Parameter importance varies among the three areas. Regional, prior-day PM2.5 concentrations and wind speeds (surface and aloft) are important to the classification for all three areas. Relative humidity is also important for all three areas (but less so for Chassahowitzka). Persistence is important for St. Mark's and Chassahowitzka, indicating that the gulf breeze or recirculation may play a role in visibility along the Florida coast.

Average parameter importance for all three areas is displayed in Figure 84.

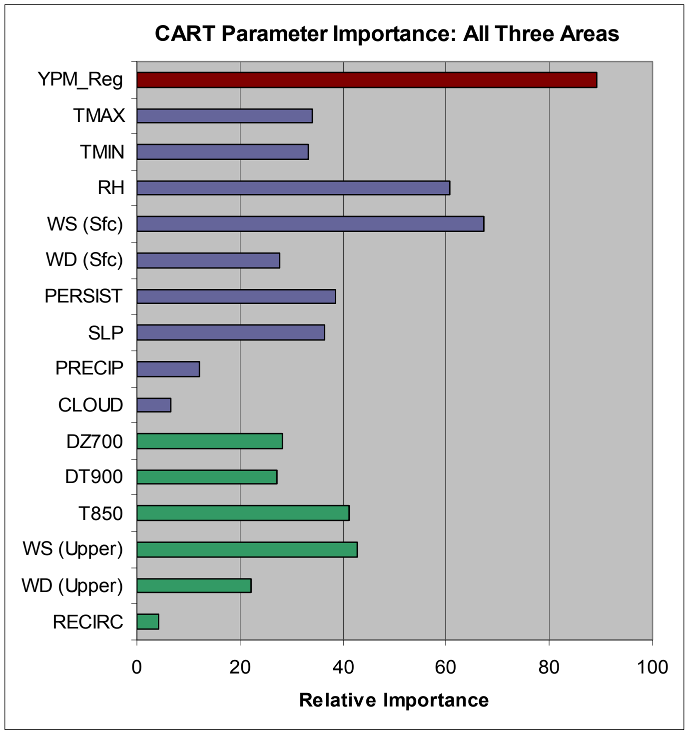


Figure 84. Average parameter importance for the MMS synthesis visibility CART analysis: Average over all areas.

On average, the most important parameters include: prior day regional PM2.5 concentration, surface wind speed, relative humidity, upper-level wind speed, 850 mb temperature and persistence. Many of the meteorological parameters are used in the development of the CART trees and have average relative importance values of 20 percent or more.

Characteristics of High Extinction (Categories and Bins)

In this section, the CART input data and results are used to further explore the relationships between the meteorological parameters and the air quality metrics, and the specific combinations of parameters (conditions) that lead to poor visibility.

Categorical Comparisons

Tables 26 through 28, presented in Section 2 of this report, examined the variations in extinction coefficient versus meteorology. The meteorological parameters listed in these tables are the same as the CART input parameters for visibility. The extinction coefficient categories are the same as those used for the CART analysis. Referring back to those tables, a brief summary of the characteristics and categorical variations in selected parameters associated with high values of extinction in each area of interest is provided. Emphasis is on those parameters that are most different between low and high extinction (good and poor visibility) days.

For the Breton NWA (refer to Table 26), high values of extinction coefficient are associated with:

- Moderate regional $PM_{2.5}$ concentrations on the previous day ($PM_{2.5}$ increases with each higher extinction coefficient category),
- High relative humidity (also increases with each higher extinction category),
- Low wind speeds near the surface and low to moderate wind speeds aloft,
- No precipitation, and
- Stable conditions.

For St. Mark's NWA (refer to Table 27), high extinction coefficients are associated with:

- Low to moderate regional $PM_{2.5}$ concentrations on the previous day ($PM_{2.5}$ generally increases with each higher extinction coefficient category),
- High temperature,
- High relative humidity (also generally increases with each higher extinction category),
- Very low wind speeds near the surface and moderate wind speeds aloft, and
- Stable conditions (stability increases with each higher category).

For the Chassahowitzka NWA (refer to Table 28), poor visibility is associated with:

- Low to moderate regional $PM_{2.5}$ concentrations on the previous day ($PM_{2.5}$ increases with each higher extinction coefficient category),
- High temperature,
- High relative humidity (generally increases with each higher extinction category),
- Very low wind speeds near the surface and low to moderate wind speeds aloft,
- Low persistence (possible gulf breeze or recirculation), and
- No rainfall.

For all three areas, both regional $PM_{2.5}$ and relative humidity increase with increasing extinction coefficient (decreasing visibility). Low winds speeds and generally stable conditions are associated with poor visibility for all three areas. For Chassahowitzka, stability is less well correlated with extinction compared to the other sites, but persistence is well correlated and decreases with increasing extinction. These results suggest that there are certain prevailing conditions that are conducive to visibility impairment across the eastern Gulf Coast region. Wind directions and conditions (e.g., persistence) vary by region. None of the results indicate a strong connection between wind direction and visibility.

Analysis of Key Bins

Each extinction coefficient category may be represented in the CART tree by more than one bin, allowing for the possibility that different combinations of the independent parameters can be associated with the specified range of visibility.

In this section we further explore the characteristics of the key bins that represent the high extinction days for each area. Key bins were defined as those containing at least five days and the greatest number of correctly classified days. Three key high-ozone bins corresponding to the highest and second highest extinction coefficient categories for each area were identified and the characteristics of those bins were examined and compared. Figure 85 displays and compares selected parameters for the key high extinction bins for each area. The parameters are grouped as follows: air quality related parameters, relative humidity, temperature parameters, stability and persistence parameters, wind speed parameters and wind direction parameters. The bin category and number of days in each bin is also given. As a reminder, the categories are defined based on the 20, 50, 80 and 95 percentile values of extinction coefficient for each site such that Category 1 includes the 20% best visibility days and Categories 4 and 5 combined include the 20% worst days.

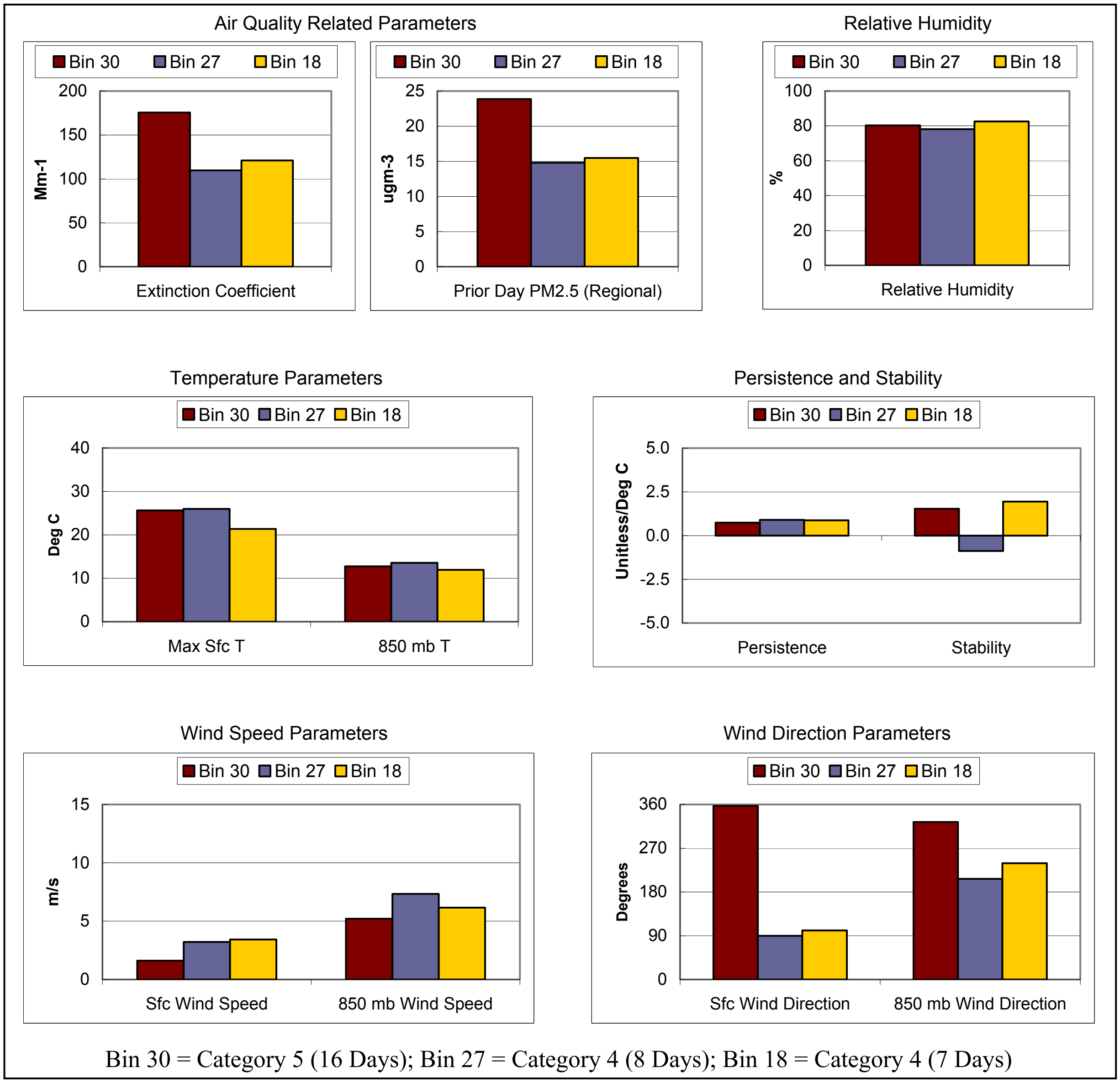
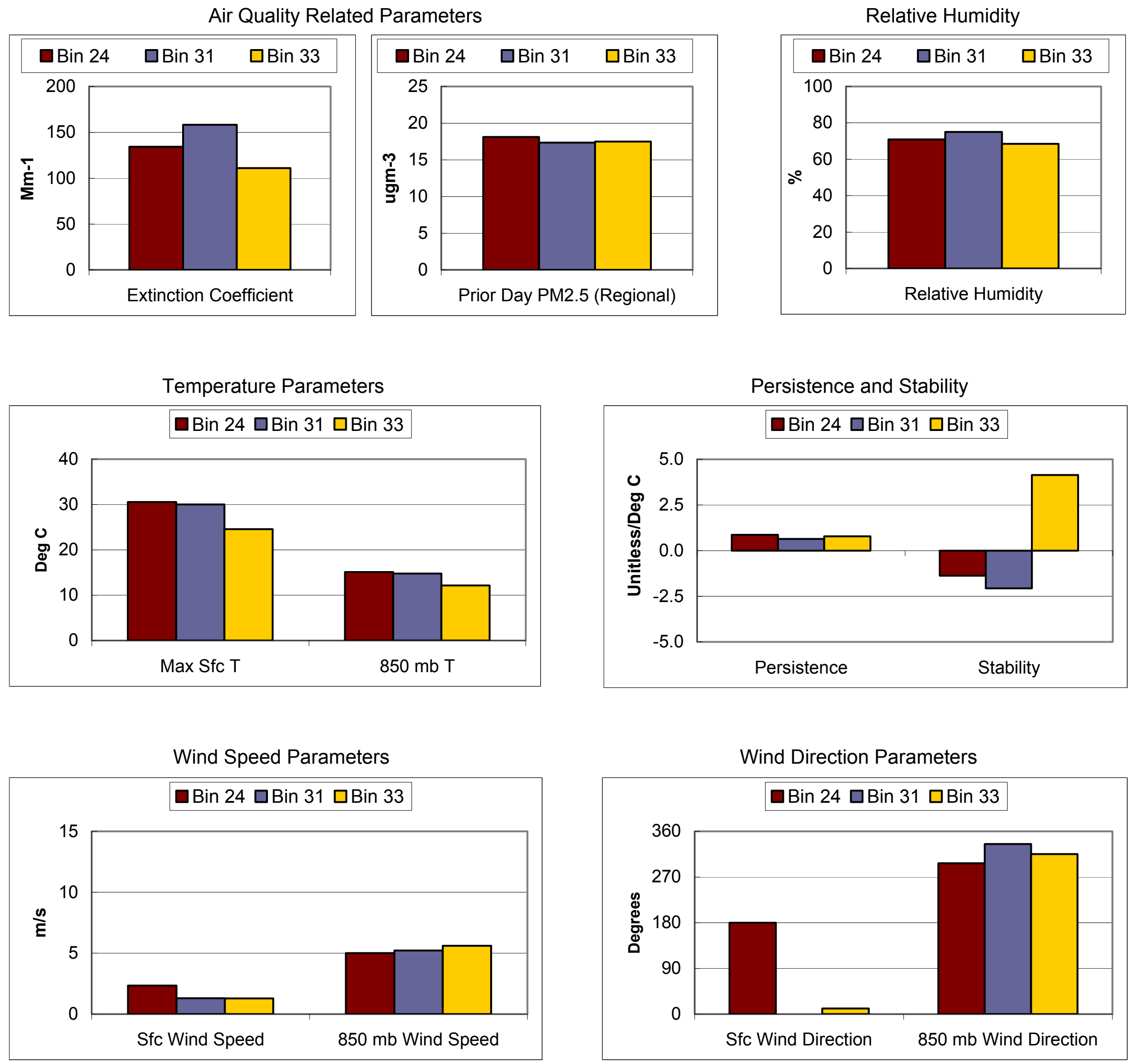


Figure 85a. Average values of selected parameters by bin for the key high extinction bins: Breton.



Bin 24 = Category 5 (7 Days); Bin 31 = Category 5 (7 Days); Bin 33 = Category 4 (14 Days)

Figure 85b. Average values of selected parameters by bin for the key high extinction bins: St. Mark's.

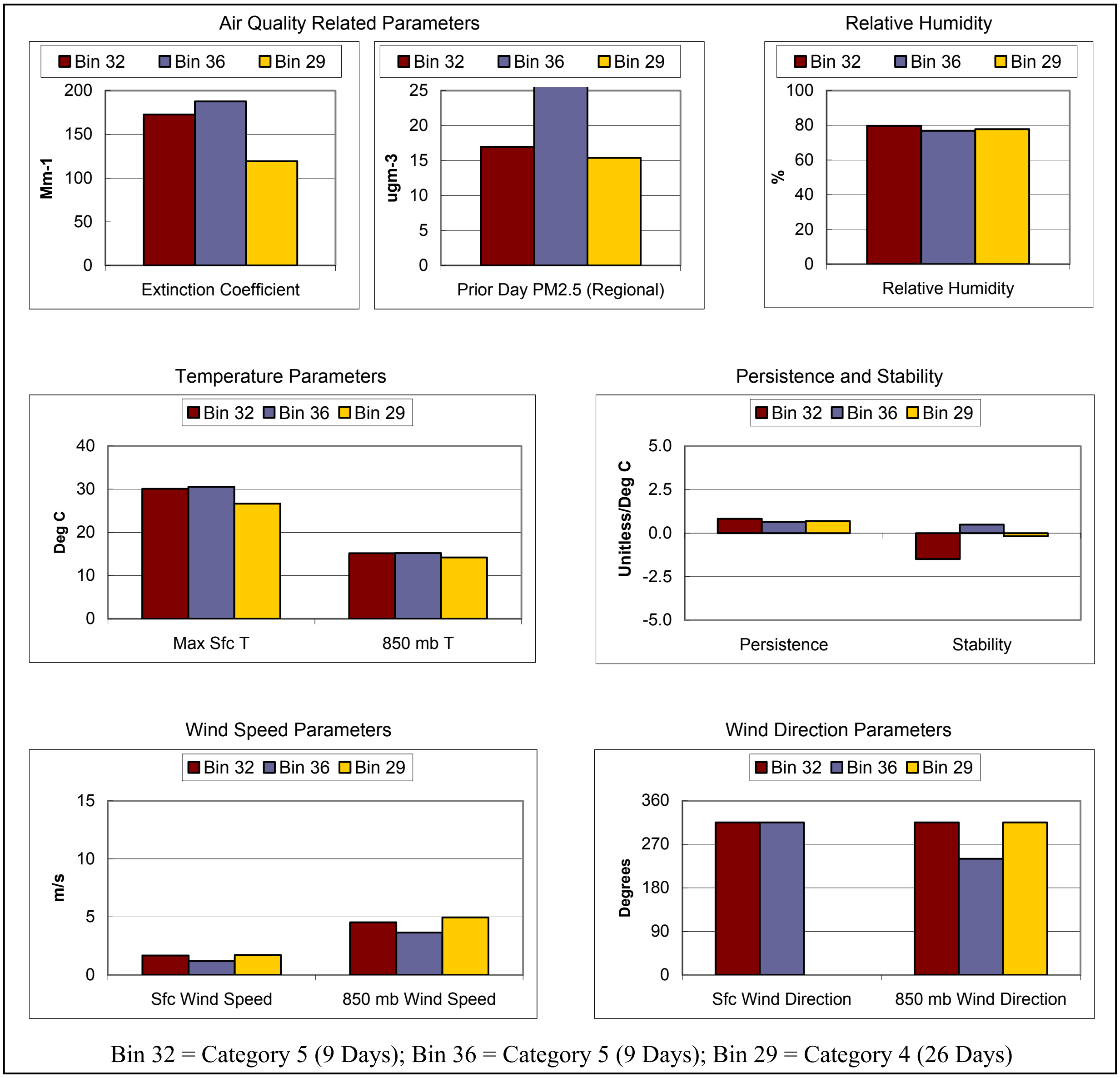


Figure 85c. Average values of selected parameters by bin for the key high extinction bins: Chassahowitzka.

There are both similarities and differences in the conditions that describe the key bins. For discussion purposes, we examine the results for the Breton NWA.

For Breton, the extinction coefficient ranges for Categories 4 and 5 are 105 to 160 and greater than or equal to 160 Mm^{-1}, respectively. One Category 5 bin (Bin 30) and two Category 4 bins (Bins 27 and 18) are highlighted in Figure 85a, and, as expected, average extinction coefficient is higher for the Category 5 bin (Bin 30). Average values of relative humidity, surface temperature and 850 mb temperature are similar for the three bins. Bin 30, the Category 5 bin, is distinguished by higher prior day regional $PM_{2.5}$ values, less persistence, lower wind speeds, northerly rather than easterly surface winds and northwesterly rather than southwesterly 850 mb winds. A comparison of the two Category 4 bins shows that days in Bin 27 are less stable and have, on average, higher 850 mb wind speeds than days in Bin 18. There are also some small differences in average wind direction between the two bins. The results for Breton, as well as those for St. Mark's and Chassahowitzka, show that different combinations of parameters can result in similar extinction coefficients (and poor visibility).

It is also interesting to examine the composition of $PM_{2.5}$ for poor visibility days and whether this differs among the key bins. Figure 86 shows the average composition for the key visibility bins for each of the three IMPROVE sites. The charts display elemental carbon, ammonium nitrate, organic matter (1.4 times the organic carbon), and ammonium sulfate.

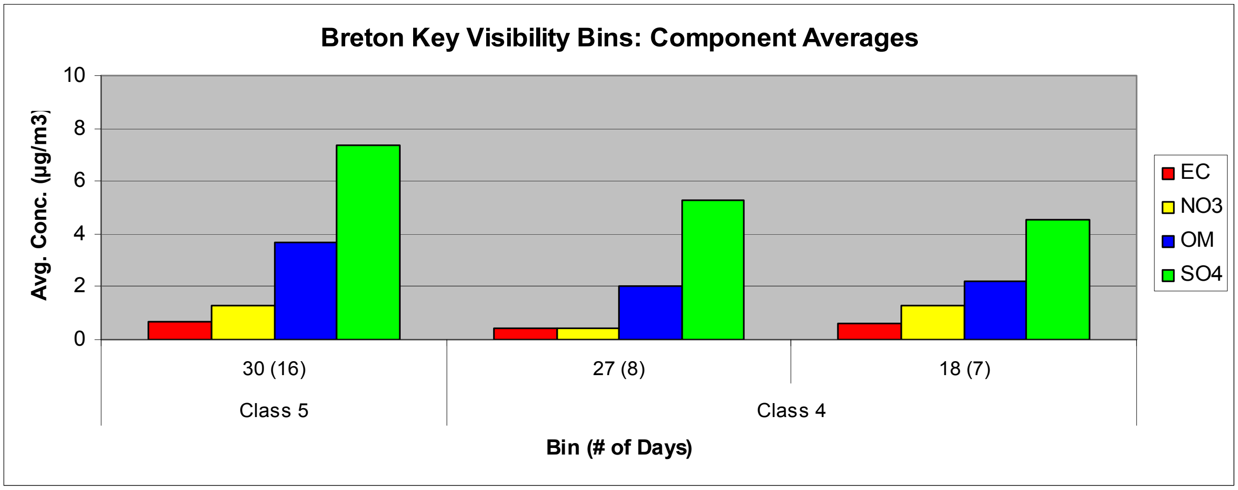


Figure 86a. Average elemental carbon (EC), ammonium nitrate (NO_3), organic matter (OM), and ammonium sulfate (SO_4) concentrations (μgm^{-3}) for selected poor visibility bins: Breton.

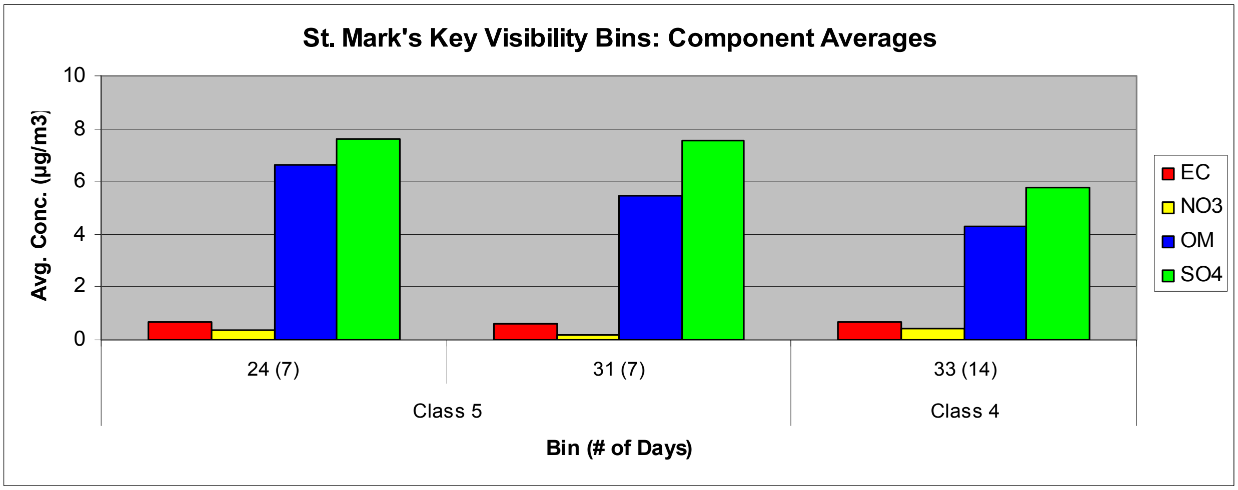


Figure 86b. Average elemental carbon (EC), ammonium nitrate (NO_3), organic matter (OM), and ammonium sulfate (SO_4) concentrations (μgm^{-3}) for selected poor visibility bins: St. Mark's.

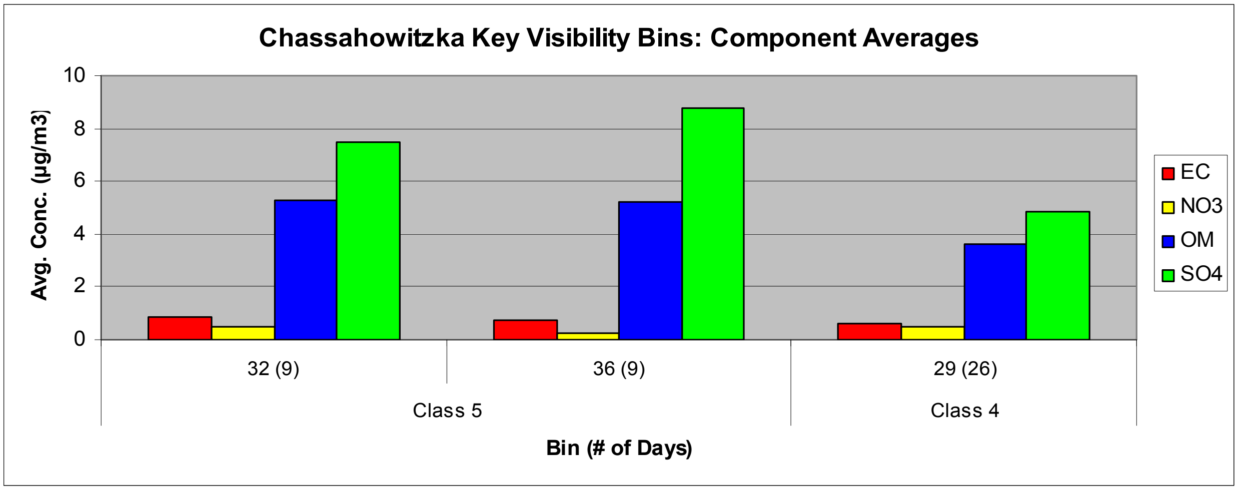


Figure 86c. Average elemental carbon (EC), ammonium nitrate (NO_3), organic matter (OM), and ammonium sulfate (SO_4) concentrations (μgm^{-3}) for selected poor visibility bins: Chassahowitzka.

The compositional charts indicate that ammonium sulfate and organic matter contribute to visibility impairment at all three sites. The ratio of sulfate to organic matter is greatest for Breton (about 2 for the key bins), and less than that for Chassahowitzka (about 1.5) and St. Mark's (about 1.2). The compositional charts also illustrate that the relative contributions of various $PM_{2.5}$ components vary by bin for each of the sites, but only slightly. For example, consider the three poor visibility bins for Breton (Bins 30, 27 and 18). All $PM_{2.5}$ components are higher for Bin 30, compared with the two Category 4 bins. Bin 18 has lower sulfate but higher nitrate compared to Bin 27. This could be related to greater stability for days within Bin 18.

6.2.3. Summary of Findings

The CART analysis, together with the selected air quality and meteorological input parameters, correctly classifies, on average, approximately 72 percent of the days for 2000-2004 according to daily extinction coefficient. CART classification accuracy for the three Class I areas ranges from 68 to 74 percent. Classification accuracy for extinction coefficient is lower than that for ozone and $PM_{2.5}$ and this reflects the complexity of the light extinction parameter (each component of light extinction could be affected differently by ambient conditions) and the role of moisture in this analysis (used in calculating light extinction and as a separate input parameter). When only meteorological data are used as input to the CART analysis, classification accuracy is two to ten percent lower. This indicates that the selected meteorological data are incomplete indicators of visibility in the Class I areas along the Gulf Coast.

Exploratory analyses conducted for the Breton NWA revealed that 1) using a reduced dataset (December 2000 - September 2001 compared to December 2000-2004) significantly reduces the complexity of the CART classification tree, but does change classification accuracy, 2) offshore, special-studies surface data for nearby Breton Island Platform (BIP) improved the ability of CART to correctly identify and classify the days according to visibility, but routine buoy data did not have the same result, and 3) high-resolution, upper-air data (primarily wind data) for BIP also improved the classification. These results suggest that additional, local upper-air wind data may be needed to fully characterize air quality mechanisms at Breton and along the Gulf Coast.

On average, the most important CART classification parameters for visibility include: prior-day regional $PM_{2.5}$ concentration, surface wind speed, relative humidity, upper-level wind speed, 850 mb temperature and persistence. However, parameter importance varies among the three areas. Regional, prior-day $PM_{2.5}$ concentrations and wind speeds (surface and aloft) are important to the classification for all three areas. Relative humidity is also important for all three areas. Persistence is important for St. Mark's and Chassahowitzka, indicating that the gulf breeze may play a role in visibility along the Florida coast.

Analysis of the variations in the input parameters across defined $PM_{2.5}$ concentration categories reveals that, for all three areas, both regional $PM_{2.5}$ and relative humidity increase with increasing extinction coefficient (decreasing visibility). Low winds speeds and generally stable conditions are associated with poor visibility for all three areas. These results suggest that there are certain prevailing conditions that are conducive to visibility impairment across the eastern Gulf Coast region. Wind directions and conditions (e.g., persistence) vary by region and the data do not indicate a strong connection between wind direction and visibility.

Poor visibility days for each area are divided among several bins. The results for Breton, St. Mark's and Chassahowitzka all show that different combinations of parameters can result in similar extinction coefficients (and poor visibility) for a given area. In terms of particulate composition, ammonium sulfate and organic matter contribute to visibility impairment at all three sites. The ratio of sulfate to organic matter is greatest for Breton (about 2 for the key bins), and less than that for Chassahowitzka (about 1.5) and St. Mark's (about 1.2). The relative contributions of various $PM_{2.5}$ components vary by bin for each of the sites, but only slightly.

7.0 AIR QUALITY TRENDS ANALYSIS

This section further examines the role of meteorology in determining the air quality characteristics of selected areas along the Gulf Coast.

7.1. BACKGROUND AND OBJECTIVES

There are several reasons for further developing this information. One reason is that the analysis of air quality trends requires an understanding of the relationships between air quality and meteorology, and, in particular, how the variations in meteorology during a given period influence the ambient air quality. Another reason is that, as noted earlier in this report, certain air quality metrics (design values) are use to characterize the air quality of an area and determine whether or not air quality standards are met. These metrics can be influenced by year-to-year variations in meteorology and this can reduce the stability of the standards. Year-to-year variations in meteorology and especially unusually persistent meteorological conditions during one or more of the years comprising a design-value cycle can lead to a design value that is not representative of typical conditions. Recent variations in the design values for sites along the eastern Gulf Coast have indicated that the metric is not stable when weather conditions (either ozone conducive or not) persist over the region for large portions of the ozone season. All of the data presented in this section are included in the GMAQDB.

7.2. METHODOLOGY FOR ESTIMATING METEOROLOGICALLY ADJUSTED AIR QUALITY TRENDS

This section summarizes the development of meteorologically adjusted 8-hour ozone, $PM_{2.5}$ and visibility for selected areas along the Gulf Coast. The approach relies on results of the CART analysis, presented in Sections 4, 5 and 6 of this report. CART was applied separately for ozone, $PM_{2.5}$ and visibility for the period 2000-2004. Each day was placed into a classification bin that corresponds to a certain range of concentration (ozone and $PM_{2.5}$) or extinction coefficient (visibility) and a specific set of meteorological conditions. While the category of a bin reflects the value of the air quality metric (i.e., concentration or severity) associated with the bin's meteorological conditions, the number of days in a bin represents the frequency with which those conditions occur. Since the bins are determined using a multi-year period, individual years may be normalized such that the different sets of meteorological conditions are represented no more or less than they are on average over all years in the period. This is the basis for the meteorologically adjusted design values presented in this section. Meteorologically adjusted air quality values were calculated for each CART application following the steps outlined below:

Step 1. Determine the number of days to include from each bin.

- Use the average number of days per year.

Step 2. For each year, add days to underrepresented bins.

- Use the average value of days within that bin, for that year, if available.
- Otherwise, use the average value of days within that bin for the following year, if available.
- Otherwise, use the average value of days within that bin for the five-year span.

Step 3. For each year, eliminate excess days from overrepresented bins.

- Assign random numbers to each day and eliminate excess days based on the random numbers

Step 4. Use resulting values from the normalized years to calculated meteorologically-adjusted air quality metrics.

This approach retains the day-specific information needed to calculate certain metrics like the fourth highest 8-hour average ozone concentration and the 98th percentile 24-hour average $PM_{2.5}$ concentrations.

7.3. RESULTS

Meteorologically-adjusted ozone, $PM_{2.5}$ and visibility values are presented in this section.

7.3.1. Ozone

Meteorologically adjusted 8-hour ozone concentrations were calculated for the following areas: Northwest Houston, Central Houston, Southeast Houston/Galveston, Beaumont/Port Arthur, Lake Charles, Baton Rouge, Gulfport, Mobile and Pensacola. The CART analysis results presented in Section 4 provide the basis for the meteorological adjustment. The analysis period is 2000-2004, April through October only.

The daily 8-hour ozone concentrations for each normalized year were used to calculate several ozone air quality metrics. These include: number of 8-hour ozone exceedance days per year, average 8-hour ozone concentration over all exceedance days, average 8-hour ozone concentration over all days and 8-hour ozone exposure (the sum of the ozone concentrations over all days in the ozone season). The actual and meteorologically adjusted values for each of these metrics for each of the areas of interest are provided in Figure 87.

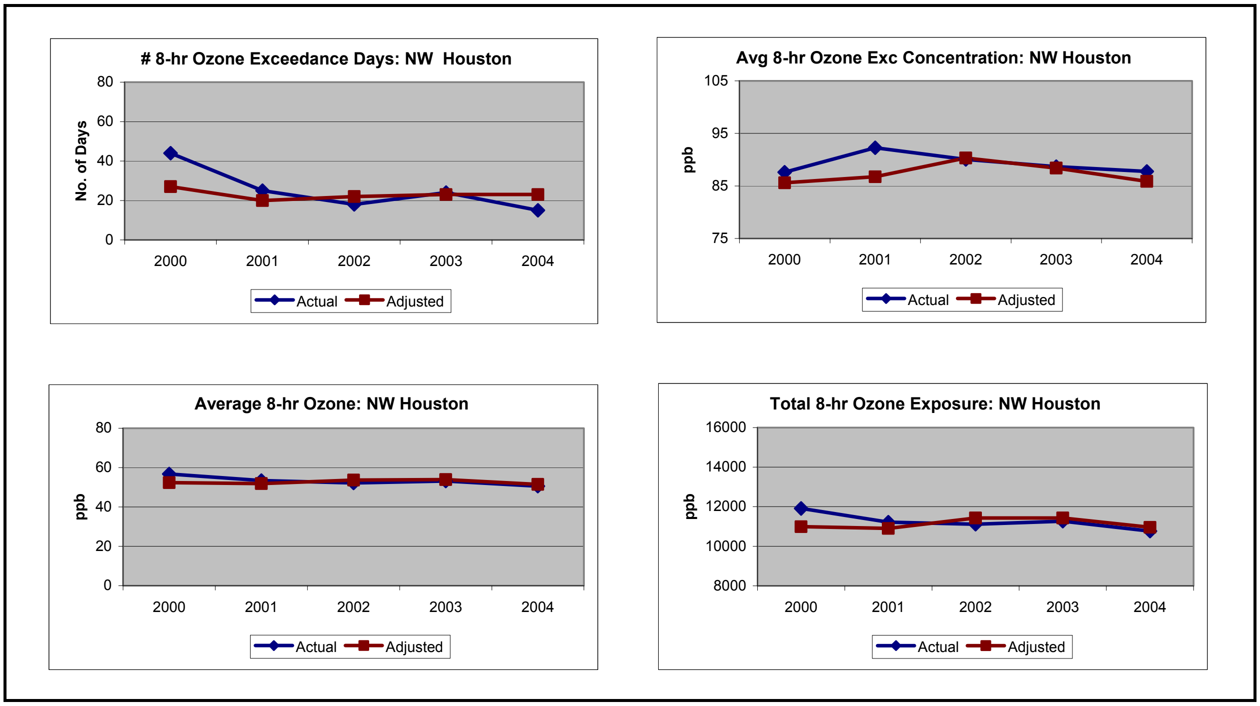


Figure 87a. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Northwest Houston.

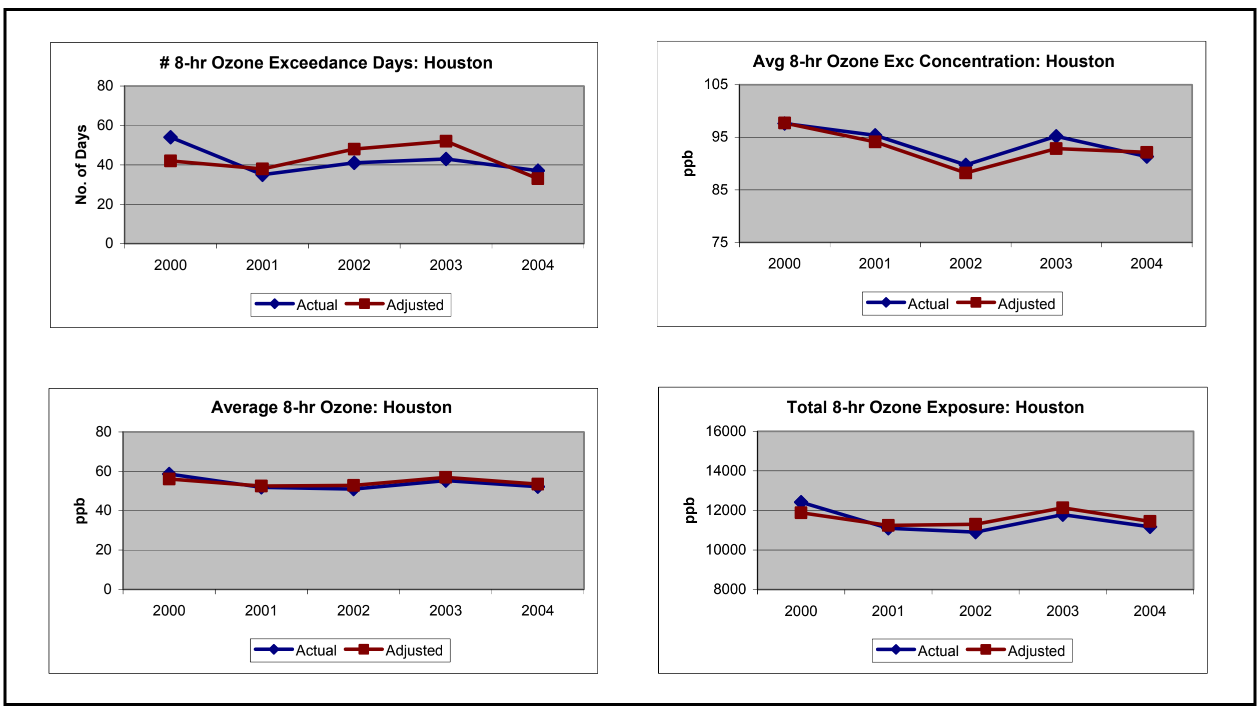


Figure 87b. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Central Houston.

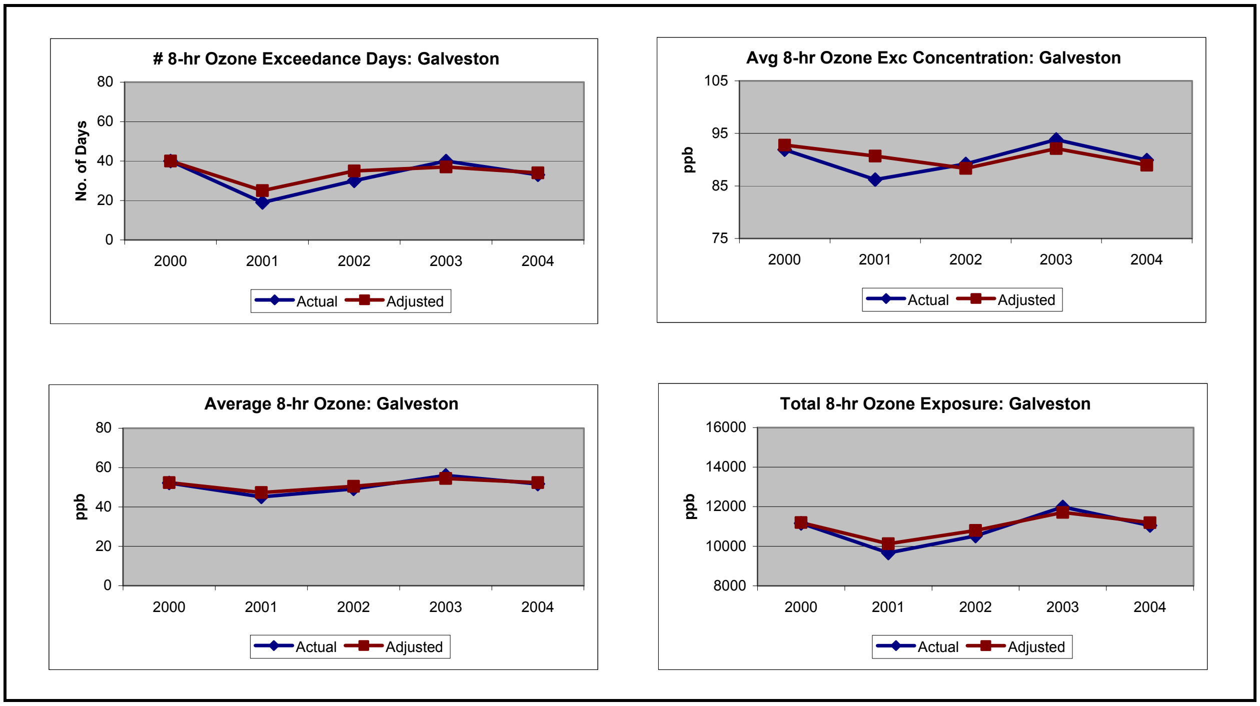


Figure 87c. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Southeast Houston/Galveston.

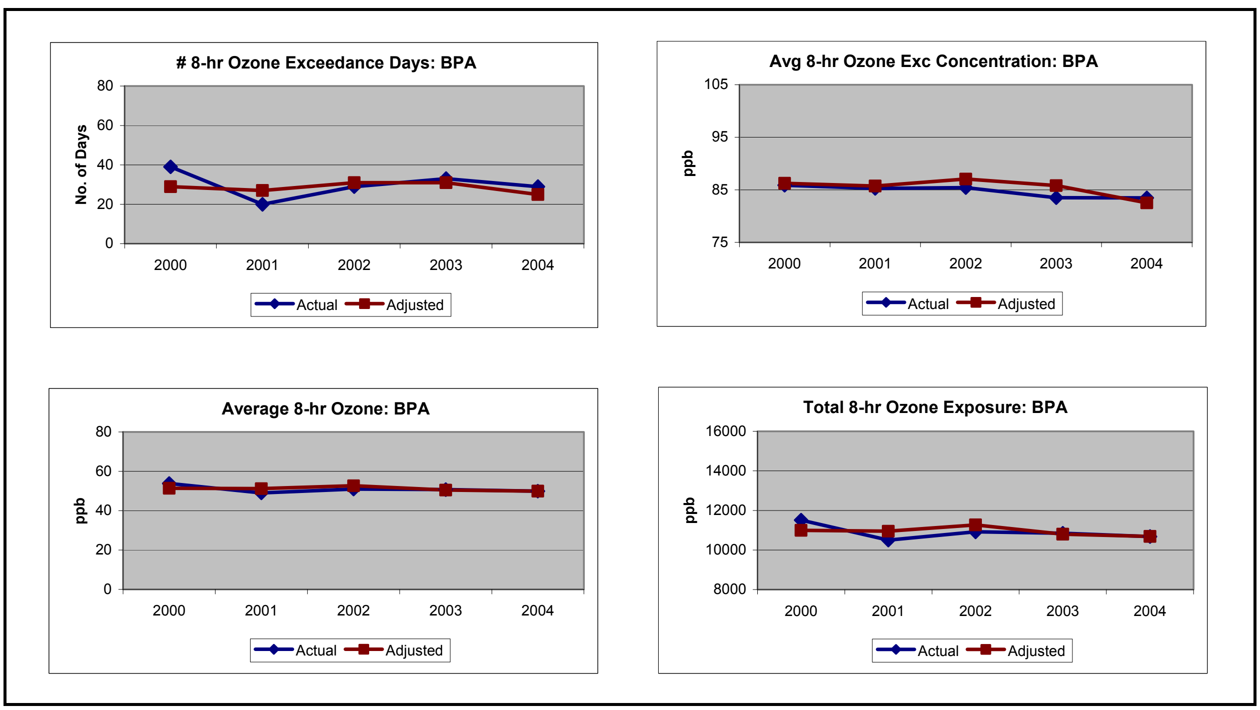


Figure 87d. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Beaumont/Port Arthur.

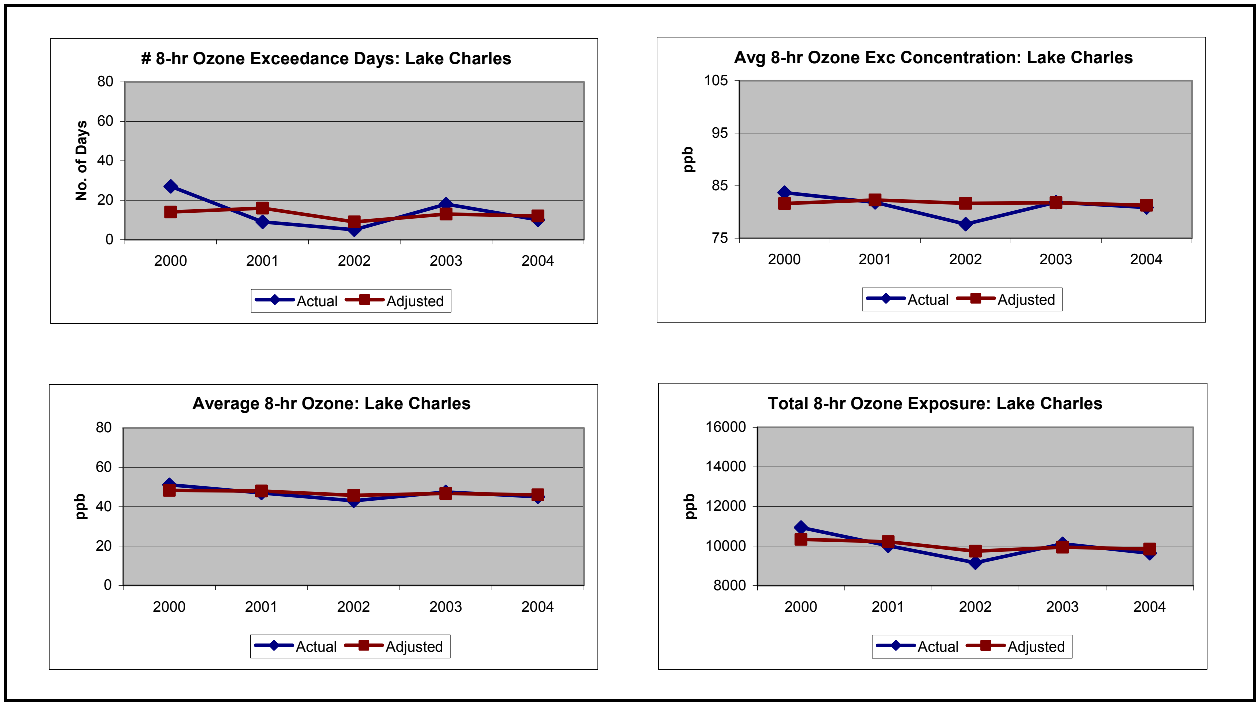


Figure 87e. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Lake Charles.

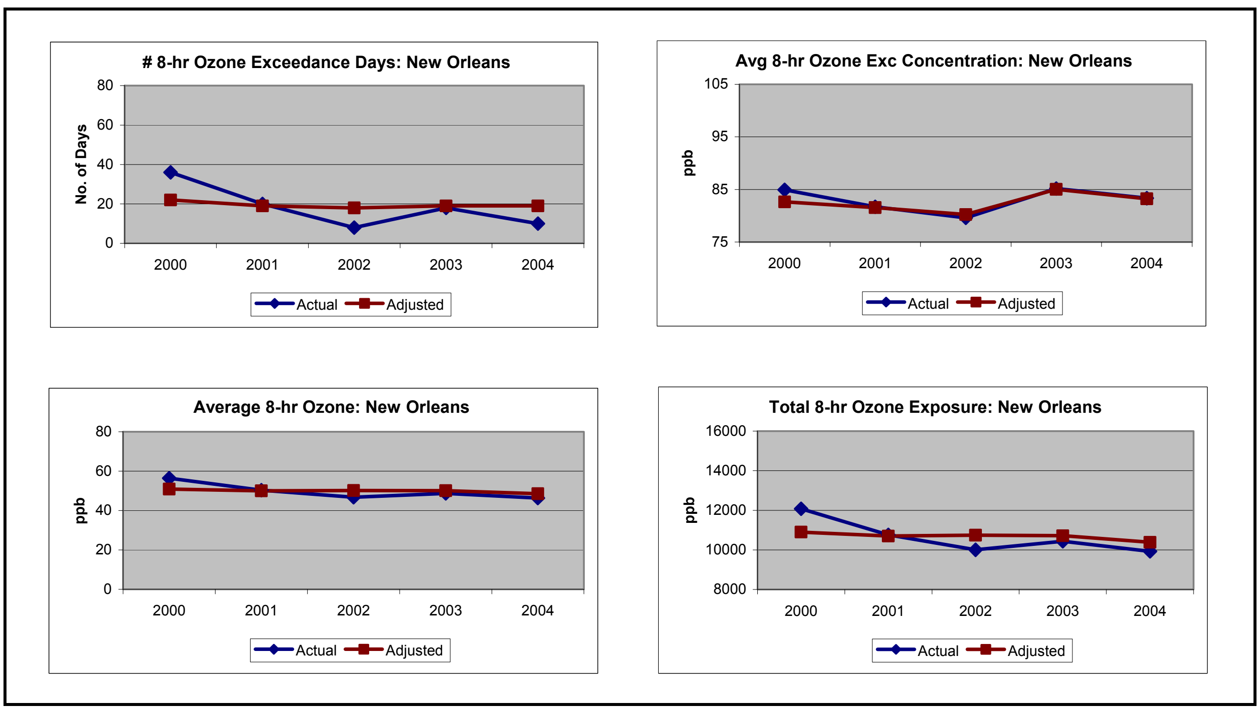


Figure 87f. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: New Orleans.

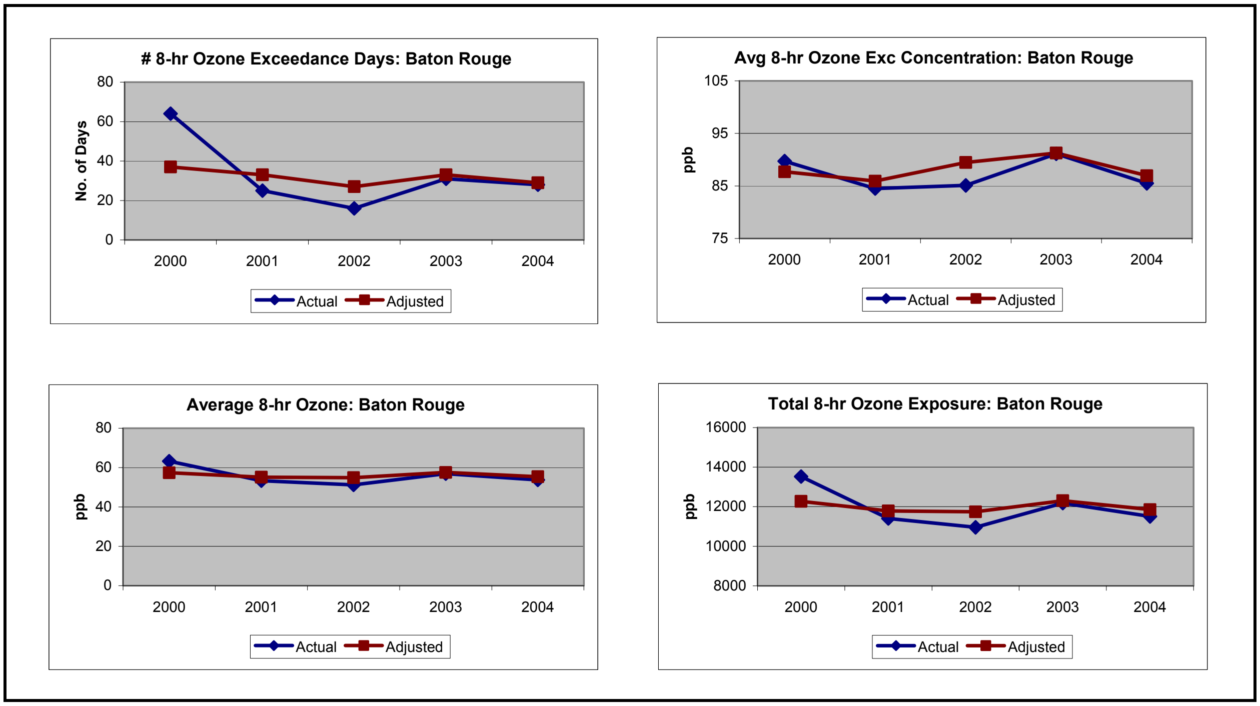


Figure 87g. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Baton Rouge.

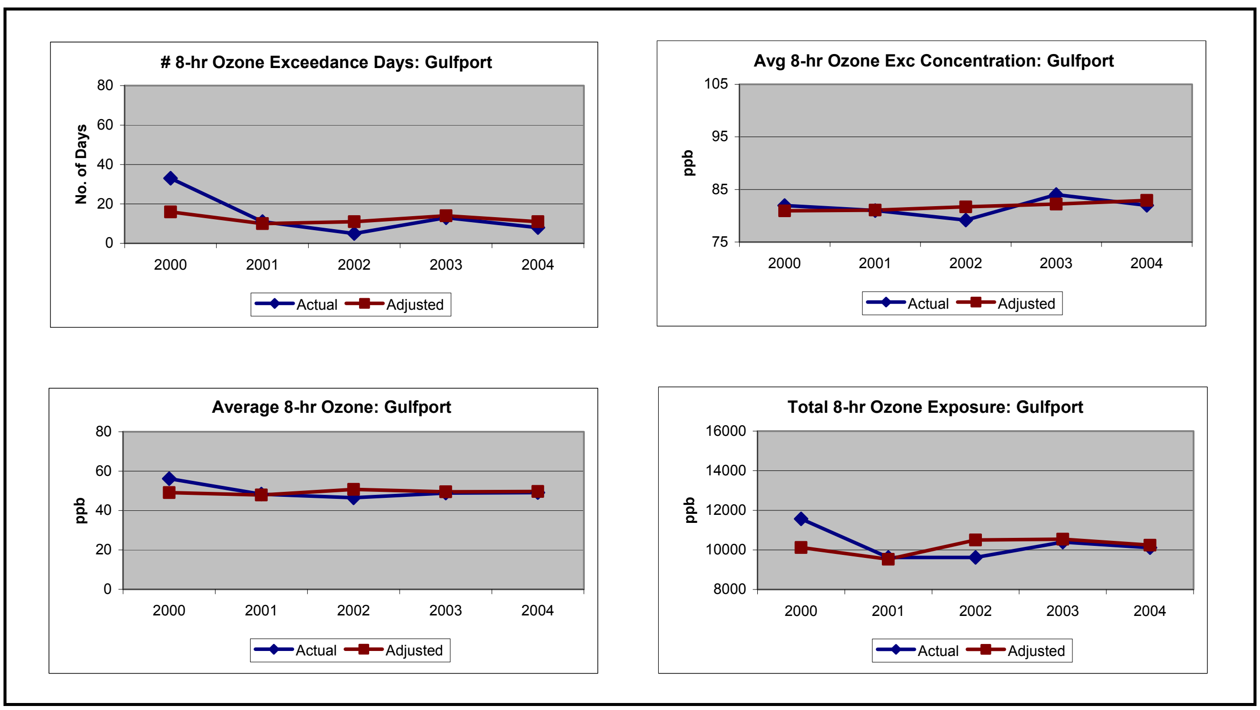


Figure 87h. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Gulfport.

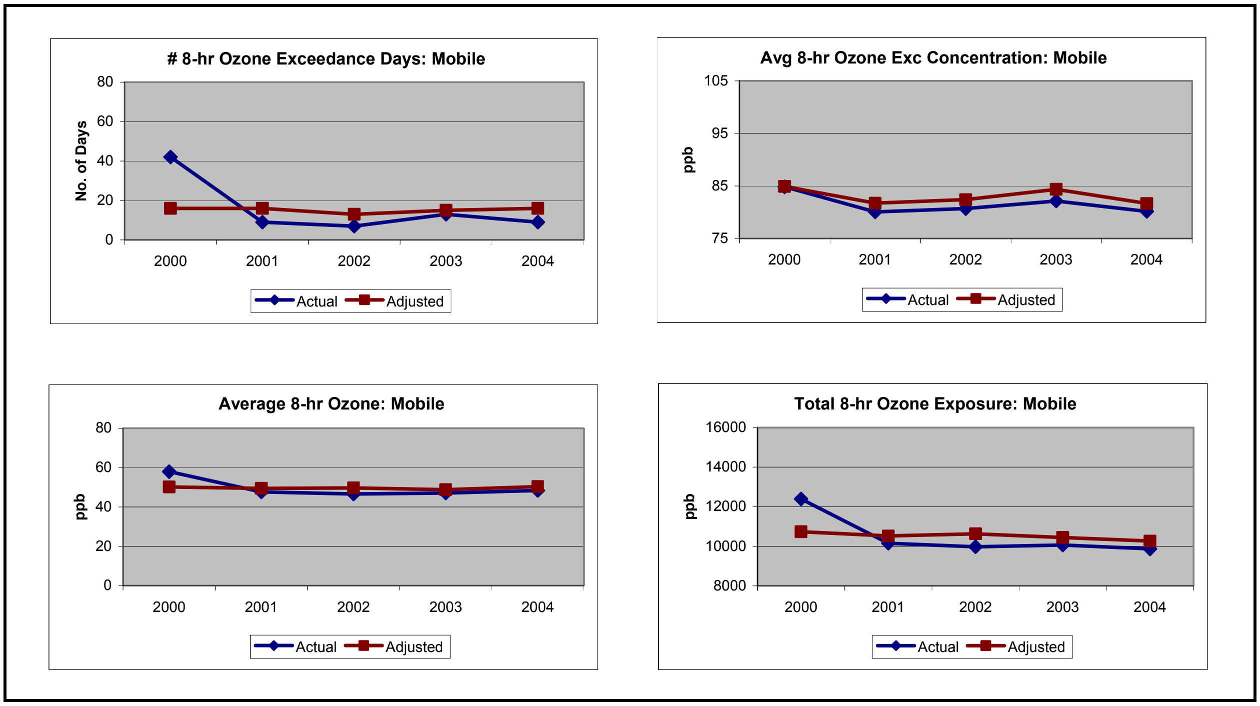


Figure 87i. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Mobile.

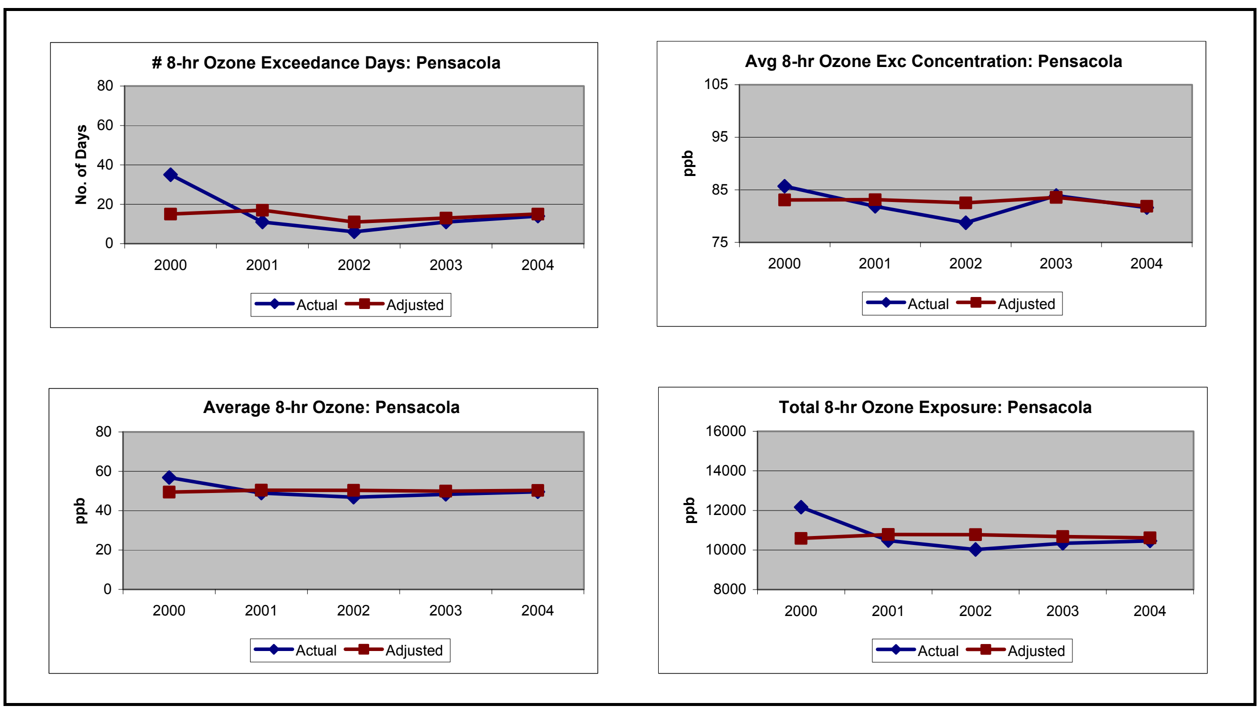


Figure 87j. Meteorologically adjusted ozone concentrations and metrics based on the MMS synthesis 8-hour ozone CART analysis results: Pensacola.

In most cases, the meteorological adjusted values show less variation from year to year and indicate that for most areas ozone concentrations for 2000 were higher than normal due to the effects of meteorology and that for several areas (especially along the eastern Gulf Coast) ozone concentrations for 2002 were lower than normal due to the effects of meteorology. These results also indicate that the year-to-year trend in ozone (based on these metrics) is relatively flat between 2000 and 2004.

7.3.2. PM2.5

Meteorologically adjusted PM2.5 concentrations were calculated for the following areas: Northwest Houston, Central Houston, Southeast Houston/Galveston, Beaumont/Port Arthur, Lake Charles and Baton Rouge. The CART analysis results presented in Section 5 provide the basis for the meteorological adjustment. The analysis period is 2000-2004.

The daily 24-hour $PM_{2.5}$ concentrations for each normalized year were used to calculate several air quality metrics. These include: number of days per year with $PM_{2.5}$ concentrations greater than 15 μgm^{-3}, average over all concentrations that exceed 15 μgm^{-3}, average $PM_{2.5}$ concentration over all days, $PM_{2.5}$ exposure (the sum of the $PM_{2.5}$ concentrations over all days), number of days per year with $PM_{2.5}$ concentrations greater than 35 μgm^{-3} and average over all concentrations that exceed 35 μgm^{-3}. The actual and meteorologically adjusted values for each of these metrics for each of the areas of interest are provided in Figure 88.

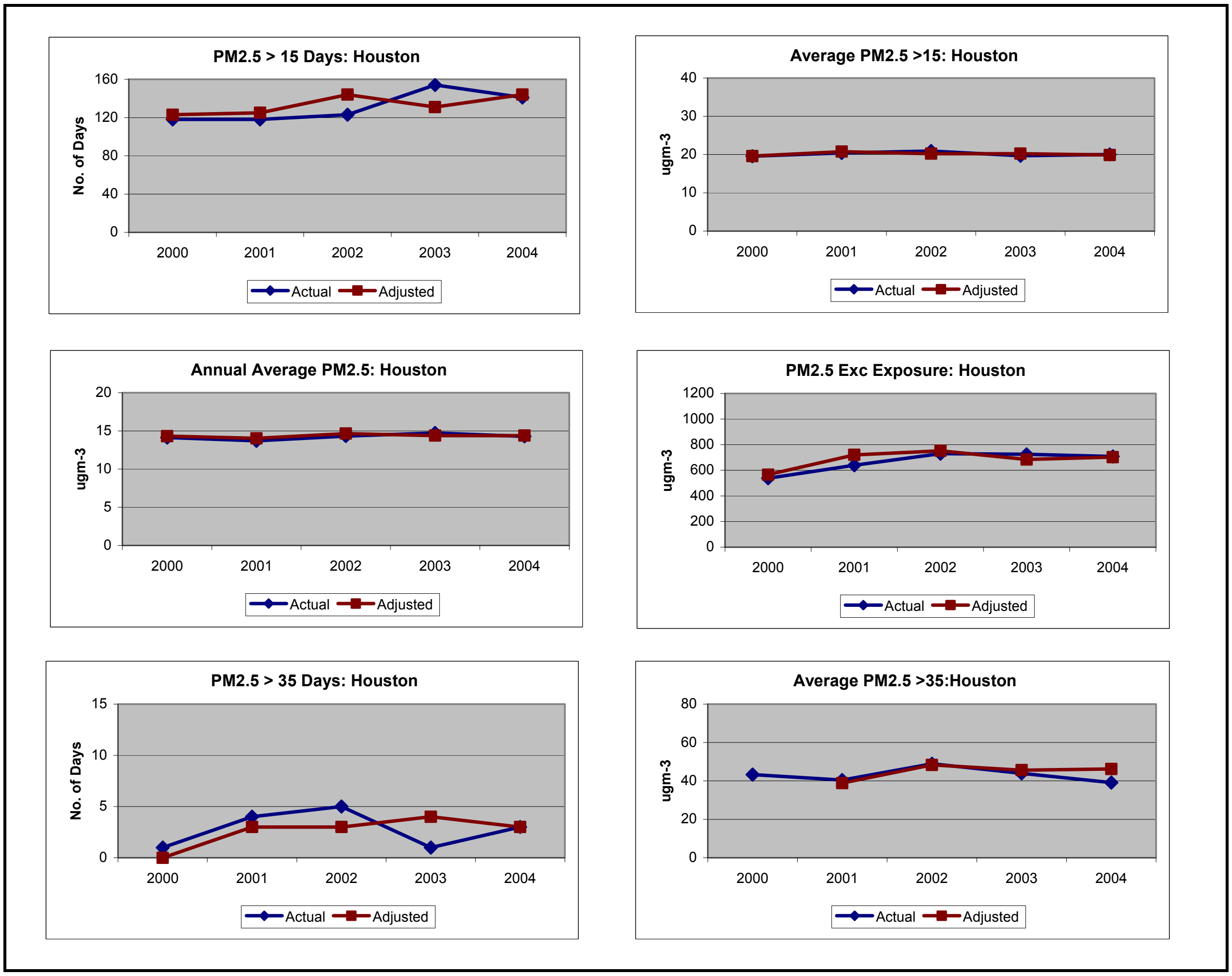


Figure 88a. Meteorologically adjusted $PM_{2.5}$ concentrations and metrics based on the MMS synthesis $PM_{2.5}$ CART analysis results: Houston.

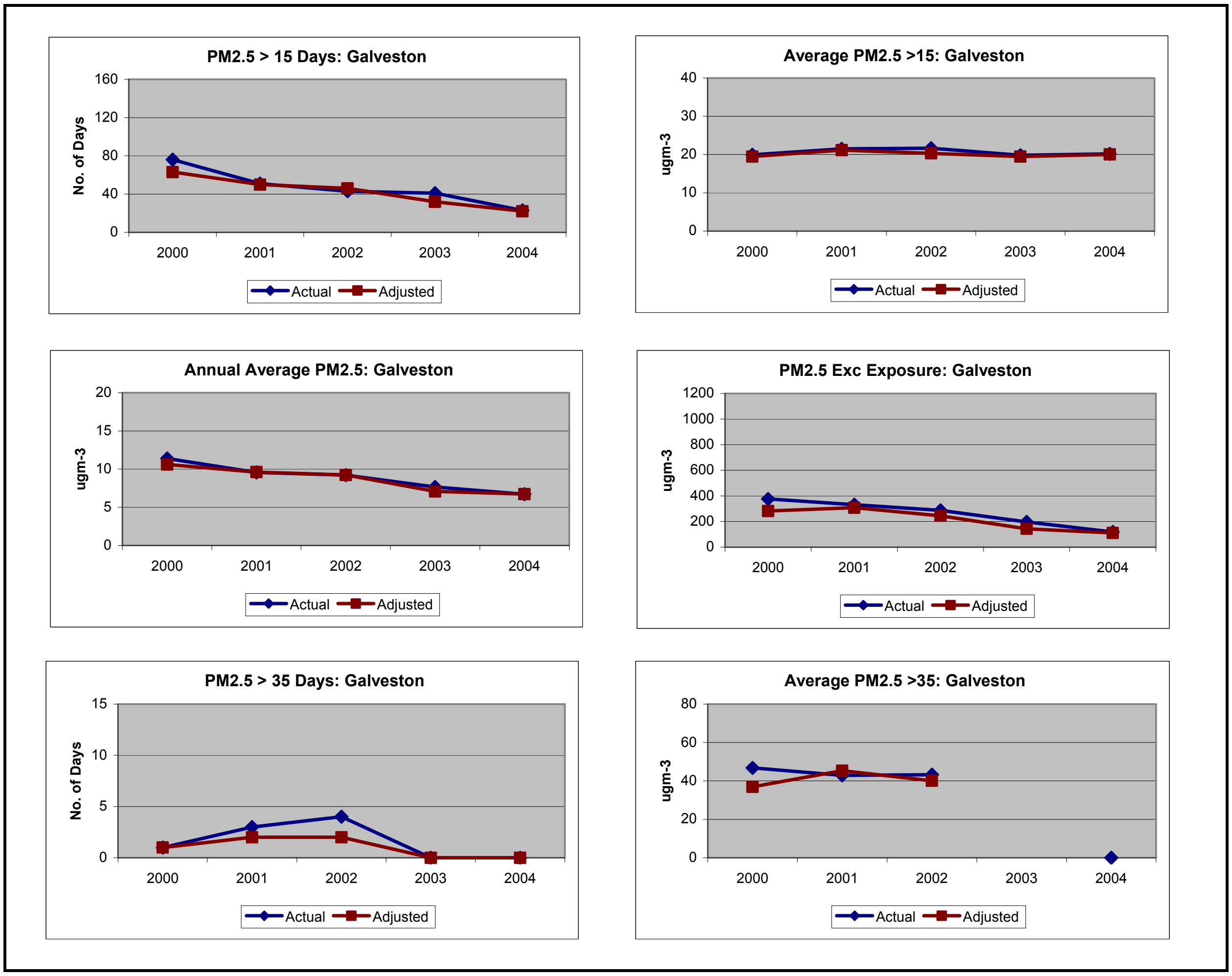


Figure 88b. Meteorologically adjusted $PM_{2.5}$ concentrations and metrics based on the MMS synthesis $PM_{2.5}$ CART analysis results: Southeast Houston/Galveston.

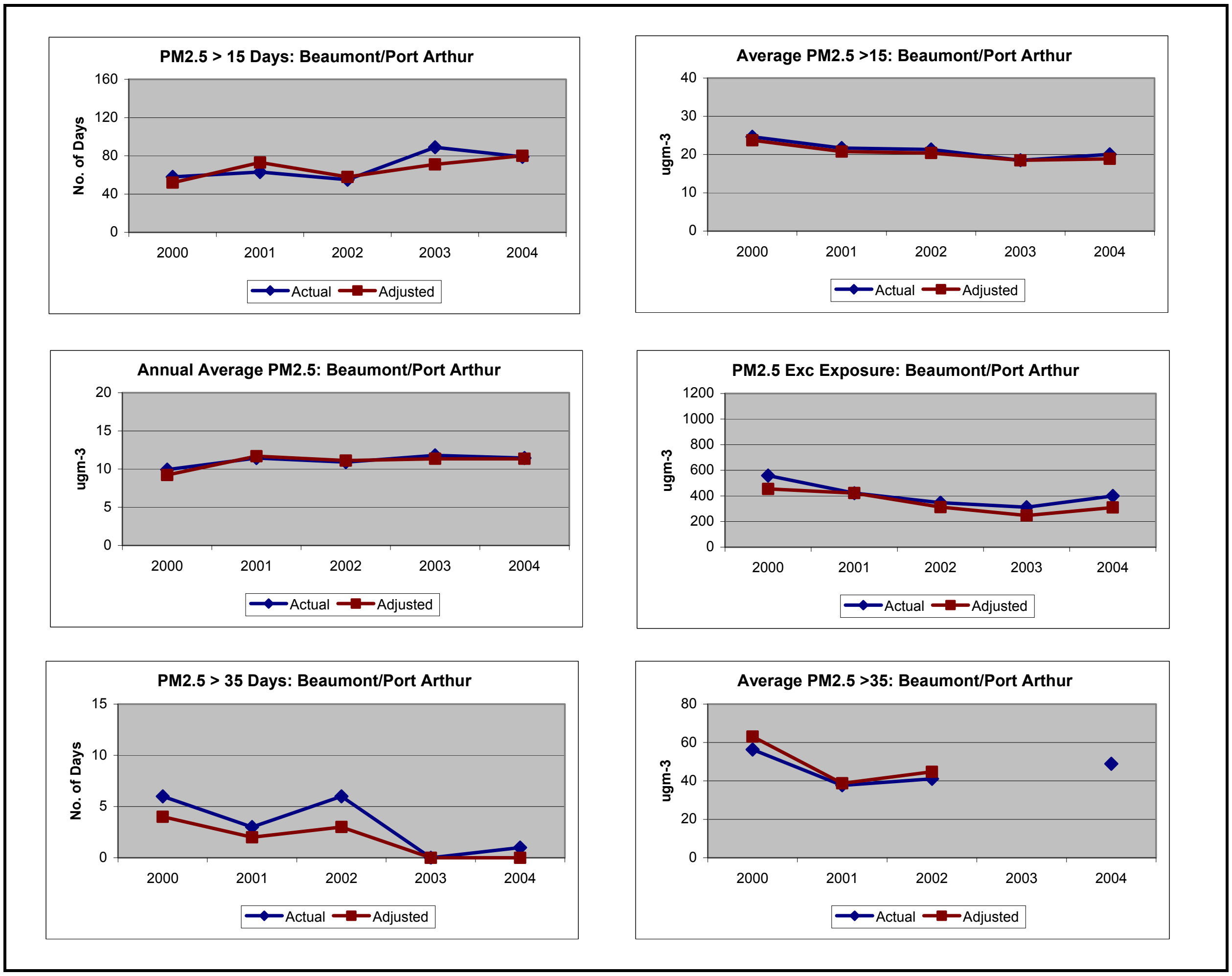


Figure 88c. Meteorologically adjusted $PM_{2.5}$ concentrations and metrics based on the MMS synthesis $PM_{2.5}$ CART analysis results: Beaumont/Port Arthur.

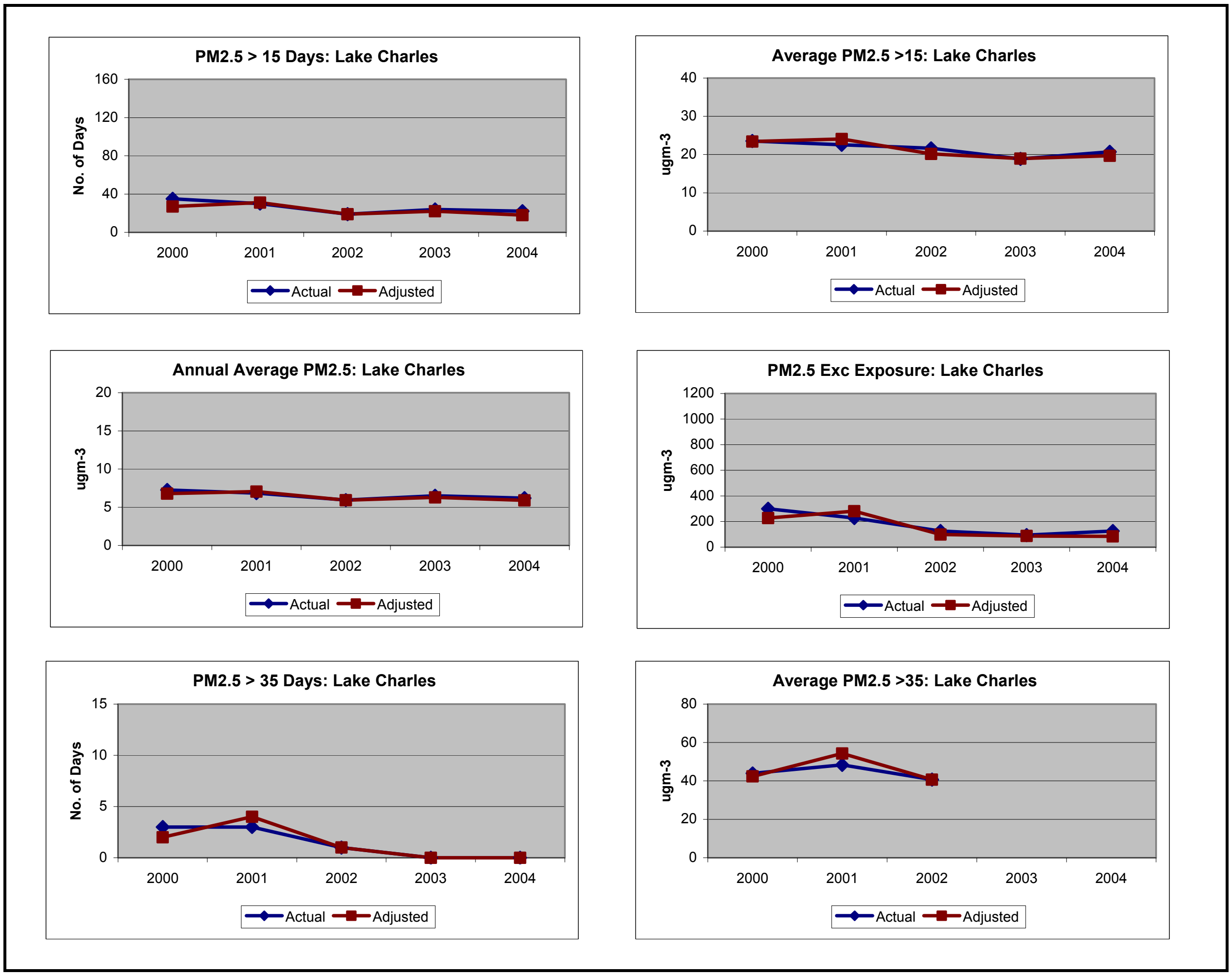


Figure 88d. Meteorologically adjusted $PM_{2.5}$ concentrations and metrics based on the MMS synthesis $PM_{2.5}$ CART analysis results: Lake Charles.

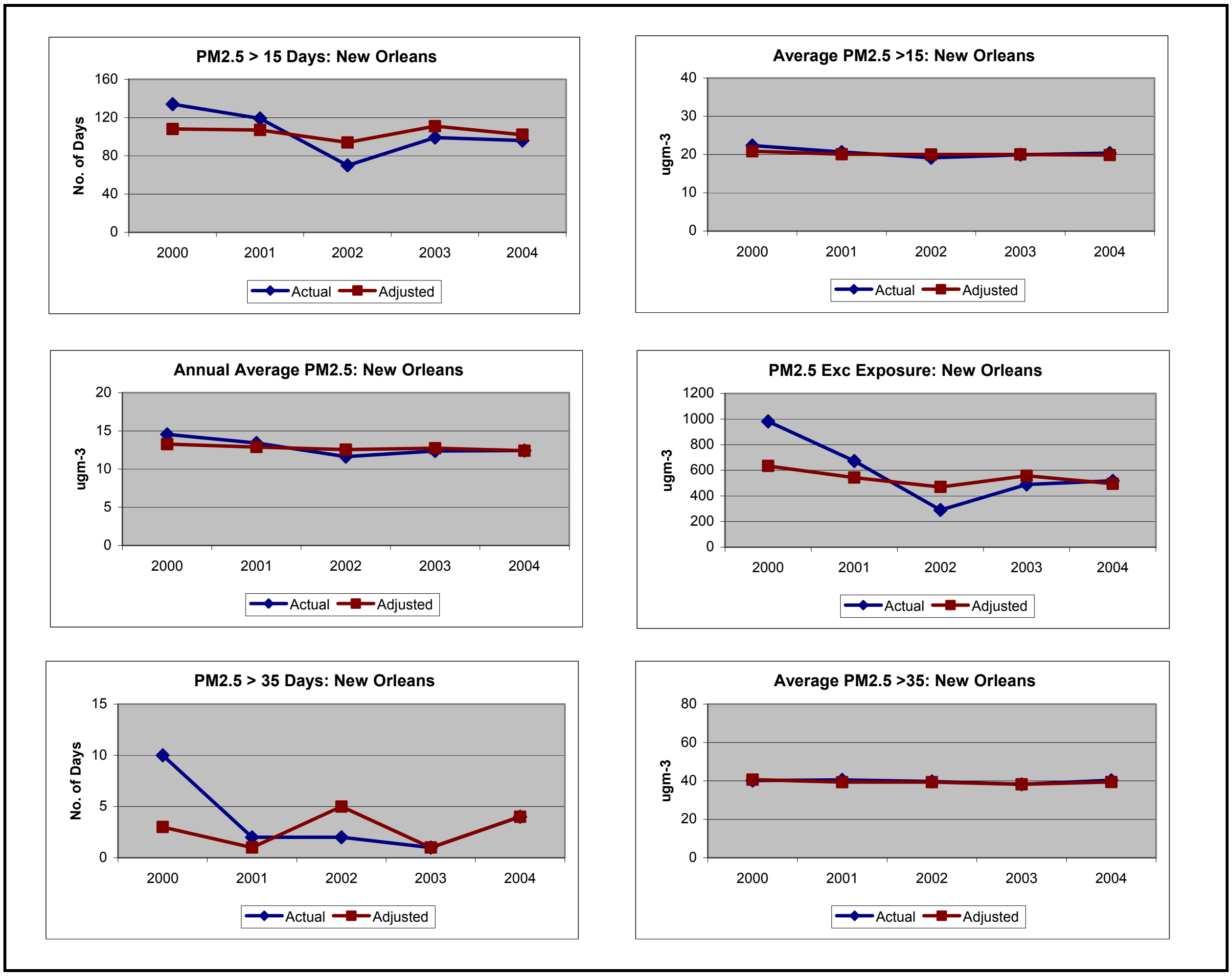


Figure 88e. Meteorologically adjusted $PM_{2.5}$ concentrations and metrics based on the MMS synthesis $PM_{2.5}$ CART analysis results: New Orleans.

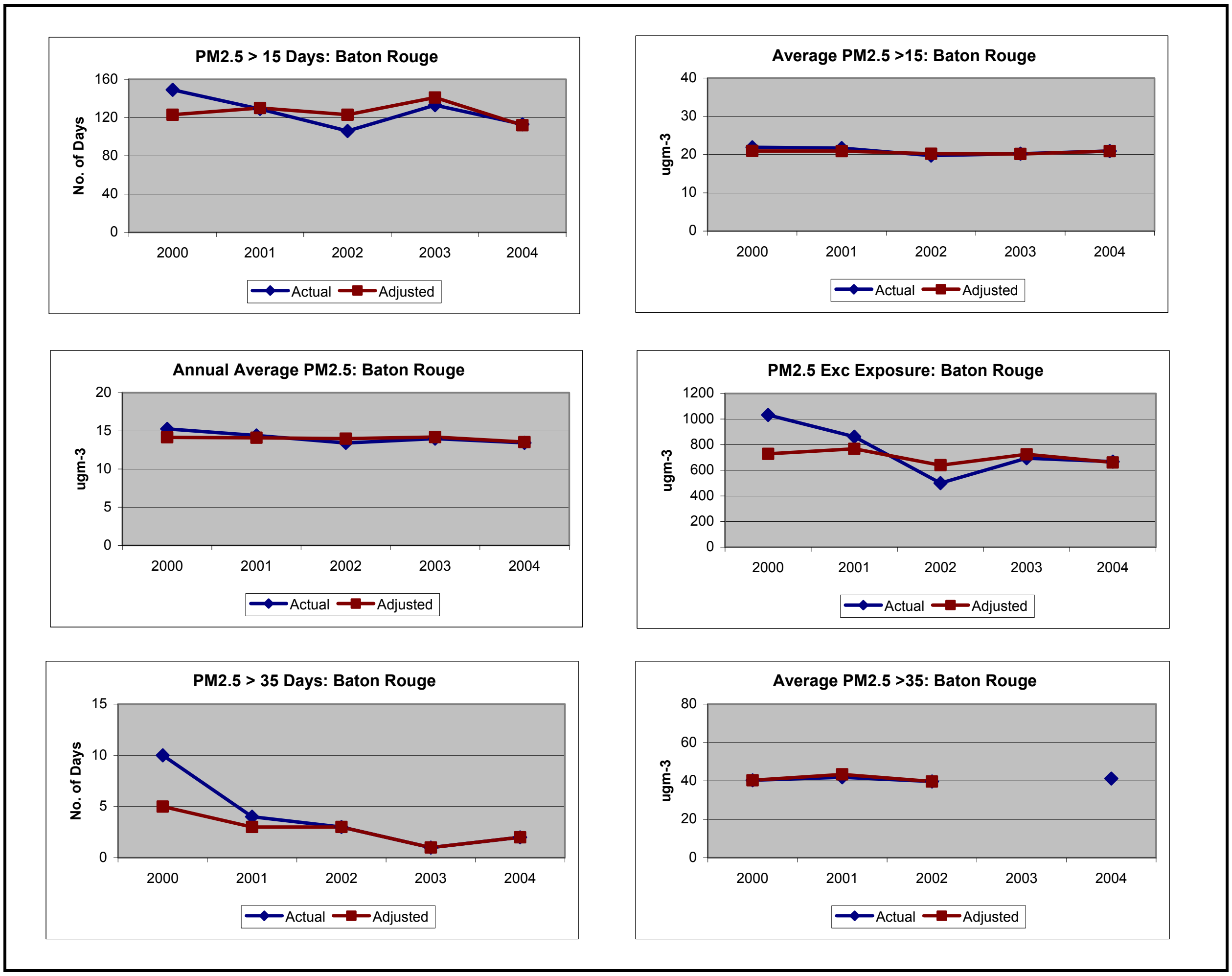


Figure 88f. Meteorologically adjusted $PM_{2.5}$ concentrations and metrics based on the MMS synthesis $PM_{2.5}$ CART analysis results: Baton Rouge.

Again, the meteorological adjusted values show less variation from year to year. Several of the metrics (with the exception of the number of days with concentrations greater than 35 μgm^{-3}) indicate a slight upward trend in $PM_{2.5}$ for Houston, both with and without the meteorological adjustment. For all other areas, there is a downward trend in $PM_{2.5}$ between 2000 and 2004, and the meteorologically adjusted values confirm the tendencies indicated by the actual data.

7.3.3. Visibility

Meteorologically adjusted extinction coefficients were calculated for the following three Class I areas: Breton, St. Mark's and Chassahowitzka. Each is represented by an IMPROVE site. The CART analysis results presented in Section 6 provide the basis for the meteorological adjustment. The analysis period is 2000-2004.

The daily extinction values for each normalized year were used to calculate several visibility related metrics. These include: number of days per year with extinction coefficients is greater than 120 Mm^{-1}, maximum extinction coefficient, 98^{th} percentile extinction coefficient and annual average extinction coefficient. The actual and meteorologically adjusted values for each of these metrics for each of the areas of interest are provided in Figure 89.

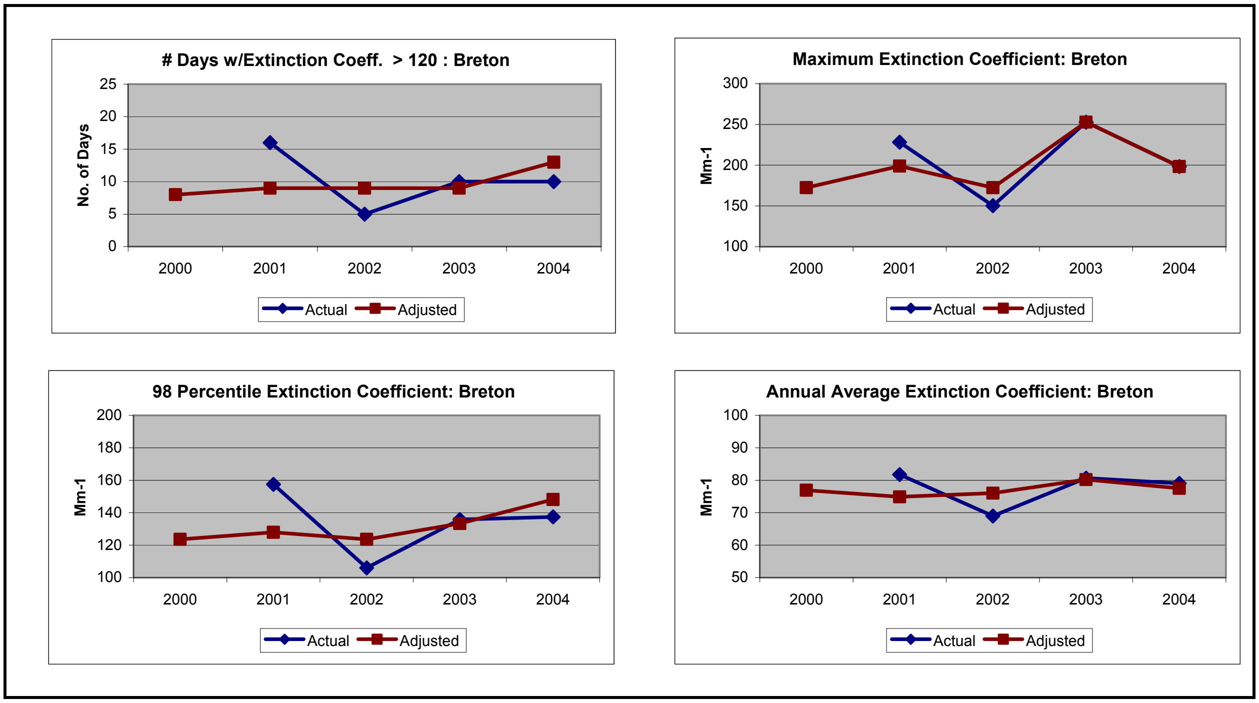


Figure 89a. Meteorologically adjusted extinction coefficient and visibility metrics based on the MMS synthesis visibility CART analysis results: Breton NWA.

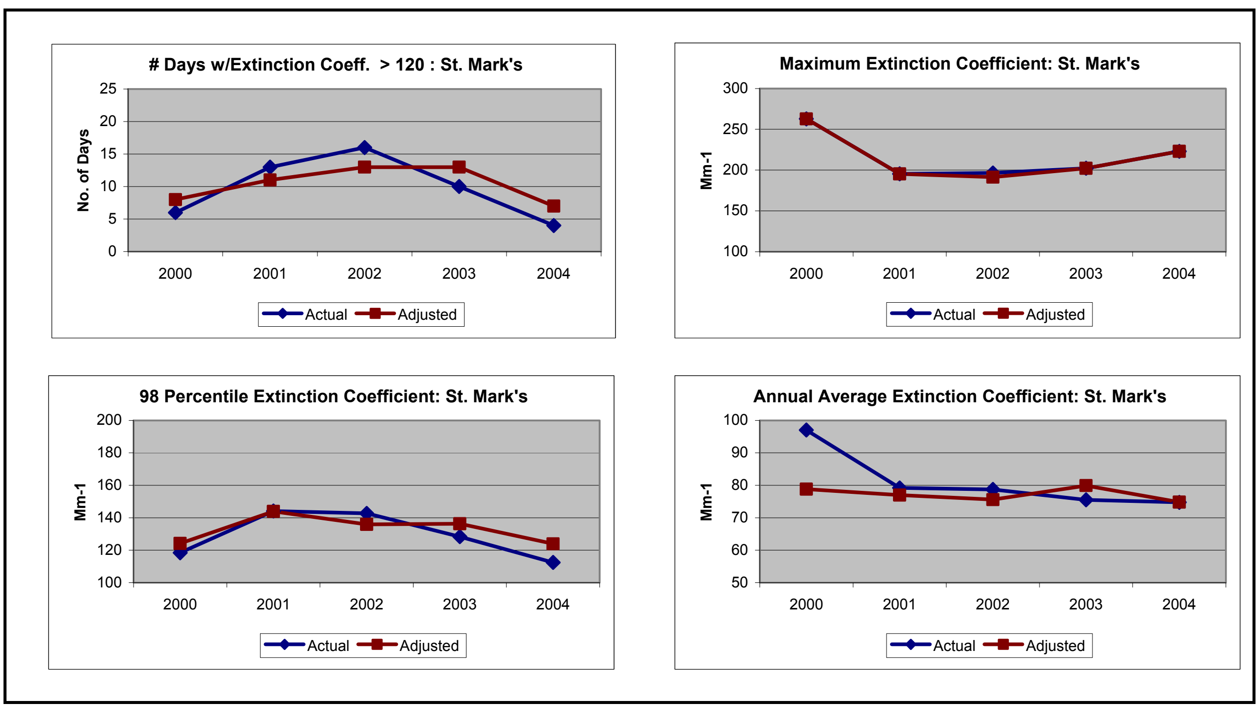


Figure 89b. Meteorologically adjusted extinction coefficient and visibility metrics based on the MMS synthesis visibility CART analysis results: St. Mark's NWA.

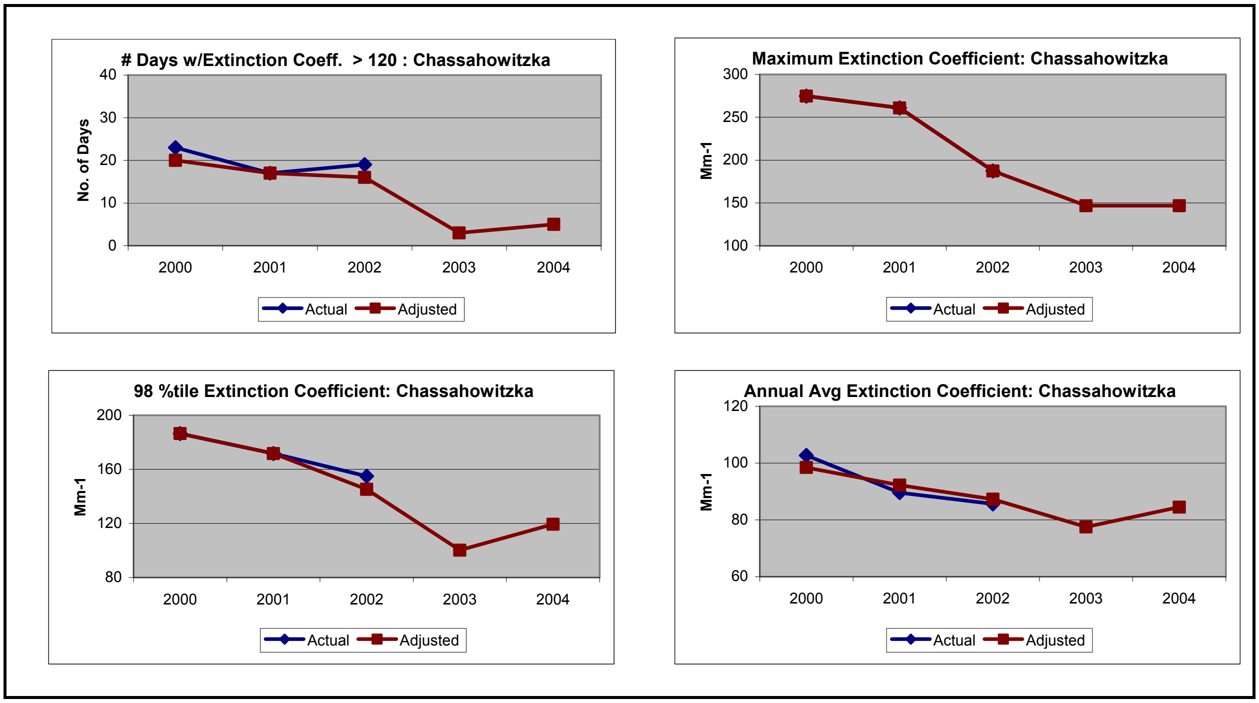


Figure 89c. Meteorologically adjusted extinction coefficient and visibility metrics based on the MMS synthesis visibility CART analysis results: Chassahowitzka NWA.

Neither the actual nor the adjusted values are very stable from year to year, and this may be caused by the limited dataset. Data are available every three days, and thus it was not possible to fully account for the range and frequency of the meteorological conditions in either the data sampling or the normalization. Overall, there is a slight upward tendency in (toward poorer visibility) for Breton $PM_{2.5}$ between 2000 and 2004, and a downward tendency for the other two sites.

7.4. Comparison with Emissions Data

Changes in offshore NO_x, VOC, and CO emissions between 2000 and 2005 are illustrated in Figure 90. Comparing these totals directly is complicated by differences in the quality of the platform equipment and activity data, the disruptions that occurred due to the hurricanes in the fourth quarter of 2005 and the use of different emission factors for diesel engines. Thus, it is difficult to identify any type of definitive increase or decrease due strictly to changes in offshore equipment counts and associated activity levels. For example, the relatively large increase in non-platform and other offshore source NO_x emissions in 2005 is primarily due to the use of different diesel engine emissions factors. For 2005, the offshore VOC and CO emissions are slightly smaller than 2000. With the small differences in the offshore emissions it is difficult attribute the changes in air quality at the coastal sites with these differences.

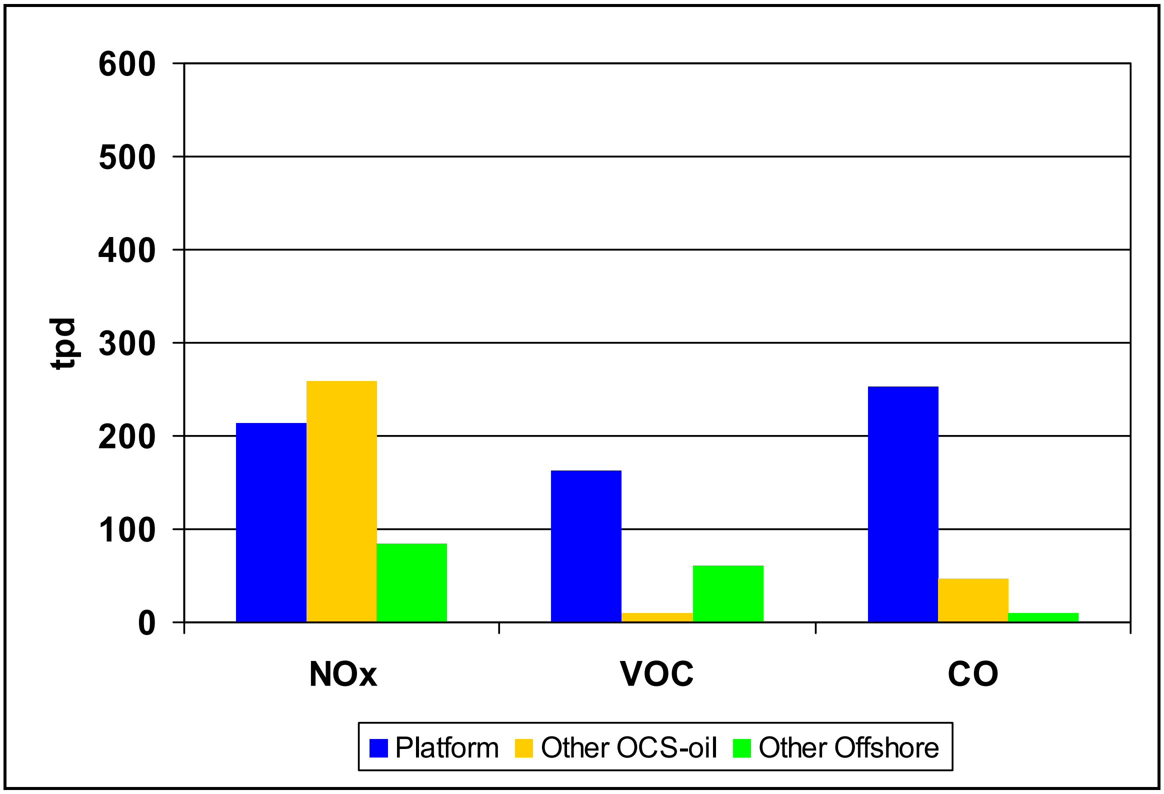


Figure 90a. Emissions for offshore platform, oil-and-gas-related non-platform and other sources for 2000 for the Gulf of Mexico.

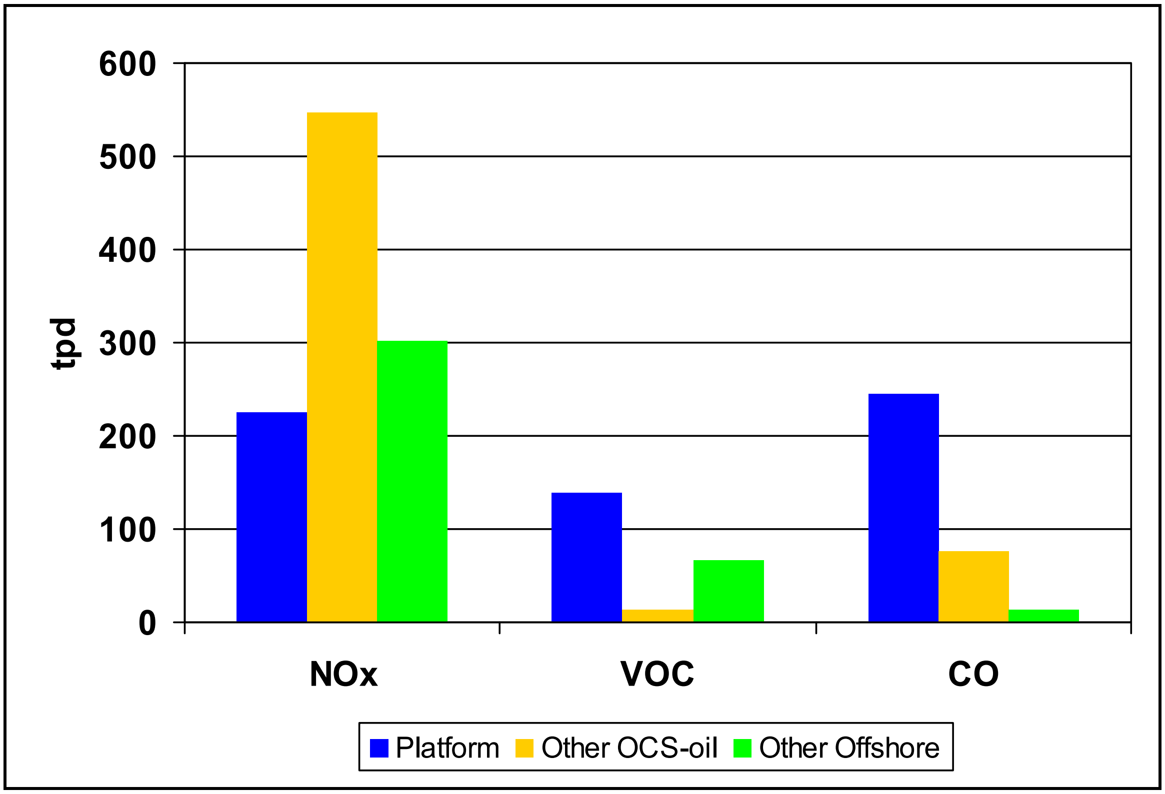


Figure 90b. Emissions for offshore platform, oil-and-gas-related non-platform and other sources for 2005 for the Gulf of Mexico.

In addition to the offshore emissions, the changes in onshore emissions for the various coastal areas of interest were examined. Figure 91 presents emissions for NO_x, VOC, CO, SO_2, and $PM_{2.5}$ for Houston/Galveston, Beaumont/Port Arthur, Lake Charles, Baton Rouge, New Orleans, Gulfport, Mobile, Pensacola and Bay County, FL. Also included in these plots are emission totals for 2000 and 2005 for all offshore oil and gas development related sources. With a few exceptions, the figures indicate an overall slight reduction in precursor emissions in the onshore areas between 1999 and 2005, of as much as 25 percent in some areas for some species. These reductions reflect the net of growth in equipment numbers and activity with changes (decreases) due to federal, state, and local controls, including reductions in mobile emissions associated with a newer fleet of vehicles as well as reductions due to various control programs on a variety of stationary sources. The overall slight downward trend in the coastal onshore emissions is likely offset somewhat by apparent increases in the offshore emissions (except for VOC emissions), especially if 2005 had been a typical production year offshore. However, as noted above, it is difficult to determine the actual causes and resulting changed in offshore emissions between 2000 and 2005. For ozone, the somewhat mixed changes in onshore NO_x and VOC emissions appear to corroborate the relatively flat trend in observed air quality for most regions. The decreases in the onshore NO_x, SO_2, and $PM_{2.5}$ emissions support the observed downward trends in $PM_{2.5}$ at most sites along the coast.

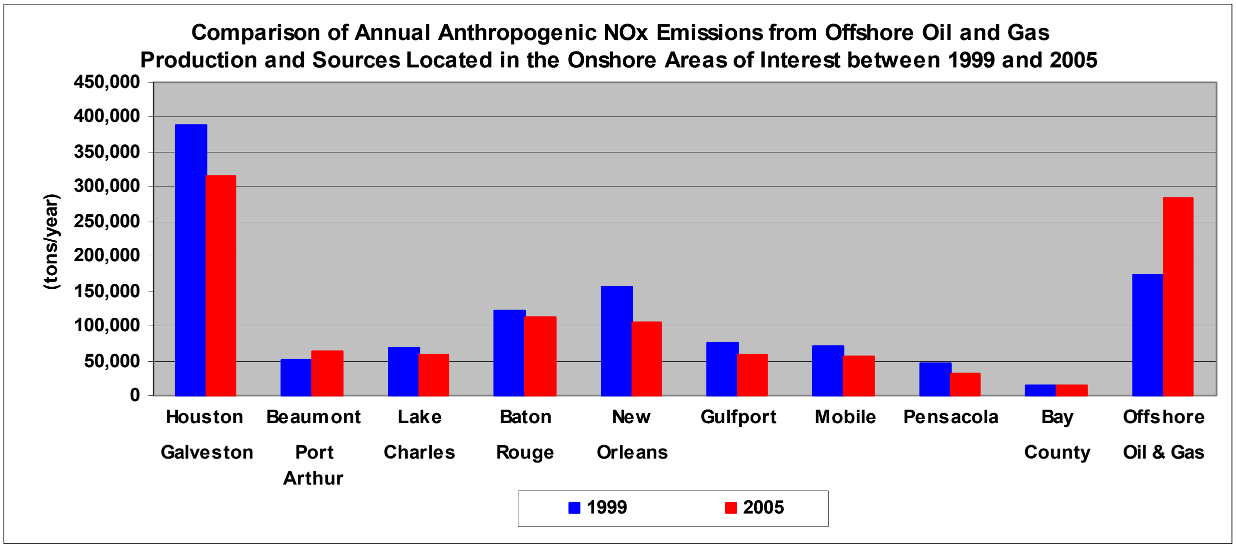


Figure 91a. Annual anthropogenic NO_x emissions for 1999 and 2005 from EPA's NEI.

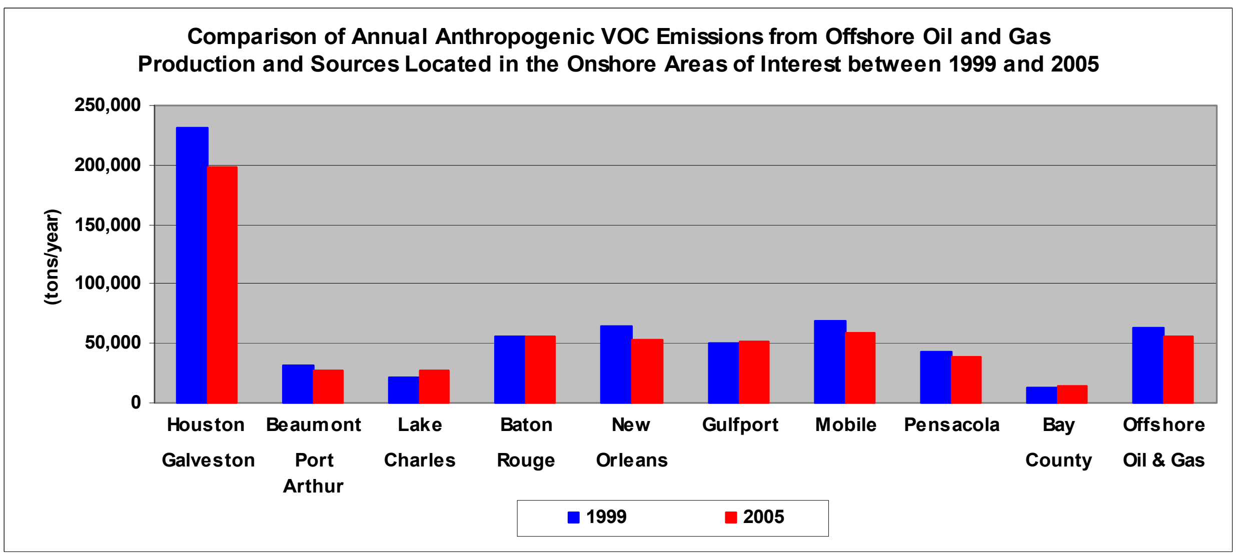


Figure 91b. Annual anthropogenic VOC emissions for 1999 and 2005 from EPA's NEI.

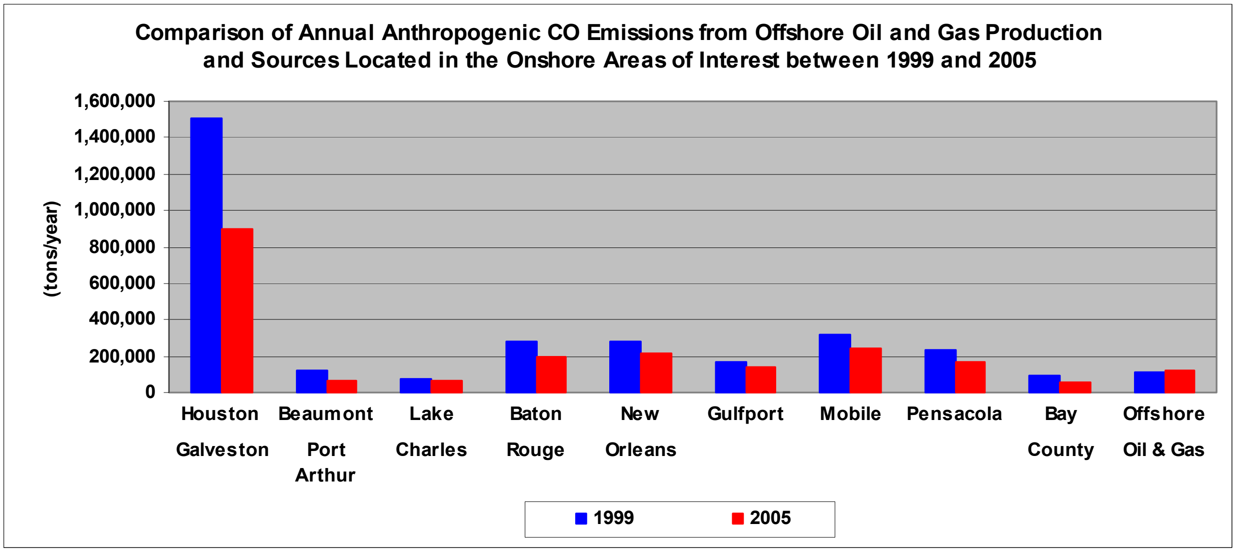


Figure 91c. Annual anthropogenic CO emissions for 1999 and 2005 from EPA's NEI.

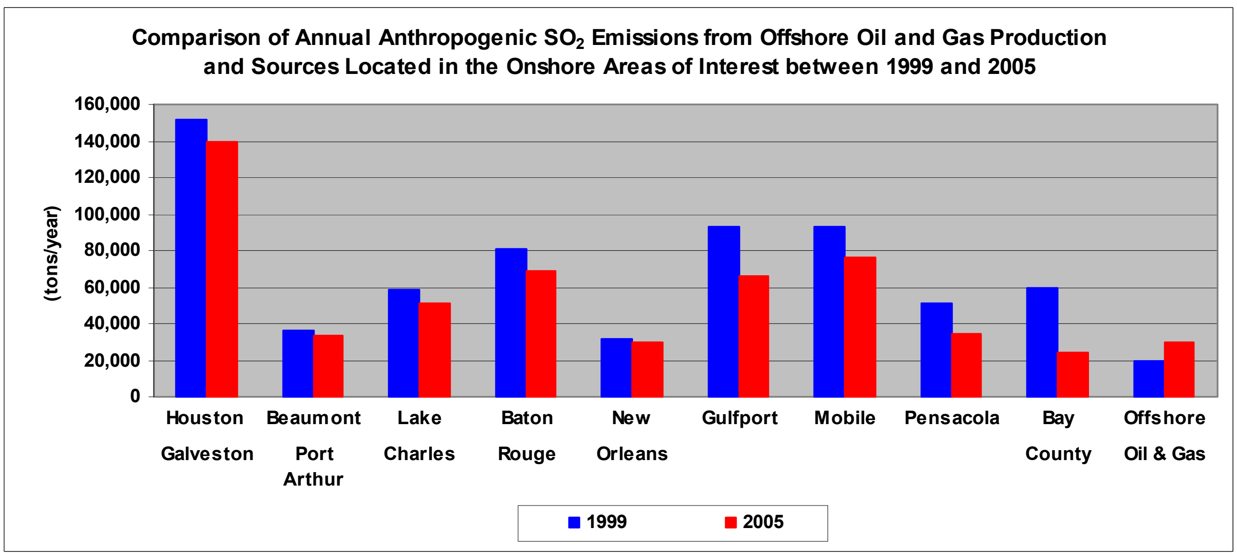


Figure 91d. Annual anthropogenic SO_2 emissions for 1999 and 2005 from EPA's NEI.

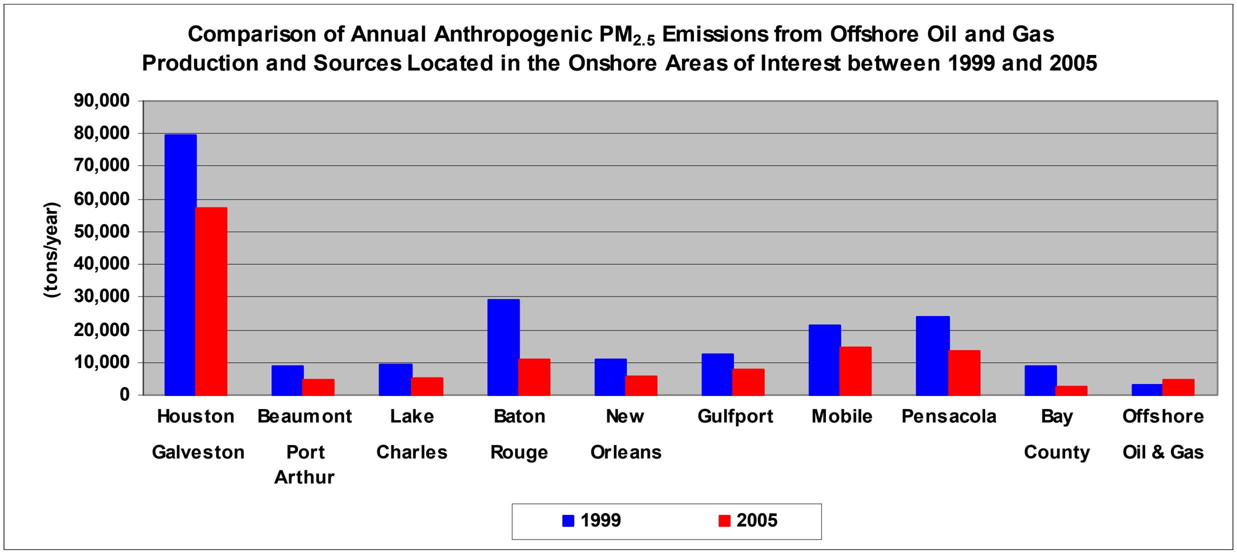


Figure 91e. Annual anthropogenic $PM_{2.5}$ emissions for 1999 and 2005 from EPA's NEI.

7.5. Summary of Findings

The development of meteorologically adjusted 8-hour ozone, $PM_{2.5}$ and visibility estimates relied on the CART classification results. Specifically, the frequency of occurrence of the conditions within each of the classification bins was used to define a typical year, and the individual years were normalized such that the different sets of meteorological conditions are represented no more or less than they are for this typical year.

The meteorological adjusted values show less variation from year to year than the actual values. For most areas, the results for ozone indicate that the high observed ozone concentrations for 2000 and the low concentrations for 2002 are attributable to the effects of meteorology. The results also indicate that the year-to-year trend in ozone is relatively flat between 2000 and 2004.

The results for $PM_{2.5}$ indicate a slight upward trend in $PM_{2.5}$ concentrations for Houston, both with and without the meteorological adjustment. For all other areas, there is a downward trend in $PM_{2.5}$ between 2000 and 2004, and the meteorologically adjusted values confirm the tendencies indicated by the actual data.

For visibility, neither the actual nor the adjusted values are very stable from year to year, possibly due to the limited (every three day) dataset. Overall, there is a slight upward tendency (toward poorer visibility) for Breton between 2000 and 2004, and a downward tendency for the other two sites.

Comparisons of the offshore emissions between 2000 and 2005 are complicated by changes in estimation methodology and other factors, so it is difficult to attribute changes in observed onshore air quality to the offshore emissions. The onshore emissions, with a few exceptions, do show slight decreases on all precursor species between 1999 and 2005 and so the relatively flat trends in ozone and the slight decreases in observed $PM_{2.5}$ at a number of sites is not inconsistent with these changes.

8.0 COMPARISON OF PRIOR METEOROLOGICAL MODELING RESULTS WITH ABL DATA

8.1. BACKGROUND AND OBJECTIVES

Prior photochemical modeling studies of the Gulf Coast have used dynamic meteorological models to simulate the meteorology of the region and prepare input fields for the photochemical modeling. In most cases, few over-water measurements (especially over-water, upper-air measurements) were available to assess whether the meteorological models were able to accurately represent the over-water conditions. This task was designed to assess whether the meteorological inputs used for the Gulf Coast Ozone Study (GCOS) photochemical modeling analysis (Douglas et al., 2001 and 2005) are consistent with the available over-water measurements from the MMS-sponsored Atmospheric Boundary Layer (ABL) study.

The meteorological inputs for the GCOS photochemical modeling application were generated using the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model, Version 5 (MM5). MM5 was applied with a 4-km horizontal resolution and 20 vertical layers. Key features of the MM5 modeling system that were employed include multiple nested-grid capabilities, incorporation of observed meteorological data using a four-dimensional data-assimilation technique, detailed treatment of the planetary boundary layer and the ability to accurately simulate features with non-negligible vertical velocity components such as the gulf breeze (a non-hydrostatic option). The emphasis of this comparison is on the vertical profiles of temperature, wind speed and wind direction for the two over-water locations with ABL measurements: Vermillion and South Marsh Island platforms. These are shown in Figure 92.

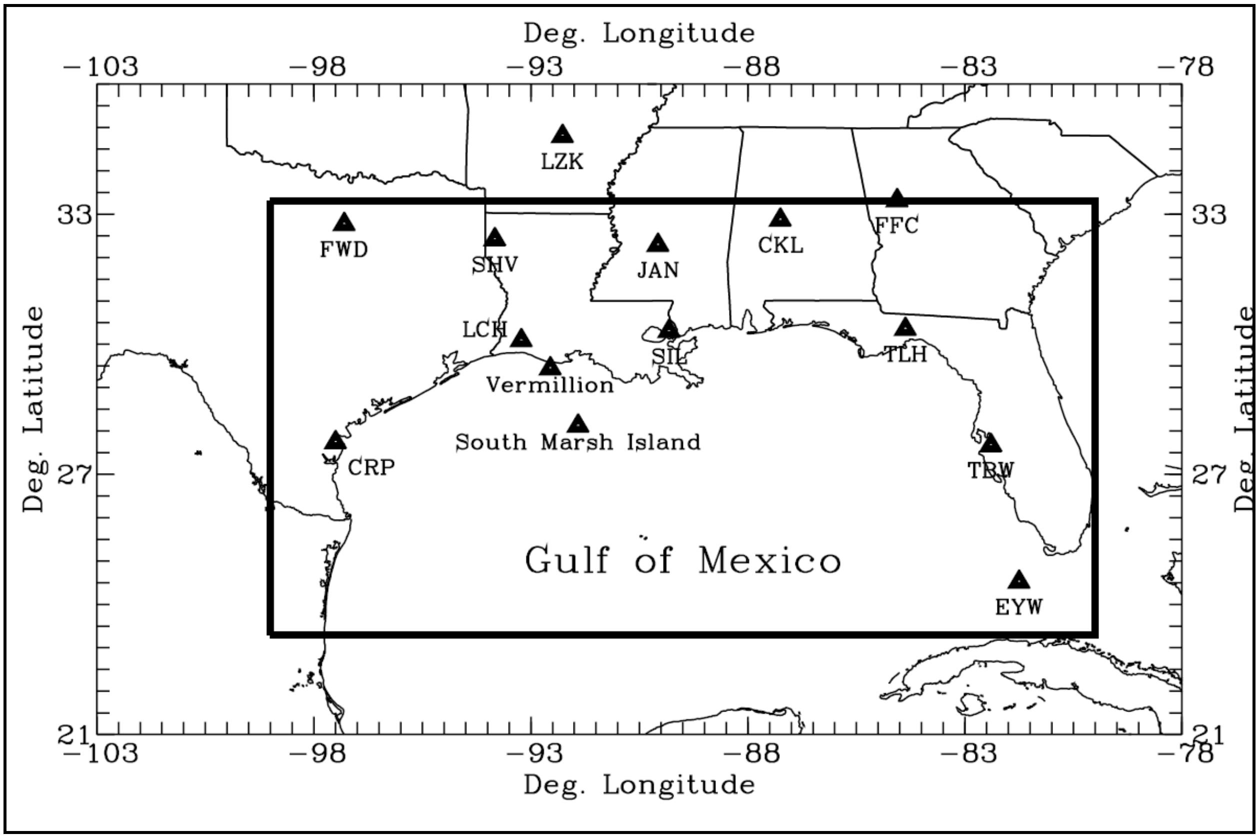


Figure 92. Monitoring locations for the MMS-sponsored Atmospheric Boundary Layer (ABL) study together with the locations of standard NWS radiosondes in the region.

The first step in this analysis was to match up the GCOS simulation periods with the available data from the ABL study. Three of the GCOS simulation periods occurred during the ABL study: 4-9 July 1998, 1-8 August 1999 and 13-26 July 2000. The ABL data for these periods were then extracted and processed for use in the comparison.

8.2. RESULTS

As part of the ABL study, vertical profiles of temperature for the two offshore locations were obtained using Radio Acoustic Sounding System (RASS) instruments. RASS measures virtual temperature (the temperature that an air parcel would achieve if all moisture were removed). For comparison purposes, the MM5 temperature and moisture fields were used to calculate virtual temperature profiles for the two locations. Figure 93 compares the MM5-derived and RASS virtual temperature profiles for the Vermillion Platform for selected high ozone days (one day for each of the three simulation periods). Specifically, days with high ozone in New Orleans, Baton Rouge or both areas were selected for presentation. Results for all days, however, were reviewed as part of the comparison. In this figure, each panel consists of four charts with results for 0700, 1000, 1600 and 1900 LST. The MM5-derived virtual temperature profile is shown with a solid line and the RASS virtual temperature is plotted with a dashed line. Note that the vertical extent of the RASS data typically ranges from about 100 or 200 m to about 500 or 750 m agl. For a few of the hours shown, RASS data are not available (although there was an attempt to minimize this in selecting the days).

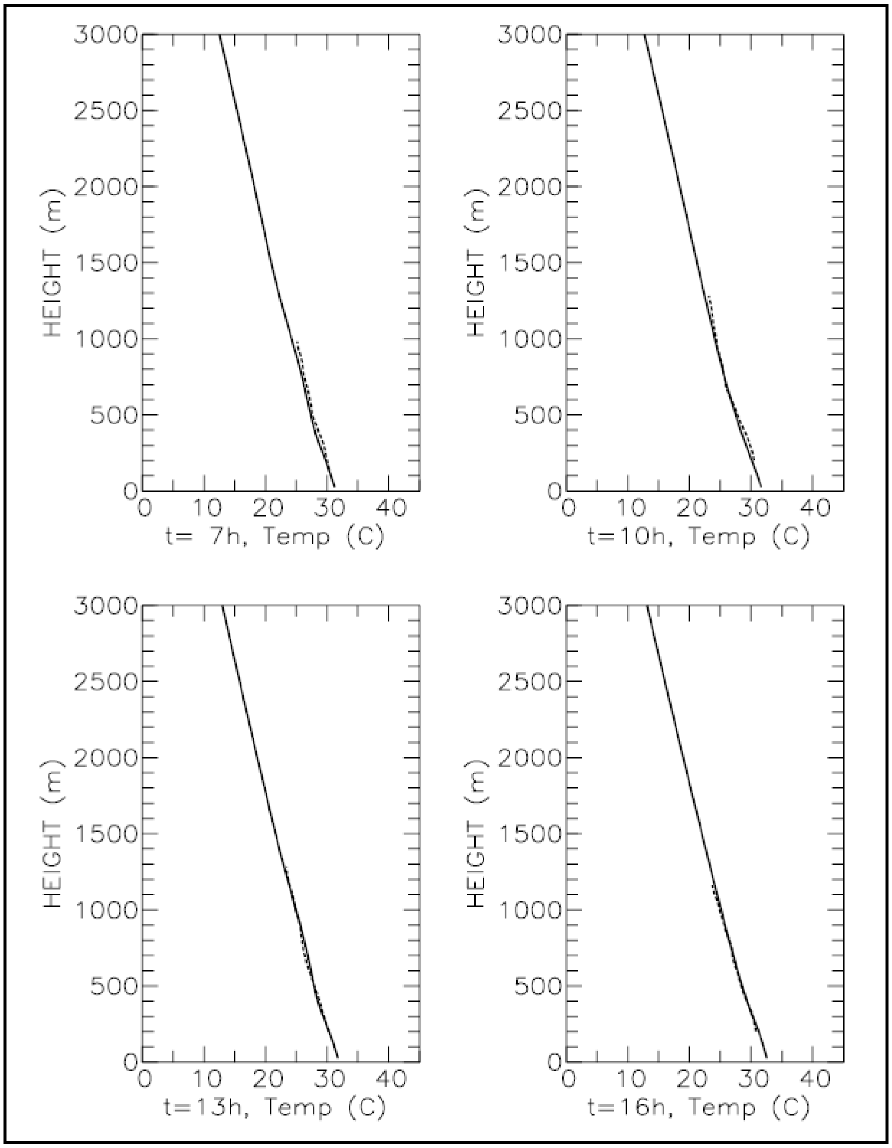


Figure 93a. Comparison of MM5-derived (solid) and observed (RASS-derived) (dashed) virtual temperature profile (°C) for the Vermillion Platform: 8 July 1998.

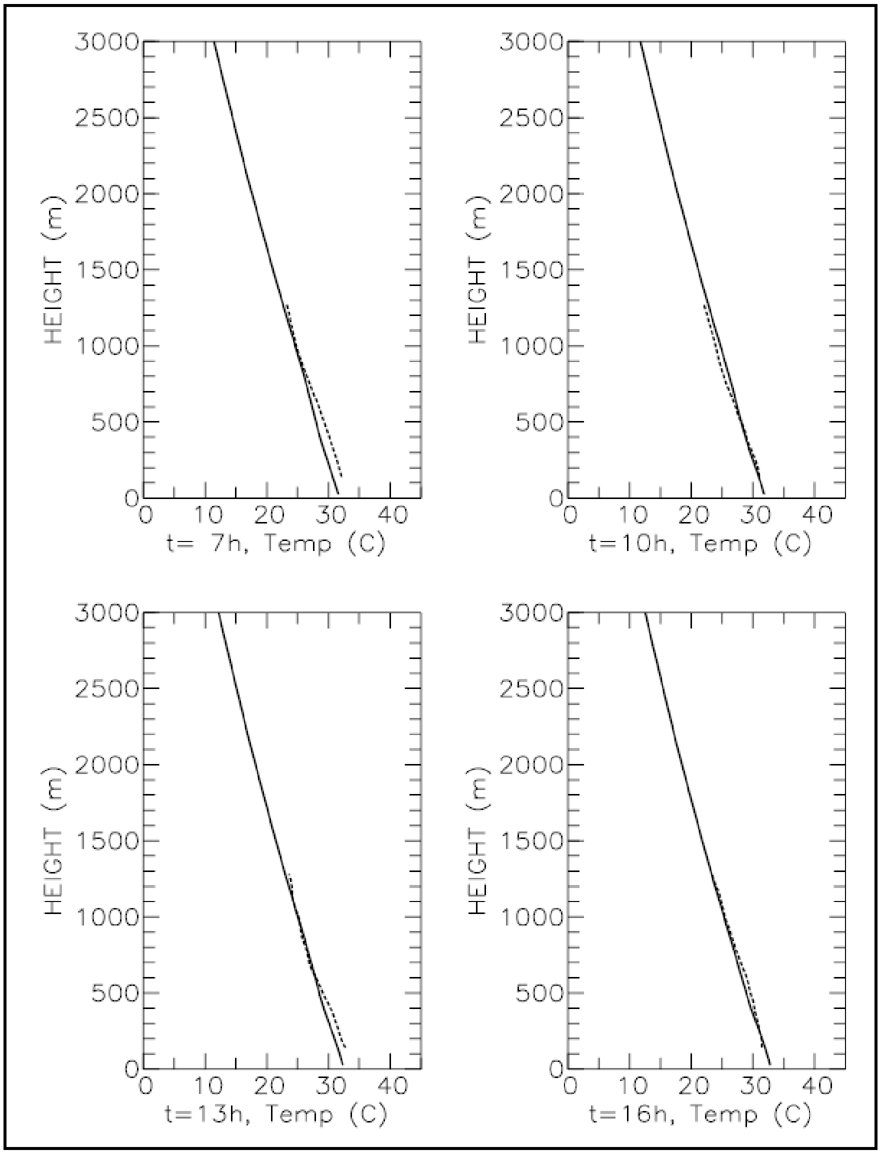


Figure 93b. Comparison of MM5-derived (solid) and observed (RASS-derived) (dashed) virtual temperature profile (°C) for the Vermillion Platform: 7 August 1999.

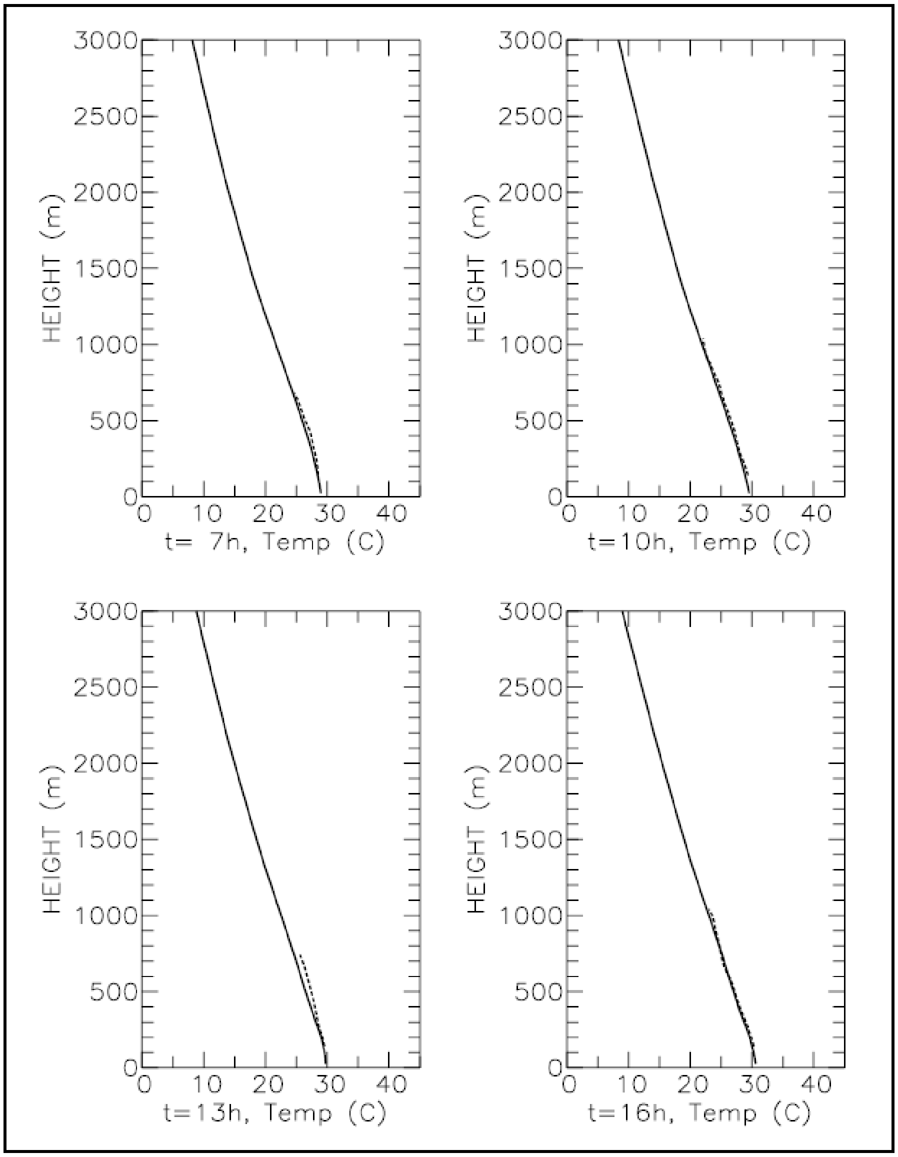


Figure 93c. Comparison of MM5-derived (solid) and observed (RASS-derived) (dashed) virtual temperature profile (°C) for the Vermillion Platform: 26 July 2000.

Figure 94 compares the MM5-derived and RASS virtual temperature profiles for South Marsh Island Platform for the same high ozone days. Again, the MM5-derived virtual temperature profile is shown with a solid line and the RASS virtual temperature is plotted with a dashed line.

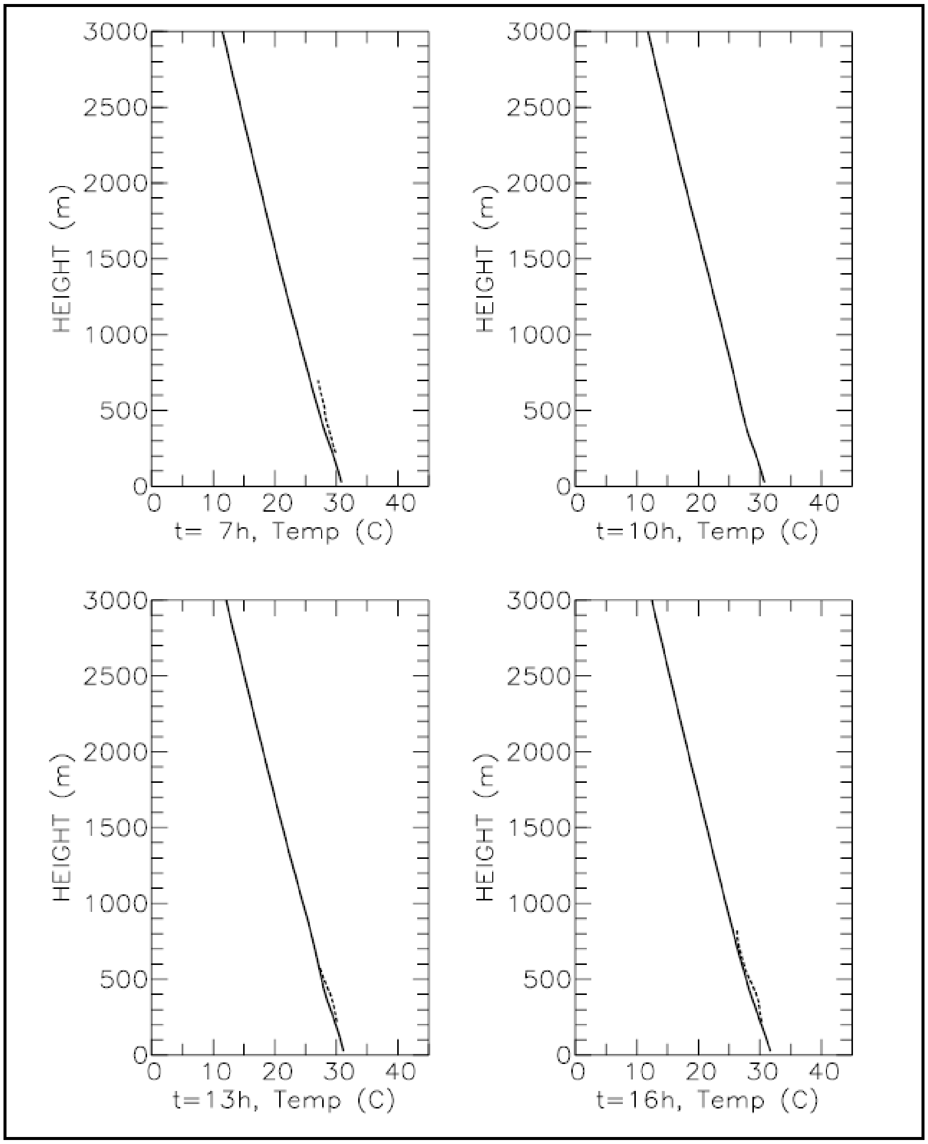


Figure 94a. Comparison of MM5-derived (solid) and observed (RASS-derived) (dashed) virtual temperature profile (°C) for the South Marsh Island Platform: 7 July 1998.

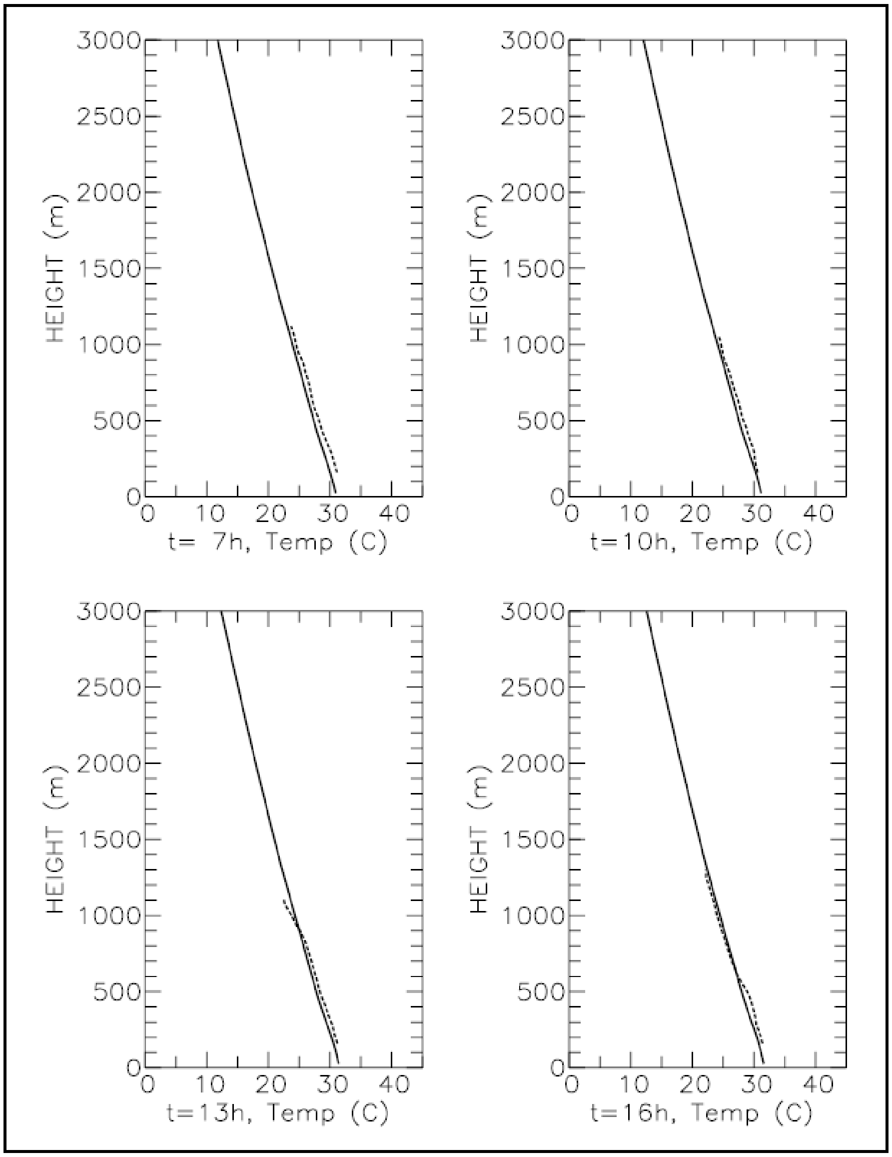


Figure 94b. Comparison of MM5-derived (solid) and observed (RASS-derived) (dashed) virtual temperature profile (°C) for the South Marsh Island Platform: 7 August 1999.

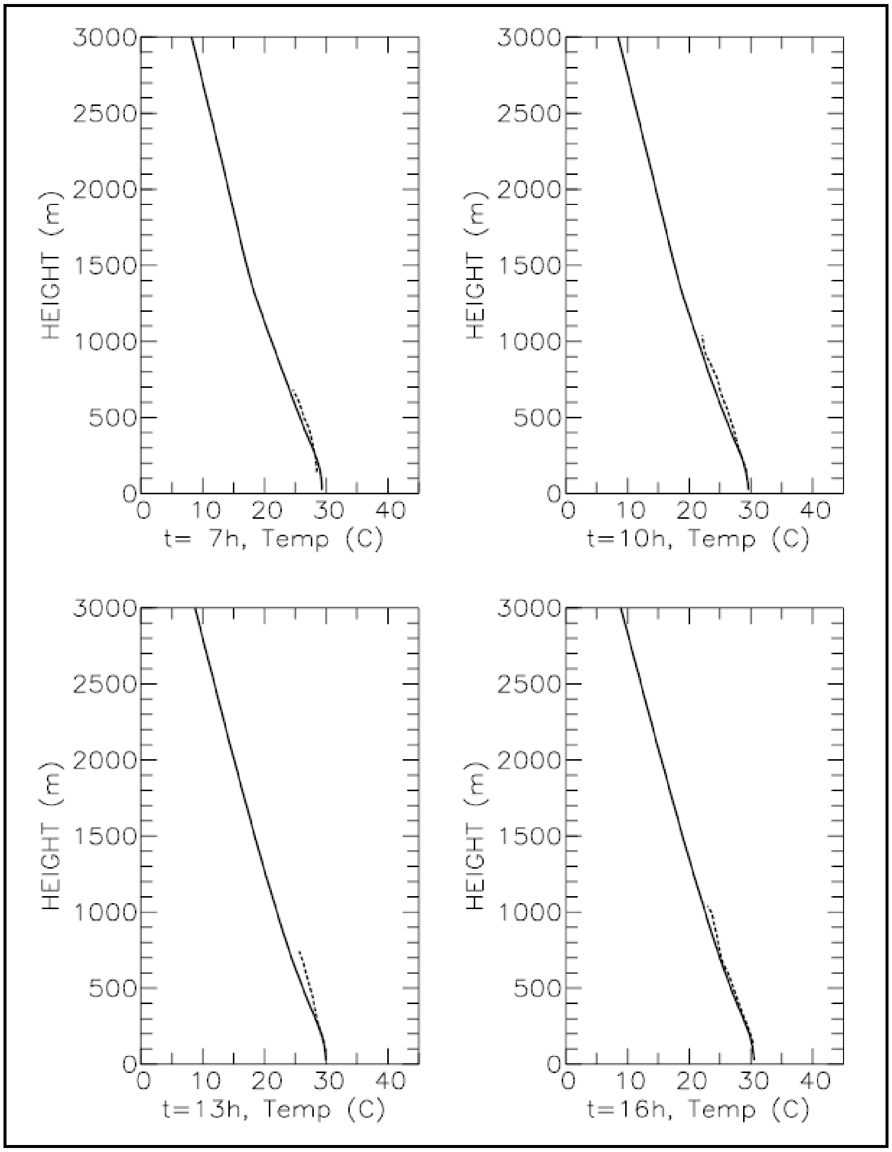


Figure 94c. Comparison of MM5-derived (solid) and observed (RASS-derived) (dashed) virtual temperature profile (°C) for the South Marsh Island Platform: 26 July 2000.

Figure 95 compares MM5- and profiler-derived vertical wind profiles for the Vermillion Platform for the selected high ozone day. Again results for all days were reviewed as part of the comparison. In this figure, the winds are displayed at hourly intervals. For each hour, the profiler data are plotted first and the MM5 results are shown next to these. Wind barbs indicate the direction from which the wind is blowing by the angle of the wind barb (a horizontal wind barb with the flag on the right indicates that winds are from the east) and speed by the length and number of the perpendicular bars (or flags), where each half bar is equal to 2.5 ms^{-1} or approximately 5 knots (kts). Color is also used to indicate speed. Note that the vertical extent of the profiler data typically ranges from about 200 or 300 m to more than 3000 m agl. The MM5 winds are shown at the levels used for the photochemical modeling and begin near the surface. For some of the days/hours shown, profiler data are not available.

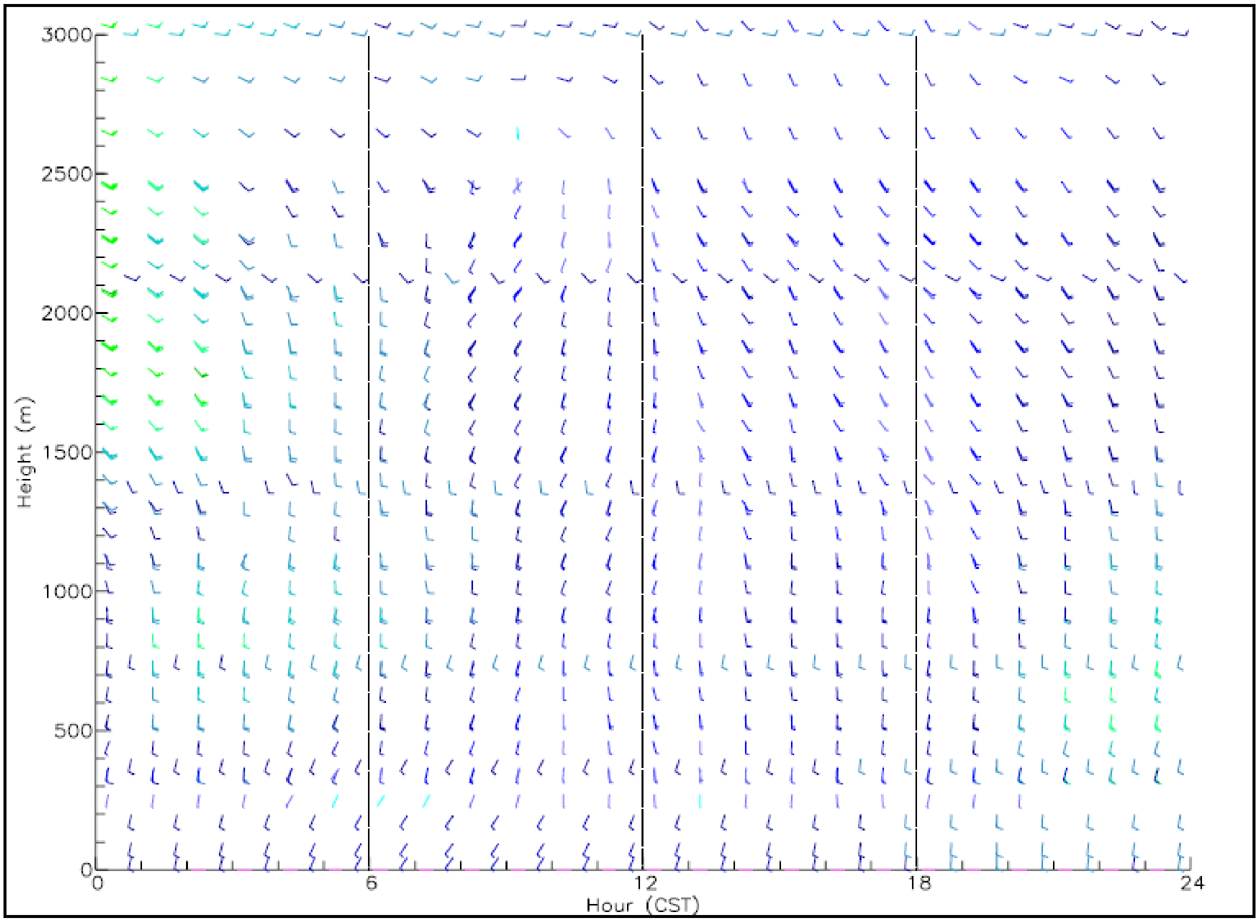


Figure 95a. Comparison of MM5-derived and observed (profiler-derived) winds for the Vermillion Platform: 8 July 1998. For each hour, the profiler winds are plotted first followed by the MM5-derived winds.

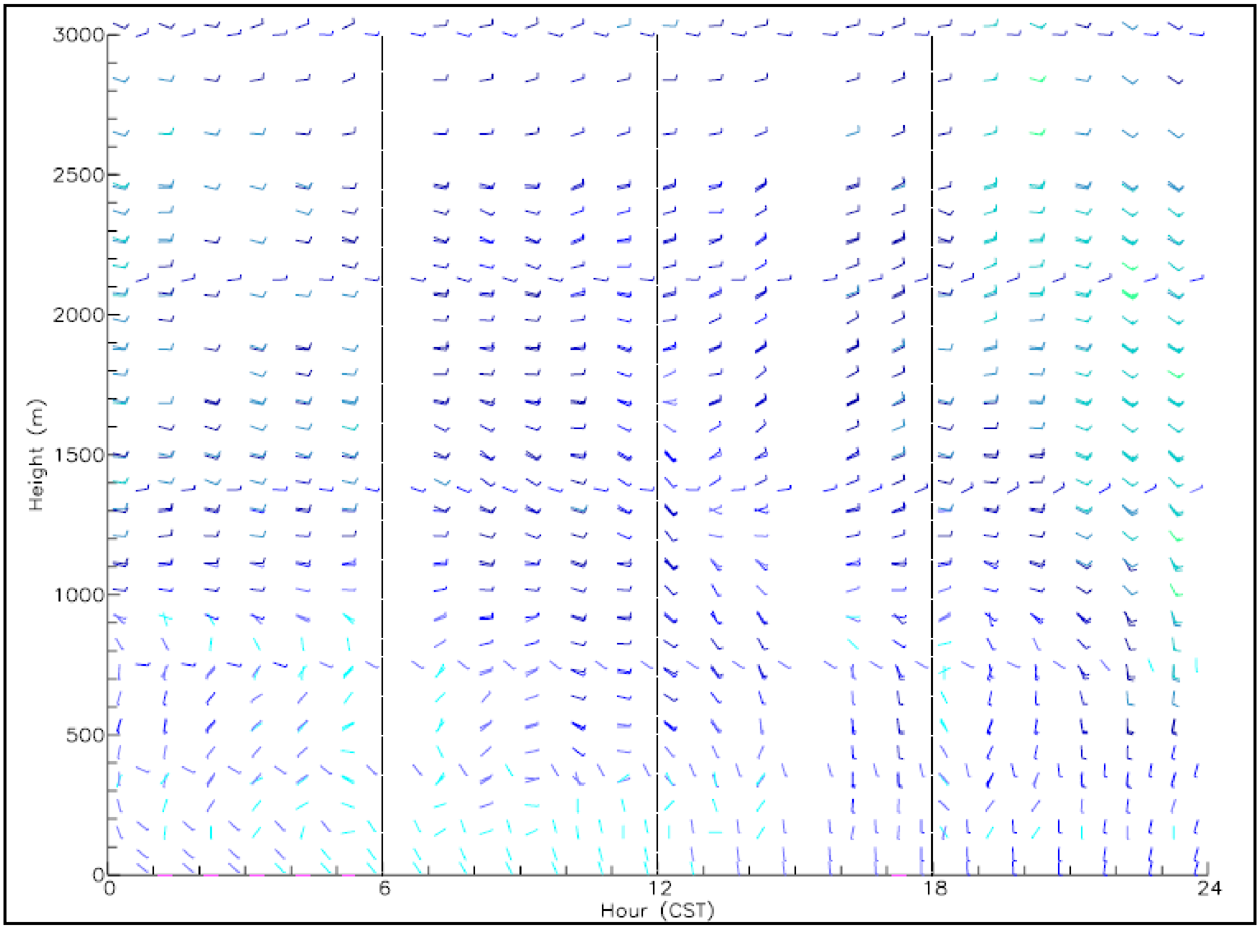


Figure 95b. Comparison of MM5-derived and observed (profiler-derived) winds for the Vermillion Platform: 7 August 1999. For each hour, the profiler winds are plotted first followed by the MM5-derived winds.

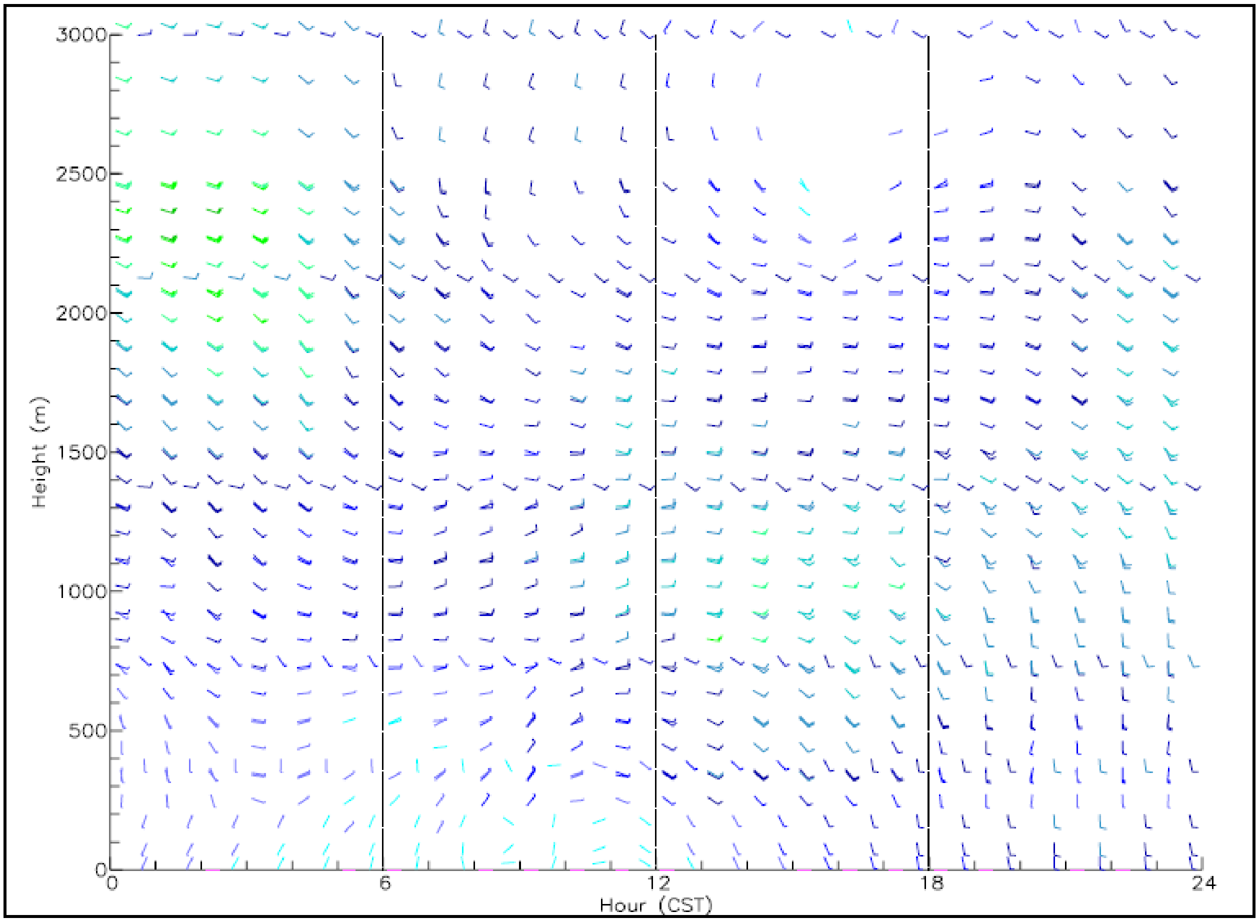


Figure 95c. Comparison of MM5-derived and observed (profiler-derived) winds for the Vermillion Platform: 26 July 2000. For each hour, the profiler winds are plotted first followed by the MM5-derived winds.

Figure 96 compares the MM5- and profiler-derived wind profiles for South Marsh Island Platform for the same high ozone days. Again, the profiler data are presented first, followed by the MM5-derived values.

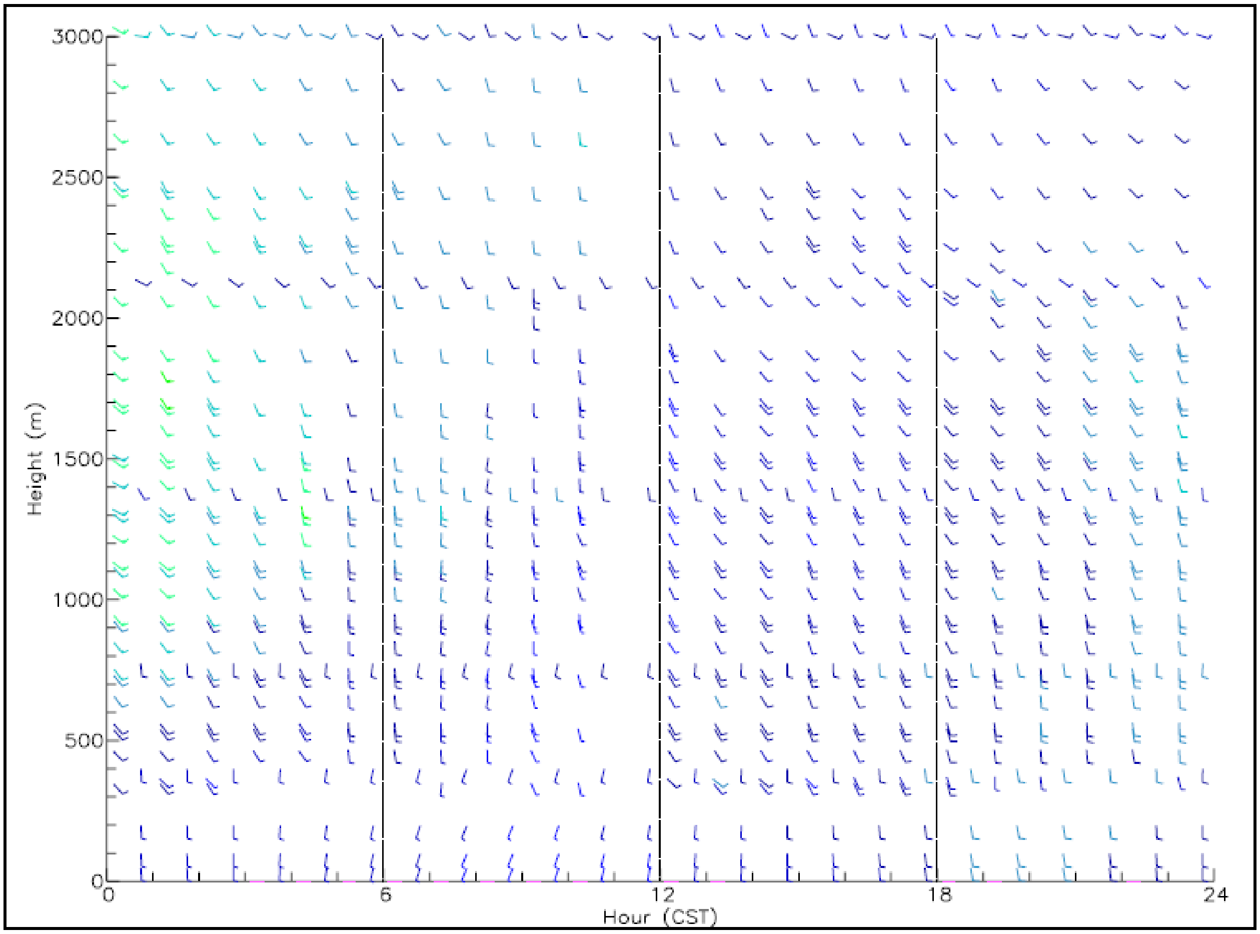


Figure 96a. Comparison of MM5-derived and observed (profiler-derived) winds for the South Marsh Island Platform: 8 July 1998. For each hour, the profiler winds are plotted first followed by the MM5-derived winds.

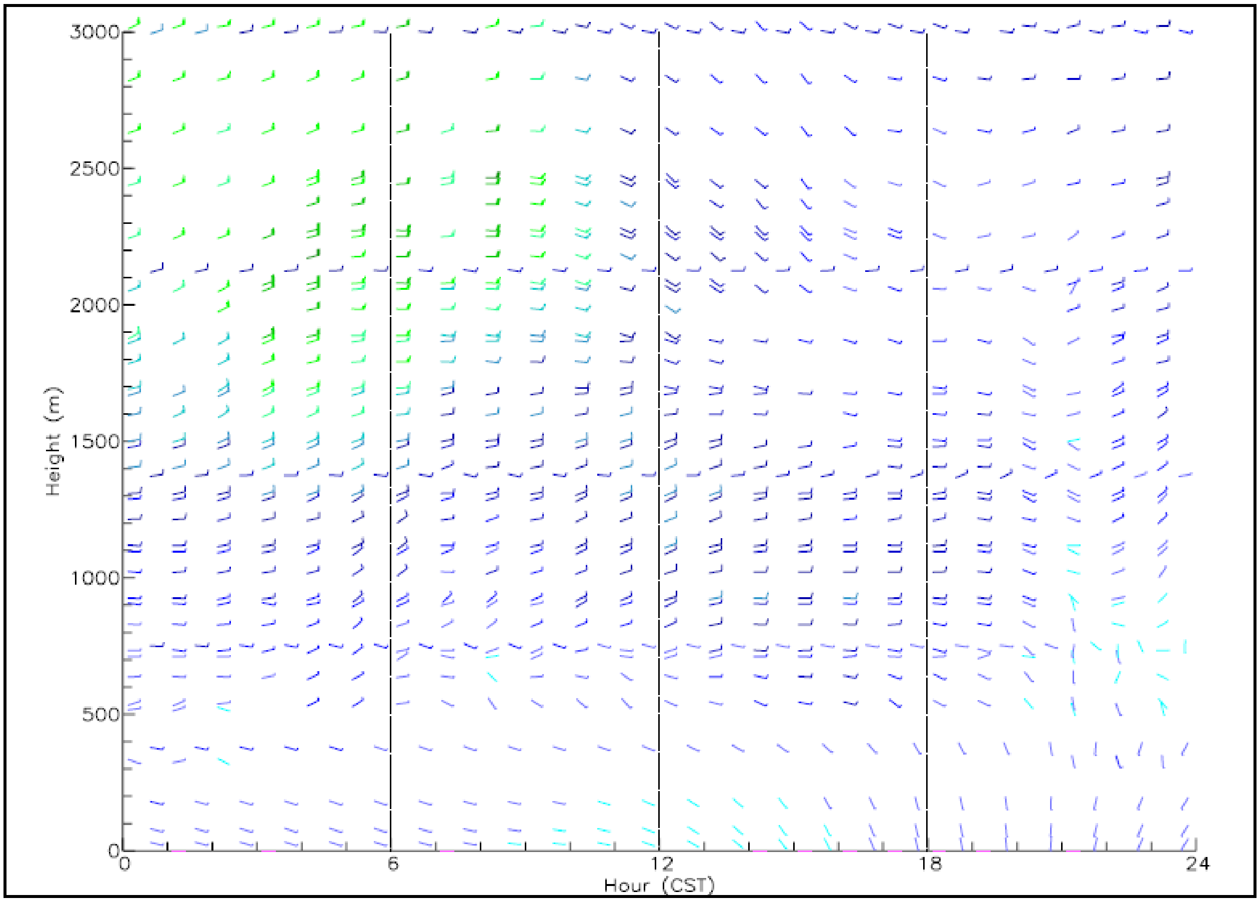


Figure 96b. Comparison of MM5-derived and observed (profiler-derived) winds for the South Marsh Island Platform: 7 August 1999. For each hour, the profiler winds are plotted first followed by the MM5-derived winds.

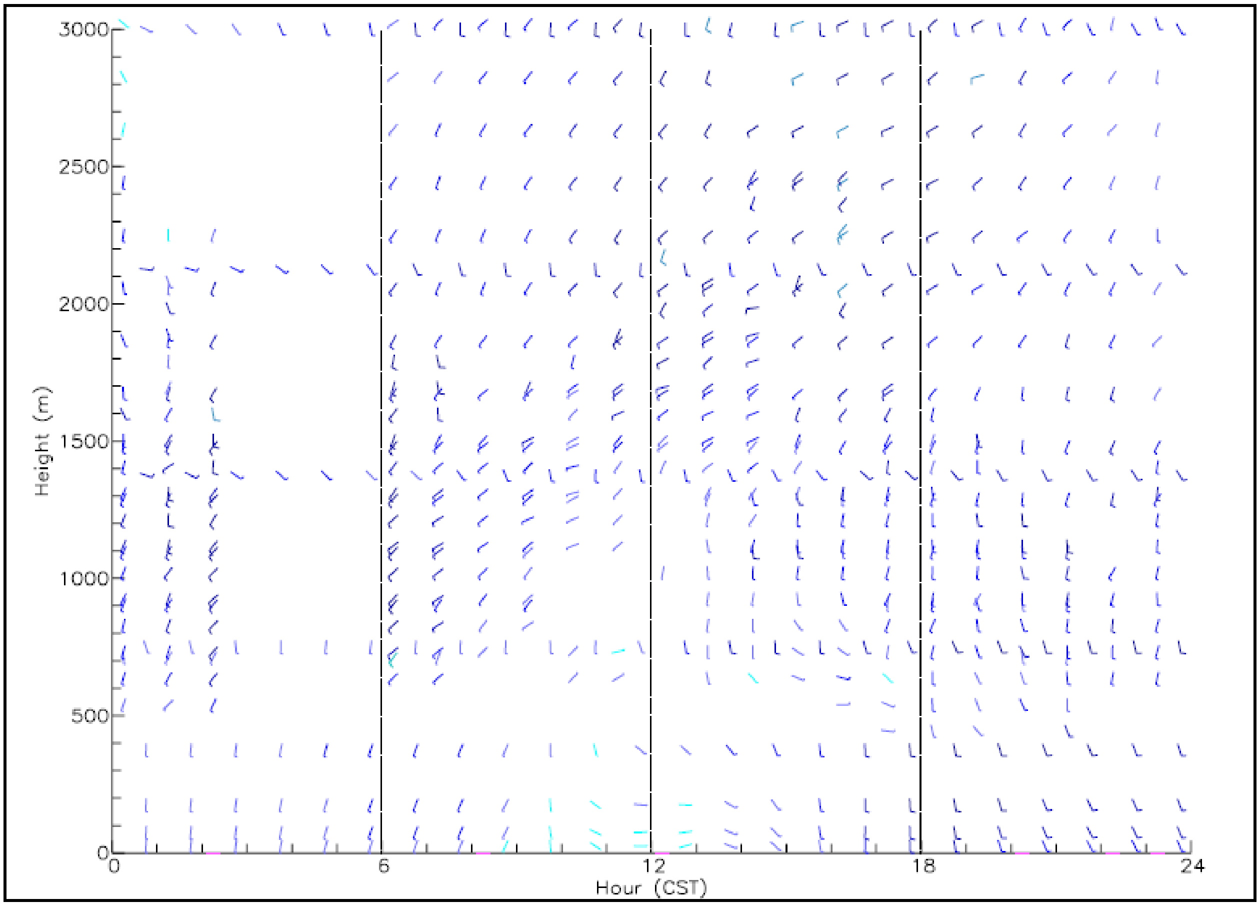


Figure 96c. Comparison of MM5-derived and observed (profiler-derived) winds for the South Marsh Island Platform: 26 July 2000. For each hour, the profiler winds are plotted first followed by the MM5-derived winds.

The virtual temperature profiles at the two offshore locations are generally very well represented by the MM5 model. For a few of the cases that are not shown here, the data have more structure and vary more in the vertical than the simulation-derived values.

In many cases, the wind profiles are also well represented by MM5. However, performance is least good during periods of low wind speeds and changing wind direction with time (transition periods).

Overall, it appears that the MM5 results from the GCOS modeling study were very reasonable for the two offshore locations. This good performance may have been helped by the assimilation of data from nearby onshore locations (depicted in Figure 92). However, the MM5 results indicate some skill in simulating the temperature and wind features that characterize the atmospheric boundary layer structure of over the Gulf during these three high ozone periods. Additional MM5 layers could further improve the representation of the over-water features.

9.0 SUMMARY OF KEY FINDINGS AND RECOMMENDATIONS FOR FURTHER STUDIES

The MMS synthesis database can be used to support a variety of air quality studies for the Gulf of Mexico (GOM) region. The geographical, meteorological and emissions characteristics influence the air quality of the GOM region. Air quality issues affect the entire region but are especially pronounced in the coastal urban and industrial areas of Texas and Louisiana (Houston/Galveston, Beaumont/Port Arthur, Baton Rouge). Ozone is an air quality concern for most (monitored) areas along the Gulf Coast. The calculated design values for the most recent periods are above the 8-hour standard for a number of coastal urban areas in Texas, Louisiana, Mississippi, Alabama, and Florida. $PM_{2.5}$ concentrations tend to be relatively low along the Gulf Coast (e.g., compared to national standards), but some high values have been observed recently in the Houston area. Visibility (while generally good) is an important metric for the Class I areas (in the region). Future improvements in visibility are needed to achieve the mandated regional-haze goals for these areas.

9.1. DATA SUMMARIES

Data summaries provide an overview of the meteorological, air quality and emissions data and highlight key features/components of the integrated database. A number of routine and region-specific meteorological parameters were examined to assess the meteorological characteristics of the GOM region, and to examine how meteorological conditions vary throughout the region and throughout the year.

9.1.1. Meteorological Data

Based on the surface meteorological data, temperatures within the region exhibit the expected seasonal characteristics. Wind speeds are lower and precipitation amounts are higher during the summer months (compared to the winter months). Southerly winds (winds from the south) tend to appear and dominate during the summer months. Precipitation amounts and the month-to-month variations in precipitation vary throughout the region. There are slight year-to-year variations in several parameters, and considerable annual variability in precipitation. With a few exceptions, the average persistence index does not vary much from year to year and is similar among all sites, indicating that no years stand out as having a much greater frequency of gulf breeze conditions compared to other years. Of course, these general findings can be further refined for each area.

At the buoy sites, sea surface temperature exhibits the expected seasonal variations but does not vary much from year to year. Wind speeds are lower and daytime winds (on average) exhibit a southerly component during the summer months (compared to the remainder of the year). The average persistence index shows much more month-to-month variability than for the onshore locations, but does not vary much from year to year and is similar among all sites. Considering only the ozone season months, the gulf breeze is most likely to occur in August and in September.

The upper-air data for all sites exhibit similar characteristics at the 850 mb level. Higher dew-point temperatures during the warmer months reflect the relatively humid conditions of the region. Wind speeds aloft are lowest during the summer months. Easterly and northerly winds aloft dominate the average 850 mb wind directions for July–October for Lake Charles, August through October for Slidell, September and October for Tallahassee and October for Tampa (onset is later for each location, from west to east). For the remaining months, winds aloft are generally southwesterly for Lake Charles, westerly for Slidell and Tallahassee and southwesterly to southerly for Tampa. The stability index indicates greater stability during the winter months and less stability during the summer months.

9.1.2. Ozone Data

Ozone is one of the key air quality issues affecting the coastal urban areas. Most of the urban and/or industrial areas along the coast are expected to be nonattainment areas relative to the current 8-hour ozone standard of 75 ppb. The highest ozone concentrations are observed in the Houston/Galveston, Beaumont/Port Arthur and Baton Rouge areas. Thus, while all of the monitored areas experience high ozone, the severity of the ozone problem is correlated with the size of the urban area and the amount and type of emissions.

Without fully accounting for year-to-year differences in meteorology, a downward trend in the design values is apparent for most sites for the period 1999 (or 2000) to 2004. The design values for Houston show a downward trend from 1995 to 2004. On the other hand, the design values for Lake Charles show no tendency to either increase or decrease during that same period.

In the western part of the region, the highest ozone concentrations tend to occur in August and September. Further eastward, the timing pattern of the ozone season changes. For example, high ozone/exceedance days occur in May, July and August in Gulfport, Pensacola and several other areas and in May in the Tampa area.

Site-specific, average diurnal profiles also show some distinct differences that may be related to proximity to the coastline and the influence of the gulf breeze. Coastal sites exhibit a prolonged period of moderate to high ozone during the daytime hours that is consistent with photochemical production early in the day followed by the onshore transport of ozone from over the Gulf by the gulf breeze during the afternoon hours.

The categorical comparisons reveal some expected patterns. For most areas, there are clear relationships between ozone concentration and 1) prior-day ozone concentrations, 2) temperature, 3) relative humidity, 4) wind speed, both near the surface and aloft, and 5) stability. Higher ozone concentrations are associated with higher prior day ozone concentrations (carryover), higher temperatures, lower relative humidity, lower wind speeds, and greater stability. For several areas, such as Galveston, Beaumont/Port Arthur and Pensacola, higher ozone is associated with less persistent wind directions (a greater tendency for a gulf breeze). Overall, the data suggest that the relationship between ozone and meteorology is rather complex (and that no single meteorological parameter or group of parameters easily defines this relationship).

The combined analysis of wind and ozone data indicates that higher ozone concentrations tend to occur under conditions of low surface wind speeds and westerly to southeasterly winds aloft. The lowest concentrations tend occur with southerly or southwesterly winds, although this varies slightly from area to area.

Analysis of the effects of the gulf breeze or recirculation reveals that, for all areas of interest, the average 8-hour ozone concentration for days with recirculation and a possible gulf breeze is higher than for days without recirculation. The difference ranges from about 2 ppb for Northwest Houston to 20 ppb for Galveston. On average, considering all locations, days with recirculation and a possible gulf breeze have a maximum 8-hour ozone value about 9 ppb greater than days without recirculation.

9.1.3. $PM_{2.5}$ Data

Annual average $PM_{2.5}$ concentrations for the selected areas are typically within the range of 10 to 15 μgm^{-3} during the 2000 to 2004 period, with a few values greater than 15. Similarly, the 98^{th} percentile 24-hour average $PM_{2.5}$ values for each year are typically less than 35 μgm^{-3}. Several areas, however, have 98^{th} percentile concentrations greater than 30 μgm^{-3}, especially in 1999, 2000 and 2004. The design values reflect attainment of the both the annual and 24-hr $PM_{2.5}$ standards for most sites and design-value periods.

For all areas, the average daily concentrations do not vary considerably from month to month. The average maximum concentrations are highest for most of the selected sites in July, August and September, with some additional high values in October and May.

Without fully accounting for year-to-year differences in meteorology, a downward trend in both the annual and 24-hour design values is apparent for most sites for the period 1999 (or 2000) to 2004. Several of the sites along the eastern Gulf coast also show an increase in the 24-hour design value for one or more of the later averaging periods.

Categorical comparisons reveal that higher $PM_{2.5}$ concentrations are associated with higher prior day concentrations (carryover), lower wind speeds and greater stability.

The combined analysis of wind and $PM_{2.5}$ data indicates that, for most sites, higher $PM_{2.5}$ concentrations occur under conditions of low surface wind speeds and northerly to easterly wind aloft.

Analysis of the effects of the gulf breeze or recirculation reveals that, for all areas, the average $PM_{2.5}$ concentration for days with recirculation and a possible gulf breeze is higher than for days without recirculation. The difference ranges from about 0.3 μgm^{-3} for Lake Charles, to 1.5 μgm^{-3} for Central Houston and Galveston, to 1.6 μgm^{-3} for New Orleans. On average, considering all locations, days with recirculation and a possible gulf breeze have a maximum $PM_{2.5}$ value about 1 μgm^{-3} greater than days without recirculation.

9.1.4. Visibility

In this study, visibility was examined for three Class I areas along the coast: the Breton, St. Mark's and Chassahowitzka National Wilderness Areas. IMPROVE network monitors are located in all three of these areas and current data indicate that some future improvement in visibility will be needed for all three areas to achieve EPA's regional haze goals. For all three areas, the visibility metrics vary from year to year and there is no clear trend in visibility during the baseline period.

The worst visibility days occur under a variety of conditions. The distribution of the 20 percent worst visibility days was examined relative to $PM_{2.5}$ concentrations and relative humidity. $PM_{2.5}$ concentrations were classified as very high, high, moderate or low based on the 70, 90 and 97 percentile values from the observed data. Relative humidity values were also classified as very high (greater than or equal to 95 percent), high (85-95 percent), moderate (75-85 percent), low-moderate (60-75 percent) or low (less than 60 percent). The predominant conditions for the worst visibility days include very high $PM_{2.5}$ and low to moderate relative humidity, high to moderate $PM_{2.5}$ and relative humidity, and low $PM_{2.5}$ and high relative humidity.

The combined analysis of wind and visibility data indicates that, for all three areas, higher extinction coefficients occur under a range of wind speeds and wind directions. Poor visibility conditions for these areas can be attributed to high $PM_{2.5}$ and/or high relative humidity. Since most offshore emissions sources are adjacent to Texas and Louisiana, Breton is most likely to be affected by emissions from offshore sources, among the three Class I areas. The high extinction coefficients under conditions of onshore flow are potentially the combined result of high humidity and particulate matter formed from emissions from offshore sources.

Analysis of the effects of the gulf breeze or recirculation on visibility reveals that the average extinction value for days with recirculation and/or a possible gulf breeze is higher than for days without recirculation. The differences are 3.7 Mm^{-1} for Breton, 8.6 Mm^{-1} for St. Mark's and 24 Mm^{-1} for Chassahowitzka. The average difference is 12.1 Mm^{-1}. This analysis indicates that recirculation leads to higher pollutant concentrations and poorer visibility in all three areas. For those areas where this recirculation is due to the presence of a gulf breeze, it follows that the gulf breeze circulation contributes to visibility issues along the Gulf Coast.

9.1.5. Emissions Data

Offshore and onshore emissions inventory information was examined to evaluate potential relationships with observed air quality in the coastal regions. Precursor emissions related to oil and gas development and other offshore activity are relatively small compared to emissions in various metropolitan areas along the Gulf Coast, but do contribute somewhat to observed ozone and $PM_{2.5}$ concentration levels. Due to various complicating factors, it is difficult to see a distinct trend in offshore precursor emissions. However, with a few exceptions, the onshore emissions do show a slight reduction between 1999 and 2005 and this correlates with the relatively flat trends shown for ozone and the slightly downward trends for $PM_{2.5}$ observed at a number of the coastal sites.

9.2. CART ANALYSES

The CART analysis, together with the selected air quality and meteorological input parameters, correctly classifies, on average, approximately 83 percent of the ozone season days for 2000-2004 according to daily maximum 8-hour ozone concentration. When only meteorological data are used as input to the CART analysis, classification accuracy is one to five percent lower for the individual areas. This indicates that the selected meteorological data are reasonably good indicators of ozone concentration for most areas along the Gulf Coast.

For $PM_{2.5}$, CART correctly classifies, on average, approximately 81 percent of the days for 2000-2004 according to 24-hour average $PM_{2.5}$ concentration. When only meteorological data are used as input to the CART analysis, classification accuracy is lower by two percent for the Lake Charles area and five to eight percent for all other areas. This indicates that the selected meteorological data are incomplete indicators of $PM_{2.5}$ concentration for most areas along the Gulf Coast. In the context of the CART analyses, prior-day air quality data are more important for $PM_{2.5}$ than for ozone.

For visibility, CART correctly classifies, on average, approximately 72 percent of the days for 2000-2004 according to daily extinction coefficient. Classification accuracy for extinction coefficient is lower than that for ozone and $PM_{2.5}$ and this reflects the complexity of the light extinction parameter and the role of moisture in this analysis. When only meteorological data are used as input to the CART analysis, classification accuracy is two to ten percent lower. This indicates that the selected meteorological data are incomplete indicators of visibility in the Class I areas along the Gulf Coast.

9.2.1. Ozone

Exploratory CART analyses for ozone revealed that 1) using a reduced dataset (2000-2004 compared to 1996-2004) does not significantly reduce the complexity of the CART classification tree, but does improve classification accuracy, 2) classification categories defined based on the new EPA 8-hour ozone are less well suited to classification by CART than those associated with the prior standard (especially for the lower ozone categories) and 3) for some areas buoy data may provide information about the mechanisms leading to onshore ozone.

The CART classification technique can provide information about the relative importance of the various independent parameters in distinguishing days with different ozone air quality characteristics. Parameter importance varies considerably among the different areas, suggesting that the different combinations of prior day air quality and meteorological parameters lead to high ozone in each area. On average, the most important parameters include: prior day maximum 8-hour ozone concentration in the area of interest, prior-day maximum 8-hour ozone concentration in upwind areas, relative humidity, stability, temperature and upper-level wind direction. Of secondary importance are surface wind speed and direction and persistence.

Analysis of the variations in the input parameters across defined ozone concentration categories reveals that there are numerous similarities among the areas and that high ozone days are characterized by low relative humidity, low wind speed, little or no precipitation and stable conditions, compared to lower ozone days. For some parameters variations across the ozone concentration categories are different for the different areas of interest. These parameters include wind direction, prior-day ozone, change in geopotential height and the recirculation and persistence indexes. This suggests that there are certain prevailing conditions that are conducive to ozone formation across the Gulf Coast region, but that, for each area, different combinations of regional meteorology, local meteorology and carryover and/or transport of ozone comprise an ozone episode.

Several of the areas have predominantly southerly winds or southerly wind components on the high ozone days. Of these, Lake Charles, Gulfport and Pensacola are truly coastal and based on wind direction alone are the most likely to be influenced by offshore emissions. This finding however is mitigated by the fact that most of the emissions sources are located off the coast of Louisiana and Texas and thus not directly offshore from Gulfport and Pensacola.

High ozone days for each area are divided among several CART bins, and this indicates that different combinations of the input parameters can lead to high ozone in each area (i.e., that there are multiple pathways to high ozone). Analysis of the key high ozone bins (bins containing the most number of high ozone days) reveals that one of the key distinguishing factors among the high ozone bins is wind direction. Differences in the prior-day regional ozone concentrations among the bins suggests that regional transport can be a factor in determining the ozone level, but that it is not always a dominant factor. Local conditions can also be important and different combinations of local parameters can result in high ozone concentrations. For several of the areas, subtle differences in meteorology and prior day ozone can mean the difference between exceedance days and non-exceedance days. This finding has implications for air quality forecasting and attainment strategy development.

9.2.2. $PM_{2.5}$

Exploratory CART analyses for $PM_{2.5}$ revealed that 1) classification ranges based on the ranges used by EPA for air quality forecasting for are well suited to the CART analyses for the selected areas and 2) buoy data do little to improve the $PM_{2.5}$ analyses for Houston, Beaumont/Port Arthur and Lake Charles.

are well suited to the CART analyses for the selected areas and 2) buoy data do little to improve the $PM_{2.5}$ analyses for Houston, Beaumont/Port Arthur and Lake Charles.

The importance of the various input parameters in distinguishing days with different $PM_{2.5}$ concentrations varies among the different areas, suggesting that the different combinations of prior day air quality and meteorological parameters lead to high $PM_{2.5}$ concentrations in each area. For all areas, prior-day $PM_{2.5}$ concentrations are an important factor in determining the $PM_{2.5}$ category and this suggests that carryover and transport play an important role in determining $PM_{2.5}$ concentration. On average, the most important parameters include: prior-day $PM_{2.5}$ concentration in the area of interest, prior-day $PM_{2.5}$ concentration in upwind areas, surface wind speed, surface temperature and 850 mb temperature. Of secondary importance are relative humidity, sea-level pressure, stability and upper-air wind speed.

Analysis of the variations in the input parameters across defined $PM_{2.5}$ concentration categories reveals that, on an annual basis, high $PM_{2.5}$ concentrations occur in connection with a regional build up of $PM_{2.5}$ concentrations, low wind speed and stability. This is the case for all areas. Wind directions and the variation in wind direction across the $PM_{2.5}$ categories are different for each area. Quarterly summaries indicate that different mechanisms lead to high $PM_{2.5}$

concentrations during different times of the year. Specifically, the regional build up of $PM_{2.5}$ is an important mechanism during the warmer months while local factors such as low temperatures, low wind speeds and stability are important during the colder months. For most of the areas, the meteorological conditions that typically occur during April-June are least conducive to $PM_{2.5}$.

High $PM_{2.5}$ days for each area are divided among several bins. Analysis of the key high $PM_{2.5}$ bins (containing the most number of high $PM_{2.5}$ days) reveals that for all areas there are some differences in the conditions that describe the key bins. As noted earlier, the CART trees suggest that the regional-scale buildup and transport of $PM_{2.5}$ is of primary importance in distinguishing low $PM_{2.5}$ days from high $PM_{2.5}$ days. However, differences in this parameter among the high $PM_{2.5}$ bins indicate that local and regional meteorological conditions also influence $PM_{2.5}$ levels. Different combinations of the input parameters can lead to high $PM_{2.5}$ in each area.

9.2.3. Visibility

Exploratory analyses conducted for the Breton NWA revealed that 1) using a reduced dataset (2000-2001 compared to 2000-2004) significantly reduces the complexity of the CART classification tree, but does change classification accuracy, 2) offshore, special-studies surface data for nearby Breton Island Platform (BIP) improved the ability of CART to correctly identify and classify the days according to visibility, but routine buoy data did not have the same result, and 3) high-resolution, upper-air data (primarily wind data) for BIP also improved the classification. These results suggest that additional, local upper-air wind data may be needed to fully characterize air quality mechanisms at Breton and along the Gulf Coast.

On average, the most important CART classification parameters include: prior-day regional $PM_{2.5}$ concentration, surface wind speed, relative humidity, upper-level wind speed, 850 mb temperature and persistence. However, parameter importance varies among the three areas. Regional, prior-day $PM_{2.5}$ concentrations and wind speeds (surface and aloft) are important to the classification for all three areas. Relative humidity is also important for all three areas. Persistence is important for St. Mark’s and Chassahowitzka, indicating that the gulf breeze may play a role in visibility along the Florida coast.

Analysis of the variations in the input parameters across defined extinction coefficient categories reveals that, for all three areas, both regional $PM_{2.5}$ and relative humidity increase with increasing extinction coefficient (decreasing visibility). Low winds speeds and generally stable conditions are associated with poor visibility for all three areas. These results suggest that there are certain prevailing conditions that are conducive to visibility impairment across the eastern Gulf Coast region. Wind directions and conditions (e.g., persistence) vary by region and the data do not indicate a strong connection between wind direction and visibility.

Poor visibility days for each area are divided among several bins. The results for Breton, St. Mark’s and Chassahowitzka all show that different combinations of parameters can result in similar extinction coefficients (and poor visibility) for a given area. In terms of particulate composition, ammonium sulfate and organic matter contribute to visibility impairment at all three sites. The ratio of sulfate to organic matter is greatest for Breton (about 2 for the key bins), and less than that for Chassahowitzka (about 1.5) and St. Mark’s (about 1.2). The relative contributions of various $PM_{2.5}$ components vary by bin for each of the sites, but only slightly.

9.3. AIR QUALITY TRENDS

The CART results were also used as the basis for the development of meteorologically adjusted 8-hour ozone, $PM_{2.5}$ and visibility for selected areas along the Gulf Coast. Specifically, the frequency of occurrence of the conditions within each of the classification bins was used to define a typical year and the individual years were normalized such that the different sets of meteorological conditions are represented no more or less than they are for this typical year.

The meteorological adjusted values show less variation from year to year than the actual values. For most areas, the results for ozone indicate that the high observed ozone concentrations for 2000 and the low concentrations for 2002 are attributable to the effects of meteorology. The results also indicate that the year-to-year trend in ozone is relatively flat between 2000 and 2004.

The results for $PM_{2.5}$ indicate a slight upward trend in $PM_{2.5}$ concentrations for Houston, both with and without the meteorological adjustment. For all other areas, there is a downward trend in $PM_{2.5}$ between 2000 and 2004, and the meteorologically adjusted values confirm the tendencies indicated by the actual data.

For visibility, neither the actual nor the adjusted values are very stable from year to year, possibly due to the limited (every three day) dataset. Overall, there is a slight upward tendency in (toward poorer visibility) for Breton $PM_{2.5}$ between 2000 and 2004, and a downward tendency for the other two sites.

9.4. MM5 CASE STUDY ANALYSES

An additional task examined whether the meteorological inputs used for the Gulf Coast Ozone Study (GCOS) photochemical modeling analysis are consistent with the available over-water measurements from the MMS-sponsored Atmospheric Boundary Layer (ABL) study.

The meteorological inputs or the GCOS photochemical modeling application were generated using the MM5 meteorological model. MM5 was applied with a 4-km horizontal resolution and 20 vertical layers. Routine measurements were incorporated into the MM5 simulation using a four-dimensional data-assimilation technique. Simulated and observed vertical profiles of temperature, wind speed and wind direction were compared for two over-water locations with ABL measurements: Vermillion and South Marsh Island platforms.

Overall, the MM5 results from the GCOS modeling study were very reasonable for the two offshore locations. This good performance may have been helped by the assimilation of data from nearby onshore locations. Additional MM5 layers could further improve the representation of the over-water features.

9.5. RECOMMENDATIONS

- Incorporate additional meteorological and air quality data collected in recent years (2005-2008) into the existing GMAQDB tool. This will provide a more up-to-date and comprehensive compilation of both historical and recent data for the Gulf of Mexico area.

- Update selected data analyses, including the CART analysis and the trends analysis using the additional data. This would ensure that the findings regarding the relationships between meteorology and air quality are robust and would bring these analyses up to date with the period to be used by EPA for attainment designations.
- Conduct detailed air quality and emissions trends analyses for selected areas, considering changes in spatial and temporal distributions of emissions, VOC-to-NO_x ratios, and reactivity in addition to emissions totals.
- With the additional data added to the GMAQDB, conduct analyses aimed at identifying any emerging climate change indicators, such as might be revealed with trends in ambient temperature, wave heights, wind speeds, sea surface temperature, etc.
- Use CART analysis results to select annual and/or episodic simulation periods for future air quality modeling of the Gulf Coast area.
- Establish one or more upper-air meteorological monitoring sites along the eastern Gulf Coast, preferably with the capability to collect high temporal and vertical resolution data. These data would enhance future data analysis and monitoring studies.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.