

**SOURCES OF AMBIENT SULFUR DIOXIDE (SO₂)
IN THE METRO ATLANTA AREA**

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**SOURCES OF AMBIENT SULFUR DIOXIDE (SO₂)
IN THE METRO ATLANTA AREA**

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SUMMARY

Sulfur Dioxide (SO_2) is a difficult air pollutant to characterize spatially since it is primarily emitted from a few point sources typically having tall stacks. A better comprehension of the behavior and advection of ambient SO_2 in metro Atlanta will help in the interpretation of epidemiologic analyses as well as establish an understanding of the source contributions to ambient SO_2 in Atlanta.

The operation and SO_2 emission characteristics of four coal-fired power plants and a coal-fired cement kiln, all of which lie in the vicinity of Atlanta, were examined. Data retrieved from three downtown Atlanta monitoring stations that record ambient SO_2 concentrations were also examined. Trends from ambient SO_2 data agree with emission trends from the four coal-fired power plants, suggesting that one or more of the power plants are contributing to the ambient SO_2 in Atlanta.

SO_2 rose plots using concentration and wind direction data from downtown monitoring stations were developed to identify from which direction the elevated levels of ambient SO_2 were originating. A strong peak in the northwest direction of Atlanta suggests that Plant Bowen, Plant McDonough, or Lafarge Building Materials may be contributing to high concentrations of ambient SO_2 in Atlanta. Further analysis concluded that Lafarge was not a likely contributor to the northwest peak. The plumes of Plant Bowen and Plant McDonough were modeled using air parcel trajectories and the Gaussian dispersion model. The results suggest that, when the wind is blowing from the northwest direction, Plant McDonough's plume is the primary contributor to the elevated levels of SO_2 recorded by downtown Atlanta monitoring stations.

Chapter 1

INTRODUCTION

As one of the Environmental Protection Agency's six criteria pollutants established under the Clean Air Act, sulfur dioxide (SO₂) is an important atmospheric pollutant to monitor and study due to the impact it has on human health and the condition of the environment. SO₂ is a primary pollutant emitted from several point, area, and mobile sources. Sulfur is prevalent in raw materials, such as crude oil, coal, and ore that contain common metals like aluminum, copper, zinc, lead, and iron. SO₂ gases are formed when fuel containing sulfur, such as coal or oil, is burned, and when gasoline is extracted from oil or metals are extracted from ore (US EPA, 2006). SO₂ emissions from natural sources, such as volcanoes and biologically produced dimethylsulfide [DMS_(g)] and hydrogen sulfide [H₂S_(g)] are noteworthy on a global basis, but do not contribute significantly to the ambient conditions of an urban setting (Jacobson, 2002).

1.1 Sources of SO₂

1.1.1 SO₂ Sources in United States

In the United States, anthropogenic SO₂ is emitted from several sources. According to the National Emission Inventory (NEI) performed by the EPA in 2002, an estimated 85% of the U.S. SO₂ emissions originate from point sources, 10% from area sources, and the remaining 5% from mobile sources (See Figure 1.1) (US EPA-CHIEF, 2007).

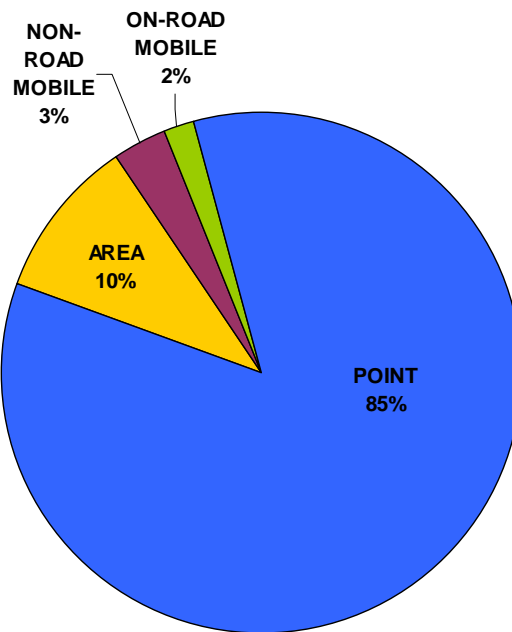


Figure 1.1: SO₂ Source Types in U.S.

Figures 1.2 through 1.5 show the breakdown of the source types: point, area, non-road mobile, and on-road mobile, in the U.S. according to the EPA's 2002 emission inventory. Figure 1.2 illustrates that the estimated majority of the SO₂ emissions from point sources originate from electric power plants (79%), while industries such as petroleum refining and the manufacturing of chemicals, pulp and paper, and metals make up the remainder of the national SO₂ point source emissions. Figure 1.3 shows that while SO₂ emissions from area sources are spread out among a larger number of industries, industrial coal combustion boilers emit nearly half, 47%, of the SO₂ emissions from area sources.

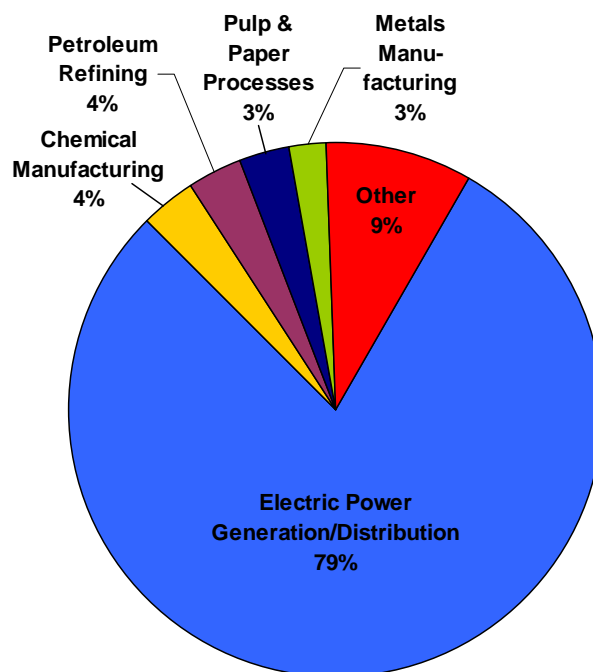


Figure 1.2: Point Sources of SO₂ in U.S.

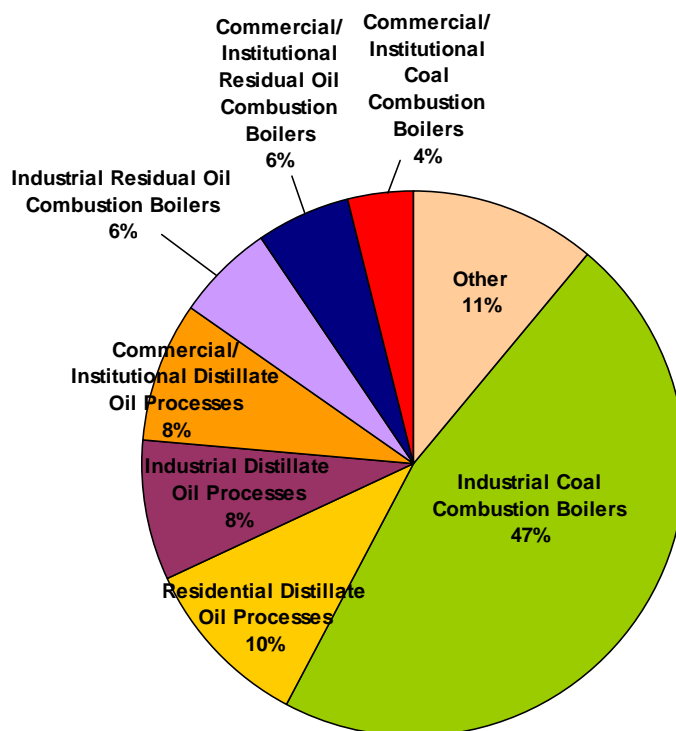


Figure 1.3: Area Sources of SO₂ in U.S.

The distribution of SO₂ emissions from non-road mobile sources is shown in Figure 1.4, with marine vessels and off-highway diesel vehicles, such as construction and agricultural equipment, comprising an estimated 83% of the emissions from non-road mobile sources.

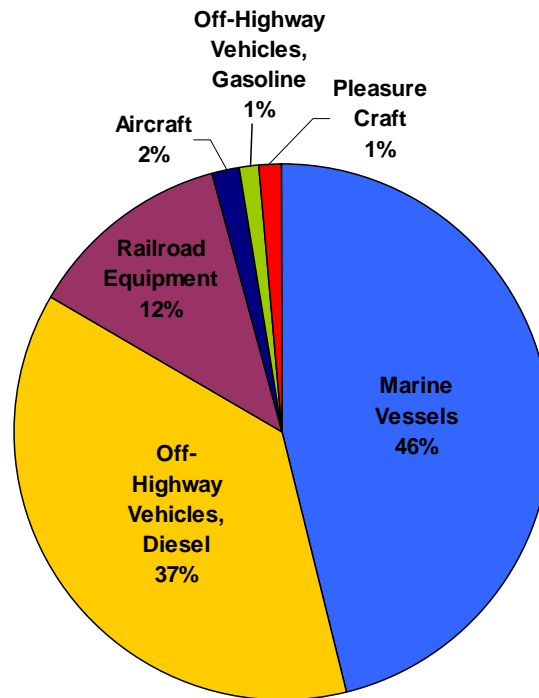


Figure 1.4: Mobile Non-Road Sources of SO₂ in U.S.

Finally, Figure 1.5 illustrates that the SO₂ emissions from on-road mobile sources are essentially split between three sources: light duty gasoline vehicles, light duty gasoline trucks, and heavy duty diesel vehicles (US EPA-CHIEF, 2007).

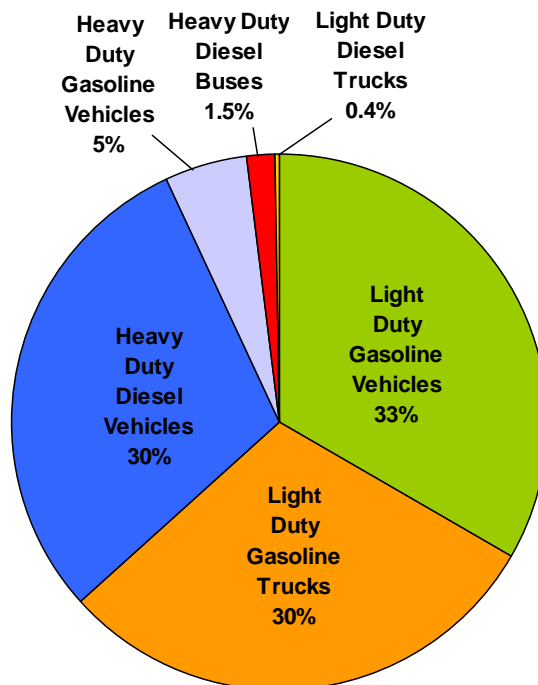


Figure 1.5: Mobile On-Road Sources of SO₂ in U.S.

1.1.2 SO₂ Sources in Georgia

Similar to that of the U.S., the sulfur dioxide emitted in the state of Georgia primarily originates from point sources. In fact, electricity power plants that utilize coal, oil, and gas as fuel emitted an estimated 88% of the total atmospheric SO₂ in Georgia in 2002, according to the EPA Emission Inventory. An estimated 9% of the remainder of the SO₂ in Georgia was emitted from area sources, 2% from on-road mobile sources, and 1% from non-road mobile sources. (See Figure 1.6).

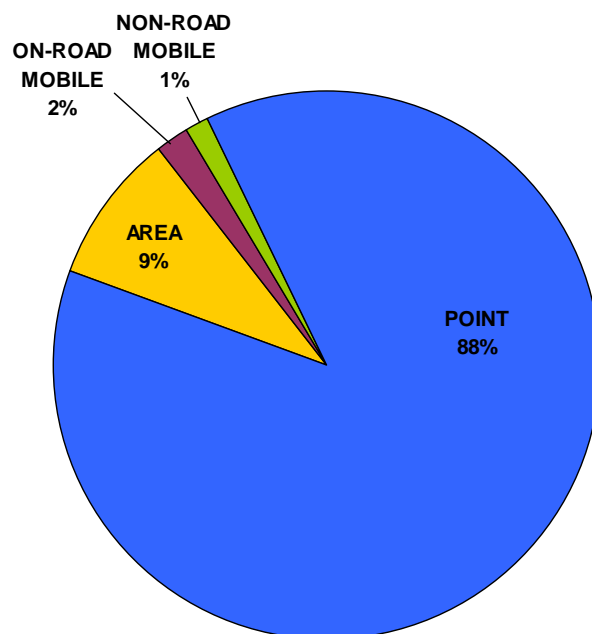


Figure 1.6: Source Types of SO₂ in Georgia

Figure 1.7 displays the point sources that contributed to the SO₂ emissions in Georgia in 2002. Plant Bowen, which is estimated to have contributed more SO₂ than any other point source in Georgia, also produced more electricity in 2002 than any other Georgia point source (US EPA-CAM, 2007).

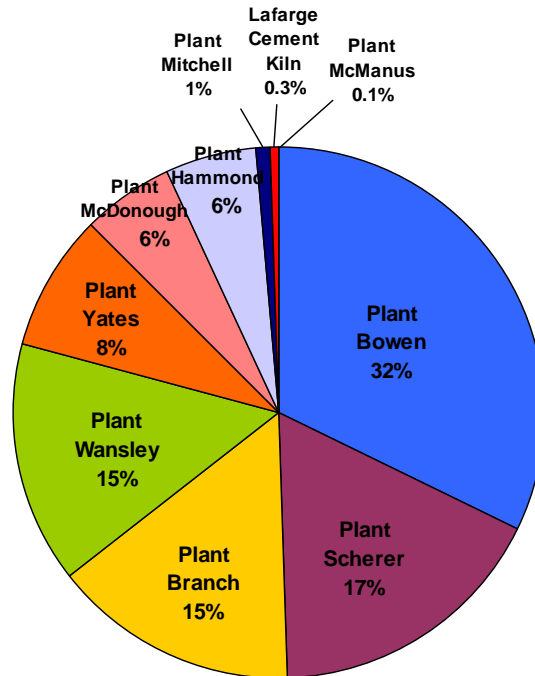


Figure 1.7: Point Sources of SO₂ in Georgia

The breakdown of the area, on-road mobile, and non-road mobile sources are shown in Figures 1.8 through 1.10. Because these sources are not the major contributors of SO₂ levels in Georgia, they leave less room for improvement and are therefore not as prominently studied when considering methods to reduce atmospheric SO₂ concentration.

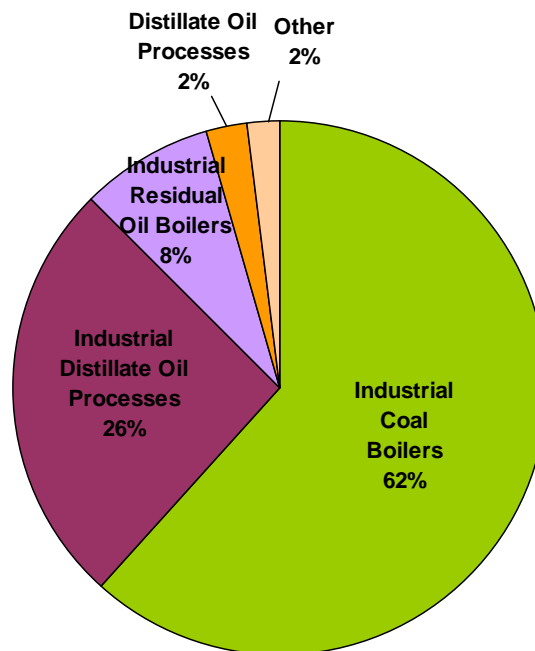


Figure 1.8: Area Sources of SO₂ in Georgia

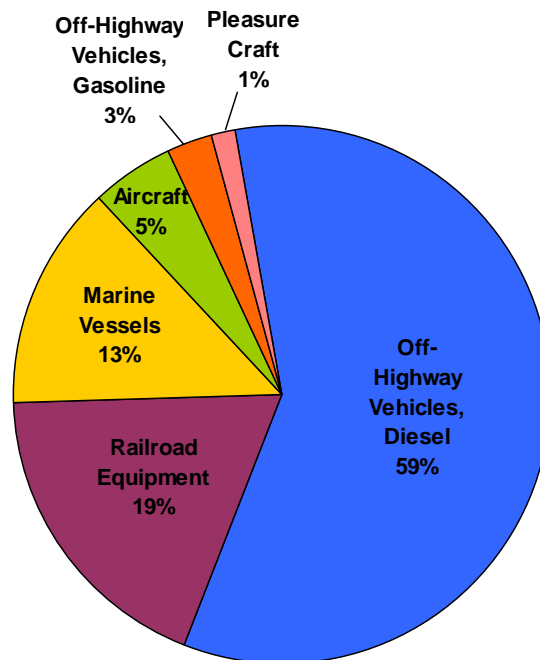


Figure 1.9: Mobile Non-Road Sources of SO₂ in Georgia

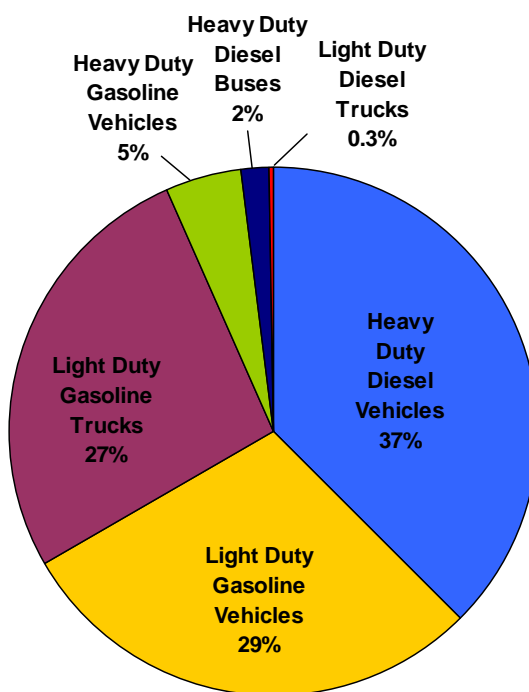


Figure 1.10: Mobile On-Road Sources of SO₂ in Georgia

1.2 Adverse Effects of SO₂

There are several reasons why it is important to study the sources and emission patterns of SO₂. One of the more obvious reasons is the impact that atmospheric SO₂ has on human health. Long term exposure to high concentrations of SO₂ can contribute to respiratory illness, particularly in children and the elderly, and aggravate existing heart and lung diseases (US EPA, 2006). High levels of SO₂ emitted over a short period, such as a day, can be particularly problematic for people with asthma and may have effects such as wheezing, shortness of breath, and chest tightness (US EPA, 2006; Masters, 1997).

High concentrations of ambient SO₂ (above 3.0 ppm) are also accompanied by a pungent, irritating odor (Wark et al., 1998). Although odor is an adverse effect that is

aesthetic in nature, it is highly undesirable and provides another reason to study and understand ambient SO₂ emissions.

1.3 SO₂ and Sulfate Particulate Matter

An additional reason to study atmospheric SO₂ is due to its direct relationship with particulate matter (PM). Atmospheric SO₂ can be converted to sulfate (SO₄) particulate matter by reactions in gas, aerosol, and aqueous phases (Seinfeld and Pandis, 1998). Although sulfate in the atmosphere can be primary and thus directly emitted in the form of sulfuric acid (H₂SO₄), sulfur trioxide (SO₃), or particulate sulfates, most of the sulfate in the atmosphere is secondary and results from reactions involving gaseous SO₂ (Hazi et al., 2003). In Atlanta, the largest component of ambient PM_{2.5}, on average, is sulfate, which accounts for approximately 28% of total PM_{2.5} mass (Marmur et al., 2005). Sulfate particulate matter is important to study and understand since it has been found to cause adverse effects on the health of humans, animals, and their environment.

SO₂ is highly water soluble, therefore, when inhaled, it is likely to be absorbed in the moist passages of the upper respiratory tract, the nose and upper airways, where there is less chance of long-term damage. Sulfate particles, however, are more likely to be deposited deeper into the lungs due to their aerodynamic properties (Masters, 1997). A number of studies have associated increased particle levels with increased hospital admissions and emergency room visits. The health effects experienced from particulate matter can be both long and short-term. Long-term exposure can result in decreased lung function, the development of chronic bronchitis, and even premature death. Short-term exposure to particles, which may occur over a matter of hours or days, can aggravate lung

disease, cause asthma attacks and acute bronchitis, and may also increase susceptibility to respiratory infections (US EPA, 2003). SO₂ and sulfate particles are especially harmful when inhaled together due to the fact that SO₂ is reported to reach the lower respiratory tract only after absorption onto suspended particulate matter (Matooane and Diab, 2003).

Sulfate particles are not only detrimental to the health of humans, they are also reported to have adverse effects on the environment. While still in the air, sulfate particles can contribute to a reduction in visibility and a discoloration of the atmosphere in many parts of the U.S.; however, the majority of the damage from particle pollution comes from acid deposition. Through wet deposition, acidic sulfate particles can become incorporated into cloud and rainwater which lowers the pH of the rainwater and can then result in the acidification of surface waters and subsequent damage to aquatic ecosystems, damage to forests and vegetation, as well as damage to building materials and structures. The process of dry deposition can remove sulfate particles from the atmosphere and result in effects similar to those seen in wet deposition (Seinfeld and Pandis, 1998).

1.4 Overview of Study

This study is intended to examine the key sources of SO₂ that are impacting Atlanta air quality and their emission patterns in order to better understand where the SO₂ in metro Atlanta is originating as well as to where it is traveling.

While atmospheric levels of SO₂ have decreased in the U.S. by 63% in the last 25 years, the U.S. EPA has stated that “further reductions of SO₂ are needed to reduce acid rain as well as the formation of tiny particles that can cause serious health problems” (US

EPA, 2006). Studies such as this one that may help to identify the sources and emission patterns of SO₂ are a vital part in identifying ways to reduce the adverse effects that SO₂ and the sulfate particles that are formed from SO₂ have on human health and the environment.

Chapter 2

OBJECTIVES

The purpose of this study is to establish a better understanding of the sources of ambient sulfur dioxide (SO₂) in the metro Atlanta area. In order to accomplish this objective, a number of specific tasks were undertaken.

The primary task of this study was to investigate the principal sources of SO₂ that are impacting Atlanta air quality. There are five monitoring sites for SO₂ located in the metro Atlanta area, three of which belong to the EPA's Air Quality System (AQS), and two that belong to Atmospheric Research & Analysis, Inc. as part of their SouthEastern Aerosol Research and Characterization Study (SEARCH). Data recorded by these monitors from 1980 to 2005 were collected to help establish which sources of ambient SO₂ are impacting Atlanta, as well the relative magnitude of each source's contribution. The collected data also allow for a better understanding of the hourly, daily, monthly, and annual patterns of ambient SO₂ concentrations in Atlanta. Studying these patterns facilitate an ability to estimate and describe SO₂ emissions originating from the sources in question, and, in turn, qualify how these emissions contribute to the day-to-day variation of ambient SO₂ exhibited by data collected from the Atlanta monitoring stations.

The results of this research will contribute to a number of epidemiologic analyses, being conducted under SOPHIA (Study of Particles and Health in Atlanta), that examine relationships between acute health effects and ambient air pollutant concentrations. SO₂ is one of the more difficult air pollutants to characterize because SO₂ is emitted largely

from a few point sources via tall stacks. The transport and fate of these SO₂ plumes are highly complex. Uncertainty in exposure to SO₂ tends to attenuate any association between acute health effects and ambient SO₂. (For more detailed information on results from SOPHIA, see Metzger et al., 2004 and Peel et al., 2005.) Thus, there is a need to better characterize and understand the behavior and advection of ambient SO₂ in metro Atlanta. This knowledge will help in the interpretation of epidemiologic results as well as understanding the source contributions to ambient SO₂ in Atlanta.

The following results chapters describe the research performed to achieve the listed objectives. Chapter 3 provides information relating to the attributes and operation of the point sources that emit SO₂ in Georgia and are near enough to impact Atlanta. Chapter 4 presents and interprets the SO₂ data recorded by the air quality monitoring stations in Atlanta. Chapter 5 describes and explains the significance of SO₂ rose plots constructed from downtown Atlanta monitors. Finally, Chapter 6 uses modeled trajectories and plumes from SO₂ point sources to examine the behavior of the plumes believed to be impacting Atlanta.

Chapter 3

PRIMARY METRO ATLANTA SULFUR DIOXIDE POINT SOURCES

3.1 Introduction

In order to determine the sources of ambient sulfur dioxide (SO₂) in Atlanta, the sources that emit the majority of SO₂ in the vicinity of Atlanta must be identified and understood. Information such as the distance from the source to Atlanta, design and operation specifications, and any changes or improvements that would increase or decrease their rate of emissions are all key in understanding the patterns of ambient SO₂ concentration in Atlanta.

3.2 Methods

This part of the study involved collecting data from several sources. Information pertaining to the details and operation of the point sources in question were primarily provided by employees who were knowledgeable about the equipment and processes of the facility at which they worked. With their assistance, data that would otherwise be difficult to locate such as the preventive maintenance schedule, the dimensions of the stacks, and if and when any process improvements were implemented was made available for the use of the study.

An additional source of information for this part of the study was a website maintained by the U.S. Environmental Protection Agency's Clean Air Markets Division, a branch that manages various market-based regulatory programs designed to improve air quality. The website, entitled *Data and Maps*, provides a historical account of emissions

data for point sources located in the United States whose emissions are monitored and reported to the EPA. The Emissions module accesses emissions data either at the unit level or monitoring location level for several facilities. Emissions are available for years 1980, 1985, 1990, and annually from 1995-present (US EPA-CAM, 2007). The CAM database was particularly helpful for obtaining emissions data for point sources believed to contribute to the ambient SO₂ levels in Atlanta.

3.3 Overview of SO₂ Point Sources in the Atlanta Area

According to the 2002 EPA Emission Inventory, point sources emit an estimated 88% of the total ambient SO₂ in Georgia. Unlike SO₂ emissions from mobile sources, which will have a relatively constant impact on Atlanta's air quality due to the broad area over which they are emitted, the impacts from SO₂ emitted by point sources will vary significantly when conditions such as meteorology and plant output vary. The point sources in Georgia were plotted on a map in order to ascertain which sites are impacting the air quality around the metro Atlanta area. As shown in Figure 3.1, there are four coal-fired Georgia Power plants and one coal-fired cement kiln in the vicinity of Atlanta: Plant Bowen, Plant McDonough, Plant Wansley, Plant Yates, and Lafarge Building Materials. Therefore, the emission characteristics and patterns of these five facilities are the foci of this study.

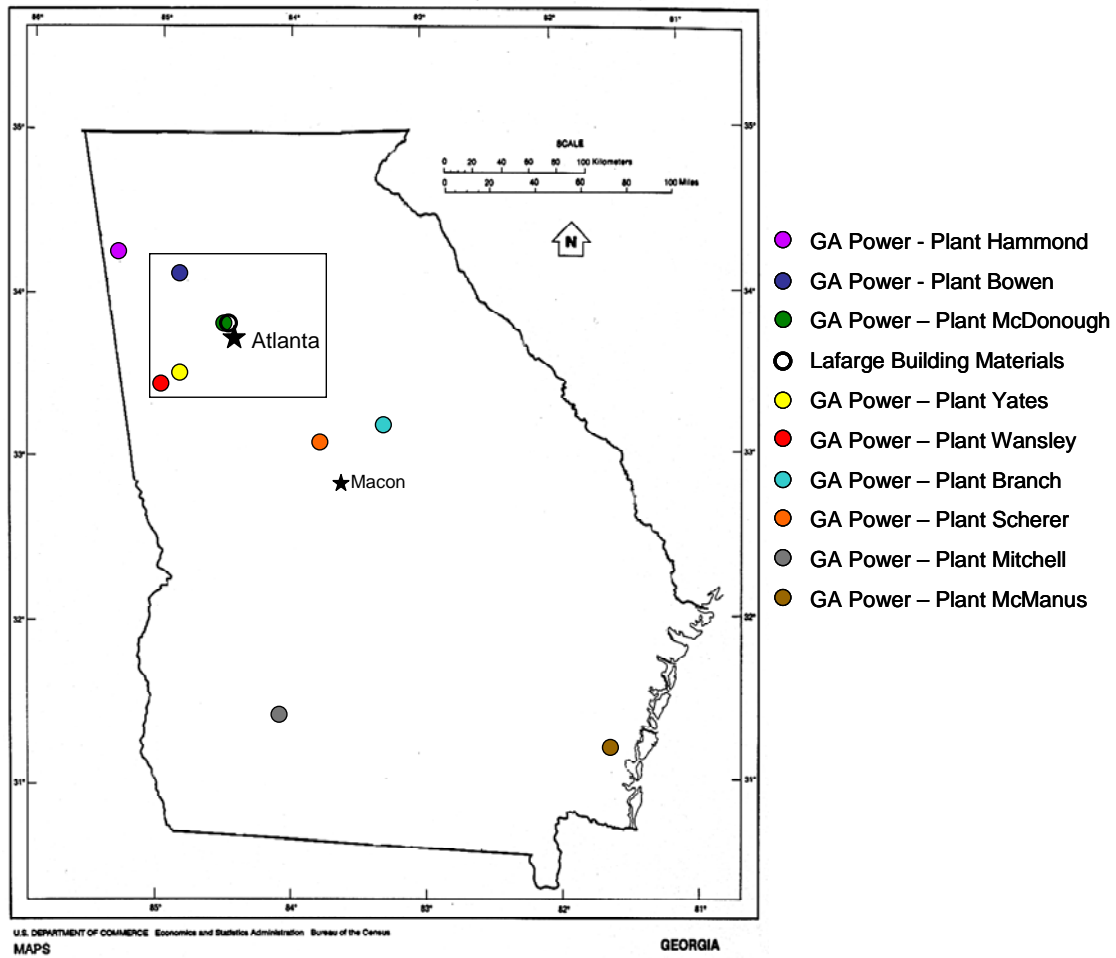


Figure 3.1: Map of primary SO₂ point sources in Georgia as listed in the 2002 EPA Emission Inventory

Information was gathered on the basic operation and aspects of each facility.

Table 3.1 displays various information collected about each facility including the facilities' location, hours of operation, preventative maintenance schedule, description of stack(s), coal usage rate, and any steps taken by the facility in order to reduce SO₂ emissions (Chi, 2006; Cunningham, 2006; Keiser, 2006).

Table 3.1: Descriptive information of SO₂ emitting facilities impacting Atlanta

	Plant Bowen	Plant McDonough	Plant Wansley	Plant Yates	Lafarge
Facility Address	Cartersville, GA	Smyrna, GA	Roopville, GA	Newnan, GA	Atlanta, GA
Facility Coordinates	34.126° Lat - 84.919° Long	33.824° Lat -84.475° Long	33.417° Lat -85.033° Long	33.462° Lat -84.899 ° Long	33.823° Lat -84.472° Long
Distance to Georgia Tech Monitor	61.7 km	8.7 km	70.8 km	57.7 km	8.4 km
Daily Hours of Operation	24 hours; 7 days/week	24 hours; 7 days/week	24 hours; 7 days/week	24 hours; 7 days/week	24 hours; 7 days/week
Stack information and description	2 stacks; each ~1000 ft in height; 2 more stacks being built	1 stack; ~800 ft in height	1 stack: ~1000 ft in height	3 stacks; 256 ft, 805 ft and 830 ft in height	No stacks; rectangular box attached to dust collector that blows emissions sideways
Estimated coal usage rate	Four units combined average ~22,700 tons/day	Two units combined average ~4,000 tons/day	Two units combined average ~12,300 tons/day	Seven units combined average ~7,000 tons/day	Two kilns combined average ~240 tons/day
Steps taken to reduce SO₂ emissions	1994-1995 - substituted 3% sulfur coal for 1% sulfur coal; Currently installing two scrubbers	1994-1995 - substituted 3% sulfur coal for 1% sulfur coal	1994-1995 - substituted 3% sulfur coal for 1% sulfur coal; Currently installing two wet scrubbers	1994-1995 - substituted 3% sulfur coal for 1% sulfur coal; One scrubber installed	None known

3.4 Plant Bowen

According to the EPA Emission Inventory from 2002, Plant Bowen emits more SO₂ than any other point source in the state of Georgia (US EPA-CHIEF, 2007).

However, Plant Bowen is a large plant, and in 2002, had more output in MWh than any other Georgia Power plant (see Figure 3.2).

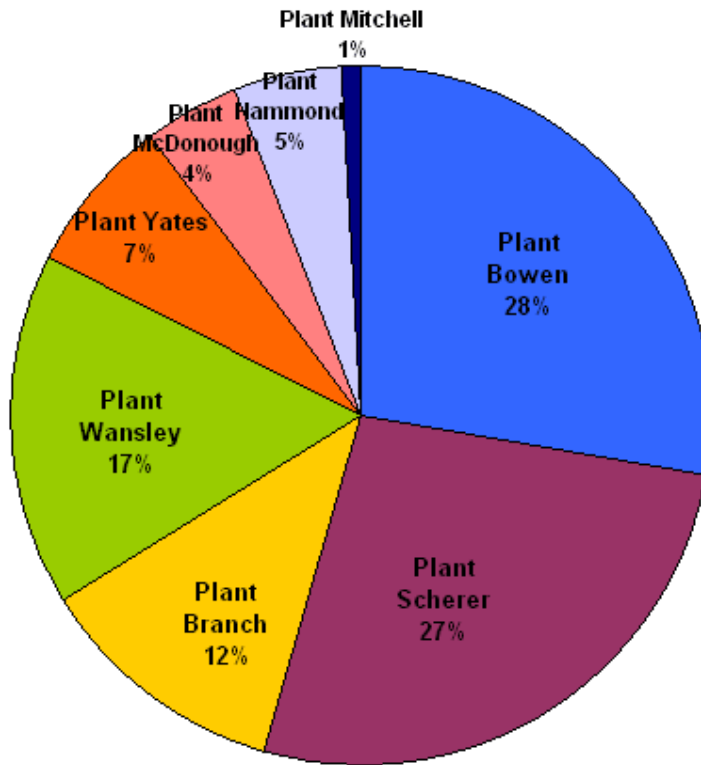


Figure 3.2: Total MWh of Georgia Power Plants in 2002

Figure 3.3 displays the energy output in megawatt-hours (MWh) and the SO₂ emissions from Plant Bowen between the years of 1980 and 2005. Both sets of data were pulled from the EPA's Clean Air Markets website, however, the energy output for electricity generating units is only available from 1997 to the present (US EPA-CAM, 2007). The most noticeable characteristic of Figure 3.3 is the significant drop in SO₂ emissions from 1990 to 1995. This reduction of SO₂ occurred when Georgia Power plants replaced 3% sulfur coal with 1% sulfur coal in late 1994 (Wilder, 2006). Figure 3.3 also demonstrates that although Plant Bowen's annual energy output has oscillated since 1997, the trend has remained fairly steady. In addition, Figure 3.3 indicates that there is a positive relationship between Plant Bowen's energy output and their SO₂ emissions.

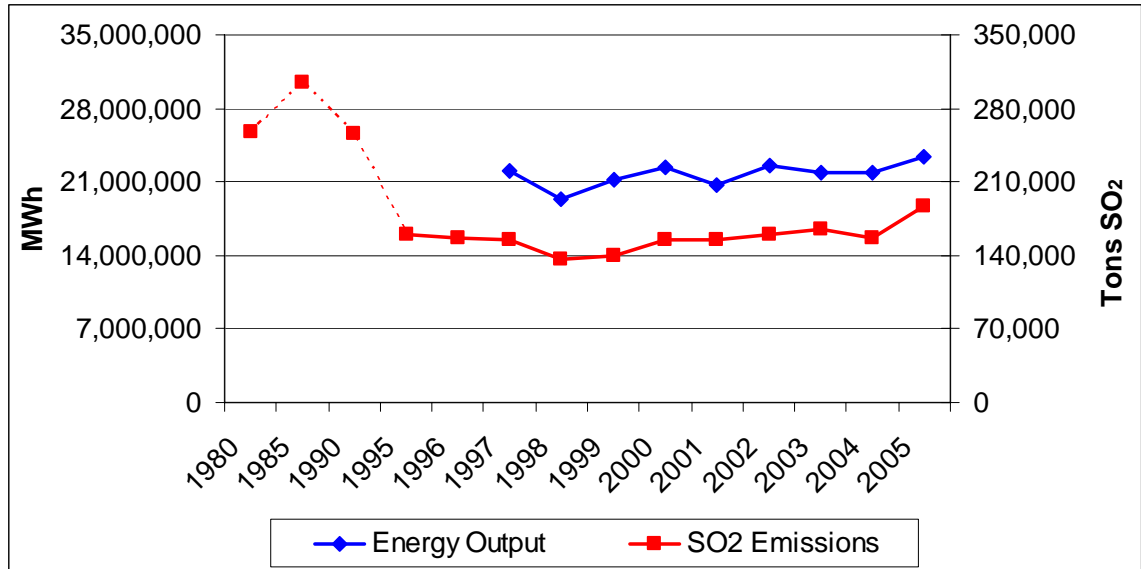


Figure 3.3: Energy output and SO₂ emissions from Plant Bowen, 1980-2005

3.5 Plant McDonough

Plant McDonough is the second closest point source of SO₂ to the city of Atlanta, only behind Lafarge Building Materials. Plant McDonough, on average, produces about six times less energy than Plant Bowen and emits about six times less SO₂ (US EPA-CAM, 2007). However, Plant McDonough's proximity to Atlanta, which is nearly nine kilometers, is the primary reason why its SO₂ emissions are likely to have a significant impact on the metro Atlanta area. Figure 3.4 shows the energy output and SO₂ emissions from Plant McDonough between 1980 and 2005. This data was retrieved from the same database as the data for Plant Bowen. Plant McDonough's energy output and SO₂ emissions have similar patterns to those seen from Plant Bowen; the sharp decrease in SO₂ emissions between 1990 and 1995 was also due to the substitution of low sulfur coal, and a positive relationship exists between energy output and SO₂ emissions.

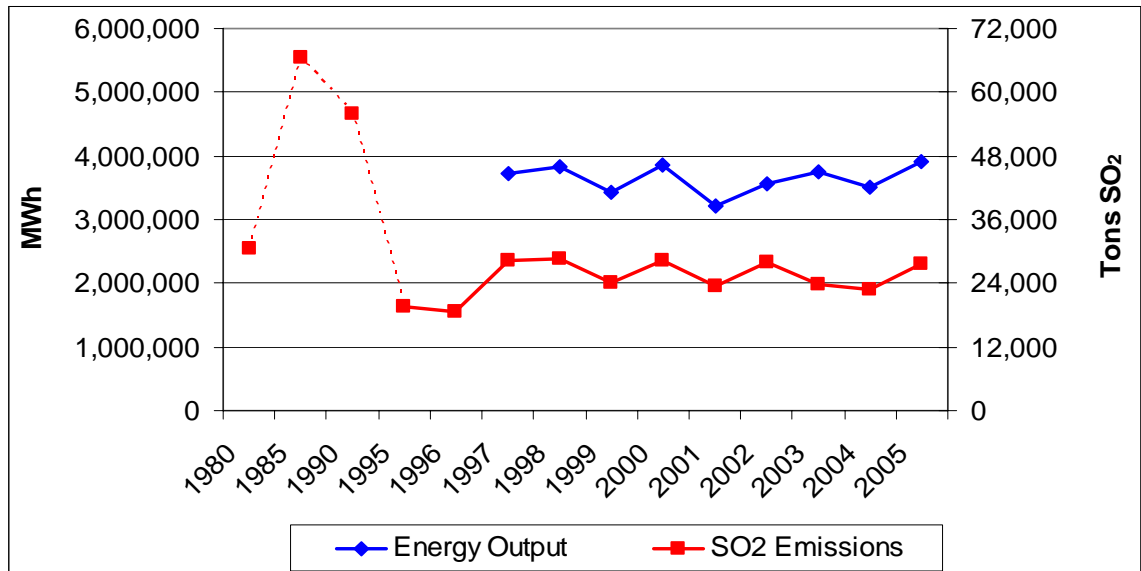


Figure 3.4: Energy output and SO₂ emissions from Plant McDonough, 1980-2005

3.6 Lafarge Building Materials

Because the Lafarge plant in Atlanta burned enough coal in their kilns to generate the heat necessary to produce cement, the plant was included in this study as an SO₂ point source that may contribute to the SO₂ concentrations recorded by the air quality monitoring stations in Atlanta. The EPA's Emission Inventory in 2002 is one of the few sources of recent emission data for the Atlanta Lafarge plant since no emission monitors were ever installed at the plant. While this inventory estimated that the Lafarge cement plant in Atlanta emitted only 0.3% of the SO₂ from point sources in Georgia, the fact that the plant is only about eight kilometers away from downtown Atlanta means that the plant's emissions cannot be entirely ignored (US EPA-CAM, 2007). However, research into the operation of the cement plant revealed that the kilns are no longer in use and have, in fact, been permanently removed; one kiln was removed in June 2002 and the other removed in December 2004. After the removal of the first kiln in 2002, the cement plant began to significantly cut production. In 2003, the second kiln ran only 64% of the

year; in 2004, the kiln ran for 104 days, but did not always run 24 hours per day (see Table 3.2). By 2005, there was no cement production at all from the plant. The Atlanta Lafarge site is now primarily a grinding facility and does not burn coal for any of its processes (Cunningham, 2006). Therefore, while it is clear that this Lafarge plant is not currently contributing to the SO₂ levels observed in Atlanta, whether it was a significant contributor during the time it was fully operational will be discussed in subsequent chapters.

Table 3.2: 2004 Production schedule for Lafarge Building Materials – Atlanta Plant

Start Date	Stop Date
02/27/04	04/03/04
06/12/04	07/11/04
10/04/04	11/02/04
12/07/04	12/23/04

3.7 Plants Wansley and Yates

For the purpose of this study, Plants Wansley and Yates will primarily be referred to as one emission source. The two plants reside in close proximity to one another (13 kilometers), and for the emissions of these plants to impact Atlanta, the plume from Plant Wansley would have to combine with the plume from Plant Yates before reaching Atlanta. Another reason that it is helpful to examine Plants Wansley and Yates together is because the characteristics of the two plants combined closely resemble those of Plant Bowen, therefore providing a point of reference that will prove to be helpful later in the study. Comparing Figures 3.3 and 3.5 reveals that by 2005, the energy output and SO₂ emissions from Plants Wansley and Yates combined had come within ten percent of the energy output and SO₂ emissions from Plant Bowen. In addition, Plant Yates resides

only four kilometers closer to the Georgia Tech monitoring station than Plant Bowen, which means that under similar meteorological conditions, the plumes from Plant Bowen and from Plants Wansley and Yates would be similar enough for comparison purposes. Figure 3.5 illustrates the energy output and SO₂ emissions from Plant Wansley, Plant Yates, and the two plants combined between 1980 and 2005.

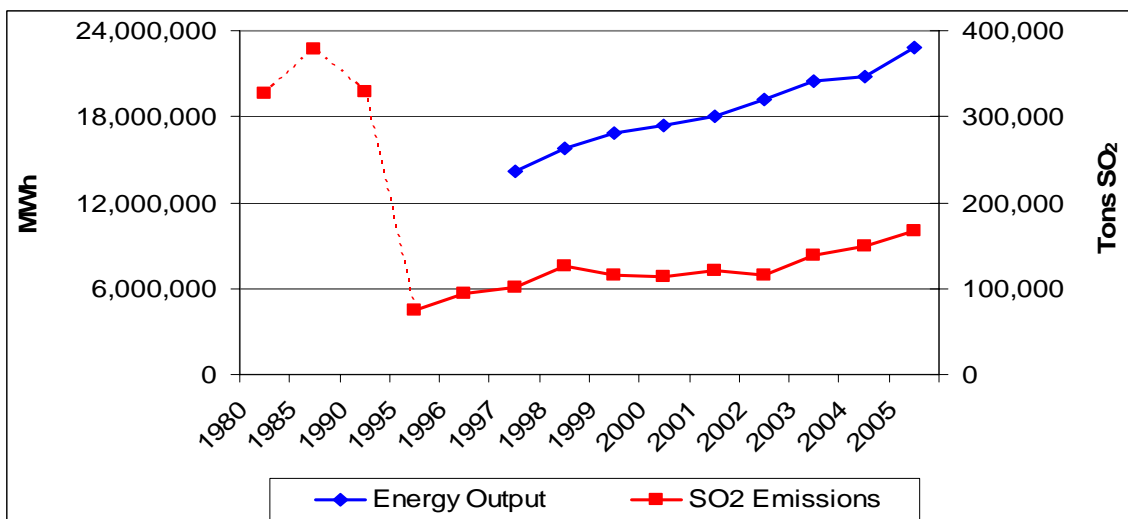
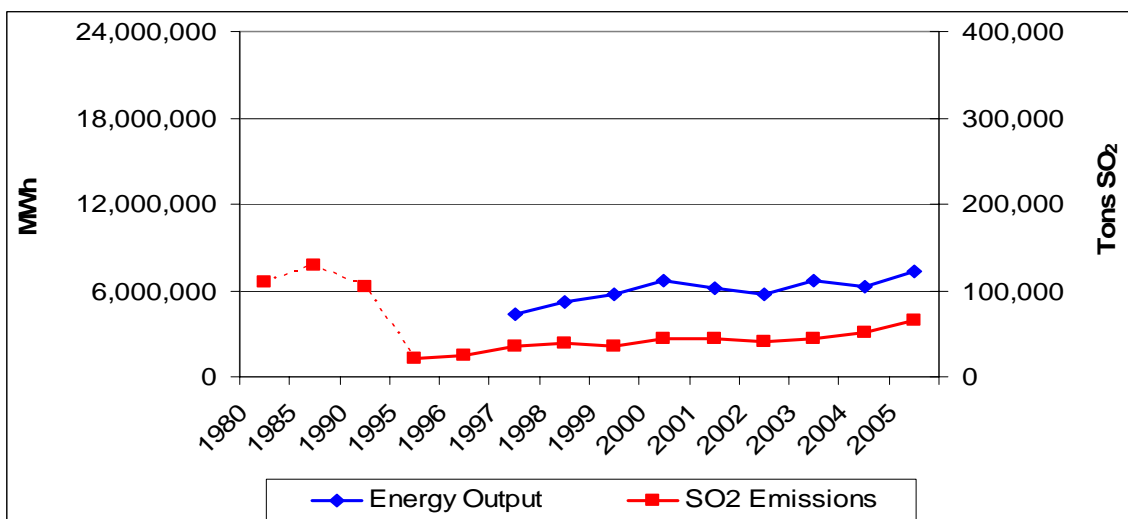
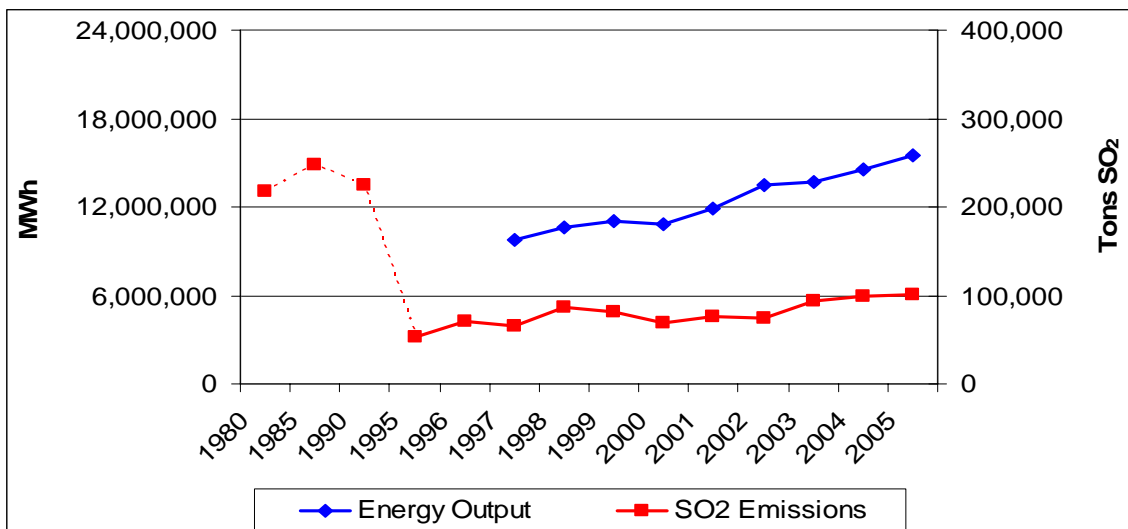


Figure 3.5: Energy output and SO₂ emissions from Plant Wansley (top), Plant Yates (middle), and Plant Wansley and Yates combined (bottom), 1980-2005

3.8 Emission Trends

After studying the four power plants individually, it is helpful to compare the plants' energy output and SO₂ emissions in order to recognize any trends or patterns from each plant and to determine how one plant's trends relate to those from another plant.

3.8.1 Annual Trends

Figure 3.6 shows the annual energy output and SO₂ emissions from Plant Bowen, Plant McDonough, Plant Wansley, Plant Yates, and Plants Wansley and Yates combined between 1997 and 2005.

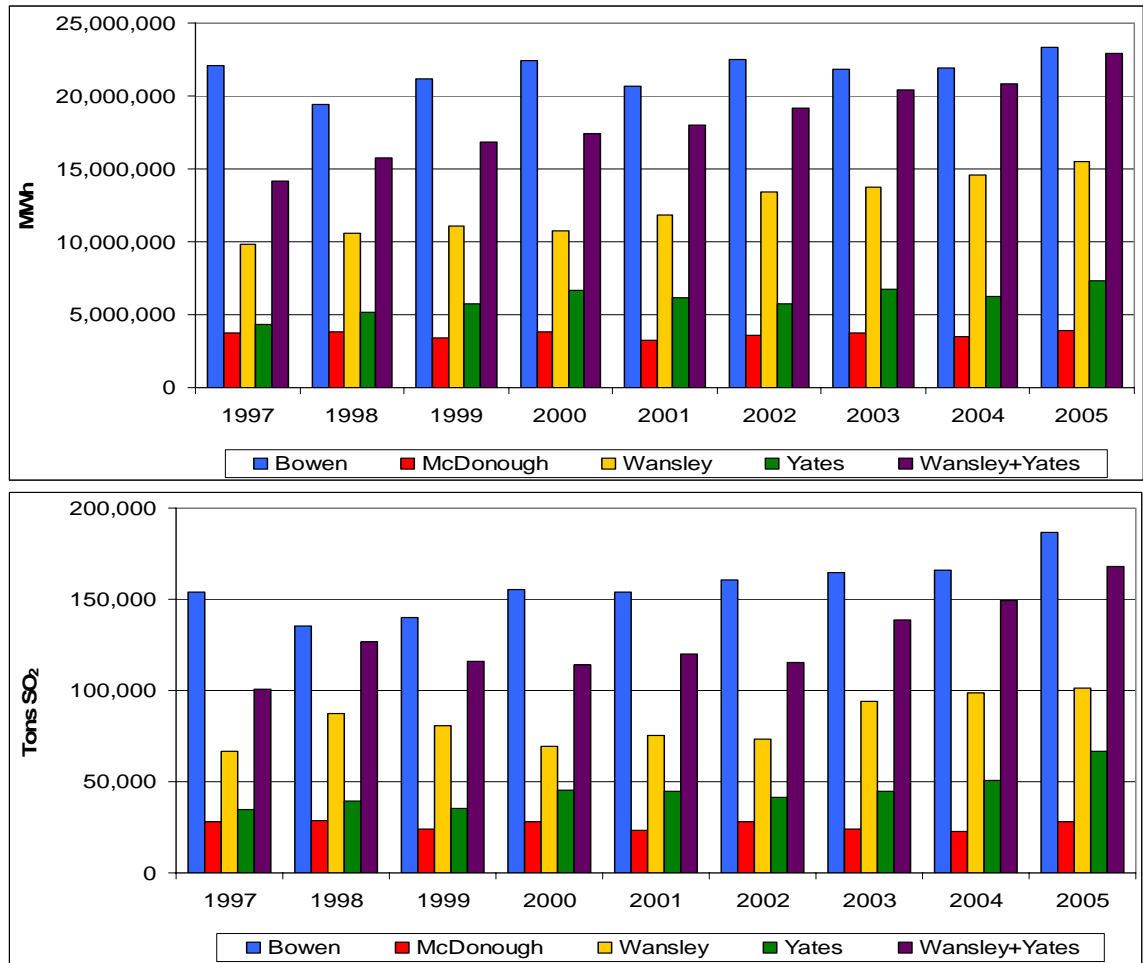


Figure 3.6: Annual totals of energy output (top) and SO₂ emissions (bottom) for all four Georgia Power plants, 1997-2005

Figure 3.6 effectively illustrates the differences in operation, on an annual basis, between the four plants involved in this study. For example, in 1997, the energy output and SO₂ emissions of Plants Wansley and Yates combined were approximately 65% of those from Plant Bowen; by 2005, the energy output of Plants Wansley and Yates combined had come within 2% of that from Plant Bowen, and the two plants' combined SO₂ emissions were within 10% of those from Plant Bowen.

3.8.2 Monthly Trends

Figure 3.7 displays the monthly averages of the daily energy output and SO₂ emissions from the four plants between 1997 and 2005.

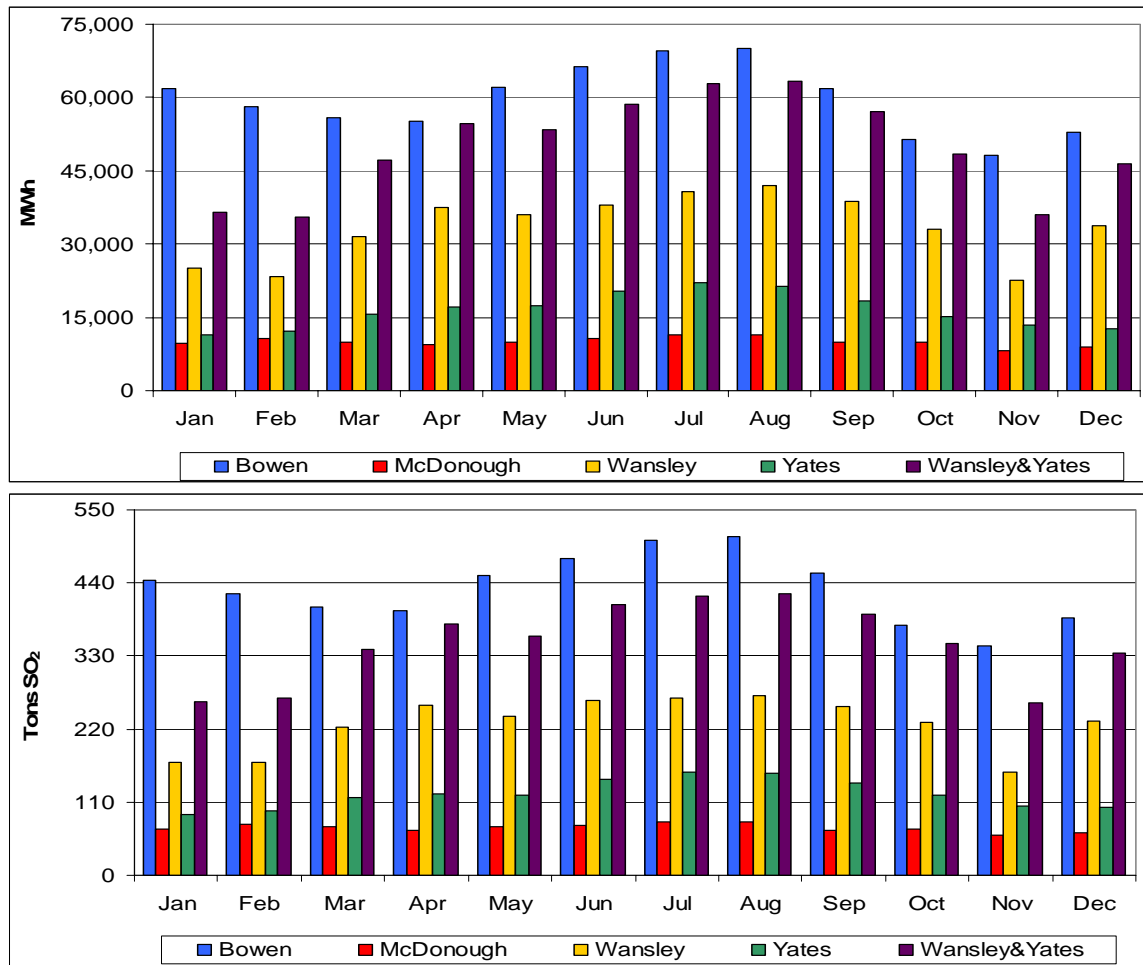


Figure 3.7: Monthly averages of daily energy output (top) and SO₂ emissions (bottom) for all four Georgia Power plants, 1997-2005

Figure 3.7 illustrates that all four plants' energy output and SO₂ emissions peak most significantly in the summer months, while the values for Plant Bowen and McDonough also peak in the winter months, though less notably. This trend undoubtedly stems from higher electricity demand that occurs during the months with more extreme

temperatures, as opposed to the months when the temperatures are milder and energy demand is lower.

3.8.3 Daily Trends

Figure 3.8 displays the average for each day of the week for energy output and SO₂ emissions from the four plants between 1997 and 2005.

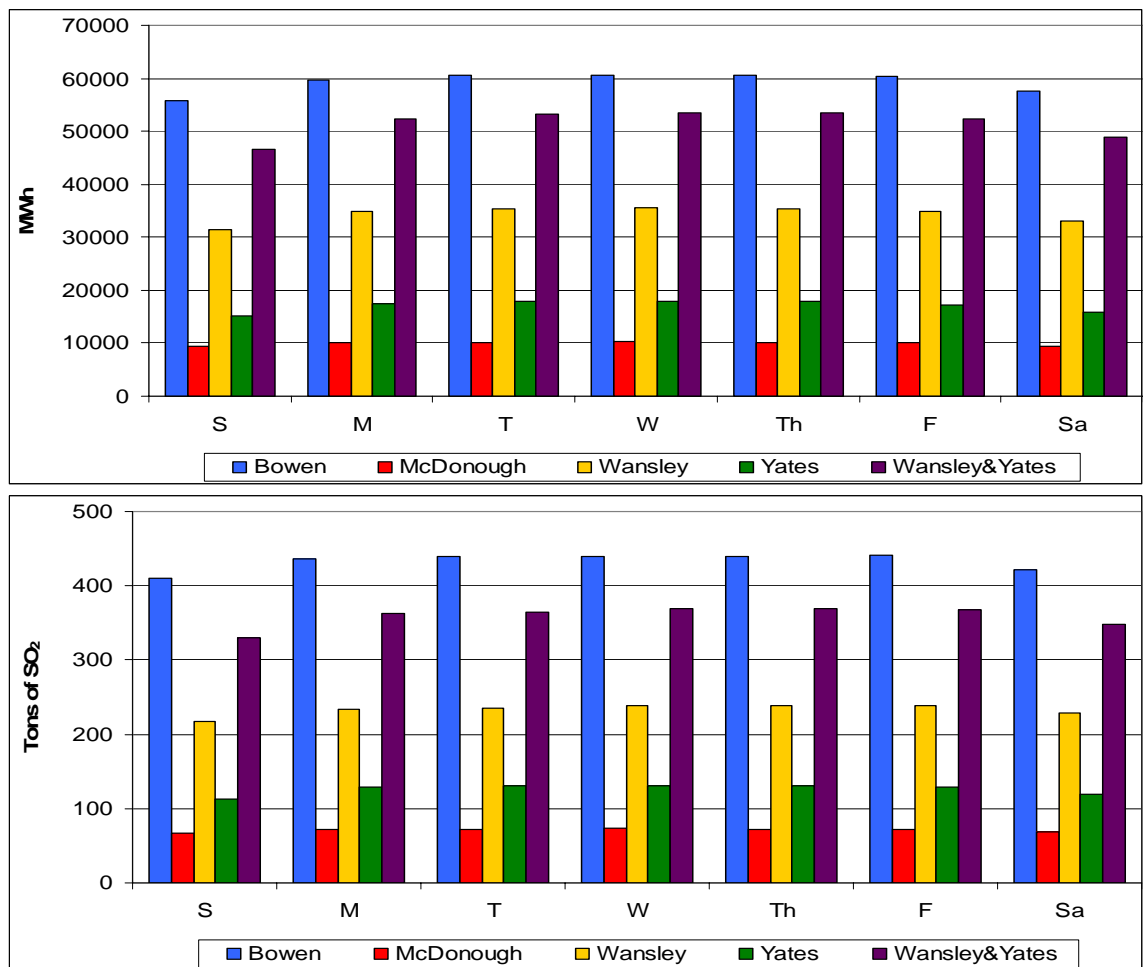


Figure 3.8: Daily averages of energy output (top) and SO₂ emissions (bottom) for all four Georgia Power plants, 1997-2005

Figure 3.8 illustrates that all four plants follow the same trend during the week: the energy output and SO₂ emissions peak during the middle of the week and decline on the weekends. These trends convey that energy demand is consistently higher during the middle of the week and lower on weekends.

3.9 Summary

There are five point sources of ambient SO₂ located in the vicinity of Atlanta that can be considered as possible contributors to elevated levels of ambient SO₂ in Atlanta: Plant Bowen, Plant McDonough, Plant Wansley, Plant Yates, and Lafarge Building Materials. SO₂ emissions at Lafarge were reduced by half in 2002 when one of the two kilns was removed, and then ceased when the second kiln was removed in late 2004. There was a significant decrease in SO₂ emissions (from 37% to 80%) at all Georgia Power plants from 1990 to 1995 when the company converted to low sulfur coal in 1994. Since this time, SO₂ emissions from Plants Bowen and McDonough have remained relatively constant, whereas SO₂ emissions from Plants Wansley and Yates have increased somewhat due to a rise in energy production.

Understanding the basic operation and design of each facility described in this chapter is a crucial first step in concluding not only whether or not any or all of them contribute to the ambient SO₂ in Atlanta, but also to determine the capacity and magnitude each of the facilities does so. After completing this task, the next step is to examine the patterns of ambient SO₂ in Atlanta recorded by the city's monitoring stations and compare them to the emission patterns from each facility in order to acquire a more

comprehensive understanding of where the SO₂ in Atlanta is originating and its behavior after being emitted.

Chapter 4

SULFUR DIOXIDE MONITORING STATIONS DATA AND TRENDS

4.1 Introduction

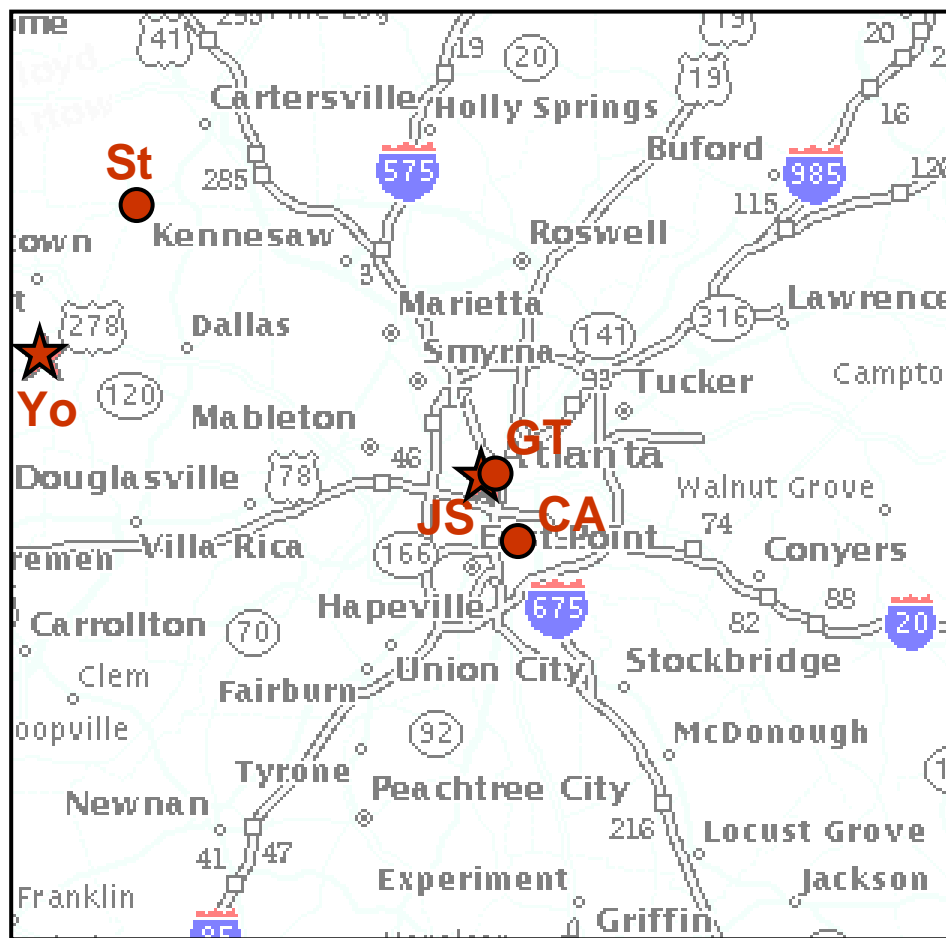
In addition to understanding the operation and emissions of the SO₂ point sources in the metro Atlanta area, it is important to study and interpret the data retrieved from the monitoring stations located in Atlanta that record ambient SO₂ concentrations. These data are key in identifying the concentration of SO₂ being transported in the atmosphere after being emitted from a point, area, or mobile source. Daily, monthly, and annual trends of measured SO₂, as well as time series plots of ambient SO₂ concentration are all instrumental in obtaining a better understanding of the dynamic behavior of ambient SO₂ in metro Atlanta.

4.2 Methods

The majority of the data for this part of the study came from the monitoring stations that record ambient SO₂ levels in the metro Atlanta area. There are currently five monitoring stations in metro Atlanta: Jefferson Street (JS), Yorkville (Yo), Georgia Tech (GT), Confederate Avenue (CA), and Stilesboro (St). Basic information for the aforementioned monitors can be found in Table 4.1, and the location of each monitor is mapped in Figure 4.1.

Table 4.1: Metro Atlanta SO₂ Monitor Information (US EPA, 2007; ARA, 2003)

Monitor	Maintained by	Site ID	Latitude	Longitude
Jefferson St	SEARCH	-	33.777	-84.417
Yorkville	SEARCH	-	33.928	-85.046
Georgia Tech	AQS	13-121-0048	33.792	-84.417
Confederate Ave	AQS	13-121-0055	33.721	-84.358
Stilesboro	AQS	13-015-0002	34.103	-84.915



130 km x 130 km

Figure 4.1: Map of the five SO₂ monitoring sites in the metro Atlanta area

The data recorded by all five monitors are assembled into a comprehensive database for use by Georgia Tech and Emory researchers (Wade, 2005). The three AQS monitoring sites, Georgia Tech, Confederate Avenue, and Stilesboro, started recording SO₂ data in 1982, 1991, and 1987, respectively (AtlAQData). The two SEARCH monitoring sites, Jefferson Street and Yorkville, which have been recording SO₂ data since 1998 and 1993, respectively, also record meteorological data such as wind speed, wind direction, temperature, relative humidity, barometric pressure, and solar radiation.

4.3 SO₂ Trends

A great deal of information can be learned by plotting the SO₂ data recorded by the Atlanta monitoring sites and examining the trends. The data recorded by the Yorkville and Stilesboro sites are not plotted since the monitors lie beyond the city of Atlanta, and thus outside of the scope of this study.

4.3.1 Annual Trends

Figure 4.2 displays the annual average of the 1-hr maximum values for Georgia Tech, Confederate Avenue, and Jefferson Street. The 1-hr max value represents the highest hourly concentration for a 24 hour day recorded by each monitor. The graph begins with 1983 Georgia Tech data, 1992 Confederate Avenue data, and 1999 Jefferson Street data since those were the first full years that each monitor recorded ambient SO₂ data.

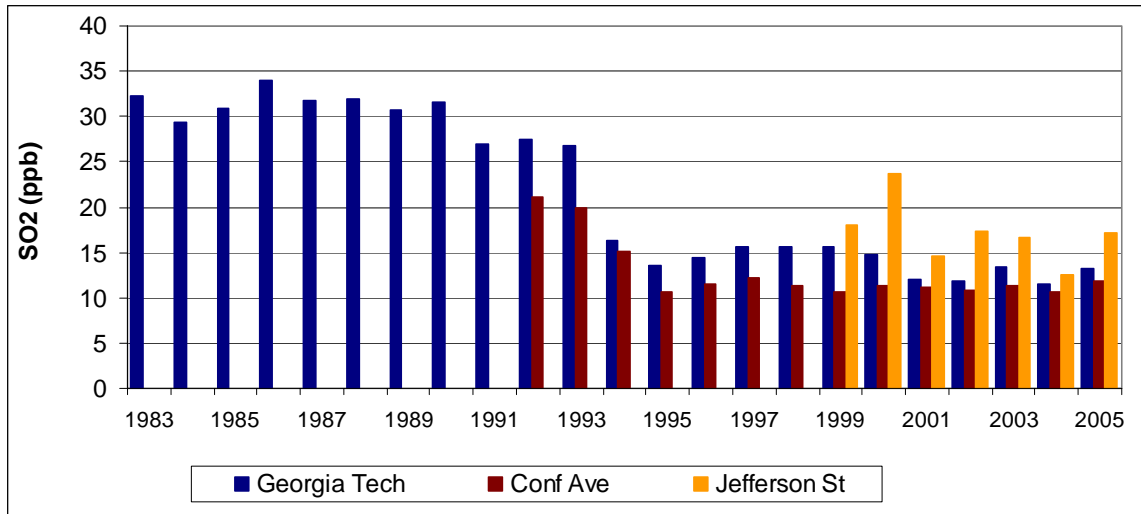


Figure 4.2: Annual averages of 1-hr Max values of SO₂ for GT, CA, and JS

Figure 4.2 reveals a significant trend that was exhibited by both GT and CA. During the years of 1994 and 1995, a sharp decrease in ambient SO₂ was observed and has since continued. This time frame matches markedly well to the period of time when Georgia Power plants converted from 3% sulfur coal to 1% sulfur coal. The change was implemented in late 1994 to comply with Phase I of the acid deposition reduction program initiated by Title IV of the Clean Air Act (Wilder, 2006). This program was established to reduce the annual SO₂ and NO_x emissions by ten million and two million tons, respectively, below 1980 levels. Phase I, which began January 1995, tightened emission limits primarily on coal-burning electric utility plants located in 21 eastern and mid-western states, thus driving Georgia Power to make the necessary changes to reduce SO₂ and NO_x emissions (US EPA-ARP, 2007). Low sulfur (1%) coal has been used at all four plants since, which explains the trend shift that takes place during the years of 1994 and 1995. The SO₂ emissions from the power plants, plotted in Chapter 3 as Figures 3.3, 3.4, and 3.5, follow the same trend as the ambient SO₂ levels, plotted in Figure 4.2, which

implies that the one or more of the power plants has a significant impact on ambient SO₂ concentrations in Atlanta.

Another trend present in Figure 4.2 that should be noted pertains to the higher SO₂ averages from Jefferson Street as compared to those from Georgia Tech and Confederate Avenue. There are two possible reasons for this difference. The first relates to the manner in which the Jefferson Street monitor records SO₂ data; the monitor is designed to reduce loss of SO₂ due to water absorption, which would likely lead to higher recorded SO₂ concentrations. The other possible reason could be that an SO₂ source is located in close proximity to the Jefferson Street monitor and is resulting in higher recorded SO₂ levels. Whatever the cause, the trend of higher averages from Jefferson Street is evident in all graphs that compare its SO₂ levels to those from the other Atlanta monitoring stations.

4.3.2 Monthly Trends

In order to establish any seasonal SO₂ trends that may exist in Atlanta, it is important to examine the monthly ambient SO₂ averages recorded by the monitors in Atlanta. Figure 4.3 illustrates the monthly averages of the 1-hr maximum values for the Georgia Tech, Confederate Avenue, and Jefferson Street monitoring stations from 1999 to 2005.

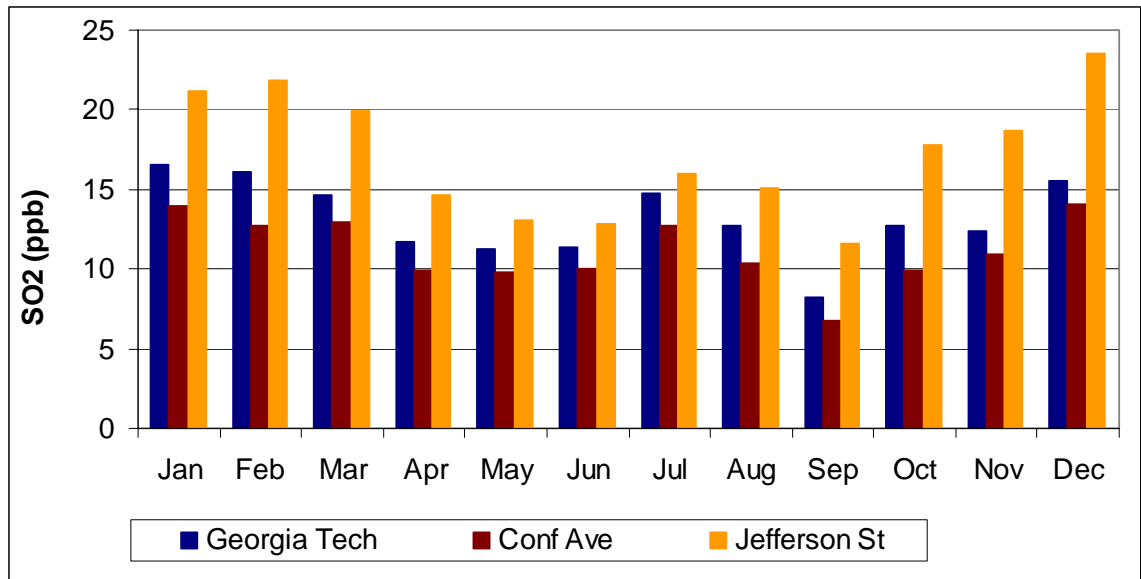


Figure 4.3: Monthly averages of 1-hr Max values of SO₂ for GT, CA, and JS, 1999-2005

Figure 4.3 confirms that there are definite seasonal trends of SO₂ in Atlanta, which are indicated by all three monitoring stations. Ambient SO₂ levels in Atlanta peak in the colder, winter months of December, January and February and then again in the warmer, summer months of July and August; SO₂ levels are lower during the months that usually bring milder temperatures. The monthly averages of the SO₂ emissions from Plants Bowen, McDonough, Wansley, and Yates, shown in Figure 3.7, exhibit a similar trend as that seen in Figure 4.3 which, as with the annual averages, implies that one or more of the power plants has a significant impact on ambient SO₂ concentrations in Atlanta.

4.3.3 Weekly Trends

The data recorded by the Atlanta monitors can also be used to ascertain the ambient SO₂ trends present during the week. Figure 4.4 illustrates the 1-hr maximum

SO₂ average for each day of the week for the Georgia Tech, Confederate Avenue, and Jefferson Street monitoring stations from 1999 to 2005.

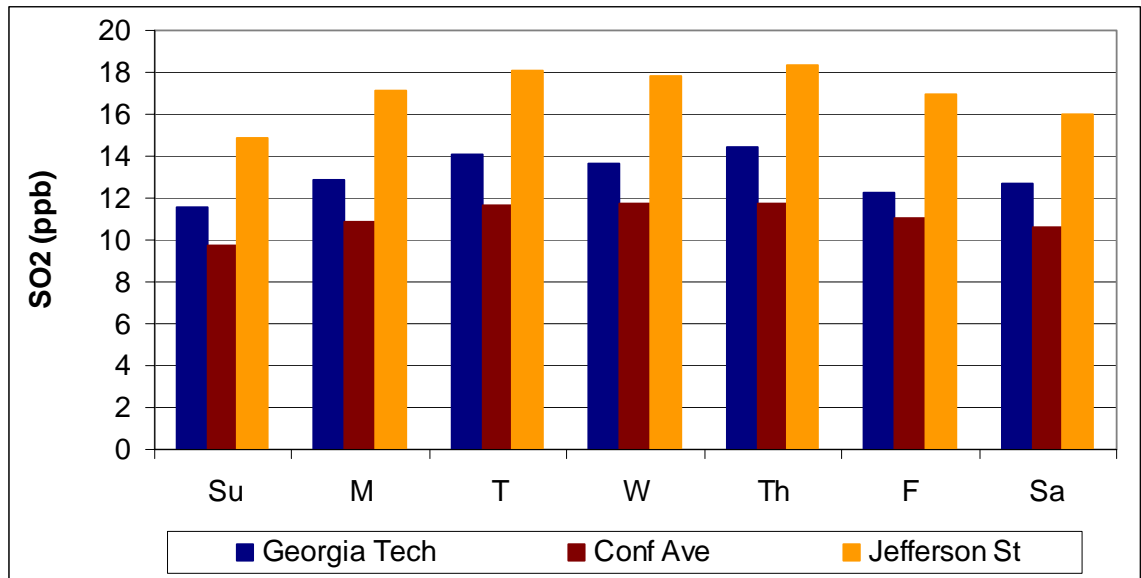


Figure 4.4: Daily averages of 1-hr Max values of SO₂ for GT, CA, and JS, 1999-2005

There is a clear trend displayed by Figure 4.4: ambient SO₂ concentrations in Atlanta peak during the middle of the week and decrease on the weekends. Similar to the annual and monthly trends, this daily trend was also seen when the average energy output and SO₂ emissions by Plants Bowen, McDonough, Wansley, and Yates for each day of the week were plotted in Figure 3.8.

4.3.4 Diurnal Profile

Finally, in order to get a comprehensive view of the ambient SO₂ trends in Atlanta, it is essential to examine the diurnal profile of ambient SO₂ recorded by the three monitoring stations, Georgia Tech, Confederate Avenue, and Jefferson Street. Figure 4.5 displays the average diurnal profile from 2002 to 2004 from all three monitoring stations.

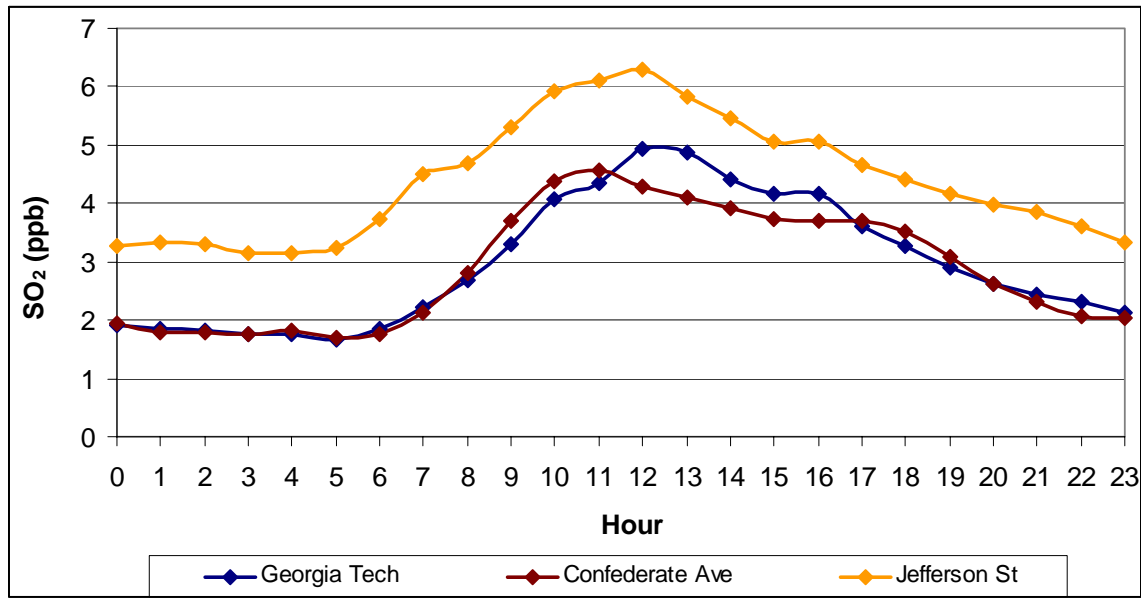


Figure 4.5: Average diurnal profiles for ambient SO₂ for GT, CA, and JS, 2002-2004

All three stations illustrate similar diurnal profiles that peak during the middle of the day and decline at night. Since the majority of Atlanta's SO₂ is estimated to originate from point sources, primarily coal-fired power plants, the trend seen in Figure 4.5 is expected for two reasons. The first reason stems from the fact that power plants produce most of their electricity and thus burn the largest volume of coal during the day when energy demand is the highest. The second reason is due to the atmospheric mixing height which is higher during the day than at night, and will likely drive a plume closer to ground-level, thus having a more significant impact on the monitor.

4.4 Variability of SO₂ in Atlanta

The primary objective of this study is to establish a better understanding of the sources of ambient SO₂ in the metro Atlanta area. The graphs shown so far have represented average values of ambient SO₂ and have not illustrated the day-to-day

variation in ambient SO₂ in Atlanta. In order to understand the daily variation of SO₂, it is helpful to compare its variability to that of some of the other atmospheric pollutants present in Atlanta. Pollutant concentration variability can be portrayed a number of ways, but one of the more effective way to describe it is by comparing the top 10% of the pollutant concentrations to the bottom 10% of the pollutant concentrations. Equation 4.1 provides a relative value that can be used to measure the difference between the highest recorded concentrations and the lowest recorded concentrations. Thus, a higher ratio corresponds to more variability for a particular pollutant.

$$VariabilityRatio = \frac{90th\ percentile}{10th\ percentile} \quad (4.1)$$

Figure 4.6 illustrates the variability ratios for five atmospheric pollutants in Atlanta: SO₂, NO_x, CO, O₃, and PM_{2.5} from 1999 to 2004 using the ambient levels recorded at the Jefferson Street monitoring station. The values from JS were used because it is the only Atlanta monitor that measures concentrations for all five pollutants.

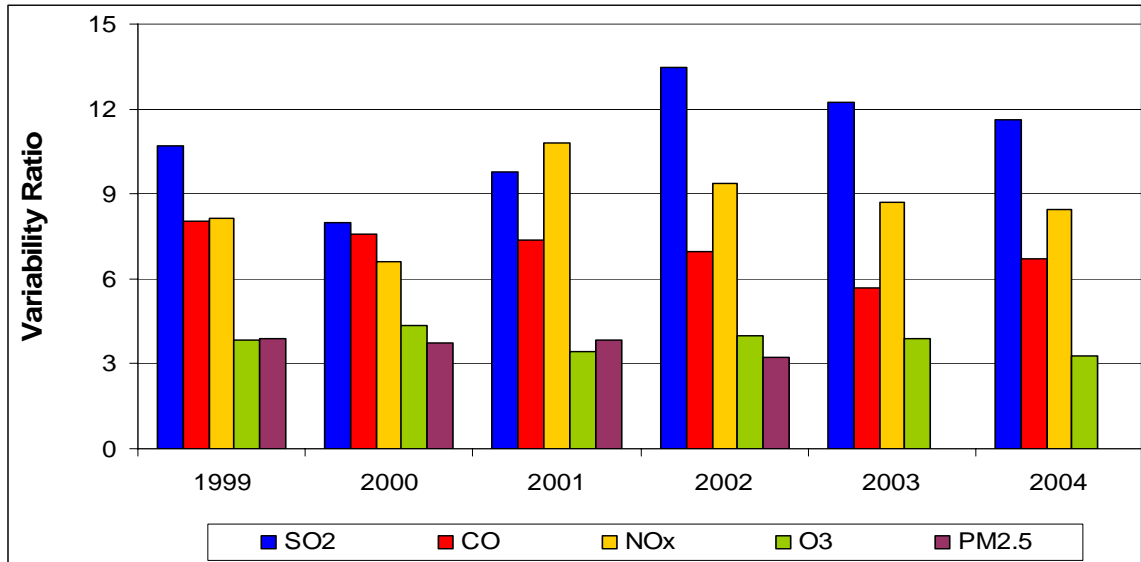


Figure 4.6: Variability Ratios for SO₂, CO, NO_x, O₃, and PM_{2.5} from Jefferson Street, 1999-2004

Figure 4.6 shows that for five out of the six years displayed, the variability in ambient SO₂ was higher than that from any of the other pollutants, which affirms that the daily variation in SO₂ concentration in Atlanta is noteworthy and important to study.

Figure 4.7 also illustrates the variation in SO₂ concentrations in Atlanta, but does so by separating the days in a particular year according to their 1-hr maximum value and plotting the average diurnal profiles. If the 1-hr maximum value for a particular day was above 20 ppb, its hourly diurnal profile is averaged with the other days in which the 1-hr max was above 20 ppb. This was also done for the days in which the 1-hr max was below 7 ppb and between 7ppb and 20 ppb. The plots shown in Figure 4.7 represent the diurnal averages from the three Atlanta monitoring stations, GT, CA, and JS, averaged for three years from 2002 to 2004.

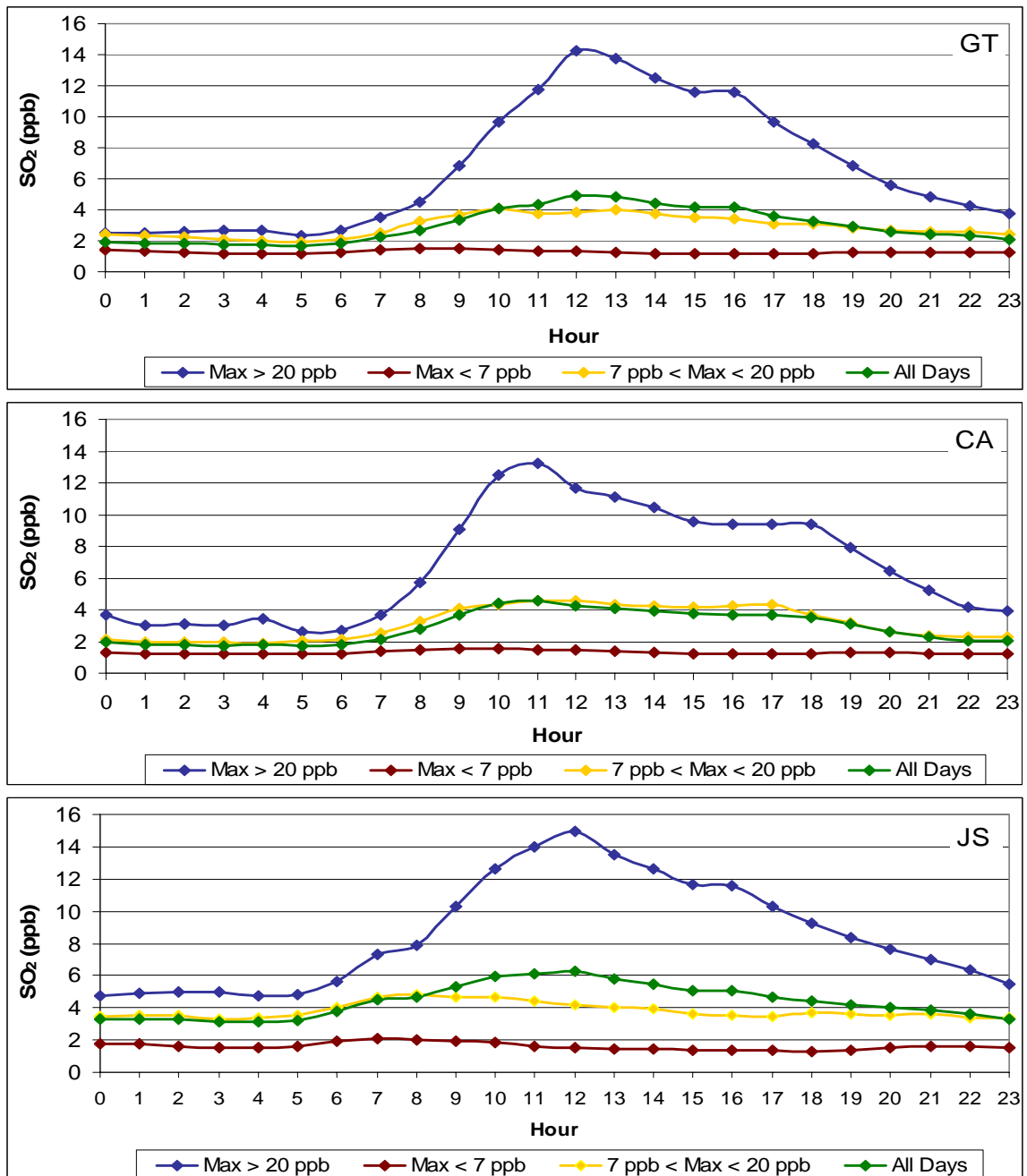


Figure 4.7: Diurnal averages from GT (top), CA (middle), and JS (bottom) broken down by 1-hr max values, averaged from 2002-2004

Figure 4.7 further describes the existing variability in ambient SO₂ in Atlanta. All three monitors illustrate that when the daily 1-hr max value exceeds 20 ppb, the average diurnal profile peaks significantly during the middle of the day; however, when the daily 1-hr max value does not exceed 7 ppb, the average diurnal profile is considerably flatter and averages less than 2 ppb for most of the 24-hour period.

The trends from Figure 4.7 also confirm that the sources contributing to the day-to-day variation of ambient SO₂ in Atlanta are point sources that are likely emitting a concentrated plume that is either not occurring every day or is not reaching the Atlanta monitors every day. Meteorological conditions undoubtedly contribute to the behavior of the plume and, therefore, are probably playing a significant role in the daily variability of SO₂ in Atlanta. This role will be discussed in detail in subsequent chapters.

4.5 Summary

The data recorded by the three Atlanta monitors, Georgia Tech, Confederate Avenue, and Jefferson Street, are relied on heavily to assist in understanding the behavior of ambient SO₂ in Atlanta. Time series plots of these data describe trends that can shed light on any significant changes that may have occurred to alter the ambient concentrations, as well as providing insight into which source or sources are contributing to the ambient SO₂ levels in Atlanta so that appropriate action can be taken to reduce emissions and thus decrease ambient levels in Atlanta. Average annual, monthly, and weekly trends of ambient SO₂ recorded by Georgia Tech, Confederate Avenue, and Jefferson Street agree well with trends of SO₂ emissions from the four power plants described in Chapter 3. Data from these monitors can also be used to describe the day-to-

day variation of ambient SO₂ in Atlanta as well as the magnitude by which it exceeds that of other pollutants.

Since emission data from the possible point sources and recorded concentration data from the Atlanta monitoring sites have both been analyzed, the next step in this study is to investigate the fate and transport of ambient SO₂ from a particular point source and how meteorological conditions impact its behavior.

Chapter 5

SULFUR DIOXIDE ROSE PLOTS

5.1 Introduction

Air pollutant roses are commonly used in air quality studies for source attribution and the identification local point sources. A pollutant rose is a polar plot of pollutant concentration versus the wind direction over a chosen period of time. Sources are indicated as lying at some distance along a straight line from the point of measurement in the direction of peak average concentration (Rigby et al., 2006). Constructing these plots for SO₂ in Atlanta is particularly beneficial since the emission inventories have shown that the greater part of ambient SO₂ in Atlanta originates from only a handful of sources, all of which are point sources. Analysis of the SO₂ rose plots for Atlanta provides a unique perspective on which source or sources are most contributing to the ambient SO₂ in Atlanta.

5.2 Methods

In order to construct SO₂ roses for Atlanta, hourly SO₂ concentration data from three monitoring stations in Atlanta, Georgia Tech, Confederate Avenue, and Jefferson Street, were used along with hourly wind direction data from the Jefferson Street monitoring site. The data were divided into 30 different wind direction bins of 12 degrees each. The average concentration for each bin was then plotted versus the wind direction on a 360° scatter plot (Wade, 2005). In addition, the average of all 30 bins was plotted with each

SO₂ concentration rose to show which peaks are above average and may point toward a local source of SO₂.

There are some limiting factors that accompany pollutant rose plots. First, there must be sufficient data from each of the bins. Too few data points in one bin would result in an unsubstantiated value for that bin. For the SO₂ rose plots presented in this chapter, the number of data points in one bin ranges from 49 hours to 666 hours. Second, there can be factors that confound the analysis, such as seasonal and/or diurnal patterns of wind direction. For example, the wind may originate from one direction more often at night or in the winter when mixing height is lower. However, the impact of these factors on SO₂ rose plots have been previously examined and found to be small (Wade et al., 2006).

To interpret pollutant rose plots, it is important to understand the spatial relationships among the sources and monitors. Figure 5.1 illustrates this relationship for the three downtown Atlanta monitoring sites: Georgia Tech, Confederate Avenue, and Jefferson Street, and the five SO₂ point sources in question: Plant Bowen, Plant McDonough, Lafarge Building Materials, Plant Wansley, and Plant Yates.



Figure 5.1: SO₂ point sources and monitoring sites in and around Atlanta

5.2 SO₂ Rose Plots

SO₂ rose plots were constructed using concentration data from Georgia Tech, Confederate Ave, and Jefferson Street along with wind direction data from Jefferson Street, as it is the only monitor out of the three that records meteorological data. Therefore, the SO₂ roses were plotted for the years that Jefferson Street has been fully operational, 1999-2005. The rose plots using Jefferson Street SO₂ concentration and wind direction data are displayed in Figure 5.2. Plots using Georgia Tech and Confederate Ave concentration data show similar results and can be found in Appendix A. Figure 5.2 shows that for each year from 1999-2005, a pronounced peak exists in the northwest direction around 300°. This peak points to the direction in which Plant Bowen, Plant McDonough, and Lafarge Building Materials lie. A smaller, though distinguishable, peak also exists in the southwest direction between 230-240°. This peak

points to the direction in which Plants Wansley and Yates lie. Table 5.1 lists the direction and distance of each point source from the Jefferson Street monitor. A corresponding table for directions and distances from Georgia Tech and Confederate Ave can be found in Appendix A.

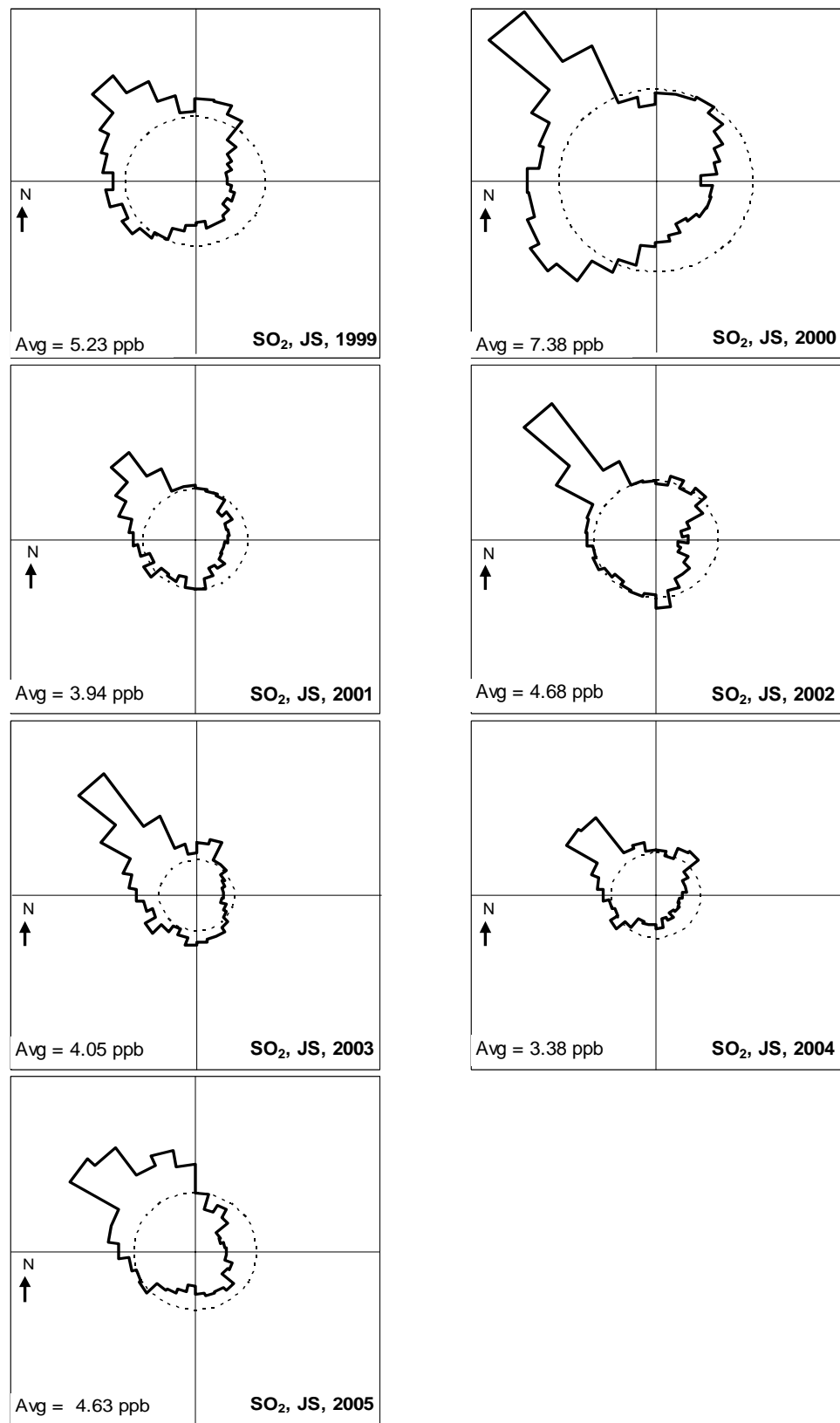


Figure 5.2: SO₂ Rose Plots from JS, 1999-2005. Scale is 14 ppb. Dashed circle represents average value.

Table 5.1: Direction and distance from Jefferson Street monitor to point sources

	Direction	Distance
Plant Bowen	310°	60.4 km
Plant McDonough	314°	7.5 km
Lafarge Building Materials	315°	7.2 km
Plants Wansley/Yates	233°	56.6 km

5.3 Examining SO₂ Rose Plots

As previously mentioned, the SO₂ rose plots constructed from concentration data recorded by Atlanta monitors are used to identify local point sources. The plots in Figure 5.2 are valuable because they clearly illustrate from which direction the high concentrations of SO₂ are coming. Each year from 1999-2005, the plots' most evident peak consistently points to the northwest direction of Atlanta toward Plant Bowen, Plant McDonough, and Lafarge Building Materials. There are smaller peaks which also seem to be consistent from year to year, such as the one that points in the southwest direction toward Plants Wansley and Yates; however these peaks do not compare in magnitude to the northwest peak and are not likely to be as significant in terms of their impact on air quality in Atlanta. For these reasons, it is safe to assume that the elevated levels of ambient SO₂ in Atlanta can be attributed to one or more of the three sources located northwest of the city. What the SO₂ roses cannot discern, however, is what role each of these three sources play in contributing to the high SO₂ concentrations recorded when the wind is blowing from the northwest direction. The remainder of this chapter will address this point by delving into the operation of each source in order to get an indication of the relative contributions of these three sources.

5.3.1 Lafarge Building Materials

SO₂ emissions from Lafarge, during the time that the kilns were operational, were estimated by the EPA's 2002 Emission Inventory to be approximately 100 times less than those of Plant Bowen and nearly 20 times less than those of Plant McDonough (US EPA-CHIEF, 2007). However, the SO₂ roses in Figure 5.2 show that high SO₂ concentrations are originating from one or more sources in the northwest direction, which includes Lafarge; therefore, it must be considered as a possible contributor to the elevated SO₂ levels in Atlanta recorded while Lafarge was in operation. It is important to note that Lafarge releases emissions at ground-level, or receptor-level, while the power plants release emissions at stack height.

One way to determine if Lafarge had an impact on ambient SO₂ levels in Atlanta during its operation is to compare the SO₂ data that was recorded by the Atlanta monitors before and after the Lafarge kilns were removed. The difference between this data represents the impact that the Lafarge cement kilns had on Atlanta SO₂ levels. The first kiln, which was of equal size and capacity to the second kiln, was taken offline in June 2002, thus theoretically cutting Lafarge's emissions by half. The second kiln was taken offline in December 2004. Figure 5.3 is a time series plot of the monthly averages of ambient SO₂ values recorded by three Atlanta monitors, Georgia Tech, Confederate Ave, and Jefferson Street, from 2001 to 2005. It also shows when each kiln was shutdown. Table 5.2 provides the annual average from each monitor as well as the percentage of each year when the wind is from the northwest direction.

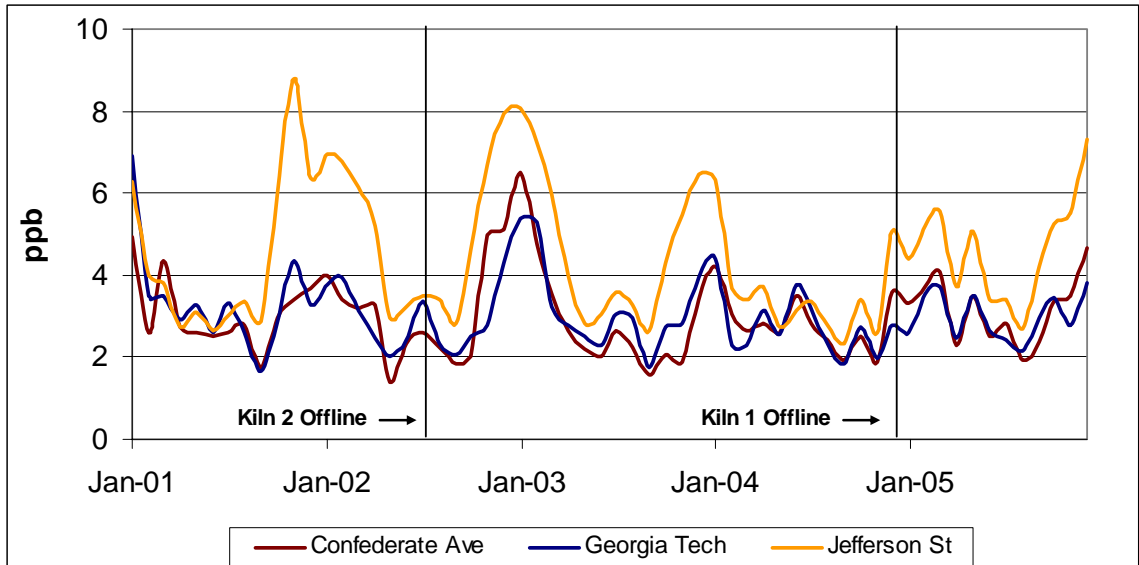


Figure 5.3: Monthly averages of SO₂ 24-hr average concentration from GT, CA, and JS, 2001-2005

Table 5.2: Annual SO₂ and wind direction data from GT, CA, and JS, 2001-2005

	Annual SO ₂ Average at GT, using 1-hr average concentrations (ppb)	Annual SO ₂ Average at CA, using 1-hr average concentrations (ppb)	Annual SO ₂ Average at JS, using 1-hr average concentrations (ppb)	% of Year Wind is from NW direction (300-335°), from JS data
2001	3.41	3.08	4.41	19%
2002	2.94	3.00	5.02	19%
2003	3.33	2.96	4.61	18%
2004	2.77	2.83	3.57	12%
2005	3.03	3.16	4.65	11%

Figure 5.3 does not show a consistent increase or decrease in the monthly average SO₂ concentration during the periods of time after the kilns were removed. In addition, the data in Table 5.2 does not reveal a consistent increase or decrease in annual SO₂ averages in the years after the kilns were removed. Hence, the emissions from the Lafarge cement kilns do not appear to have had a significant impact on the ambient SO₂

averages in Atlanta; however, it still may be possible that they had an impact on the magnitude of the northwest peak exhibited by the SO₂ rose plots in Figure 5.2, but a different kind of analysis is needed to determine this.

A separate, more detailed set of SO₂ roses are analyzed to provide more insight on the role that the Lafarge cement kiln had on SO₂ levels at the downtown monitors. The emissions from the kilns at Lafarge Building Materials did not exit from a stack; instead, there was a rectangular box located near ground level that blew the exhaust sideways. Examining a rose plot that focuses on a period of time with low mixing height will minimize the impact on ambient SO₂ from point sources that release emissions from a stack and emphasize the impact from ground-level sources, such as Lafarge. Therefore, since the atmospheric mixing height is typically lower at night than during the daytime, SO₂ roses can be constructed that only utilize data recorded at night. Figure 5.4 displays SO₂ roses that utilize nine hours of nighttime data (9pm-6am) recorded by the Georgia Tech monitor from the colder months of the year: January, February, November, and December, averaged from 1999-2004. These months are chosen because they will illustrate the maximum impact that Lafarge had on Atlanta SO₂ since the mixing height also tends to be lower in the winter as opposed to the summer.

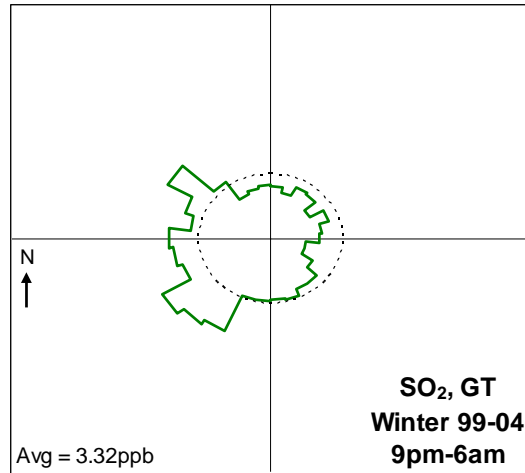


Figure 5.4: Nighttime (9pm-6am) SO₂ Rose Plot from Georgia Tech for Jan, Feb, Nov, and Dec, averaged from 1999-2004. Scale = 12 ppb. Dashed circle represents average value.

In order to provide a plot with which to compare Figure 5.4, a daytime SO₂ rose plot averaged over the summer months from 1999-2004 is represented by Figure 5.5. As opposed to Figure 5.4, this figure plots the data recorded during the day (11am-7pm) in June, July, August, and September, or the time periods when the mixing height is higher. This rose plot will emphasize the impact from sources that emit SO₂ from higher elevations and will minimize the impact from ground-level sources of SO₂.

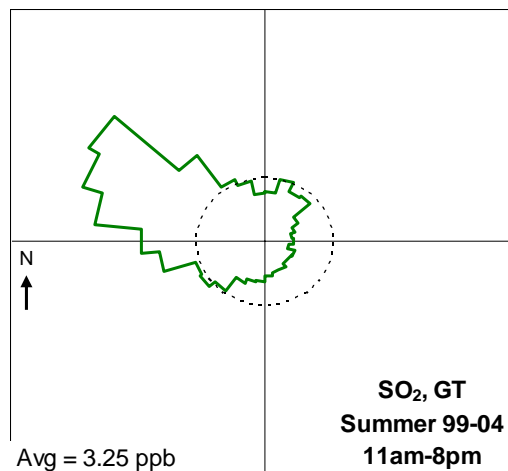


Figure 5.5: Daytime (11am-7pm) SO₂ Rose Plot from Georgia Tech for Jun, Jul, Aug and Sep, averaged from 1999-2004. Scale = 12 ppb. Dashed circle represents average value.

The difference in magnitudes of the northwest peaks in Figures 5.4 and 5.5 suggest that, of the three SO₂ point sources in the northwest direction, the larger sources of ambient SO₂ are those that affect the monitoring station when mixing height is high, such as Plant Bowen and Plant McDonough. Because of this, as well as the conclusion drawn by examining Figure 5.3, it appears that Lafarge did not contribute to a substantial portion of the elevated levels ambient SO₂ recorded in Atlanta.

5.3.2 Plant McDonough

After Lafarge, Plant McDonough is the closest SO₂ point source to Atlanta, being only 7.5 kilometers away from the Jefferson St monitoring station. Because of its close proximity, which is also directly in line with the northwest peak evident in the SO₂ rose plots, Plant McDonough is a viable source of the elevated levels of ambient SO₂ in Atlanta. After concluding in the previous section that Lafarge was not contributing substantially to the elevated SO₂ levels coming from the northwest direction, the emissions of Plant McDonough and Plant Bowen should be focused on as potential

sources of the northwest SO₂ peak. The primary objective for the remainder of this chapter then is to estimate the relative contributions of the two plants to the elevated SO₂ levels when the wind is from the northwest direction.

As with the analysis of Lafarge's contribution to SO₂ levels, a more detailed set of SO₂ rose plots can be constructed to play a role in understanding Plant McDonough's contribution to the elevated SO₂ levels in Atlanta. Plant McDonough consists of two electricity generating units with equal capacities. On average, each unit will shut down for preventative maintenance once a year for a period of time ranging from a few days to several weeks, depending on the maintenance schedule. The schedule changes from year to year so that a unit is not being shut down for the same period of time every year (Keiser, 2006). In order to try to understand the impact that shutting down one of Plant McDonough's units will have on the northwest SO₂ peaks exhibited by the rose plots, Figure 5.6 was constructed using concentration data recorded by the Georgia Tech monitor. This figure consists of three SO₂ rose plots: the complete SO₂ rose for all days averaged from 1999-2005, the SO₂ rose for the days when both units at Plant McDonough were in operation, averaged from 1999-2005, and the SO₂ rose for the days when one or both of the units at Plant McDonough were shut down, averaged from 1999-2005. The operating hours of each unit at Plant McDonough are available from the U.S. EPA Clean Air Markets database (US EPA-CAM, 2007). From 1999-2005, one or both of the Plant McDonough units were shut down for more than 18 hours a day approximately 20% of the time.

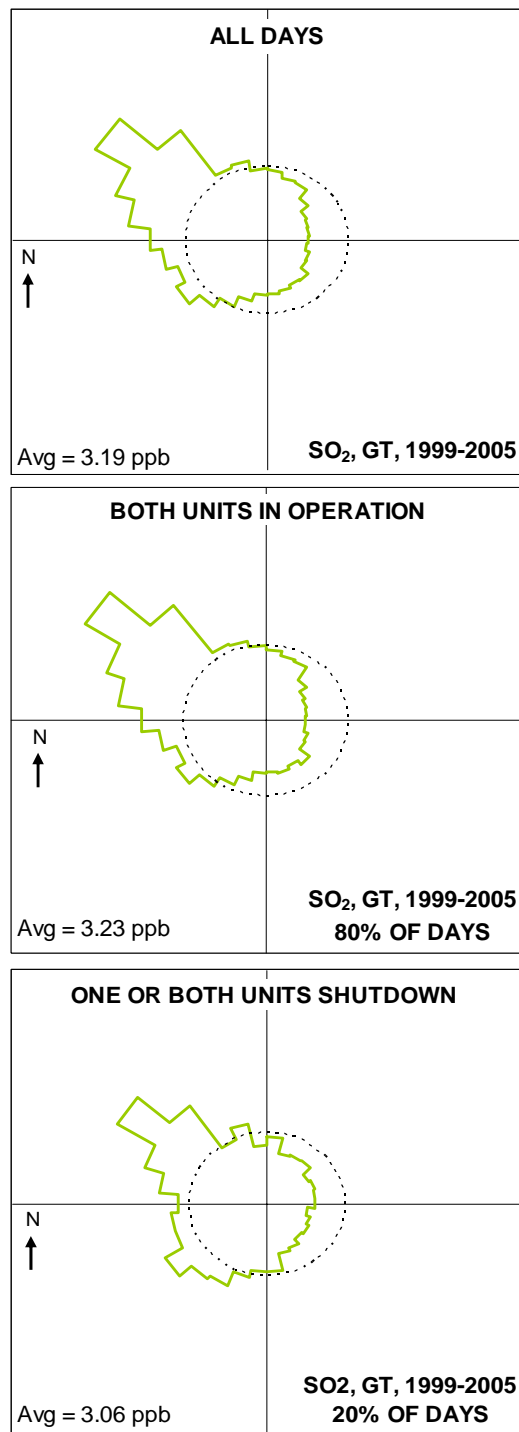


Figure 5.6: (a) SO₂ Rose Plots for All Days, (b) the days both units were in operation, (c) and the days one or both units were shutdown; averaged from 1999-2005.

Figure 5.6 illustrates that there is a difference between the magnitudes of not only the northwest peak, but also the southwest peak when Plant McDonough is fully operational versus when it is only partially operational. Table 5.3 describes the northwest and southwest peaks seen in the SO₂ rose plots in Figure 5.6 by listing the differences between the average of the rose plot and the value of the largest peak in the northwest and southwest direction, as well as the ratio between the southwest peak and the northwest peak.

Table 5.3: Descriptive data of northwest and southwest peaks in SO₂ rose plots (from Figure 5.6)

	Average of rose plot (ppb)	NW Peak – Average (ppb)	SW Peak – Average (ppb)	$\frac{(SW\ peak - Avg)}{(NW\ peak - Avg)}$
All Days	3.19	4.63	0.94	20%
Fully Operational	3.23	4.99	0.79	16%
Partially Operational	3.06	3.75	1.59	42%

The table above shows that when Plant McDonough is partially operational, the northwest peak is smaller and the southwest peak is larger than when Plant McDonough is fully operational. Also, the final column in Table 5.3, which computes the ratio between third and fourth columns in the table, reveals that the magnitude of the southwest peak is much closer to that of the northwest peak when Plant McDonough is not operating at full capacity. This trend demonstrates that when Plant McDonough is fully operational (i.e. with both units running), the emissions may be high enough to dampen the impact of emissions originating from the southwest direction, such as those

from Plants Wansley and Yates. This suggests that SO₂ emissions from Plant McDonough have a large impact on the ambient SO₂ levels recorded in Atlanta. To investigate this further, the characteristics and advection of Plant McDonough's plume are examined in the following chapter.

5.3.3 Plant Bowen

While Plant Bowen is the furthest distance from the Atlanta monitors among the three sources in question, it has the highest SO₂ emissions. For this reason, and that it lies directly in line with the northwest peak exhibited in the SO₂ rose plots, it should be considered as a possible contributor to the elevated levels of ambient SO₂ observed in Atlanta. Plant Bowen consists of four electricity generating units of equal capacity, and preventative maintenance is never scheduled for more than one unit at a time. Reducing emissions by one-quarter on a limited number of days might not be a considerable enough decrease to determine Plant Bowen's impact on Atlanta SO₂ levels, given the major role meteorological variables play in determining the magnitude of this impact. Therefore, SO₂ roses like those constructed for Plant McDonough that utilize full and partial capacity data were not used. However, other means of analyses can be applied to qualitatively estimate Plant Bowen's impact.

Figure 3.6, in which the annual averages of energy output and SO₂ emissions from the four Georgia Power plants around Atlanta were plotted, illustrates that by 2005, the combined SO₂ emissions from Plants Wansley and Yates had come within 10% of those from Plant Bowen. Plant Yates and Plant Wansley are located 56.6 km 69.6 km, respectively, from the Jefferson St monitor, only slightly closer than Plant Bowen. Because the SO₂ emissions and the distance to the monitor are so similar for Plant Bowen

and Plants Wansley/Yates, it might be expected that they project similar peaks onto the SO₂ rose plots.

Table 5.4 describes the northwest and southwest peaks seen in the annual SO₂ rose plots in Figure 5.2 by listing the fraction of the year when the wind blew from each direction, the differences between the annual average and the value of the largest peak in the northwest and southwest direction, as well as the ratio between the southwest peak and the northwest peak.

Table 5.4: Descriptive data of northwest and southwest peaks in annual JS SO₂ rose plots

	Annual Average of rose plot (ppb)	% of Year Wind from NW (300-335°)	% of Year Wind from SW (215-250°)	NW Peak – Annual Average (ppb)	SW Peak – Annual Average (ppb)	$\frac{(SW\ peak - Avg)}{(NW\ peak - Avg)}$
1999	5.23	13%	14%	5.37	1.17	21.8%
2000	7.38	17%	16%	9.72	3.62	37.2%
2001	3.94	19%	14%	4.66	0.56	12.0%
2002	4.68	19%	10%	8.82	-0.18	2.0%
2003	4.05	18%	12%	7.95	0.45	5.7%
2004	3.38	12%	10%	4.42	0.62	14.0%
2005	4.63	11%	4%	6.37	0.37	5.8%

Table 5.4 provides data that can be used to compare the northwest peak (direction of Plant McDonough and Plant Bowen) and the southwest peak (direction of Plant Wansley and Plant Yates). First is the comparison between the fraction of the year that the wind blew from the northwest and the southwest. For the majority of the years, the fraction is higher for northwest winds, although, the fraction for southwest winds is

similar. Another important point is the difference observed in NW and SW peaks when the peaks are subtracted from the annual average to determine the actual magnitude of each peak; the difference of the peaks from the average in the northwest direction is much higher than those from the southwest direction. In the final column of Table 5.4, the ratio between this difference is shown. From 1999-2005, the southwest peak ranges from comprising only 2% to comprising 37% of the peak in the northwest direction. This table reveals that although the wind blew from the two directions comparable amounts of time from year to year, the southwest peak is much smaller in magnitude than the northwest peak. Due to the previously stated similarities between the plume from Plant Bowen and the plume from Plants Wansley/Yates, one conclusion that can be drawn from Table 5.4 is that Plant Bowen is likely responsible for a small fraction of the northwest peak seen in the SO₂ rose plots in Figure 5.2; however, the fraction should be similar in magnitude to the peak seen from the southwest. This possibility will be evaluated further in the following chapter when the characteristics and advection of Plant Bowen's plume are examined.

5.4 Summary

The annual SO₂ rose plots using Jefferson Street data show that from 1999-2005, the highest levels of ambient SO₂ were recorded by the monitor when the wind was blowing from the northwest direction. These peaks are consistent from year to year, which implies that one or more of the three northwest point sources are responsible for the elevated levels. The Lafarge cement plant, due to its low emission rates compared to the other two point sources, did not appear to have an impact on the Jefferson Street

monitor. Between the two northwest power plants, analysis of the data suggests that emissions from Plant McDonough may be the more likely source of the elevated concentrations of SO₂ that occur when the wind originates from the northwest than Plant Bowen; however, the next chapter will attempt to estimate the amount of SO₂ that each plant contributes to the northwest peak evident in the SO₂ rose plots by modeling the plumes of each plant.

Chapter 6

PLUME MODELING

6.1 Introduction

The behavior of contaminant plumes released from elevated point sources is greatly affected by the condition of the atmosphere. The impact of a plume depends on the complex processes of plume trajectory and dispersion. Provided that sufficient meteorological and emission data are available, plume modeling can lead to a better understanding of an emission source impact. Modeling plumes that exit the stacks of power plants provides an estimate of the SO₂ level present in the plume at the time it reaches an air quality monitoring station. For this study, a Gaussian dispersion model is used to model the plumes from the power plants whose SO₂ emissions are impacting Atlanta air quality: Plant Bowen, Plant McDonough, and Plants Wansley/Yates. On days when the SO₂ concentration was especially high in Atlanta, the Gaussian dispersion model can be applied to indicate if a plume from one of the power plants in question may have contributed to or caused the elevated ambient SO₂ levels.

6.2 Methods

Wind speed, wind direction, temperature and solar radiation are all important factors to consider when modeling a point source plume. Variation in meteorological conditions can shift a plume such that its impact on a monitor ranges from no impact to direct impact. The NOAA (National Oceanic and Atmospheric Administration) provides an internet-based trajectory modeling program that can be run using archived

meteorological data to estimate whether an air parcel released from a point source at a given date and time will come within the vicinity of an air quality monitoring station. The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model computes the advection of a single pollutant particle either in a forward direction or a backward direction. The online program can then produce a plot of the air parcel's trajectory for user-specified starting heights and times (NOAA, 2006). This trajectory acts as a centerline of the plume for which the dispersion can then be calculated using the Gaussian model.

The basic Gaussian dispersion model assumes that the pollutant concentration follows a normal distribution about its centerline in both the vertical and the horizontal directions (Masters, 1997). The Gaussian point-source dispersion equation for plumes containing gaseous pollutants not absorbed by the ground (Equation 6.1) relates the source's emission rates, wind speed, effective stack height, and atmospheric conditions:

$$c_i(x, y, z) = \frac{q}{2\pi\bar{u}\sigma_y\sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right) \right] \quad (6.1)$$

where c_i is the concentration of the pollutant at the point (x,y,z), q is the emission rate of the pollutant, \bar{u} is the average wind speed at the effective stack height, H , and σ_y and σ_z are the horizontal and vertical dispersion coefficients (Seinfeld and Pandis, 1998). For this study, the meteorological data used in the Gaussian dispersion model comes from the Jefferson Street monitoring station, the effective stack height is taken to be the height of the elevation of the stacks at each power plant, and plume rise is neglected.

6.3 Plant Bowen and Plant McDonough Plumes

The SO₂ rose plots in Chapter 5 revealed noticeably high SO₂ concentrations when the wind originated from the northwest. Although three point sources have been identified in that direction (Chapter 3), Lafarge was ruled out as playing a significant role in the elevated SO₂ levels (Chapter 5), leaving one or both of the remaining two sources, Plant Bowen and Plant McDonough, as the primary contributors. In addition to the methods applied in previous chapters, plume modeling is another means of understanding the contributions made by each power plant to the daily variation of SO₂ recorded in Atlanta by the downtown monitoring stations, Georgia Tech, Confederate Avenue, and Jefferson Street.

Four days were chosen from 2003 when the recorded ambient SO₂ concentration in Atlanta peaked during the day, suggesting that the elevated concentrations were a result of a plume being pulled down to ground-level due to an increase in the mixing height. Table 6.1 provides some meteorological data recorded by the Jefferson Street monitoring station on the four days in question, and Figure 6.1 shows their diurnal profiles.

Table 6.1: Meteorological data for four days in 2003 with elevated SO₂ concentrations

	% of Day Wind Came from NW (300-335°)	1-hr Maximum Wind Speed (m/s)	24-hr Average Wind Speed (m/s)	1-hr Maximum Temperature (°C)	24-hr Average Temperature (°C)
Jan 13, 2003	67%	3.02	1.54	6.89	1.48
Feb 18, 2003	38%	2.61	1.88	6.81	2.82
Mar 10, 2003	75%	3.25	2.04	18.89	11.92
Nov 14, 2003	58%	2.36	1.37	14.36	7.54

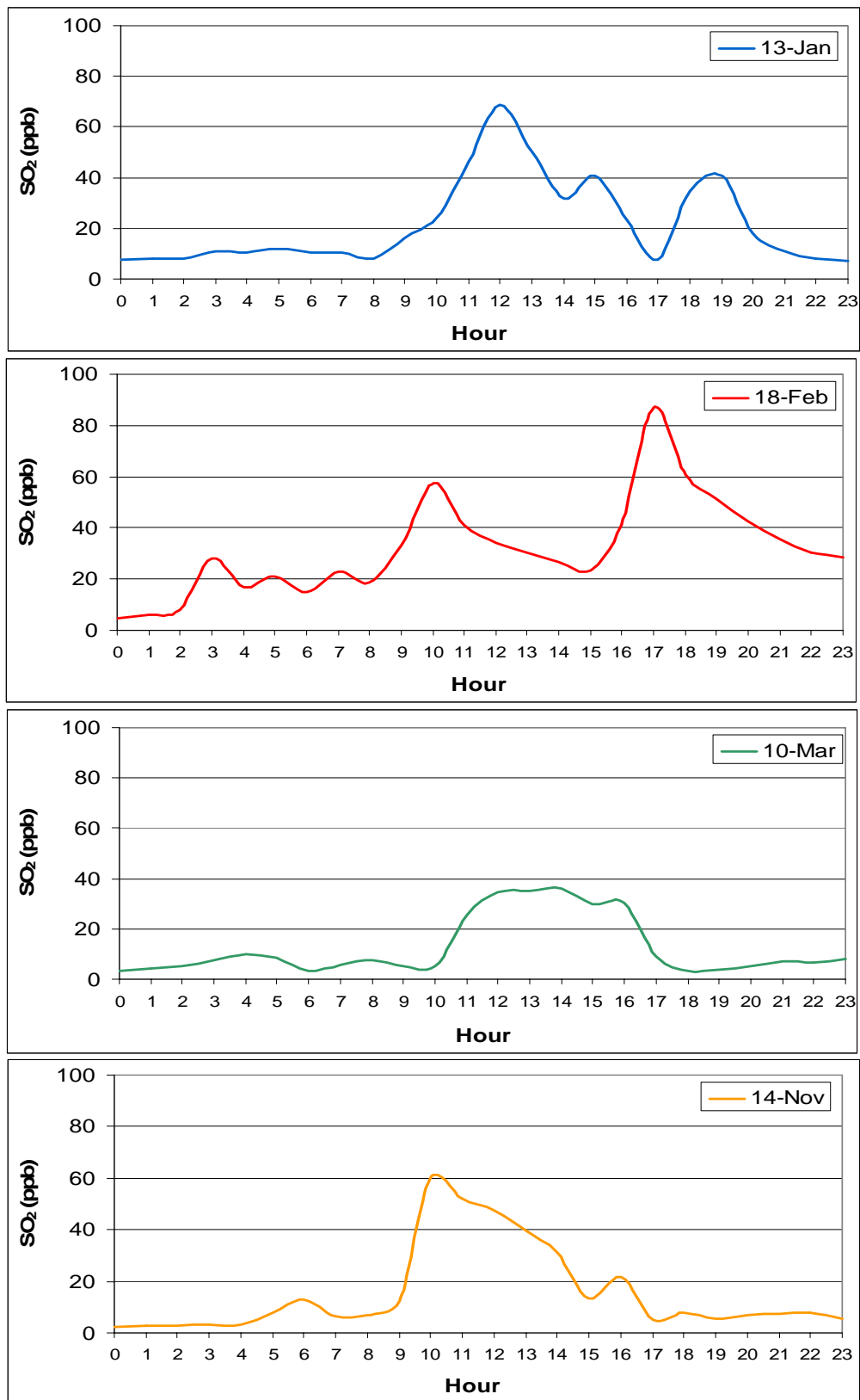


Figure 6.1: Diurnal Profiles for four days in 2003 with elevated SO₂ concentrations

Figure 6.1 shows that the ambient SO₂ concentration for the four selected days is lower during the nighttime when mixing height is lower and peaks during the daytime when mixing height is higher. This trend suggests that these peaks are most likely the result of a plume emitted from an elevated stack being pulled down to ground-level when mixing height increases. The data listed in Table 6.1 shows that for all four days, the wind was blowing from the northwest direction for a significant portion of the day, which suggests that Plant Bowen and/or Plant McDonough are responsible for the peaks in SO₂ concentrations on January 13, 2003, February 18, 2003, March 10, 2003, and November 14, 2003. The forward trajectories from each plant for each day were computed using the NOAA HYSPLIT internet-based model. The mapped trajectory could then be used to determine the distance that the centerline of the plume had to travel to reach its nearest point to the Jefferson Street monitor, as well as the shortest distance from centerline to the Jefferson Street monitor. The Gaussian dispersion model is then applied in order to estimate the SO₂ concentration of the plume's centerline at its nearest point to the Jefferson Street monitor, which theoretically represents the maximum value of SO₂ that will impact the monitor, as well as the SO₂ concentration of the portion of the dispersed plume that passes over the Jefferson Street monitor.

6.3.1 January 13, 2003

On January 13, 2003, the ambient SO₂ concentration reached its peak of 68.7 ppb at 12:00pm. However, in order to ensure that the mixing height was sufficiently high enough for the plumes to descend to the elevation of the monitor, the forward trajectories from Plant Bowen and Plant McDonough begin at 12:00pm (17:00 UTC) and 3:00pm (20:00 UTC), respectively. Due to the difference in proximity to the monitor, the two

trajectories were started at the given times so that they would reach their nearest point to the Jefferson Street monitor at approximately the same time, between 3:00pm and 4:00 pm, in this case. Figure 6.2 displays the two trajectories from each plant. The estimated plume, calculated by the Gaussian dispersion model, for one standard deviation in the y and z directions, σ_y and σ_z , is also illustrated on the map.

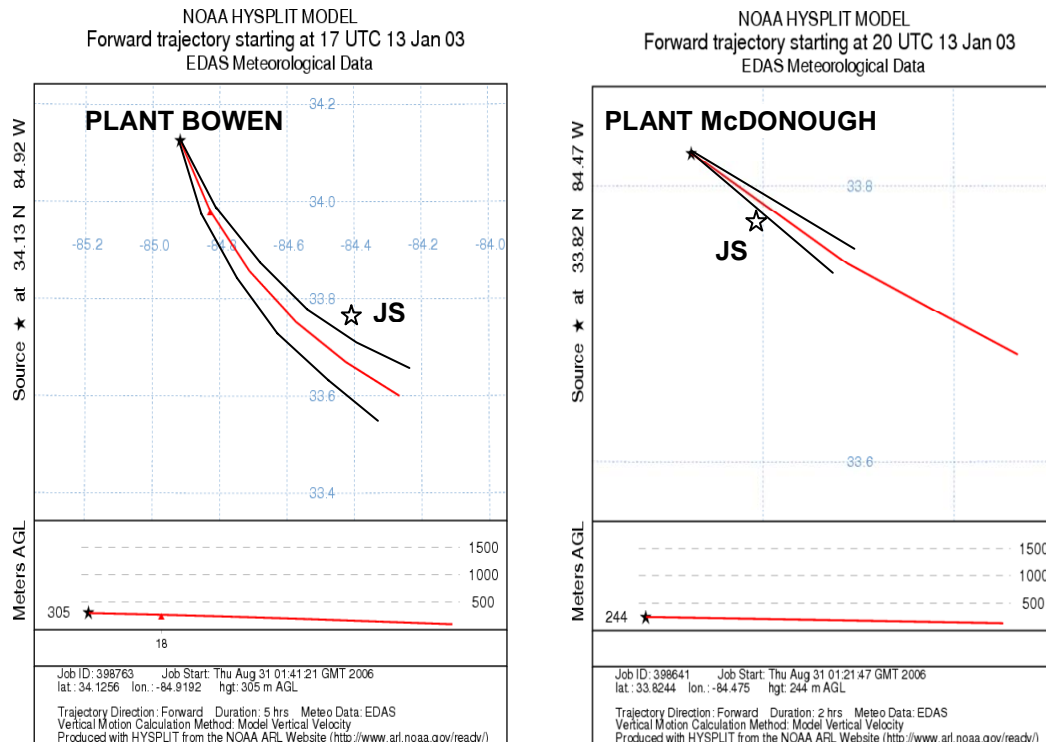


Figure 6.2: Forward trajectories from Plants Bowen and McDonough-January 13, 2003

There are a few points that should be noted regarding the trajectories above and the subsequent trajectories that will be exhibited in this chapter. First, the scales of the two maps are different so that the details of each plume are viewable; the latitude and longitude lines illustrate the difference in scale. Next, the elevation plot below the trajectory tracks the air parcel in the vertical direction over the same period of time as the

horizontal trajectory displayed above it. Finally, the trajectory shows that, for the chosen period of time, the wind direction remained steady from the northwest direction.

While Figure 6.2 shows that both plumes travel to a point reasonably close to the Jefferson Street monitor, the center of the plume from Plant McDonough actually comes closer than the center of the plume from Plant Bowen. The specifications of the trajectories in Figure 6.2, as well as the results of the Gaussian dispersion equation for January 13, 2003 are listed in Table 6.2.

Table 6.2: Distance and SO₂ Data of Plumes from Plants Bowen and McDonough on January 13, 2003

		JANUARY 13, 2003				
		Distance (km)		SO₂ concentration (ppb)		
	# of Units in Operation	Shortest distance from plume centerline to JS	Distance plume traveled from stack to shortest distance to JS	SO ₂ of plume centerline at shortest distance to JS	SO ₂ of portion of plume passing over JS	Average hourly SO ₂ at JS when plume passes over
Plant Bowen	3 of 4	10.5	64.1	6.5	1.2	40.8
Plant McDonough	2 of 2	1.7	7.7	96.2	3.2	40.8

Although McDonough emits an average of six times less SO₂ emissions than Bowen, its plume does not have to travel as far to reach the monitor, therefore, its dispersion is less and the SO₂ concentration at the centerline is higher at the time it reaches the Jefferson Street monitor. According to the values estimated by the Gaussian dispersion model, the SO₂ concentration at the centerline of the McDonough plume is 96.2 ppb when it reaches the nearest point to the Jefferson Street monitor. However, the

shortest distance from the centerline to the monitor is 1.7 km, and the estimated SO₂ concentration of the plume at the monitor is only 3.2 ppb. Clearly, there is a significant difference between the SO₂ levels in the center of the plume and the levels on the outside of the plume; thus, if the wind shifted either direction, even for a short period of time, the portion of the McDonough plume that passed over the monitor could have an SO₂ concentration ranging from 0 ppb to 96.2 ppb. This makes sense when reviewing the average hourly SO₂ concentration recorded by the Jefferson Street monitor during the time when the Bowen and McDonough plumes were at their closest points to the monitor, which was 40.8 ppb, since it falls squarely between the given range for the McDonough plume. From these calculations, it is much more likely that the plume from Plant McDonough, rather than the plume from Plant Bowen, was a source of the elevated ambient SO₂ levels recorded by the Jefferson monitor on January 13, 2003.

While Plant Bowen is a much larger facility than Plant McDonough, it is eight times further away from the Jefferson Street monitor; its plume will logically be wider and more dispersed by the time it reaches the monitor. According to the values estimated by the Gaussian dispersion model, the SO₂ concentration at the centerline of the Bowen plume is 6.5 ppb when it reaches its nearest point to the Jefferson Street monitor, and the estimated SO₂ concentration of the plume at the monitor, which is approximately 10.5 km from the centerline, is 1.2 ppb. Unlike McDonough's plume, there is not a great difference between the concentration at the centerline of the plume and the concentration on the outside of the plume; therefore, a shift in the wind would only result in a range of SO₂ from 0 ppb to 6.5 ppb impacting the monitor. While the plume from Plant Bowen

probably had some impact on the Jefferson Street monitor on January 13, 2003, it is not likely that it had a major impact on the high SO₂ levels illustrated by Figure 6.1.

6.3.2 February 18, 2003

On February 18, 2003, the ambient SO₂ concentration peaked twice: 57.7 ppb at 10:00am and 86.7 ppb at 5:00pm. In order to discern what may have caused the peak at 5:00pm, the forward trajectories from Plant Bowen and Plant McDonough, shown in Figure 6.3, begin at 12:00pm (17:00 UTC) and 5:00pm (22:00 UTC), respectively. As with Figure 6.2, the two trajectories were started at the given times so that they would reach their nearest point to the Jefferson Street monitor at approximately the same time, between 5:00pm and 6:00 pm, in this case. Again, the estimated plume, calculated by the Gaussian dispersion model, for one standard deviation in the y and z directions, σ_y and σ_z , is also illustrated on the map.

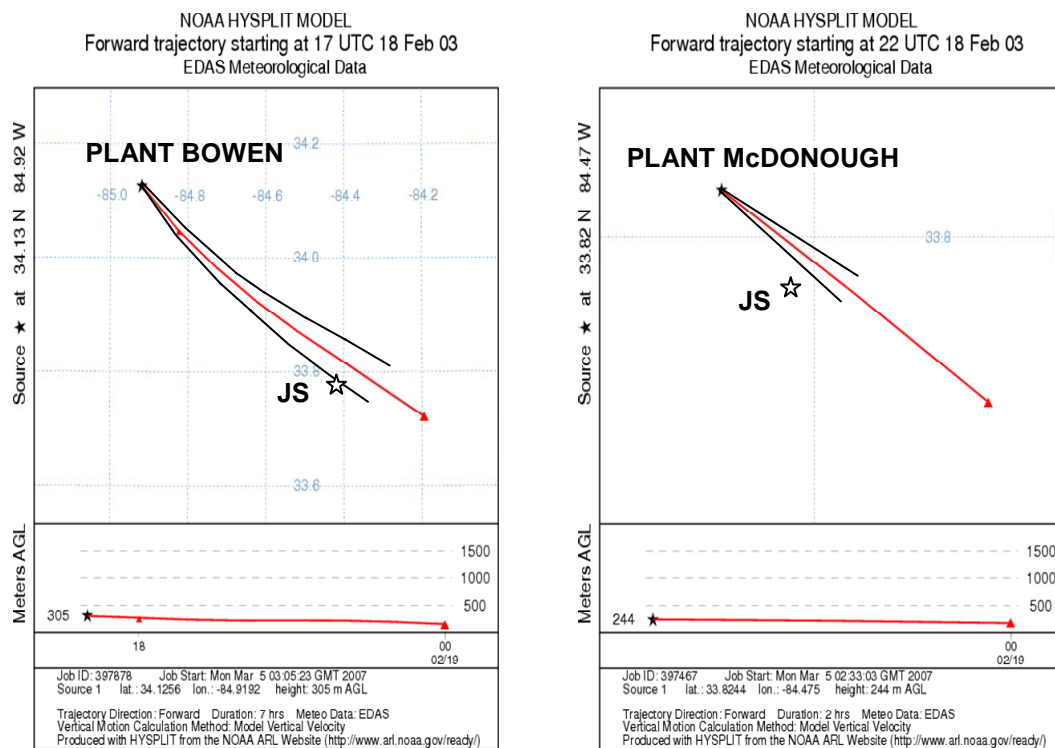


Figure 6.3: Forward trajectories from Plants Bowen and McDonough-February 18, 2003

As with the trajectories in Figure 6.2, the trajectories in Figure 6.3 show that both plumes are carried by rather steady northwesterly winds and come reasonably close to the Jefferson Street monitor. The specifications of the trajectories in Figure 6.3, as well as the results of the Gaussian dispersion equation for February 18, 2003 are listed in Table 6.3.

Table 6.3: Distance and SO₂ Data of Plumes from Plants Bowen and McDonough on February 18, 2003

		FEBRUARY 18, 2003				
		Distance (km)		SO₂ concentration (ppb)		
	# of Units in Operation	Shortest distance from plume centerline to JS	Distance plume traveled from stack to shortest distance to JS	SO ₂ of plume centerline at shortest distance to JS	SO ₂ of portion of plume passing over JS	Average hourly SO ₂ at JS when plume passes over
Plant Bowen	4 of 4	4.6	60.8	28.5	14.9	86.7
Plant McDonough	2 of 2	1.8	7.3	140.7	2.3	86.7

The calculated SO₂ values from the plumes emitted from Plant Bowen and Plant McDonough on February 18 are similar in some respects to those seen on January 13, but differ in other respects. The first similarity is that the SO₂ concentration at the centerline of the McDonough plume (140.7 ppb) is much larger than the SO₂ at the centerline of the Bowen plume (28.5 ppb). However, while both centerline concentrations increased from January 13, the ratio of the McDonough value to the Bowen value has decreased, which means that Bowen's centerline concentration increased more than McDonough's. This observation is understandable since Bowen was operating all units on February 18 and only operating 3 of 4 units on January 13. Nevertheless, even though Plant Bowen's centerline SO₂ concentration significantly increased, it is still too low to account for the average hourly SO₂ concentration recorded by the Jefferson Street monitor at the time that the plumes are at their closest points. Therefore, by modeling the plumes emitted on the afternoon of February 18, 2003, it has been demonstrated that Plant McDonough is very likely the source of the elevated SO₂ levels recorded by the Jefferson Street monitor;

and, while Plant Bowen is almost certainly contributing to the high SO₂ levels recorded by the downtown monitor, its contribution is plausibly several times less than the contribution made by Plant McDonough.

6.3.3 March 10, 2003

The ambient SO₂ data recorded by the Jefferson Street monitor on March 10, 2003 is unique compared to the data recorded on the previous two days presented in this section (see Figure 6.1). Instead of the spikes seen on January 13 and February 18, the average hourly ambient SO₂ concentration on March 10 rises in the 11:00 hour to nearly 30 ppb and stays in the 30-40 ppb range for six hours. This day was chosen because it appears to illustrate a stabilization of the increased mixing height during the daytime. The forward trajectories from Plant Bowen and Plant McDonough, shown in Figure 6.4, begin at 11:00am (16:00 UTC) and 1:00pm (18:00 UTC), respectively. As with the previously shown trajectories, the two trajectories in Figure 6.4 were started at the given times so that they would reach their nearest point to the Jefferson Street monitor at approximately the same time, between 1:00pm and 2:00 pm, in this case. It should be noted that Table 6.1 reveals that the wind speed was higher on March 10 than the other listed days, which accounts for why the plumes, especially the plume from Plant Bowen, reach their nearest point to the monitor in such a short period of time.

Again, the estimated plume, calculated by the Gaussian dispersion model, for one standard deviation in the y and z directions, σ_y and σ_z , is also illustrated on the map.

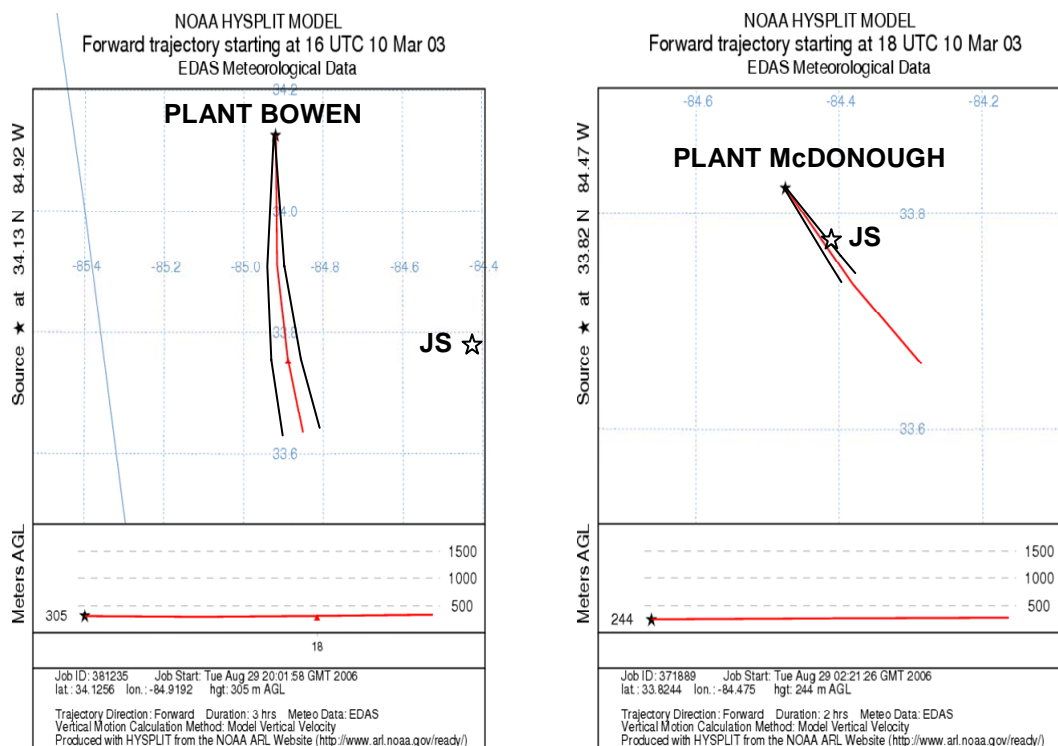


Figure 6.4: Forward trajectories from Plants Bowen and McDonough-March 10, 2003

Just by examining the trajectories in Figure 6.4, it seems rather unmistakable which plume is impacting the Jefferson Street monitor on March 10, 2003. However, it is important to examine the details of the trajectories and the modeled plumes in Figure 6.4 to discern if either plant is contributing to the prolonged increase in ambient SO_2 concentration exhibited by the Jefferson Street monitor on March 10. The specifications of the trajectories, as well as the results of the Gaussian dispersion equation for March 10, 2003 are listed in Table 6.4.

Table 6.4: Distance and SO₂ Data of Plumes from Plants Bowen and McDonough on March 10, 2003

		MARCH 10, 2003				
		Distance (km)		SO₂ concentration (ppb)		
	# of Units in Operation	Shortest distance from plume centerline to JS	Distance plume traveled from stack to shortest distance to JS	SO ₂ of plume centerline at shortest distance to JS	SO ₂ of portion of plume passing over JS	Average hourly SO ₂ at JS when plume passes over
Plant Bowen	3 of 4	43.3	48.0	16.6	0	35.2
Plant McDonough	2 of 2	0.9	7.7	71.9	28.4	35.2

The data listed in Table 6.4 confirms the conjecture formed when observing the plumes displayed in Figure 6.4: the plume originating from Plant Bowen never comes close enough to the Jefferson Street monitor to have any impact on the SO₂ levels recorded on March 10, 2003. For a plume exiting the stack at 11am, its nearest distance to the Jefferson Street monitor is more than 43 kilometers, and according to the Gaussian dispersion model, the SO₂ concentration of the plume 43 kilometers from the centerline is zero. Consequently, it is highly unlikely that the plume from Plant Bowen contributes to the SO₂ values on March 10, 2003 in any way.

The plume from Plant McDonough, on the other hand, comes within one kilometer from the Jefferson Street monitor on March 10. At this point, the SO₂ concentration of the plume's centerline is 71.9 ppb, and 0.9 kilometers away from the centerline, the SO₂ concentration of the plume is 28.4 ppb. The circumstances of McDonough's plume on March 10 are remarkably similar to those on January 13 and February 18; a shift of the wind direction would result in a wide range of SO₂ values

impacting the monitor from 0 ppb to 71.9 ppb, depending on the direction and magnitude of the shift. This scenario could easily result in the average hourly SO₂ concentration recorded by the Jefferson Street monitor of 35.2 ppb, which again suggests that the McDonough plume significantly contributed to the elevated SO₂ levels on March 10, 2003.

6.3.4 November 14, 2003

The ambient SO₂ data recorded by the Jefferson Street monitor on November 14, 2003 is somewhat of a hybrid between the data recorded on January 13 and the data recorded on March 10; a visible peak occurs during the 10:00 hour, but instead of descending quickly as seen on January 13, the SO₂ concentration falls gradually over a period of seven hours. The forward trajectories from Plant Bowen and Plant McDonough, shown in Figure 6.5, begin at 10:00am (15:00 UTC) and 12:00pm (17:00 UTC), respectively. As with the previously shown trajectories, the two trajectories in Figure 6.5 were started at the given times so that they would reach their nearest point to the Jefferson Street monitor at approximately the same time, between 12:00pm and 1:00 pm, in this case. In addition to the trajectories, the estimated plume, calculated by the Gaussian dispersion model, for one standard deviation in the y and z directions, σ_y and σ_z , is also illustrated on the maps in Figure 6.5.

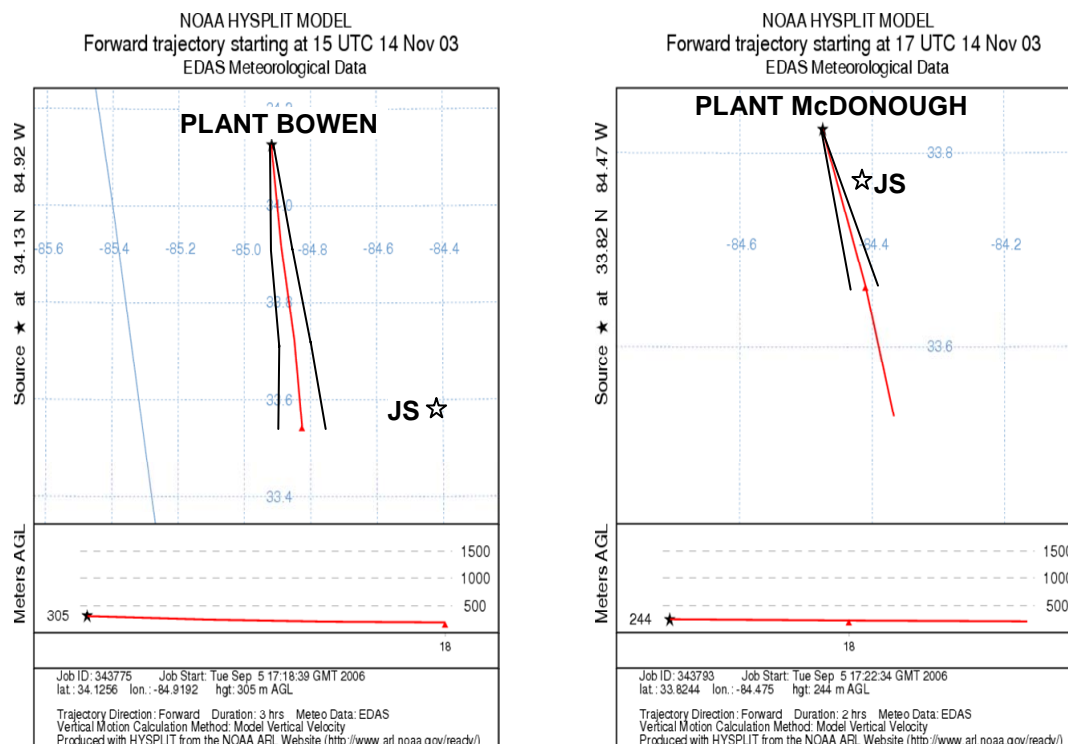


Figure 6.5: Forward trajectories from Plants Bowen and McDonough-November 14, 2003

The trajectories and plumes shown in Figure 6.5 resemble those from March 10 shown in Figure 6.4; the McDonough plume comes much closer to the Jefferson Street monitor than the Bowen plume, which may mean that the Bowen plume, again, probably did not contribute to the elevated values recorded by the Jefferson Street monitor, but the calculated concentration values should be analyzed to draw such a conclusion. The specifications of the trajectories, as well as the results of the Gaussian dispersion equation for November 14, 2003 are listed in Table 6.5.

Table 6.5: Distance and SO₂ Data of Plumes from Plants Bowen and McDonough on November 14, 2003

		NOVEMBER 14, 2003				
		Distance (km)		SO₂ concentration (ppb)		
	# of Units in Operation	Shortest distance from plume centerline to JS	Distance plume traveled from stack to shortest distance to JS	SO ₂ of plume centerline at shortest distance to JS	SO ₂ of portion of plume passing over JS	Average hourly SO ₂ at JS when plume passes over
Plant Bowen	3 of 4	40.9	45.1	14.6	0	47.5
Plant McDonough	2 of 2	3.4	6.6	117.5	0	47.5

Table 6.5 shows that by the time the Bowen plume travels 45.1 kilometers to reach the shortest distance to the Jefferson Street monitor, the concentration of the centerline of the plume is estimated to be 14.6 ppb. However, since the shortest distance from the centerline of the plume to Jefferson Street is 40.9 kilometers, the concentration of the plume near the monitor is zero. As is the case with the previously described days in this chapter, it appears that the Bowen plume simply travels too far and disperses too greatly to be responsible for the notably elevated ambient SO₂ levels recorded by the downtown monitors in Atlanta.

Table 6.5 also shows, once again, that the McDonough plume, without question, has the capability to result in elevated SO₂ values in Atlanta on November 14, 2003. Although the shortest distance from the centerline of the plume to the Jefferson Street monitor is 3.4 kilometers, nearly twice as far as the furthest distance seen in the previously discussed days, the SO₂ concentration at the center of the plume, 117.5 ppb, is

a sufficient level to result in an average hourly monitor concentration of 47.5 ppb at Jefferson Street.

6.4 Plants Wansley/Yates Plume

The SO₂ rose plots in Chapter 5 confirmed that the plume from Wansley/Yates is not significantly contributing to the elevated levels of ambient SO₂ concentration in Atlanta; however, examining the characteristics of this plume can be useful because of the similarities between Plant Bowen and Plants Wansley/Yates. On each of the four days described earlier in this chapter, the plume originating from Plant Bowen's stack was too wide and dispersed by the time it reached the Jefferson Street monitor to contribute any large concentration of SO₂. Because Plant Bowen and Plants Wansley/Yates have similar SO₂ emissions and are located similar distances from the Jefferson Street monitor, it is expected that, on days when the wind is blowing steadily from the southwest, the Wansley/Yates plume will resemble the Bowen plumes that have been shown in the earlier part of this chapter.

6.4.1 January 9, 2002 and January 29, 2003

According to the meteorological data recorded by the Jefferson Street monitor, the wind does not often blow from the southwest steadily for an extended period of time; therefore, one day from 2002 and one day from 2003, January 9 and January 29, respectively, were chosen to examine the behavior of the Wansley/Yates plume on days when the wind carries it into Atlanta. Table 6.6 provides some meteorological data recorded by the Jefferson Street monitoring station on these two days that experienced a steady southwesterly wind for a significant portion of the day.

Table 6.6: Meteorological data for two days with steady southwesterly wind

	% of Day Wind Came from NW (215-250°)	1-hr Max Wind Speed (m/s)	24-hr Avg Wind Speed (m/s)	1-hr Max Temperature (°C)	24-hr Avg Temperature (°C)
Jan 9, 2002	63%	3.48	1.89	18.08	8.36
Jan 29, 2003	58%	3.38	2.19	13.12	10.76

Figure 6.6, which displays the diurnal profiles for these two days using data recorded by the Jefferson Street monitor, illustrates that the SO₂ concentration peaked during the daytime on these days similarly to the daytime peaks seen in Figure 6.1. Although the peaks in Figure 6.6 are smaller in magnitude to the ones seen in Figure 6.1 (note the scale of the y-axes), the diurnal profiles suggest that these peaks are most likely the result of a plume emitted from an elevated stack being pulled down to ground-level when mixing height increases. Therefore, these days should appropriately represent the behavior of the Wansley/Yates plume when the wind transports it so that it may impact the monitors in Atlanta.

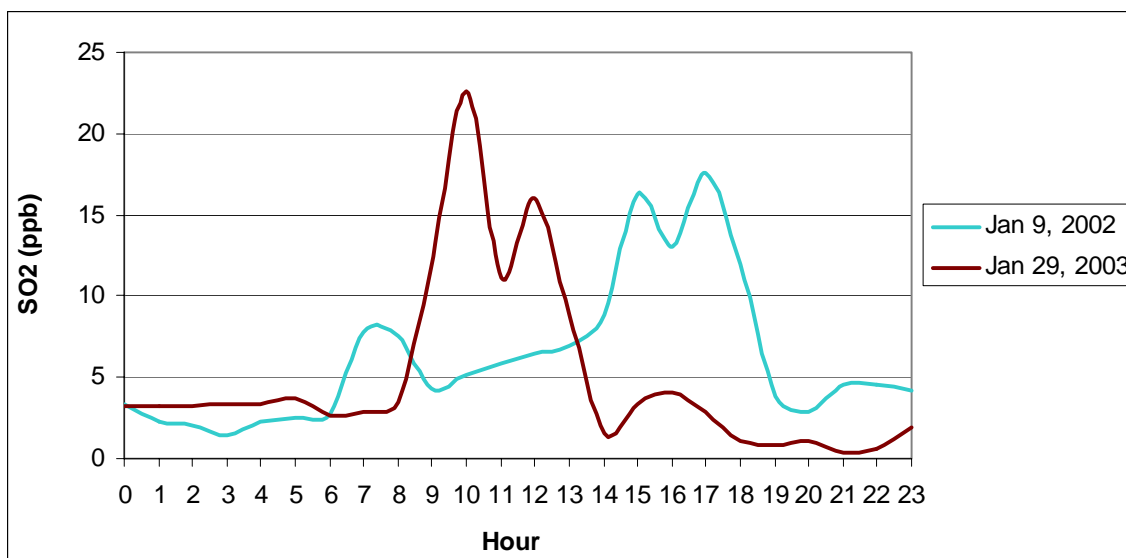


Figure 6.6: Diurnal profiles for two days with steady southwesterly wind

Table 6.6 and Figure 6.6 have established that not only was the wind blowing from the southwesterly direction on January 9, 2002 and January 29, 2003, but the Jefferson Street monitor was very likely impacted by a plume originating from the southwest direction. Since no other significant point sources from that direction are known, it is likely that the SO₂ peaks from Jefferson Street are a result of the impact that the Wansley/Yates plume had on the monitor. In order to analyze this hypothesis further, the forward trajectories from Plants Wansley Yates, shown in Figure 6.7, begin at 11:00am (16:00 UTC) on January 9, 2002 and at 9:00am (14:00 UTC) on January 29, 2003. The two trajectories in Figure 6.7 were started at the given times so that they would reach their nearest point to the Jefferson Street monitor at the time when the SO₂ concentration peaked, at 4:00pm and 10:00 am, respectively. In addition to the trajectories, the estimated plume, calculated by the Gaussian dispersion model, for one standard deviation in the y and z directions, σ_y and σ_z , is also illustrated on the maps in Figure 6.7.

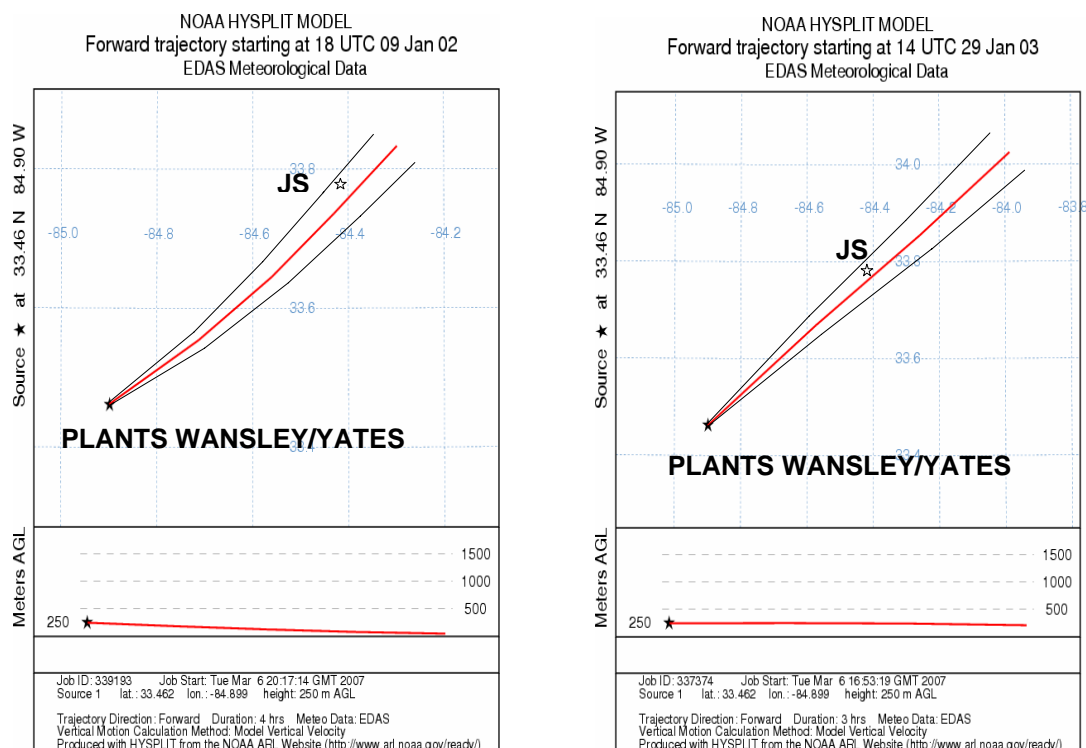


Figure 6.7: Forward trajectories from Plants Wansley/Yates – January 9, 2002 and January 29, 2003

For the two days shown in Figure 6.7, the plume from Plants Wansley/Yates comes very close to the Jefferson Street monitoring station. From examining the trajectories above, the hypothesis that the Wansley/Yates plume contributed to the SO_2 peaks seen during the day on January 9, 2002 and January 29, 2003 may be confirmed. However, the calculated concentration values should be analyzed before drawing such a conclusion. The specifications of the trajectories, as well as the results of the Gaussian dispersion equation for January 9, 2002 and January 29, 2003 are listed in Table 6.7.

Table 6.7: Distance and SO₂ Data of Plumes from Plants Wansley/Yates on January 9, 2002 and January 29, 2003

		PLANTS WANSLEY/YATES				
		Distance (km)		SO₂ concentration (ppb)		
	# of Units in Operation	Shortest distance from plume centerline to JS	Distance plume traveled from stack to shortest distance to JS	SO ₂ of plume centerline at shortest distance to JS	SO ₂ of portion of plume passing over JS	Average hourly SO ₂ at JS when plume passes over
Jan 9, 2002	8 of 9	2.3	56.4	9.7	8.0	13.1
Jan 29, 2003	7 of 9	1.6	60.6	7.0	6.5	22.6

The data listed in Table 6.7 establishes that the SO₂ concentration of the Wansley/Yates plume centerline was not high enough on either day to cause the peak in SO₂ concentration. However, it is likely that the Wansley/Yates plume contributed partly to the SO₂ recorded by the Jefferson Street monitor and other types of sources, such as area and mobile sources, partly contributed as well.

As suspected, the Wansley/Yates plume has many characteristics that coincide with the characteristics of the Bowen plume that was examined. Both plumes travel an extended distance to reach the Atlanta monitors. This distance results in a wide, highly dispersed plume that has a small range of SO₂ levels throughout, meaning that even if the wind shifts direction and blows the centerline of the plume directly over the monitoring station, the SO₂ concentration from these two plumes will not be great enough to result in the elevated levels of SO₂ exhibited by the downtown Atlanta monitors.

6.5 Summary

By utilizing NOAA's HYSPLIT model to compute trajectories from nearby power plants and the Gaussian dispersion model to estimate SO₂ concentrations throughout their plumes, some very valuable information is ascertained. Data presented in Chapter 3 illustrated that the energy output, SO₂ emissions, and distance from Atlanta for Plant Bowen and Plants Wansley/Yates are remarkably similar. Correspondingly, the trajectories and estimated plume calculations introduced in this chapter illustrate that the behavior of their plumes is also remarkably similar. Since there are no other known point sources in the direction of Plants Wansley/Yates, it is possible to isolate the impact that its plume has on the Atlanta monitoring stations. This also provides a means of estimating the impact that the Bowen plume has on Atlanta given the likeness of their plumes. Therefore, after analyzing the modeled plumes presented in this chapter, it can be concluded that on days when the wind direction is originating from the northwest and Atlanta SO₂ concentrations reach very high levels during the day, although Bowen's plume is plausibly contributing a small fraction of the recorded SO₂, Plant Bowen is not responsible for the considerably large SO₂ peaks recorded by Atlanta monitors.

The final piece of valuable information ascertained in this chapter comes from analyzing the estimated SO₂ concentrations throughout Plant McDonough's plume. The short distance from Plant McDonough to downtown Atlanta is the main reason that its plume is more narrow and concentrated than Plant Bowen's plume. These characteristics make McDonough's plume the most probable source of the large SO₂ peaks recorded in Atlanta. The chances of McDonough's plume impacting an Atlanta monitoring station greatly depend on several meteorological factors, such as temperature, wind direction,

and wind speed. The variability of these factors explains why the daytime peaks in SO₂ concentration are not seen consistently in Atlanta. If the conditions are right, the concentrated portion of Plant McDonough's plume could directly impact the monitoring station resulting in noticeably high values of ambient SO₂; however, as meteorological conditions change, McDonough's plume may travel in a different direction resulting in an evident decrease of ambient SO₂ levels. Although elevated levels of ambient SO₂ in Atlanta can come from a number of sources, the data presented earlier in this chapter substantiate the position that, if the wind is coming from the northwest direction, Plant McDonough's plume is the primary contributor to the elevated levels of SO₂ displayed as peaks recorded by the Atlanta monitoring stations.

Chapter 7

CONCLUSIONS

7.1 Conclusions

SO₂ is an atmospheric pollutant that is important to characterize and understand due to its health effects and contribution to sulfate particulate matter. In the 2002 National Emission Inventory, the EPA estimated that 85% of the SO₂ emissions in the U.S. and 88% of the SO₂ emissions in Georgia originate from point sources. This study's objective is to examine the point sources that are believed to be impacting ambient SO₂ levels in Atlanta and to establish a better understanding of the contribution made by each source to the ambient SO₂ recorded by the downtown Atlanta monitoring stations.

Five point sources of ambient SO₂ located in the vicinity of Atlanta were addressed as possible contributors to elevated levels of ambient SO₂ in Atlanta: Plant Bowen, Plant McDonough, Plant Wansley, Plant Yates, and Lafarge Building Materials, all of which burn coal as fuel. For each point source, various components of the design and operation, such as location, stack height, and averages and trends of SO₂ emissions, were studied to obtain a better picture of the manner by which these sources emit SO₂ into the atmosphere. Correspondingly, SO₂ trends recorded by three downtown monitors, Georgia Tech, Confederate Avenue, and Jefferson Street, were also studied in order to establish any relationship between the SO₂ in Atlanta and the SO₂ emitted by any or all of the sources. A positive relationship was found between the annual, monthly, and daily averages of SO₂ emitted by Plants Bowen, McDonough and Wansley/Yates and the SO₂ recorded by the Georgia Tech, Confederate Avenue, and Jefferson Street monitoring

stations. This correlation suggests that these power plants are significant contributors to the average values of ambient SO₂ levels in Atlanta and should be further studied to determine if they are contributing to the elevated levels of ambient SO₂ in Atlanta. The SO₂ emissions from Lafarge Building Materials were not monitored; therefore, no conclusion can be drawn as to its contribution to average ambient SO₂ levels in Atlanta based on emission analysis.

The SO₂ rose plots from the Jefferson Street monitor for 1999-2005 illustrated that the elevated SO₂ concentrations are consistently originating from a source in the northwest direction, which suggests that Plant Bowen, Plant McDonough, or Lafarge could all be possible sources of the elevated SO₂ concentrations. From examining SO₂ rose plots when mixing height is low, it was determined that Lafarge did not significantly contribute to the high levels of ambient SO₂ in Atlanta while it was in operation. Further analysis into the SO₂ rose plots revealed that Plant McDonough has a higher probability of being the primary contributor of the elevated levels of ambient SO₂ in Atlanta than Plant Bowen.

The trajectories and plumes originating from Plants Bowen and McDonough were modeled using NOAA's HYSPLIT program and the Gaussian dispersion equation, respectively. The results of modeling four days in 2003 when the average hourly SO₂ concentrations were remarkably high during the daytime revealed that Plant Bowen's plume is typically too wide and dispersed by the time it reaches Atlanta to account for the large peaks of ambient SO₂ recorded on those particular days. Conversely, although Plant McDonough emits approximately six times less SO₂ than Plant Bowen, its plume travels a much shorter distance and is more narrow and concentrated when it reaches

Atlanta. The impact from Plant Bowen's plume is more likely to be of lower concentrations of SO₂, but occurring more often and not as highly dependent on wind direction as the plume from Plant McDonough. Plant McDonough's plume, on the other hand, may deliver extremely high values of SO₂, but the occurrence of its impact is less often and largely dependent on wind direction. Thus, while a number of sources contribute to the ambient SO₂ levels in Atlanta, Plant McDonough appears to be responsible for the elevated levels and the day-to-day variation of ambient SO₂ recorded by the downtown Atlanta monitoring stations.

APPENDIX A

SO₂ Rose Plots

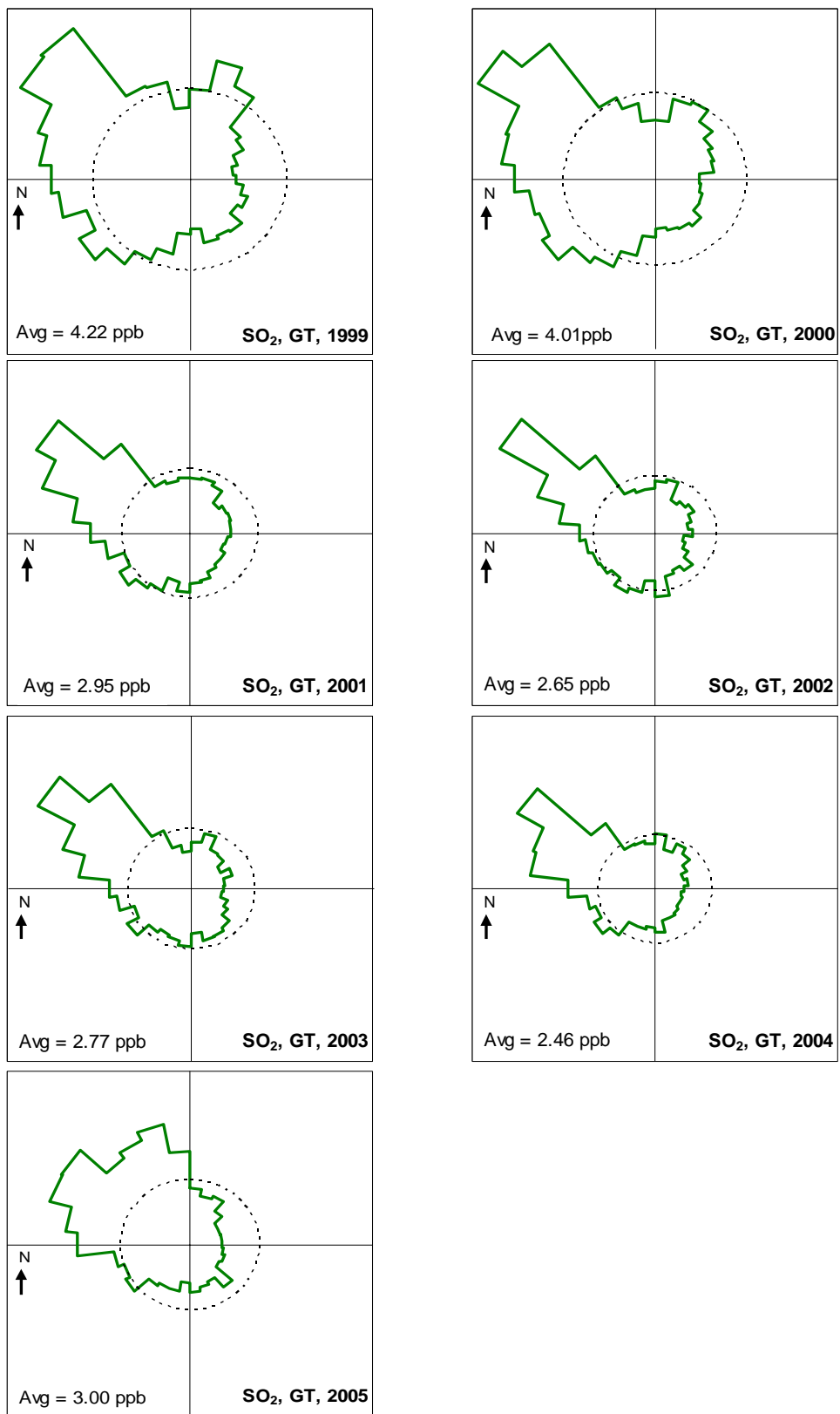


Figure A.1: SO₂ Rose Plots from Georgia Tech, 1999-2005. Scale is 8 ppb. Dashed circle represents average value.

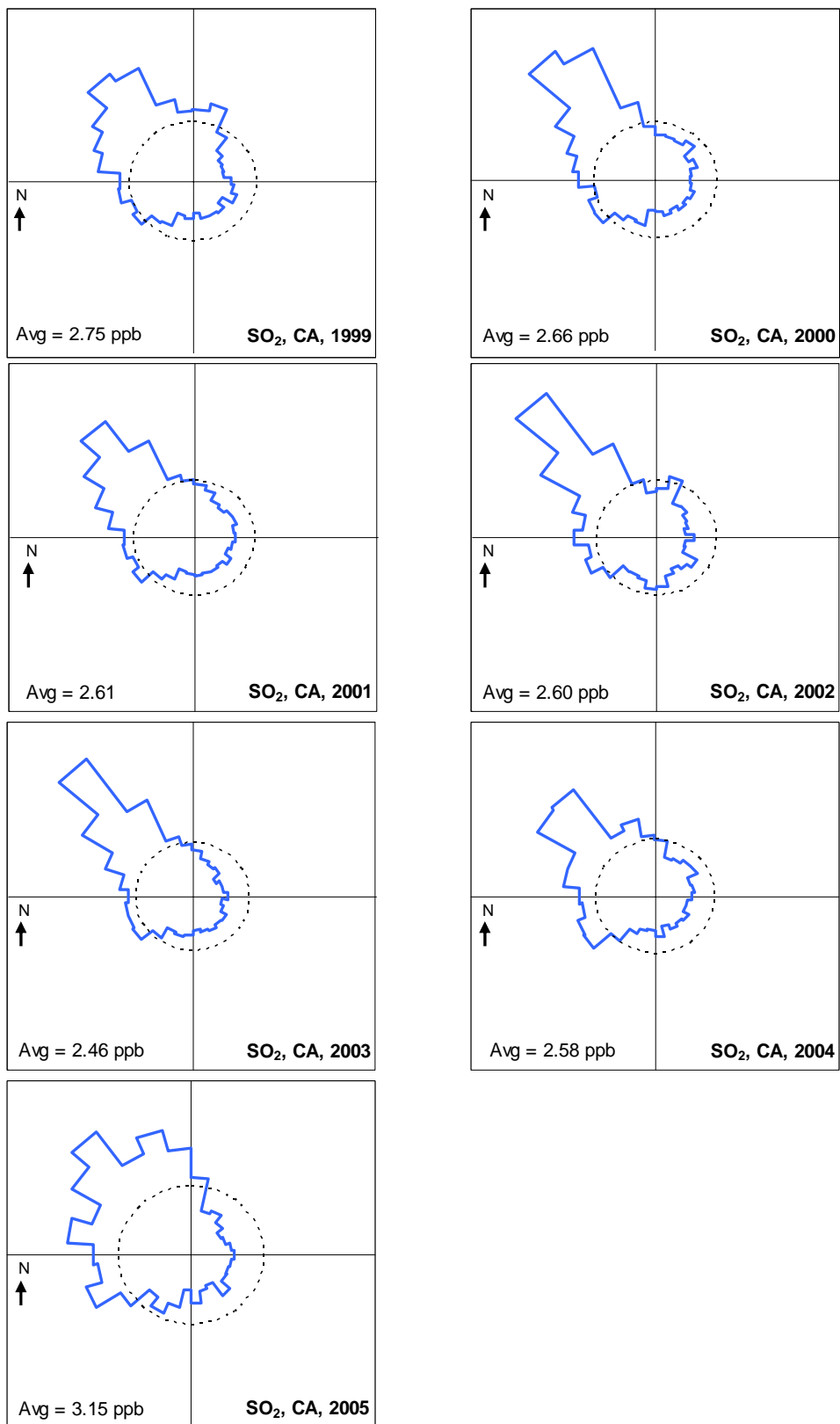


Figure A.2: SO₂ Rose Plots from Confederate Avenue, 1999-2005. Scale is 8 ppb. Dashed circle represents average value.

Table A.1: Direction and distance from Georgia Tech monitor to point sources

	Direction	Distance
Plant Bowen	309°	61.7 km
Plant McDonough	308°	8.7 km
Lafarge Building Materials	308°	8.4 km
Plants Wansley/Yates	234°	57.7 km

Table A.2: Direction and distance from Confederate Avenue monitor to point sources

	Direction	Distance
Plant Bowen	311°	68.6 km
Plant McDonough	317°	15.8 km
Lafarge Building Materials	317°	15.5 km
Plants Wansley/Yates	241°	57.7 km

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