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The 1977 Surface Ozone Study of Eastern Virginia

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THE 1977 SURFACE OZONE STUDY OF EASTERN VIRGINIA

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SUMMARY

To better understand the nature of the ozone distribution in the eastern Virginia region, the Wallops Flight Center, along with other governmental and educational organizations, participated in a surface ozone investigation during the summer of 1977. The study was conducted by the Virginia State Air Pollution Control Board and consisted primarily of twelve ground stations positioned throughout the area. This report summarizes the Wallops analysis of the ozone and wind data. The most prominent results are the existence of a bias in the ozone concentrations between stations and a linear correlation between average ozone concentration and latitude. In addition, higher ozone levels were found with surface winds from certain preferred directions at the various sites. The results, however, do not conclusively substantiate the transport of ozone or its precursors.

INTRODUCTION

Surface ozone, the contaminant chosen as the indicator of photochemical air pollution, has been under observation by the Virginia State Air Pollution Control Board since 1972. It was noted that, during each summer season, the ozone levels in the Tidewater area of Virginia exceeded the National Ambient Air Quality Standard, which is currently defined for public health protection as 0.08 parts per million (ppm). In determining more exactly the nature of ozone and its distribution, the Virginia State Air Pollution Control Board in cooperation with NASA Wallops Flight Center, NASA Langley Research Center, Old Dominion University School of Science, the U.S. Department of Agriculture, Beltsville, Maryland, and the Virginia Polytechnic Institute and State University, conducted an investigation of the oxidant levels in the rural/urban areas of Eastern Shore - Tidewater, Virginia, and in North Carolina during the summer of 1977.

EXPERIMENTAL DESIGN

The 1977 investigation involved a network of twelve ground stations positioned throughout the area. Figure 1 shows the location of these monitoring sites which lie roughly along a line chosen to match the expected prevailing wind direction during the summer and connecting Colerain, North Carolina and Wallops Island, Virginia. Ozone

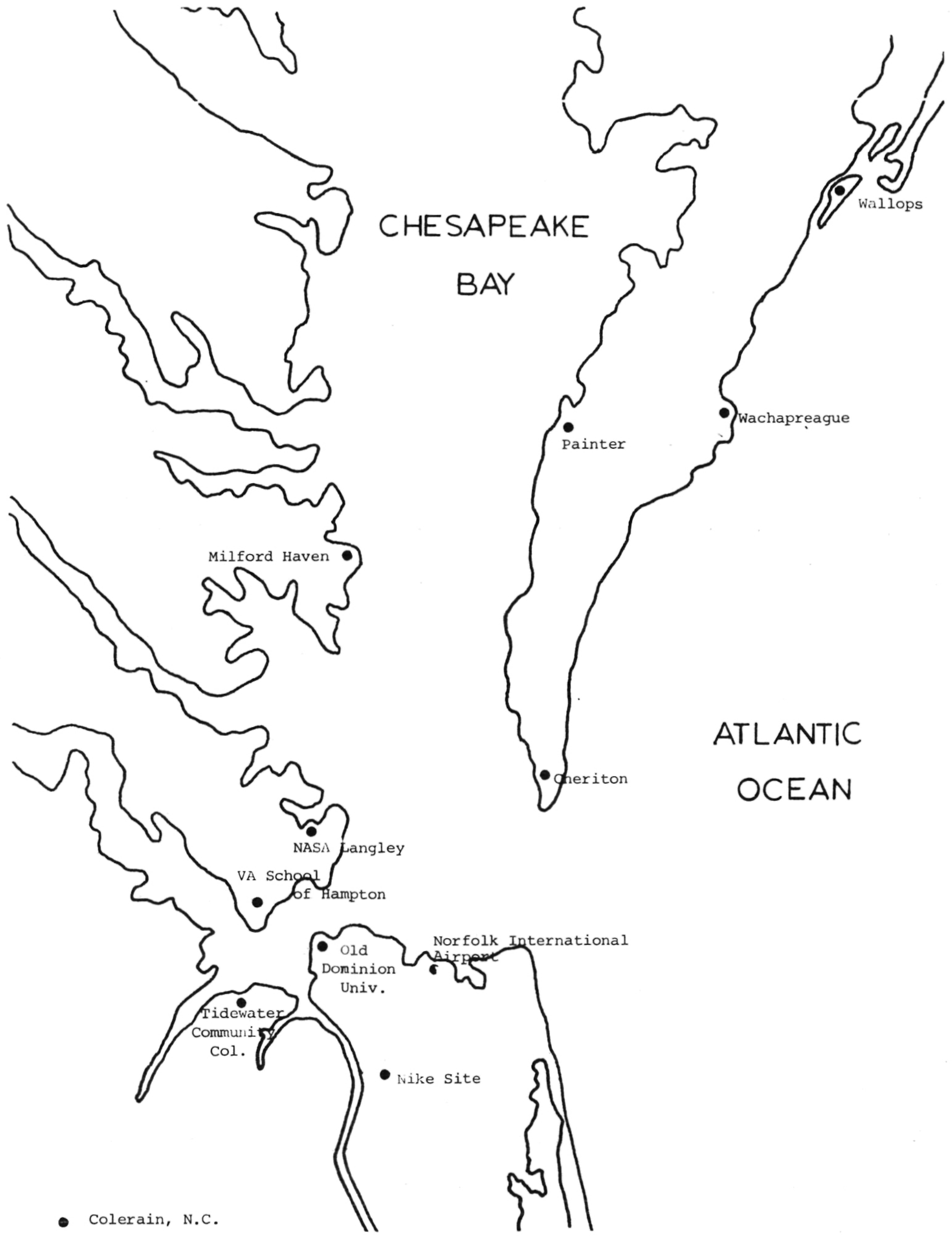

Figure 1. Locations of ozone monitoring sites.

monitors, which operate on an ultraviolet absorption principle (ref. 1), were installed at most of the sites except the Old Dominion and Painter stations where chemiluminescent and Mast* monitors were used. Calibration of instruments was performed twice during the summer by the Virginia State Air Pollution Control Board. The calibration procedure was traceable to a neutral buffered potassium iodide standard established as the primary reference and maintained at Richmond by the Virginia Air Pollution Control Board. Wind anemometers were used for collecting wind data at all stations except the Painter and Cheriton sites. The limits of the data collection period were from early June to late September.

In addition, nitrogen oxides (NO_x) and hydrocarbon concentrations were also measured at the Old Dominion and Nike sites for part of the summer period. Ozonesonde and aerial measurements of ozone were also collected at Wallops Flight Center during selected periods for studying the vertical profile of ozone. This report, however, concerns only the results from the ground measurements of ozone and wind data.

RESULTS AND DISCUSSION

An example of the hourly averaged ozone data that were collected during the 1977 sampling period is shown in Figure 2. The two curves represent the hourly ozone levels at Wallops Flight Center and the Norfolk International Airport during the week of July 19, 1977. In addition to both sites having similar diurnal variations, there is a distinct bias, or difference, in the ozone levels between the stations, probably owing to a higher concentration of NO_x in the Norfolk urban area (ref. 2). On the average, the nighttime ozone value at Norfolk for this particular week was 0.020 ppm and at Wallops it was 0.050 ppm. These ozone levels that occur in the absence of solar radiation are defined as the background levels. From an analysis of this kind of data over the entire summer, it can be shown that these background levels are modulated by photochemistry during a 24-hour diurnal oscillation and by weather occurring in fluctuations with periods of several days to several weeks. In understanding completely the role of ozone in our atmosphere, we must be able to explain the changes in the ozone concentration on all of these time scales. Our efforts thus far have been directed towards the study of lower frequency ozone variations. The high frequency changes of periods of one day or less are, in comparison, more complicated and therefore require more study.

In a cursory look, however, all the ozone data for Wallops and Norfolk were averaged versus the time of day to yield the average diurnal cycle for the two sites. Figure 3

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*Mast Development Company, 2212 East 12th Street, Davenport, IA 52803

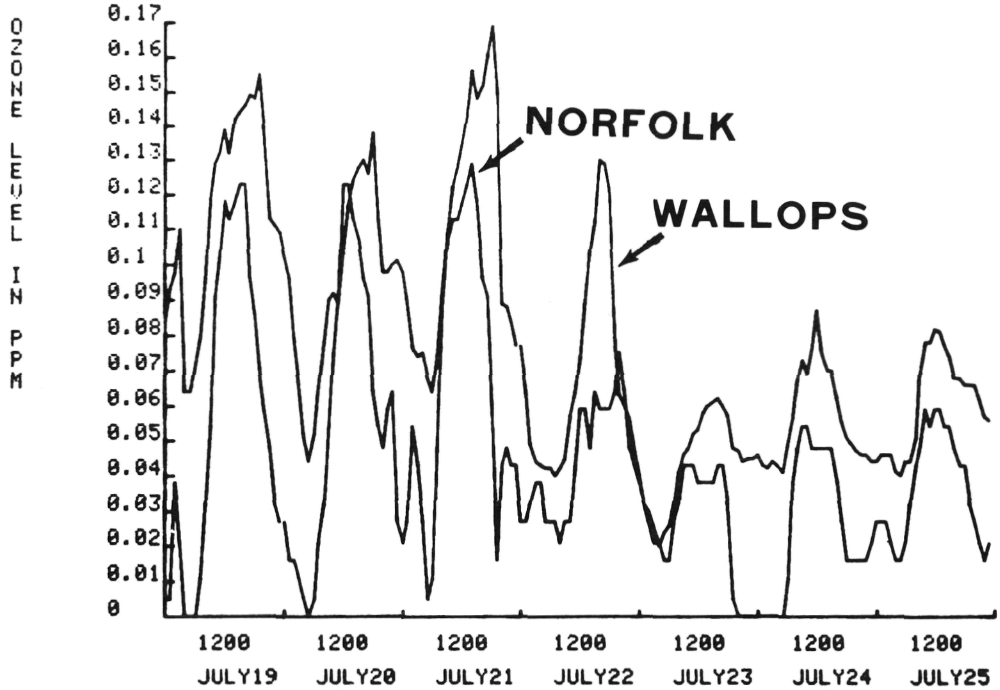

Figure 2. Hourly averaged ozone levels in ppm for Wallops Flight Center (top curve) and Norfolk International Airport (bottom curve) for the period July 19-25, 1977.

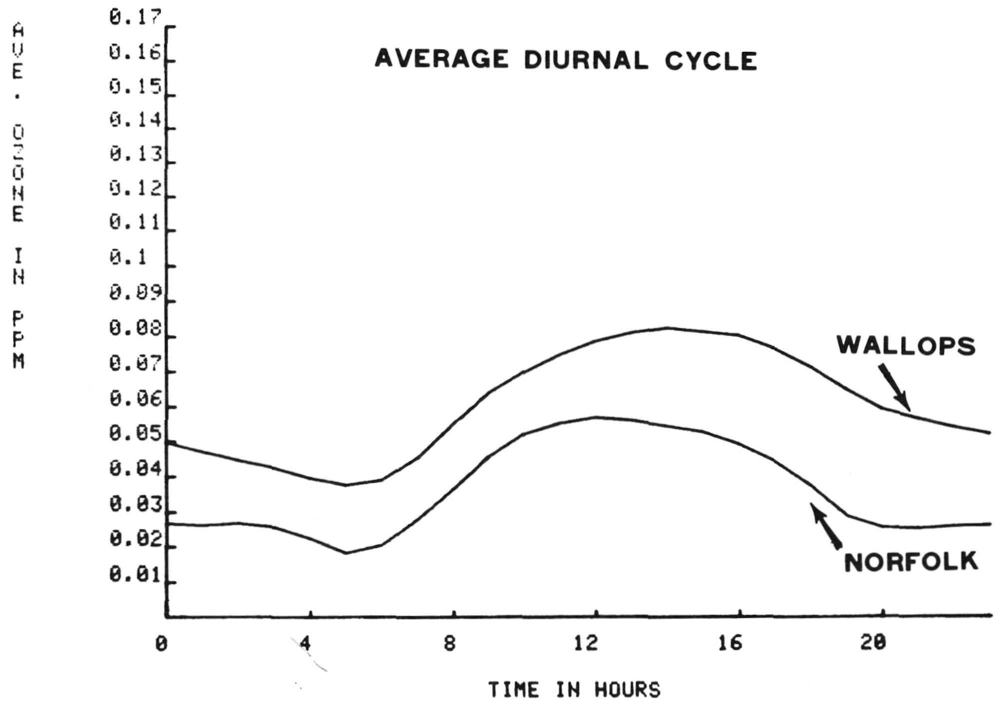

Figure 3. Mean ozone concentration in ppm for summer of 1977 vs time of day for Wallops Flight Center (top curve) and Norfolk International Airport (bottom curve).

demonstrates that both stations peak in the afternoon with the Norfolk peak occurring some 1 to 2 hours earlier. The average peak at Wallops was 0.085 ppm whereas Norfolk's was 0.055 ppm. Notice that the bias between the two stations as seen in the raw data (Fig. 2) is still quite evident and appears to be relatively constant throughout the day.

Figure 4 exhibits another method that was used in analyzing the diurnal cycle of ozone (ref. 3). For the Wallops data the number of days are plotted in which peak ozone levels occurred at a particular time of day. The graph shows that the majority of the maximum ozone levels, resulting from photochemical activity, occurred in the afternoon. For a few days, peak concentrations up to 0.109 ppm occurred during early hours, which suggests the morning mixing of surface air with the air aloft. The ozone levels rarely reached a maximum in the late evening, possibly indicating transport from a non-local source of ozone. Subsequently we can conjecture that, although the majority of the peak ozone levels at Wallops are due to photochemical activity, high O_3 concentrations resulting from vertical and horizontal transport are experienced.

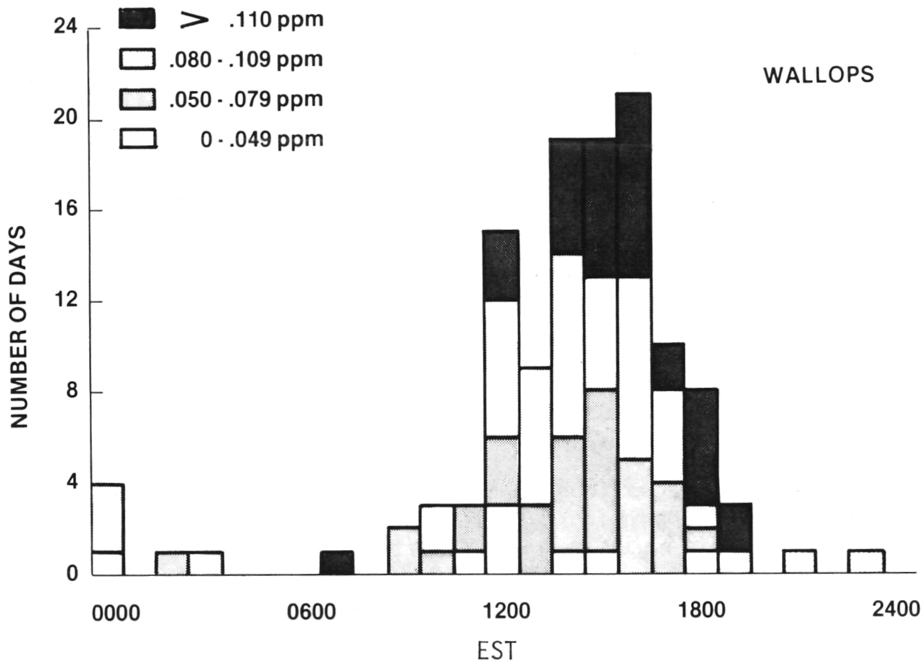

Figure 4. Time of occurrence of maximum hourly mean ozone concentration at Wallops Flight Center for summer of 1977.

Pending more detailed study of the high frequency ozone variations, these components were filtered from the rest of the analyses by using an 81 point equally-weighted midpoint filter. Figure 5 shows these smoothed ozone levels ($\bar{O}_3$) for the entire summer of 1977 for Wallops, Wachapreague, and Norfolk. For the latter two months of the sampling period, the ozone concentrations dropped to significantly lower levels than during the first two months. This drop in the ozone concentration occurred on July 21, 1977, when a cold front

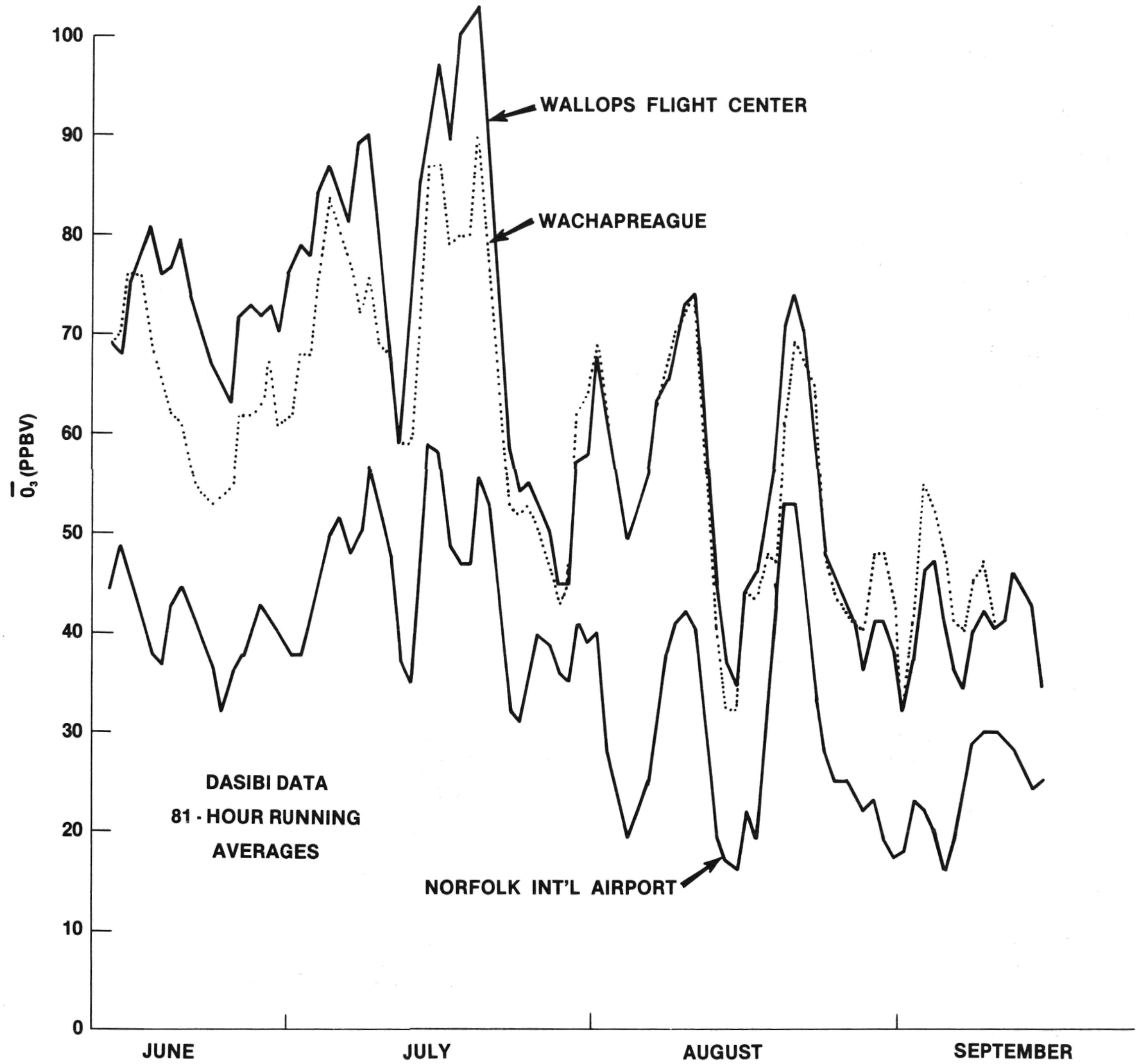

Figure 5. Mean ozone averages ($\bar{O}_3$) in ppbv using 81 point equal-weighted midpoint filter for Wallops Flight Center (top curve), Wachapreague (dotted curve), and Norfolk International Airport (bottom curve).

passed through the area. After that occurrence, the ozone levels stayed at lower levels for the remainder of the sampling period. Possibly this particular air mass change was strong enough to force out most of the ozone precursors such as NO_x and hydrocarbon pollutants, which had previously accumulated in the area. Because of an insufficient data set, we can only speculate on the relationship between this frontal passage and lower ozone levels.

Not only did a distinct drop occur in the ozone levels during this time period, but a similar trend is found in the biases as shown in Figure 6. The upper curve represents the bias between the ozone levels at Wallops and Norfolk, and the lower curve exhibits the bias between Wallops and Wachapreague. Before the frontal passage on July 21, the Wallops-

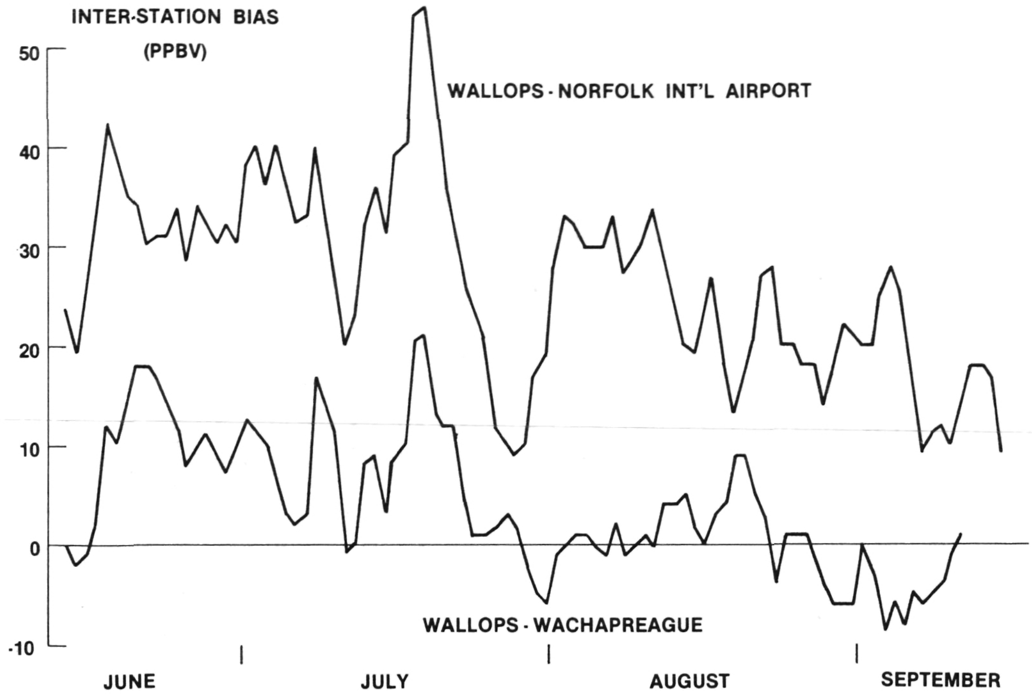

Figure 6. Mean ozone bias in ppbv between the Wallops Flight Center and Norfolk International Airport (top curve) and the Wallops and Wachapreague Stations (bottom curve).

Norfolk bias was on the average 0.035 ppm, while the Wallops-Wachapreague bias was 0.010 ppm. Afterwards, the biases between the stations dropped. The Wallops-Norfolk bias dropped to 0.020 ppm, while the ozone levels at Wachapreague equaled or slightly exceeded those occurring at Wallops. Notice that the inter-station biases persisted throughout the summer period regardless of changes in wind direction or other meteorological parameters.

Since weather seemingly affects the lower frequency ozone variations, we have taken a detailed look at how wind data correlates with the ozone data in determining whether it is also a major forcing function. It can be reasoned that ozone and/or its precursors are being transported up from the Norfolk urban area and therefore causing areas northeast of Norfolk to have higher ozone concentrations. Typically the south to southwest wind directions are predominant during the summer at Wallops. Since Norfolk is south-southwest of Wallops, then is the ozone concentration for surface winds from that direction abnormally high? Figure 7 is a plot of the ozone levels at Wallops versus the wind directions during the sampling period. Although high ozone levels occurred with all wind directions, it is seen that somewhat higher ozone levels occurred with southeast and westerly winds, and a slight drop in the concentrations occurred with winds from the south and southwest. Figures 8a and 8b show that these south winds were observed for a higher percentage of time than any other wind direction at Wallops, but only 26% of those hours occurred with

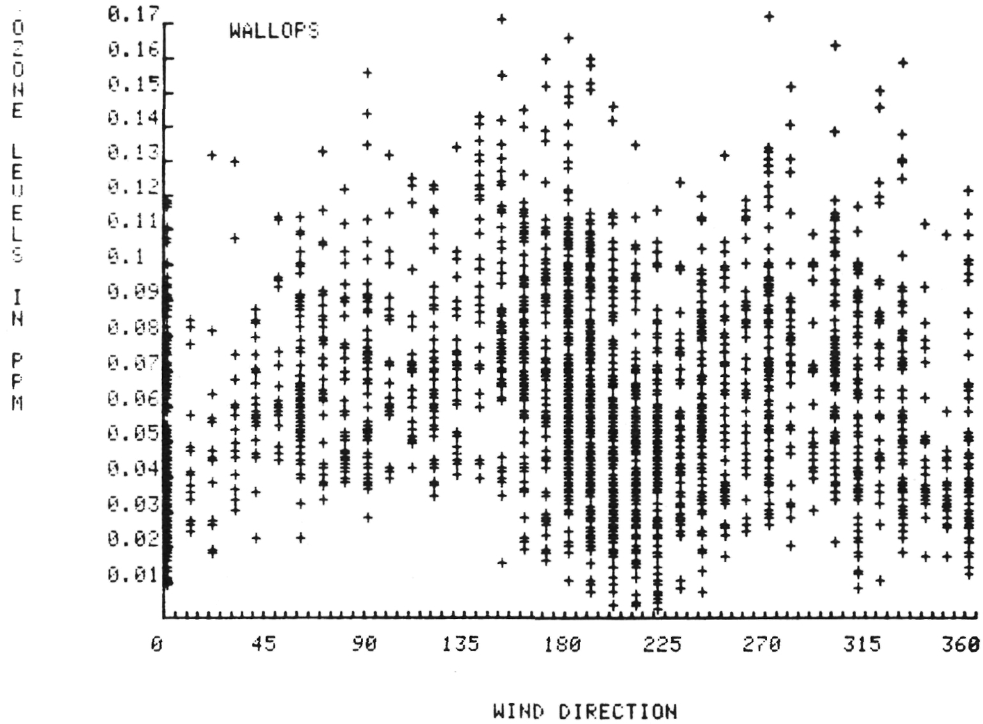

Figure 7. Hourly mean ozone concentration in ppm vs wind direction at Wallops Flight Center. 0° = calm.

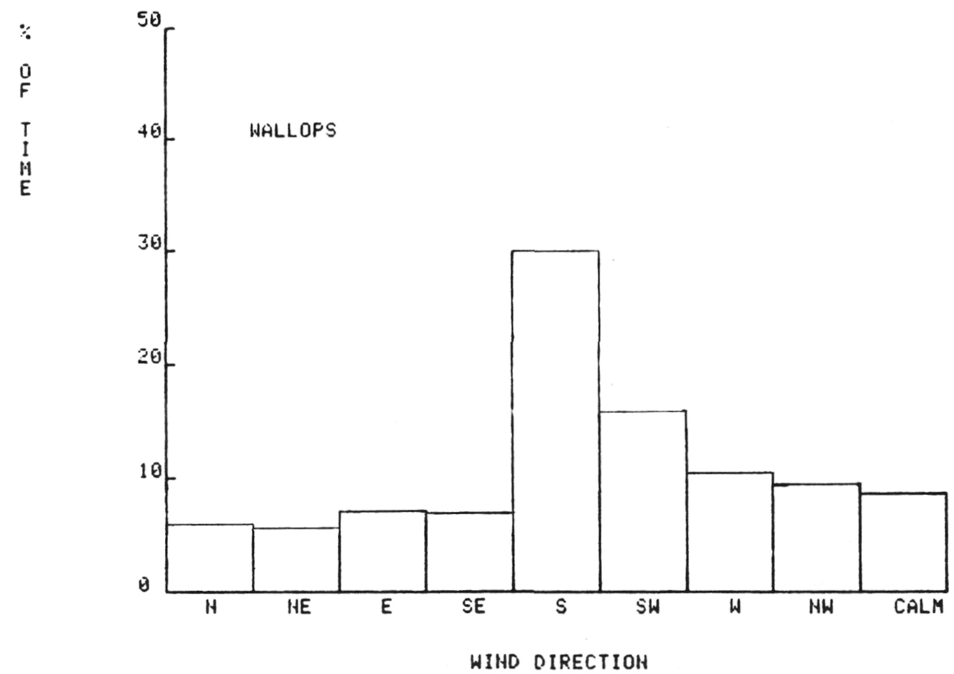

Figure 8a. Plot of the percentage of the total number of hours with wind in a given direction at Wallops Flight Center. Any direction from 337.5°-22.5° is taken as N, 22.5°-67.5° as NE and so on.

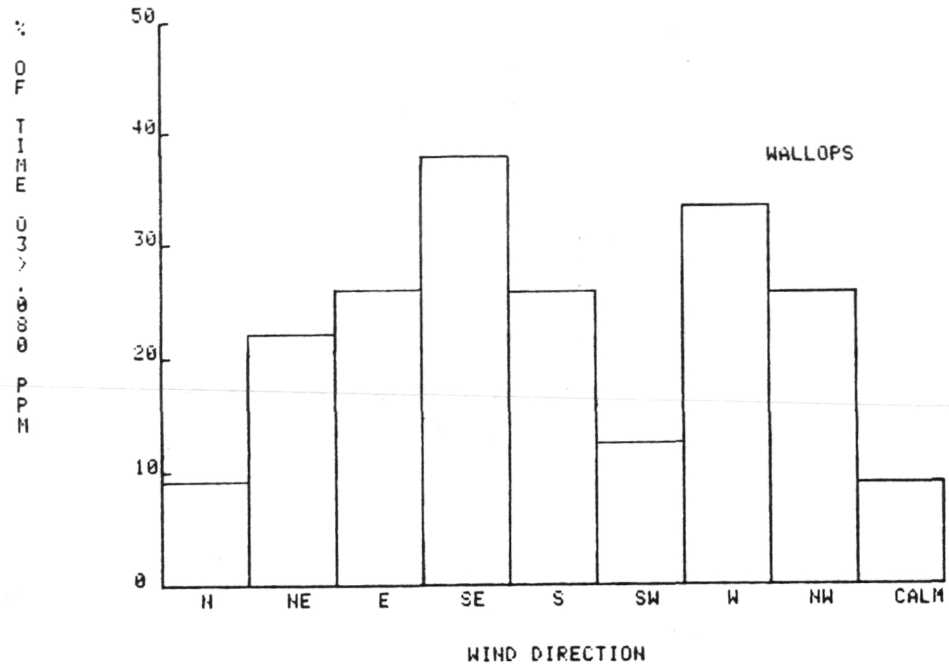

Figure 8b. Plot of the percentage of hours that wind in a given direction occurred with ozone (O_3) concentrations > 0.080 ppm at Wallops.

ozone levels exceeding 0.08 ppm. Instead, the highest percentages of high ozone levels occurred with southeast (38%) and westerly (33%) wind directions as indicated in Figure 8b.

Because mass transport can be defined to be the cross-sectional area of the flow times the density of air times the velocity vector, the possible effect of windspeed on the ozone levels at Wallops has also been examined. The histogram of average windspeed as a function of wind direction indicates that, during the summer months, similar windspeeds are found at Wallops regardless of the direction of the flow. Hence, mass flow or transport in this region, when studied on a seasonal mean basis, must be influenced to a greater degree by the direction of the wind than by its speed. Further analysis using windspeeds includes a plot of the ozone level at Wallops as a function of the windspeed during the sampling period. High ozone levels were found to occur with both high and low wind speeds, which directs our attention again to wind direction as a possible forcing function of the lower frequency ozone variations.

The three graphs in Figure 9 show the number of hours that various ozone concentrations occurred with south, southeast, and westerly wind directions at Wallops during the 1977 sampling period. Figure 9a demonstrates that the peak number of hours during south winds occurred with ozone concentrations below 0.080 ppm, and fewer hours occurred with

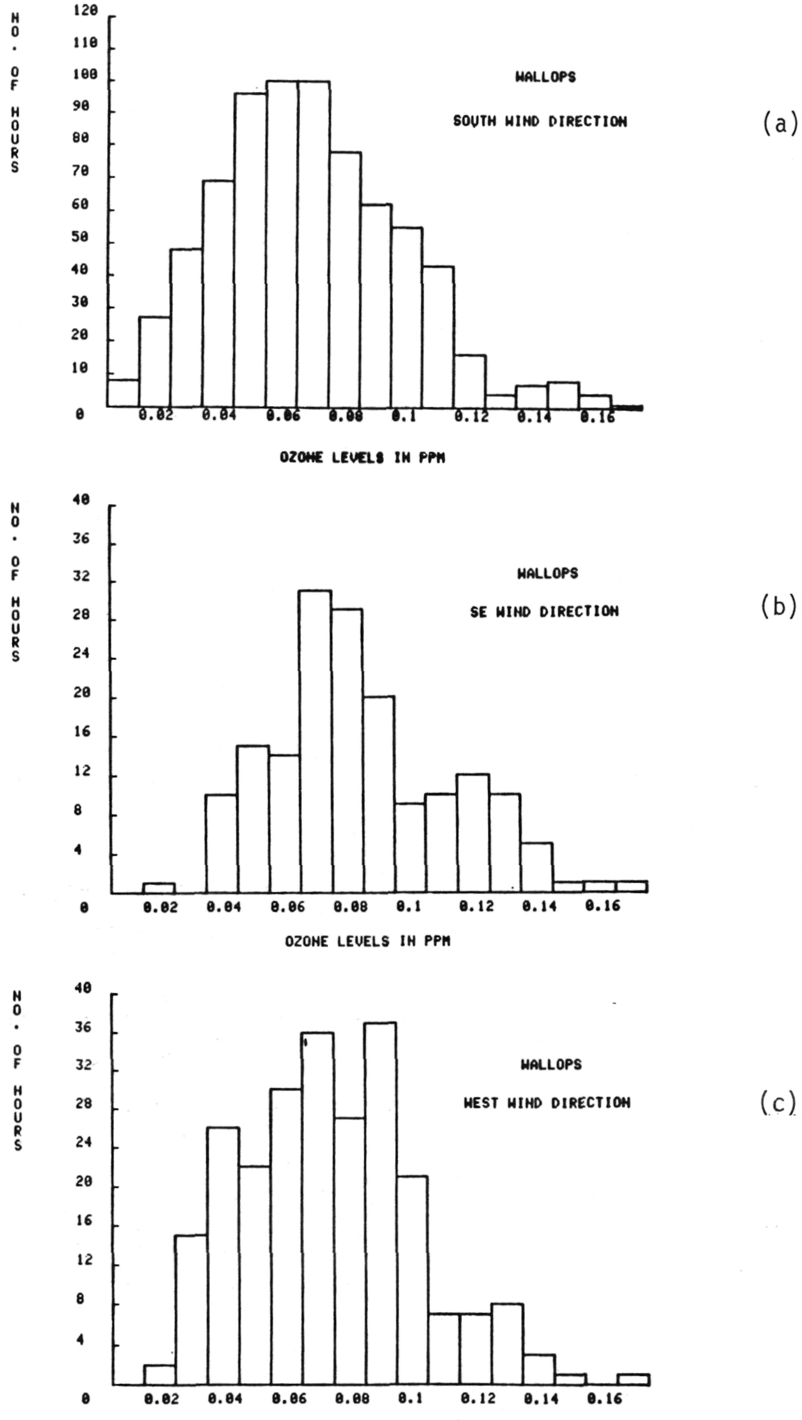

Figure 9. Plot of the number of hours with given ozone concentrations in ppm occurring with: a, south wind direction; b, southeast wind direction; c, west wind direction at Wallops Flight Center.

higher ozone levels. The south winds were observed for 726 hours, 26% of which occurred with ozone levels greater than 0.08 ppm. At Wallops, the average ozone concentration occurring with the south winds was 0.063 ppm. Figure 9b is a similar synopsis of the southeast winds. This time the distribution has been shifted to slightly higher ozone concentrations as compared to the one for the south winds. These winds occurred for a total of 169 hours, 38% of which occurred with high ozone levels ($\geq$ 0.08 ppm). The average ozone concentration with this southeast wind direction was 0.079 ppm. For the west winds (Fig. 9c), the majority of the ozone levels were between 0.03 and 0.09 ppm. West winds occurred at Wallops for 243 hours, 33% of which occurred with high ozone levels. These winds had an average ozone concentration of 0.068 ppm.

Thus far this synopsis of the south, southeast and west wind directions confirms the interpretation of Figure 8. Even though the south winds occurred the highest percentage of time, they do not correlate well with the high ozone levels observed during this summer period. Another factor, however, that should be considered in interpreting Figure 8 is the time at which these winds occurred. Since ozone concentrations vary diurnally, then those winds, for example, occurring predominantly during the day would correspond to higher ozone levels than those occurring at night. In Figures 10-13, we have defined those winds occurring from 0700 to 1900 EST as day winds, from 0700 to 1300 EST as morning winds, 1400 to 1900 EST as afternoon winds, and 2000 to 0600 EST as night winds. Figures 10-12 show that throughout the day the south winds were predominant, but the southeast, east, and northwest morning wind directions and the afternoon west winds had higher percentages of time occurring with high ozone levels. Figure 13a shows that the south winds were also predominant at night. Although the percentages of night winds occurring with high ozone levels (Fig. 13b) were naturally lower than those percentages during the day, nonetheless it is clear that these nocturnal south winds correlated with a higher percentage of the high ozone levels. It is our speculation that perhaps there is a nighttime pollution transport taking place at Wallops. Since the nocturnal ozone levels at Wallops rarely dropped to zero during this sampling period, this pollution transport may have been responsible for these significant nighttime levels. On the other hand, are these south winds traceable to the Norfolk urban area? Without back trajectories, one can only surmise the route of Norfolk's urban plume and the wind trajectories at Wallops.

Similar examinations of the winds at Norfolk and the Nike Site were performed. According to Figure 14a, the predominating wind direction at Norfolk was southwest, but the winds having the highest percentage of high ozone levels ($\geq$ 0.08 ppm) were the north and northeasterly wind directions (Fig. 14b). The appendix shows the Norfolk winds divided into day, morning, afternoon and night regimes. Generally the southwest winds were predominant except in the afternoon where the northeast, southeast, and south to southwest winds occurred for about the same percentage of time. The north and northeast winds had the highest percentage of time occurring with high ozone levels. In the after-

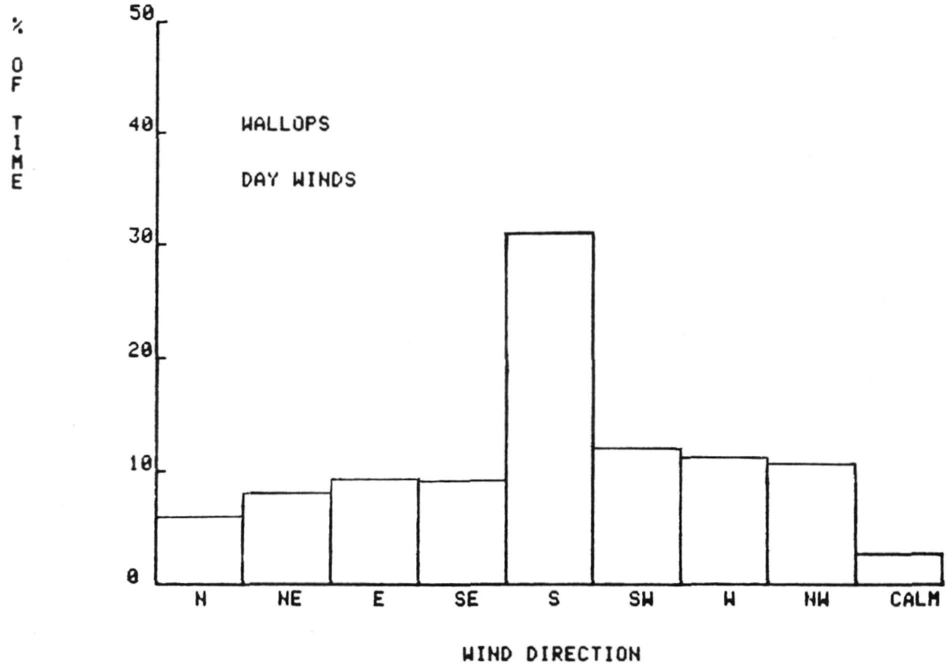

Figure 10a. Plot of the percentage of the total number of daytime (0700-1900) hours with wind in a given direction at Wallops Flight Center.

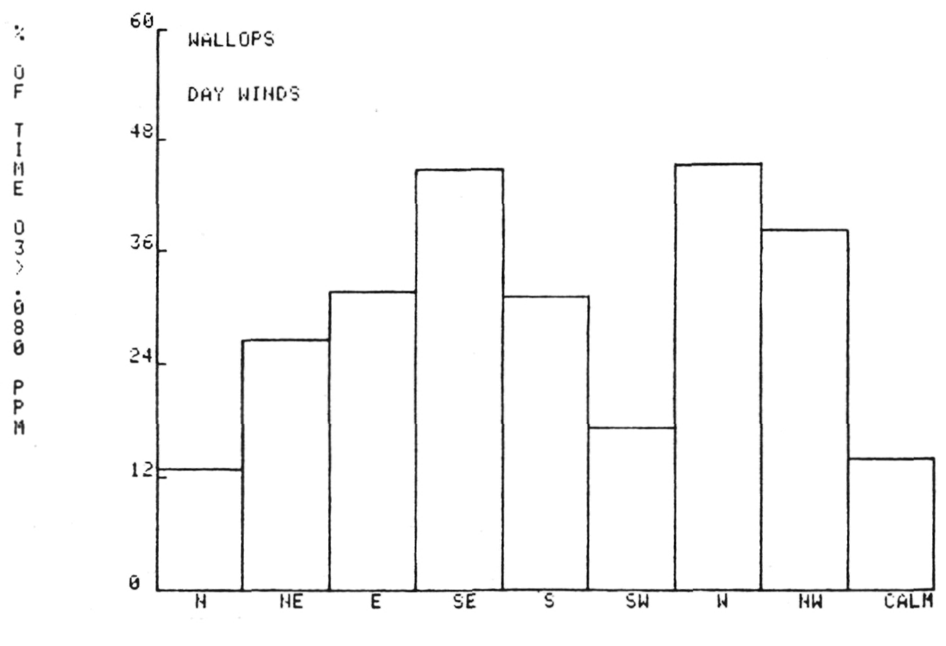

Figure 10b. Plot of the percentage of daytime hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Wallops.

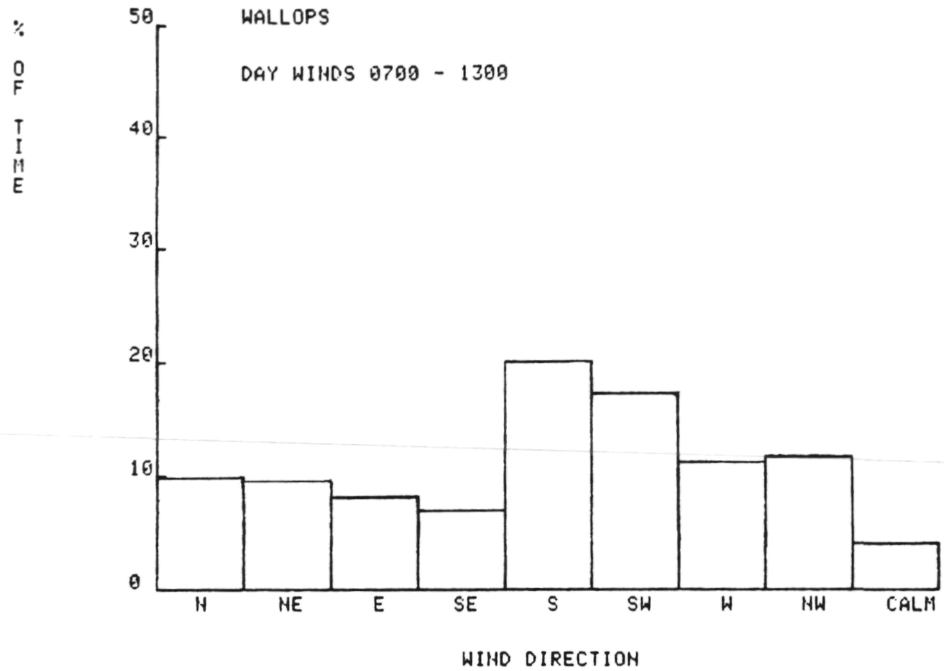

Figure 11a. Plot of the percentage of the total number of morning (0700-1300) hours with wind in a given direction at Wallops.

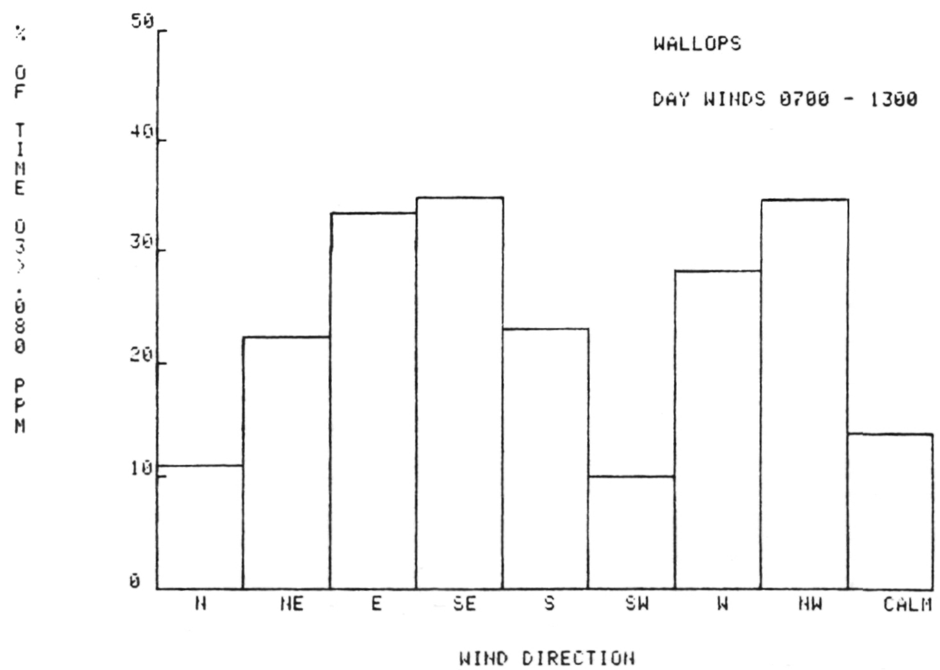

Figure 11b. Plot of the percentage of morning hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Wallops.

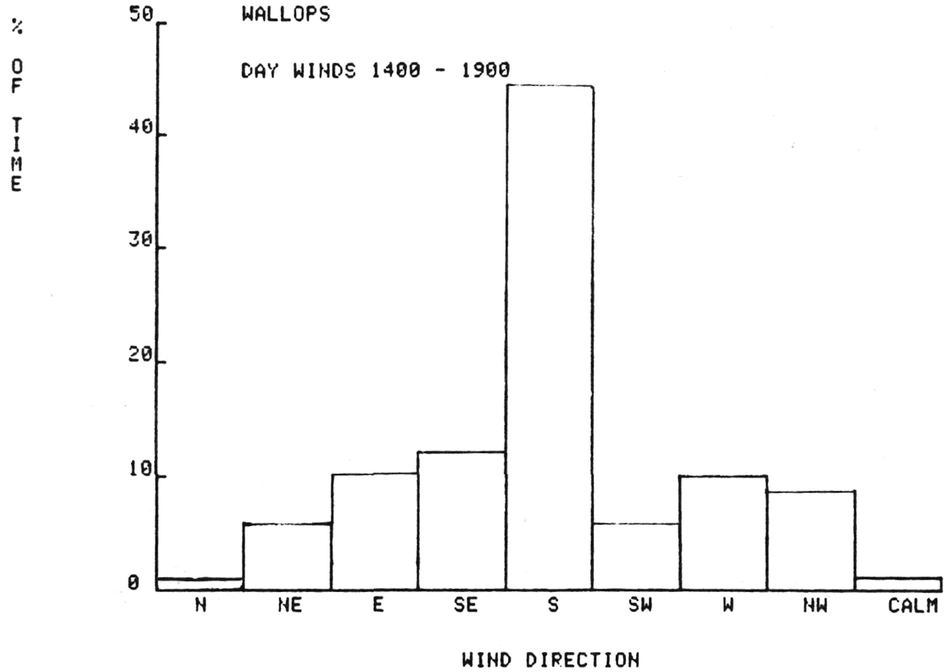

Figure 12a. Plot of the percentage of the total number of afternoon (1400-1900) hours with wind in a given direction at Wallops.

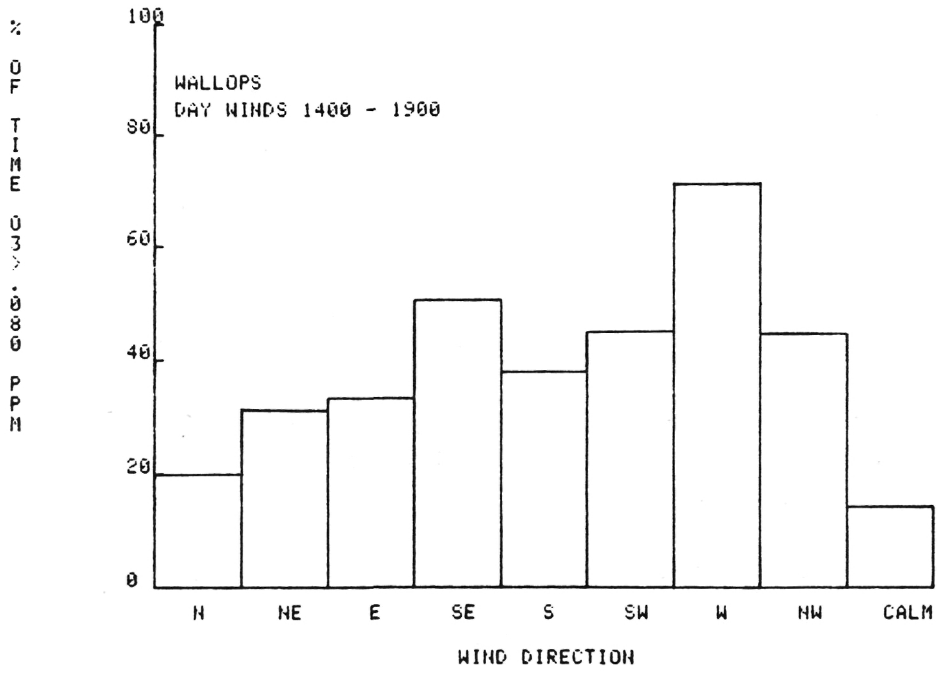

Figure 12b. Plot of the percentage of afternoon hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Wallops.

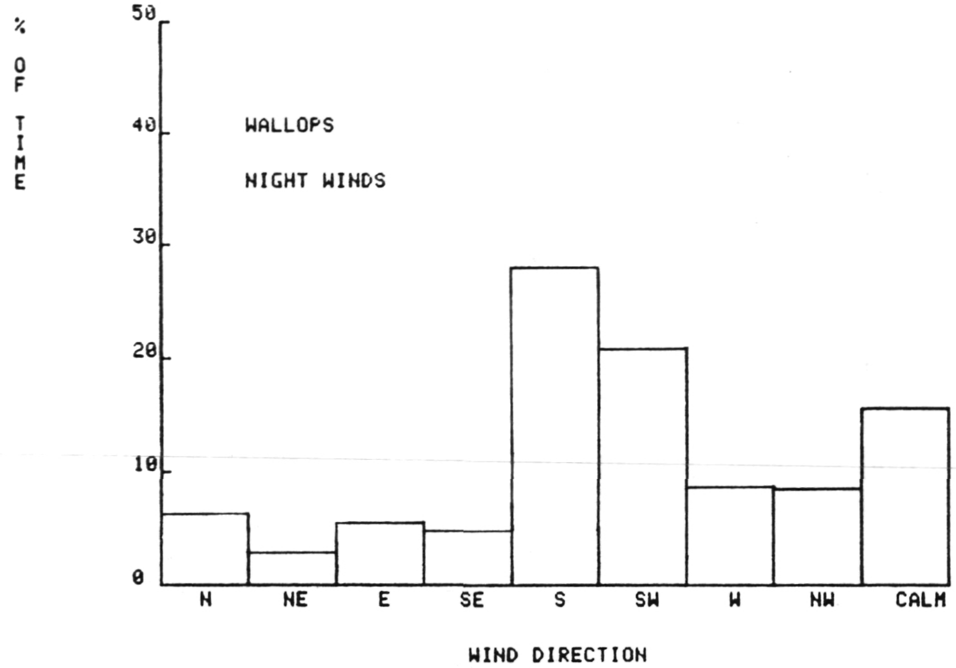

Figure 13a. Plot of the percentage of the total number of nighttime (2000-0600) hours with wind in a given direction at Wallops.

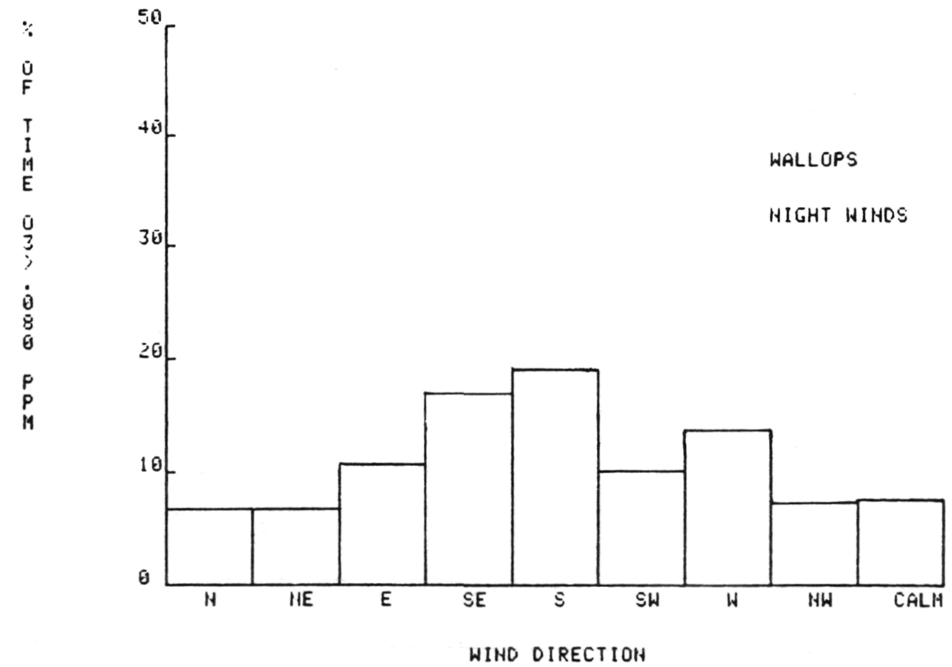

Figure 13b. Plot of the percentage of nighttime hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Wallops.

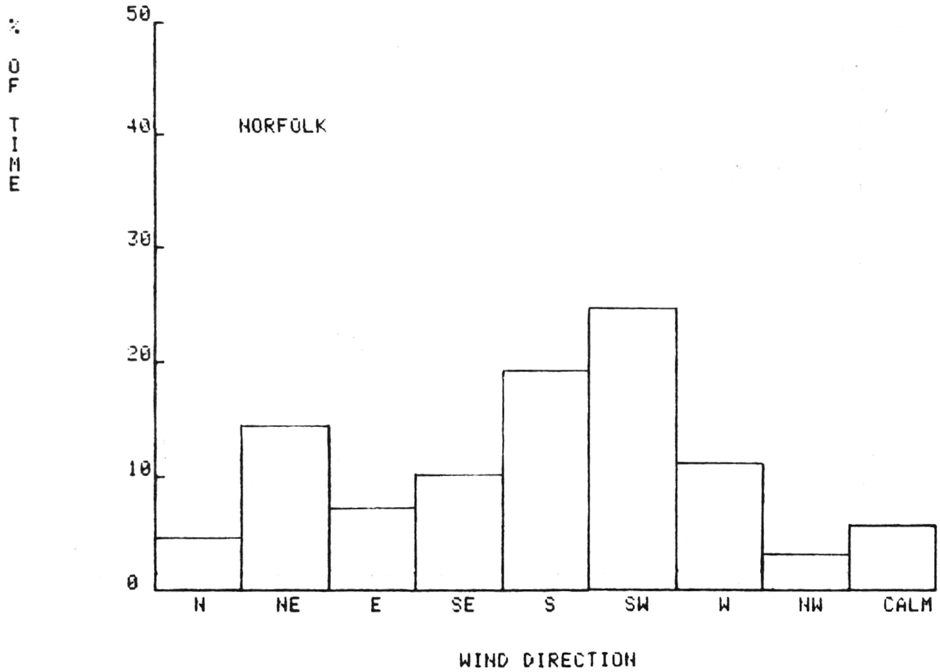

Figure 14a. Plot of the percentage of the total number of hours with wind in a given direction at Norfolk International Airport.

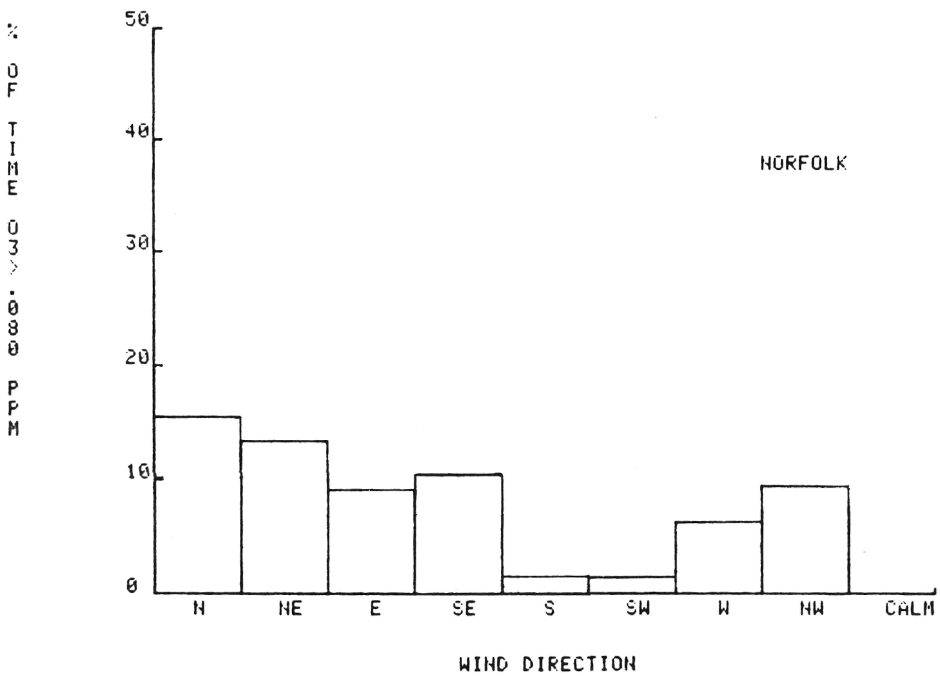

Figure 14b. Plot of the percentage of hours that wind in a given direction occurred with O_3 concentrations > 0.080 ppm at Norfolk.

noon, even though the northwest winds occurred for only a small percentage of time, a higher percentage of that time corresponded to high ozone levels. Again, as with the Wallops winds, the night situation differed. This time, at Norfolk, the south to southwest winds were predominant with virtually no ozone levels occurring above 0.08 ppm except for a small percentage from an easterly direction. The percentages of high ozone levels at Norfolk during all hours were significantly lower than those at Wallops, probably owing to a higher concentration of NO_x in the Norfolk urban area (ref. 2). Other than the fact that higher ozone concentrations were observed with certain wind directions, our results offered no explanation of these trends.

A similar situation existed at the Nike Site. The predominant wind direction was southwest (Fig. 15a), but higher ozone levels were experienced for winds with northwest, north and easterly azimuths. The Nike Site day, morning, and afternoon winds, as shown in the appendix, are proportioned similarly to those in Figure 15. The night winds differed slightly. Although the southwest azimuth was the predominant wind direction, calm conditions were prevalent. Lower percentages of high ozone levels occurred, with east winds, the principle direction of high ozone. Can these winds that seem to occur with high ozone levels be traced to any particular urban area? Again our results are inconclusive. Transport cannot be definitely identified in the data.

These winds that we have discussed thus far were surface winds. We also correlated ozone levels versus winds occurring at 2000 feet since these winds tend to be less influenced by surface obstacles. Radiosonde wind data were taken twice a day during the summer at 0800 and 2000 EST. The predominating wind direction (Fig. 16a) at this altitude for Wallops was southwest. High ozone levels occurred in every wind direction except for the southeast azimuths. Of the winds occurring at the surface, the southeast winds had the highest percentage of time occurring with high ozone levels. Further information, including the back trajectories of these winds, might explain this occurrence and perhaps denote a possible relation to transport.

Thus far it has been shown that there is a bias in the ozone levels at Wallops and Wachapreague when compared to the Norfolk data. In summarizing the biases seen in the data, the monitoring sites can be arranged in order according to their position along the line connecting Colerain at the lower end with Wallops, the northernmost station. The stations listed along the abscissa of Figure 17 (Langley and Cheriton sites not listed owing to an incomplete data set for June and July) were located in rural areas, and those located at Tidewater Community College, Norfolk International Airport, Old Dominion University, and Hampton, Virginia were the urban sites. When the locations of these stations are correlated with the percentage of time that each had ozone levels in excess of 0.08 ppm, we see (Fig. 17) that as latitude increases, the average ozone increases. Notice the drop in the average ozone concentrations occurring at the urban sites, indi-

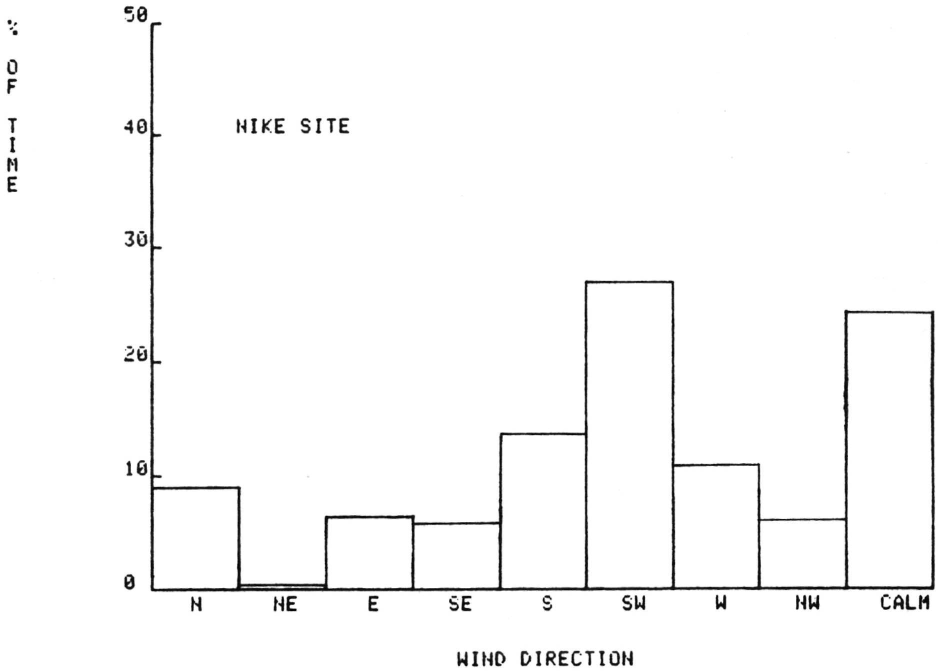

Figure 15a. Plot of the percentage of the total number of hours with wind in a given direction at the Nike Site for June and July 1977.

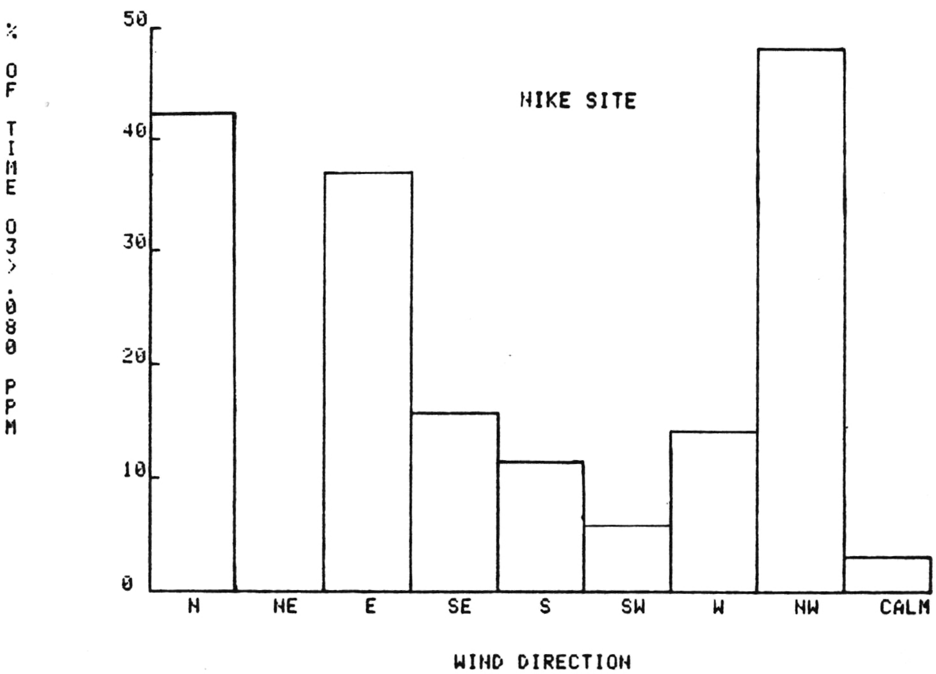

Figure 15b. Plot of the percentage of hours that wind in a given direction occurred with O_3 concentrations > 0.080 ppm at the Nike Site for June and July 1977.

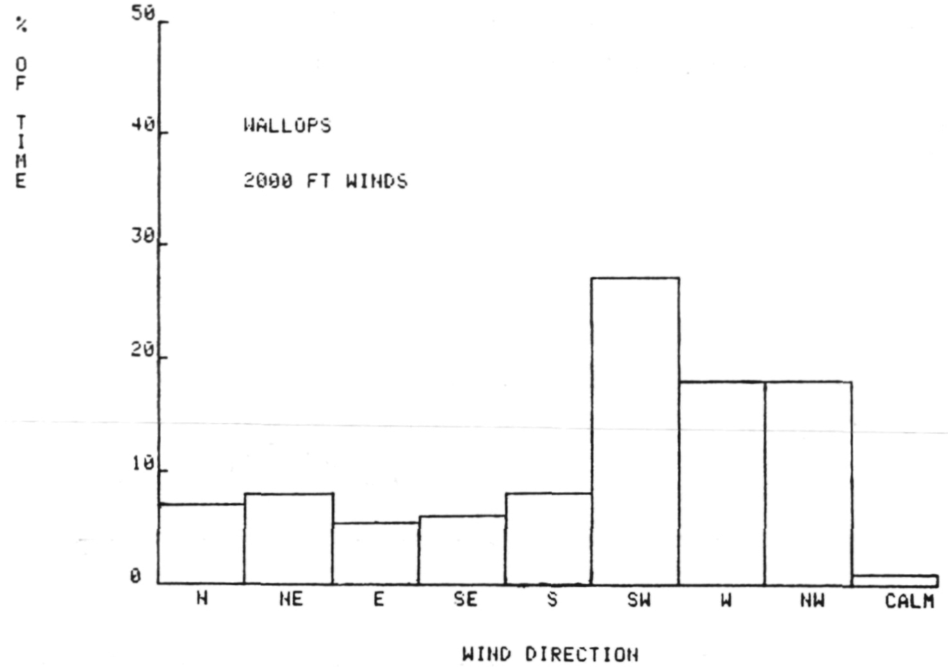

Figure 16a. Plot of the percentage of the total number of hours occurring with winds at 2000 ft. in a given direction at Wallops.

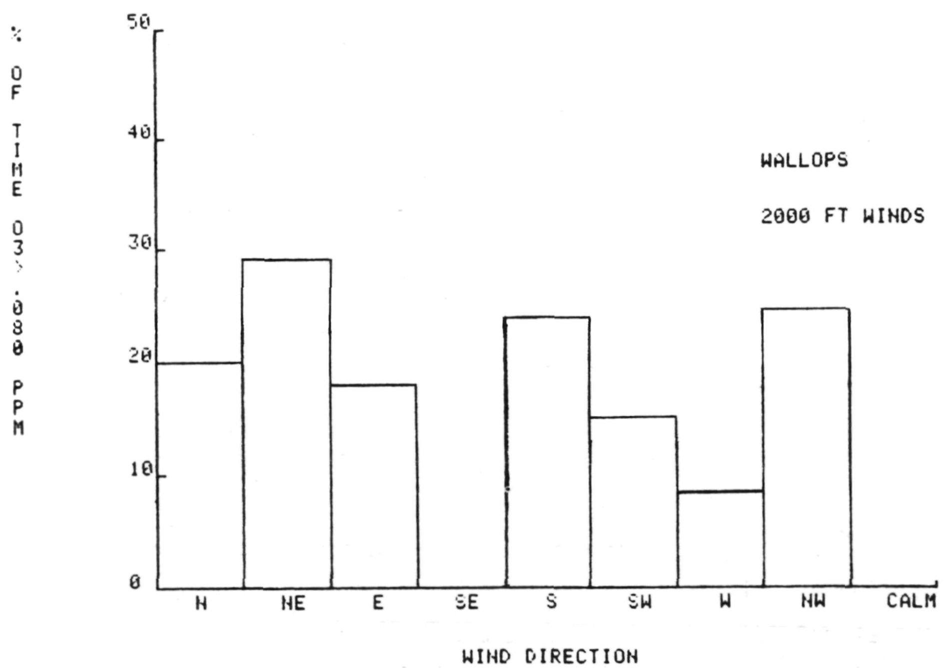

Figure 16b. Plot of the percentage of hours that wind in a given direction at 2000 ft. occurred with O_3 concentrations > 0.080 ppm at Wallops.

cating the destruction of ozone by high urban NO_x concentrations (ref. 2). Perhaps this trend is the result of a regional air mass extending into the eastern Virginia area. We cannot draw any definite conclusions without further scientific analysis.

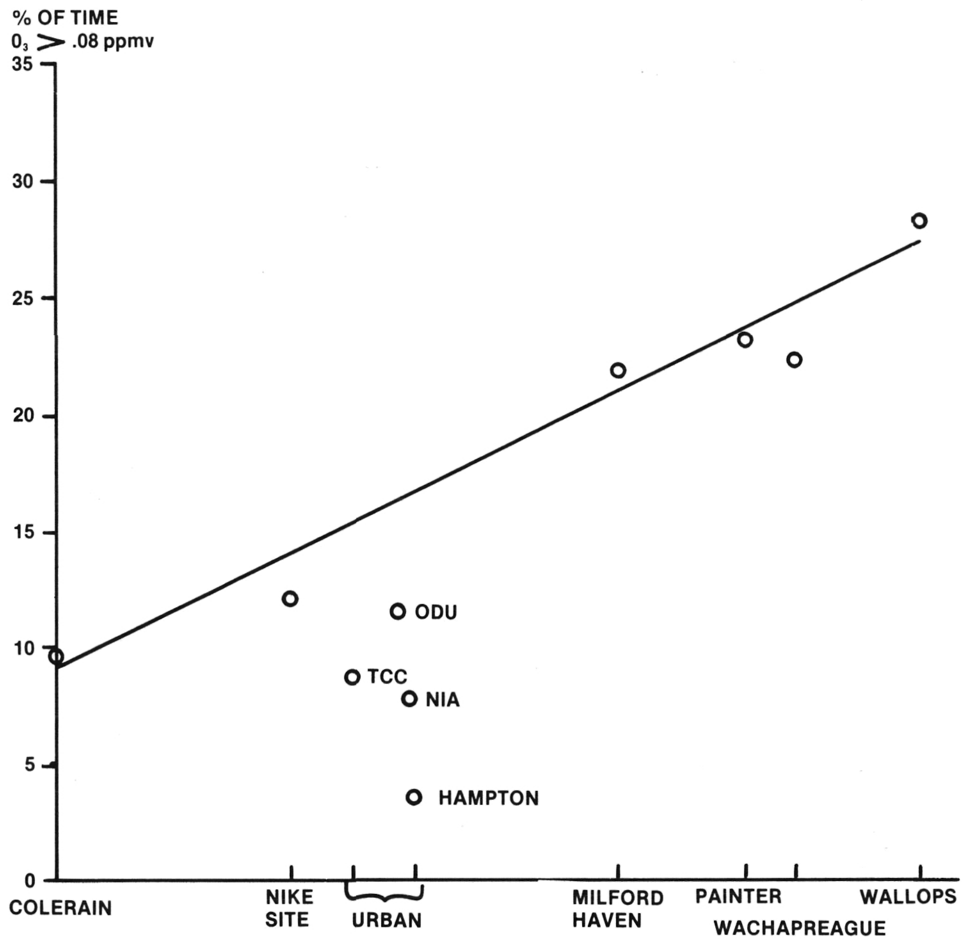

Figure 17. Plot of the percentage of time that O_3 levels at the given stations were > 0.080 ppm vs the stations in latitudinal sequence for the summer of 1977.

SUMMARY OF RESULTS

The main objective of this study was to investigate the ozone level in the eastern Virginia region to better understand its nature and distribution. Our results show that there is a definite bias existing in the ozone concentrations along the eastern Virginia shorelines. According to the position of the stations along the southwest wind vector, it was found that the average ozone levels were increasing latitudinally. All monitoring sites recorded levels exceeding the National Ambient Air Quality Standard during this 1977 sampling period. Although our results showed higher concentrations occurring with certain wind directions, we saw no actual evidence of regional or local transport. Perhaps future investigations will explain the causes of these trends and their relation to the total ozone distribution experienced in this area.

APPENDIX

ANALYSIS OF THE DEPENDENCE OF ELEVATED OZONE LEVELS ON WIND DIRECTION

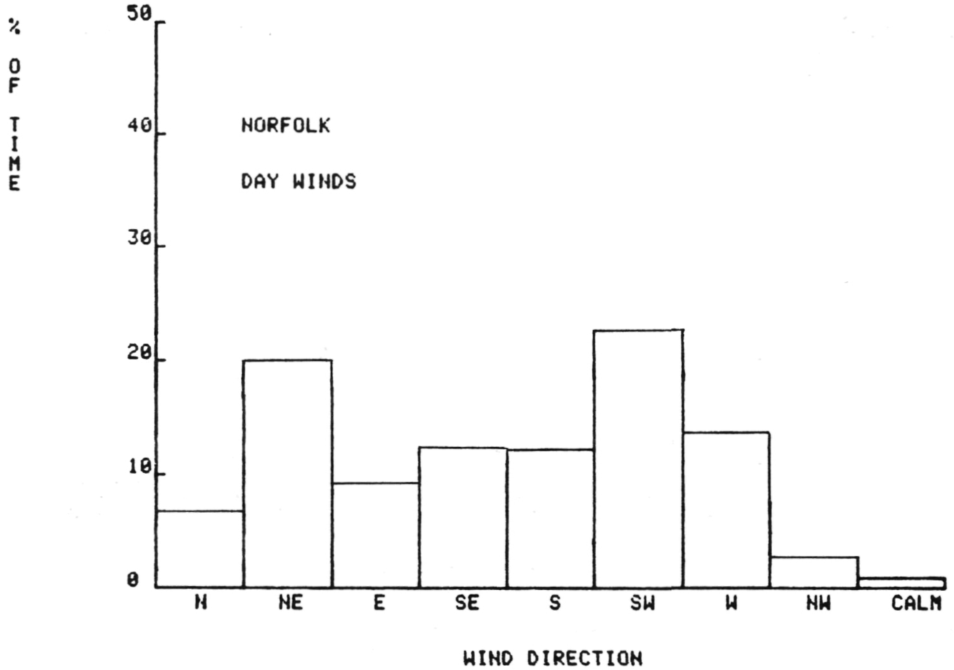

Figure 18a. Plot of the percentage of the total number of daytime hours with wind in a given direction at Norfolk.

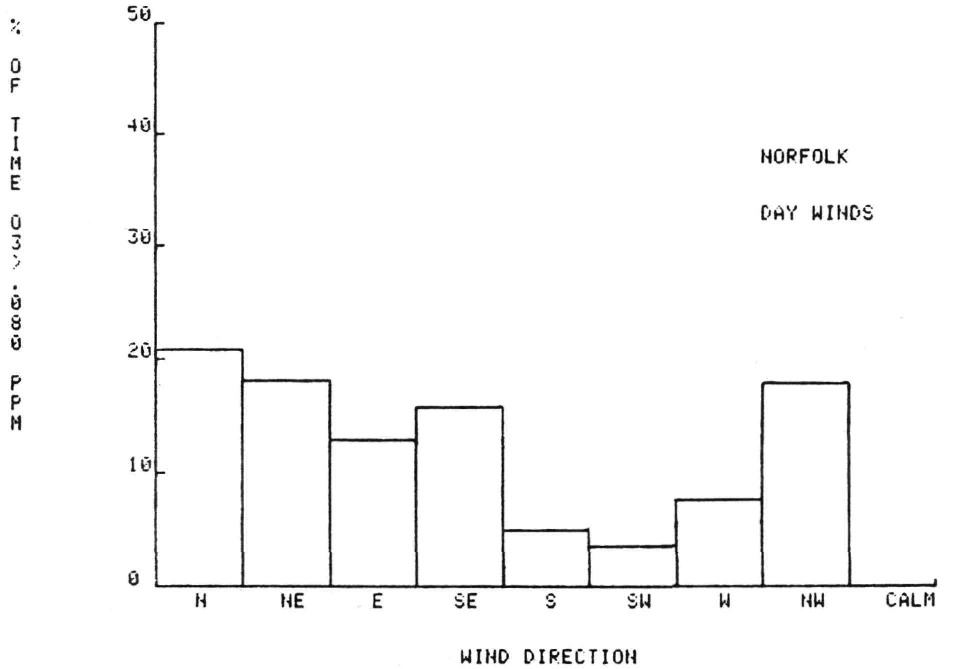

Figure 18b. Plot of the percentage of daytime hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Norfolk.

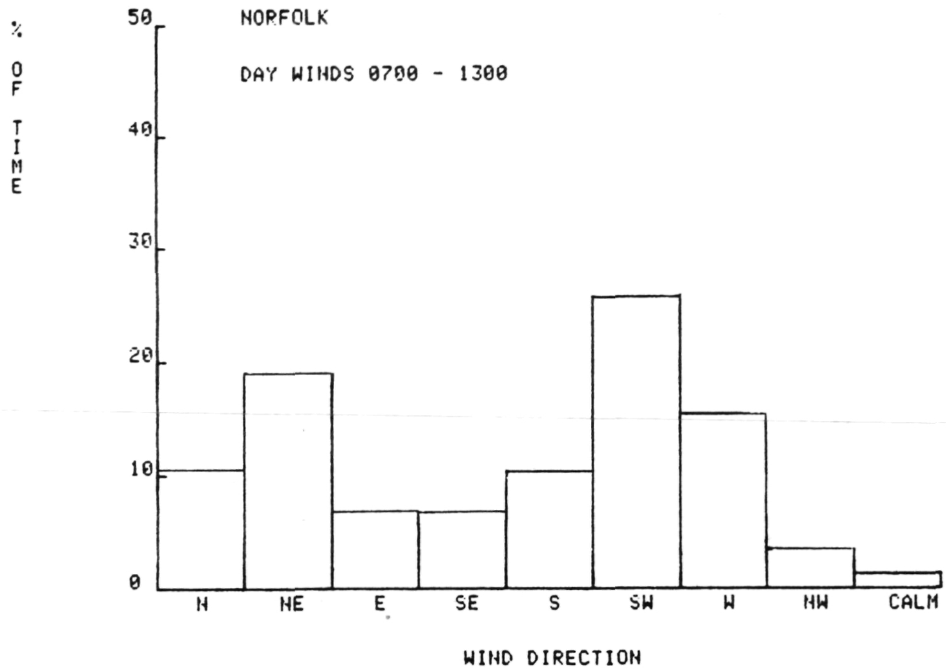

Figure 19a. Plot of the percentage of the total number of morning hours with wind in a given direction at Norfolk.

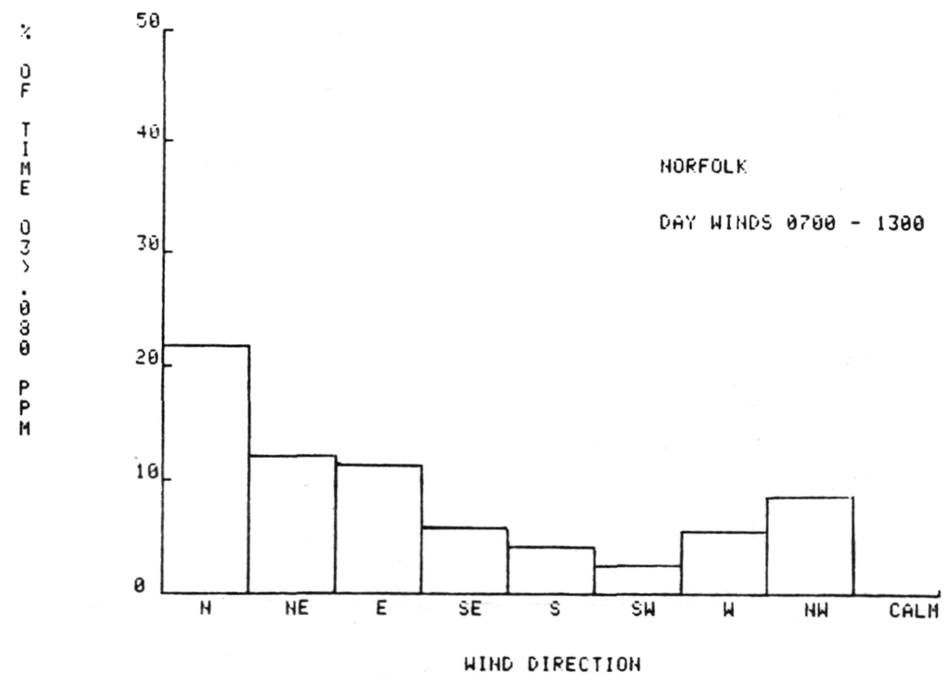

Figure 19b. Plot of the percentage of morning hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Norfolk.

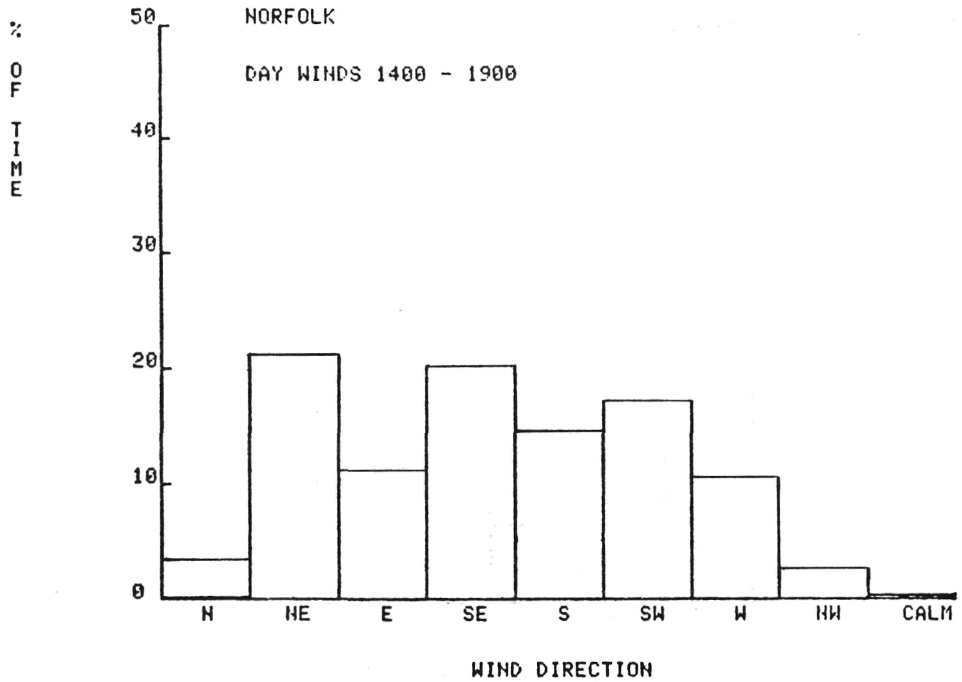

Figure 20a. Plot of the percentage of the total number of afternoon hours with wind in a given direction at Norfolk.

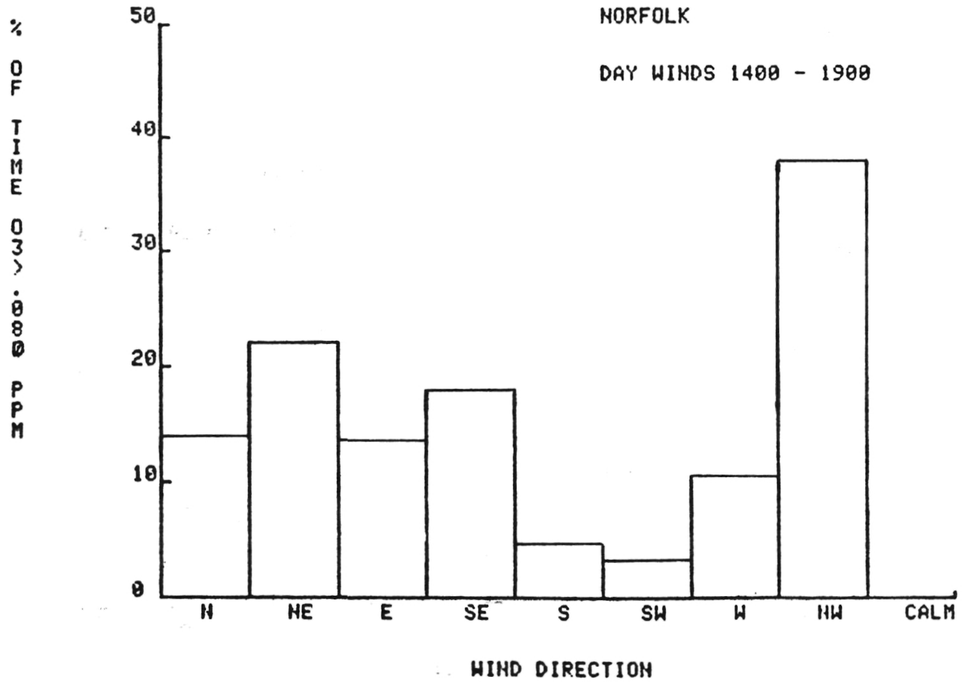

Figure 20b. Plot of the percentage of afternoon hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Norfolk.

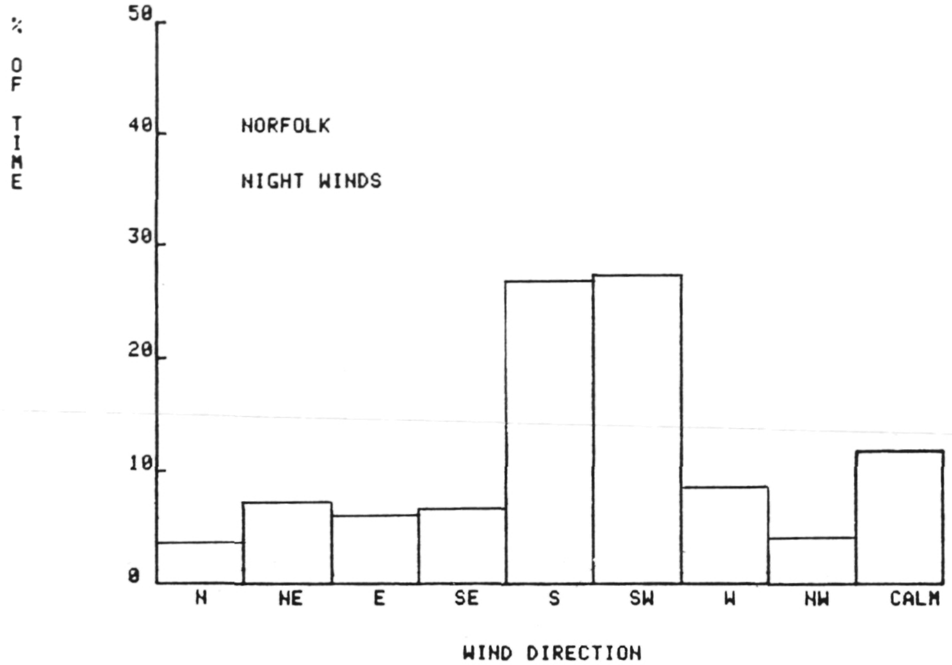

Figure 21a. Plot of the percentage of the total number of nighttime hours with wind in a given direction at Norfolk.

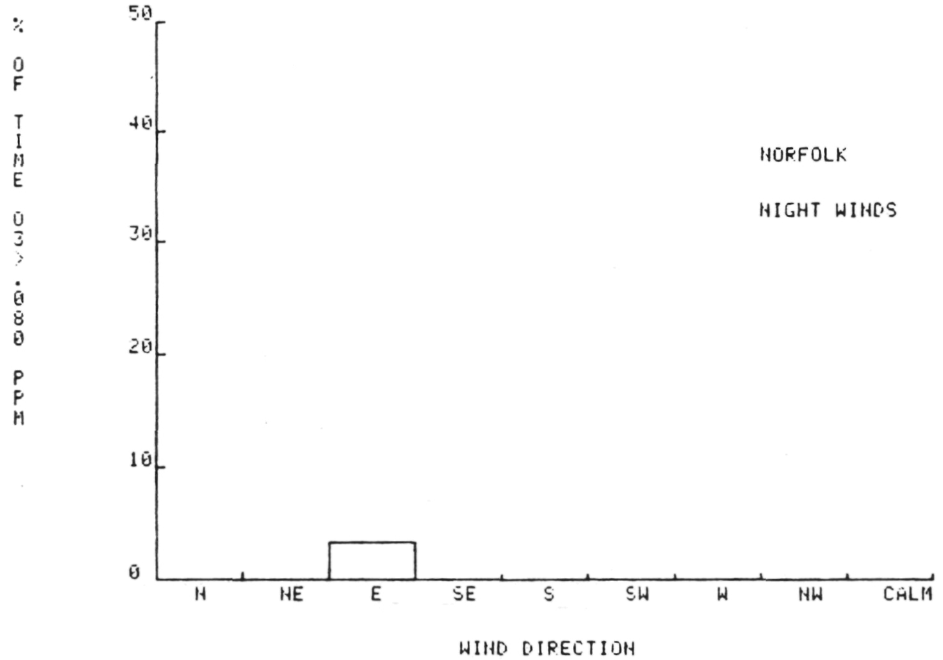

Figure 21b. Plot of the percentage of nighttime hours with O_3 concentrations > 0.080 ppm as a function of wind direction at Norfolk.

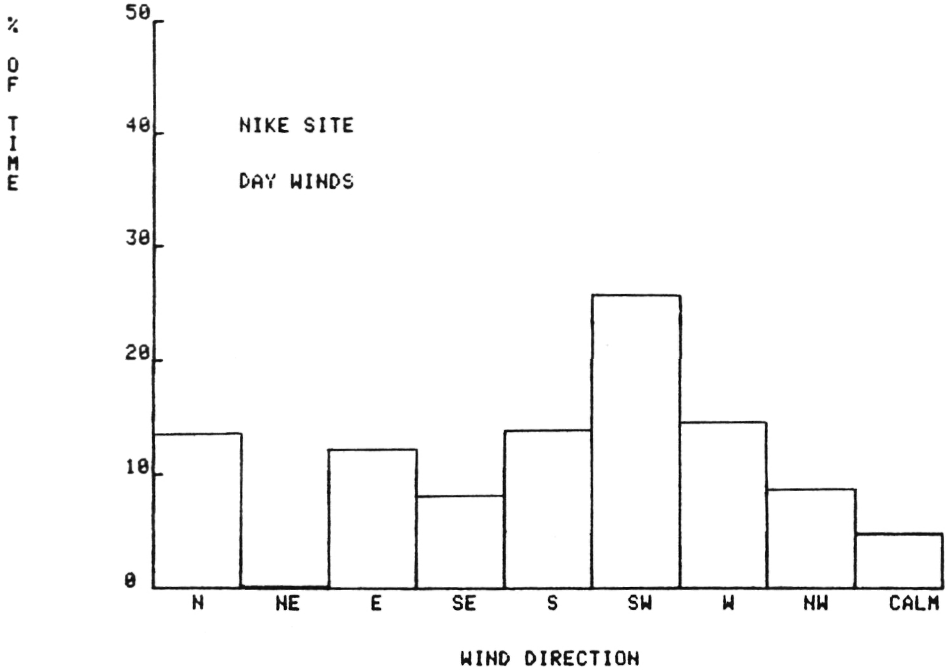

Figure 22a. Plot of the percentage of the total number of daytime hours with wind in a given direction at the Nike Site for June and July 1977.

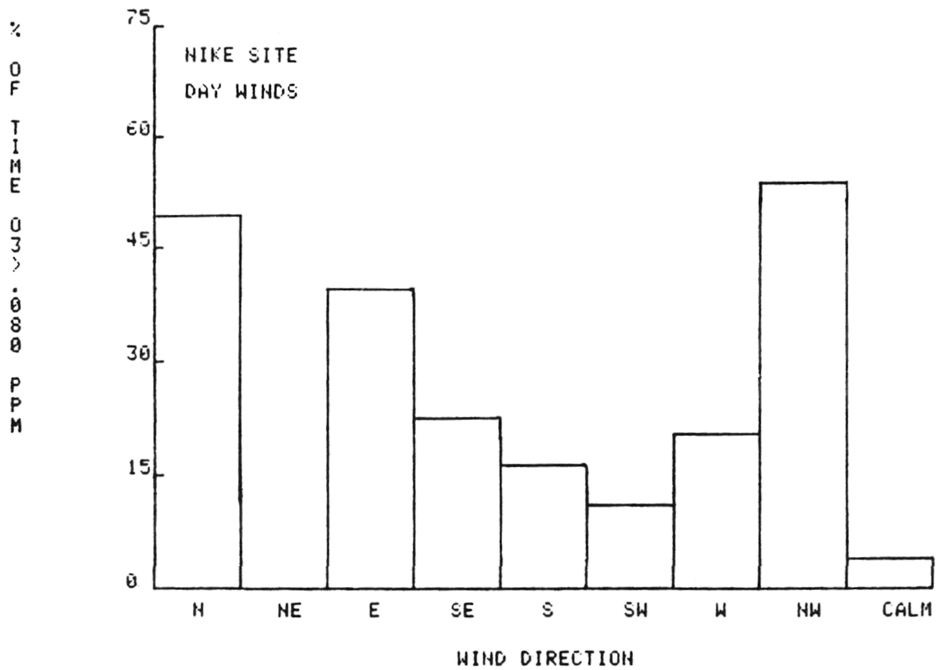

Figure 22b. Plot of the percentage of daytime hours with O_3 concentrations > 0.080 ppm as a function of wind direction at the Nike Site for June and July of 1977.

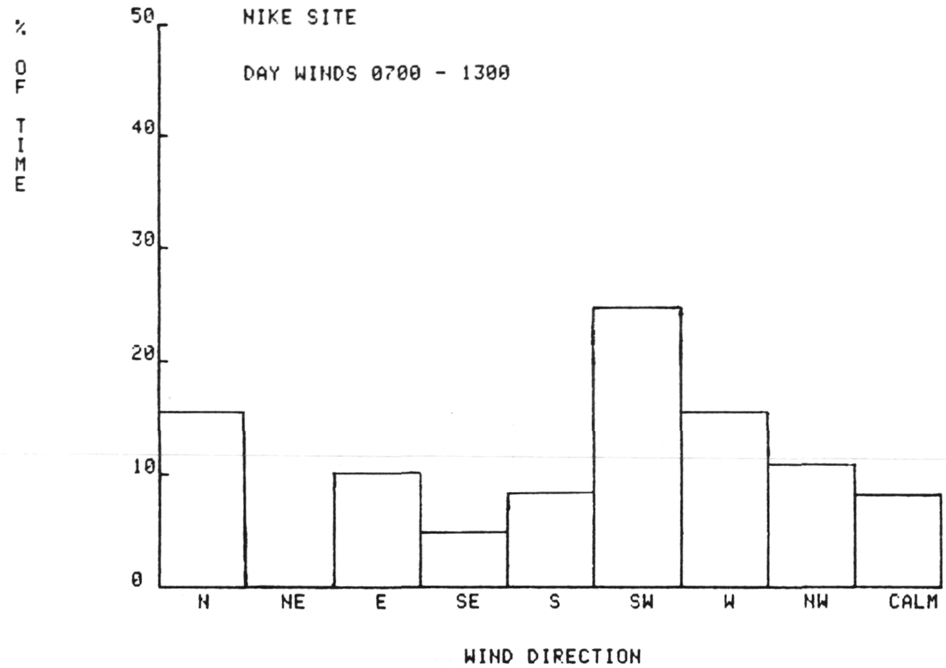

Figure 23a. Plot of the percentage of the total number of morning hours with wind in a given direction at the Nike Site for June and July of 1977.

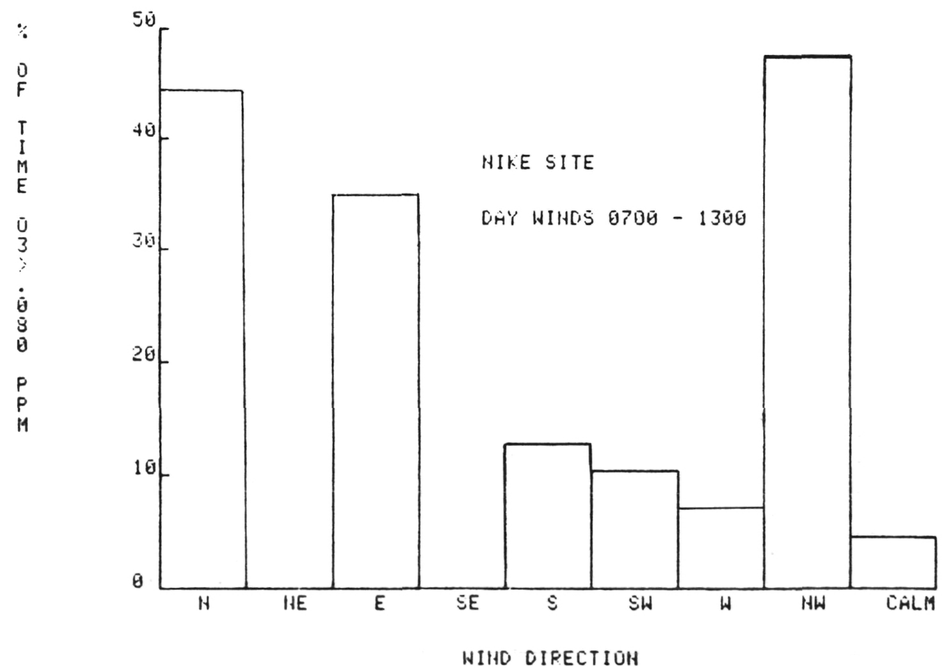

Figure 23b. Plot of the percentage of morning hours with O_3 concentrations > 0.080 ppm as a function of wind direction at the Nike Site for June and July of 1977.

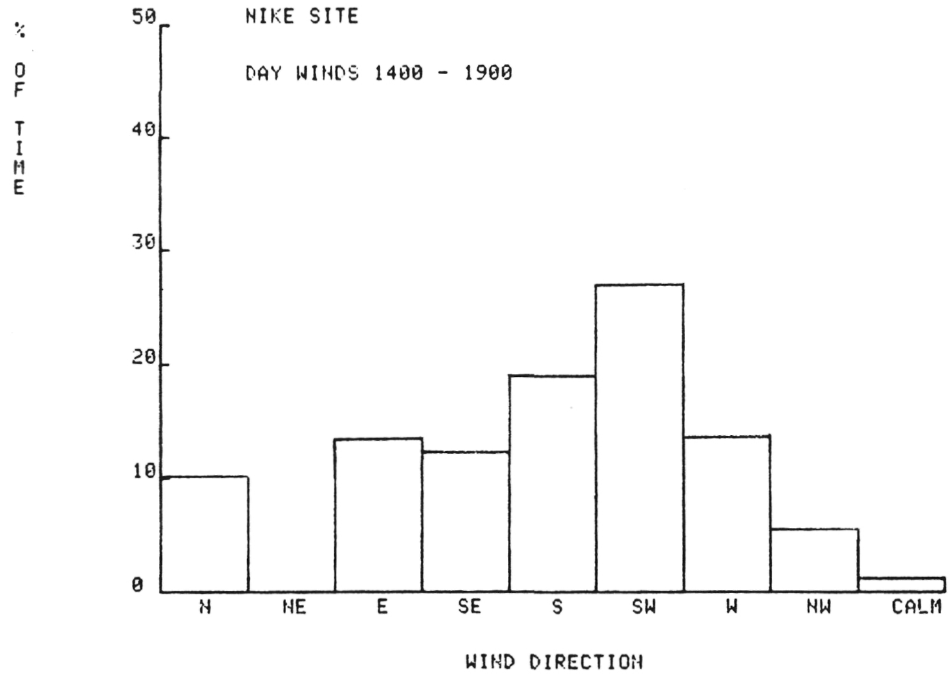

Figure 24a. Plot of the percentage of the total number of afternoon hours with wind in a given direction at the Nike Site for June and July of 1977.

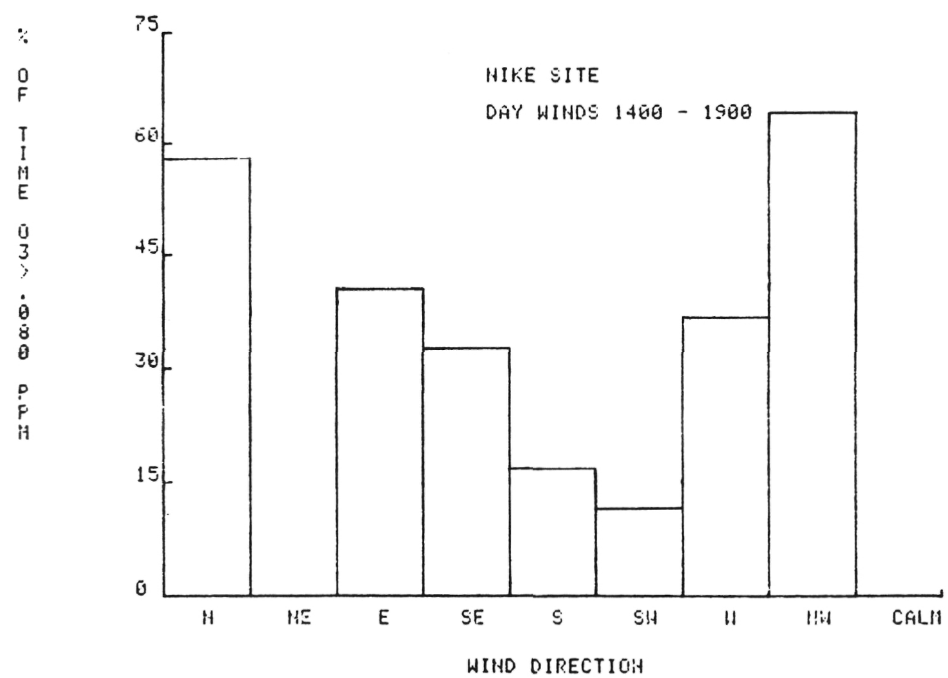

Figure 24b. Plot of the percentage of afternoon hours with O_3 concentrations > 0.080 ppm as a function of wind direction at the Nike Site for June and July of 1977.

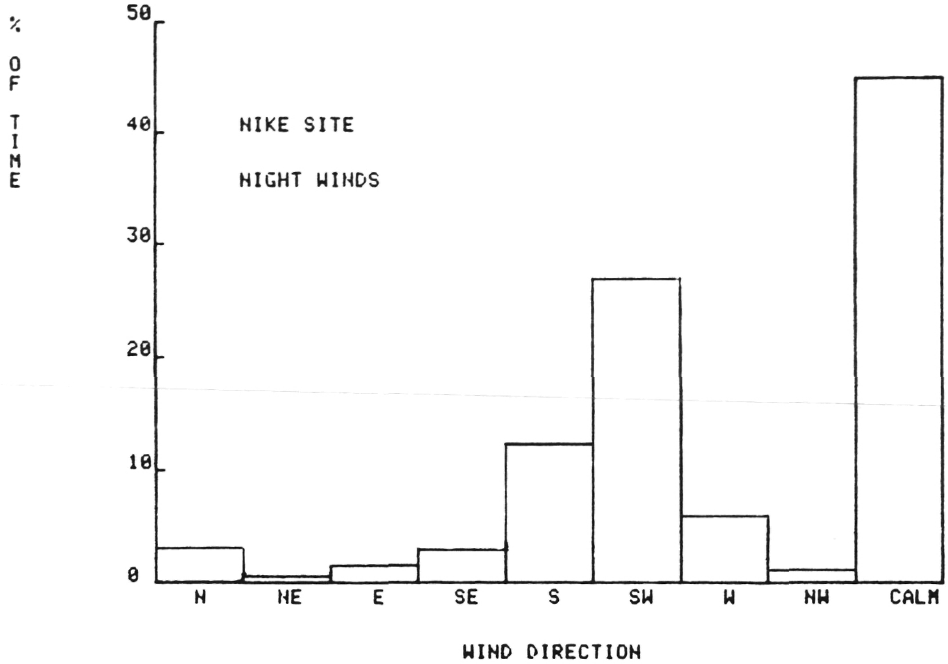

Figure 25a. Plot of the percentage of the total number of nighttime hours with wind in a given direction at the Nike Site for June and July of 1977.

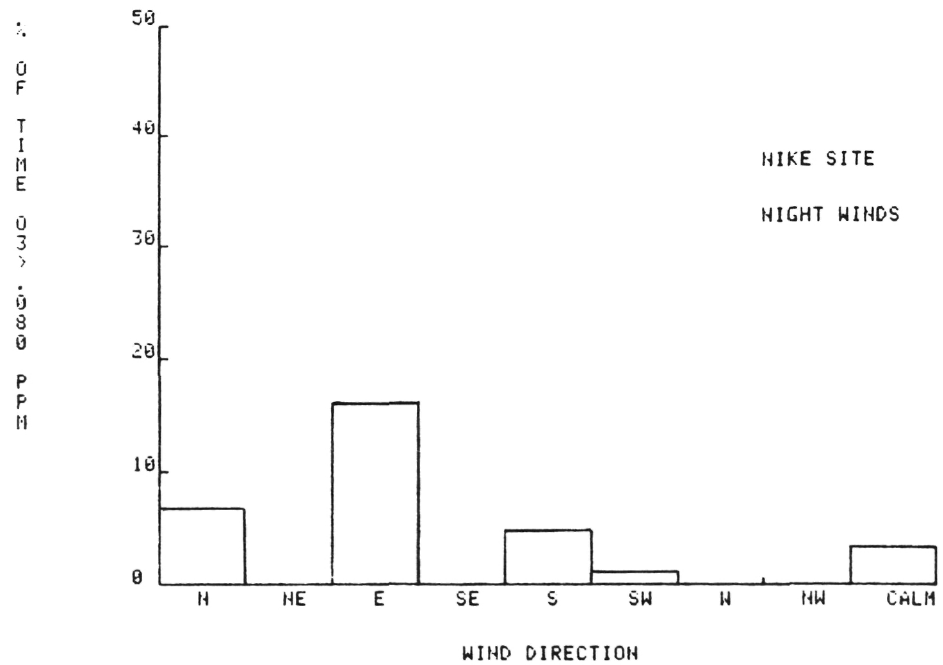

Figure 25b. Plot of the percentage of nighttime hours with O_3 concentrations > 0.080 ppm as a function of wind direction at the Nike Site for June and July of 1977.

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15. Supplementary Notes

16. Abstract

During the summer of 1977, the Wallops Flight Center, along with other governmental and educational organizations, participated in a surface ozone investigation. The study was conducted by the Virginia State Air Pollution Control Board and consisted primarily of twelve ground stations positioned throughout the Eastern Shore - Tidewater area of Virginia and North Carolina. From an analysis of the ozone and wind data, certain trends were found such as the existence of a bias in the ozone concentrations between stations and a linear correlation between average ozone concentration and latitude. In addition, higher ozone levels were found with surface winds from certain preferred directions at the various sites. The results, however, do not substantiate ozone or ozone precursor transport.

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