A Summary of Ambient Air at John F. Kennedy Space Center with a Comparison to Data from the Florida Statewide Monitoring Network (1983-1992)

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Abstract

The EPA criteria air pollutants were monitored at Kennedy Space Center (KSC) since 1983 to comply the prevention of significant deterioration requirements under the Clean Air Act amendments passed by Congress in 1977 and 1990. Monitoring results show that monthly maximum 24-hour total suspended particulates decreased from 144.6 $\mu g/m^3$ in 1988 to 73.0 $\mu g/m^3$ in 1991 and increased to 149.3 $\mu g/m^3$ in 1992. Inhalable particulates increased from 56.1 $\mu g/m^3$ in 1983 to 131.4 $\mu g/m^3$ in 1988, and then decreased to 38.5 $\mu g/m^3$ in 1992. Sulfur dioxide monthly maximum 24-hour average concentrations decreased each year from 135.2 $\mu g/m^3$ in 1983 to 33.8 $\mu g/m^3$ in 1992. Nitrogen dioxide concentrations increased from 5.1 $\mu g/m^3$ in 1983 to 5.9 $\mu g/m^3$ in 1988, then decreased to 4.5 $\mu g/m^3$ in 1992. Carbon monoxide annual average concentrations decreased from 6.2 $\mu g/m^3$ in 1983 to 1.1 $\mu g/m^3$ in 1988, and increased to 1.2 $\mu g/m^3$ in 1992. Ozone maximum 1-hour concentrations increased from 98 parts per billion (ppb) in 1983 to 134 ppb in 1989, and then decreased to 80 ppb in 1992. Total annual rainfall ranged from 37.47 inches to 57.47 inches and shows a 6.6 percent increase over this same ten year period.

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1.0 Introduction

Environmental Protection Agency (EPA) criteria air pollutants at John F. Kennedy Space Center (KSC) on north Merritt Island, Florida have been monitored since January, 1983 as part of the Ecological Program for the KSC Biomedical Office (Hall et al. 1992). This program includes activities in areas such as air quality, surface and groundwater quality, threatened and endangered species population characteristics, vegetation communities distribution, soil chemistry, rain volume and chemistry, and launch operations effects.

Kennedy Space Center is required to meet the prevention of significant deterioration (PSD) requirements under the Clean Air Act (CAA) amendments passed by Congress in 1977 and 1990, since it is located in an area of the state designated as an "attainment area" (i.e., ambient air quality standards are being met). KSC is also subject to the National Emission Standards of Hazardous Pollutants (NESHAPS), and the New Source Performance Standards (NSPS) as administered by the Florida Administrative Code (FAC) 17-2 (EG&G Florida, Inc. et al. 1992). In addition, air quality monitoring is performed to provide data for use in permitting, and to honor the commitment made in the NASA Environmental Impact Statement(NASA 1979).

Since KSC is classified as a PSD attainment area for all of the criteria air pollutants, data are collected to

evaluate trends in air pollutant concentrations and any potential impacts on air quality from KSC operations on an urban scale (4-50 km). Daily air quality levels are influenced primarily by vehicular traffic, utilities fuel combustion, standard refurbishment and maintenance operations, incinerator operations, and emissions from two regional power plants that are located approximately 6 km to the southwest from the permanent air monitoring station A (PAMS A). Space Shuttle launch operations, training fires, and prescribed burning on Merritt Island National Wildlife Refuge influence air quality as localized episodic events (EG&G Florida, Inc. et al. 1992).

The Florida statewide air quality monitoring program provides the public and government with the identification of: (1) areas where the ambient air quality standards are being violated, and (2) areas where the ambient standards are being met and for which plans are needed to ensure maintenance of acceptable levels of air quality in the face of anticipated population and industrial growth (Florida Department of Environmental Regulation 1987).

The purpose of this paper is to present a 10-year summary of KSC data and to compare the ambient air quality data collected at KSC with Florida statewide data to determine relationships between levels and trends for the two data sets.

1.1 Methods

KSC data were collected at a permanent air monitoring station (PAMS A) which is an 8x8x16 foot trailer configured to monitor the following parameters: ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), wind speed, wind azimuth, temperature, relative humidity, and particulates, both total suspended (TSP) and inhalable (PM-10). Data were collected continuously on a once per minute basis and stored on a Hewlett Packard 9000 series mainframe computer for all of the parameters except particulates, which were collected on a 6-day schedule. PAMS A is located at the Central Instrumentation Facility (CIF) antenna site, 1.6 kilometers north of the KSC Headquarters Industrial area and the NASA Causeway (Figure 1). Other potential emissions and particulate sources are located, in relation to the sampling site, as shown in Table 1.

The analyzers used for monitoring at KSC were as follows: Ozone...Bendix 8002b Chemiluminescent Analyzer through 1989, followed by a Thermo-environmental 45 Ultraviolet Absorbtion Analyzer; Sulfur Dioxide...Thermo-environmental 43 and 43A Ultraviolet Absorbtion Analyzers; Nitrogen Dioxide...Monitor Labs 8840 Chemiluminescent Analyzer followed by a Thermo-environmental Model 42 Chemiluminescent Analyzer; Carbon Monoxide...Thermo-environmental Model 48 Pulsed Infrared Detector;

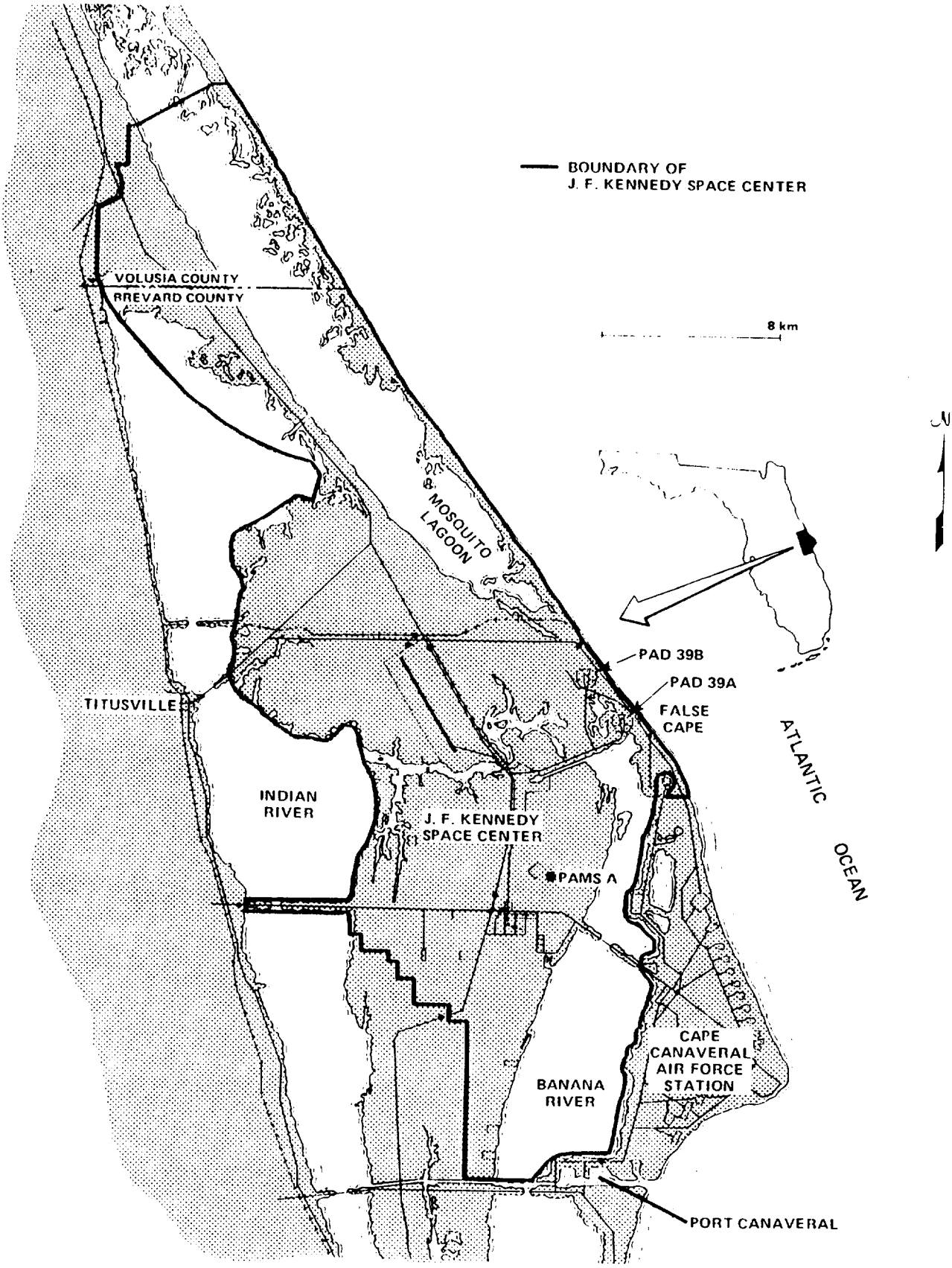

Figure 1. Map of John F. Kennedy Space Center (KSC) Showing Location of Permanant Air Monitoring Station A (Pams A).

Table 1. Potential Sources Surrounding Pams A.

NAME	DISTANCE (KM)	DIRECTION HEADING
Vehicle Assembly Building	5.4	North
Launch Pad 39 B	10.2	Northeast
Launch Pad 39 A	8.5	Northeast
Atlantic Ocean	7.9	East
Cape Canaveral Air Force		
Station	8.0	Southeast
Port Canaveral	15.6	South-Southeast
Cape Canaveral/ Cocoa Beach	19.5	South-Southwest
Merritt Island	19.5	South-Southwest
Cocoa	20.5	Southwest
Florida Power & Light and		
Orlando Utilities		
Commission Oil-fired	14.4	West-Southwest
Power Plants		
Titusville	18.5	Northwest

Particulates...Sierra Anderson Model 231E Dichotomous Sampler (10 micron cut point) and General Metal Works High Volume Sampler; meteorological instruments were R.M. Young until 1988, when they were replaced by Climatronics instruments.

All continuous gas analyzers were subjected to Florida Department of Environmental Regulation (FDER) Quality Assurance Guidelines consisting of routine bi-weekly precision and Level I checks, as well as multipoint calibrations either quarterly or after instrument repairs (Varn 1980). Independent audits were performed two or three times per year through 1991 on the gas analyzers, the particulate samplers, and the meteorological sensors.

Data analysis and statistical analyses (α=0.05) were conducted with SPSS on an IBM PC (SPSS, Inc. 1993) or computed manually. These tests include an analysis of variance (ANOVA) to assess the inter-year and intra-year significant differences for the total suspended particulates and inhalable particulates using SPSS and a manual computation of the Kendall's K statistic as a trends test for each parameter. Either the coefficient of rank correlation or the Kendall Tau can be used to describe trend, or perform a test of significant trend. The null hypothesis of the Kendall Tau test was that there was no trend, with the one-sided alternatives being that Y_i exhibits an upward or downward trend. The asymptotic approximate p-value was calculated as a z value and compared

to a reference table of z scores. This use of Tau to test for trend was originally proposed by Mann (1945) (Gibbons 1976). Another discussion of this topic can be found in the Air Quality Report, 1992 (FDEP 1992). Graphs were prepared with 'GRAFIT' software on the HP 9000 computer (GRAFIT USER'S GUIDE 1987).

The Florida air quality monitoring network consisted of approximately 300 monitors located in 35 counties throughout the state in 1985; it decreased to 168 monitors in 18 counties in 1992. The data used in this paper were obtained from the 1985 Ambient Air Quality in Florida reports and the 1986 through 1992 data ALLSUMS (Florida Department of Environmental Regulation 1985, 1992). As of 1992, Brevard County had two O_3, four TSP, and four PM-10 monitors and Orange County had two CO, two lead (Pb), one NO_2, two O_3, one SO_2, and seven PM-10 monitors on line (FDEP 1992).

2.0 Results and Discussion

The results of monitoring for the criteria pollutants mentioned previously will be discussed below in separate sections for each parameter. Each section will begin with a background, present the data from KSC, followed by the state data, and then a comparison between the two data sets. The data tables for KSC can be found in Appendix A in Tables 2 through 8.

3.0 Particulates

Particulate matter (PM) is defined as dispersed airborne solid or liquid particles (other than uncombined water) ranging in size from about 0.001 to 500 microns (μm) in diameter and depending on their size, these particles may be suspended in the air for a period of time varying from a few seconds to several months (Florida Department of Environmental Regulation 1992).

3.1 Total Suspended Particulates (TSP)

3.1.1 Background

The original primary and secondary particulate standards were set by EPA in 1971 for total suspended particulate (TSP). The primary standard was set for 260 $\mu g/m^3$ 24-hour average, 75 $\mu g/m^3$ annual average, and the secondary standard was set for 150 $\mu g/m^3$, all of which not to be exceeded more than once per year. The particle size measured as TSP was between 0.1 and 50.0 microns. The EPA proposed changes in the standards based on a review of health based criteria on March 20, 1984. These changes were finally adopted as law and published (Federal Register 1987).

3.1.2 Statewide Trends

The Florida total suspended particulate matter monitoring network started with 146 monitoring sites in 35 counties in 1983, and consisted of 35 monitoring sites in 13 counties in 1992. The annual statewide TSP geometric means from 1983 to 1992 ranged from 24.9 $\mu g/m^3$ in 1992 to 33.2 $\mu g/m^3$ in 1984. The second-highest maximum 24-hour value from the state network ranged from 50.0 $\mu g/m^3$ in 1992 to 91.0 $\mu g/m^3$ in 1985 and 1989. Since the state began changing its sampling network from TSP to PM-10 after 1987, there are insufficient data available to determine PM-10 trends and no mention is made of the TSP data (FDER 1992).

3.1.3 KSC Trends

Measurements of TSP began at KSC in 1987, and the monthly maximum 24-hour TSP values have decreased from 144.6 $\mu g/m^3$ in 1988 to 73.0 $\mu g/m^3$ in 1991, and increased to 149.3 $\mu g/m^3$ in 1992 (Table 2.b)(Figure 2). The test of the Kendall's K statistic yields a significant minor trend of -0.194 (p=0.0202).

A graph of the monthly means of particulate mass shows that the highest monthly mean mass occurs during February and March (49.7 and 49.2 $\mu g/m^3$) and the lowest occurs during September (25.4 $\mu g/m^3$). The curve reflects maximum levels in

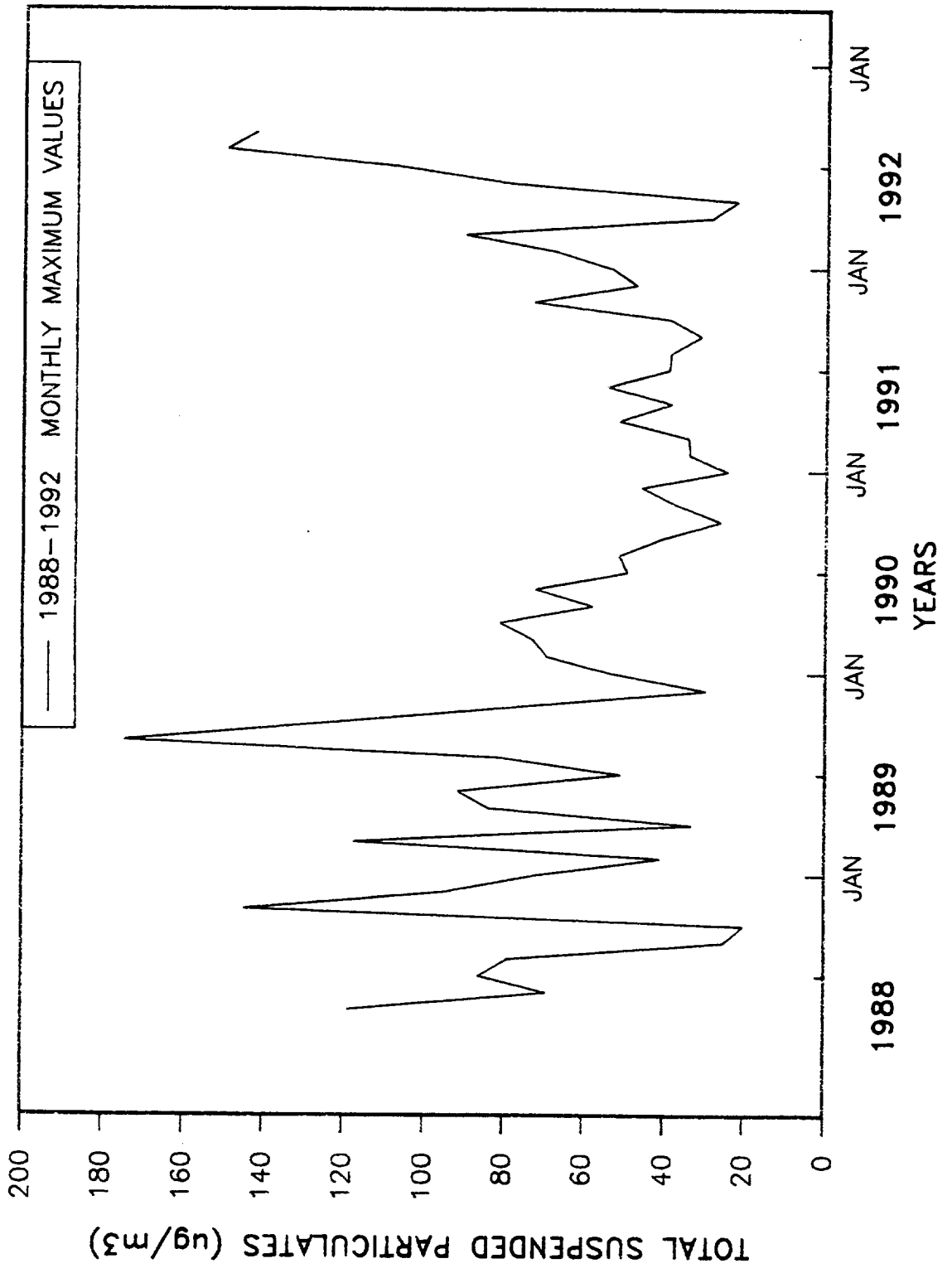

Figure 2. Monthly Maximum Total Suspended Particulates (1987-1992).

the spring (February through May) and a minimum in the summer (July through September), which may reflect seasonal rainfall patterns (Figure 3). The high mean for the month of July (50.9 $\mu g/m^3$), was excluded from Figure 3 as an outlier, because it included the mean of the high readings from 1992 (89.9 $\mu g/m^3$). These high readings were a result of major construction at the Space Station facility about 2 kilometers south of PAMS A. The mean for July from 1988 through 1991 was 30.5 $\mu g/m^3$.

An Analysis of Variance test was performed on the TSP data set for KSC to define significant differences. The data was first log-transformed to normalize the distribution and to achieve homogeneity of variances. There were no significant differences between months of the year, but there was a statistically significant difference between years (α=0.05).

The annual state TSP geometric means, the second-highest maximum values from 1983 through 1992, the annual KSC geometric means, and the second-highest maximum values from 1987 through 1992, are displayed in Figure 4. The state data used were values from the St. Johns River District including Brevard, Indian River, Orange, Seminole, and Volusia counties. The highest geometric mean for the state data occurred in 1984 (33.2 $\mu g/m^3$) when there were no data taken at KSC.

The highest KSC geometric mean (52.5 $\mu g/m^3$) occurred in 1992, when the state value was about half (24.9 $\mu g/m^3$). The

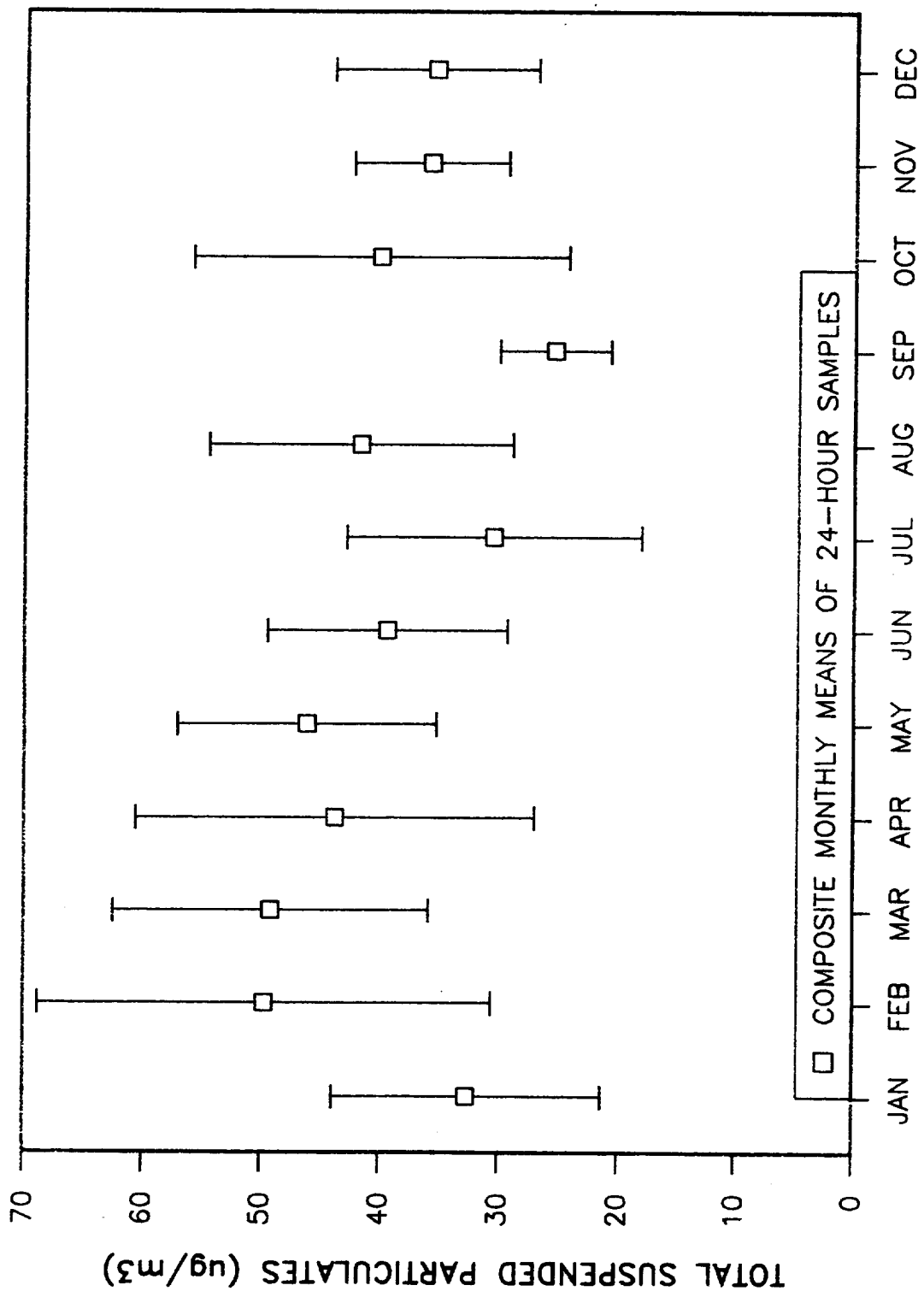

Figure 3. Composite Monthly Means Of Total Suspended Particulates (1987-1992).

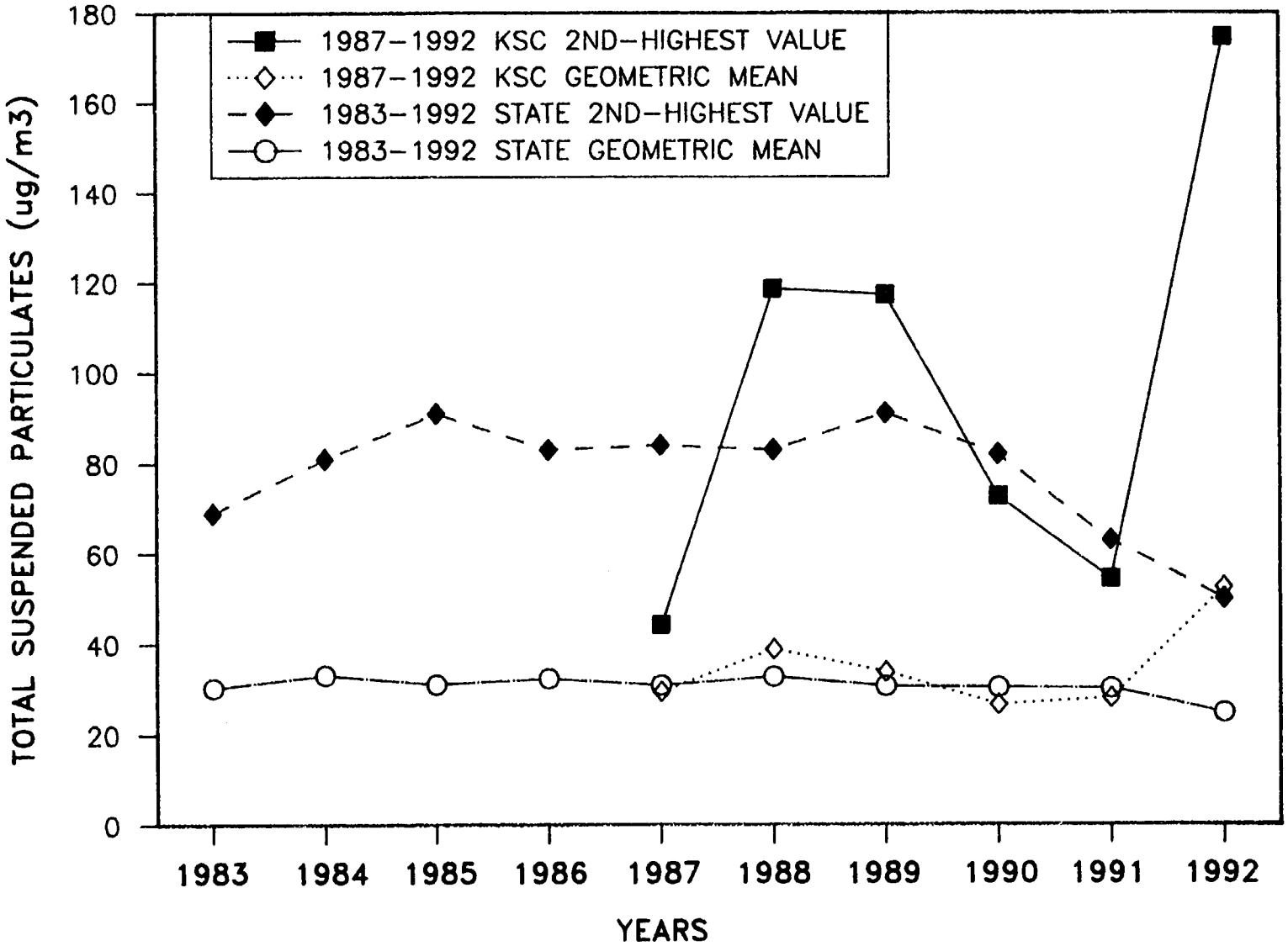

Figure 4. Comparison Of Total Suspended Particulates At KSC And Statewide (1983-1992).

KSC data and the state data do not appear to be significantly different for the period from 1987 through 1990, in terms of the geometric means. There was more variation in the second-highest values with KSC tending to be higher, except for 1987. The very large difference for 1992 reflects the 174.6 $\mu g/m^3$ value (24-hr. Avg.) in the July average (89.9 $\mu g/m^3$) discussed above. The maximum second-highest 24-hour average measured at KSC of 174.6 $\mu g/m^3$ was below the old TSP standard of 260 $\mu g/m^3$.

3.2 Inhalable Particulates (PM-10)

3.2.1 Background

The new particulate standards were for a smaller sized inhalable particle having a diameter less than 10 microns called PM-10. The 24-hour primary PM-10 standard was set at 150 $\mu g/m^3$ not to be exceeded more than once per year. The annual primary standard was set at 50 $\mu g/m^3$ expected annual arithmetic mean and the secondary TSP standard was replaced with 24-hour and annual standards identical to the new primary standards (Federal Register 1987).

There have been a number of studies in the last five years showing statistical correlations between airborne particulate matter and increased mortality and sickness. These effects include increased risks of respiratory, cardiovascular, and cancer-related deaths, as well as

pneumonia, lung function loss, hospital admissions, asthma, and other respiratory problems (Reichhardt 1995).

The latest focus is on "ultrafine" particles as small as one hundredth of a micrometer in diameter. Although these particles have very low mass, there are many of them, so they present a large total surface area in the alveoli of the lungs. Once bound to the alveoli, they may induce oxidant production, lung inflammation, and hyperactivity. Of particular concern are the effects of organic matter and transition metals, such as iron, attached to the particles surface, which could react with cell membranes, proteins, and cell receptors. The EPA is currently evaluating the particulate standard and a new one will be published in November, 1996 to take effect in 1997 (Reichhardt 1995).

On a nationwide basis, PM-10 levels have dropped approximately 20 per cent from 1988 through 1993. Overall PM-10 emissions have dropped approximately 10 per cent for the same time period, primarily as a result of diesel emissions controls from heavy-duty trucks (34 per cent decrease). Other important sources in this area are fugitive dust emissions, wind erosion, and wildfires and managed burning, all of which have a high year-to-year variability (Curran 1993).

3.2.2 Statewide Trend

Florida's ambient air quality standard for PM-10 is a 24-hour mean of 150 $\mu g/m^3$ and an annual arithmetic mean of 50 $\mu g/m^3$. The 24-hour standard is attained if the average number of expected exceedances per year, over a three-year period, is less than or equal to one. The Florida inhalable particulate matter monitoring network started with 14 monitoring sites in 7 counties in 1989, and consisted of 70 monitoring sites in 22 counties in 1992. There were no exceedances of the standards in 1992, and concentrations were generally less than 50 percent of the 24-hour standard and less than 70 percent of the annual standard (FDEP 1992). Since the state began changing its sampling network from TSP to PM-10 after 1987, there are insufficient data available to determine PM-10 trends (FDER 1992).

3.2.3 KSC Trends

Monitoring of inhalable particulates (PM-10) at KSC began in 1983 using a dichotomous sampler through 1989, and monitoring with a high-volume sampler fitted with a size-selective inlet (SSI) started in 1992. These methods were both certified as equivalent by EPA. Monthly maximum 24-hour values ranged from 56.1 $\mu g/m^3$ in 1983 to 131.4 $\mu g/m^3$ in 1988. The highest value in the last three months of 1992 was 38.5 $\mu g/m^3$ (Table 3.b)(Figure 5). The Kendall's K trends

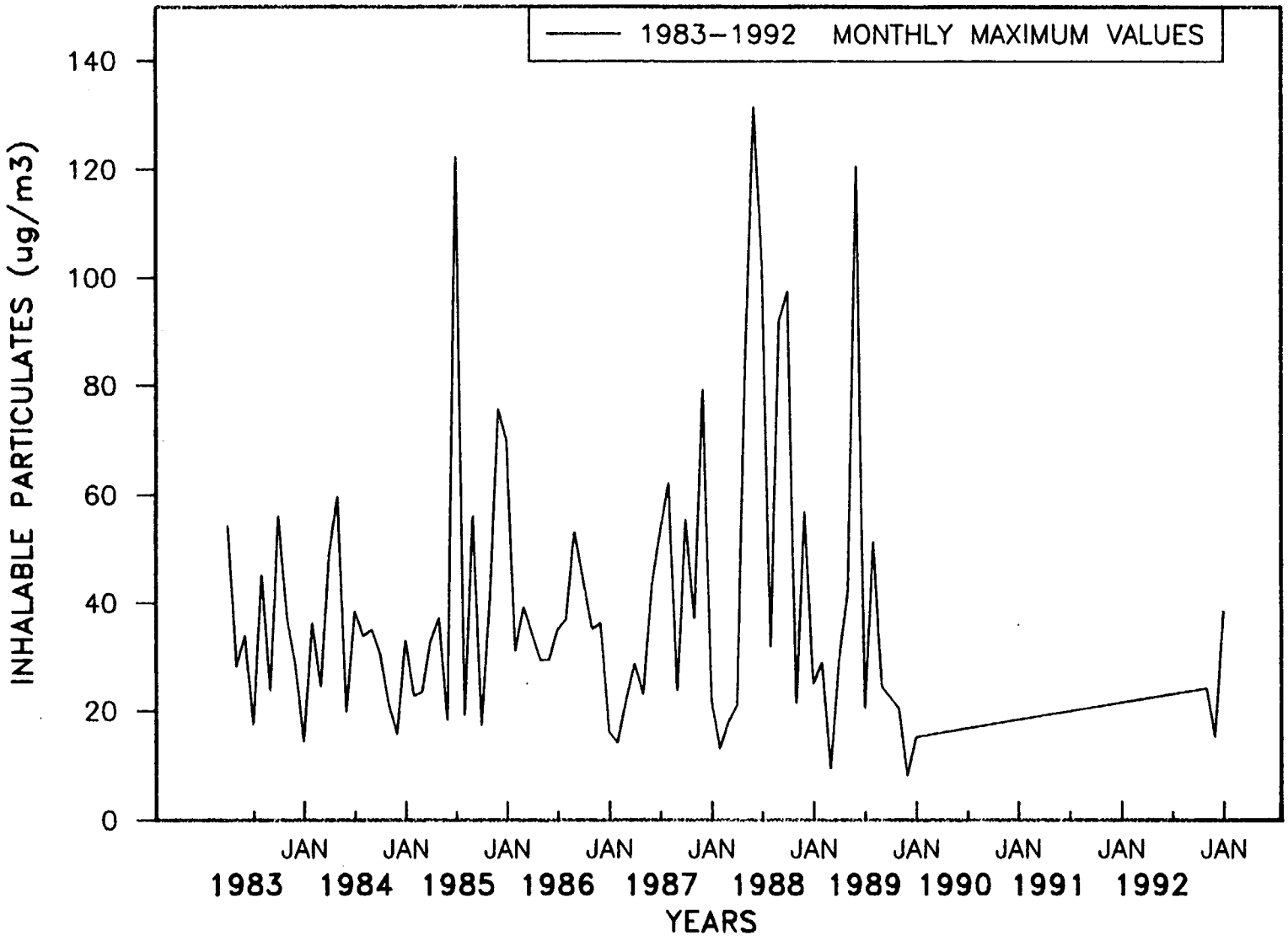

Figure 5. Monthly Maximum Inhalable Particulates (1983-1992).

test yields a non-significant minor trend of -0.011 (p=0.2578).

A plot of monthly means shows that levels increase from January (18.6 $\mu g/m^3$) to a maximum in June (37.7 $\mu g/m^3$), and then decreases through December (19.1 $\mu g/m^3$) (Figure 6). The means for January, February, and December are lower than the June and July means. This pattern of monthly means is in direct contrast to the TSP plot in Figure 2 discussed previously, since the TSP peaks occurred February through May.

An Analysis of Variance test was performed on the PM-10 data set to define statistically significant differences. The data was first log-transformed to normalize the distribution and to achieve homogeneity of variances. There was no significant difference between the months of the year, but there was a significant difference between years (α=0.05).

The plot of PM-10 annual averages at KSC with 95% confidence intervals from 1983 through 1989 and 1992, show no apparent trend, either up or down. The maximum second-highest value for KSC (102.6 $\mu g/m^3$) in 1988 is much higher than the state maximum (60.0 $\mu g/m^3$) in 1990. However, the state values for 1989 and 1990 (45.3 $\mu g/m^3$, 45.8 $\mu g/m^3$) are both higher than the previous years' KSC annual means (22.9 $\mu g/m^3$) for 1983 though 1989 (Figure 7).

There is some interest in the ratio of PM-10 to TSP and its seasonality as it applies to an area's attainment

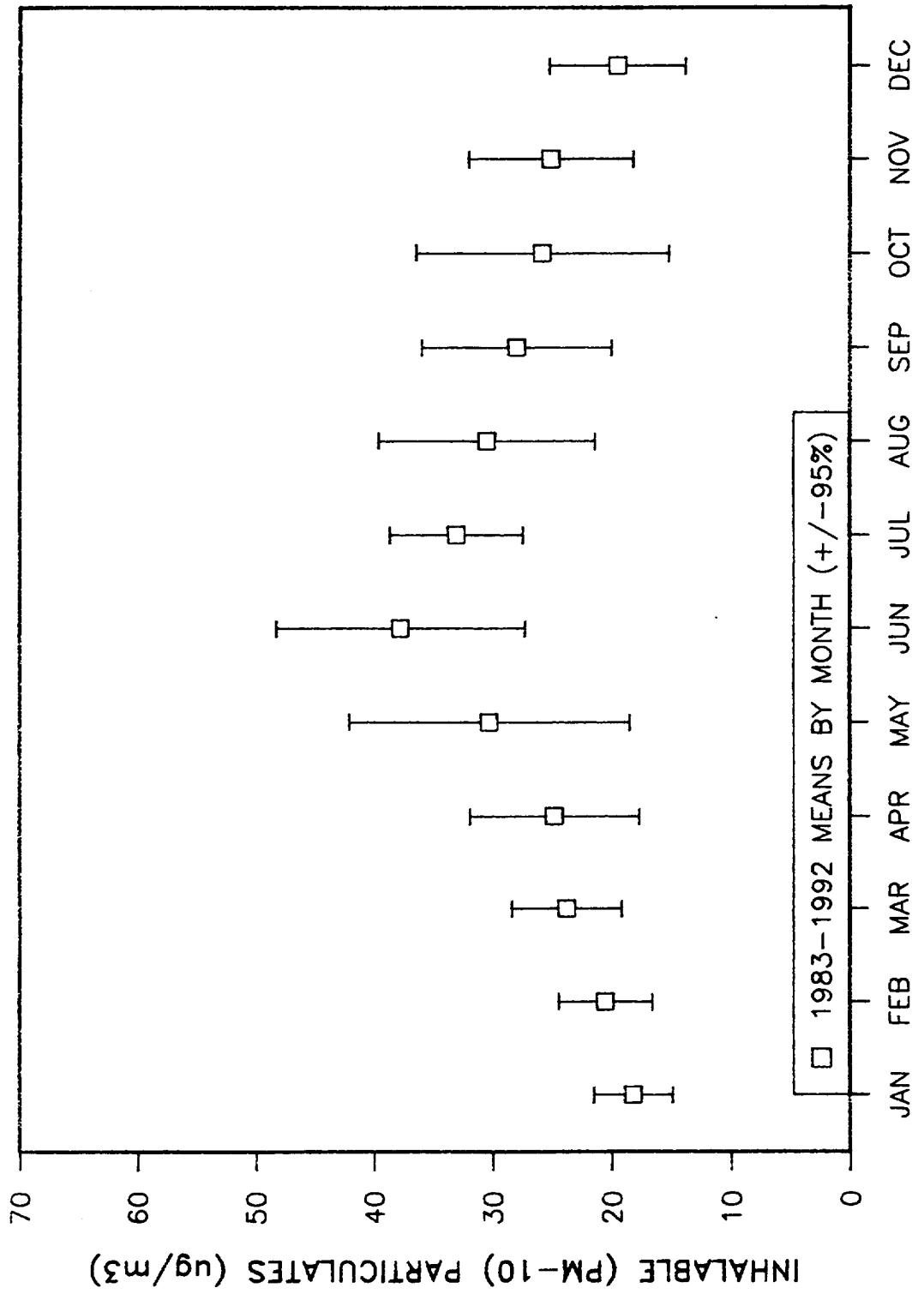

Figure 6. Composite Monthly Means Of Inhalable Particulates (1983-1992).

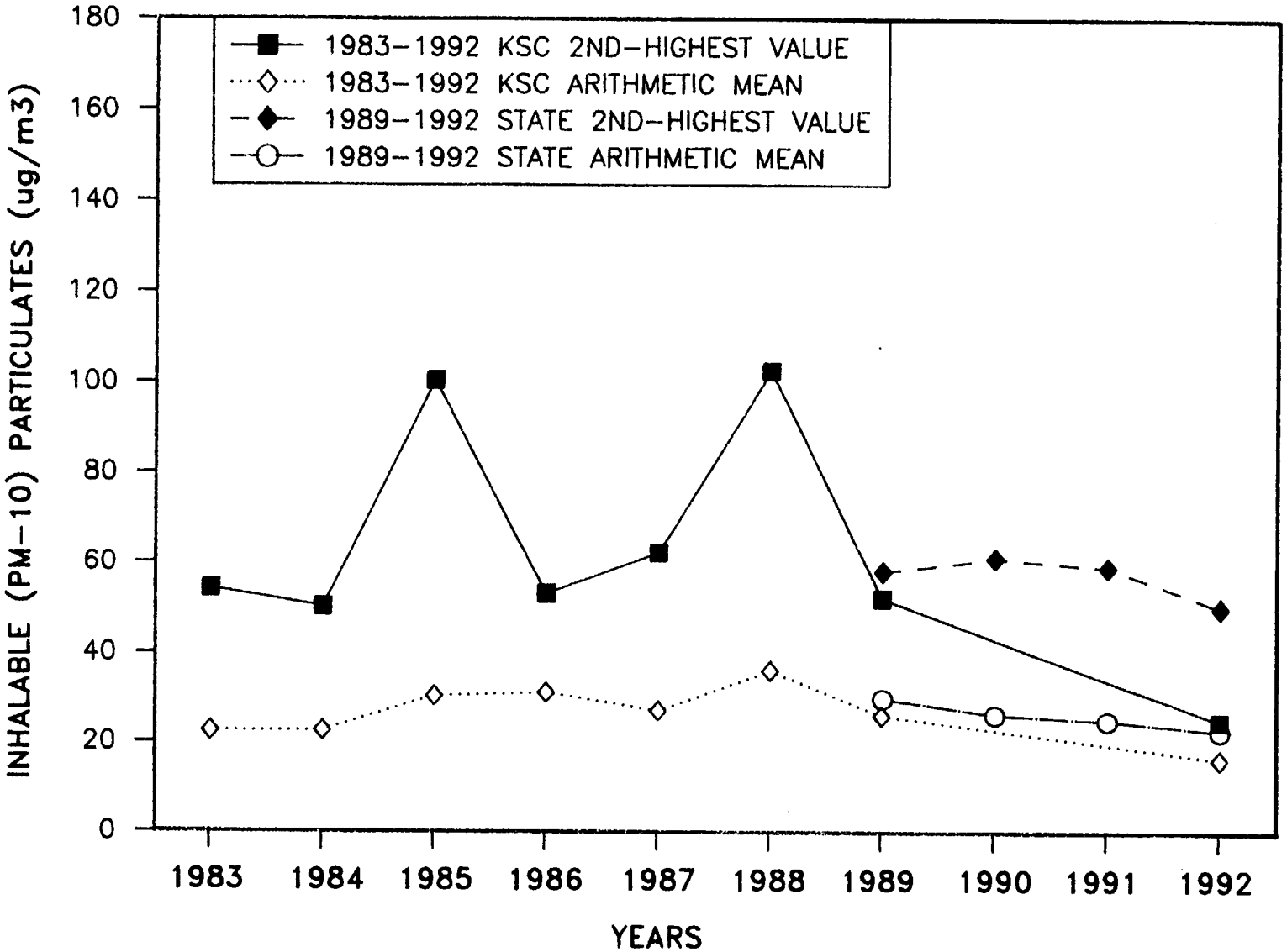

Figure 7. Comparison Of Inhalable Particulates At KSC And Statewide (1983-1992).

status. The overall ratio at KSC is 0.53 which is larger than the ratio of 0.47 derived from a 900 sample study performed in 1982-1983. Another study performed in 1987 found that the ratio for EPA's Region IV was 0.63. Summer was found to be the season with the highest ratio in the East, which could be from increased photochemical particulates and sulfates (Berg 1990). The ratio at KSC is also highest in the summer (0.66), compared to an average of 0.50 for the rest of the year.

4.0 Sulfur Dioxide

Sulfur forms a number of oxides but only sulfur dioxide (SO_2) and sulfur trioxide (SO_3) are of any importance as gaseous air pollutants. Sulfur trioxide is generally emitted at about one to five per cent of the SO_2 concentration and it rapidly combines with water vapor to form sulfuric acid mist (H_2SO_4), which is associated with atmospheric haze and poor visibility (Urone 1976).

4.1 Background

Sulfur dioxide is a colorless gas with a pungent, irritating odor, and most people can detect it by taste at 0.3 to 1.0 parts per million (ppm) (780 to 2620 $\mu g/m^3$) (Urone 1976). It is emitted into the atmosphere mainly as a result of volcanoes by nature and by combustion of sulfur-

laden coal and oil by man. In the atmosphere, it is partially converted by photochemical and catalytic reactions to sulfur trioxide, sulfuric acid, and sulfate particles, which can also have adverse health and welfare effects (FDEP 1992).

Sulfur dioxide is a pulmonary irritant of the upper respiratory tract, whereas sulfate particles can penetrate deep into the lung and either stay as metallic sulfates or become converted into sulfuric acid droplets (Williamson 1973). Sulfur dioxide can also damage plants like lettuce and spinach, and building materials like metals and limestone and marble (Wark and Warner 1976).

Meteorological conditions favor the formation of clouds which improves the visibility, but these clouds can produce acid rain. Rainfall in Florida has been measured as six to twelve times more acidic than geochemically pure rainfall. The rainfall in the northern part of the state is about twice as acidic as the southern part, with sulfuric acid accounting for 65 percent of the acidity and nitric acid supplying most of the rest. The resulting acidic rainfall can cause environmental stress to the aquatic and terrestrial ecosystems, both flora and fauna (FDEP 1992).

Globally, man-made emissions of SO_2 account for about one-third of the total sulfur compounds emitted. The rest are hydrogen sulfide from decay of organic matter or sulfate particles from sea-spray (FDEP 1992). The major anthropogenic sources of SO_2 are the combustion of coal and

oil at an estimated level of 146 X 10^6 tons per year. The atmospheric background concentration is 0.52 $\mu g/m^3$ and the calculated atmospheric residence time is 4 days. The removal reactions and sinks are the oxidation to sulfate by ozone or, after absorption, by solid and liquid aerosols (Robinson and Robbins 1972). The background SO_2 concentration in Florida is estimated to be approximately 10 $\mu g/m^3$ (0.004 ppm). This level is lower than other areas of the eastern United States due to lower space heating emissions and ventilation from prevailing winds (FDEP 1992).

Nationwide, the sulfur dioxide trends from 1984-1992 show a 23 percent decrease of the annual arithmetic means at 474 sites from 0.0100 ppm to 0.0077 ppm. The 24-hour second high at 469 sites shows a 36 percent decrease from 0.047 ppm to 0.029 ppm. For the same time period, sulfur oxides emissions show a six percent decrease from 21,225 to 19,857 thousand metric tons per year (Curran 1993).

4.2 Statewide Trends

Florida's ambient air quality standards for sulfur dioxide are 60 $\mu g/m^3$ (23 ppb)(annual arithmetic mean), 260 $\mu g/m^3$ (100 ppb)(24-hour average), and 1300 $\mu g/m^3$ (500 ppb)(3-hour average) not to be exceeded more than once per year (FEDP 1992).

The sulfur dioxide monitoring network in Florida ranged from 58 monitoring stations in 20 counties in 1983 to 33

monitoring stations in 14 counties in 1992. Escambia County had the highest reading of the second-highest 3-hour standard of 1016 $\mu g/m^3$, or 78 percent of the standard. It also had the highest reading of the second-highest 24-hour average of 182 $\mu g/m^3$ (70 percent of standard), and annual average of 22 $\mu g/m^3$ (36 percent of the standard). Statewide, there were no other counties with monitors measuring greater than one-half of the state standard. Considering an analysis of annual SO_2 concentrations for the period 1983-1992, no statewide trend can be established, but three monitors in Duval County did show a downward trend (FDEP 1992).

4.3 KSC Trends

Monthly maximum 24-hour KSC SO_2 averages have decreased each year from 135.2 $\mu g/m^3$ in 1983 to 33.8 $\mu g/m^3$ in 1992 (Figure 8). The test of the Kendall's K trends statistic yields a significant minor trend of -0.1536 ($p=0.0096$). The highest 24-hour SO_2 average each year, ranging from 187.9 $\mu g/m^3$ to 26.1 $\mu g/m^3$, was higher than values for all other state monitoring locations on the east coast of Florida except Duval and Nassau counties (1982 to 1992), Broward County ('83), Volusia County ('88), and Orange County ('88). High KSC values may have been caused by downwash plumes from the two oil-fired power plants on the west shore of the Indian River to the southwest.

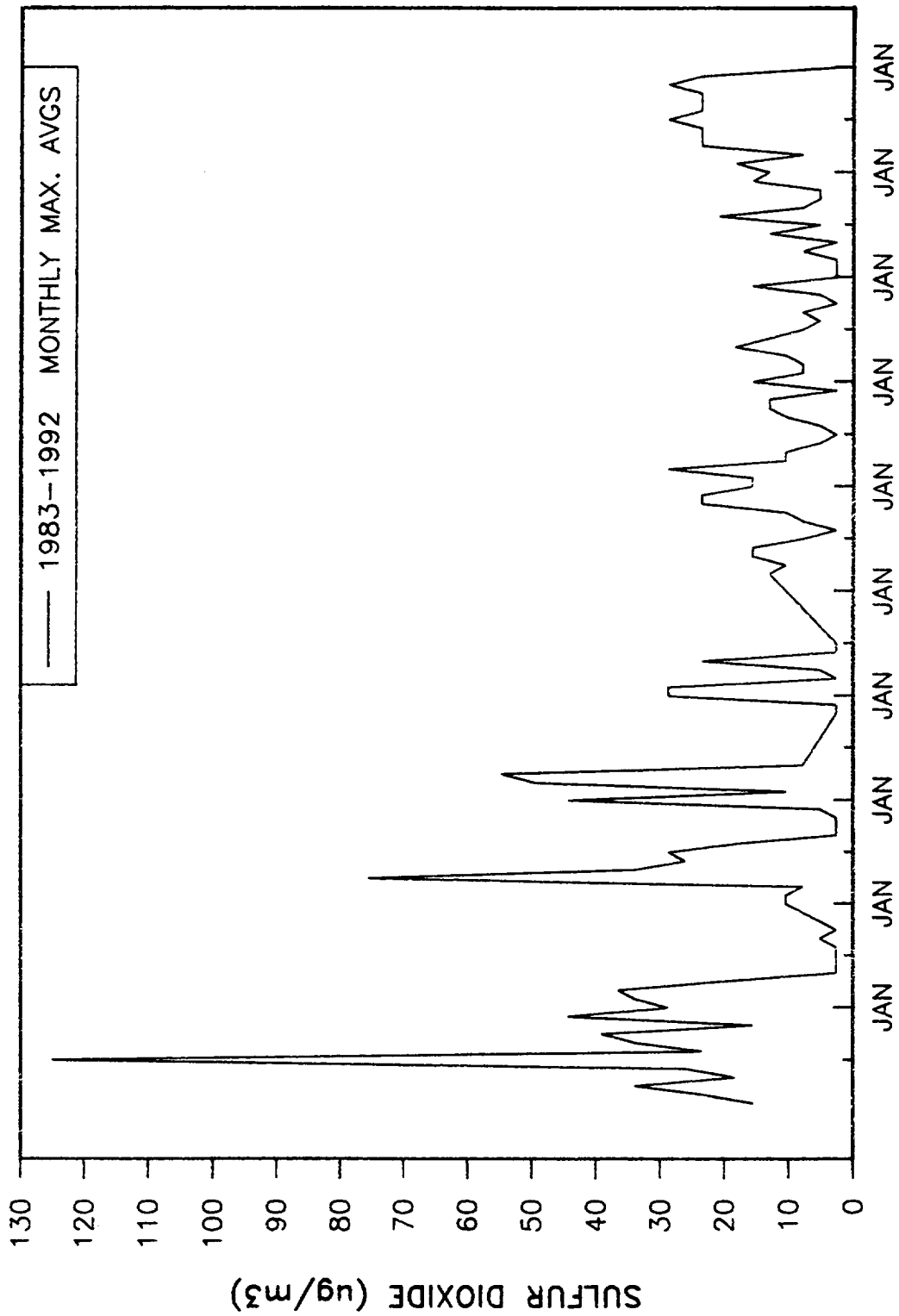

Figure 8. Monthly Maximum Sulfur Dioxide Averages.

The 10-year means of the monthly maximum 1-hour averages for March and June are higher and have much greater deviation about the mean than the rest of the months, which are fairly consistent (Figure 9).

The second highest 24-hour average SO_2 levels (regulatory level not to exceed 260 $\mu g/m3$ more than once per year) were lower than the reported statewide nine-station composite averages for each year except 1983 and 1985 (Figure 10). The KSC data show a decreasing trend from 120 $\mu g/m3$ in 1983 to 21 $\mu g/m3$ in 1990, followed by an increasing trend to 31 $\mu g/m3$ in 1992. In comparison, there was no clear statewide trend as values dropped from 103 $\mu g/m3$ in 1983 to 78 $\mu g/m3$ in 1985, increased to 106 $\mu g/m3$ in 1987, and finally decreased to a constant level of 83 $\mu g/m3$ in 1989 and 1990. Since the KSC values of SO_2 are lower than the state values and are decreasing, air quality (in terms of SO_2) at KSC is good.

5.0 Nitrogen Dioxide

Nitrogen forms the very stable diatomic gas, N_2, which makes up over 78 percent of the atmosphere and it forms a large number of gaseous and non-gaseous compounds essential to living matter. These compounds are produced by bacterial fixation, biological growth and decay, lightning, and forest and grassland fires (Urone 1976). Nitrogen forms many oxides, but only three are normally found in the atmosphere

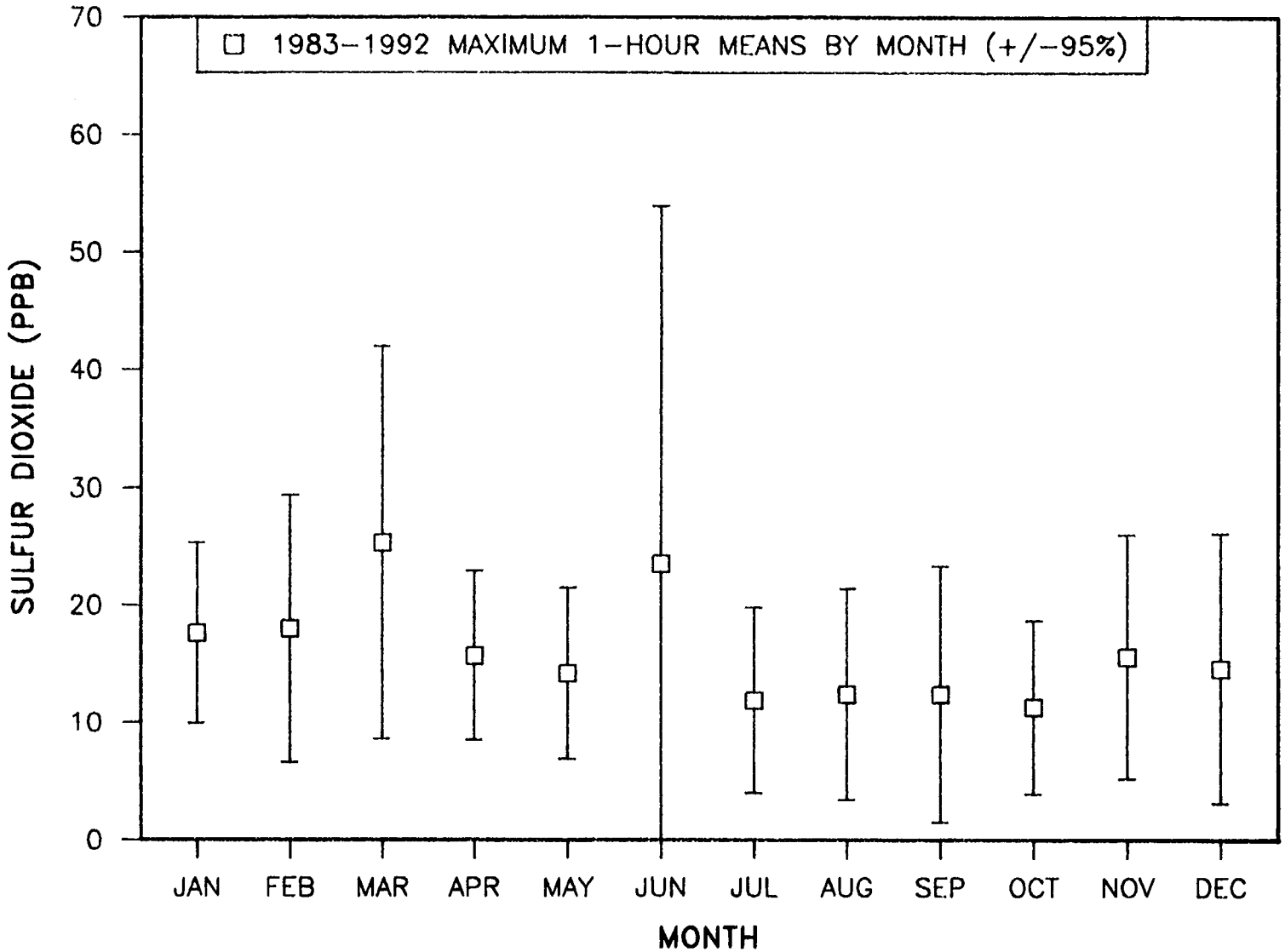

Figure 9. Composite Monthly Means Of Maximum 1-Hour Sulfur Dioxide Averages (1983-1992).

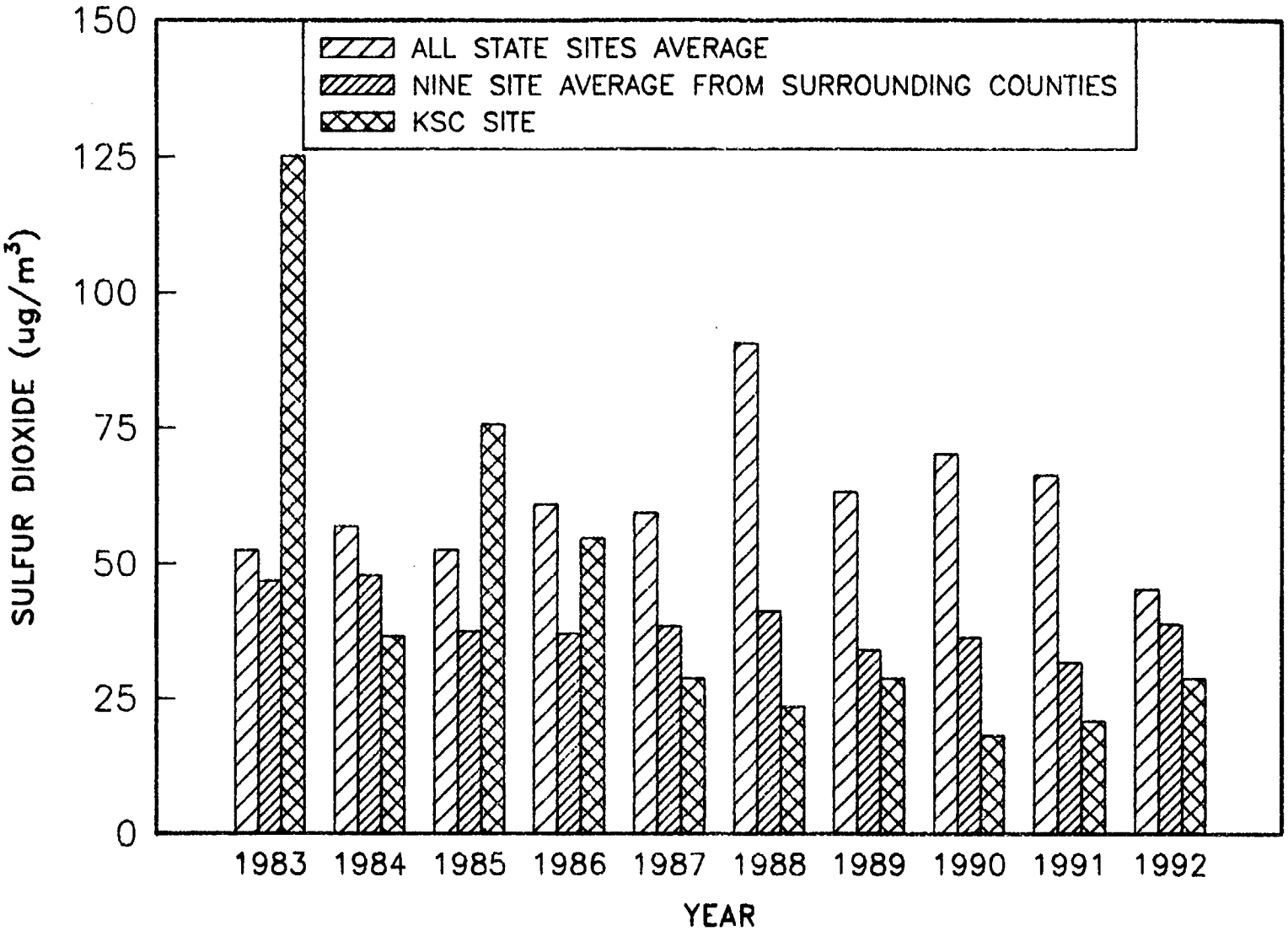

Figure 10. Comparison Of Second-Highest 24-Hour Sulfur Dioxide Averages At KSC And Surrounding Counties.

in any quantities. These are nitrous oxide (N_2O), nitrogen oxide (NO), and nitrogen dioxide (NO_2).

5.1 Background

Nitrous oxide (laughing gas), is a colorless, slightly sweet, nontoxic gas with anesthetic qualities found in the atmosphere in relatively large amounts (0.25 ppm). It is formed from biological activity in the soil and possibly the oceans (Urone 1976). A nitrous oxide worldwide production rate of 10^8 metric tons per year and a residence time of four years has been estimated (Robinson and Robbins 1972).

Nitric oxide is a colorless, odorless, tasteless gas produced in nature by biological action and combustion processes. It is oxidized rapidly in air by atmospheric ozone and photochemical processes to form nitrogen dioxide. Worldwide natural emissions are estimated to be 390 X 10^6 metric tons per year with background concentrations ranging from 0.25 ppm to 6.0 ppm and a residence time in air of about 5 days (Robinson and Robbins 1972).

Globally, emissions of nitrogen oxides from natural sources are about 10 times greater than man-made sources. However, the man-made sources are more important as pollutants because they are produced in more populated areas (FDEP 1992). The major anthropogenic sources of NO_2 are combustion and vehicular exhaust (48 X 10^6 metric tons per year (mtpy)) and the major natural sources are bacterial

action in soil and fixation by lightning (597 X 10^6 mtpy). The atmospheric background concentration of NO is 0.4-4.0 $\mu g/m3$; NO_2 is 1.0-8.0 $\mu g/m3$ with a calculated atmospheric residence time of 5 days. The removal reactions and sinks are oxidation to nitrate after sorption by solid and liquid aerosols, and hydrocarbon photochemical reactions (Robinson and Robbins 1972).

Nitrogen dioxide is a pulmonary irritant that can cause increased pulmonary airway resistance at exposures of 0.7 to 5.0 ppm NO_2 for 10 to 15 minutes. The greater health potential is the photochemical conversion to ozone and its associated health effects. Neither NO nor NO_2 causes direct damage to materials but NO_2 can combine with moisture in the air to form nitric acid, which causes about one third of the acid rain in Florida (FDEP 1992).

Nationwide, the nitrogen dioxide trends from 1984 to 1992 show a 9 percent (0.023 ppm to 0.021 ppm) decrease in the annual mean for 201 sites. The nationwide emissions for the same time period show a one percent increase from 21,022 to 21,230 thousand metric tons per year. While fuel combustion emissions were three percent higher, the emissions from highway vehicles decreased by 11 percent (Curran 1993).

5.2 Statewide Trend

Florida's ambient air quality standard for nitrogen dioxide is 100 $\mu g/m3$ (0.050 ppm) annual arithmetic mean, which is identical to the Federal primary and secondary standard. In 1992, the nitrogen dioxide monitoring network in Florida consisted of 11 monitoring stations in eight counties, down from 27 stations in 10 counties in 1983. The highest annual average for 1991 was 30 $\mu g/m3$ at a site in Miami, and levels were found to be less than 35 percent of the standard throughout the rest of the state. There are insufficient data available in the Florida statewide network to determine any long-term (10-year) trends for NO_2, but four monitors have sufficient data to determine short-term (5-year) trends. There was no trend identified for the period 1988 through 1992 (FDEP 1992).

5.3 KSC Trends

The plot of monthly maximum NO_2 averages for 1983 through 1992 shows that there were significant peak values occurring in January, 1985 (58 ppb), June, 1986 (32 ppb), and March, 1989 (44 ppb)(Figure 11). The test of the Kendall's K trends statistic of the NO_2 annual averages yields a non-significant minor trend of -0.0561 (p=0.4641). The 10-year means of the monthly maximum 1-hour averages for January, March, and August were higher and had greater

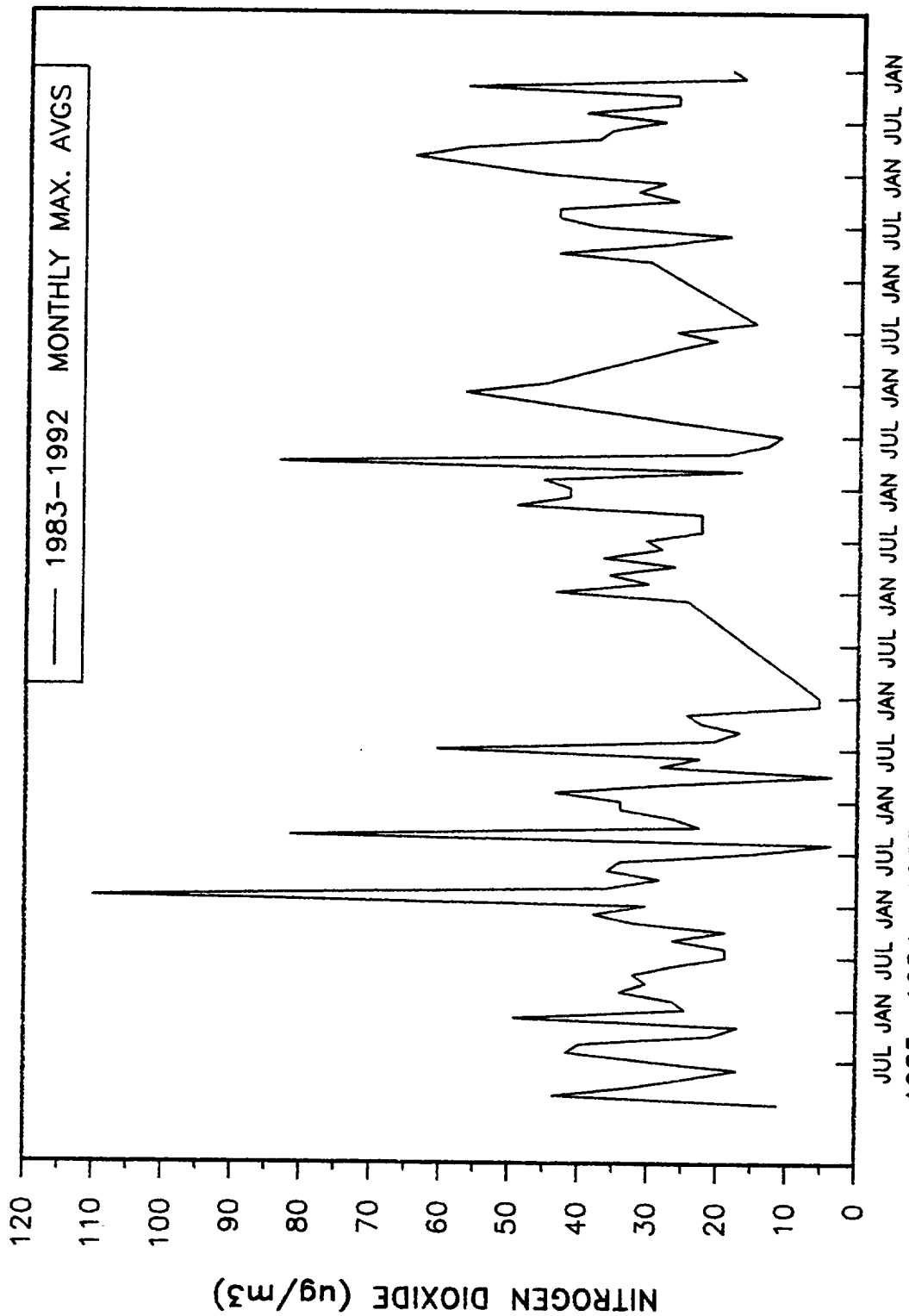

Figure 11. Monthly Maximum Nitrogen Dioxide Averages.

deviations about the mean than the rest of the months of the year. The month of September has the smallest deviation about the mean (Figure 12).

The estimated KSC NO_2 annual averages displayed a slight increase from 5.1 $\mu g/m3$ in 1983 to 5.9 $\mu g/m3$ in 1988, followed by a decrease to 4.5 $\mu g/m3$ in 1992, with an overall average of 5.1 $\mu g/m3$. These values were much lower than the statewide nine-station composite average values of 23.5 $\mu g/m3$ (Figure 13). The statewide values display no trend of increasing or decreasing NO_2 concentrations. The highest NO_2 annual average recorded in the state in this period was 56 $\mu g/m3$ in Tampa in 1983 and 1984. This was more than an order of magnitude greater than the 5.1 $\mu g/m3$ and 4.1 $\mu g/m3$ that occurred at KSC. Since the NO_2 concentrations are much lower than the state maxima, the air quality (in terms of NO_2) at KSC is good.

6.0 Carbon Monoxide

6.1 Background

Carbon monoxide is a colorless, odorless, and tasteless gas slightly lighter than air. Nature produces huge quantities of CO (2.7 to 581 X 10^9 metric tons per year) compared to 0.250 X 10^9 metric tons per year from worldwide anthropogenic sources. It is produced in nature as a result of photochemical oxidation of methane through an OH radical

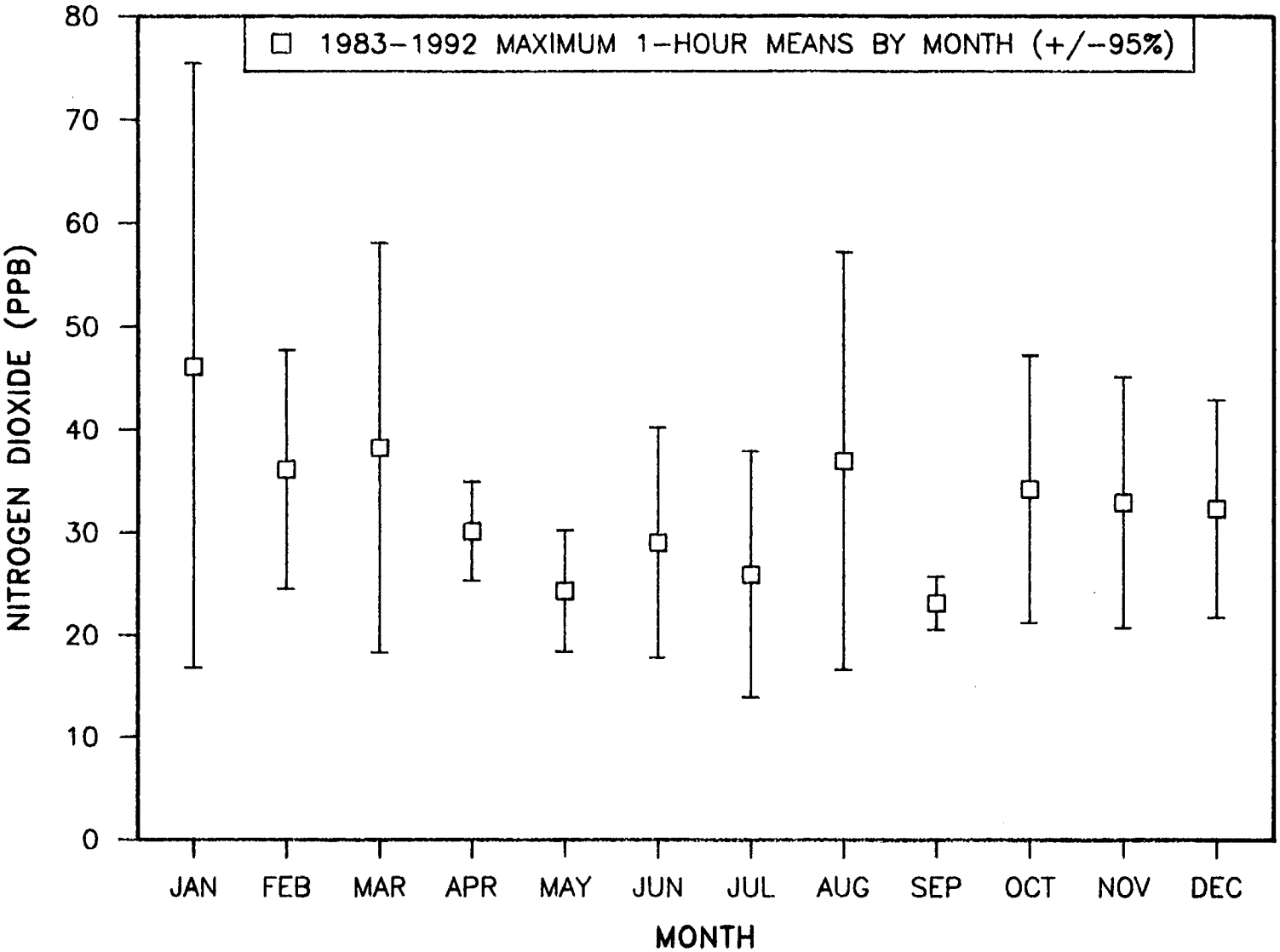

Figure 12. Composite Monthly Means Of Maximum 1-Hour Nitrogen Dioxide Averages (1983-1992).

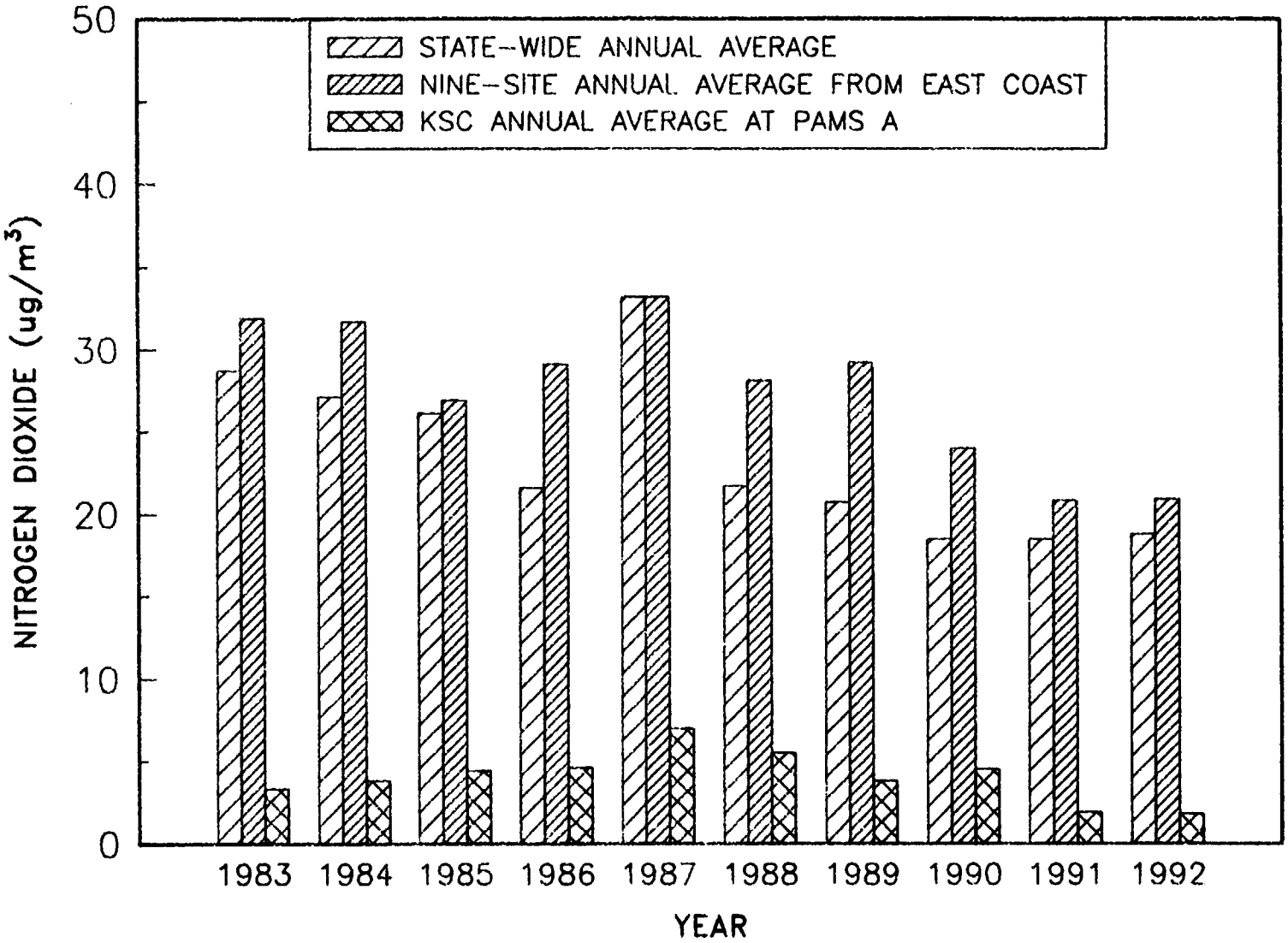

Figure 13. Comparison Of Annual Averages Of Nitrogen Dioxide At KSC, Statewide and East-Coast Sites.

mechanism, decomposition of chlorophyll in the fall (0.18 to 0.45 X 10^9 metric tons per year), volcanoes, natural gas, forest fires, and bacterial action in the oceans (0.14 X 10^9 metric tons per year) (Urone 1976).

The major anthropogenic sources of CO are automobile exhaust and other incomplete combustion at an estimated emission rate of 304 X 10^6 tons per year. Natural sources include forest fires, prescribed burns, oceans, and terpene reactions at an estimated rate of 30 X 10^6 metric tons per year. The atmospheric background concentration is 0.11 $\mu g/m^3$ with a calculated atmospheric residence time of between 2 to 6 months, on average. The removal reactions and sinks are probably soil organisms (Robinson and Robbins 1972). Estimates for removal processes are believed to be oxidation by OH radicals (>80 percent) and uptake by soils (<15 percent) (Khalil and Rasmussen 1984).

Studies of global trends of CO have shown an annual rate of increase of about 2 to 4 percent per year. However, there are large seasonal variations of plus or minus 50 percent per year with the highest concentration occurring in winter and lowest in summer, responding to the expected seasonal variation of OH radicals. The increased CO is believed to control the OH radicals, thereby reducing the yearly removal of dozens of natural and anthropogenic trace gases, including CH_4, CH_3Cl, CH_3CCl_3, and $CHClF_2$ (Freon-22), which may further reduce the atmospheric OH concentrations (Khalil and Rasmussen 1994).

Another global study showed that most concentrated CO sources (30 percent) are in the industrialized regions bounded by 30°N and 50°N, which is only 12 percent of the Earth's surface area. This study claims that CO is increasing world-wide at rates between one and two percent per year (Khalil and Rasmussen 1990). They give the annual tropospheric concentration to be about 90 ppbv, which corresponds to 380 teragram (tg) of CO in the atmosphere. They conclude that about 60 percent of the global production of CO is of anthropogenic origin.

A study of atmospheric CO concentrations in the Southern Hemisphere (Brazil) shows that CO concentrations in the wet season are about 3 to 4 times lower than the dry season. Also, the Atlantic coastal site had the lowest averages of 107 ppbv CO, whereas the Pantanal inland region shows averages of 262 ppbv and 317 ppbv. This is a region with much biomass burning (Kirchhoff and Marinho 1989).

Finally, an economic forecasting analysis was performed for large geographic regions for 1960, 1975, 2000, and 2025. The results showed that future global CO emissions from combustion are likely to decrease because of regulations in the developed nations and fuel-switching in the developing nations (Kavanaugh 1987).

Carbon monoxide kills more people directly than any other criteria pollutant. It competes with oxygen in the bloodstream to combine with hemoglobin and thus decreases

the amount of oxygen reaching the brain. The threshold limit value (TLV) is 25 ppm for an 8-hour day, and at 100 ppm most people will experience symptoms including dizziness, headaches, and lethargy (FDEP 1992).

A personal exposure study to carbon monoxide in Denver, Co. with 454 participants between the ages of 18 and 70 years old showed that: 1) the diurnal patterns for personal exposure were similar to the fixed site monitoring data, and 2) CO exposures in microenvironments associated with motor vehicles were higher than exposures without motor vehicles. The highest 1-hour CO concentration from the 15 fixed-site monitors was 44.1 ppm. The highest 8-hour CO concentration was 20.7 ppm, and five fixed-site monitors reported daily maximum 8-hour values exceeding 15.0 ppm. The personal exposures showed daily maximum 1-hour and 8-hour values of 10.3 ppm and 4.9 ppm, respectively. Finally, the mean indoor residential exposure was increased 2.59 ppm by gas stove operation, 1.59 ppm by smokers, and 0.41 ppm by attached garages (Johnson 1984).

A second, enhanced study reported that over 10 percent of residents in Denver, Co. and 4 percent of the Washington, D.C. residents were exposed to CO levels above 9.0 ppm for 8 hours during the study period. In both cities, the percentage of maximum daily 8-hour personal exposures exceeding the standard level of 9.0 ppm was considerably greater than the percentage of fixed-site 8-hour

measurements exceeding the standard level (Akland et.al. 1985).

Nationwide, the carbon monoxide trends from 1984 through 1992 at 314 sites show a 33 percent decrease in the 8-hour second high from 7.74 ppm to 5.16 ppm and a 91 percent decrease in the 8-hour exceedances (Curran 1993).

Florida's ambient air quality standards for carbon monoxide are 35 ppm, maximum one-hour average, and 9 ppm, eight-hour average, neither to be exceeded more than once per year. These standards are identical to the federal primary standards (FDEP 1992).

6.2 Statewide Trends

The carbon monoxide monitoring network in Florida has ranged from 28 monitoring stations in 8 counties in 1983 to 30 monitoring stations in 8 counties in 1992. The monitors are all strategically located in each of Florida's major urban areas. Of the 17 monitoring sites operating since 1983, nine have experienced a downward trend for CO. Over the last five years, three monitors have shown a downward trend. This trend analysis focuses on the 8-hour average results because the 8-hour standard is generally the more restrictive limit. In 1992, maximum CO concentrations at monitoring sites in Florida were, generally, less than 40 percent of the 35 ppm 1-hour standard and less than 50 percent of the 9 ppm 8-hour standard (FDEP 1992).

6.3 KSC Trends

Monthly maximum 1-hr CO averages at KSC decreased from an annual average of 6.18 $\mu g/m3$ in 1983 to 1.09 $\mu g/m3$ in 1988, and has been increasing since that time to 1.28 $\mu g/m3$ in 1992. There was an overall 8 percent decrease in the CO monthly maximum 1-hour averages over the 10-year period (Figure 14). There was an exceedance of both the primary and secondary standards due to a controlled burn by the USFWS on November 6, 1983. The 1-hour standard of 35 ppm was exceeded by a minimum value of 50 ppm, and the 8-hour standard of 9 ppm was exceeded by a minimum value of 32 ppm. Accurate values were indeterminable since the instrument was "pegged" for 5 hours at >50 ppm (Drese 1983). Other significant peaks include 3.17 $\mu g/m3$ on May 15, 1985; 4.92 $\mu g/m3$ on January 13,1989; and 3.44 $\mu g/m3$ on November 18,1990. The test of the Kendall's K trends statistic of the CO 1-hour averages yields a non-significant minor trend of -0.0170 (p=0.490).

The 10-year means of the monthly maximum 1-hour means for January and July through November were higher than the rest of the months. January, August, September, and November have higher deviations than the rest of the months. March and April had the smallest deviations about the mean (Figure 15).

The state data show a decreasing trend in the 1-hour, 8-hour, and annual values from 1983 to 1992. The 1-hour and 8-hour data for KSC show fairly constant levels from 1983

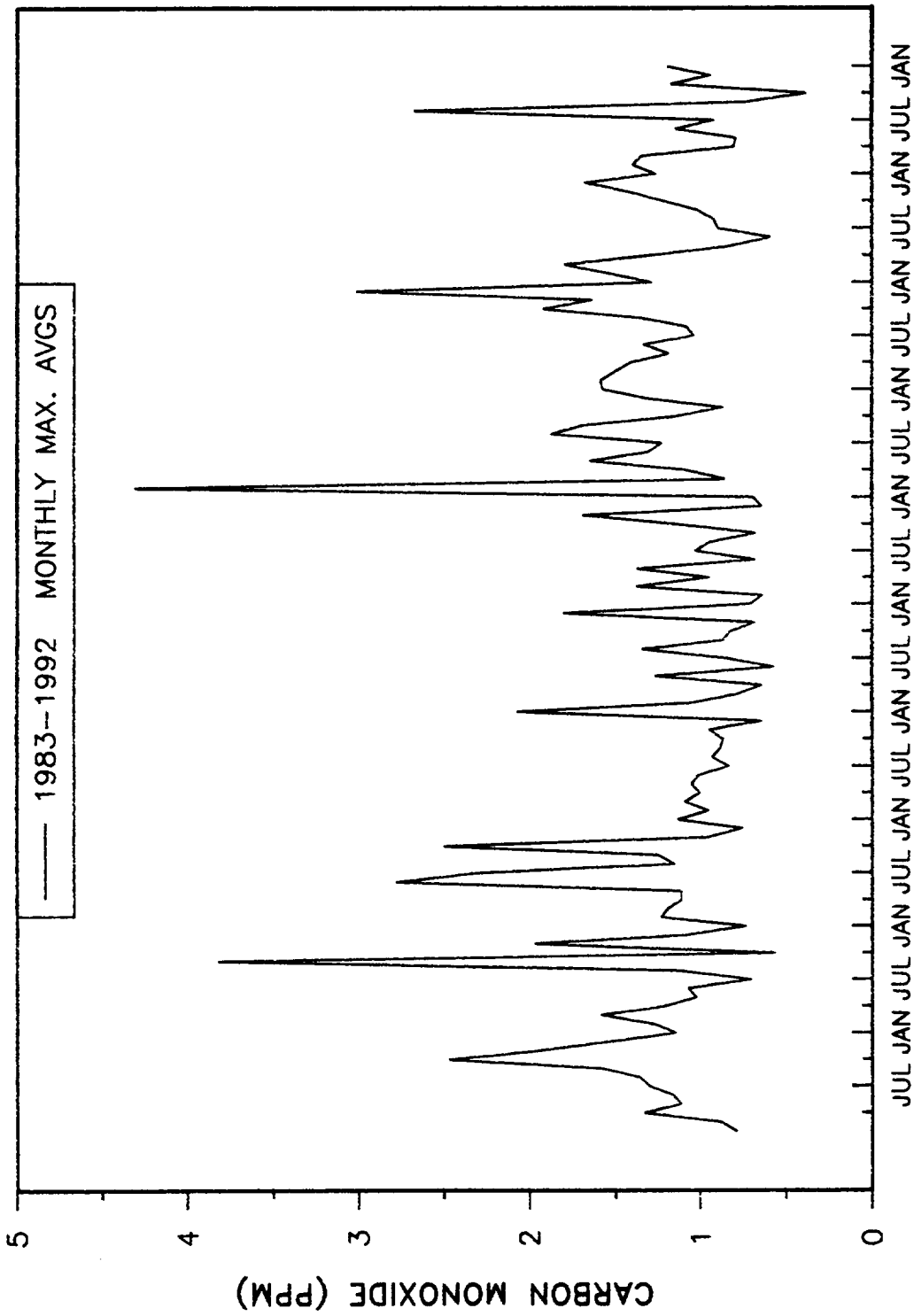

Figure 14. Monthly Maximum Carbon Monoxide Averages.

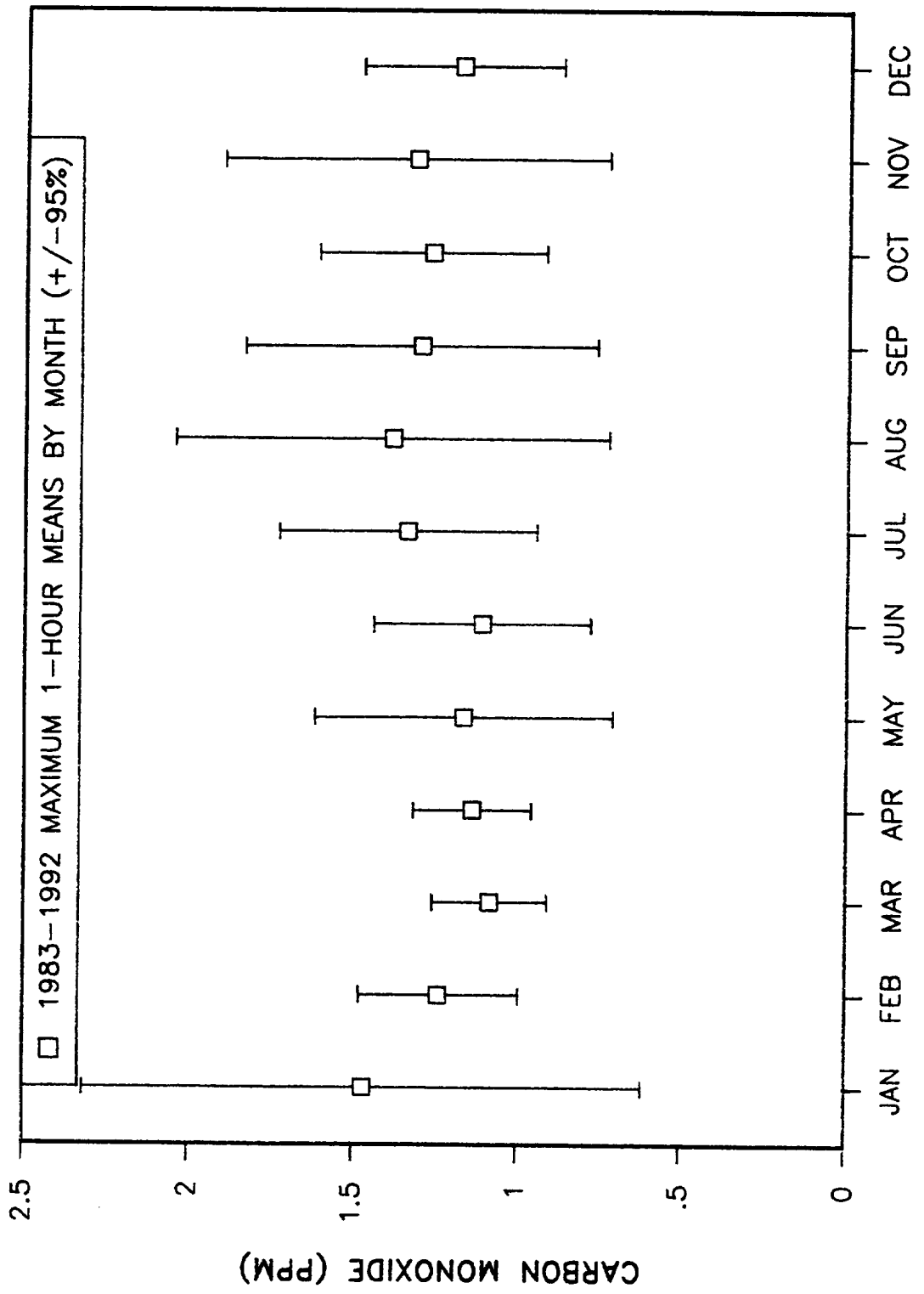

Figure 15. Composite Monthly Means Of Maximum 1-Hour Carbon Monoxide Averages (1983-1992).

through 1988, followed by increases in 1989, and decreases through 1992 (Figure 16).

7.0 Ozone

7.1 Background

Ozone is a highly reactive, bluish gas that is about 1.6 times as heavy as air; it is formed in nature in the upper atmosphere by photochemical reactions involving molecular and atomic oxygen. Its concentration is greatest in the stratosphere, about 0.20 ppm at an altitude of 20 km, and its concentration in rural areas is about 0.02 ppm. Very minor amounts are formed during lightning and thunderstorms (Urone 1976).

In the lower atmosphere, ozone is the predominant component of photochemical smog. Ozone is not emitted directly into the atmosphere, but results from photochemical reactions between NO_2 and volatile organic carbons (VOC's). This process begins shortly after dawn due to increasing sunlight and VOC emissions from vehicular traffic and once started, these reactions are sustained until the precursor pollutants are used up, or the intensity of sunlight decreases. During the night, ozone is depleted by chemical reactions in the atmosphere and at the ground (FDEP 1992). Night-time O_3 losses are apparently related to deposition and the presence of local nitric oxide (NO) sources with O_3

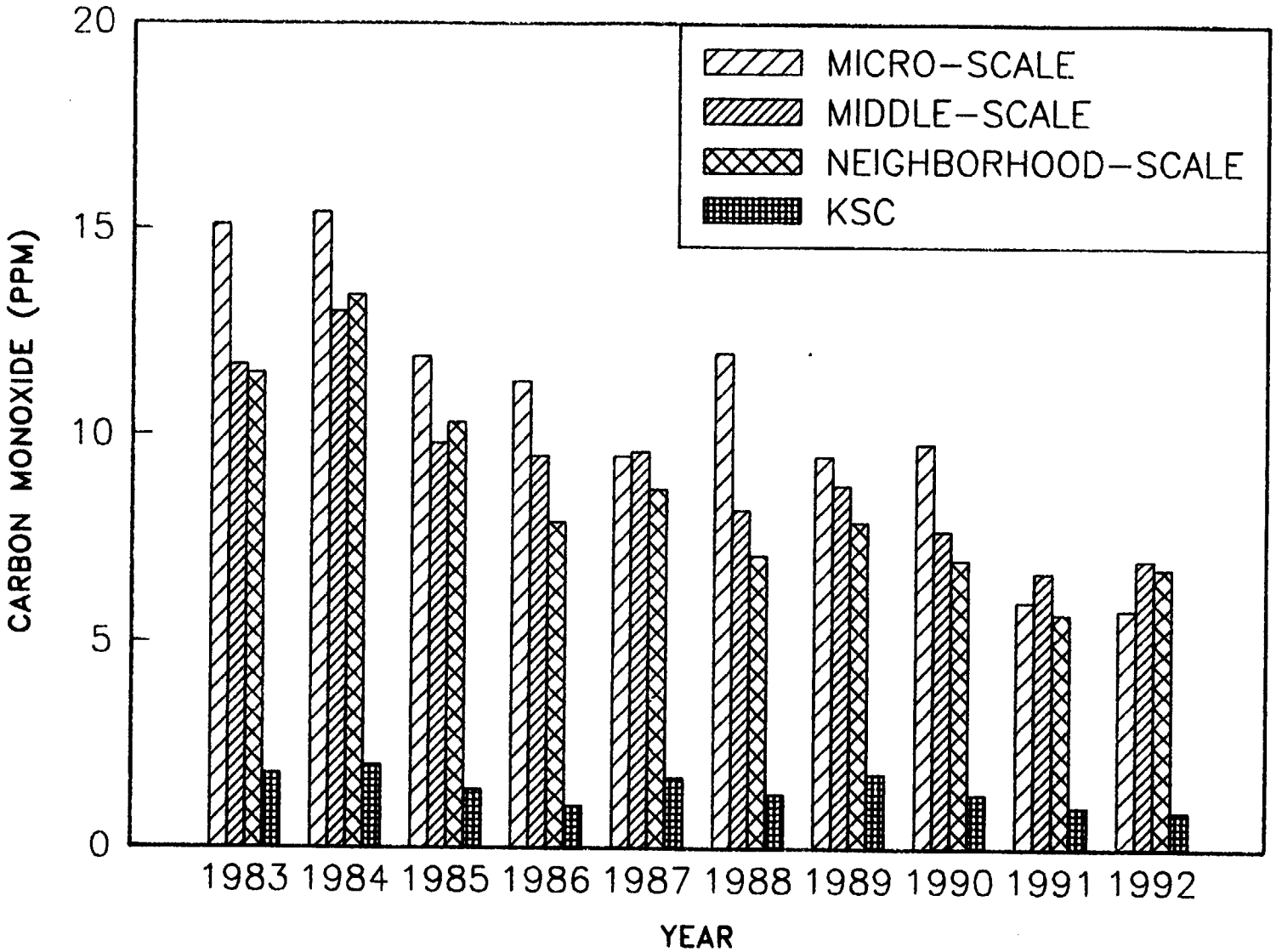

Figure 16. Comparison Of Annual Carbon Monoxide Averages At KSC And State Sites.

being consumed by the reaction: $NO + O_3 \rightarrow NO_2 + O_2$ (Meagher et al. 1987).

Ozone is a pulmonary irritant that affects the mucous lining, other lung tissue, and respiratory function and causes increased airway resistance and decreased ventilatory performance. These lung function changes can be accompanied by short-term symptoms that include sore throat, chest pain, cough, nose irritation, and headache (FDEP 1992). Ozone reacts rapidly with bioorganic compounds containing double bonds, such as structurally and functionally essential unsaturated fatty acids (Pryor et al. 1983; Menzel 1984 in Tilton 1989). Ozone will also react with sulfhydryl and amino groups that are found in enzymes and other essential proteins (Mudd 1969 in Tilton 1989).

Studies of attenuation to exposures to ozone show that lower-level exposures do not attenuate responses to higher-level exposures (Gliner 1983 in Tilton 1989). Other studies show that the time required for attenuation may be related to the magnitude of the concentration and the maximum decrements in lung function that occurred (Linn 1982 in Tilton 1989). Because ozone has been shown to affect several components of the host-defense system, decreased resistance to infection as a consequence of ozone exposure has been hypothesized. These effects include reduced or absent ciliary beating, delayed mucosiliary clearance, reduced viability and numbers of Alveolar macrophages, reduced interferon production, epithelial type I cell injury

followed by proliferation of type II cells (respiratory bronchitis), increased collagen in interalveolar septa or interstitium (mild fibrosis), and finally, structural changes in distal airways with bronchioles having thickened interalveolar septa and bronchial walls (EPA 1986 in Tilton 1989).

Ozone can also cause leaf injury or reductions in growth and yield of some plants. High levels can also cause degradation of synthetic rubber, cellulose in textiles, fading of fabrics, and paint weathering. Damage to ozone can result from prolonged exposure to low concentrations or short-term exposures to higher concentrations (FDEP 1992).

Globally, the maximum ozone concentration due to natural sources ranges between 0.02 ppm and 0.06 ppm. These sources include the photochemical reactions of VOC's from vegetation and downwash from the upper atmosphere. While high levels on the ground are primarily an urban problem, levels of 0.04 ppm can be transported to rural areas, and values as high as 0.10 ppm due to transport have been observed on days with wind blowing from areas of high VOC emissions (FDEP 1992).

Ozone was originally considered an urban pollutant with high concentrations occurring in or near large urban areas under conditions of high solar insolation and poor ventilation but is now recognized as a pollutant of regional (e.g., Wolff and Lioy 1980 in Meagher et al. 1987) and global (e.g., Routhier et al. 1980 in Meagher et al. 1987)

significance. The economic costs of widespread crop yield reductions as a result of O_3 exposure have been estimated at between \$2-3 X 10^9 annually for the United States (Adams and Crocker 1982; Shriner et al. 1982 in Meagher et al. 1987).

Rural O_3 levels are thought to be primarily influenced by two processes: 1) long-range transport of O_3 and its precursors from urban areas and large point sources such as fossil fuel power plants and, 2) downward mixing of stratospheric air. However, the results of a study of spring-time O_3 measurements at Giles, Tennessee support photochemistry and transport rather than direct downward mixing of stratospheric O_3 as the dominant influence (Meagher et al. 1987).

Aircraft studies have demonstrated (e.g., Davis et al. 1974; Miller et al. 1978; Luria et al. 1983 in Meagher et al. 1987) the formation of "ozone bulges" in plumes downwind of large power plants. Under favorable meteorological conditions, the NO_x emitted from the power plant can combine with hydrocarbons in the background air to produce plume O_3 levels significantly in excess of levels in the surrounding air (White 1977; Meagher and Luria 1982 in Meagher et al. 1987). Elevated O_3 levels have also been measured in aging smoke plumes from biomass burning. In addition, total annual O_3 exposure in rural areas can exceed urban exposure because of enhanced O_3 depletion at night in urban areas (Meagher et al. 1987).

Nationwide, the ozone trends from 1984 to 1992 show a 14 percent decrease in the average second-highest daily maximum 1-hour value from 0.126 ppm to 0.108 ppm at 532 sites. There has also been a 54 percent decrease in the number of exceedances at these same 532 sites. For this same time period, there has been a 10 percent decrease in VOC emissions from 23,199 to 20,884 thousand metric tons per year (Curran 1993).

A monitoring network of 25 stations called the Operational Evaluation Network (OEN) was established by the Electric Power Research Institute (EPRI) in the eastern United States over an area roughly 1500 X 1500 kilometers. Ozone monitors were deployed in 24 of these stations, since ozone plays an important role in the chemical transformations of both sulfur oxides (SOx) and nitrogen oxides (NOx). An analysis was performed on the data from the summer months (June, July, August) for 1988 and 1989. During 1989, less than 10 percent of the daily maximum values exceeded 80 ppb, and only five values (less than 1 percent) exceeded the NAAQS value of 120 ppb. However, more than 5 percent of station-wide maximum values were above 100 ppb in 1988, and 24 values were above 120 ppb. Results for summer 1988 and summer 1989 show distinct differences, both in the magnitude and in the spatial pattern of peak concentrations. Also, observed concentrations decreased from 1988 to 1989 at every site. Previous studies have shown the strong influence of meteorological factors on peak ozone values, and

synoptic-scale weather systems commonly extend over distances of 500 km or more. The frequent occurrence of multi-day high ozone episodes in the Northeast is further evidence of the importance of regional-scale transport (Londergan and McNaughton 1993). Also, measurements of ozone lifetimes in the troposphere have shown that the half-life of ozone above the nocturnal inversion layer (and away from sources of oxides of nitrogen) is 16 to 34 hours (Sickles et al. 1977 in Wight et al. 1978). An average of 29.4 hour lifetime was based on a series of aerial measurements (Wolff et al. 1977 in Wight et al. 1978). Half-lives of this magnitude clearly support the possibility of long-range transport (Wight et al. 1978).

7.2 Statewide Trends

The Florida ambient air quality standard for ozone is 0.120 ppm 1-hour average not to be exceeded as more than once per year, over a 3-year period, as a calculated expected exceedance value. This is the same as the federal standard (FDEP 1992).

The ozone monitoring network in Florida has changed from 27 monitoring stations in 14 counties (1983) to 38 monitors in 17 counties (1992). Most monitors in Florida have not exhibited any obvious trend over the last 10 years, but six monitors have shown a downward trend in the second highest ozone concentration recorded per year. In 1992,

three monitors that exceeded the 0.120 ppm standard and they were located in Escambia, Hillsborough, and Orange counties (FDEP 1992).

Studies have investigated the Hillsborough and Pinellas Counties' ozone formation and transport. In the presence of high solar insolation, nitrogen dioxide breaks down to form nitric oxide and atomic oxygen, the latter which can combine with atmospheric oxygen to form ozone. Ozone usually requires from 15 minutes to 3 hours to form, and normally, ozone would react with any nitric oxide but if hydrocarbons are present, they will compete with the ozone for the nitric oxide, which allows the ozone concentration to build (DER 1985 in Stowers et al. 1989).

Another study of the Pinellas County ozone transport looked at meteorological conditions that enhanced transport. It was found that the coastal circulation pattern consisted of two parts: first, a vertical looping with onshore surface motion during the day and an offshore surface motion during the night and, second, a horizontal convergence occurring over the Pinellas peninsula and divergence over Tampa Bay. Other findings were that ozone precursors tend to pool in areas of surface convergence. A long-range transport component is evident during the March through May time period from the west to northwest, and long-range transport can account for 60-80 ppb of the springtime ozone exceedances, but insignificant during the summer season. Additionally, ozone concentration gradients of 10 to 20 ppb

per 1.6 kilometer were indicated by the ozone isopleths implying that data collected at existing monitors may not be representative at distances greater than 3.2 to 4.8 kilometers from that monitor (Stunder et al. 1990).

7.3 KSC Trends

Of all of the criteria pollutants monitored at KSC, ozone is consistently high compared to the federal and state standard of 120 ppb maximum 1-hour average. The KSC ozone maximums have been increasing yearly from 1983 until 1989 (98, 101, 102, 109, 118, 129, and 134 ppb) and then decreasing through 1992 (118, 71, and 80 ppb)(Drese 1987). The plot of these monthly maximum 1-hour averages shows these increasing and decreasing values, as well as the decrease in the monthly means (Figure 17). The highest annual mean of 40.5 ppb occurred in 1988. The test of the Kendall's K trends statistic of the O_3 1-hour averages yields a significant minor trend of -0.156 (p=0.0058).

A plot of the means of monthly maximum 1-hour averages shows the typical bi-annual peaks in April, May, and October. The months of April and August have the largest deviation about the mean (Figure 18). Lower values June through August are due to reduced insolation, more cumulous clouds, numerous afternoon thunderstorms, and more active vertical mixing and dispersion (Chu 1987). The month of May

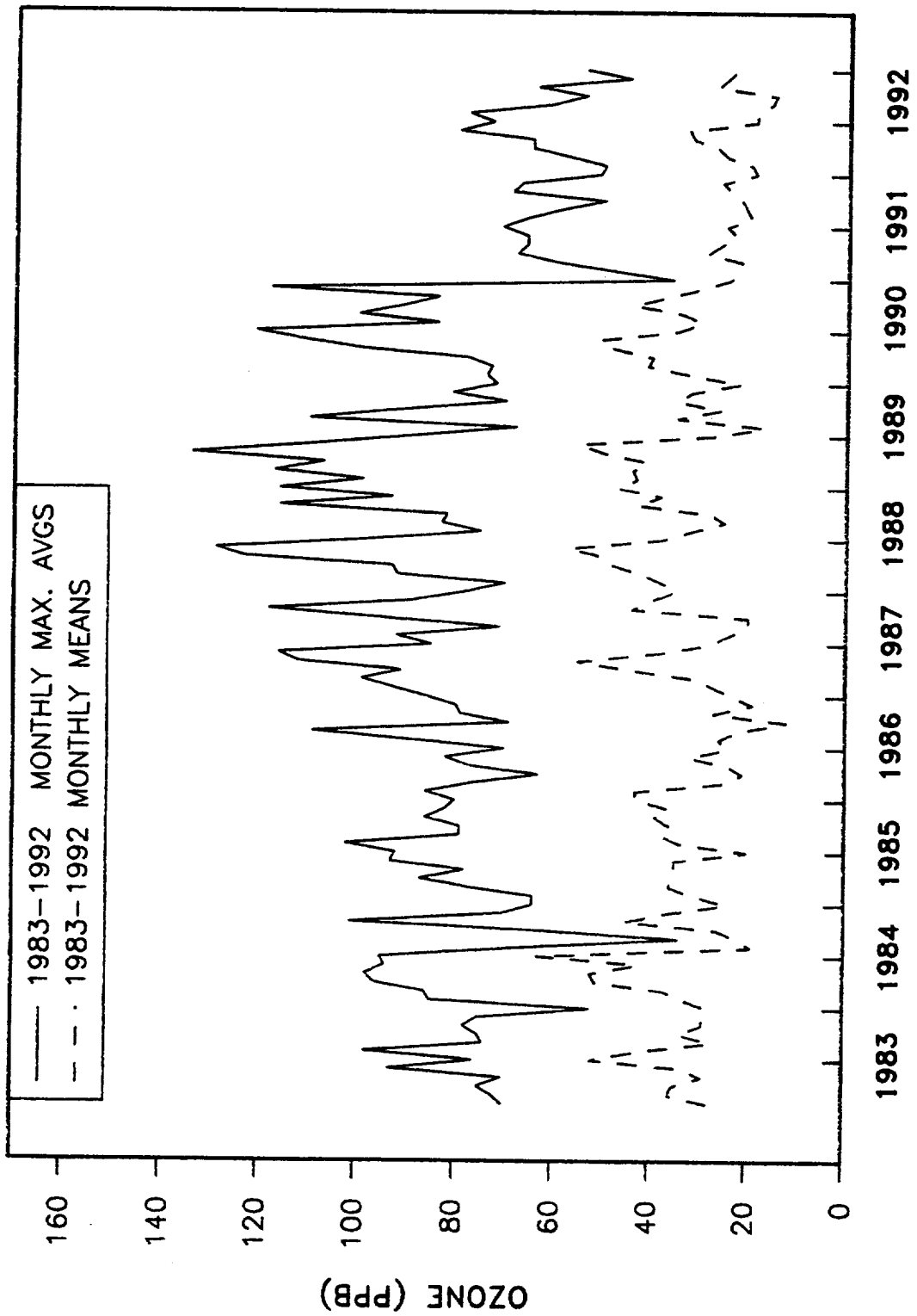

Figure 17. Monthly Maximum Ozone Averages.

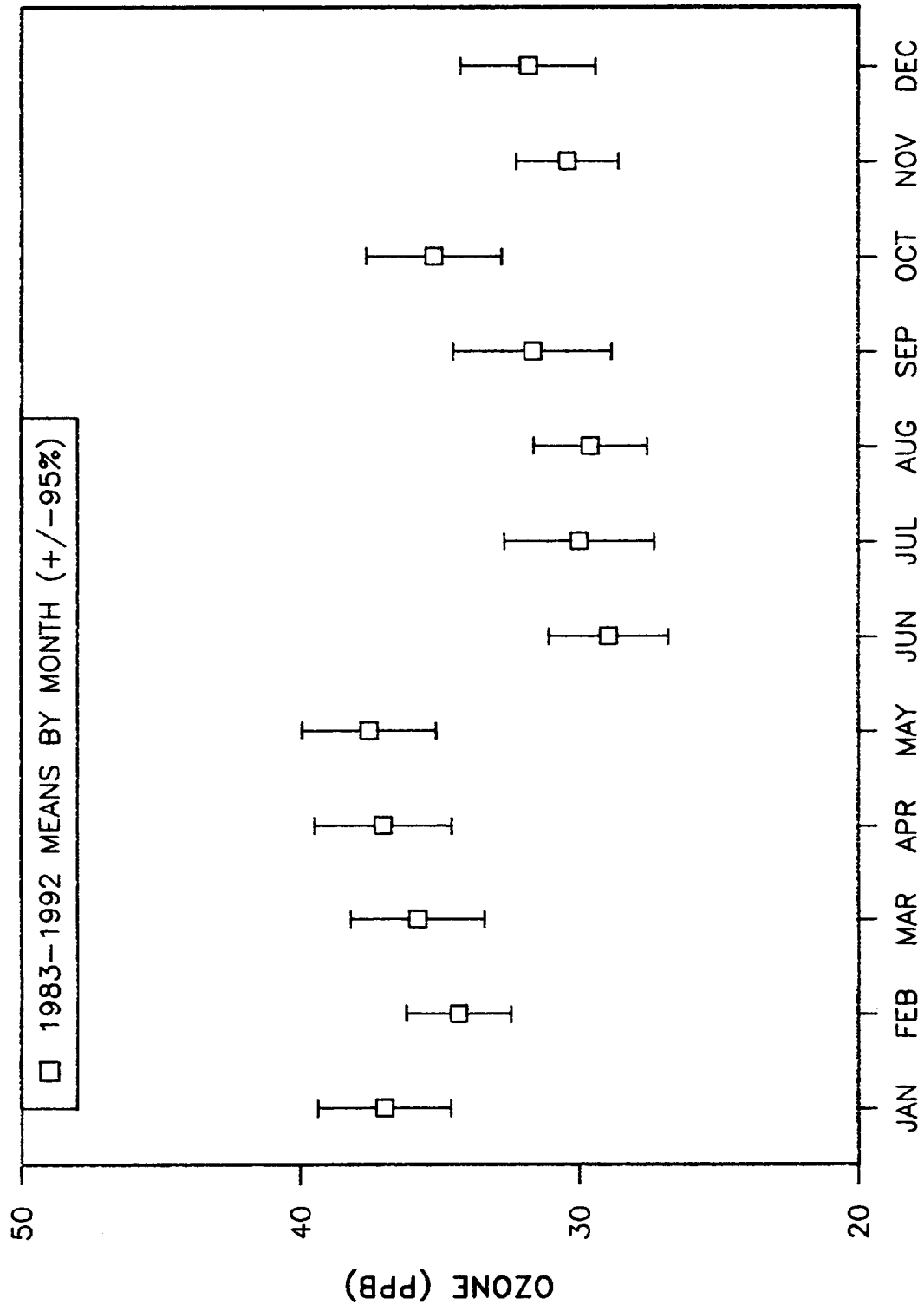

Figure 18. Composite Monthly Means Of Maximum 1-Hour Ozone Averages (1983-1992).

was found to be significantly (α=0.05) higher than July, using an Analysis of Variance test.

A plot showing the comparison of the maximum annual 1-hour KSC values of ozone to the mean of Brevard County and the other five non-attainment counties of the state (Orange, Palm Beach, Broward, Duval, and Hillsborough) shows that the KSC values have increased over the years from 25 percent of the state mean in 1983 to the highest (119 percent) compared to the state mean in 1989 (Figure 19). Maximum 1-hour O_3 concentrations (regulatory values) at KSC ranked in increasing order compared to the average of six statewide maximum values as follows: 1983 (84.5 percent), 1984 (91.5 percent), 1985 (95.4 percent), 1986 (96.0 percent), 1987 (97.0 percent), 1988 (114.4 percent), 1989 (119.4 percent), 1990 (116.7 percent), 1991 (74.7 percent), and 1992 (74.3 percent).

Minimum dilution roses are informative, and pollution roses can be invaluable in identifying sources and evaluating their impact on air quality (McCormick and Holzworth 1976). A pollution rose generated from the 10 years of monthly maximum averages displays the contribution of wind direction (potential sources) on the measured concentrations (Figure 20). While the highest frequency of winds yielding high-ozone values are from the east-south/southeast, north, and northeast, there is not a corresponding trend in the maxima per quadrant. The highest average ozone concentrations are from the northwest (105.0

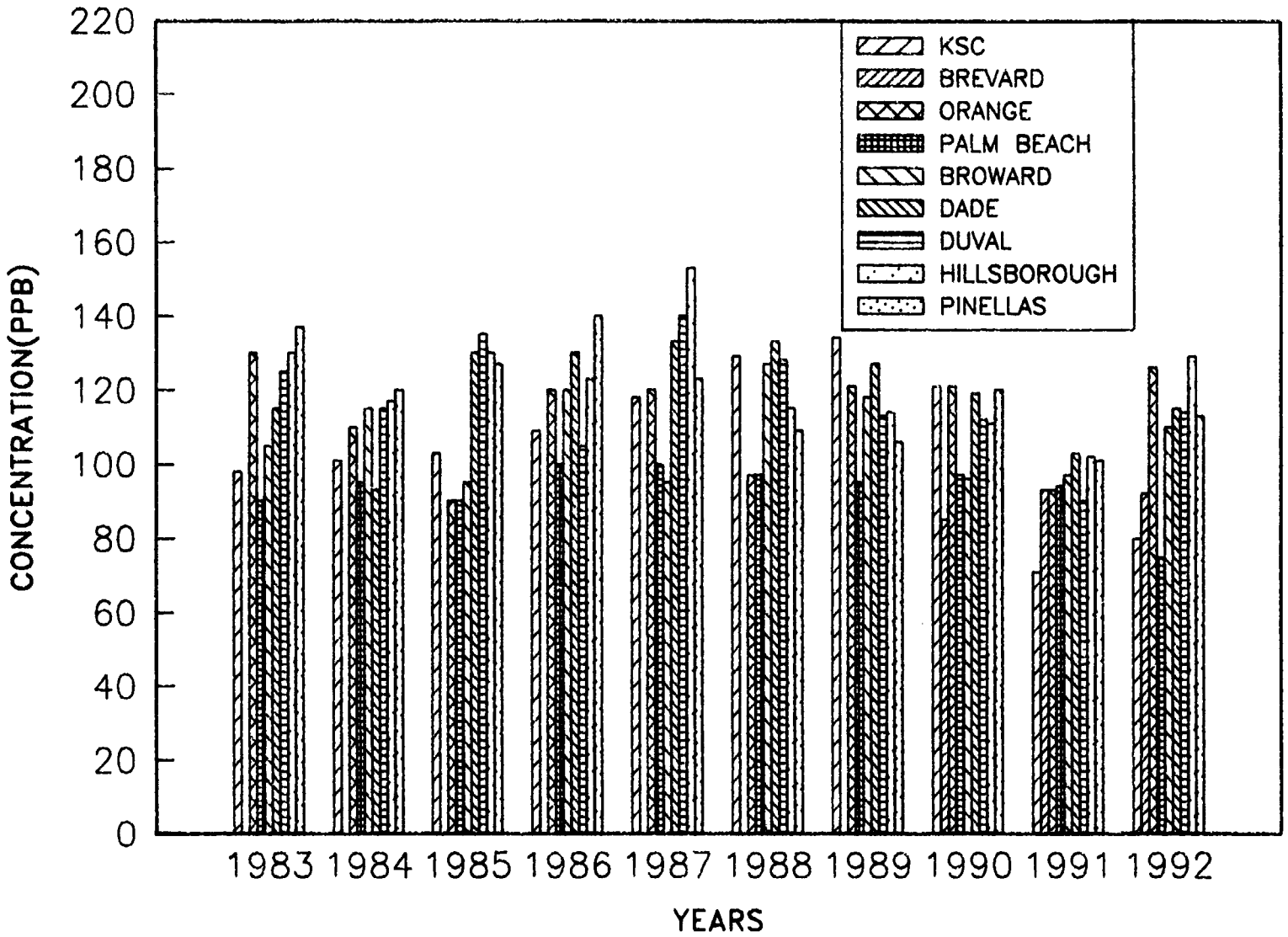

Figure 19. Comparison Of Annual Maximum Ozone 1-Hour Averages At KSC And Surrounding Counties.

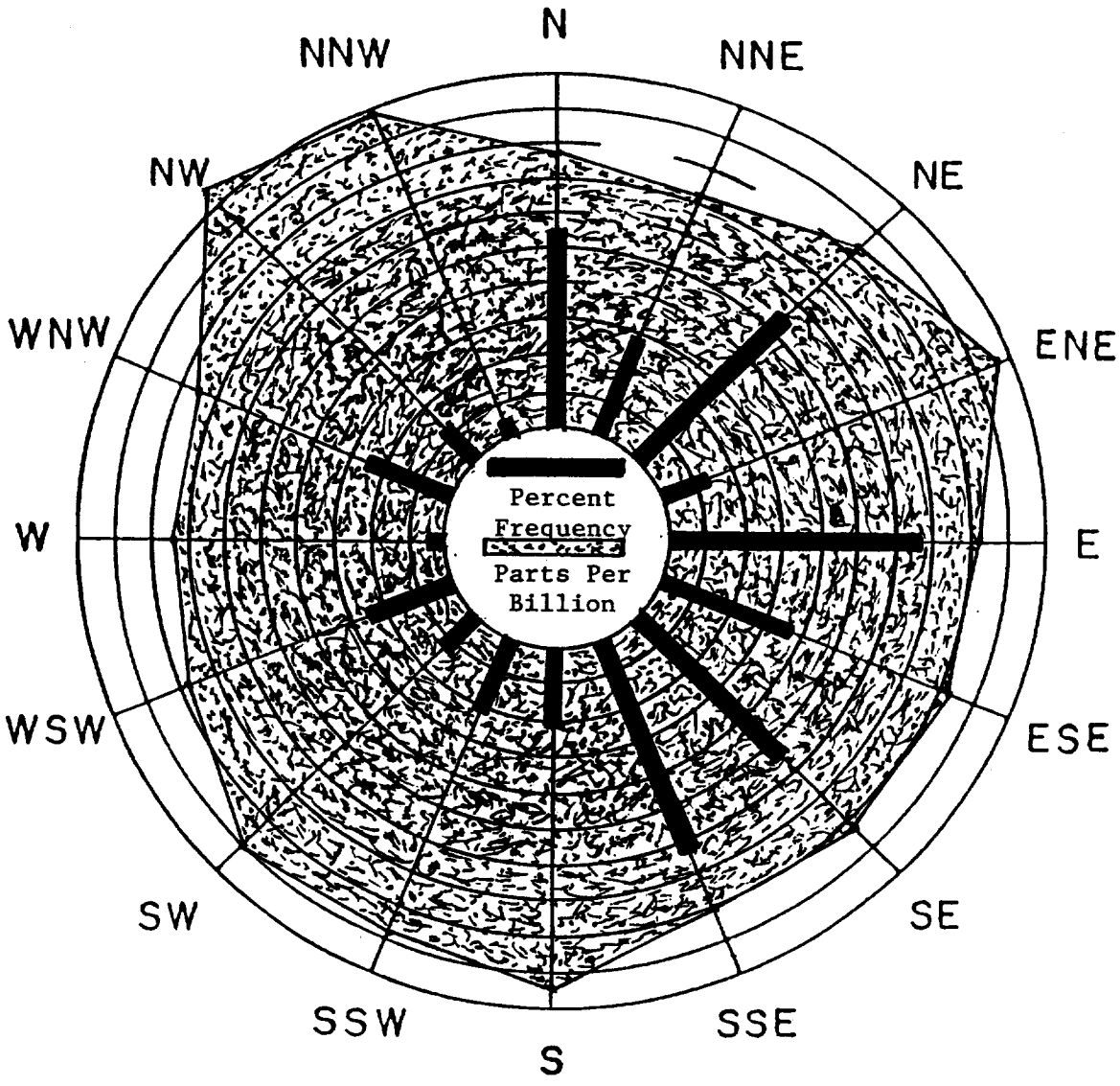

Figure 20. Ozone Pollution Rose.

ppb), north-northwest (99.0 ppb), and east-northeast(97.0 ppb). The fourth highest quadrant average (94.8 ppb) contained the highest of the 1-hour averages (134 ppb). The presence of high ozone with winds from the NW, NNW, and SW indicates that precursors exist on the mainland and are being transported into KSC. The cities of Titusville, Merritt Island, and Cocoa are located on these azimuth headings from Pams A.

Brevard County began monitoring ozone in the fall of 1988 at two sites: Cocoa Beach and Palm Bay. The data measured at KSC in 1989 are consistently higher than the two county sites, especially in the first six months (Figure 21). The Palm Bay site on the mainland yields higher ozone than the Cocoa Beach site, which is well ventilated by ocean breezes. The similarity of peaks and valleys at all three of the sites supports the claim that O_3 is a regional pollutant.

7.4 Weather Effects

Special weather patterns reportedly play a dominant role in the occurrence of O_3 exceedances in Florida. A double high pressure (Gulf and Atlantic) scenario accounts for 87 percent of observed exceedances of the O_3 standard in Florida, with the remaining 13 percent being attributed to a stationary frontal system. Over the five year period 1981-1986, only the Hillsborough/Pinellas area showed a

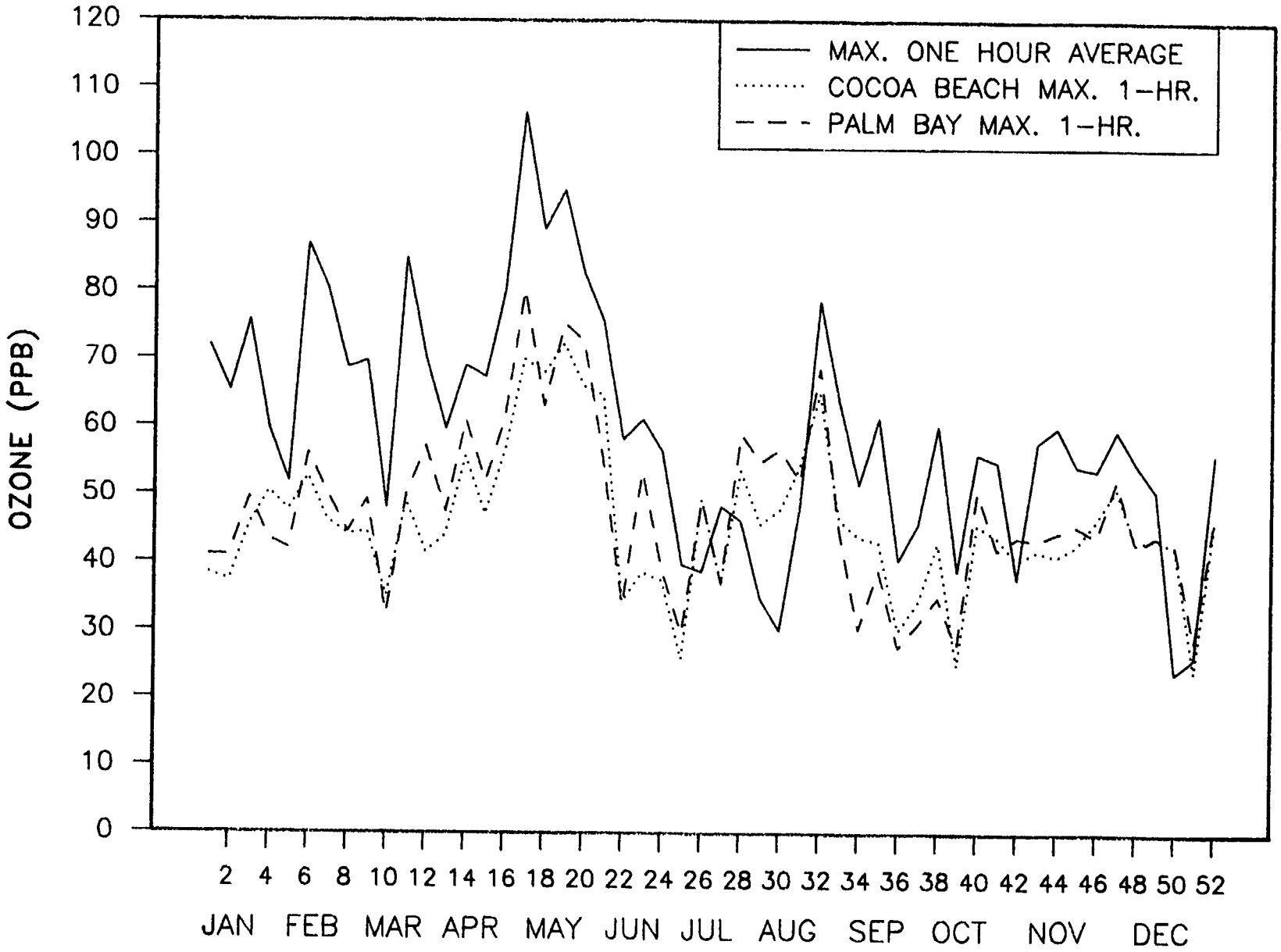

Figure 21. Comparison Of Weekly Averages Of Maximum 1-Hour Ozone Monitored At KSC, Cocoa Beach, and Palm Bay.

recognizable increase of 10-50 percent in the monthly mean concentration of ozone (Chu 1986). In addition, it was found that the proximity to the Gulf of Mexico and Tampa Bay encourages greater ozone production due to the high reflectivity of water and the resultant increase in ultraviolet radiation over the water (Hessling 1987 in Stowers et al. 1989). Also, although ozone can deteriorate readily during the transfer process, meteorological conditions such as subsidence aloft, temperature inversions, and the presence of large bodies of water tends to retard the process (Stowers and Tabb 1989).

The "high ozone" days (>90 ppb) at KSC were investigated to look at the effect of these weather systems. Sixty-eight percent were associated with high pressure systems: "double high" = 18.3 percent, "Gulf high" = 18.3 percent, "southeast high" = 13.3 percent, "Bermuda high" = 10.8 percent, "triple high" = 5.8 percent, and the "central Florida high" = 2.6 percent. Frontal patterns accounted for 31.6 percent of the high ozone days as follows: "southeastern front" = 15.0 percent, "stationary front" = 10.8 percent, "low pressure cell" = 4.2 percent, and the "Gulf front" = 0.8 percent. The last weather pattern found was that of hurricane and tropical storm that accounted for only 0.8 percent. The mechanism appears to be that as the low pressure cell impacts the Florida coast and begins to either travel up the coastline or proceeds inward, it

"drags" an air parcel behind it that contains relatively high ozone (84 ppb) (Drese 1987).

A frontal storm passed through the KSC area on September 16, 1990, from 14:40 to 15:25 causing an increase in both the ambient O_3 and CO levels (Figure 22). The surface transport of O_3 caused a 30.8 percent increase from 66.5 ppb to 87.0 ppb. The CO levels jumped from 784 ppb to 1079 ppb, a 37.6 percent increase. The average temperature dropped from 89 to 86.2 degrees Fahrenheit. The average relative humidity increased from 52.7 percent to 74.2 percent. The average wind speed only changed from 8 mph to 9 mph. Finally, the average wind direction changed from 177 (SSW) to 187 (WSW) degrees azimuth.

After the storm passed through, the O_3 levels returned to 51.7 ppb, a 40.6 percent decline. The average CO level remained elevated at 1096 ppb. The average temperature dropped to 78.7 degrees Fahrenheit. The average relative humidity dropped to 69.9 percent. The average wind speed stayed at 8 mph. Finally, the average wind direction shifted to 16 (NNE) degrees azimuth. The total rainfall from this storm totaled 0.08 inches measured at the NADP site, located 0.4 kilometers to the NW. This storm is an example of an air parcel being transported by a fast moving storm front, a typical occurrence in the Florida summer afternoons. Out of 35 rainfall events during the third quarter 1990, ten of the storms were found to have this effect to varying degrees

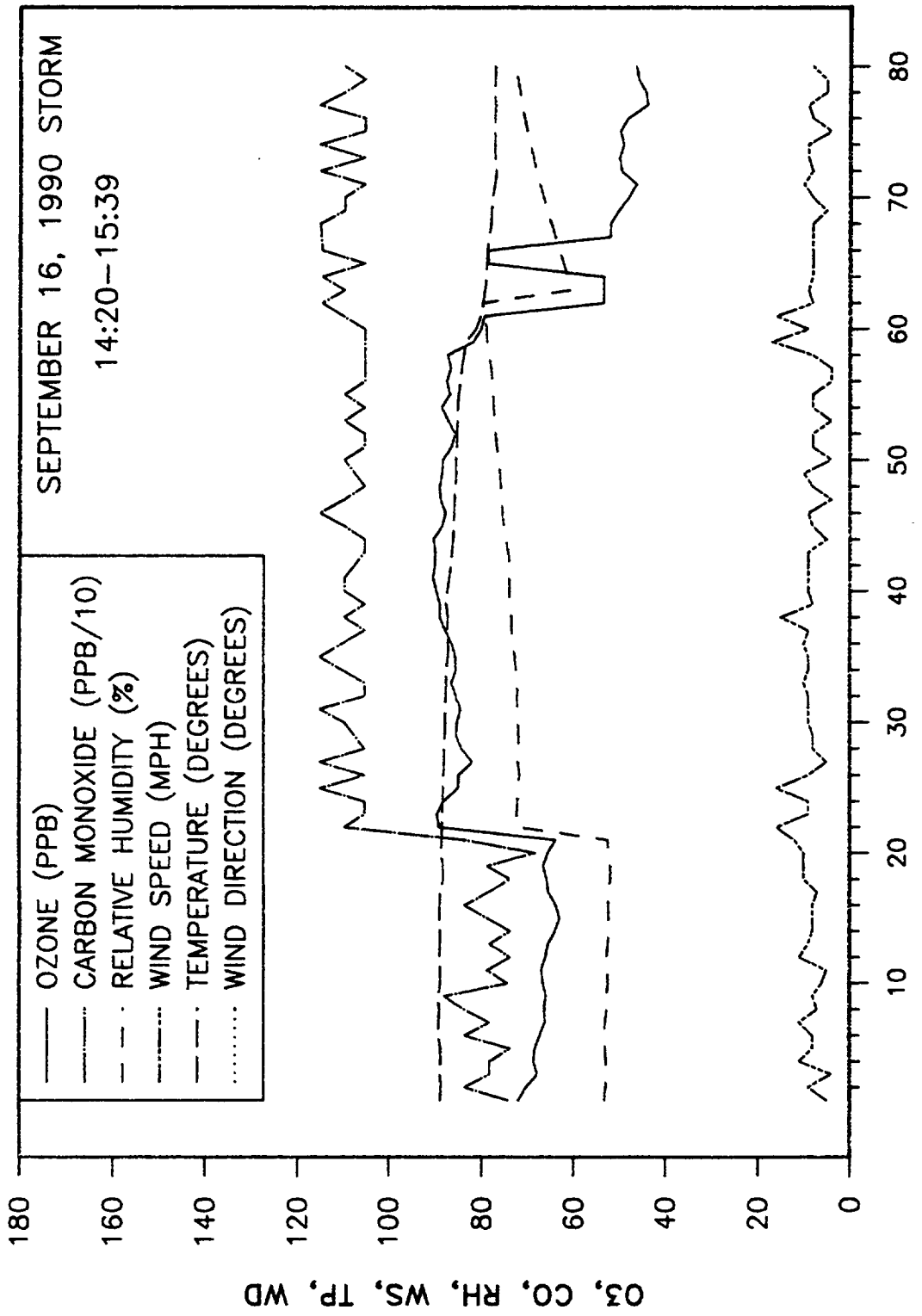

Figure 22. Ozone Transport And Parameter Changes Associated With A Storm Front Passage.

(Drese 1990). Since rainfall has such an effect, it will be discussed in the following section.

8.0 Rainfall

8.1 Background

Rainfall and precipitation have a unique relationship with both gaseous and particulate air pollutants in that they both affect and can be effected by pollutants. Wet removal by precipitation, or scavenging, is one of the most effective atmospheric cleansing mechanisms for both particles and gases. Contaminants may be incorporated into precipitation elements within clouds (rainout), and below clouds (washout) (Whelpdale and Munn 1976 in Stern 1976). Urban areas can affect the amount and timing of precipitation downwind on a regional scale. Probable mechanisms include: a) thermal enhancement, b) mechanical enhancement of updrafts caused by roughness of urban surfaces, c) modifications of particulate aerosol loadings, and d) modifications of the patterns of moisture injection into the boundary layer above urbanized and industrialized areas (Wanta and Lowery 1976 in Stern 1976).

There are numerous long-term and short-term data sets for rainfall for the vicinity of KSC. These include Merritt Island (76 complete years, 1878-1955), Titusville (86 complete years, 1888-1987), Cape Canaveral Air Force Station

(CCAFS)(21 complete years, 1958-1977), National Acid Deposition Program (NADP)(9 complete years, 1984-1992), and Launch Complex LC39A (9 complete years, 1984-1992)(Mailander, 1990).

8.2 KSC Trends

A plot of the monthly rainfall totals at the NADP site, located 0.4 kilometer to the north of Pams A from 1983 through 1992, shows a slight (6.6 percent) increase (Figure 23). The test of the Kendall's K trends statistic of the monthly rainfall totals yields a non-significant minor trend of -0.0070 (p=0.4558). The highest annual amount of rain occurred in 1987 (57.47 inches) followed by the lowest amount in 1988 (37.47 inches). The years 1987 and 1991 were the only years to have more rainfall at the NADP site than the 75-year record for the Merritt Island site that was about 10 miles to the south of the NADP site (Figure 24, Table 8)(Drese 1993).

There is a spatial nature to the rainfall patterns at KSC associated with the convergence and divergence zones occurring over Merritt Island because of the Indian and Banana Rivers and the coastal zone influence of the Atlantic Ocean. This effect is being investigated and reported in the quarterly Air Quality Summaries. For example, on October 15, 1993, 1.15 inches of rain fell at the NADP site, but only

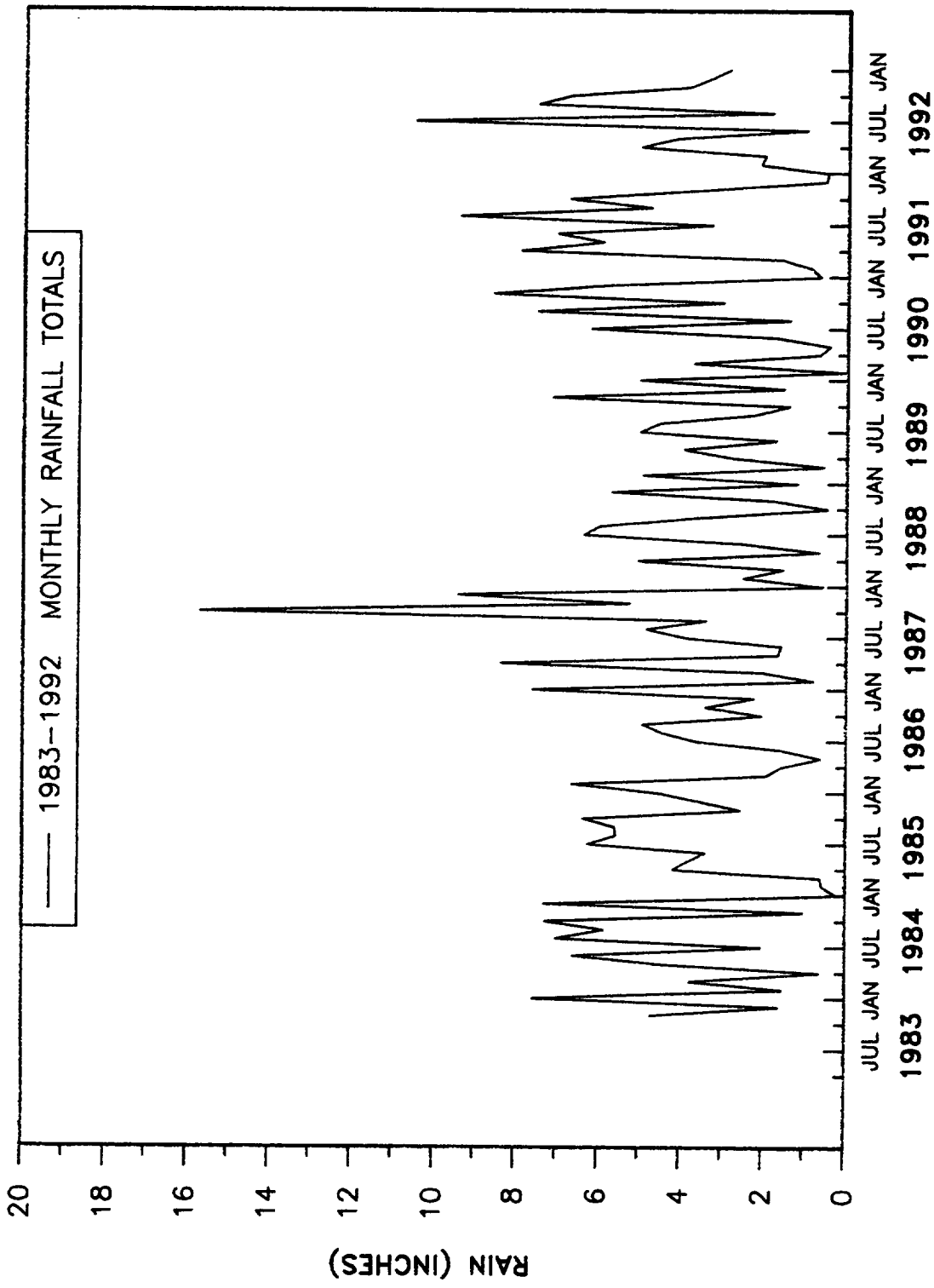

Figure 23. Monthly Rainfall Totals (1983-1992).

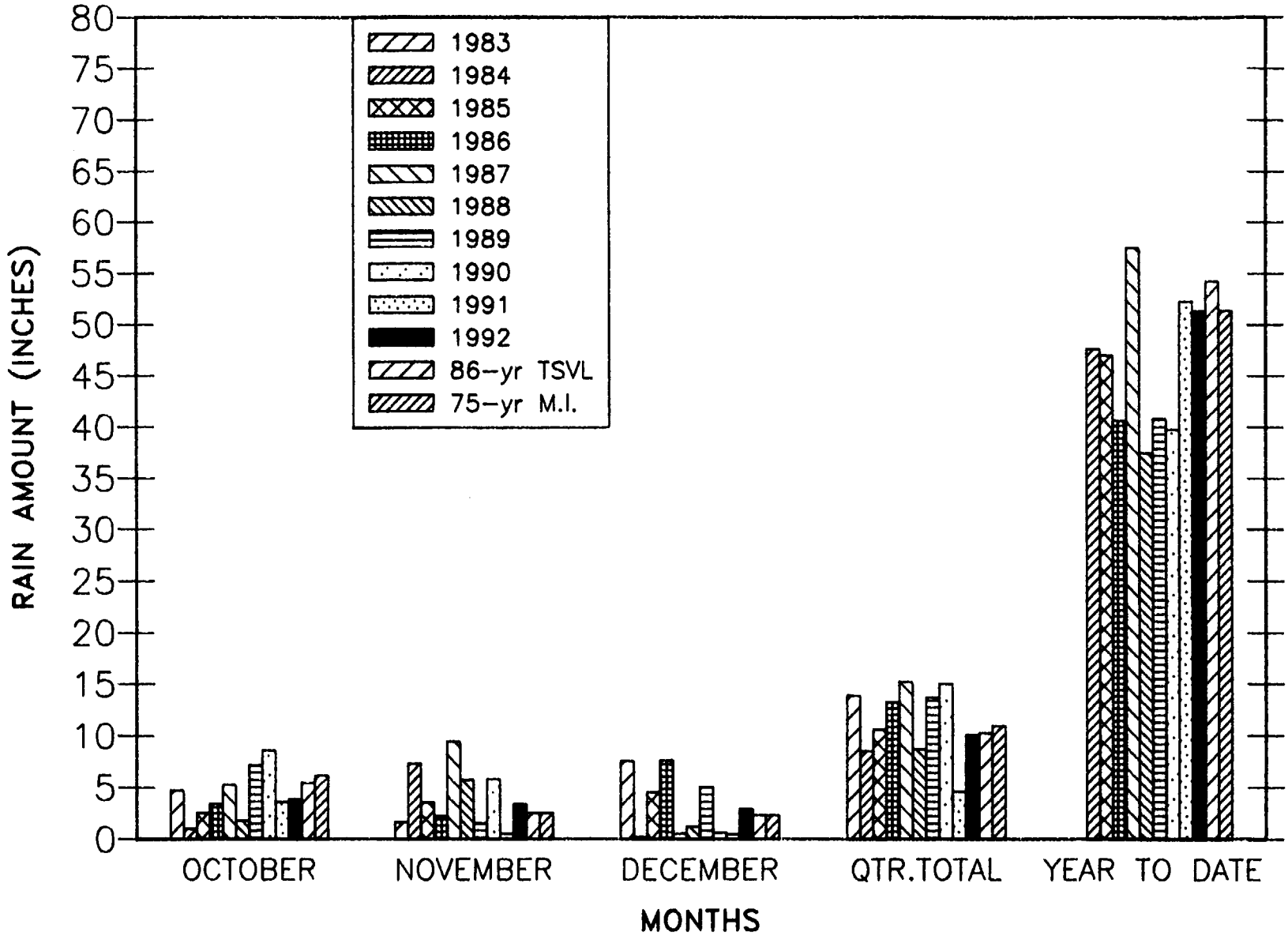

Figure 24. Comparison Of Rainfall Totals At The National Atmospheric Deposition Program (NADP) Site (1984-1992) With Historic Titusville And Merritt Island Data.

0.50 inches and 0.23 inches fell at Pams B and Pad 39A, respectively (Drese 1994).

There is a bi-modal pattern to the monthly NADP rainfall totals, with a wet season occurring from May through November and the rest of the year being relatively dry except for March. September has the most year-to-year deviation in rainfall amounts followed by March, November, and December (Figure 25). Wet season precipitation is caused primarily from convection cells, with the drier season (winter/spring) precipitation resulting from cold fronts, pre-frontal squalls, and low pressure systems (Doehring et al. 1986 in Mailander 1990).

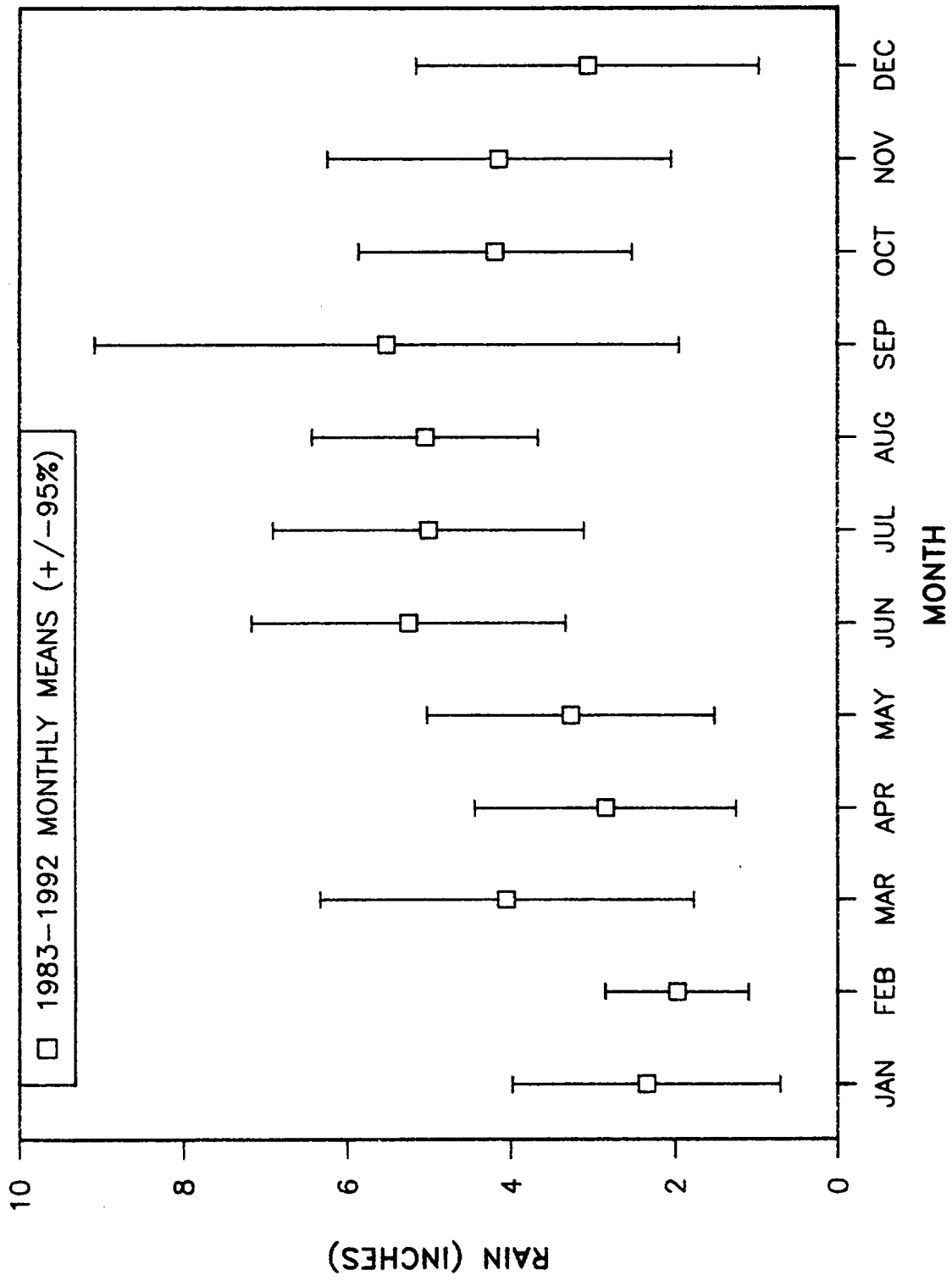

Figure 25. Composite Monthly Means Of Rainfall Totals (1983-1992).

9.0 Summary

The results of 10 years (1983-1992) of monitoring criteria pollutants at KSC have been presented and discussed above. Conclusions that can be reached will be outlined in the following section.

The five years of TSP samples reflect a seasonal trend with high readings in the spring (February through May) and low readings in the summer (July through September) which may reflect seasonal rainfall patterns. The highest reading occurred in July, 1992 (89.9 $\mu g/m^3$) resulting from the construction of the Space Station Facility and was well below the standard of 260 $\mu g/m^3$. An ANOVA showed that there is a significant difference between years at the 95 percent confidence interval. The highest KSC geometric mean (52.5 $\mu g/m^3$) occurred in 1992, while the state value was about half that (24.9 $\mu g/m^3$).

Inhalable particulates (PM-10) measured from 1983 through 1992 increase from January (18.6 $\mu g/m^3$) to June (37.7 $\mu g/m^3$) and then decreases through December (19.1 $\mu g/m^3$). This pattern is in direct contrast to the TSP values discussed above. The maximum second-highest value for KSC (102.6 $\mu g/m^3$) in 1988 was much higher than the state maximum (60.0 $\mu g/m^3$) in 1990, but the state annual mean (45.6 $\mu g/m^3$) was higher than the KSC annual mean (22.9 $\mu g/m^3$).

Monthly maximum 24-hour SO_2 averages at KSC have decreased each year from 35.6 $\mu g/m^3$ in 1983 to 9.8 $\mu g/m^3$ in

1990. The test of the Kendall's K trends statistic yields a significant minor trend of -0.1536 (p=0.0096). The highest 24-hour SO_2 average each year, ranging from 187.9 $\mu g/m^3$ to 26.1 $\mu g/m^3$, was higher than values for all other state monitoring locations on the east coast of Florida except Duval and Nassau counties (1982 to 1992), Broward County ('83), Volusia County ('88), and Orange County ('88). However, the second-highest 24-hour SO_2 average was lower than the reported statewide nine-station averages for each year except 1983 and 1985. Since the KSC values of SO_2 are lower than the state values and are decreasing, air quality (in terms of SO_2) is good.

The NO_2 annual averages are mostly stable with a few peaks occurring throughout the ten year period. The test of the Kendall's K trends statistic of the NO_2 annual averages yields a non-significant minor trend of -0.0561 (p=0.4641). January is the highest monthly mean for NO_2 followed by March and August. The mean of annual averages for KSC (4.1 $\mu g/m^3$), was much smaller than the mean of the statewide nine-station composite average values of 23.5 $\mu g/m^3$. Since the NO_2 concentrations are much lower than the state maxima, the air quality, in terms of NO_2, at KSC is good.

Monthly maximum 1-hour CO averages at KSC decreased from an annual average of 5.42 $\mu g/m^3$ (1983) to 1.09 $\mu g/m^3$ (1988) followed by an increase to 2.00 $\mu g/m^3$ (1992). There was also an overall 8 percent decrease in the CO monthly maximum 1-hour averages over the 10-year period. There was

an exceedance of the 1-hour and 8-hour standards for CO on November 6, 1983 due to a controlled burn by the USFWS. There is a bimodal distribution of the monthly means with the lower values from February through June and higher values in July through January. The statewide values and the values at KSC show a decreasing trend, but KSC values were much lower than the state values. The test of the Kendall's K trends statistic of the CO 1-hour averages at KSC yields a non-significant minor trend of -0.0170 (p=0.490). The CO values at KSC were much lower than the statewide values and is decreasing, and thus the air at KSC, in terms of CO, is good.

Ozone is the highest criteria pollutant monitored at KSC and increased steadily from 1983 through 1989, followed by a decline through 1992. There was a 12 percent decrease in ozone levels overall. The test of the Kendall's K trends statistic of the O_3 1-hour averages yields a significant minor trend of -0.156 (p=0.0058).

The highest annual mean of 40.5 ppb occurred in 1988. A plot of the monthly maximum means shows the typical bi-annual peaks for O_3 found in Florida. The maximum annual 1-hour KSC values increased compared to the mean of the five Florida non-attainment counties from 25 percent in 1983 to 119 percent in 1989, decreasing to 74 percent in 1992. Considering the above information, the air at KSC in terms of O_3, is good.

A pollution rose for O_3 at KSC shows that the highest O_3 concentrations are from the northwest, north-northwest, and east-northeast. An analysis of all three O_3 monitoring sites in Brevard County shows the regional nature of O_3. Weather patterns contribute to O_3 formation and transport of high O_3 values, with 68 percent being associated with high pressure systems and 31.6 percent associated with storm or frontal patterns. An example of storm-transported O_3 is discussed in the O_3 section.

Finally, monthly rainfall totals at KSC showed a slight (6.6 percent) increase over the 10 years with the highest amount falling in 1987 (57.47 inches). The test of the Kendall's K trends statistic of the monthly rainfall totals yields a non-significant minor trend of -0.0070 (p=0.4558). However, long term precipitation values are typically highly variable. Rainfall patterns throughout the year shows a bimodal trend with the highest monthly totals being in June through September.

Even though the levels reported in this paper were low compared to statewide values for all parameters except O_3, NASA has committed to continue monitoring these criteria pollutants. This monitoring will be conducted to continue to look both at long-term trends and impacts by center operations.

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APPENDIX A

Summary Tables For TSP, PM-10,

SO_2, NO_2, CO, O_3, and Rain

Table 2.a. Monthly Means of Total Suspended Particulate (TSP) 24-Hour Averages.

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	---	---	---	---	---	---	22.6	51.2	23.6	33.5	32.7	13.3
FEB	---	---	---	---	---	---	117.3	51.3	29.3	44.7	60.7	38.9
MAR	---	---	---	---	---	---	32.9	50.4	31.1	28.5	35.7	9.9
APR	---	---	---	---	---	75.7	53.4	41.2	23.2	22.2	43.1	22.4
MAY	---	---	---	---	---	58.3	47.7	52.4	34.8	45.6	47.8	8.7
JUN	---	---	---	---	---	82.8	23.4	33.6	29.4	64.1	46.7	25.6
JUL	---	---	---	---	---	78.8	40.4	22.6	24.6	90.2	51.3	31.3
AUG	---	---	---	---	---	12.2	98.1	27.7	23.8	48.1	42.0	33.9
SEP	---	---	---	---	---	18.0	---	21.7	30.6	---	23.4	6.5
OCT	---	---	---	---	---	76.5	---	27.2	43.3	---	49.0	25.1
NOV	---	---	---	---	---	53.2	29.5	22.8	42.4	---	37.0	13.5
DEC	---	---	---	---	---	43.3	47.0	20.9	29.8	---	35.3	12.1
Mean	0.0	0.0	0.0	0.0	0.0	55.4	51.2	35.3	30.5	47.1	42.1	20.1
Std Dev	0.0	0.0	0.0	0.0	0.0	26.4	31.8	13.1	6.8	21.7	9.9	10.9

Table 2.b. Monthly Maximums of Total Suspended Particulates (TSP) 24-Hour Averages.

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	---	---	---	---	---	---	40.7	69.3	33.9	67.5	52.9	18.2
FEB	---	---	---	---	---	---	117.3	72.8	34.2	90.2	78.6	34.8
MAR	---	---	---	---	---	---	32.9	81.0	51.5	28.5	48.5	23.9
APR	---	---	---	---	---	118.6	83.7	57.8	38.5	22.2	64.2	38.1
MAY	---	---	---	---	---	69.3	91.4	72.2	54.4	78.5	73.2	13.5
JUN	---	---	---	---	---	85.9	50.8	49.4	39.2	107.2	66.5	28.8
JUL	---	---	---	---	---	78.8	81.4	51.5	38.8	149.3	80.0	42.8
AUG	---	---	---	---	---	24.9	174.6	40.7	31.1	142.1	82.7	70.3
SEP	---	---	---	---	---	19.9	---	26.0	39.0	---	28.3	9.8
OCT	---	---	---	---	---	144.6	---	37.2	73.0	---	84.9	54.7
NOV	---	---	---	---	---	94.8	29.5	45.9	47.4	---	54.4	28.1
DEC	---	---	---	---	---	71.7	52.9	24.3	53.7	---	50.7	19.6
Mean	0.0	0.0	0.0	0.0	0.0	78.7	75.5	52.3	44.6	85.7	63.7	31.9
Std Dev	0.0	0.0	0.0	0.0	0.0	39.9	45.0	18.7	12.0	46.9	17.2	17.6

Table3.a. Monthly Means of Inhalable Particulate (PM-10) 24-Hour Averages.

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	---	22.5	17.1	24.7	13.5	9.3	28.9	---	---	---	19.3	7.3
FEB	---	19.7	19.8	33.6	22.2	13.4	9.4	---	---	---	19.7	8.3
MAR	26.7	14.0	30.3	---	23.0	14.2	18.4	---	---	---	21.1	6.7
APR	19.0	39.3	25.0	20.9	23.0	29.7	21.8	---	---	---	25.5	7.0
MAY	24.4	16.8	12.2	23.1	33.4	60.2	40.2	---	---	---	30.0	16.3
JUN	15.4	22.2	100.2	24.7	46.1	69.3	20.3	---	---	---	42.6	31.7
JUL	34.6	19.2	17.5	34.6	45.5	27.0	31.1	---	---	---	29.9	9.7
AUG	19.7	26.0	56.1	42.4	19.4	47.3	15.6	---	---	---	32.4	16.0
SEP	32.6	26.3	10.0	31.8	20.1	60.7	---	---	---	---	30.3	17.1
OCT	23.8	16.3	18.4	26.8	26.7	19.4	16.7	---	---	12.8	20.1	5.1
NOV	15.5	14.4	35.6	30.8	30.4	27.3	8.1	---	---	12.0	21.8	10.4
DEC	12.1	15.5	39.8	10.1	13.6	18.0	13.6	---	---	21.3	18.0	9.5
Mean	22.4	21.0	31.8	27.6	26.4	33.0	20.4	0.0	0.0	15.4	25.9	11.7
Std Dev	7.4	7.1	25.2	8.5	10.8	20.9	9.7	0.0	0.0	5.2	7.3	8.1

Table 3.b. Monthly Maximums of Inhalable Particulates (Pm-10) 24-Hour Averages.

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	---	36.2	22.7	31.0	14.1	13.0	28.9	---	---	---	24.3	9.4
FEB	---	24.4	23.5	39.2	22.2	18.0	9.4	---	---	---	22.8	9.7
MAR	54.2	48.6	32.8	---	28.8	21.1	29.3	---	---	---	35.8	12.8
APR	28.3	59.7	37.2	29.3	23.0	83.3	42.0	---	---	---	43.3	21.4
MAY	33.7	19.8	18.2	29.4	43.0	131.4	120.5	---	---	---	56.6	48.2
JUN	17.4	38.5	122.3	35.0	52.7	102.6	20.3	---	---	---	55.5	41.0
JUL	45.2	33.8	19.2	37.0	62.2	31.8	51.1	---	---	---	40.0	14.1
AUG	23.7	35.0	56.1	53.1	23.7	91.9	24.4	---	---	---	44.0	25.2
SEP	56.1	30.6	17.3	44.1	55.3	97.4	---	---	---	---	50.1	27.5
OCT	37.4	21.2	40.6	35.1	37.0	21.3	20.4	---	---	24.1	29.6	8.6
NOV	28.8	15.7	75.7	36.2	79.2	56.8	8.1	---	---	15.2	39.5	27.9
DEC	14.3	33.1	69.9	16.0	21.7	24.9	15.2	---	---	38.5	29.2	18.6
Mean	33.9	33.1	44.6	35.0	38.6	57.8	33.6	0.0	0.0	25.9	30.3	18.1
Std Dev	14.4	12.4	31.6	9.4	20.0	41.4	31.6	0.0	0.0	11.8	17.3	13.8

Table 4.a. Monthly Maximums of Sulfur Dioxide 24-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	6	21	4	4	4	---	7	4	---	7	7.1	5.8
FEB	9	19	3	26	5	18	12	4	1	3	10.0	8.5
MAR	15	8	5	22	3	10	4	5	1	5	7.8	6.4
APR	7	1	15	5	2	6	4	8	1	11	6.0	4.5
MAY	8	2	10	---	1	7	15	18	10	9	8.9	5.4
JUN	52	1	11	---	1	4	1	3	5	13	10.1	16.3
JUL	18	1	7	---	---	3	3	2	1	9	5.5	5.8
AUG	15	1	1	---	---	2	4	3	1	9	4.5	5.0
SEP	15	1	4	---	---	5	6	1	1	10	5.4	5.0
OCT	8	2	2	---	---	10	2	2	3	13	5.3	4.4
NOV	10	4	2	1	---	9	2	6	6	12	5.8	3.9
DEC	14	4	18	11	---	8	7	1	5	12	8.9	5.3
Mean	14.8	5.4	6.8	11.5	2.7	7.5	5.6	4.8	3.2	9.4	7.1	6.4
Std Dev	12.4	7.1	5.5	10.3	1.6	4.4	4.2	4.7	3.0	3.1	2.0	3.3

Table 4.b. Monthly Maximums of Sulfur Dioxide 3-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	19	39	15	15	14	---	8	11	---	10	16.4	9.8
FEB	20	25	4	25	19	10	11	12	6	13	14.5	7.4
MAR	28	14	7	27	8	9	9	6	10	10	12.8	8.0
APR	15	4	20	10	9	13	8	23	6	12	12.0	6.0
MAY	12	13	14	---	.3	11	11	12	21	11	11.7	5.3
JUN	98	1	12	---	1	9	4	22	7	14	18.7	30.5
JUL	12	6	11	---	---	13	8	12	29	12	12.9	6.9
AUG	22	3	3	---	---	6	13	16	20	12	11.9	7.4
SEP	22	1	11	---	---	7	14	4	12	11	10.3	6.5
OCT	17	5	4	---	---	26	8	7	4	15	10.8	7.9
NOV	7	5	8	---	---	14	7	23	8	12	10.5	5.8
DEC	25	7	27	---	---	12	13	2	6	12	13.0	8.8
Mean	24.8	10.3	11.3	19.3	8.6	11.8	9.5	12.5	11.7	12.0	12.9	9.2
Std Dev	23.8	11.3	7.1	8.1	7.3	5.3	2.9	7.3	8.1	1.5	2.5	6.8

Table 4.c. Monthly Maximums of Sulfur Dioxide 1-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	92*	59*	22*	17	15	---	10	16	---	10	13.6	3.4
FEB	64*	28*	7*	27	28	18	17	21	8	14	19.0	7.1
MAR	78*	13*	7*	28	11	10	12	7	12	11	13.0	6.8
APR	22*	12*	20*	12	26	17	10	28	15	12	17.1	7.1
MAY	28*	24*	15*	---	12	11	15	25	36	16	19.2	9.6
JUN	98*	1*	22*	---	1	13	6	33	25	33	18.5	13.8
JUL	62*	8*	11*	---	---	25	32	15	32	23	25.4	7.1
AUG	46*	7*	3*	---	---	7	19	22	28	15	18.2	7.9
SEP	60*	4*	11*	---	---	7	24	7	21	12	14.2	7.9
OCT	24*	9*	7*	---	---	37	11	5	4	18	15.0	13.5
NOV	35*	8*	8*	9	---	17	11	23	9	15	14.0	5.5
DEC	29*	8*	27*	15	---	13	16	2	6	15	11.2	5.8
Mean	53.2	15.1	12.1	18.0	15.5	15.9	15.3	17.0	17.8	16.2	16.5	8.0
Std Dev	26.6	15.9	8.1	7.8	10.1	8.8	7.1	10.0	11.2	6.3	3.8	3.1

* Maximum 1-minute value for month.

Table 5.a. Monthly Maximums of Nitrogen Dioxide 1-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	40	14	58	23	---	16	24	---	---	29	29.1	15.4
FEB	19	18	19	14	---	19	9	---	16	34	18.5	7.2
MAR	17	16	15	2	---	14	44	---	23	30	20.1	12.5
APR	13	17	19	15	---	19	10	14	15	20	15.8	3.3
MAY	9	14	18	12	---	15	7	11	10	19	12.8	4.1
JUN	16	10	8	32	---	16	6	14	20	15	15.2	7.7
JUL	22	10	9	11	---	12	---	8	23	21	14.5	6.3
AUG	---	14	11	9	---	12	---	---	23	14	13.8	4.9
SEP	---	10	12	12	---	12	---	---	14	14	12.3	1.5
OCT	---	16	14	13	---	26	---	---	17	30	19.3	7.0
NOV	26	20	18	3	13	22	30	---	15	9	17.3	8.4
DEC	13	16	18	3	23	22	24	---	24	10	17.0	7.3
Mean	19.4	14.6	18.3	12.4	18.0	17.1	19.3	11.8	18.2	20.4	16.9	3.0
Std Dev	9.2	3.3	13.1	8.6	7.1	4.6	13.6	2.9	4.7	8.5	7.5	

Table 5.b. Monthly Means of Nitrogen Dioxide 24-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	---	---	3.00	3.48	---	3.61	3.74	---	---	3.90	3.55	0.34
FEB	4.00	7.50	1.78	2.89	---	2.81	1.52	---	2.64	3.67	3.35	1.87
MAR	1.35	2.84	1.31	1.00	---	2.15	1.79	---	2.48	2.58	1.94	0.68
APR	1.14	3.36	1.95	1.57	---	2.21	1.03	5.50	1.78	1.60	2.24	1.40
MAY	1.29	1.16	3.57	1.23	---	2.32	1.23	1.39	1.34	1.61	1.68	0.79
JUN	---	1.30	3.83	2.48	---	1.67	1.12	2.27	1.86	2.06	2.07	0.85
JUL	2.61	1.26	1.11	2.74	---	1.74	---	1.26	3.25	1.48	1.93	0.82
AUG	---	---	0.90	2.81	---	2.09	---	---	2.38	1.19	1.87	0.81
SEP	---	1.19	1.43	2.13	---	2.28	---	---	0.97	1.23	1.54	0.54
OCT	---	1.20	2.89	2.35	---	3.66	---	---	1.23	1.58	2.15	0.99
NOV	---	1.62	3.00	1.32	3.13	3.97	2.93	---	1.97	1.47	2.43	0.96
DEC	---	1.48	3.96	2.00	4.38	5.03	3.52	---	2.87	1.00	3.03	1.44
Mean	2.08	2.29	2.39	2.17	3.76	2.80	2.11	2.61	2.07	1.95	2.42	0.54
Std Dev	1.23	1.98	1.11	0.77	0.88	1.04	1.11	1.98	0.72	0.95	1.18	

Table 5.c. Annual Means of Nitrogen Dioxide 24-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	---	---	3.00	3.48	---	3.71	2.81	---	---	2.22	3.04	0.59
FEB	---	2.78	1.78	2.89	---	3.48	2.7	---	2.61	2.31	2.65	0.52
MAR	---	2.79	1.70	2.50	---	3.22	2.67	---	2.59	3.32	2.68	0.53
APR	---	2.20	1.57	2.47	---	3.05	2.57	2.86	1.97	2.30	2.37	0.48
MAY	---	3.13	1.79	2.27	---	2.94	2.48	2.89	1.88	2.32	2.46	0.49
JUN	---	2.47	2.02	2.16	---	2.79	2.43	3.12	1.89	2.34	2.40	0.40
JUL	---	2.30	2.00	2.30	---	2.67	---	2.81	2.23	2.19	2.36	0.28
AUG	---	---	1.91	2.46	---	2.61	---	---	2.25	2.09	2.26	0.28
SEP	---	2.66	1.93	2.52	---	2.58	---	---	2.09	2.12	2.32	0.31
OCT	---	2.48	2.07	2.47	---	2.67	---	---	1.99	2.15	2.31	0.27
NOV	---	2.38	2.19	2.33	2.57	2.74	2.30	---	1.99	2.10	2.33	0.24
DEC	---	2.29	2.39	2.17	3.76	2.80	2.11	---	2.07	1.95	2.44	0.59
Mean	---	2.55	2.03	2.50	3.17	2.94	2.51	2.92	2.14	2.28	2.56	0.38
Std Dev	---	0.29	0.38	0.36	0.84	0.36	0.23	0.14	0.26	0.35	0.36	

Table 6.a. Monthly Maximums of Carbon Monoxide 1-Hour Averages (ppm).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.
JAN	0.79	1.27	1.23	0.95	1.046	0.636	4.309	1.584	----	1.396	1.468	1.1
FEB	0.88	1.58	1.19	1.14	0.778	1.377	0.849	1.498	1.794	1.346	1.243	0.3
MAR	1.33	1.21	1.11	1.03	0.635	0.945	0.69	1.406	1.305	0.80	1.145	0.3
APR	1.11	1.02	1.11	1.05	1.268	0.96	1.642	1.18	0.83	0.788	1.095	0.2
MAY	1.16	1.07	2.78	1.01	0.569	0.676	1.308	1.335	0.584	1.143	1.109	0.6
JUN	1.30	0.70	2.32	0.83	0.839	1.028	1.224	1.034	0.895	0.917	1.109	0.4
JUL	1.36	1.12	1.15	0.93	1.344	0.943	1.869	1.077	0.919	2.669	1.338	0.5
AUG	1.58	0.68	1.25	0.88	0.865	0.672	1.681	1.353	1.016	0.736	1.071	0.3
SEP	2.47	0.56	2.50	0.86	0.819	1.131	1.141	1.915	1.214	0.38	1.299	0.7
OCT	1.94	1.25	0.95	0.95	0.681	1.688	0.865	1.63	1.418	1.171	1.254	0.4
NOV	50	1.08	0.75	0.64	1.798	0.64	1.311	3.009	1.674	0.939	6.184	15.
DEC	1.14	0.73	1.13	2.07	1.646	0.686	1.572	1.284	1.263	1.19	1.271	0.4
Mean	5.421	1.023	1.456	1.029	1.024	0.949	1.538	1.525	1.174	1.123	1.632	1.7
Std Dev	13.448	0.288	0.642	0.337	0.386	0.314	0.905	0.506	0.351	0.541	1.377	4.1

Table 6.b. Monthly Maximums of Carbon Monoxide 8-Hour Averages (ppm).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.
JAN	.604	1.020	.833	.588	.585	.599	3.076	1.311	----	1.158	1.086	.7
FEB	.743	.900	1.12	.619	.612	.830	.743	1.301	1.562	.879	.931	.3
MAR	1.040	.950	.982	.772	.575	.861	.576	1.143	.926	.635	.846	.1
APR	.944	.846	.895	.734	.688	.861	1.539	1.089	.516	.687	.880	.2
MAY	.986	.927	.829	.821	.421	.436	1.164	1.183	.404	.679	.785	.2
JUN	1.200	.549	.625	.656	.611	.779	1.181	.807	.594	.437	.744	.2
JUL	1.148	.540	.537	.646	.685	.738	1.796	.844	.544	1.152	.863	.4
AUG	1.117	.300	.611	.773	.647	.474	1.041	1.141	.732	.341	.718	.3
SEP	1.260	.350	.728	.784	.526	.432	1.019	1.038	.888	.827	.785	.2
OCT	1.120	.814	.588	.667	.585	.314	.690	1.071	1.270	.865	.798	.2
NOV	32.0	.539	.619	.500	1.099	.491	.884	2.848	1.412	.791	4.118	9.8
DEC	1.070	.618	.772	.986	.631	.442	1.401	1.158	1.126	1.033	.924	.2
Mean	3.603	.696	.762	.712	.639	.605	1.259	1.245	.907	.790	1.123	1.1
Std Dev	8.945	.244	.178	.127	.162	.198	.675	.527	.391	.255	.948	2.7

Table 6.c. Monthly Means of Carbon Monoxide 24-Hour Averages (ppm).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.
JAN	.410	.840	.600	.514	.305	.394	.410	1.126	-----	.750	.594	.2
FEB	.631	.880	1.120	.750	.377	.299	.394	.971	.889	.585	.690	.2
MAR	1.107	.630	.750	.491	.326	.585	.383	.722	.522	.438	.595	.2
APR	.792	.700	.790	.385	.345	.577	.619	.839	.242	.395	.568	.2
MAY	.890	.400	.460	.543	.357	.224	.498	.692	.254	.385	.470	.2
JUN	.560	.399	.190	.449	.483	.433	.619	.525	.375	.089	.412	.1
JUL	1.060	.350	.450	.538	.505	.522	.873	.551	.309	.104	.526	.2
AUG	.960	.270	.570	.605	.502	.288	.624	.706	.538	.141	.520	.2
SEP	.890	.180	.490	.496	.392	.305	.577	.774	.731	.127	.496	.2
OCT	.860	.600	.480	.345	.401	.180	.323	.652	1.015	.409	.527	.2
NOV	1.020	.360	.360	.339	.504	.201	.546	.942	.823	.234	.533	.2
DEC	.810	.480	.340	.284	.383	.183	1.045	.540	.841	.486	.539	.2
Mean	.833	.507	.550	.478	.407	.349	.576	.753	.594	.345	.539	.2
Std Dev	.209	.222	.245	.129	.073	.150	.210	.187	.278	.210	.069	.0

Table 7.a. Monthly Means of Ozone 1-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	28	33	31	43	----	38	43	32	----	20	33.5	7.8
FEB	36	37	36	25	31	42	44	41	22	25	33.9	7.8
MAR	35	51	36	21	44	48	41	40	29	27	37.2	9.5
APR	29	52	35	32	55	50	50	48	26	32	40.9	11.0
MAY	33	42	35	32	38	57	55	51	23	33	39.9	11.1
JUN	32	27	20	24	28	38	27	35	25	19	27.5	6.1
JUL	42	19	34	26	24	32	17	30	20	19	26.3	8.1
AUG	27	14	32	22	20	25	35	34	18	16	24.3	7.6
SEP	34	26	38	12	20	28	26	44	22	15	26.5	10.0
OCT	29	44	39	27	44	43	35	37	24	27	34.9	7.7
NOV	29	36	36	19	40	38	32	30	26	25	31.1	6.6
DEC	28	24	43	23	35	47	22	24	19	23	28.8	9.6
Mean	31.8	33.8	34.6	25.5	34.5	40.5	35.6	37.2	23.1	23.4	32.0	
Std Dev	4.4	12.2	5.6	7.7	11.1	9.3	11.5	8.0	3.3	5.8		3.1

Table 7.b. Monthly Maximums of Ozone 1-Hour Averages (ppb).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.Dev.
JAN	65	85	64	86	----	70	99	74	----	50	74.1	15.4
FEB	72	86	77	77	99	92	117	73	60	57	81.0	18.1
MAR	75	96	87	63	91	93	107	78	68	65	82.3	14.8
APR	70	98	78	77	112	123	134	99	66	65	92.2	24.8
MAY	93	94	93	82	116	129	110	115	66	80	97.8	19.4
JUN	76	95	83	70	85	99	89	126	71	73	86.7	17.0
JUL	98	67	102	89	92	75	68	84	66	78	81.9	13.1
AUG	74	34	97	109	71	83	110	100	59	61	79.8	24.7
SEP	75	63	79	69	95	82	92	91	50	54	75.0	15.8
OCT	78	101	86	79	118	116	70	84	69	64	86.5	19.1
NOV	75	70	82	80	89	93	81	118	67	45	80.0	18.9
DEC	52	64	80	86	78	125	72	36	51	54	69.8	24.9
Mean	75.3	79.4	84.0	80.6	95.1	98.3	95.8	89.8	63.0	62.2	82.3	
Std Dev	11.8	20.1	10.1	11.8	15.2	20.3	20.7	24.4	7.1	10.9		5.8

Table 8. Monthly Rainfall Totals (inches).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	Mean	Std.
JAN		1.53	0.56	6.65	0.78	2.51	4.95	0.06	0.90	2.13	2.23	2.
FEB		3.75	0.61	1.93	2.03	1.54	0.55	3.73	1.61	2.02	1.97	1.
MAR		0.63	4.18	1.55	8.36	5.06	2.77	0.67	7.92	5.03	4.02	2.
APR		4.40	3.82	0.61	1.65	0.65	3.96	0.42	5.93	4.16	2.84	2.
MAY		6.61	3.40	1.57	1.57	2.56	1.70	1.70	7.05	1.00	3.02	2.
JUN		2.03	6.26	3.61	3.90	6.37	5.02	6.23	3.29	10.54	5.25	2.
JUL		7.02	5.57	4.45	4.85	5.99	4.52	1.39	9.43	1.83	5.01	2.
AUG		5.85	5.59	4.93	3.39	3.67	2.24	7.52	4.76	7.53	5.05	1.
SEP		7.28	6.37	2.04	15.71	0.44	1.39	3.01	6.76	6.72	5.52	4.
OCT	4.71	1.01	2.54	3.42	5.24	1.78	7.15	8.58	3.61	3.84	4.19	2.
NOV	1.63	7.31	3.54	2.23	9.44	5.71	1.53	5.79	0.53	3.35	4.11	2.
DEC	7.54	0.20	4.53	7.59	0.55	1.19	5.03	0.65	0.48	2.88	3.06	2.
Total	13.88	47.62	46.97	40.58	57.47	37.47	40.81	39.75	52.27	51.03	46.28	30.
Mean	4.63	3.97	3.91	3.38	4.79	3.12	3.40	3.31	4.36	4.25	3.91	0.
Std Dev	2.96	2.80	1.95	2.16	4.46	2.16	1.99	3.01	3.09	2.79	2.74	0.

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13. ABSTRACT *(Maximum 200 words)*

The EPA criteria air pollutants were monitored at Kennedy Space Center (KSC) since 1983 to comply the prevention of significant deterioration requirements under the Clean Air Act amendments passed by Congress in 1977 and 1990. Monitoring results show that monthly maximum 24-hour total suspended particulates decreased from 144.6 $\mu g/m^3$ in 1988 to 73.0 $\mu g/m^3$ in 1991 and increased to 149.3 $\mu g/m^3$ in 1992. Inhalable particulates increased from 56.1 $\mu g/m^3$ in 1983 to 131.4 $\mu g/m^3$ in 1988, and then decreased to 38.5 $\mu g/m^3$ in 1992. Sulfur dioxide monthly maximum 24-hour average concentrations decreased each year from 135.2 $\mu g/m^3$ in 1983 to 33.8 $\mu g/m^3$ in 1992. Nitrogen dioxide concentrations increased from 5.1 $\mu g/m^3$ in 1983 to 5.9 $\mu g/m^3$ in 1988, then decreased to 4.5 $\mu g/m^3$ in 1992. Carbon monoxide annual average concentrations decreased from 6.2 $\mu g/m^3$ in 1983 to 1.1 $\mu g/m^3$ in 1988, and increased to 1.2 $\mu g/m^3$ in 1992. Ozone maximum 1-hour concentrations increased from 98 parts per billion (ppb) in 1983 to 134 ppb in 1989, and then decreased to 80 ppb in 1992. Total annual rainfall ranged from 37.47 inches to 57.47 inches and shows a 6.6 percent increase over this same ten year period.

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