

ACADIA NATIONAL PARK

VISIBILITY AND AIR QUALITY DATA SUMMARY

VISIBILITY DATA SUMMARY

Acadia National Park presently uses the IMPROVE protocols for monitoring visibility. The IMPROVE protocols for background visibility monitoring consist of optical, view, and particle monitoring. Optical monitoring measures the optical condition of the atmosphere; view monitoring documents the appearance of the scene; and particle monitoring determines the nature of the air pollutants responsible for visual impairment. Appendix A is an overview of the purposes and objectives of the IMPROVE monitoring program.

Optical Monitoring Data Summary

Long path transmissometers are currently used to monitor the optical quality of the atmosphere. Transmissometers measure the amount of light transmitted from a calibrated incandescent light source through the atmosphere over a known distance. The light source (transmitter) and light monitoring (receiver) components of the instrument are separated by a distance of from one to fifteen kilometers depending on conditions at the monitoring location. The separation distance at Acadia National Park is 3.7 km. Measurements of the intensity of the light source, the distance between the source and the receiver, and the intensity of the transmitted light will allow direct calculation of the average atmospheric extinction due to scattering and absorption along the instrument path. Before it is possible to discuss the visibility data collected at the park, it is necessary to define several key terms used in visibility science: scattering, absorption, extinction, contrast, and standard visual range.

The passage of light through the atmosphere is affected by the constituents of the atmosphere. The atmosphere contains gases such as oxygen and nitrogen and suspended bits of matter (particles) of natural and manmade origin. The gases and particles influence light by scattering or absorbing it. Scattering is the process by which a particle takes energy from an incoming beam of light and reradiates that light into all directions. Looking through a dirty car windshield toward the sun when it is low in the sky illustrates the phenomenon of scattering. The windshield appears very bright with light and is difficult to peer through because the dirt particles scatter the sun's incoming light into many other directions. The scattered light obscures those objects that you are trying to see. Absorption is the process by which the incoming light is not redistributed, but removed and absorbed by the particle or gas molecule, thus increasing its internal energy. Diesel exhaust contains carbon particles which are very effective at absorbing light. It is difficult to see through a dense cloud of this exhaust because absorption reduces and removes the light coming from the direction the observer is looking.

The attenuation of light by both scattering and absorption processes is called extinction. The extinction coefficient, b_{ext} , is a measure of the amount of the extinction occurring in the atmosphere. This coefficient can be explained

physically as follows: If a beam of light is passing through the atmosphere, 63 percent of the beam's light energy is lost in a distance of $1/b_{\text{ext}}$. Because $1/b_{\text{ext}}$ has the units of distance or length (e.g., kilometers or km), it follows that b_{ext} has the units of one divided by length, or "inverse kilometers", $1/\text{km}$ or km^{-1} . The larger the value of b_{ext} , the more obscured is the atmosphere. Even in an extremely clean and pollution free atmosphere, there is still extinction caused by the scattering of air molecules. In the case of this very clean atmosphere, b_{ext} has a value of about 0.01 km^{-1} . A very polluted atmosphere may have extinction coefficients on the order of 0.10 km^{-1} .

Contrast is a second quantity considered in the measurement of visibility. Our eyes are able to see objects such as a distant mountain because it is brighter or darker than its background (e.g., the sky). The contrast of the mountain or other object is defined as the percent difference between the brightness of the mountain and its background. Contrast values may be positive or negative. A negative object/sky contrast indicates that the object is darker than the background sky. Conversely, a positive contrast indicates an object brighter than its background. Objects become indistinguishable from their backgrounds when contrasts are in the range of .02 to .05. A contrast value of 0.5 is considered large. The NPS has measured contrast at many National Park Service units using teleradiometers. These instruments were phased out by 1986 and, beginning in 1987, replaced by long path transmissometers.

Visual range is a quantity that has been used as a measure of how far one can see. It is defined as the greatest distance at which a large black object can be seen against the horizon sky background. Thus, the visual range has units of distance such as kilometers. Making various assumptions, one can derive equations relating visual range to b_{ext} and contrast. Thus, the visual range can be calculated from measured values of extinction and contrast. As extinction increases, visual range decreases, and conversely. Considering all the assumptions used to derive the expressions for visual range, it is probably better to interpret the visual range as a measure of the clarity of the atmosphere rather than as an absolute distance.

The visual range is often expressed in a special form called "standard visual range" or SVR. Even in a perfectly clean atmosphere consisting only of air molecules, an observer can see farther at higher elevations than at sea level. This is because the scattering caused by these air molecules (referred to as Rayleigh scattering) is less at higher elevations where the density of air is less. Thus, in order to equalize the effect of altitude for all monitoring sites, the visual range data from all sites are normalized to an altitude of about 5000 feet above sea level. The SVR is this normalized visual range, and its use facilitates the comparison of visual ranges derived from sites at different altitudes. Thus, for the same averaging time, the difference between SVR's at different monitoring sites are due to factors other than altitude.

The maximum value of SVR is 391 km. This value is associated with an extremely clean atmosphere, in which the extinction is due solely to the scattering of light by air molecules. (Because Rayleigh scattering is the

name given to this type of scattering, such clean days are referred to as "Rayleigh days.")

The transmissometers used in the IMPROVE network calculate and report average atmospheric extinction over the path length of the instrument. Along with extinction, temperature and relative humidity are also monitored at IMPROVE sites. Relative humidity is important because it affects the size of particles. In higher relative humidities, particles can grow in size and become much more effective at scattering light and obscuring visibility. The data represent one ten-minute average value for each hour of the day. The data are subsequently reduced to four daily six-hour average values: Midnight to 6 a.m., 6 a.m. to noon, noon to 6 p.m., and 6 p.m. to midnight. The transmissometer at Acadia National Park was installed on November 14, 1987. The transmissometer transmitter and receiver are located at the top of Cadillac Mountain and the maintenance area, respectively.

Figure 1 is a graph of seasonal averages of standard visual range derived from transmissometer extinction measurements made at Acadia National Park. The 10th, 50th, and 90th percentile SVR's are reported for the five seasons winter 1988 through winter 1989. The visual range is less than or equal to the 10th percentile value 10 percent of the time, and similarly for the 50th and 90th percentile values. These three percentiles describe the entire distribution of SVR values. The 10th percentile is a measure of how often the lower visibilities (i.e., SVR's) occur during a given season. The frequency of better visibility days are associated with the 90th percentile value. The 50th percentile value is the median value of the distribution which means that just as many SVR values during the season were greater than this percentile than were less than it.

Thus, Figure 1 indicates that during the winter of 1989 (i.e., December 1988, January and February 1989):

The 10th percentile SVR was 15 km. Ten percent of the time the visibility was 15 km or less. Conversely, ninety percent of the time the visibility was better than 15 km.

The 50th percentile SVR was 56 km. Half the time during the season the visibility was worse than 56 km and half the time it was better than 56 km.

The 90th percentile SVR was 93 km. Ninety percent of the time the visibility was 93 km or less. Conversely, ten percent of the time the visibility was better than 93 km.

The plot of seasonal visual ranges at Acadia National Park indicates that the greatest visibilities were recorded during the spring of 1988 (50th percentile SVR = 63 km, and 90th percentile SVR = 95 km). The median 1988 summer visibility of 19 km was significantly lower than that of the other seasons (39-63 km) of the other four seasons. Data recovery during the winter 1988 through fall 1988 seasons were low and the corresponding SVR percentiles may not be representative of the entire season. We anticipate much better data recovery in the months ahead. Quite often, when new types of monitors are

used in a large national network, it is not unusual to have a "shakedown" period characterized by instrument malfunctions and data recovery problems.

Figures 2 through 6 are transmissometer data summary sheets for the above five seasons. These sheets are typically used to summarize optical data collected in the IMPROVE network. The top graph is a time plot of all collected six-hour average values of extinction (and SVR). The dashed line at an SVR of 2 km ($b_{\text{ext}} = 1.96 \text{ km}^{-1}$) represents a point at which the error in measuring the extinction becomes relatively large. When b_{ext} is greater than 1.96 km^{-1} , the time line becomes dashed indicating an increased uncertainty in the measurement. The next graph presents a time plot of six-hour average relative humidity measurements. This allows the determination of the effect of increasing relative humidity on the measured extinction, b_{ext} . See, for example, the Figure 6 time plot in the region of the curve around January 20, 1989. Long periods of relative humidity near 100% usually result in corresponding periods of high b_{ext} , and are probably associated with precipitation events. This assumption can only be verified by reviewing simultaneous photographic data.

The third plot is a cumulative frequency plot of six-hour average extinction (and SVR) values. The 10th to 90th percentile values are plotted in 10 percent increments. The 10th, 50th, and 90th percentile values of SVR and extinction are printed in the small table to the right of the plot. These SVR and extinction percentiles are interpreted differently because the two quantities vary inversely, i.e., as the air becomes cleaner the SVR increases and the extinction value decreases. Therefore, while the 10th percentile SVR means that ten percent of the time the SVR is less than or equal to this value, the 10th percentile extinction means that ten percent of the time the extinction is greater than or equal to this value. These seasonal 10th, 50th, and 90th percentile visual ranges were plotted in Figure 1.

The listing at the bottom contains data recovery statistics for the three month season. The number and percentages of total possible and usable six-hour averages in the time period are reported. A three month season with 90 days has 360 (90×4) total possible six-hour extinction (or SVR) averages in this time period. Assuming that all of these six-hour averages are usable, 36 of these SVR values would be as low or lower than the 10th percentile SVR, and 324 would be as low or lower than the 90th percentile SVR. In practice, the number of usable averages may be less than the total possible averages in the seasonal time period.

Transmissometer data recovery at Acadia National Park varied from 13 to 70 percent during the five reported seasons. These statistics are important when Acadia's seasonal averages are compared with another site's. Ideally, comparisons of seasonal averages between sites should be made among data sets of approximately equal size. That is, one site's seasonal average derived from one month's data may not be adequately representative when comparing to another site's seasonal average based on a full three months of data.

Figure 7 is a plot of Acadia National Park seasonal SVR percentiles for the years 1984 through 1987. The data used to create this graph were generated from NPS contrast measurements using teleradiometers and color 35mm slides.

The SVR and extinction can be derived from the teleradiometer contrast measurements or from measurements on color slides. Specifically, the contrast between the sky and a suitable target can be measured off the slide using an instrument called a scanning microdensitometer. The extinction and SVR can be calculated from these contrast measurements. Extinction and SVR data determined in this way are subject to a greater uncertainty than those available from the transmissometer. However, studies have shown that there is good agreement between SVRs calculated using teleradiometer data and those calculated using microdensitometry.

Automatic teleradiometers were operated at the park between October, 1979 and February, 1986 and were used to derive estimates of standard visual range. Between October, 1979 and May, 1983, a multiwavelength automatic teleradiometer with a cassette data logger were used. Data collection during this period was not very good because of problems with the filter turret getting stuck and the cassette data tapes not being readable. In June, 1983, the equipment was replaced with a new teleradiometer and experimental automatic data collection platform. The platform collected the visibility measurements made every minute, calculated hourly averages, and transmitted them via satellite to a central location for processing. Spring, 1984 was the first season during which the new Acadia visibility station was considered operational.

An automatic 35mm camera system has been in operation at the park since 1980. Blue Hill is the chosen target. Standard visual ranges reported between spring 1986 and fall 1987 were based on measurements off the 35mm color slides. Visual ranges reported after fall 1987 are based on transmissometer extinction measurements.

Figure 7 indicates median seasonal SVR's of about 50 to 130 km, with 90th percentile SVR's in the range of about 150 to 350 km, and 10th percentile SVR's generally less than 50 km.

Figures 8 through 11 present 1987 seasonal contour plots of the median standard visual range (50th percentile values) measured at NPS visibility monitoring sites. These maps are provided to illustrate regional spatial and temporal trends. The data used to create these contour plots were generated from NPS contrast measurements from 35mm color slides. Acadia median visual ranges for 1987 were about half the magnitude of the corresponding values for stations in the Colorado Plateau of the western United States.

These 1987 seasonal plots illustrate some spatial and temporal trends and are similar to seasonal plots for other years. The highest mean SVR is typically found in the high plateau areas of southeastern Utah and northwestern New Mexico, and the geographic area containing the Grand Canyon and extending up through Nevada into parts of Oregon, Idaho and Wyoming. The lowest visual range is found at the eastern U.S. stations. Most western and eastern NPS stations record the highest values of SVR during winter and the lowest values during the summer. However, during 1987, Acadia recorded the highest seasonal median SVR in the summer. Eastern visibilities are generally much lower than those in the west. For example, during the summer of 1987, the median visual

ranges in the east were about two to five times smaller than corresponding visual ranges in the west.

Caution should be used in comparing Acadia transmissometer-based seasonal SVR's with teleradiometer or color slide derived seasonal SVR's. The first year of Acadia's transmissometer data may not be representative because of the gaps in each season's data set, as discussed above. Future monitoring will verify the representativeness of this first year's data set.

Also, the transmissometer provides a more complete sampling of visual range than the teleradiometer. The transmissometer based SVR's were generated from data collected during every hour of the day while those derived from the teleradiometer were based on daylight observations only. SVR's calculated from color slide measurements were based on only three observations per day at Acadia. Also, on a given day, the transmissometer and color slide derived SVR values may differ because the transmissometer values are six-hour averages while those derived from the slides are instantaneous values.

Furthermore, the seasonal percentage of contrast observations useable for SVR calculations at Acadia National Park varied considerably. These percentages were generally in the range of 40 to 70 percent. Those observations that were able to be used to generate the distribution of SVR's may have been biased towards cleaner, clearer days, with correspondingly higher visual ranges.

View Monitoring Summary

View monitoring documents the general appearance of a specific scene and the presence of plumes, layered, or uniform hazes. The IMPROVE/NPS monitoring programs use automated 35mm photographic systems to monitor the visual resource of the class I area. This is very important because the transmissometers and particle monitors only sample a small part of the scene. View monitoring literally provides the needed description of what is happening within "the big picture."

The photographic system consists of a 35mm camera, lens, camera databack, timer, and shelter. The time and day a particular exposure was made is imprinted on the film using the camera databack. A battery powered timer is used to trigger the camera to take a photograph three times per day (9:00 a.m., noon, and 3:00 p.m. local time). Kodachrome ASA 25 36 exposure roll slide film was used in the program through May 1989. In June, 1989, a switch was made to Kodachrome ASA 64 film because of the lack of availability of camera data backs capable of writing to ASA 25 film. All tests indicate that quantitative analysis of Kodachrome 64 is comparable to Kodachrome 25-based analysis. The color response of Kodachrome 64 is slightly different than Kodachrome 25, and there will be a perceptible change in slide color. The design of this camera system allows unattended operation for at least ten days. The automated camera system at Acadia National Park has been operating at its present location since March, 1986. The vista currently being photographed by the camera includes the Blue Hill target.

The slides are not routinely used for quantitative analysis. However, they are considered a valuable source of information for interpretation of concurrent measurements, for documentation of perceived visual conditions, and

for future qualitative and quantitative investigations. To aid in the use of the slides, a computer index is maintained which contains qualitative information on scene appearance, meteorology, air quality, and identification information for each color slide.

The entire set of color slides taken at Acadia National Park was reviewed last year and five subsets of them were chosen to represent the spectrum of observed visual conditions. Two spectrum slide sets illustrate the range of uniform haze conditions observed at both 9:00 a.m. and 3:00 p.m. The slides represent a range of SVR's from about 35 km to approximately 390 km. The SVR values were derived from measurements on the color slides. The contrast between the sky and a suitable target (Blue Hill) was measured off the slide using a scanning microdensitometer. The extinction and SVR were calculated from these measurements.

A smaller third set of slides describes the appearance of layered hazes. The fourth and fifth subset respectively included slides taken on days when the measured fine particulate matter concentration was relatively high or low. These sets of slides were sent to Acadia National Park in 1988.

Particle Monitoring Summary

Particle monitoring in the IMPROVE/NPS network is accomplished by a combination of particle sampling and sample analysis. The sampler employed was designed specifically for the IMPROVE/NPS programs by the NPS and the Environmental Protection Agency. It collects four simultaneous samples: one PM-10 sample (particles less than 10 micrometers [or μm] in diameter) on a teflon filter and three PM-2.5 samples (particles less than 2.5 micrometers in diameter) on teflon, nylon, and quartz filters. Each of the four samples is collected by a separate subsystem (or module) including everything from the inlet to the pump with only the support structure and controller/timer in common. The particle size segregation for the PM-10 module is accomplished by a wind insensitive inlet with a 10 micron cutoff, while the PM-2.5 segregation is produced by passing the sampled air through a cyclone separator. Constant sample flow (18.9 liters per minute for the PM-10 module and 21.7 liters per minute for each of the PM-2.5 modules) is maintained by a critical orifice in each module. The IMPROVE sampler is programmed to automatically collect two 24-hour duration samples per week on Wednesday and Saturday. The IMPROVE particle monitor was installed at Acadia National Park on October 10, 1987 at park headquarters.

This IMPROVE particle monitor more completely characterizes the chemical composition of the particulate matter, as compared to the stacked filter unit (SFU) monitors previously used by the NPS prior to 1987. The SFU particle monitor was used at Acadia National Park headquarters between September, 1985 and November, 1987. (The SFU monitor was programmed to collect 72-hour samples prior to June, 1986 and 24-hour samples after that date.) The samples collected by the IMPROVE monitor are analyzed for total (0-10 μm diameter particles) and fine (0-2.5 μm diameter particles) mass concentrations; concentrations of over 50 chemical elements; ion (sulfate, nitrate, ammonium, and chloride) mass concentrations; and carbonaceous mass concentration and optical absorption. Additionally, a filter pack using a chemically treated

quartz filter can be attached in series with the PM-10 module to measure sulfur dioxide concentrations. The above data are necessary for investigating the origin of the pollution responsible for visibility impairment.

Data summaries of the Acadia National Park IMPROVE particle data are provided for the spring and summer months of 1988. The winter 1988 season (December 1987, January and February 1988) was a break-in period for the IMPROVE sampler and consequently data summaries are not available. Figure 12 displays the March through August 1988 monthly averages of Acadia total and fine mass, sulfate, nitrate and soil concentrations in micrograms per cubic meter. Tables I and II list the monthly, seasonal, minimum and maximum concentrations for total and fine mass, and some 20 chemical species. Figures 13 and 14 are time series plots of the concentrations of various particle species for the spring and summer seasons at Acadia National Park. The concentrations in these graphs are reported in nanograms per cubic meter. (One microgram per cubic meter equals 1000 nanograms per cubic meter. Therefore, divide the Figure 13 and 14 concentrations by 1000 to convert to micrograms per cubic meter.) Table III and IV list various particle concentrations (in nanograms per cubic meter) measured on each of the samples in spring and summer 1988.

Most visibility reduction is caused by the scattering of light by particles and liquid drops between 0.3 and 1 micrometer in diameter. These particles are collected by the fine particle stages of the IMPROVE sampler. Sulfur is considered the largest single cause of visibility reduction and is generally present as ammonium sulfate. It is generally produced by industrial emissions of sulfur dioxide gas which convert in the atmosphere to ammonium sulfate. The particulate ammonium sulfate is very effective at scattering light and causing visibility impairment.

Organic matter is another major cause of visibility reduction and is estimated from the measured organic carbon. Organic matter sources include industrial emissions, fires, and biogenic emissions. The Acadia carbon data are not reported here (as well as data from other network stations) because of various initial technical issues involving procedures used to analyze the filters for carbon. These issues now have been resolved, and the NPS contractor is now proceeding with the carbon filter analysis for all monitoring stations.

At some sites ammonium nitrate and soils may be significant. The soil concentration is estimated from the soil-derived elements of silicon, iron, calcium, and aluminum. Other elements may be significant as tracers of specific emission sources, such as zinc (Zn) and copper (Cu) [copper smelters], lead (Pb) [smelters and motor vehicles], bromine (Br) [motor vehicles], selenium (Se) [coal combustion], potassium (K) [potash industry and smoke from fires], and vanadium (V) [fuel oil combustion]. Hydrogen (H) is associated with sulfates, nitrates and organics and generally correlates strongly with mass.

To place the Acadia National Park particle data in perspective, Figures 15 and 16 respectively plot spring and summer seasonal average particle concentrations measured throughout the IMPROVE/NPS network. (Note that the fine mass, total mass, and ammonium sulfate concentrations are expressed in

micrograms per cubic meter, while the fine soil, nitrate, and potassium concentrations are in nanograms per cubic meters.)

The SFU particulate data are summarized in Figures 17, 18, and 19. Figure 17 presents maps of isopleths of fine mass concentration, and percent of fine mass as ammonium sulfate, soil, soot and remaining mass averaged for the period June, 1982 to February, 1985. (Remaining mass represents the fine mass less the sulfate, soil and soot components.) Figures 18 and 19 plot 1985-1987 seasonal concentrations of fine mass and fine ammonium sulfate measured with the stacked filter unit (SFU) sampler at Acadia National Park.

The following can be inferred from the IMPROVE particle data:

The IMPROVE Acadia seasonal averages of most particle components were higher for the summer season. Total and fine mass concentrations were about twice as great in the summer of 1988 than in the spring.

Sulfates, nitrates, and soil were the largest constituents of the fine mass measured at Acadia.

The areas with the lowest measured levels of fine and total mass, and ammonium sulfate were generally northern Arizona and New Mexico, and Utah, Colorado, and Wyoming. Shenandoah and Great Smoky Mountains National Parks were the areas with the highest measured levels in the IMPROVE network. Particle concentrations measured at Acadia generally were lower than those measured at Shenandoah and Great Smoky Mountains but higher than those measured at Texas, California and Colorado Plateau sites during both seasons.

The following can be inferred from the SFU particle data:

For the period June 1982 to February 1985 in the western United States, the highest average fine mass concentration of about 5 ug/m^3 was measured in southwest Texas and northern Washington and Montana. This average fine mass concentration is lowest in a strip from northern California/southern Oregon to the Four Corners region and is highest in the east, with the concentration in the east (approximately 10 ug/m^3) around four times that in the clean region. The SFU sampler at Acadia was not in operation during this time period.

Nationally, the ammonium sulfate contribution to the total fine mass varies from around 20 percent in most of the northwest to 50 percent in the east. Soil contribution is low in the east and parts of the northwest, with contributions of 5 to 10 percent, but is considerably higher throughout most of the west, with values of 15 to 30 percent. The soot carbon component varies from 5 percent in the east to 10 percent in the west. The fraction of remaining mass varies widely with 50 to 67 percent throughout the northwest and Yosemite, decreasing to 20 percent in Texas. The average fraction of remaining mass in the east is 38 percent, the same as that for the average western site.

In a given season there is considerable variation in the measured pollutant levels as illustrated by the 10, 50, and 90 percentile seasonal fine mass and fine sulfate concentrations as illustrated by Figures 18 and 19. Concentrations of fine mass and fine sulfate throughout the NPS network, often show strong seasonal variations, with highest concentrations generally occurring in the summer and lowest concentrations in the winter. This effect is less pronounced at Acadia. In most areas, the higher summer pollutant concentrations can account for the lower summer visual range, and the lower winter pollutant concentrations explain the higher winter visual ranges.

Source Apportionment of Particulate Sulfate Concentrations at Acadia

K. Gebhart and W. Malm of the NPS Air Quality Division presented a paper on the source apportionment of particulate sulfate concentrations at Acadia, Great Smoky Mountains and Shenandoah National Parks at the October, 1989 Air and Waste Management Association specialty conference on Visibility and Fine Particles.

Two separate analyses were performed to investigate the air pollutant source regions impacting the fine ammonium sulfate concentrations at the three parks. The first analysis, source contribution function analysis, was used to locate the source regions which impact Acadia; and, on those days when measured sulfate concentrations at Acadia were relatively high, to determine which pathways the air mass took in transporting its pollutant-laden air to the park. The second analysis, trajectory mass balance, uses the results of the first technique along with the source area emission rates, to estimate the annual average fraction each source area contributes to measured sulfate levels at Acadia.

High sulfur concentrations at Acadia most often occur when air masses arrive from industrial and urban areas along the Great Lakes in both the United States and Canada. Air masses from the east coast and midwestern states also bring sulfates to the park.

The three most dominant sulfur source areas affecting Acadia are Sudbury, Ontario, Canada; Northern New York; and the New York City/Philadelphia region. The sulfur dioxide emissions at Sudbury originate at the Inco, Ltd. nickel smelter, the world's largest single source of sulfur dioxide.

GASEOUS POLLUTANT DATA SUMMARY

Ozone

Ozone and other photochemical oxidants are not emitted directly into the atmosphere, but rather are formed there as products of reactions involving organic compounds, nitrogen oxides and sunlight. In high enough ambient concentrations, ozone can affect the health of humans and vegetation. Ozone can cause eye and lung irritation in people, and potentially serious foliar injury and growth damage to native vegetation such as certain species of pines

and hardwoods, and commercial salad and citrus crops. Additionally, its effects include damage to textiles, discoloration of dyes and disintegration of rubber.

The National Park Service has been operating an ozone and sulfur dioxide gaseous pollutant monitoring network consisting of about 40 stations with various combinations of ozone, sulfur dioxide and meteorological monitoring equipment. Acadia National Park is now part of this network. Originally, the state of Maine monitored ozone in the park between late 1982 and 1987. The NPS assumed responsibility for operating the ozone monitor in the spring of 1988. Also at that time, the NPS began operating a sulfur dioxide monitor. Both monitors are located at park headquarters. The NPS is operating the two monitors throughout the year, whereas the state of Maine operated the ozone monitor only during the April to October "ozone season."

Ozone is monitored continuously by the ultraviolet photometric method. The concentration of ozone is determined in an absorption cell from the measurement of the amount of light absorbed at the ultraviolet light wavelength of 254 nanometers. The ozone analyzer contains an ultraviolet light source and a detector on opposite sides of the cell. An air sample is directed through a scrubber that removes any ozone present. The ozone free sample flows through the absorption cell, and the amount of ultraviolet light transmitted through it is measured. At a preset time, a second air sample flows directly into the absorption cell, bypassing the scrubber, and its ultraviolet light transmittance is measured. The ozone concentration is determined from the two measured transmittances, the optical path of the absorption cell, the temperature and pressure of the samples, and the ozone absorption coefficient at 254 nanometers.

The monthly highest and second highest hourly average ozone concentrations are reported for the period May, 1988 to March, 1989 in Figure 20. Data were not collected during the December, 1988 to February, 1989 winter months. Ozone concentrations are about 100 percent higher during the summer months in the park than in the fall or spring months. Higher ozone concentrations are generally observed in summer because of the season's greater solar insolation and higher temperatures. The 0.12 parts per million (ppm) level corresponds to the National Ambient Air Quality Standard (NAAQS) for ozone. This standard, if met, is designed to prevent ozone effects on human health and vegetation. In reality, there are data that suggest that vegetation may be affected by ozone at a level one half the National Ambient Air Quality Standard.

The National Ambient Air Quality Standards allow one exceedance of the ozone standard per year. The standards are violated if the second highest concentration exceeds the level of the NAAQS. In 1988, the highest and second highest hourly concentrations were 0.179 and 0.153 ppm, respectively. Figure 21 presents the same statistics for the years 1982 through 1987. (Note that sampling began in late 1982 and data were collected that year only for about one month.) The second highest hourly concentrations of 1983 and 1987 also exceeded the 0.12 ppm NAAQS level.

The 1988 second highest ozone concentrations for all of the NPS ozone monitoring stations are plotted on a map of the United States in Figure 22. The stations with the highest ozone concentrations (and in excess of the NAAQS) are in California, the northeast and the Great Lakes region of the United States. The Acadia National Park second highest value of 0.153 ppm (or 153 parts per billion in the units of Figure 22) was the second highest of all NPS ozone monitoring stations. The highest second high value was recorded at Santa Monica Mountains National Recreation Area (0.204 ppm) and the lowest second high value was recorded at Olympic National Park (0.050 ppm). The color scheme of Figure 22 is based on screening criteria developed by the U.S. Forest Service. The stations marked in red have concentrations likely to produce vegetation damage. The green marked stations have levels that probably would not cause any vegetative impacts. Lastly, the yellow marked stations have ozone concentrations that may or may not cause injury to the native vegetation.

Sulfur Dioxide

Sulfur dioxide is an air pollutant that in sufficiently high concentrations can affect human health and welfare. This gas can cause or contribute to respiratory system problems in people. Sulfur dioxide can cause serious injury and growth loss to lichen, Douglas fir, ponderosa pine, white pine, forest shrubs, and various crops including alfalfa, grains, squash, cotton, grapes and apples. It is also extremely corrosive to a variety of materials, including metals, building materials, paints, and electrical equipment.

The National Park Service has been monitoring sulfur dioxide at Acadia since the spring of 1988 at park headquarters. The gas is monitored continuously by the pulsed fluorescence method. The air to be sampled is drawn in to a chamber and is exposed to a short-pulsed, high-intensity ultraviolet light source with a wavelength of about 210 nanometers. The ultraviolet light excites the sulfur dioxide molecules and causes them to emit a characteristic 350 nanometer wavelength light. This light is detected by a photomultiplier tube and processed electronically to yield a voltage that is directly proportional to the sulfur dioxide concentration of the sample being analyzed.

The monthly highest and second highest hourly average sulfur dioxide concentrations are reported for the period May, 1988 to March, 1989 in Figure 23. Data were not collected during the winter of 1989 (December, 1988 through February, 1989). The one-hour average sulfur dioxide concentrations were all less than or equal to 0.010 ppm. The maximum 24-hour average concentration measured during this period was 0.005 ppm, which is considerably less than the 24-hour sulfur dioxide NAAQS of 0.140 ppm. (There are also 3-hour and annual average sulfur dioxide NAAQS of 0.5 and 0.03 ppm, respectively. The corresponding Acadia concentrations are far below the levels of these standards as well.) For comparison with other NPS monitoring sites, the maximum 24-hour sulfur dioxide concentration measured at Indiana Dunes National Lakeshore between 1981 and 1986, and Shenandoah National Park between 1983 and 1987 was 0.060 ppm and 0.040 ppm, respectively.

Figure 1.

ACADIA NATIONAL PARK TRANSMISSOMETER STANDARD VISUAL RANGE

10TH PERCENTILE 50TH PERCENTILE 90TH PERCENTILE

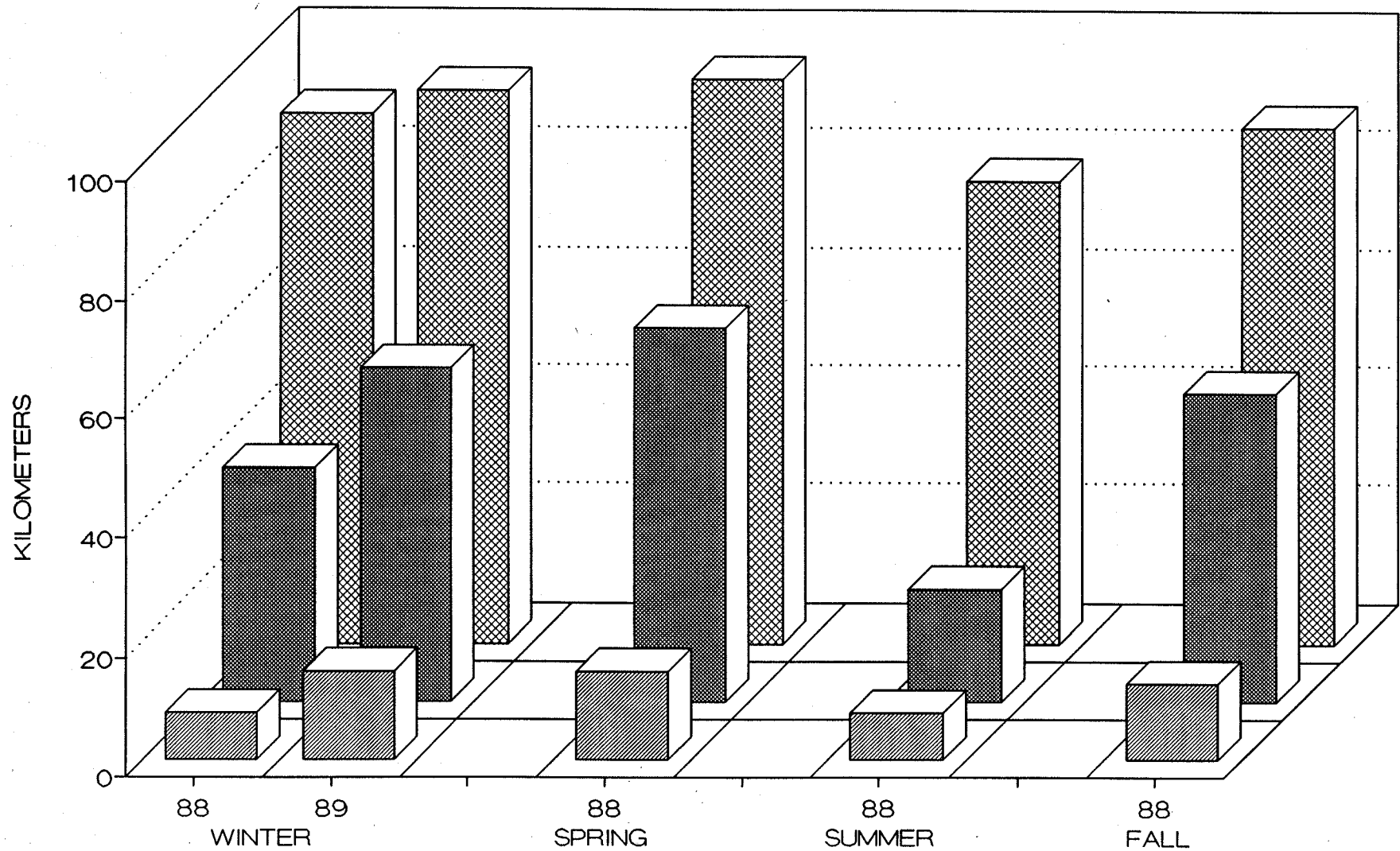
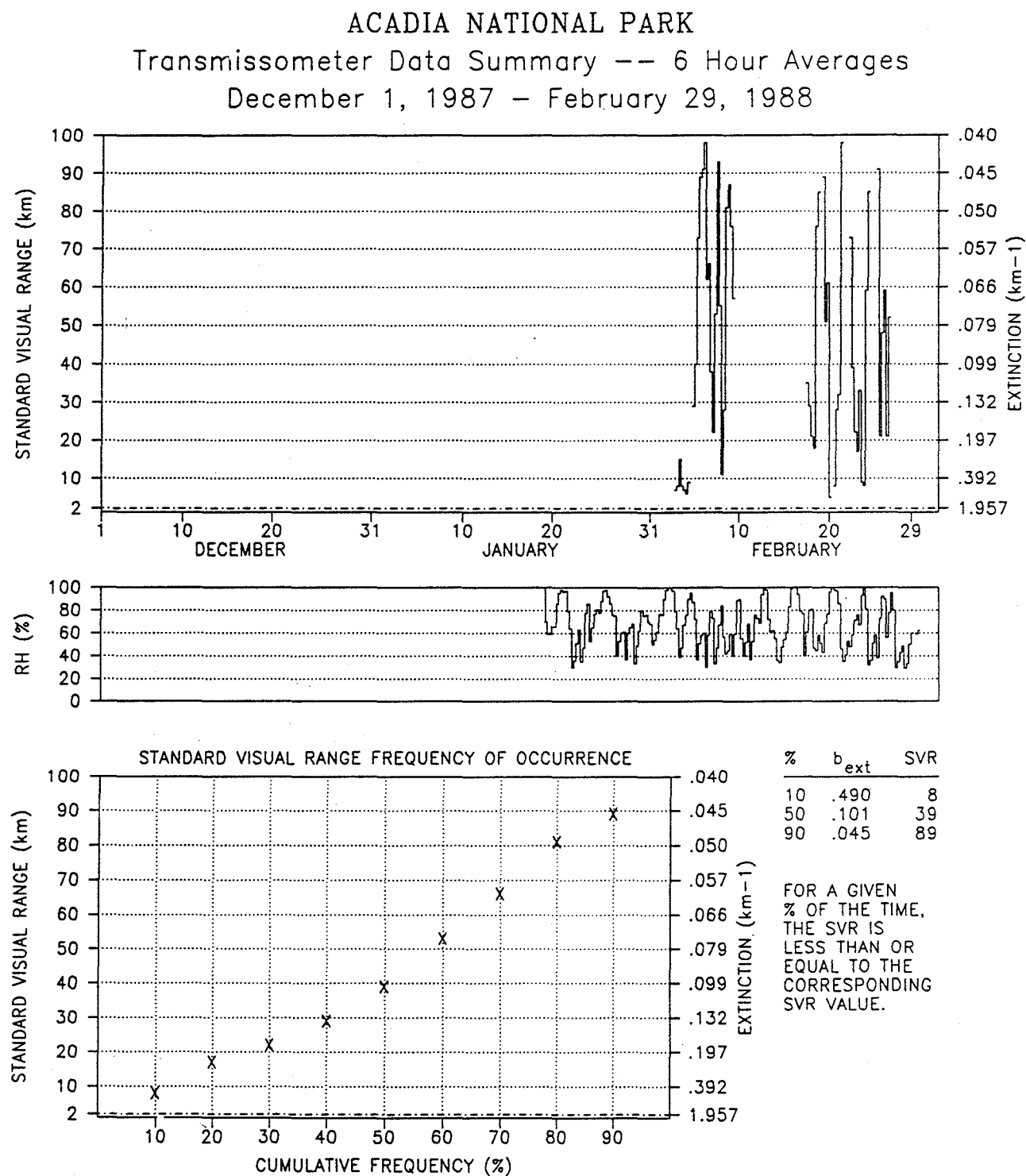


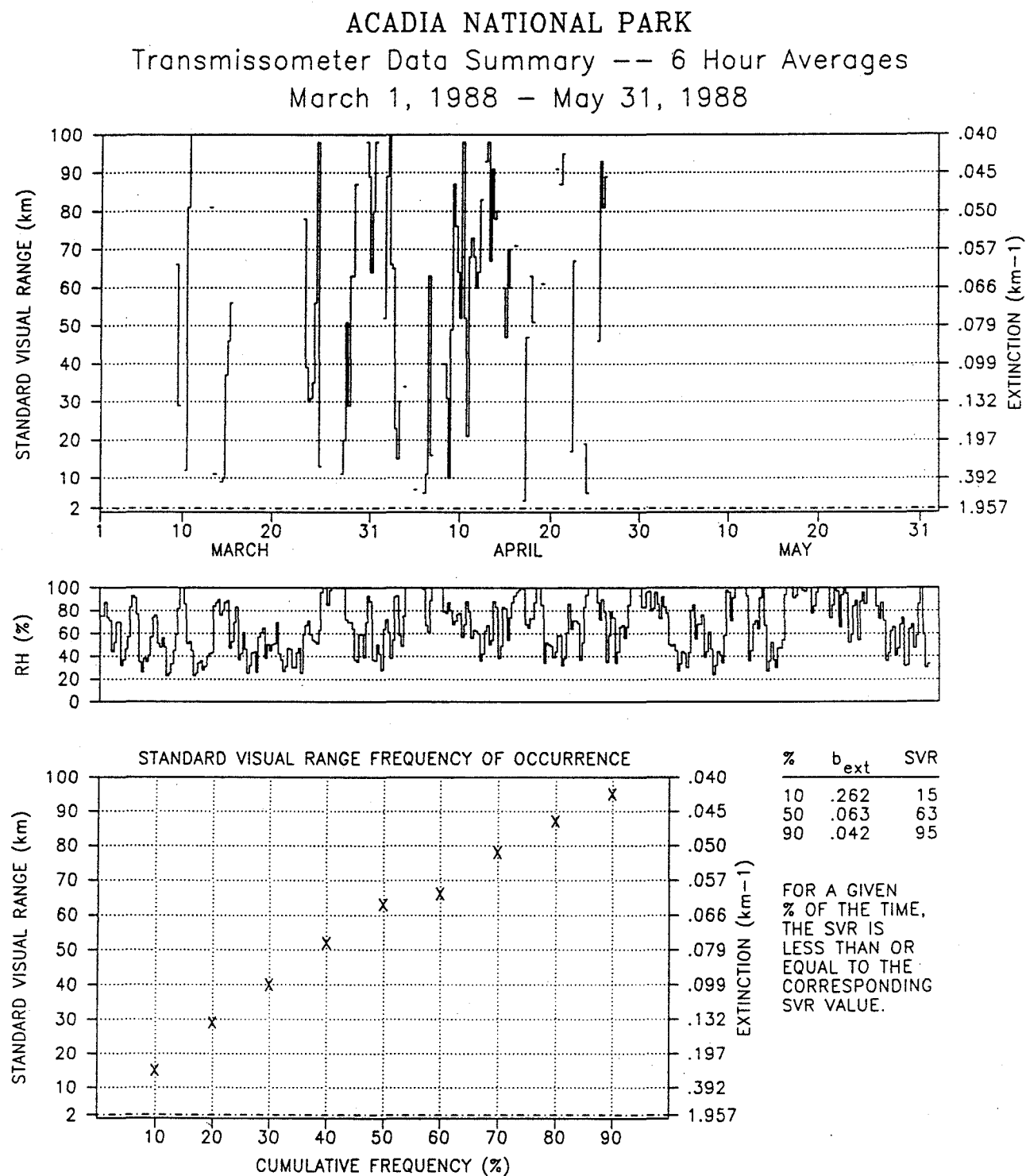
Figure 2.



TRANSMISSOMETER DATA RECOVERY STATISTICS

CATEGORY	NUM	%
TOTAL POSSIBLE 6-HOUR AVERAGES IN THE TIME PERIOD	364	100
USABLE 6-HOUR AVERAGES IN THE TIME PERIOD	49	13

Figure 3.

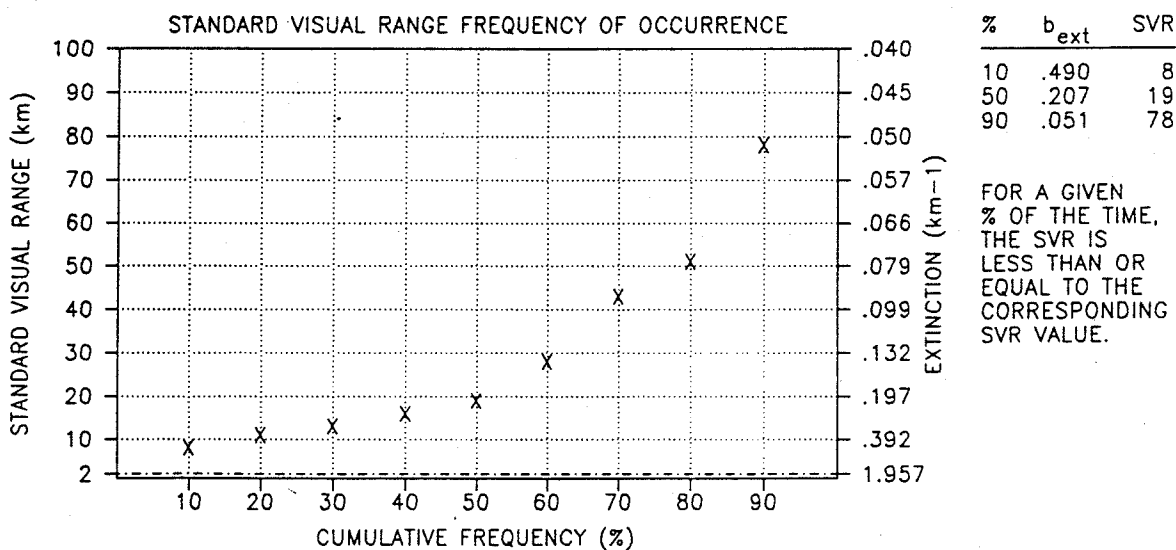
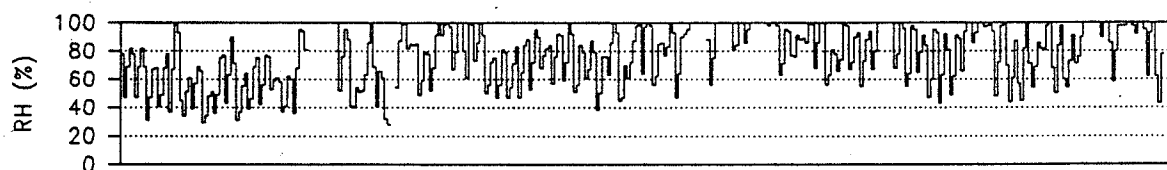
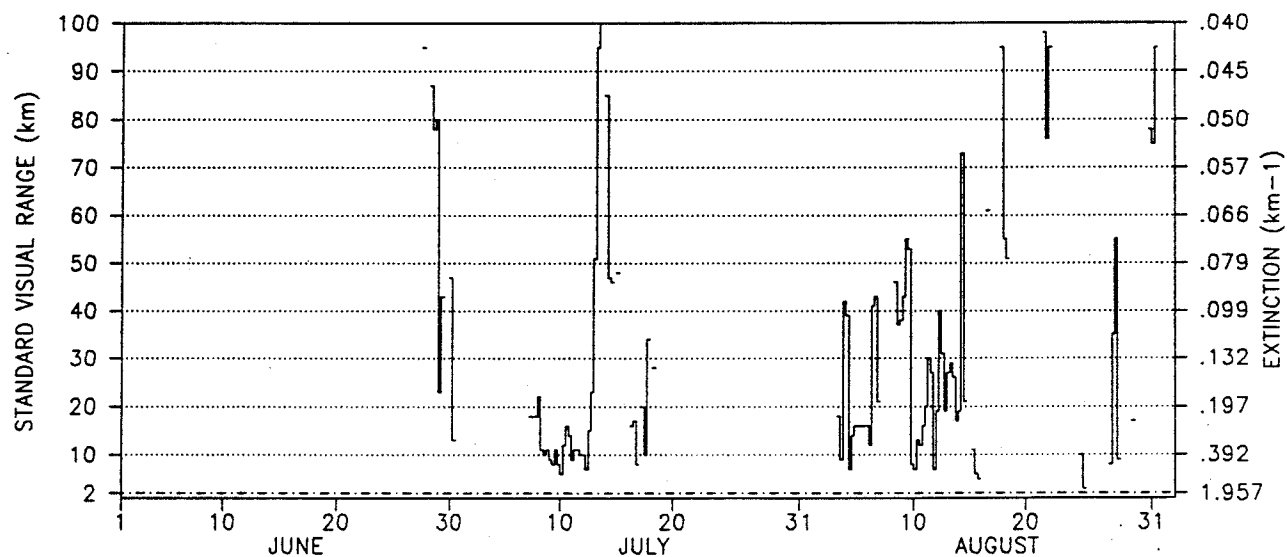


TRANSMISSOMETER DATA RECOVERY STATISTICS

CATEGORY	NUM	%
TOTAL POSSIBLE 6-HOUR AVERAGES IN THE TIME PERIOD	368	100
USABLE 6-HOUR AVERAGES IN THE TIME PERIOD	85	23

Figure 4.

ACADIA NATIONAL PARK
Transmissometer Data Summary -- 6 Hour Averages
June 1, 1988 - August 31, 1988



TRANSMISSOMETER DATA RECOVERY STATISTICS

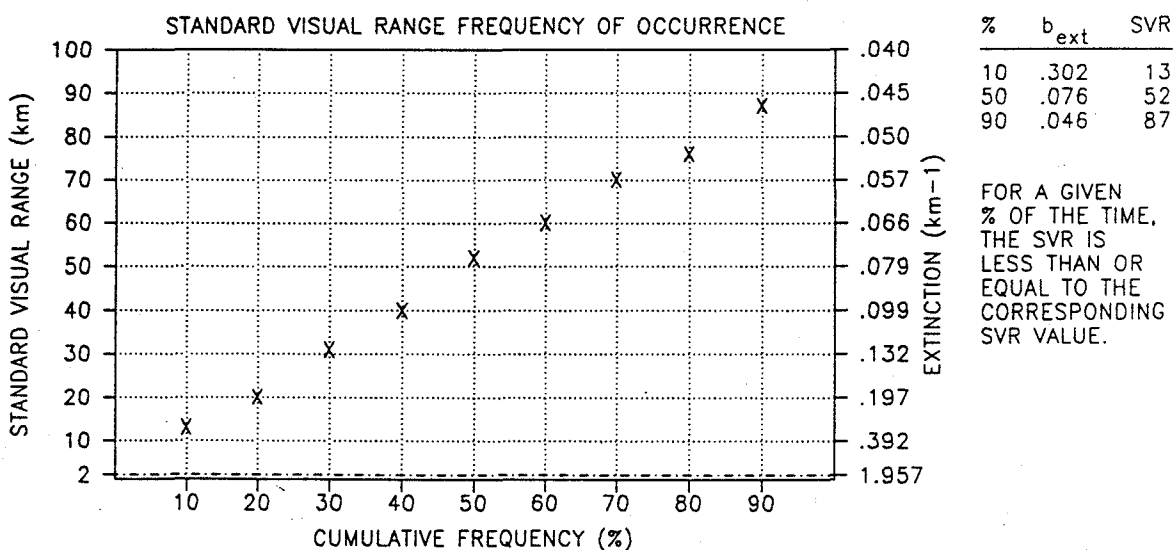
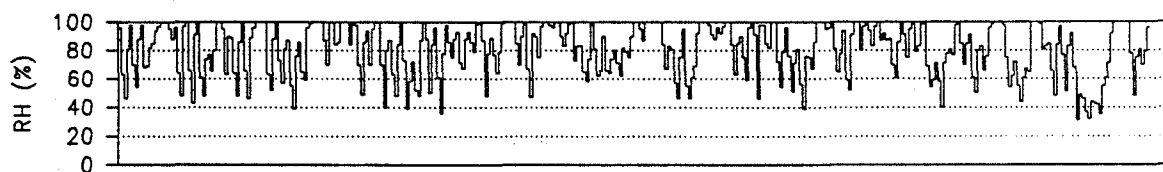
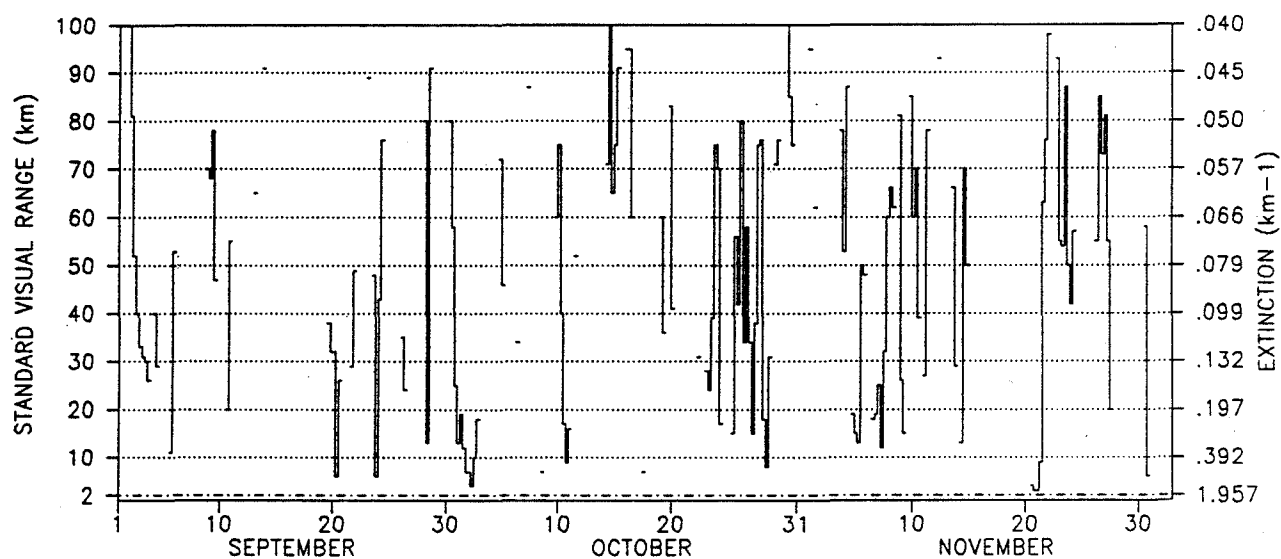
CATEGORY	NUM	%
TOTAL POSSIBLE 6-HOUR AVERAGES IN THE TIME PERIOD	368	100
USABLE 6-HOUR AVERAGES IN THE TIME PERIOD	98	26

Figure 5.

ACADIA NATIONAL PARK

Transmissometer Data Summary -- 6 Hour Averages

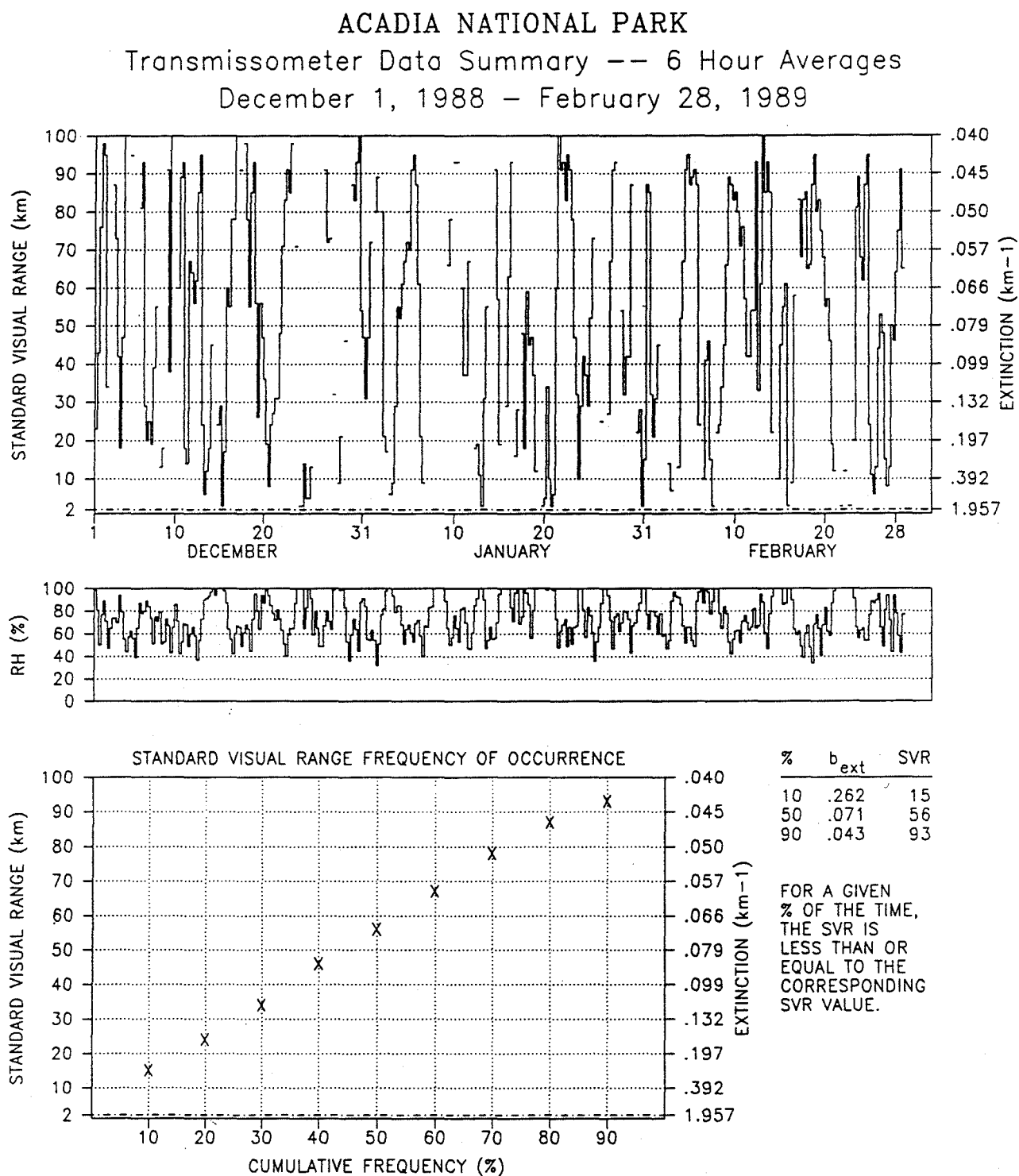
September 1, 1988 - November 30, 1988



TRANSMISSOMETER DATA RECOVERY STATISTICS

CATEGORY	NUM	%
TOTAL POSSIBLE 6-HOUR AVERAGES IN THE TIME PERIOD	364	100
USABLE 6-HOUR AVERAGES IN THE TIME PERIOD	139	38

Figure 6.



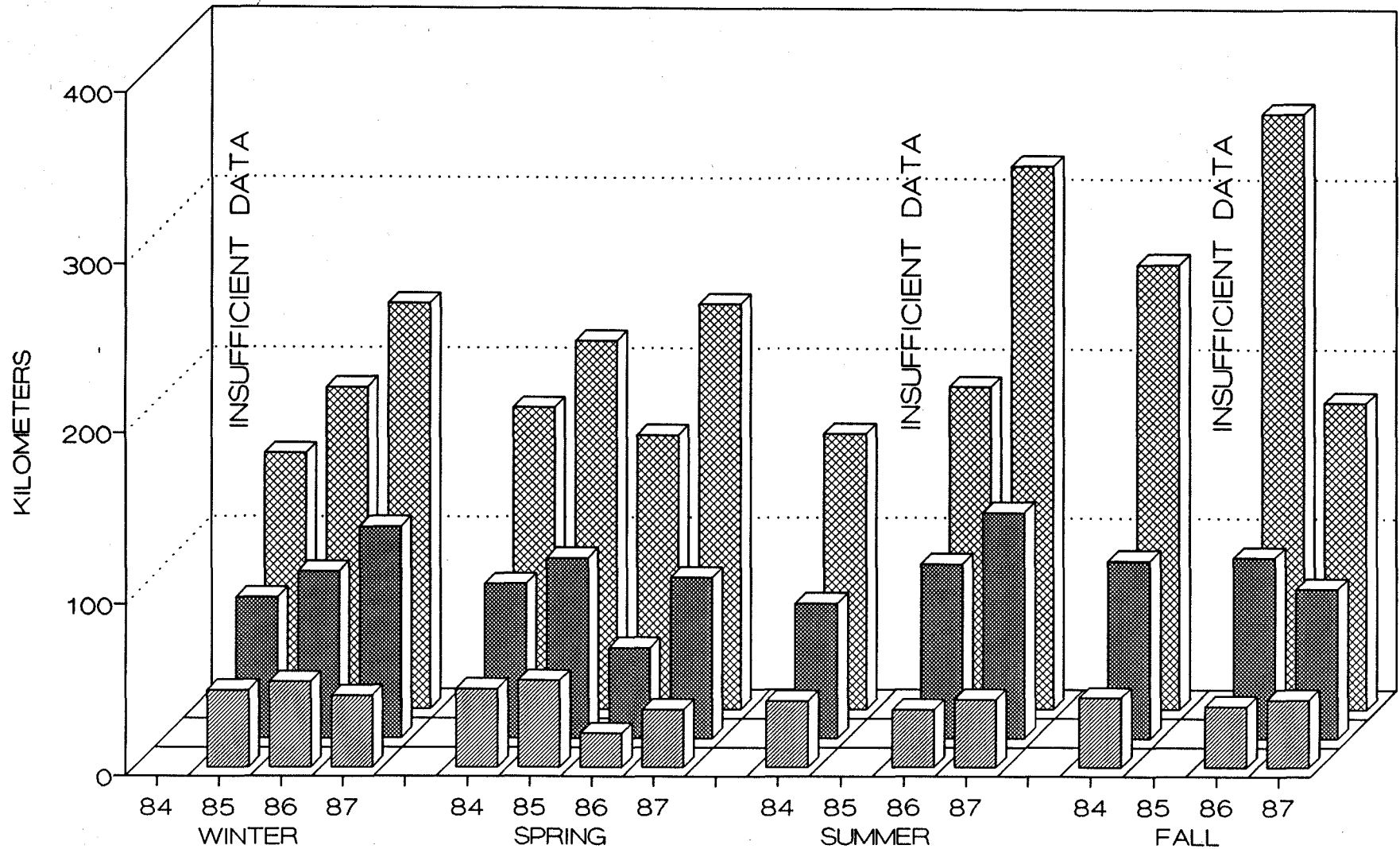
TRANSMISSOMETER DATA RECOVERY STATISTICS

CATEGORY	NUM	%
TOTAL POSSIBLE 6-HOUR AVERAGES IN THE TIME PERIOD	360	100
USABLE 6-HOUR AVERAGES IN THE TIME PERIOD	253	70

Figure 7.

ACADIA NATIONAL PARK STANDARD VISUAL RANGE

10TH PERCENTILE
 50TH PERCENTILE
 90TH PERCENTILE



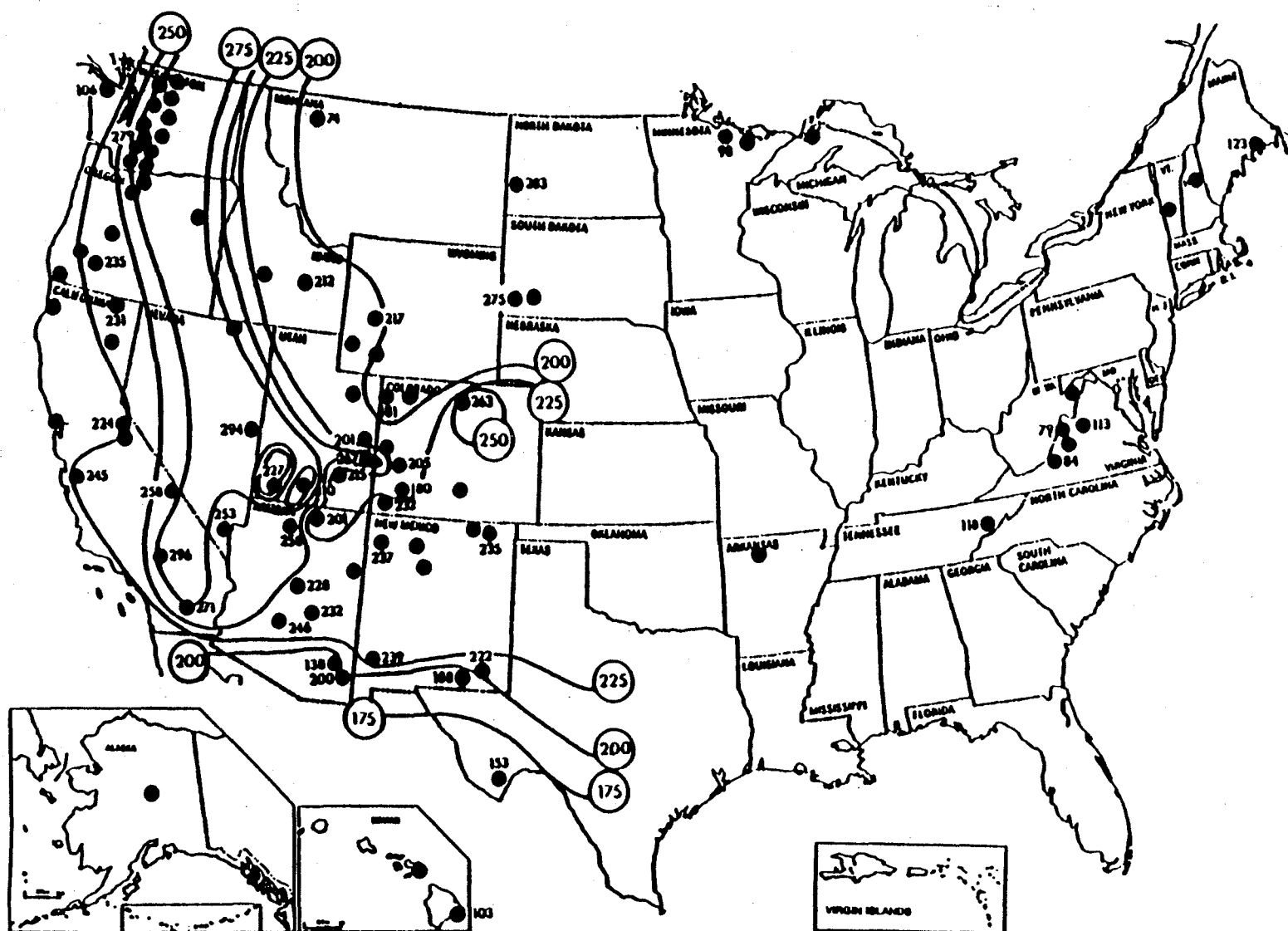


Figure 8. Winter 1987 Contour Plot of Seasonal Mean Standard Visual Ranges (50% SVR Value).

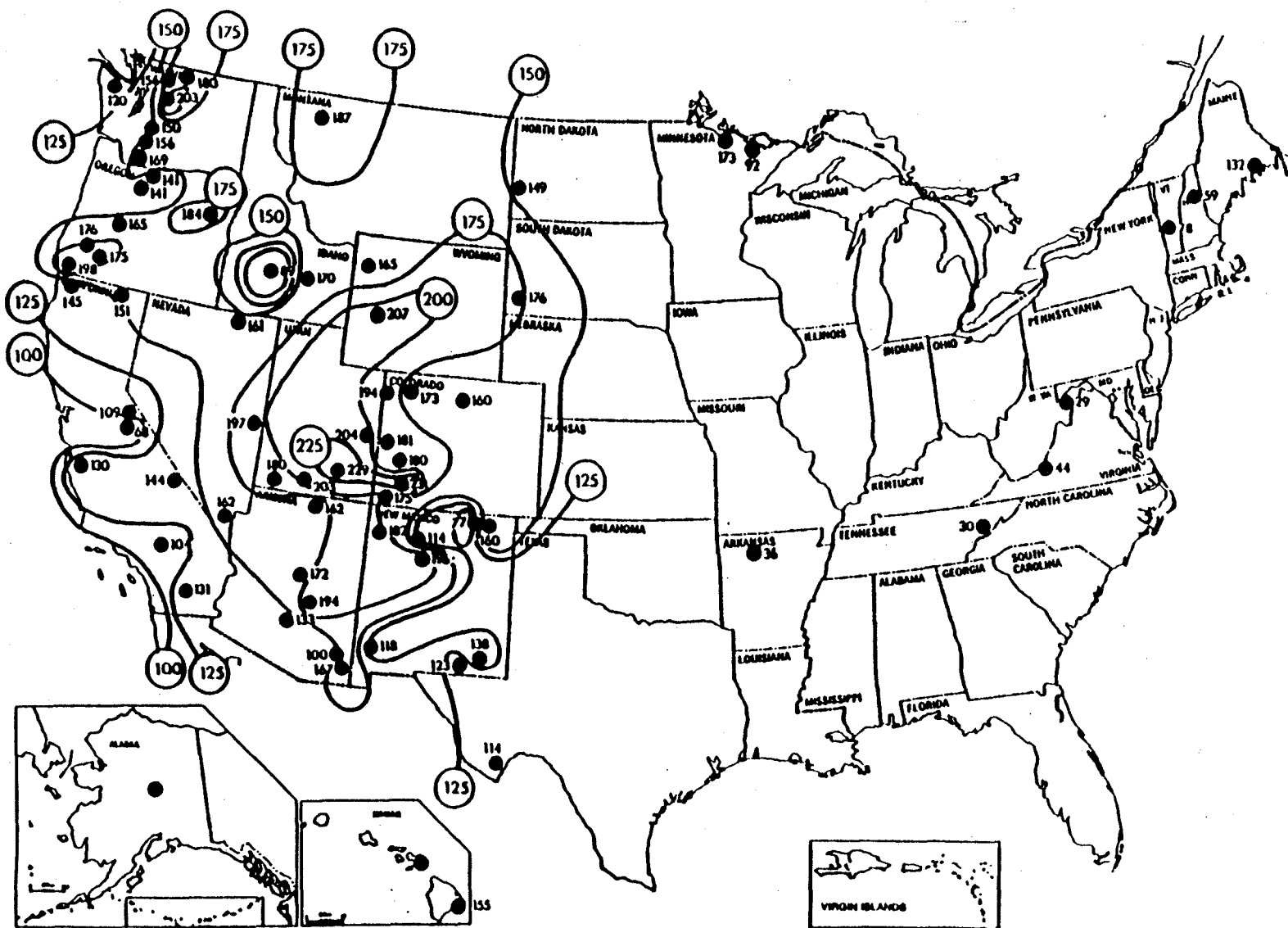
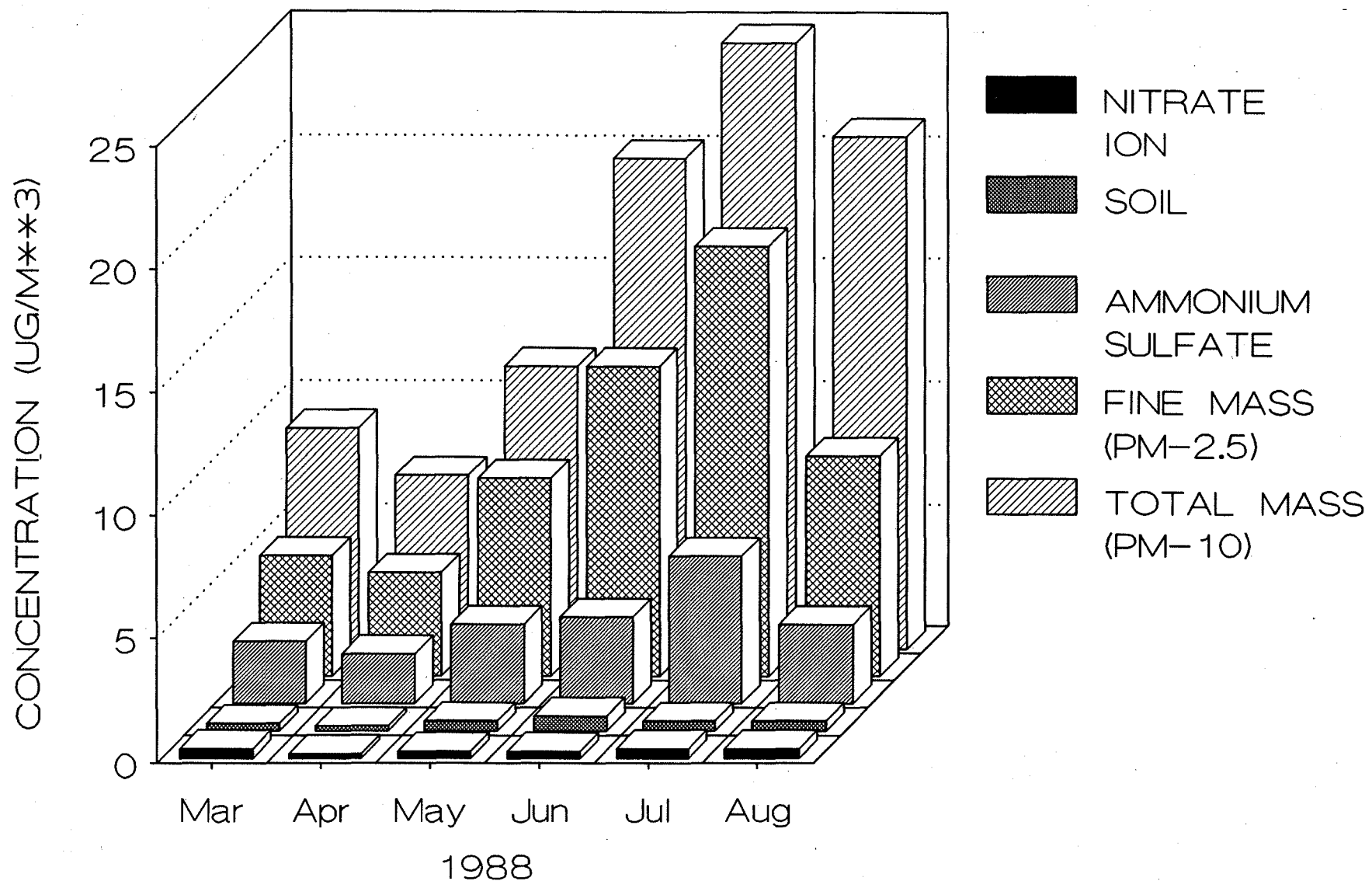


Figure 10. Summer 1987 Contour Plot of Seasonal Mean Standard Visual Ranges (50% SVR Value).

Figure 12.

ACADIA NATIONAL PARK PARTICULATE MATTER



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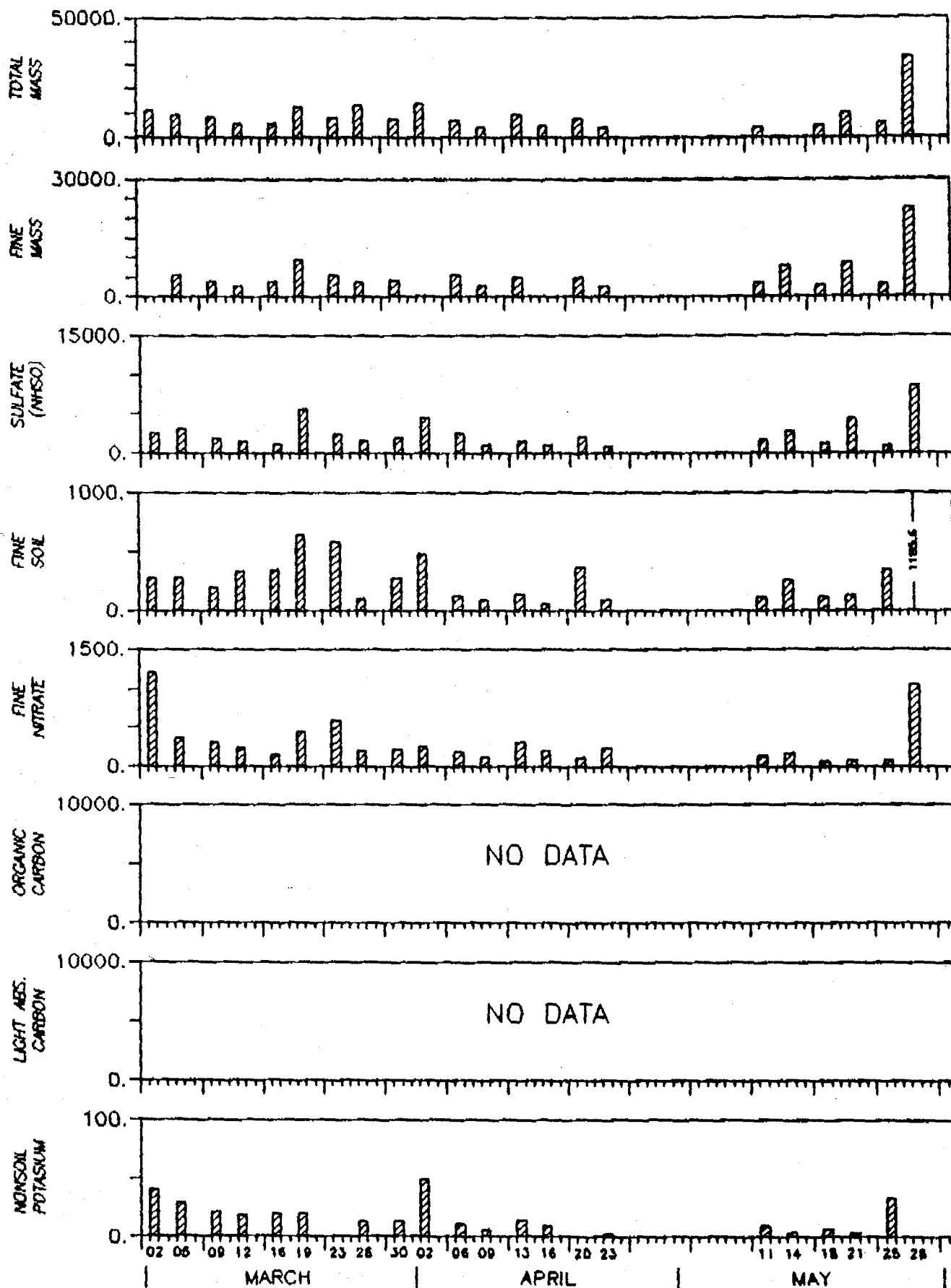
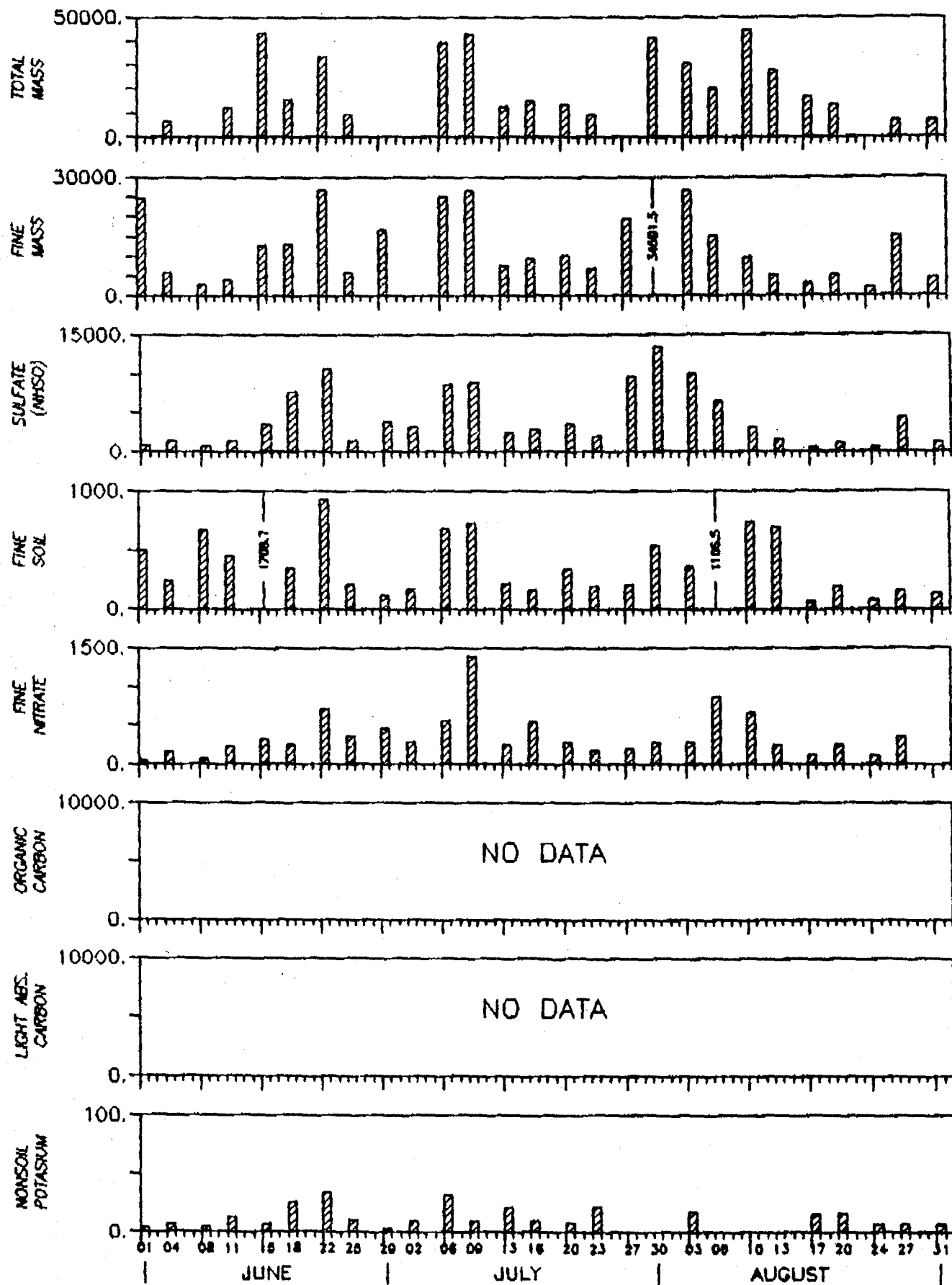
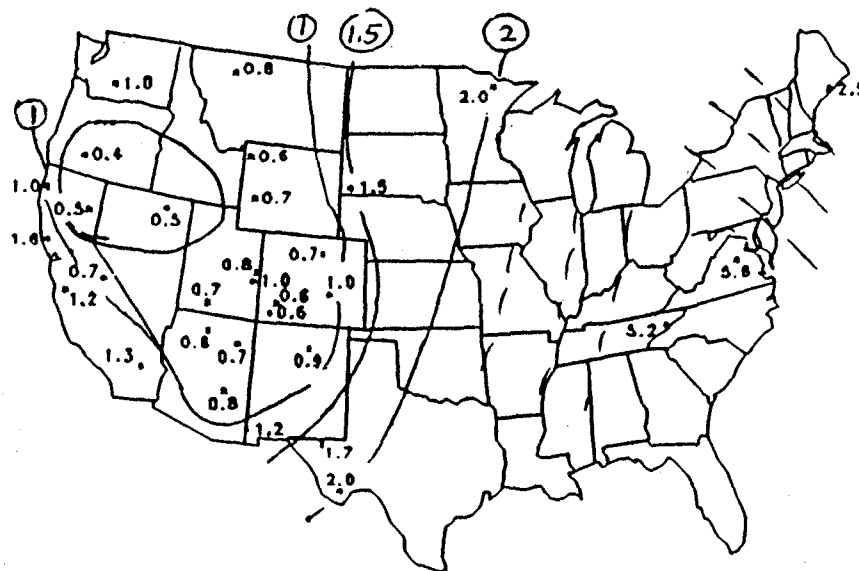
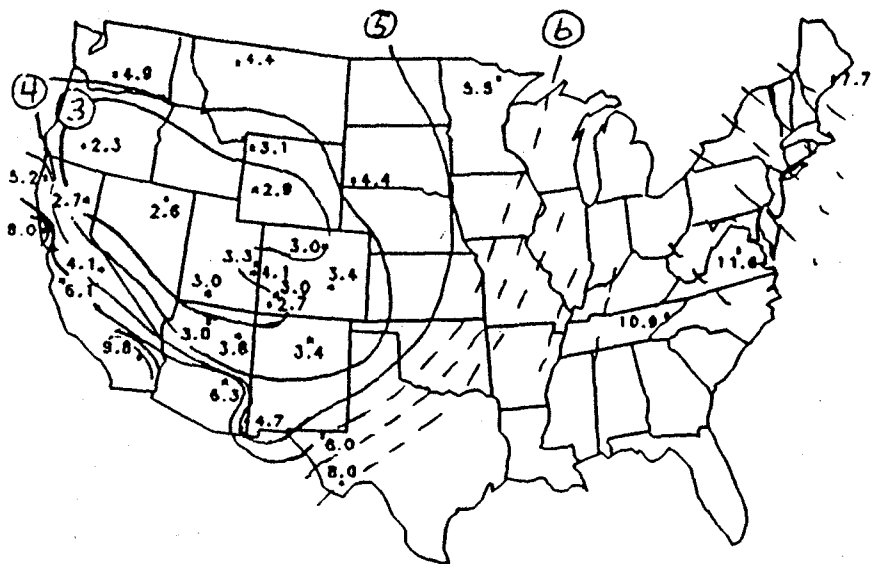


Figure 14.

SUMMER 1988 ACADIA NATIONAL PARK



AMMONIUM SULFATE



FINE SOIL

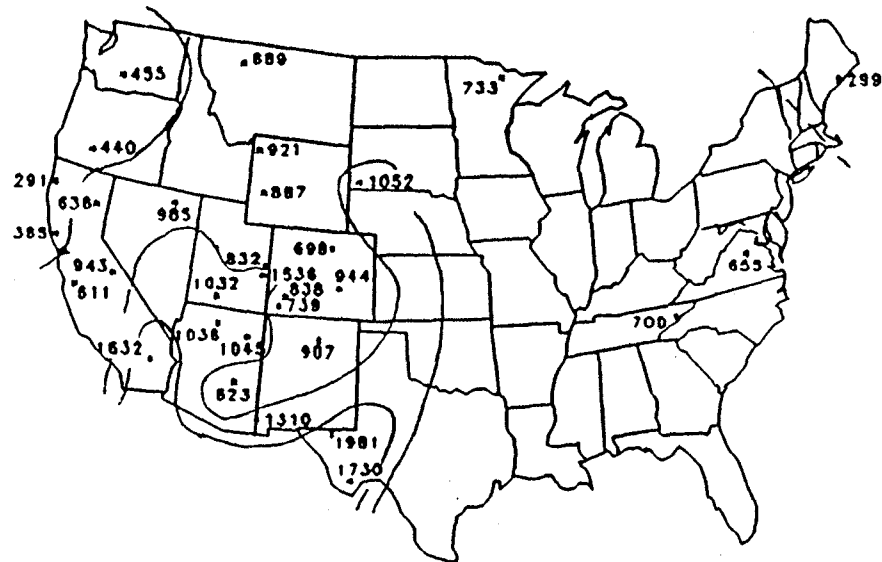
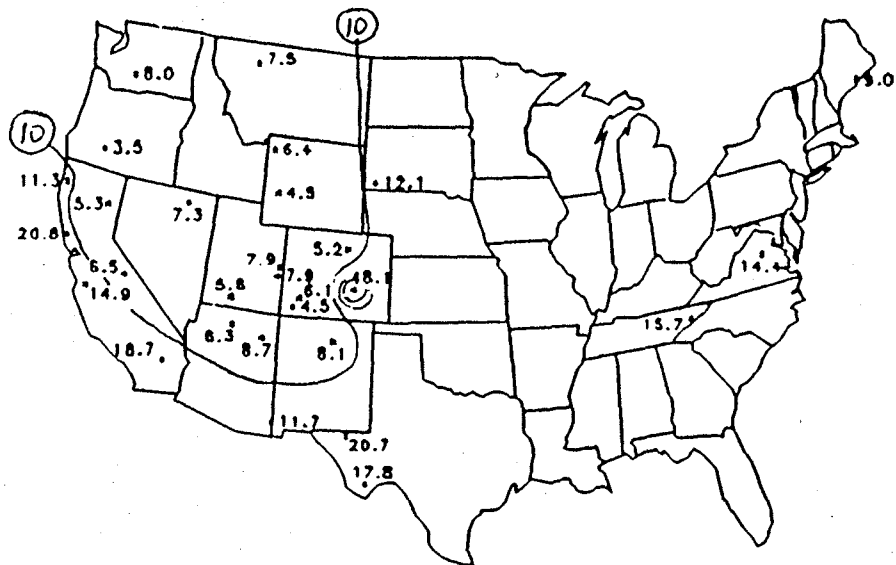


Figure 15.

IMPROVE NETWORK SPRING 1988

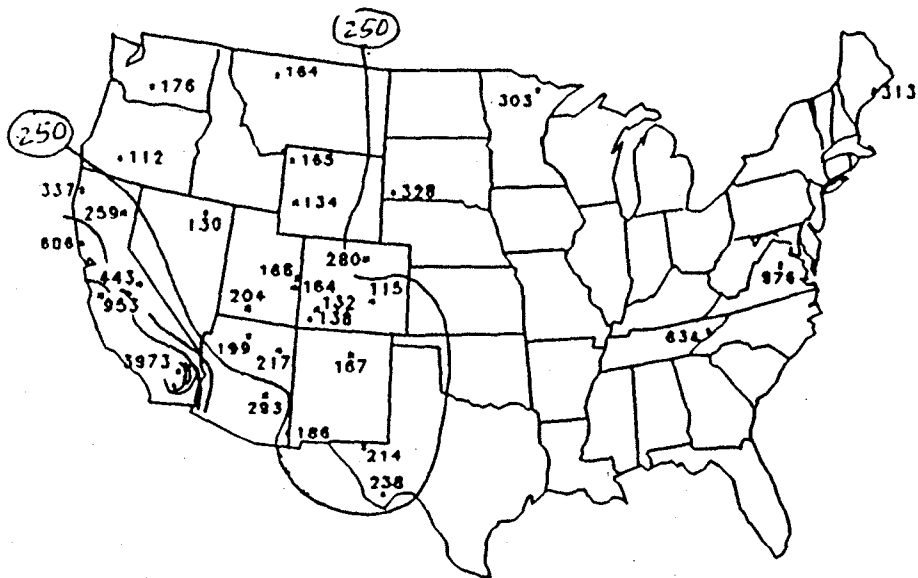
ORGANIC CARBON



LIGHT ABSORBING CARBON



NITRATE



NONSOIL POTASIIUM

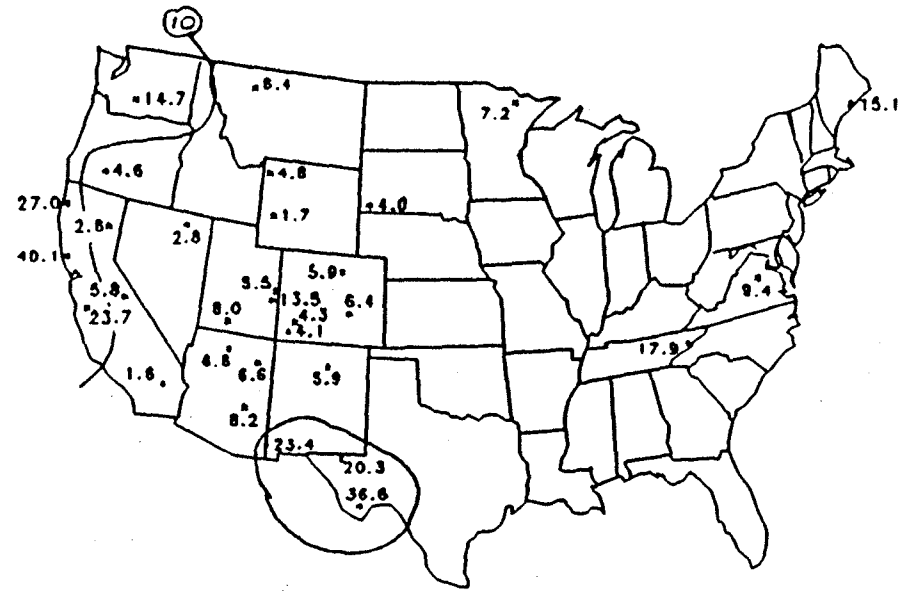
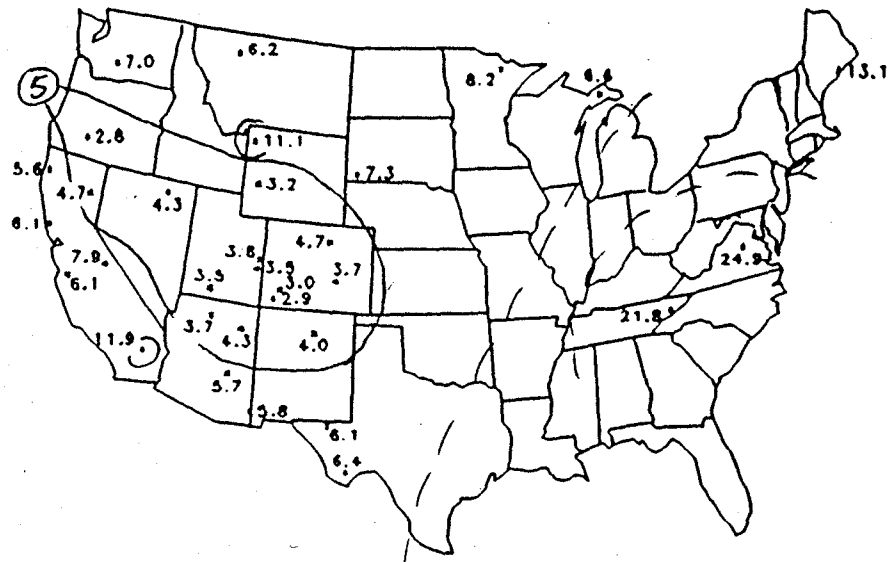
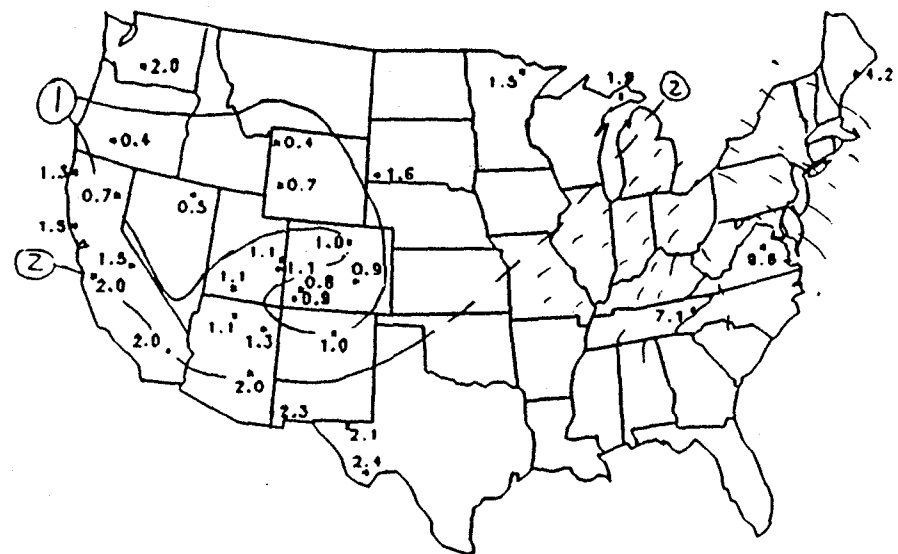


Figure 15. (con't)

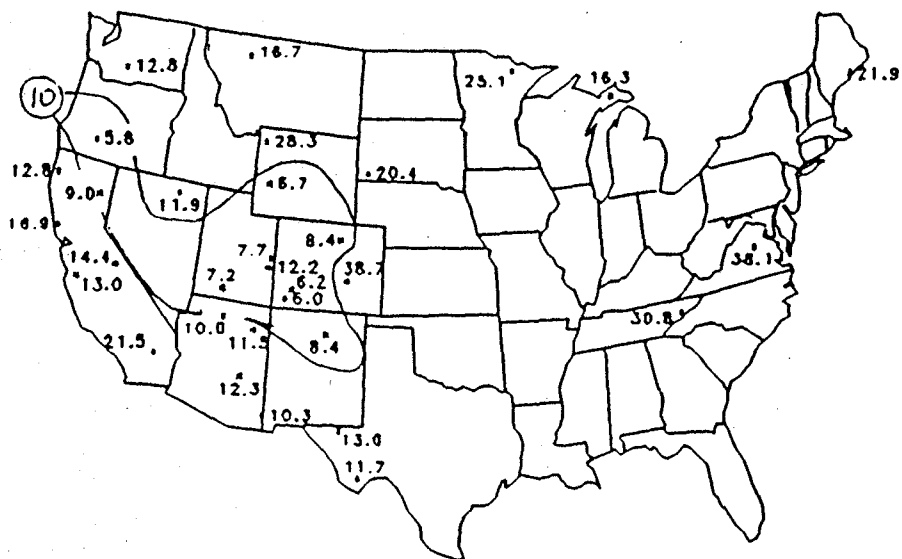
FINE MASS



AMMONIUM SULFATE



TOTAL MASS



FINE SOIL

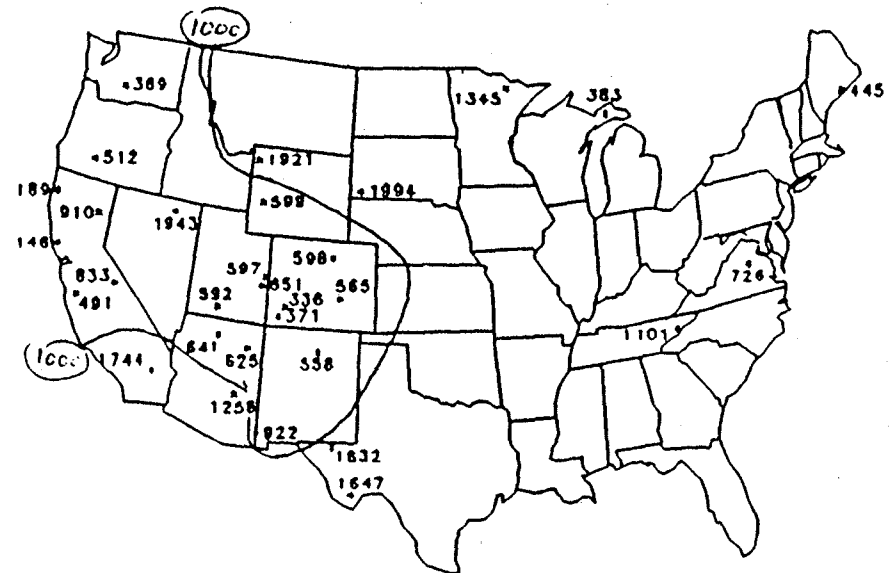


Figure 16.

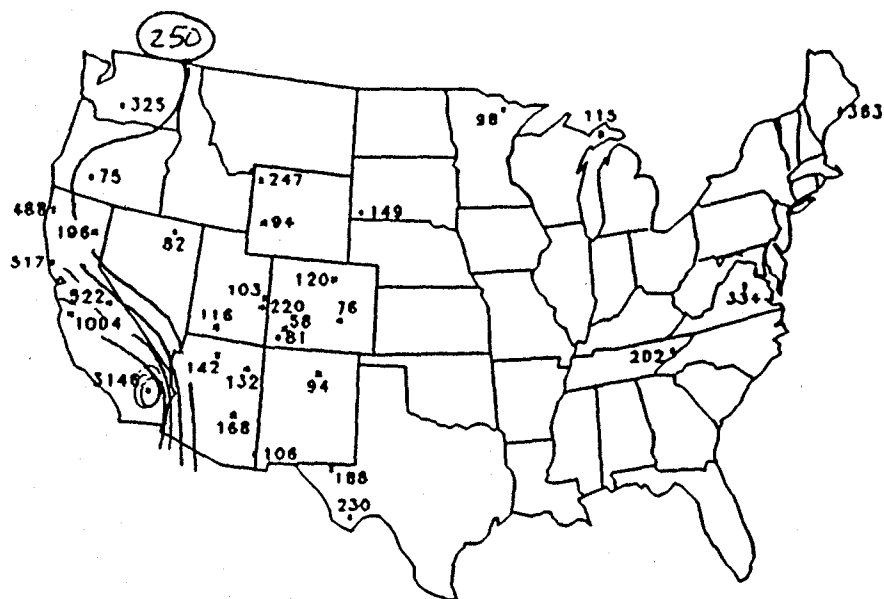
ORGANIC CARBON



LIGHT ABSORBING CARBON



NITRATE



NONSOIL POTASIAM

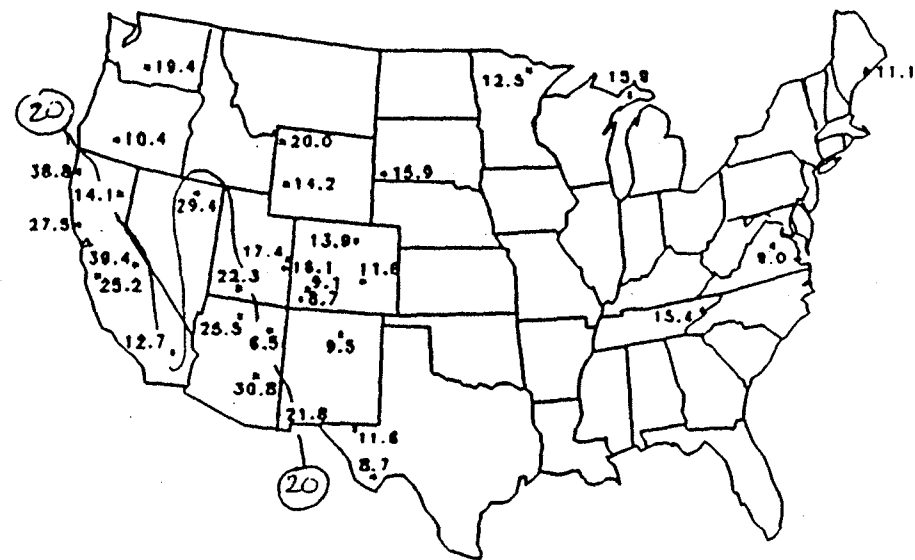


Figure 16. (con't)



Figure 17. Fine mass (concentration of all fine particles) in $\mu\text{g}/\text{m}^3$ and percent of fine mass as ammonium sulfate, soil, soot, and remaining mass. Average values over two year period.

Figure 18.

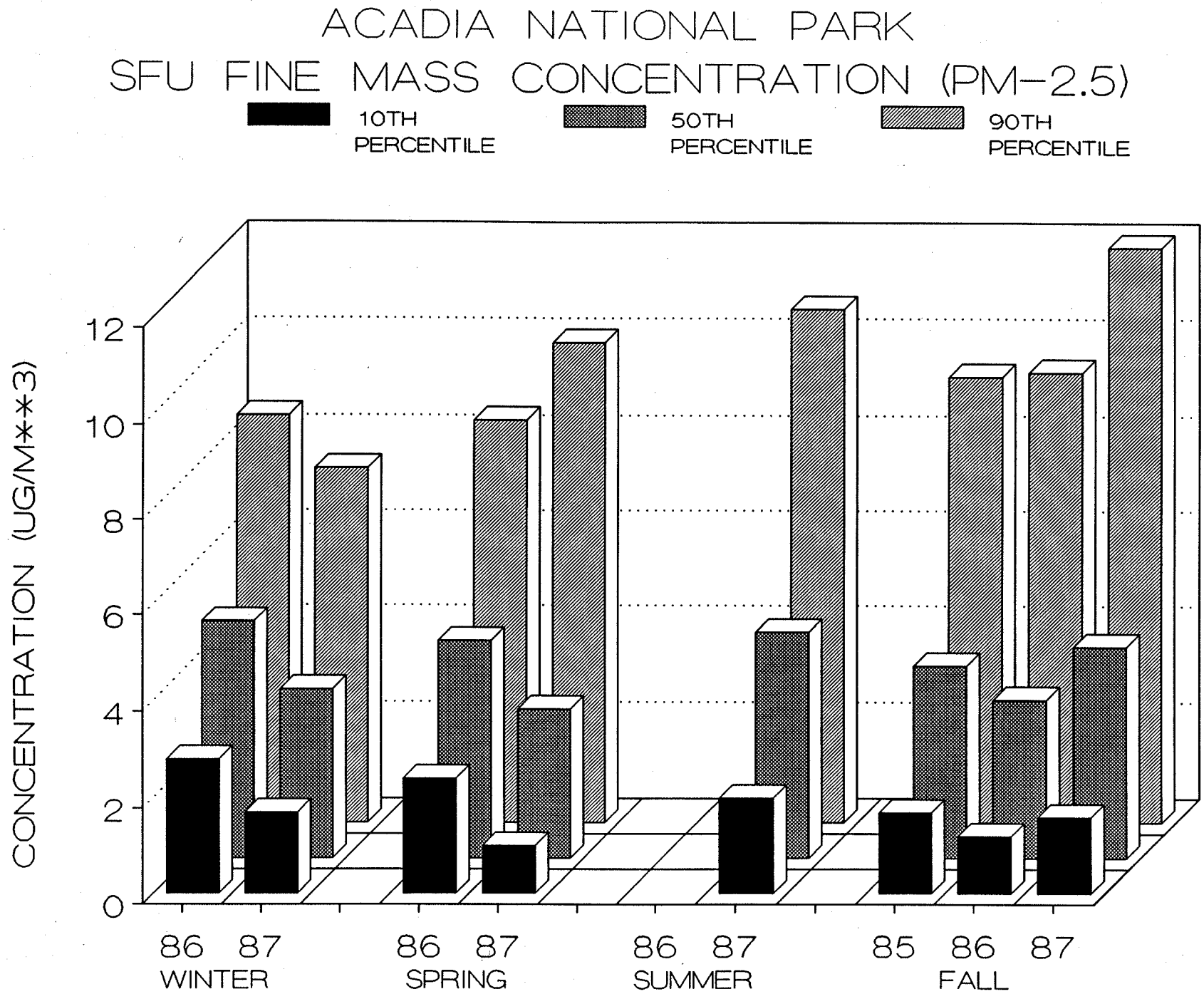


Figure 19.

ACADIA NATIONAL PARK SFU FINE AMMONIUM SULFATE CONCENTRATION

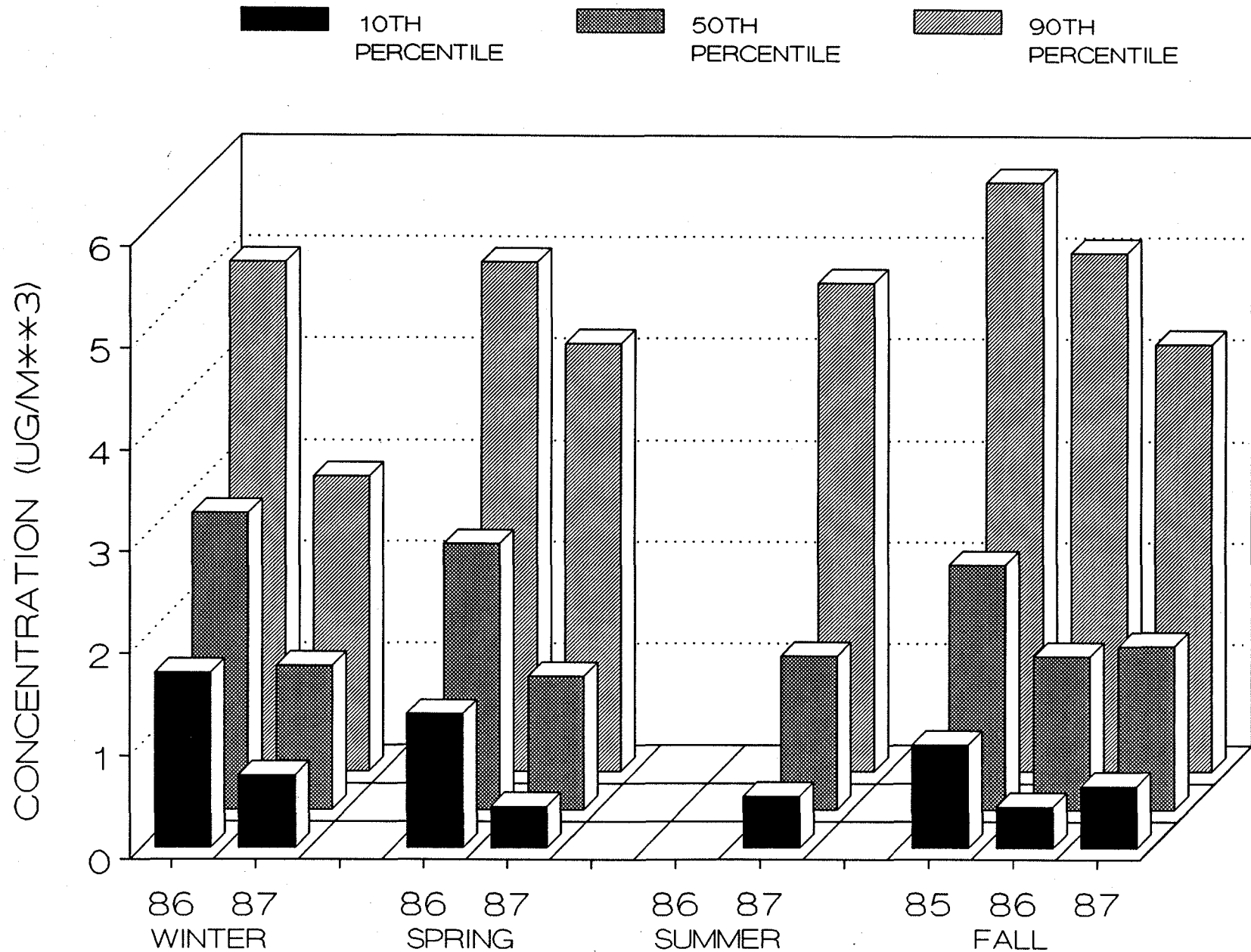


Figure 20.

ACADIA NATIONAL PARK MONTHLY HIGHEST HOURLY OZONE AVERAGES

2ND HIGHEST HIGHEST

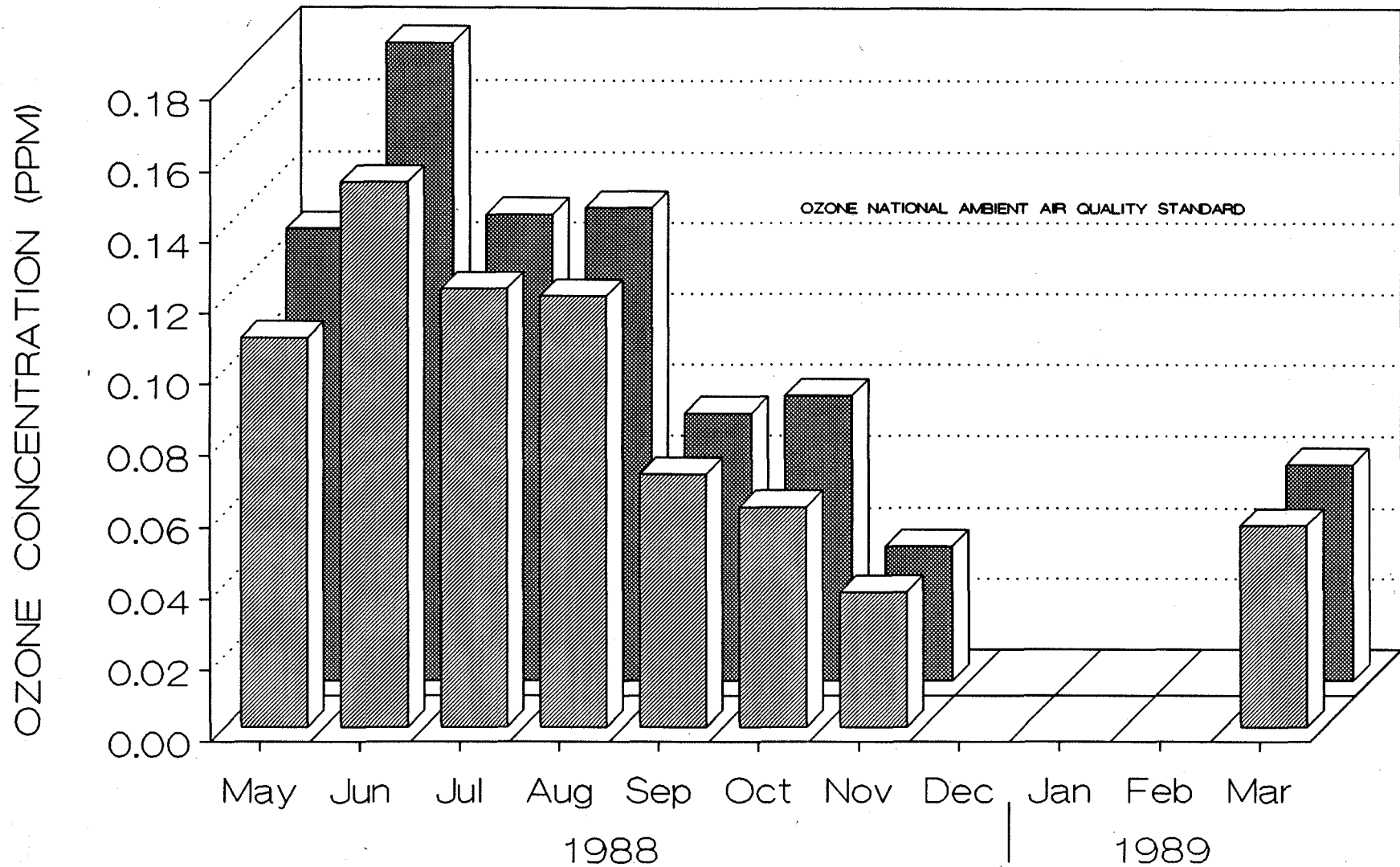
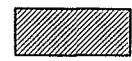
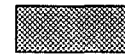


Figure 21.

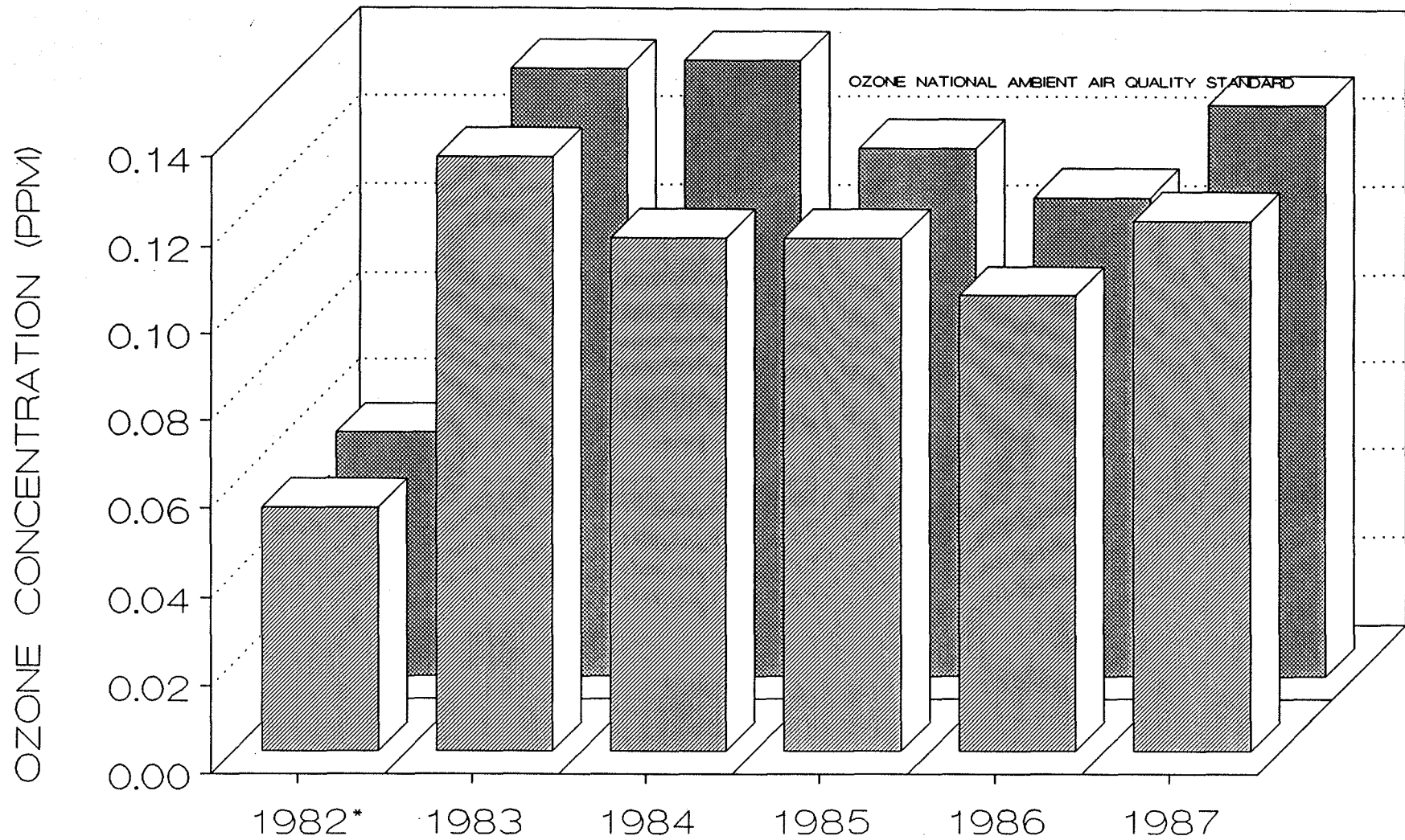
ACADIA NATIONAL PARK YEARLY HIGHEST HOURLY OZONE AVERAGES



2ND HIGHEST



HIGHEST



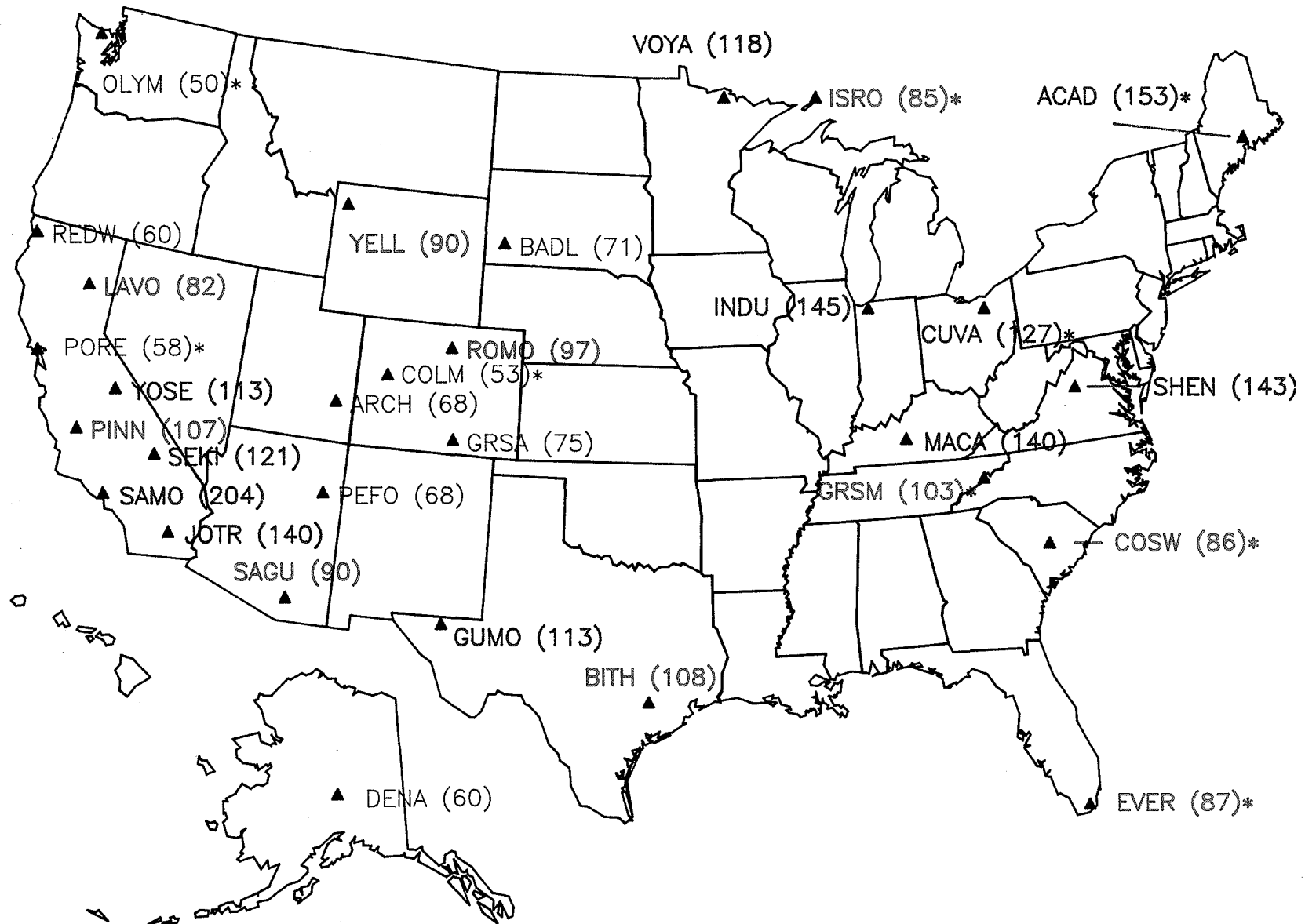
* Sampled for less than full ozone season

Figure 22.

1988 NATIONAL PARK SERVICE OZONE MONITORING DATA

SECOND HIGHEST HOURLY VALUE (ppb); * - DENOTES PARTIAL YEAR DATA

RED = > 110 ppb ; YELLOW = 76 ppb TO 109 ppb ; GREEN = < 75 ppb

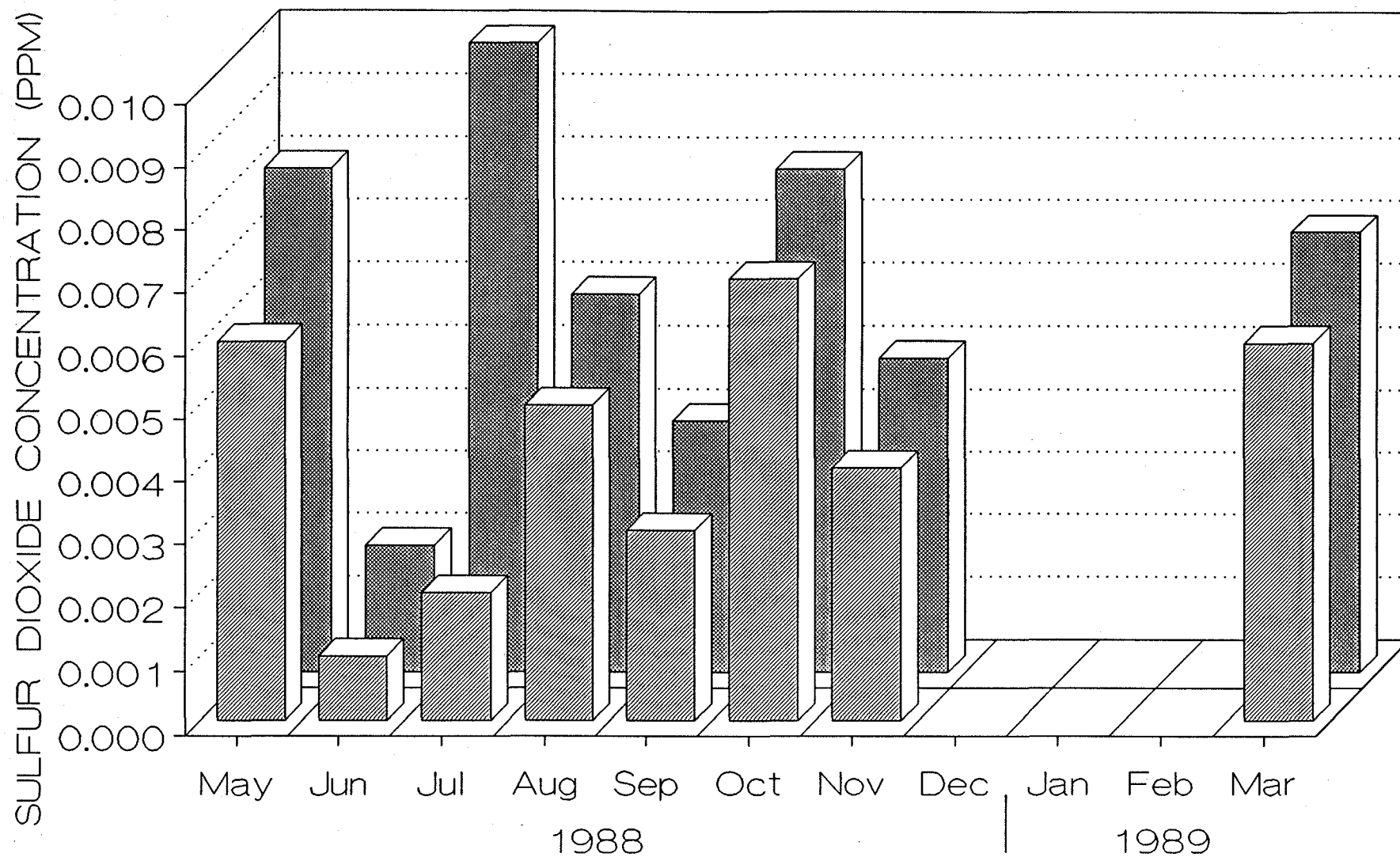


BASED ON U.S. FOREST SERVICE SCREENING CRITERIA

Figure 23.

ACADIA NATIONAL PARK MONTHLY HIGHEST HOURLY SULFUR DIOXIDE AVERAGES

2ND HIGHEST HIGHEST



IMPROVE PARTICULATE NETWORK

Concentrations in nanograms/cubic meter for particles smaller than 2.5µm
PM10 is mass for particles smaller than 10µm.

		arithmetic mean concentrations				distribution of concentrations		
	cases found	MAR	APR	MAY	season	minimum	median	maximum
PM10	21	8999	7075	11543	8963	3852	7471	33558
MASS	21	4856	4220	8080	5720	2672	4110	22699
AL	11	22	11	33	21	3	6	86
SI	22	68	48	69	62	11	52	208
S	22	597	475	782	609	209	476	2053
K	22	41	26	27	33	8	30	72
CA	19	27	11	19	20	1	17	81
TI	17	2.4	1.3	2.7	2.1	0.9	1.5	7.0
FE	22	33	18	32	28	6	19	131
NI	8	1.0	1.1	1.8	1.2	0.3	0.5	7.7
CU	12	1.3	0.4	2.0	1.2	0.4	0.7	4.8
ZN	22	6.2	4.4	10.1	6.7	1.4	4.6	32.8
AS	5	0.5	0.5	0.7	0.6	0.3	0.5	1.2
SE	7	0.6	0.5	0.7	0.6	0.2	0.4	2.0
BR	15	4.8	1.9	2.4	3.2	0.4	2.9	11.2
PB	21	6.9	5.3	9.4	7.1	1.3	6.2	30.9
OC	0	INSUFFICIENT DATA						
LAC	0	INSUFFICIENT DATA						
NO3-	22	423.9	208.7	268.1	312.9	67.0	223.3	1210.5
SO2	0	INSUFFICIENT DATA						
NHSO	22	2464.4	1960.1	3226.3	2511.7	863.0	1962.7	8469.8
SOIL	22	338.3	196.7	357.6	298.5	64.8	265.4	1185.6
KNON	22	19.9	13.6	9.8	15.1	0.3	11.8	50.3

"OC" IS ORGANIC CARBON.

"LAC" IS LIGHT ABSORBING CARBON.

"NO3-" IS NITRATE ION.

"SO2" IS SULFUR DIOXIDE GAS

"NHSO" IS AMMONIUM SULFATE, CALCULATED AS 4.125 TIMES S.

"SOIL" IS THE SUM OF AL, SI, CA, TI, AND FE, ESTIMATED OXIDES, SOIL POTASIAM AND MINOR COMPONENTS.

"KNON" IS NONSOIL POTASIAM, ESTIMATED FROM FE AND K.

ACADIA NATIONAL PARK

Table II

JUN - AUG 1988
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IMPROVE PARTICULATE NETWORK

Concentrations in nanograms/cubic meter for particles smaller than 2.5µm
PM10 is mass for particles smaller than 10µm.

		arithmetic mean concentrations				distribution of concentrations		
	cases found	JUN	JUL	AUG	season	minimum	median	maximum
PM10	21	20013	24746	20940	21944	6198	9134	44781
MASS	26	12620	17458	9027	13109	2205	9603	34502
AL	22	48	22	27	32	2	25	150
SI	27	124	77	92	97	12	70	384
S	27	841	1459	777	1026	122	741	3233
K	27	41	34	25	33	13	26	94
CA	26	31	23	22	25	1	19	99
TI	27	5.8	5.3	5.5	5.5	0.7	4.9	13.9
FE	27	40	32	26	33	6	25	95
NI	18	2.8	5.0	3.0	3.6	0.2	2.4	10.3
CU	16	1.3	4.2	1.5	2.3	0.2	0.8	9.6
ZN	27	8.3	11.9	6.4	8.9	1.7	8.2	21.3
AS	0			INSUFFICIENT DATA				
SE	7	0.5	0.6	0.4	0.5	0.1	0.4	1.2
BR	25	2.2	1.7	1.4	1.8	0.4	1.5	4.3
PB	27	6.6	7.0	5.1	6.2	1.5	6.0	12.8
OC	0			INSUFFICIENT DATA				
LAC	0			INSUFFICIENT DATA				
NO3-	26	290.4	437.5	362.1	363.4	56.7	267.3	1386.0
SO2	0			INSUFFICIENT DATA				
NHSO	27	3470.2	6016.8	3204.7	4230.6	502.0	3057.8	13337.4
SOIL	27	576.5	363.8	395.5	445.3	71.0	333.7	1708.7
KNON	27	12.8	12.7	8.0	11.1	4.1	8.5	34.6

"OC" IS ORGANIC CARBON.

"LAC" IS LIGHT ABSORBING CARBON.

"NO3-" IS NITRATE ION.

"SO2" IS SULFUR DIOXIDE GAS

"NHSO" IS AMMONIUM SULFATE, CALCULATED AS 4.125 TIMES S.

"SOIL" IS THE SUM OF AL, SI, CA, TI, AND FE, ESTIMATED OXIDES, SOIL POTASIAM AND MINOR COMPONENTS.

"KNON" IS NONSOIL POTASIAM, ESTIMATED FROM FE AND K.

IMPROVE PARTICULATE NETWORK

24 hour average concentrations in nanograms/cubic meter for particles smaller than 2.5µm.
PM10 is mass for particles smaller than 10µm.

DATE	PM10	MASS	AL	SI	S	K	CA	TI	FE	NI
03/02	10830	N/A	3*	55	649	60	49	2.6	26	1.8
03/05	9038	5497	3*	67	760	50	24	4.9	29	0.4*
03/09	8256	3836	3*	49	482	32	25	1.6	16	0.4*
03/12	5683	2673	34	60	366	39	24	3.2	28	0.4*
03/16	6000	3704	41	64	317	38	16	2.4	25	1.1
03/19	12742	9529	79	114	1352	53	30	2.5	47	2.7
03/23	7752	5559	6*	126	593	45	40	2.0	84	0.8*
03/26	13216	3940	4*	18	389	21	23	1.2*	12	0.5*
03/30	7471	4110	21	56	470	31	16	1.2	26	0.5*
04/02	13580	N/A	52	106	1086	72	17	1.2*	30	2.9
04/06	7043	5596	3*	37	645	19	8	1.3	12	0.5*
04/09	3852	2914	3*	26	236	13	6	1.0	10	1.0
04/13	9129	4926	4*	28	390	28	19	1.3*	19	0.5*
04/16	4361	N/A	9	11	249	14	3	1.1*	6	0.5*
04/20	7658	4980	4*	110	511	23	13	1.9	33	0.5*
04/23	3903	2672	3*	20	209	14	9	1.1*	16	1.6
05/11	4100	3344	9	30	375	16	1*	1.4	8	0.5*
05/14	N/A	7815	23	55	693	15	11	0.9	17	0.5*
05/18	4686	2925	7	32	309	14	1*	1.5	8	0.3*
05/21	9776	8522	3*	46	1051	8	1*	3.5	6	1.1
05/25	5593	3185	70	43	212	48	19	2.2	20	0.5*
05/28	33558	22689	86	208	2053	63	81	7.0	131	7.7

DATE	CU	ZN	AS	SE	BR	PB	OC	LAC	N03-	S02
03/02	1.6	9.3	0.6	0.4*	8.6	6.6	N/A	N/A	1210.5	N/A
03/05	1.4	8.6	0.4*	0.7	4.4	11.9	N/A	N/A	370.6	N/A
03/09	1.7	4.2	0.4*	0.4*	4.7	3.8	N/A	N/A	324.8	N/A
03/12	1.0	4.5	0.3*	1.0	4.8	6.5	N/A	N/A	253.1	N/A
03/16	1.0	3.0	1.1	0.4*	1.5	3.9	N/A	N/A	162.6	N/A
03/19	2.2	12.5	0.5*	0.7	4.5	9.4	N/A	N/A	451.5	N/A
03/23	1.9	9.5	0.7*	0.8*	7.3	11.2	N/A	N/A	595.8	N/A
03/26	0.4*	1.5	0.4*	0.4*	3.9	2.1	N/A	N/A	218.9	N/A
03/30	0.4*	3.0	0.4*	0.5*	3.1	6.5	N/A	N/A	227.6	N/A
04/02	0.4*	9.2	0.8	0.2	2.7	7.3	N/A	N/A	258.1	N/A
04/06	0.4	3.9	0.5*	0.5*	3.5	6.1	N/A	N/A	196.9	N/A
04/09	0.4*	1.4	0.4*	0.9	0.6*	5.6	N/A	N/A	117.1	N/A
04/13	0.5*	2.4	0.5*	0.5*	3.1	2.5	N/A	N/A	312.5	N/A
04/16	0.4*	3.7	0.4*	0.4*	2.3	6.3	N/A	N/A	207.5	N/A
04/20	0.4*	7.2	0.5*	0.5*	0.6*	5.2	N/A	N/A	128.8	N/A
04/23	0.4*	2.8	0.4*	0.4*	0.5*	4.5	N/A	N/A	239.9	N/A
05/11	0.4*	4.8	0.4*	0.4*	0.5*	6.4	N/A	N/A	145.3	N/A
05/14	0.4*	3.3	1.2	0.4	0.6*	1.3*	N/A	N/A	178.0	N/A
05/18	1.0	8.2	0.3*	0.3*	0.4*	8.8	N/A	N/A	67.0	N/A
05/21	1.5	6.0	1.1	0.4*	0.5*	5.6	N/A	N/A	87.8	N/A
05/25	4.8	5.5	0.4*	0.4*	1.4	3.7	N/A	N/A	88.7	N/A
05/28	4.1	32.8	0.6*	2.0	11.2	30.9	N/A	N/A	1041.9	N/A

*analytical minimum detectable limit; actual concentration is less than this amount.

ACADIA NATIONAL PARK

Table IV

JUN - AUG 1988

IMPROVE PARTICULATE NETWORK

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24 hour average concentrations in nanograms/cubic meter for particles smaller than 2.5µm.
PM10 is mass for particles smaller than 10µm.

DATE	PM10	MASS	AL	SI	S	K	CA	TI	FE	NI
06/01	N/A	24823	51	103	197	25	23	7.4	30	0.5*
06/04	6198	5987	32	36	326	23	11	6.4	22	0.5*
06/08	N/A	2925	67	157	168	30	22	3.9	35	0.4*
06/11	12065	4206	41	90	337	35	27	8.9	31	0.4*
06/15	43488	12839	150	384	826	74	99	9.2	95	0.5*
06/18	15765	13312	28	75	1841	44	23	1.6	25	6.9
06/22	33429	26911	56	195	2587	94	52	6.7	85	8.9
06/25	9134	5759	10	45	355	24	16	4.0	18	0.4*
06/29	N/A	16821	3*	30	934	15	4	3.9	15	6.9
07/02	N/A	N/A	27	18	741	23	16	1.4	19	5.6
07/06	39431	24953	45	143	2058	73	37	12.2	60	5.9
07/09	42790	26364	39	151	2170	51	61	11.9	58	8.5
07/13	12509	7594	21	50	598	31	12	2.9	12	0.3*
07/16	14982	9500	5	24	690	26	15	1.6	23	0.4*
07/20	13494	10126	23	70	858	30	13	5.0	30	5.1
07/23	8996	7098	25	32	477	32	14	2.8	14	3.2
07/27	N/A	19531	4*	64	2300	14	1*	2.1	24	5.4
07/30	41021	34502	6*	139	3233	31	40	7.9	50	10.3
08/03	30563	26785	5*	95	2414	41	24	9.3	33	7.3
08/06	20211	15284	94	253	1555	42	42	13.9	68	8.9
08/10	44781	9707	59	181	753	24	31	8.8	37	4.5
08/13	27934	5228	50	167	373	24	42	4.9	35	1.5
08/17	16809	3269	4	12	140	20	10	0.7	6	0.4
08/20	13177	5227	15	39	268	25	19	2.2	13	1.1
08/24	N/A	2205	6	16	122	13	5	1.5	8	0.2*
08/27	6892	N/A	2*	36	1054	21	11	6.3	19	2.4
08/31	7148	4511	10	27	313	15	11	1.7	12	0.7

DATE	CU	ZN	AS	SE	BR	PB	OC	LAC	NO3-	SO2
06/01	0.5*	3.8	0.5*	0.5*	1.5	5.0	N/A	N/A	56.7	N/A
06/04	0.5*	4.2	0.5*	0.5*	1.2	7.1	N/A	N/A	163.1	N/A
06/08	3.1	2.9	0.4*	0.4*	2.1	3.4	N/A	N/A	77.8	N/A
06/11	0.3*	8.1	0.3*	0.4*	2.4	6.0	N/A	N/A	225.6	N/A
06/15	0.5*	9.5	0.4*	0.5*	2.9	12.8	N/A	N/A	310.7	N/A
06/18	0.4*	9.6	0.4*	0.4*	0.9	4.9	N/A	N/A	249.1	N/A
06/22	5.7	21.3	0.6*	0.7	4.3	9.3	N/A	N/A	718.7	N/A
06/25	0.4*	7.1	0.3*	0.4*	3.1	4.2	N/A	N/A	351.8	N/A
06/29	0.4*	8.3	0.4*	0.4*	1.0	6.3	N/A	N/A	460.3	N/A
07/02	2.9	7.1	0.5*	0.5	2.3	4.1	N/A	N/A	279.9	N/A
07/06	4.4	18.7	0.5*	0.7	2.3	10.9	N/A	N/A	553.8	N/A
07/09	5.9	15.2	0.5*	0.5	2.8	9.5	N/A	N/A	1386.0	N/A
07/13	0.3*	8.8	0.3*	0.4*	0.4*	3.7	N/A	N/A	244.9	N/A
07/16	0.4*	6.4	0.4*	0.4*	1.4	3.4	N/A	N/A	534.3	N/A
07/20	3.8	10.8	0.4*	0.5*	1.8	8.2	N/A	N/A	288.3	N/A
07/23	2.6	8.9	0.4*	0.4*	1.2	6.6	N/A	N/A	170.3	N/A
07/27	9.6	12.1	0.5*	0.5*	0.6*	5.1	N/A	N/A	193.1	N/A
07/30	7.7	19.0	0.6*	1.0	2.5	11.7	N/A	N/A	286.7	N/A
08/03	0.6*	11.9	0.5*	0.7	2.6	7.8	N/A	N/A	279.4	N/A
08/06	3.5	8.2	0.5*	1.2	2.4	6.1	N/A	N/A	876.2	N/A
08/10	2.3	6.5	0.3*	0.3*	2.2	9.3	N/A	N/A	657.7	N/A
08/13	2.5	11.1	0.4*	0.5*	0.8	8.5	N/A	N/A	238.9	N/A
08/17	0.6	1.7	0.2*	0.2*	1.1	1.5	N/A	N/A	133.1	N/A
08/20	0.8	3.9	0.2*	0.2*	1.1	2.8	N/A	N/A	255.1	N/A
08/24	0.2*	2.0	0.2*	0.2*	0.8	2.4	N/A	N/A	108.9	N/A
08/27	2.6	8.1	0.3*	0.3*	1.2	4.1	N/A	N/A	347.2	N/A
08/31	0.7	4.3	0.1*	0.1*	0.8	3.1	N/A	N/A	N/A	N/A

*analytical minimum detectable limit; actual concentration is less than this amount.

APPENDIX A

Overview of the IMPROVE Monitoring Program

In section 169A of the Clean Air Act As Amended August 1977, Congress declared as a national goal "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution." Mandatory class I Federal areas are national parks greater in size than 6000 acres, wilderness areas greater in size than 5000 acres and international parks that were in existence on August 7, 1977. This section required the U.S. Environmental Protection Agency (EPA) to promulgate regulations requiring States to develop programs in their State Implementation Plans (SIP's) providing for visibility protection in these areas. EPA promulgated these regulations on December 2, 1980.

Section 51.305 of the 1980 regulations required States to develop a monitoring strategy for evaluating visibility in the mandatory class I areas and to provide a mechanism for using any available data in decisions required by the visibility protection program. On July 12, 1985, EPA promulgated federal regulations for, among other things, a visibility monitoring strategy for those states that did not submit revisions to their SIP's for visibility protection. The federally promulgated visibility monitoring strategy called for the establishment of a cooperative visibility monitoring effort between the EPA and several federal land management agencies: the National Park Service (NPS), the Fish and Wildlife Service (FWS) and the Bureau of Land Management (BLM) of the U. S. Department of the Interior; and the Forest Service (FS) of the U. S. Department of Agriculture. Interagency Monitoring of Protected Visual Environments, or IMPROVE, is the name given to this new federal monitoring program to address the specific data needs of the section 169A visibility protection program.

Section 169A Visibility Data Needs and the Objectives of IMPROVE

The major components of the section 169A visibility protection program are: 1) a review of major new stationary sources of air pollution for possible visibility impacts in class I areas; 2) a review of all mandatory class I areas for existing visibility impairment reasonably attributable to existing sources, and to remedy the existing impairment through the imposition of the Best Available Retrofit Technology (BART) on those sources; and 3) the development of a long-term strategy to assure progress in remedying existing and preventing future visibility impairment in class I areas.

Each of these three components have associated visibility data needs.

New Source Review

The new source review provisions require the determination of the impact of a new source's emissions on visibility within class I areas, within any class

I area integral vista identified by a state and generally within the area affected by the proposed new source. (The Department of the Interior has decided not to identify integral vistas pursuant to 40 CFR 51.304. However, many states have the discretion to identify integral vistas and incorporate them in their plans to protect visibility.) A second major determination is whether these predicted impacts on the visibility of a class I area are "adverse." The adverse impact determination is a site specific test which examines whether a proposed facility will unacceptably affect the air quality related values (e.g., visibility or any other resource that has the potential to be affected by air pollution) of a class I area. Section 165(d)(2)(B) of the Clean Air Act gives the Federal Land Manager (FLM) of a class I area the "affirmative responsibility" to protect the area's air quality related values and to consider whether a proposed major facility will have an adverse impact on such values.¹

Before these determinations can be made it is necessary to define what is the baseline or existing visibility of the area in order to determine whether visibility is currently being impaired by air pollution; to ascertain the nature, frequency and magnitude of such impairment; to determine the pollutants responsible; to track changes produced by anthropogenic air pollutant emissions and to define spatial and temporal variations in visibility.

Reasonably Attributable Existing Visibility Impairment

The existing impairment provisions of the section 169A program require the identification of those mandatory class I areas with existing visibility impairment. Visibility impairment may manifest itself in the form of a coherent smoke plume, layered haze, or uniform haze. It must then be determined whether this identified impairment is "reasonably attributable" to an existing source(s). Reasonably attributable means that the impairment must be attributable by visual observation or any other technique (e.g., monitoring or modeling) the state or EPA deems appropriate. A BART analysis is required for those sources suspected of causing reasonably attributable impairment. BART would then be required of the source if it were determined that it caused or contributed to "significant" visibility impairment and that cost-effective means of control were available to remedy the problem. "Significant" would be determined in a fashion similar to "adverse."

The control of reasonably attributable impairment necessitates the collection of data that documents the contribution of a given source(s) to the existing visibility impairment in a mandatory class I area. The pollutants responsible, frequency, duration, magnitude, and extent of the impairment caused by the source must be documented.

Long-term Strategy

The regulations also require the development of a long-term (10 to 15 year) strategy that will make reasonable progress toward the national visibility goal. This long-term strategy component requires background data to be collected for a long enough time period to demonstrate trends in visual and particle air quality. Special reasonably attributable follow-up studies for

BART sources as well as source attribution studies for sources not covered by BART also may be necessary to assure that reasonable progress toward the goal is being made.

Objectives of the IMPROVE Program

In consideration of the above program data needs, the objectives of the IMPROVE program are:

1. To establish the background visibility levels necessary to assess impacts of potential new sources through the development and operation of a long-term background monitoring network,
2. To determine the sources and levels of reasonably attributable visibility impairment through the design and implementation of special source attribution studies,
3. To collect data useful for assessing progress toward the national visibility goal, and
4. To promote the development of improved visibility monitoring technology and the collection of comparable visibility data by the evaluation of candidate monitoring methods and the development of quality assurance, data processing and documentation procedures.

To accomplish these objectives, a technical steering committee was formed with representation from the EPA, NPS, FWS, FS and the BLM. The committee's responsibilities include designing, deploying, and operating the entire monitoring program; selecting the sites for the various background stations and special studies; developing guidance documents for states and other parties that must monitor visibility; providing some data analysis and interpretation; establishing a database that can be accessed by outside parties and writing periodic status reports to inform the public of the status of these monitoring initiatives.

The IMPROVE Background Monitoring Network

Site Selection

Four site selection criteria were chosen to evaluate which of the 156 class I areas would become monitoring sites. The site selection criteria were: anticipated changes to the area's visibility; existing visibility problems; scenic sensitivity and scenic value; and the representativeness of the data to other class I areas. Weights were not assigned to these criteria.

Twenty long-term IMPROVE background monitoring sites were chosen and established based on the above criteria. The twenty sites include 15 national parks and 5 Forest Service wilderness areas. The NPS is presently monitoring visibility at 37 other NPS areas. Sixteen of these 37 monitoring stations,

including Acadia National Park, although not formally part of the IMPROVE program, are similarly equipped with IMPROVE-type instruments and operated according to the IMPROVE monitoring procedures. The remaining 21 NPS monitoring stations are equipped with 35mm cameras and constitute the NPS National Visibility Trend Monitoring Network. Figure A-1 shows the location of the 15 NPS IMPROVE and 16 NPS IMPROVE "look-alike" sites on a map of the United States. Figure A-2 illustrates the locations of the NPS camera only sites.

IMPROVE Monitoring Protocols

The IMPROVE protocols for background visibility monitoring consists of particle, optical, and view monitoring. The NPS was a major contributor to the development of the new monitoring protocols. View monitoring documents the appearance of the scene; optical monitoring measures the optical condition of the atmosphere; and particle monitoring determines the nature of the air pollutants responsible for visual impairment.

Particle monitoring in the IMPROVE and NPS network is accomplished by a combination of particle sampling and sample analysis. The sampler employed was designed specifically for the program. It collects four simultaneous samples: one PM-10 sample (particles less than 10 micron diameter) on a teflon filter and three PM-2.5 samples (particles less than 2.5 micron diameter) on teflon, nylon, and quartz filters. The IMPROVE sampler is programed to automatically collect two 24-hour duration samples per week.

This new particle monitor more completely characterizes the chemical composition of the particle, as compared to the stacked filter unit (SFU) monitors previously used by the NPS. The samples collected by the IMPROVE monitor will be analyzed for coarse (2.5-10um diameter particles) and fine (0-2.5um diameter particles) mass concentrations; concentrations of over 50 chemical elements; ion (sulfate, nitrate, ammonium, and chloride) mass concentrations; and carbonaceous mass concentration and optical absorption. The above data are necessary for investigating the origin of the pollution responsible for visibility impairment.

The second component of the background monitoring program is the optical monitoring of extinction using long path transmissometers. Measurements of basic optical properties of the atmosphere are used to define the atmospheric extinction², contrast³, standard visual range (SVR)⁴, or other visibility index. Transmissometers measure the amount of light transmitted from an incandescent light source through the atmosphere over a known distance. The light source (transmitter) and light monitoring (receiver) components of the instrument are separated by a distance of from one to fifteen kilometers depending on conditions at the monitoring location. Measurements of the intensity of the light source, the distance between the source and the receiver, and the intensity of the transmitted light will allow direct calculation of the average atmospheric extinction due to scattering and absorption along the instrument path.

View monitoring documents the general appearance of a specific scene and the presence of plumes, layered, or uniform hazes. The IMPROVE and NPS monitoring programs use automated 35mm photographic systems to monitor the visual resource of the class I area.

The photographic system consists of a 35mm camera, lens, camera databack, timer, and shelter. The time and day a particular exposure was made is imprinted on the film using the camera databack. A battery powered timer will be used to trigger the camera to take a photograph three times per day (9:00 a.m., noon, and 3:00 p.m. local time). Kodachrome ASA 64 36 exposure roll slide film is used in the program. The design of this camera system allows unattended operation for at least ten days.

The slides are not routinely used for quantitative analysis. However, they are considered a valuable source of information for interpretation of concurrent measurements, for documentation of perceived visual conditions, and for future qualitative and quantitative investigations. To aide in the use of the slides, a computer index is maintained which contains qualitative information on scene appearance, meteorology, air quality, and identification information for each color slide.

Temperature and relative humidity are also monitored at each location to aid in the interpretation of the optical and particle measurements. Liquid water is a labile component of the particles and dependent on the particle composition and ambient relative humidity. The liquid water content of the particles can have a significant effect on their optical property. Existing measurement techniques are unable to directly characterize this important component of the particles. Thus, to estimate the role of water, it is necessary to employ empirical methods that relate extinction coefficient to relative humidity and particle composition. Relative humidity and temperature are also valuable for distinguishing precipitation and fog events from air quality related impacts.

Notes

1. If the FLM of the class I area determines that a proposed facility will not adversely affect the class I area's air quality related values, then the permitting authority may authorize the facility even though the facility's emissions may cause or contribute to concentrations in excess of the class I increments. Conversely, if the FLM determines and convinces the permitting authority that a proposed facility would adversely affect the class I area's air quality related values even though it will not cause or contribute to concentrations in excess of the class I increments, then the permitting authority may not authorize the facility.
2. Extinction is the process of reducing the light being transferred along a path in the atmosphere by the scattering and absorption of gases and particles. Adding pollution to the atmosphere will cause more scattering and absorption and therefore increase light extinction.

3. Contrast is the relative difference in light coming from a target compared to the surrounding background.

4. Visual range is the distance at which a large black object can just be seen horizontally through a uniform atmosphere. It is a measure of how far one can see and is one indication of how clear is the air. Standard visual range (SVR) is the visual range adjusted to a standard altitude of 1550 m. This adjustment is made to facilitate comparisons of visual ranges derived from sites at different elevations.

Figure A-1

NPS VISIBILITY MONITORING NETWORK

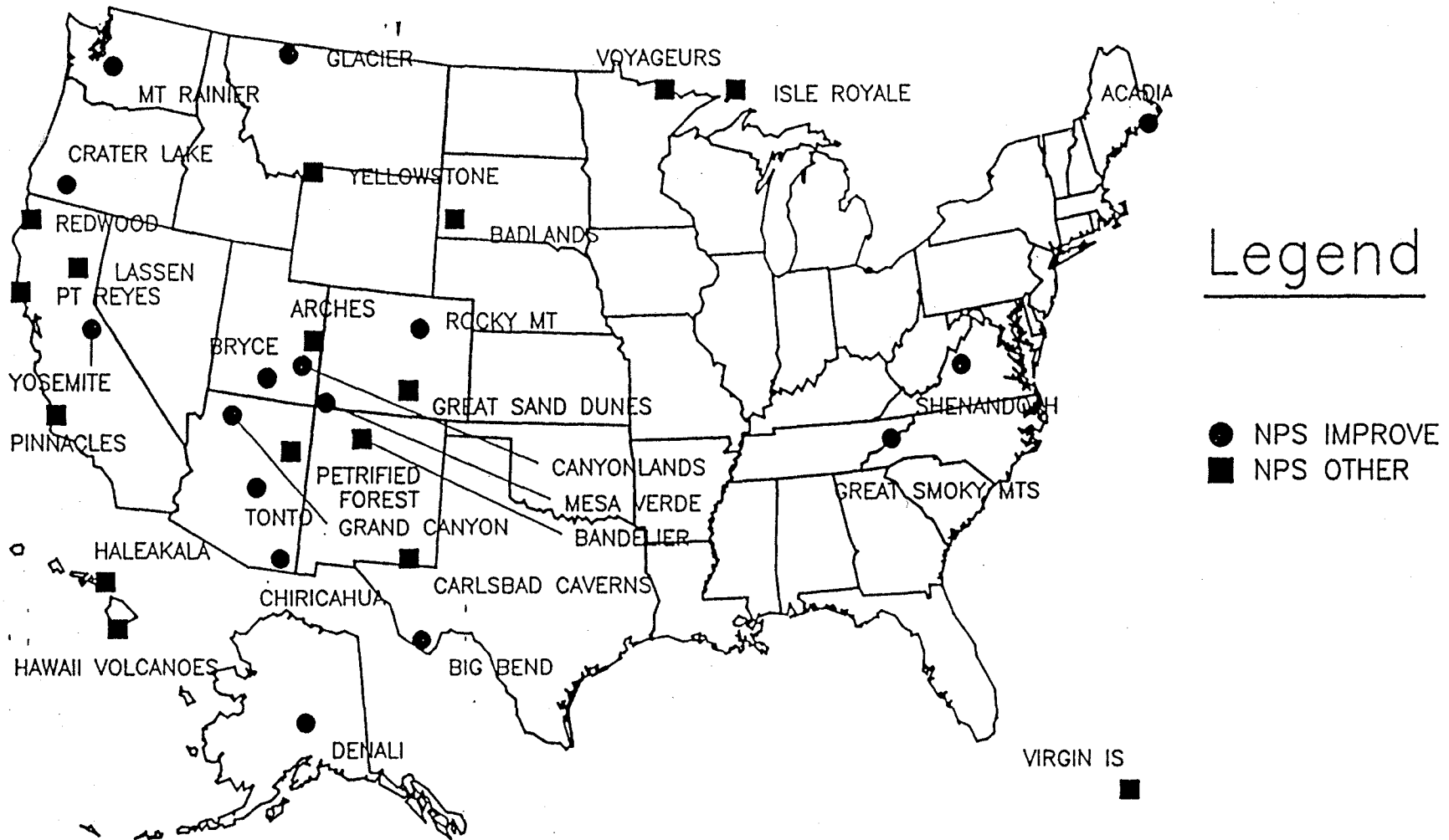


Figure A-2

NPS CAMERA-ONLY MONITORING SITES

