Final Technical Report for:

NASA CONTRACT No. NAG 8-841

AEROSOL MEASUREMENTS OVER THE PACIFIC OCEAN IN SUPPORT OF THE IR AEROSOL BACKSCATTER PROGRAM

13 August 1990 - 12 February 1992

Proposing Organization:

Division of Marine and Atmospheric Chemistry
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149-1098

Principal Investigator:

Dr. Joseph M. Prospero
Division of Marine and Atmospheric Chemistry
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149-1098
Phone: 305-361-4733

Co-Principal Investigator:

Dr. Dennis L. Savoie
Division of Marine and Atmospheric Chemistry
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149-1098
Phone: 305-361-4712

ABSTRACT

The major efforts under NASA contract NAG8-841 included:

1) Final analyses of the samples collected during the first GLOBE Survey Flight that occurred in November 1989 and collections and analysis of aerosol samples during the second GLOBE survay flight in May and June 1990. During the first GLOBE Survey Flight, daily samples were collected at four stations (Midway, Rarotonga, American Samoa, and Norfolk Island) throughout the month of November 1989. Weekly samples were collected at Shemya, Alaska, and at Karamea, New Zealand. During the second GLOBE Survey flight, daily samples were collected at Midway, Oahu, American Samoa, Rarotonga and Norfolk Island; weekly samples were collected at Shemya. These samples were all analyzed for sodium (sea-salt), chloride, nitrate, sulfate and methanesulfonate at the University of Miami and for aluminum at the University of Rhode Island (under a subcontract).
2) Samples continued to be collected on a weekly basis at all stations during the periods between and after the survey flights. These weekly samples were also analyzed at the University of Miami for the suite of water-soluble species. Aerosol measurements in support of the second GLOBE Survey Flight.
3) In August 1990, the results obtained from the above studies were submitted to the appropriate personnel at NASA Marshall Space Flight Center to become part of the GLOBE data base for comparison with data from instruments used aboard the aircraft. In addition, the data will be compared with data previously obtained at these stations as part of the Sea-Air Exchange (SEAREX) Program. This comparison will provide valuable information on the representativeness of the periods in terms of the longer term aerosol climatology over the Pacific Ocean.
4) Several publications have been written using data from this grant. The data will continue to be used in the future as part of a continuing investigation of the long-term trends and inter-annual variations in aerosol species concentrations over the Pacific Ocean.

INTRODUCTION

On a conceptual basis, it should be possible to measure the global wind field by means of a Doppler lidar system mounted on a space platform. The concept is dependent on the presence of aerosol particles in the atmosphere. By measuring the Doppler-shifted return from these particles, the velocity of the air parcel containing the particles can be retrieved. Orbiting wind sounding systems are planned for the shuttle in the early 1990's (Shuttle Coherent Atmospheric Lidar Experiment - SCALE) and for a satellite Doppler Lidar Atmospheric Wind Sounder - LAWS) in the mid 1990's. Because a knowledge of the global wind field could greatly enhance the reliability of weather analysis and forecasting, the National Oceanic and Atmospheric Administration (NOAA) considers such a system to be a major priority.

Because of the substantial cost involved in the space deployment of such a system, there must be some assurance that a reasonable backscatter return will be obtained for extended periods of time over a sufficiently large region of the troposphere. The magnitude of the return strongly depends on the concentration, composition, and physical properties of the aerosol. Hence, an assessment of the feasibility of the lidar system requires substantial knowledge of the temporal, areal, and vertical distribution of these aerosol properties on a global scale.

In view of the requirement for the feasibility assessment, the goal of the present research was to evaluate the concentrations of soil dust in the boundary layer over the Pacific Ocean. Soil dust concentrations over the ocean are important for two major reasons. First, the properties of soil dust are such that, at the proposed CO_2 wavelengths, the backscatter is more sensitive to soil dust than to any of the other types of aerosols which are expected to be present. Seasalt concentrations in the marine boundary layer should always be high enough to provide a reasonable backscatter; in contrast, the concentrations in the free troposphere are extremely low. Secondly, with no local sources, the dust concentrations at the surface over the open ocean are expected to reflect those over a substantial depth of the troposphere. Because the long-range transport of soil dust occurs primarily in the free troposphere, the concentrations in the boundary layer represent the dust which has settled or been downmixed through the marine inversion. Hence, the dust concentrations in the free troposphere are likely to be comparable to or greater than those in the boundary layer where the measurements have actually been made.

Other aerosols may also contribute to the overall backscatter. Of potential major importance is nonsea-salt (nss) $SO_4^=$ which has both natural and anthropogenic sources. Natural nss-$SO_4^=$ over the ocean is derived from the oxidation of dimethylsulfide which is produce by biogenic activity in the ocean and then emitted to the atmosphere where it is oxidized to SO_2 and methanesulfonate (MSA). This process is the overwhelmingly dominant source of MSA and hence MSA can serve as a tracer for the impact from this source. The vast majority of the biogenic nss-$SO_4^=$ will occur only in the marine boundary layer. The anthropogenic nss-$SO_4^=$ can be estimated from the total nss-$SO_4^=$ minus the biogenic component. The anthropogenic component, like dust, is derived from continental sources and hence may occur in higher concentrations in the free troposphere where the major long-range transport occurs.

Under NASA grant measurements were made at seven surface sites on islands in the Pacific Ocean Figure 1. Daily samples were collected at Midway, Rarotonga, American Samoa, and Norfolk Island during the first GLOBE flight which lasted throughout the month of November 1989. Weekly samples were collected at Shemya, Alaska, and at Karamea, New Zealand. During the second GLOBE Survey flight (May-June 1990), daily samples were collected at Midway, Oahu, American Samoa, Rarotonga and Norfolk Island. Prior to this study, no daily samles had been collected at any of these Pacific stations. These samples were all analyzed for sodium (sea-salt), chloride, nitrate, sulfate and methanesulfonate at the University of Miami and for aluminum at the University of Rhode Island.

SAMPLING AND ANALYSIS

The aerosol samples are collected by drawing air through 20x25 cm Whatman-41 filters at a flow rate of about 1.1 m^3 min^{-1}. Actual flow rates, at the beginning and the end of a sampling period, were determined from the pressure drops across calibrated orifice plates [Savoie and Prospero, 1977, 1980]. The filters were nominally changed once a week except during the periods of the intensive GLOBE Survey Flights. To minimize contamination from local sources, the sampling pumps were controlled by wind sensors and operated only when the wind was from the ocean at speeds greater than about 1 m s^{-1}. Actual operating periods were obtained from elapsed time meters.

Quarter sections of the filters were extracted in 20 mL of Milli-Q water. The concentrations of sulfate, nitrate, and MSA in the extraction solutions were determined to within ±5% by ion chromatography and that of sodium was determined to within ±2% by atomic absorption spectroscopy [Saltzman et al., 1983, 1986a; Savoie et al., 1987]. The nss sulfate concentrations were calculated by subtracting 0.2517 times the sodium concentration from the total sulfate concentration. Ammonium was detrmined to within ±5% using automated colorimetry.

Soil dust concentrations are estimated from the measured concentrations of aluminum which comprises about 8% of the mass of the soil aerosols [Uematsu et al., 1983; Schütz and Rahn, 1982; Glaccum, 1978]. The aluminum concentration is determined by instrumental neutron activation analysis with an uncertainty of less than 15% [Uematsu et al., 1983]. The detection limit for aluminum is inversely proportional to the total volume of air filtered for a given sample and directly proportional to the standard deviation of the filter blank. Based on twice the standard deviation of the filter blank (15 μg-Al/filter) and typical sample volumes ranging from 5000 to 10000 m^3 STP, the detection limit ranges between 0.003 and 0.0015 μg-Al m^{-3}. These values convert to detection limits of about 0.04 and 0.02 μg m^{-3} for soil dust.

Data from samples for which the actual sampling time was less than 10% of the total time the filter was exposed are not considered in this report. With small sampling/exposure ratios, there is much greater potential for significant contamination by locally-derived particulates; any deposition during periods of out-of-sector winds could produce large artifacts. Furthermore, unacceptably large analytical uncertainties often arise as a consequence of the small quantities of material collected during the short sampling periods.

The results from studies using dual in-line Whatman-41 filters with a 1 cm separation distance indicate that these filters have total mass collection efficiencies greater than 90% for nss sulfate and MSA, 95% for nitrate and sea salt [Savoie, 1984], and 99% for mineral aerosol (M. Uematsu, University of Rhode Island, personal communication, 1988). These results are consistent with those obtained by Watts et al. [1987] and Lowenthal and Rahn [1987] for high volume bulk aerosol samples. Although similar efficiencies were reported by Kitto et al. [1988], they presented no details of their sampling conditions or environment.

STATION INFORMATION

Each of the sampling stations has its own set of idiosyncrasies which affect the data set in one manner or another. These idiosyncrasies are discussed briefly below. The discussion begins with the most northerly station, Shemya, and continues with the consecutively more southerly stations.

Shemya (52°44'N, 174°06'E). The sampler is located on the south shore of the island and 2 m above the ground. Sampling began on May 20, 1981 and is still in progress. Because of the often horrendous weather conditions (strong winds and cold temperatures) and several additional problems including maintenance, there were lengthy periods when the station was not operable. Hence, there are fewer data from this station than from many of the others in the North Pacific.

Midway (28°13'N, 177°21'W). The station at Midway is located on the eastern shore of the island. Originally, the filter head was located on the roof of the NOAA (National Oceanic and Atmospheric Administration) tide shack. A sampling tower was installed near the same site in November 1985. Operations at this station have generally run smoothly and fairly continuously and have provided high quality data.

Oahu (21°20'N, 157°42'W). At Oahu, the sampler is located on a 20-m tower on the northeastern shoreline at Bellows Air Force Base. As with that at Midway, the station at Oahu has generally run smoothly and fairly continuously and has provided high quality data.

American Samoa (14°15'S, 170°35'W). The collection system on American Samoa was set up on the tower at the NOAA (National Oceanic and Atmospheric Administration) GMCC (Geophysical Monitoring for Climatic Change) site near Cape Matatula. Operation of this site began on 19 March 1983 and still continues. The sampler was originally on the top on a 6-m tower located on a sheer 30-m cliff; on 2 May 1985, the tower height was increased to 16-m. The probability of local contamination at this site is extremely low and, as will be discussed later, the mineral dust concentrations at this station are among the lowest ever measured in the marine boundary layer.

Rarotonga (21°15'S, 159°45'W). The site on Rarotonga, Cook Islands, was originally on a three meter high, wooden platform at the edge of the beach on the east coast. The seasalt concentrations at this site were extremely high; consequently, the surf-produced aerosols may significantly have affected the mineral dust concentrations. Funds from our NASA GLOBE contracts were used to erect a 15-m fold-over tower at the site to reduce such problems.

Norfolk Island (29°05'S, 167°59'E). The Norfolk Island site is located on a 100 meter high cliff on the southwest coast. Funds from our NASA GLOBE contracts were used to erect a 15-m fold-over tower at this station as well.

Karamea, New Zealand (41°15'S, 172°07'E). The Karamea site was located about 200 meters from the beach. A major problem with this site was the katabatic flow associated with the mountains which comprise much of the central area of the South Island; contamination by soil material from the island itself could be significant.

RESULTS

SUMMARY OF RESULTS DURING THE GLOBE FLIGHTS

The results obtained at each station during the periods of the two GLOBE flights are summarized in Tables 1 and 2. The results for the individual daily samples that were collected during each of the GLOBE flights are illustrated in Figures 2 through 6.

The average concentrations during each of the GLOBE flights continue to illustrate the spatial and temporal variations that were evident from data previously obtained as part of the SEAREX program (e.g. Prospero et al., 1985, 1989; Savoie et al., 1989). In particular, the mineral dust concentrations are by far the lowest in the tropical South Pacific at American Samoa and Rarotonga where the concentrations average between 10 and 30 ng m^{-3}. At these sites, the dust concentrations are frequently so low that they are within the uncertainties of the measurements. Prior to the installation of the tower on Rarotonga, the dust concentrations measured at this site were much higher than those at Samoa. It was speculated that this was due to the high concentrations of sea-salt that were sampled near the surf-zone and the impact of sediments that might be concurrently ejected into the atmosphere. The results from the GLOBE data sets suggest that this speculation was valid and that the mineral dust concentrations over the remote tropical South Pacific are generally among the lowest that have been measured anywhere in the marine boundary layer.

Apart from Karamea where katabatic flow from the mountains apparently caused locally high dust concentrations, the highest dust concentrations were measured at Midway Island during the second GLOBE flight. This was expected on the basis of the SEAREX results. Transport from Asia has a

substantial impact on dust concentrations over the North Pacific during the late winter and spring. Dust concentrations at Midway during Novermber 1989 (N89) were about 4 times lower than those during May-June 1990 (MJ90) but still about an order of magnitude higher than those in the tropical South Pacific. The MJ90-N89 contrast is considerably less at Shemya where the spring mean is only about 20% higher. The Asian influence at Oahu is considerably less than that at Midway; dust concentrations during MJ90 are nearly a factor of three lower at Oahu. At Norfolk Island, dust transport from Australia occurs principally during the austral summer. Note that the mean dust concentration at Norfolk during MJ90 is nearly as low as those at Samoa and Rarotonga but about an order of magnitude higher during N89.

Generally speaking, the trends in NO_3^-, nss-$SO_4^=$, and NH_4^+ tend to follow patterns that are similar to those of mineral dust. This suggests that a significant fraction of each of these species is derived from continental sources, probably but not necessarily anthropogenic. For example the highest mean NO_3^- concentration occurs at Midway during MJ90 as do the highest nss-$SO_4^=$ and NH_4^+ concentrations.

The concurrent transport of many of these from cntinental sources is better illustrated in the figures (Fig. 2-6) which illustrate the very large day-to-day variations in the concentrations of most of the species at each of the locations and also provide an easy visual comparison of the N89 and MJ90 data sets. During both flight periods at Midway, peaks generally occur concurrently in mineral dust, NO_3^-, and nss-$SO_4^=$. Such concurrences were noted previously by Prospero et al. [1985]. A significant insight that is provided by the daily data is that the NO_3^-/nss-$SO_4^=$ ratios vary considerably during even single events and the specific timing of their peaks may not be coincident. Note for example the differences between the large broad NO_3^- peak near the middle of MJ90 and the more spike peak that occurs with nss-$SO_4^=$ and NH_4^+. Note also the relative heights of the two broad peaks in mineral dust, NO_3^-, and nss-$SO_4^=$ during MJ90. The mean dust concentration is about a factor of 5 lower in the second peak whereas the NO_3^- and nss-$SO_4^=$ means are only about 20-40% lower. Similar features can be found in the MJ90 Oahu data. Hence, while it is undoubtedly true that much of the NO_3^- and nss-$SO_4^=$ that is measured over the North Pacific during the spring is associated in a meteorlogical way with the transport of dust from Asia, the ultimate source of the ionic species is unlikely to be the dust itself but rather Asian pollution.

The daily plots of the data also illustrate that while the concentrations of dust over the North Pacific are on the average much higher during the spring, there are still periods when the dust concentrations are quite low. Hence one should expect that the backscatter in the free troposphere over the North Pacific, even during the spring peak of Asian dust transport, may at times decrease to "background" levels that are more typical of those over the tropical South Pacific.

IMPACT OF BIOGENIC NONSEA-SALT SULFATE

The separation of nss-$SO_4^=$ into its two components, biogenic and anthropogenic, is of major importance. Anthropogenic nss-$SO_4^=$ is likely to have been transported through the free troposphere to the remote marine areas. While in the free troposphere, it may, in many areas, contribute significantly to the total backscatter that is important for the LAWS system. Biogenic nss-$SO_4^=$, in contrast, is largely produced within and confined to the marine boundary layer.

In order to estimate the absolute and/or relative contributions of the marine and continental sources to the total nss-$SO_4^=$ concentration, we need an independent estimate of the amount of nss-$SO_4^=$ derived from at least one of these two sources. MSA has frequently been used as a tracer for the marine biogenic component because its sole source over the ocean is believed to be the oxidation of DMS; other potential precursors, e.g. CH_3SH and CH_3SSCH_3, do not contribute significantly over the open ocean [Bates et al., 1992]. However, there has been some concern that the nss-$SO_4^=$/MSA ratio derived from the oxidation of DMS may vary significantly both from one location to another and as a function of time at a given location. It is well known, for example, that the ratio is considerably lower in high

latitude regions than in the tropics [e.g., Ayers et al., 1991; Saltzman et al., 1985; Savoie et al., 1992, 1993]. Hence it has been deemed necessary to assess the potential variations in this ratio as rigorously as possible. These assessments require a substantial data base of concurrent measurements of MSA and nss-$SO_4^=$, and few such data sets have been available.

The best locations to assess the nss-$SO_4^=$/MSA ratio that is derived from DMS are those in regions that are minimally impacted by continentally-derived material either anthropogenic or natural. American Samoa appears to be one such location. Bulk sampling for chemical analysis of atmospheric particles was established in 1983 as part of the SEAREX (Sea/Air Exchange Program) network [Riley et al., 1989]. Our data record starts in March 1983 and continues to the present [Savoie et al., 1989]. The mean concentration of ^{210}Pb (0.056 mBq m^{-3}; Turekian et al., 1989) at Samoa is among the lowest reported for temperate and tropical ocean regions. The only lower mean ^{210}Pb concentration (0.042 mBq m^{-3}) that was found during SEAREX (Sea/Air Exchange Program) was at Funafuti, Tuvalu, which lies in the same general wind regime. These values are comparable to those over Antarctica [Savoie et al., 1992]. Al and Sb concentrations at Samoa are among the lowest reported for tropospheric aerosols [Arimoto et al., 1989; Prospero et al., 1989], and concentrations of Pb at Samoa are about an order of magnitude lower than those in the North Pacific westerlies [Maring et al., 1989; Rosman et al., 1990]. Concentrations of bulk carbonaceous aerosol are also persistently low at Samoa and isotopic data suggest that natural biogenic emissions are the dominant source [Buat-Ménard et al., 1989; Cachier et al., 1986]. Consequently, the nss-$SO_4^=$ at Samoa is believed to be derived almost exclusively from the oxidation of natural sulfur gases emitted from the ocean.

The MSA/nss-$SO_4^=$ ratios at American Samoa during and apart from the GLOBE flights were discussed in detail by Savoie et al. [1994]. A brief overview is presented here. As shown in Figure 7, the trends in the nss-$SO_4^=$ concentrations consistently follow those of MSA during both of the GLOBE flight periods. The trends also match those of total aerosol scattering at 550 nm and the condensation nuclei as measured by the CMDL personnel at Samoa. These trends differ markedly from those of NO_3^- and O_3 that are shown in Figure 8. The latter difference provides evidence that the agreement among the other trends is not driven simply by common washout or other meteorological trends. If that were the case, NO_3^- would be expected to exhibit a trend similar to the sulfur aerosols.

In Figure 9, we show the a scatterplot of the weekly-averaged data from all of the Samoa samples that have been analyzed for both MSA and nss-$SO_4^=$. The plot indicates that the nss-$SO_4^=$ concentration is directly related to that of MSA. A zero intercept implies that there is no additional significant source for nss-$SO_4^=$. Consequently, the best estimate of the relative amounts of the two species that are derived from the oxidation of DMS is given by the geometric mean, nss-$SO_4^=$/MSA = 18.1 ± 0.9 (where $\pm$ indicates the 95% confidence limits of the geometric mean.

A scatterplot of the daily data collected during the GLOBE flights is shown in Figure 10. The line in the figure indicates an MSA/nss-$SO_4^=$ ratio of 0.055 which is equivalent to an nss-$SO_4^=$/MSA ratio of 18.1, i.e. the same as indicated above. With the daily samples, there appears to be significant differences between the MSA/nss-$SO_4^=$ ratios in the N89 and MJ90 data sets. However, the results of a detailed error analysis [Savoie et al., 1994] clearly shows that in neither case does the data set differ significantly from the previously noted geometric mean; the variations from the overall mean are all consistent with the overall uncertainties in the data points themselves.

The scatterplot of MSA versus nss-$SO_4^=$ concentrations at Midway during the two GLOBE flight periods is shown in Figure 11 along with a line showing the mean ratio at American Samoa. Notably, the upper tendency of the points is very close to and, in fact, does not deviate significantly from the mean at Samoa. However, during much of the first GLOBE flight, the nss-$SO_4^=$ concentrations are far in excess of that which would be expected from DMS oxidation alone as judged by the concentration of MSA. The excessive levels of nss-$SO_4^=$ relative to MSA are indicative of periods with significant contributions of anthropogenic nss-$SO_4^=$. On the basis of the mean ratio at Samoa, DMS oxidation

accounted for about 38% (0.233 $\mu g\ m^{-3}$) of the total mean (0.605 $\mu g\ m^{-3}$) nss-$SO_4^=$ concentrations during the N89 GLOBE flight. During the MJ90 GLOBE flight, DMS oxidation is estimated to account for 96% (0.96 $\mu g\ m^{-3}$) of the total mean (1.002 $\mu g\ m^{-3}$) nss-$SO_4^=$. Hence it appears that the much higher concentration of nss-$SO_4^=$ during the late spring (compared to November) is a consequence of higher biological production of DMS rather than a larger contribution from anthropogenic sources in Asia. At Oahu, during MJ90 (GLOBE 2) (Figure 12), the biogenic contribution to the total nss-$SO_4^=$ is about 93%. While the percentage at Oahu is similar to that at Midway during MJ90, the concentrations of both MSA and nss-$SO_4^=$ are about 40% lower. Hence during the spring Midway experiences much higher concentrations of both biogenic nss-$SO_4^=$ and Asian dust than does Oahu.

The scatterplot of MSA versus nss-$SO_4^=$ at Norfolk Island for the two GLOBE flight periods is shown in Figure 13. The results at Norfolk testify to the non-universality of the biogenic MSA/nss-$SO_4^=$ ratio. While the ratio is very consistent over large regions of the tropical and subtropical oceans, the ratio appears to be significantly larger at higher latitudes. The variation at higher latitudes makes it difficult to accurately estimate the relative contributions of nss-$SO_4^=$ from the two primary sources without another, and more well-behaved, tracer for one of the two sources. Even during summer, the MSA/nss-$SO_4^=$ ratios at Norfolk appear to be much high than those in the tropics.

SEASONAL CYCLES

The seasonal cycles in the concentrations of the various aerosol species at each of the seven sites used for GLOBE are summarized in Tables 3 through 9 and Figures 14 through 20. Over the northern hemisphere, the seasonal cycles in mineral dust (as indicated by aluminum) are dominated by the transport of dust from Asia with major peaks occurring in the late winter and spring. The variations during the remainder of the year are extremely location dependent. A secondary peak, apparently also a consequence of Asian dust transport, occurs at Midway during the fall but is not consistently evident at any of the other stations. In the southern hemisphere, only at Norfolk Island near Australia do the data exhibit any consistent and significant seasonality. The cycle there is quite simple with high values during the austral summer and low concentrations during the winter. The seasonal cycle of the marine biogenic component (as indicated by MSA) is strongly dependent on the latitude of the station with strong peaks during the spring/summer at high latitudes grading to virtually no seasonal trend in the southern hemisphere tropics. The seasonal cycles for most of the constituents of interest have been previously reported by Prospero et al. [1989] and Savoie et al. [1989]; however, those cycles were based on a much shorter time series.

In each of the plots we show all of the weekly-average data that was obtained at the station during the time period shown in the title. For the plots all of the data that was obtained during a given month regardless of year were assembled into a single data set. The lines connect the composited monthly means calculated from each of the monthly data sets and the error bars indicate the mean$\pm$one standard arithmetic deviation. It is important to realize that there are many ways that the data can be summarized (e.g. geometric means, medians, bimodal or multimodal distributions), and the approach that is most appropriate will depend of the specific types of comparisons that are desired. For this reason, we show both the arithmetic parameters and several non-parametric statistics in the tables. If a particular distribution is well characterized by a unimodal lognormal distribution, then the median is a close approximation to the geometric mean.

North Pacific

The seasonal cycles in the constituent concentrations at the three stations in the North Pacific are illustrated in Figures 14-16. The most prominent feature at each of the six main stations is the peak in the dust concentration during the late winter and early spring. This peak is attributed to the transport of dust from Asia eastward in the mid-latitude westerlies, around the North Pacific high pressure

center, and then westward in the low-latitude easterlies. Although all are related to the same general phenomenon, the peaks at the individual stations do not all exhibit exactly the same characteristics.

Little will be said with regard to the high latitude Shemya station except that the peak occurs during the same general time period. Because of the sparsity of data and the complexity of the meteorology, a more detailed analysis at this station would be almost pure speculation. Results from studies of Arctic haze indicate that, at times, Shemya may be affected by pollutants from Europe and North America as well as by the Asian dust. Hence, the air in that region may be very clean on only rare occasions.

At the two mid-latitude stations, Midway and Oahu, the concentrations are relatively constant from March through May after which there is a sharp decline in June to a minimum from July through September. During the peak dust period, the mean aluminum concentration at Midway (140 ng m^{-3}) is about 25% higher than that at Oahu (110 ng m^{-3}). The lower concentration at Oahu is not surprising considering that Oahu is substantially farther downstream from the source area. During the minimum, the mean concentrations at the two stations do not differ significantly with monthly means generally being less than 20 ng m^{-3}. In contrast, the mean concentrations at the two stations differ markedly from October through January. At Midway, there is a clear secondary peak which reaches a maximum during November; in January, the concentrations drop to levels comparable to those of the early summer. At Oahu, there is no evidence of a late fall maximum, instead the mean increases monotonically to the peak in March. The absence of a significant fall peak at Oahu is consistent with the dust record at Mauna Loa Observatory (Parrington et al., 1983; Parrington and Zoller, 1984). It should be noted, however, that the secondary peak at Midway appears to be a consequence of very sporadic transport. A large percentage of the samples during October and Novermber at Midway actually had concentrations that were comparable to those that normally occur during the summer.

The seasonal cycles in the concentrations of NO_3^-, nss-$SO_4^=$, and NH_4^+ tend to follow the cycle of mineral dust at the North Pacific stations. This feature is particularly evident at Midway where the seasonal cycles for all of the species are fairly clearly defined. Note that for these species, there is no significant indication of a secondary peak in the late fall.

For biogenic sulfur (as indicated by MSA), the seasonal cycle tends to be strongest in the high latitudes. At Shemya, the mean MSA concentration during summer is nearly 2 orders of magnitude higher than during winter. In comparison, the peak MSA concentration at Oahu during May is only a factor of about 3 higher than that during the minimum in December.

It is important to note that even at Midway, there are numerous samples for which the mean concentrations of aluminum, NO_3^-, nss-$SO_4^=$, and NH_4^+ during the spring are all comparable to those that occur during the annual minima. In fact, the concentrations of these species during the spring are sometimes as low as the minimum in any other month. Hence, it is not correct to say that there is a consistent "pall" of dust over the North Pacific during the late winter and spring. The transport is sporadic and strongly dependent on the meteorological conditions. There are clearly periods during the spring when the air over the North Pacific are as clean or cleaner than during any other part of the annual cycle.

South Pacific

For the most part the seasonal cycles at American Samoa are comparable to those that were previously reported by Prospero et al. [1989] and Savoie et al. [1989]. The clearest seasonal cycle is for NO_3^- for which the concentrations are highest from September through December and the lowest during April. There does not appear to be any significant seasonal cycle in either MSA or nss-$SO_4^=$. Becasue of the very low concentrations and hence inherent uncertainty, the cycle in aluminum is difficult to verify. There is a "hint" of a seasonal cycle in Al with lowest concentrations during the austral winter and highest during the austral summer. Although the inter-month differences for Al are

not significant on the basis of the arithmetic statistical parameters, they are significant on the basis of non-parametric statistics which are likely to be more reliable and more robust in this case. In any case, as discussed previously, the concentrations at American Samoa are consistently the lowest measured at any of the stations in the network. The data for American Samoa is consistent with other available evidence which indicates that the boundary layer air at American Samoa is among the most pristine that has ever been studied. Mean concentrations of the mineral dust indicator elements, Al and Co, at Samoa are comparable to those reported for the South Pole. The concentrations of Cu and Zn were lower and that of Sb was much lower at Samoa than at the South Pole, indicating that the transport of pollutants to Samoa is also minimal. These results are consistent with calculated air mass trajectories which indicate that the air, except on rare occasions, has traveled long distances over the open ocean prior to arriving at the island [Merrill et al., unpublished data].

At Rarotonga, the magnitude of the seasonal cycle in NO_3^- is enhanced somewhat over that at Samoa, but the timing of the cycle is similar with highest concentrations occuring during September through November. In contrast to that at American Samoa, a seasonal cycle in MSA is clearly evident at Rarotonga. Because of the large uncertainties in nss-$SO_4^=$ at Rarotonga (a consequence of the high sea-salt concentrations), there is no clearly defined seasonal cycle in this species. However, the results do hint at a cycle with a maximum in the austral summer and a minimum in the winter. The Al measurements are too few to assess whether or not there is a significant seasonal cycle at Rarotonga; however, for the common periods of sampling, the concentrations of Al were comparable to those at Samoa. The commonality in the NO_3^- seasonal cycles at the two sites suggests that the Al seasonal cycles may also similar.

The seasonal cycles for NO_3^-, nss-$SO_4^=$, and MSA at Norfolk Island are nearly identical to those that were previously reported by Savoie et al. [1989]. These species all exhibit higher concentrations during the austral summer. Likewise, the dust concentrations and seasonal cycle is comparable to that show previously by Prospero et al. [1989]. As with the North Pacific, the results from Norfolk Island indicate that dust transport during the summer, although stronger in the mean than during the winter, is sporadic with substantial periods of very low dust concentration.

The seasonal cycle in dust (and in NO_3^- and anthropogenic nss-$SO_4^=$ as well) is likely to be stronger in the regions to the south of Norfolk. The distributions of mica, illite, and kaolinite in the sediments of the southwest Pacific were likely a consequence of the wind-borne transport of these minerals from Australian deserts. Eolian transport of dust from Australia to New Zealand across the Tasman Sea is particularly well documented. The greatest potential for long-range transport from the central Australian deserts occurs during the austral summer and the highest incidence of dust storms in New South Wales also occurs in the late spring and summer. The inferred seasonal transport cycle is supported by the seasonal variations in the distribution of haze at sea. Clearly, the seasonal cycle of dust measured at Norfolk is consistent with these previous observations and studies.

However, the geographical area affected by the long-range dust transport from Australia has not been determined. Specifically, there is little information on the north-south extent of the area or, perhaps more importantly, on the eastward extent. It is conceivable that, as in the northern hemisphere, significant quantities of dust are transported around the central high pressure center and into the tradewind regime. Whether or not that actually occurs remains to be determined; however, the extremely low concentrations measured at American Samoa suggest that such transport is not significant. Substantial efforts are currently underway to model the generation and long-range atmospheric transport of eolian dust. Once these models are verified and/or modified to yield results that are consistent with actual measurements, the models should be extremely helpful in assessing the broader scale impact of the dust transport from Australia and other areas of the southern hemisphere.

CONCLUSIONS AND FUTURE WORK

For the respective seasons, most of the results were consistent with the long-term data sets from the weekly samples collected at these sites during and following the Sea/Air Exchange (SEAREX) program. However, there were some very significant differences as well as some additional insights from these higher frequency samples. For example, NO_3^-, nss $SO_4^=$, and mineral dust peaks which are usually concurrent in the weekly samples at Midway exhibit a more complex relationship in the daily samples. The mean MJ90 nitrate at Oahu was 40% lower than that at Midway whereas the long-term MJ means were nearly identical. Differences were also evident at the tropical South Pacific stations. The mean MJ90 MSA concentration at American Samoa (30 ng m^{-3}) was 70% higher than the November (N89) mean (18 ng m^{-3}); previous results showed little seasonal variation. In contrast, the MJ90 MSA mean at Rarotonga was 20% lower than the N89 mean. For both N89 and MJ90, the mean NO_3^- concentration at Rarotonga was 20% lower than that at Samoa; the long-term means at the two sites were essentially identical to one another. Concurrent nephelometer data at American Samoa indicate that the light scattering at 550 nm and ambient relative humidity is directly related to the concentration of nss sulfate which, at this site, is attributed predominantly to marine biogenic sources.

The data that were obtained in this study have been and are being used extensively for comparison with results from atmospheric chemistry and transport models. We expect that this effort will continue to increase into the foreseeable future to test and thence to refine the models that are necessary for extrapolating the measurements on longer time and broader spatial scales. Such extrapolations will be necessary for a full evaluation of the impact of aerosols on climate in general, of the influence of anthropogenic perturbations, and of the potential backscatter from aerosols as a function of time and location. To date, the data have been used in evaluations of modeling efforts for oxidized nitrogen species (including aerosols) by Penner et al. [1991] and Kasibhatla et al. [1993] and for oxidized sulfur species (including both nss-$SO_4^=$ and MSA) by Chin et al. [1995]. We have recently supplied our dust data to I. Tegen (currently at NASA GISS) for comparison with the results from her modeling effort involving the global generation and atmospheric transport of mineral dust. We have most recently supplied all of the data that we obtained during the second GLOBE survey flight to Raif Majeed who is working with Marcia Baker and Dean Hegg at the University of Washington to model injections of particles from the free troposphere into the marine boundary layer by synoptic-scale subsidence.

The comparisons of our measurements with those from the global-scale general circulation and transport models are particularly important. Whether the species involved is N, S, or dust, the models generally fail to transport enough material from continental sources to the remote marine sites to account for the concentrations that are actually measured. Clearly. some of the physics that is currently included in the models will need to be reassessed before the results from the models can be used to accurately extrapolate the measurements and to predict changes that may occur as a consequence of weather and climate changes.

The overview of the data that is presented above represents only the beginning of a complete analysis of the data that was obtained under this grant. A significant effort that we are beginning involves a better assessment of the frequency distributions of the concentrations of the aerosol species that we have measured for each location and for each month of the year. We will also be evaluating the changes in the frequency distribution when one considers the daily sampling periods as compared to the weekly periods. For this purpose, the daily data that we have recently acquired in the North Pacific as a part of the NASA Pacific Exploratory Mission - West will be an invaluable addition. We have already shown that the differences in the frequency distributions between weekly and daily samples at Barbados are quite significant [Savoie et al., 1987]. For some of the sites, particularly for dust at American Samoa and Rarotonga, we will need to use a technique similar to that reported in Savoie [1988] becasue the the dust concentrations are frequently near or below the detection limits of the techniques that we have used.

REFERENCES

Arimoto, R., R. A. Duce, and B. J. Ray, Concentrations, sources and air-sea exchange of trace elements in the atmosphere over the Pacific Ocean, in *Chemical Oceanography, Vol. 10, SEAREX: The Sea/Air Exchange Program*, pp. 107-149, edited by J. P. Riley, R. Chester, and R. A. Duce, Academic, San Diego, Calif., 1989.

Ayers, G. P., J. P. Ivey, and R. W. Gillett, Coherence between seasonal cycles of dimethyl sulfide, methanesulphonate and sulphate in marine air, *Nature, 349*, 404-406, 1991.

Bates, T. S., B. K. Lamb, A. Guenther, J. Dignon, and R. E. Stoiber, Sulfur emissions to the atmosphere from natural sources, *J. Atmos. Chem., 14*, 315-337, 1992.

Buat-Ménard, P., H. Cachier, and R. Chesselet, Sources of particulate carbon in the marine atmosphere, in *Chemical Oceanography, Vol. 10, SEAREX: The Sea/Air Exchange Program*, pp. 251-279, edited by J. P. Riley, R. Chester, and R. A. Duce, Academic, San Diego, Calif., 1989.

Cachier, H., P. Buat-Ménard, M. Fontugne, and R. Chesselet, Long-range transport of continentally-derived particulate carbon in the marine atmosphere: Evidence from stable carbon isotope studies, *Tellus, 38B*, 161-177, 1986.

Chin, M., D. J. Jacob, G. M. Gardner, M. Forman-Fowler, P. A. Spiro, and D. L. Savoie, A global three-dimensional model of tropospheric sulfate, *J. Geophys. Res.*, (submitted), 1995.

Glaccum, R. A., The mineralogical and elemental composition of mineral aerosols over the tropical North Atlantic: the influence of Saharan dust, M.S. thesis, University of Miami, Florida, 1978.

Kasibhatla, P. S., H. Levy II, and W. J. Moxim, Global NO_x, HNO_3, PAN, and NO_y distributions from fossil fuel combustion emissions: A model study, *J. Geophys. Res., 98*, 7165-7180, 1993.

Kitto, M. E., D. L. Anderson, and W. H. Zoller, Simultaneous collection of particles and gases followed by multielement analysis using nuclear techniques, J. Atmos. Chem., 7, 241-259, 1988.

Lowenthal, D. H., and K. A. Rahn, The use of Whatman 41 filter papers for high volume aerosol sampling: Further comments, Atmos. Environ., 21, 2732-2734, 1987.

Maring, H., C. Patterson, and D. Settle, Atmospheric input fluxes of industrial and natural Pb from the westerlies to the mid-North Pacific, in *Chemical Oceanography, Vol. 10, SEAREX: The Sea/Air Exchange Program*, pp. 84-106, edited by J. P. Riley, R. Chester, and R. A. Duce, Academic, San Diego, Calif., 1989.

Parrington, J. R., and W. H. Zoller, Diurnal and longer-term temporal changes in the composition of atmospheric particles at Mauna Loa, Hawaii, *J. Geophys. Res., 89*, 2522-2534, 1984.

Parrington, J. R., W. H. Zoller and N. K. Aras, Asian dust: seasonal transport to the Hawaiian Islands, *Science, 220*, 195-198, 1983.

Penner, J. E., C. S. Atherton, J. Dignon, S. J. Ghan, and J. J. Wilson, Tropospheric nitrogen: A three dimensional study of sources, distributions, and deposition, *J. Geophys. Res., 96*, 959-990, 1991.

Prospero, J. M., D. L. Savoie, R. T. Nees, R. A. Duce, and J. Merrill, Particulate sulfate and nitrate in the boundary layer over the North Pacific Ocean, *J. Geophys. Res., 90*, 10586-10596, 1985.

Prospero, J. M., M. Uematsu, and D. L. Savoie, Mineral aerosol transport to the Pacific Ocean, in *Chemical Oceanography*, vol. *10*, pp. 188-218, edited by J. P. Riley, R. Chester and R. A. Duce, Academic Press, London, 1989.

Riley, J. P., R. Chester and R. A. Duce (eds.), *Chemical Oceanography, Vol. 10, SEAREX: The Sea/Air Exchange Program*, 404 pp., Academic, San Diego, Calif., 1989.

Rosman, K. J. R., C. C. Patterson, and D. M. Settle, The distribution of lead between sea salt, dust, and lead-rich aerosols in the mid South Pacific easterlies at American Samoa, *J. Geophys. Res., 95*, 3687-3691, 1990.

Saltzman, E. S., D. L. Savoie, R. G. Zika, and J. M. Prospero, Methane sulfonic acid in the marine atmosphere, *J. Geophys. Res., 88*, 10,897-10,902, 1983.

Saltzman, E. S., D. L. Savoie, J. M. Prospero, and R. G. Zika, Atmospheric methanesulfonic acid and non-sea-salt sulfate at Fanning and American Samoa, *Geophys. Res. Lett., 12*, 437-440, 1985.

Saltzman, E. S., D. L. Savoie, J. M. Prospero, and R. G. Zika, Methanesulfonic acid and non-sea-salt sulfate in Pacific air: Regional and seasonal variations, *J. Atmos. Chem., 4*, 227-240, 1986a.

Savoie, D. L., Nitrate and non-sea-salt sulfate aerosols over major regions of the world ocean: concentrations, sources and fluxes, Ph.D. thesis, Univ. of Miami, Miami, Fla., 1984.

Savoie, D. L., and J. M. Prospero, Aerosol concentration statistics for the northern tropical Atlantic, *J. Geophys. Res., 82*, 5954-5964, 1977.

Savoie, D. L., and J. M. Prospero, Water-soluble potassium, calcium, and magnesium in the aerosols over the tropical North Atlantic, *J. Geophys. Res., 85*, 385-392, 1980.

Savoie, D. L., J. M. Prospero, and R. T. Nees, Frequency distribution of dust concentration in Barbados as a function of averaging time, *Atmos. Environ., 21*, 1659-1663, 1987.

Savoie, D. L., Effect of normal standard errors on lognormal distributions, *Atmos. Environ., 22*(9), 1957-1962, 1988.

Savoie, D. L., J. M. Prospero, and E. S. Saltzman, Nitrate, non-seasalt sulfate and methanesulfonate over the Pacific Ocean, in *Chemical Oceanography*, vol. *10*, pp. 219-250, edited by J. P. Riley, R. Chester and R. A. Duce, Academic Press, London, 1989.

Savoie, D. L., J. M. Prospero, R. J. Larsen, and E. S. Saltzman, Nitrogen and sulfur species in aerosols at Mawson, Antarctica, and their relationship to natural radionuclides, *J. Atmos. Chem., 14*, 181-204, 1992.

Savoie, D. L., R. Arimoto, J. M. Prospero, R. A. Duce, W. C. Graustein, K. K. Turekian, J. N. Galloway, and W. C. Keene, Oceanic and anthropogenic contributions to nonsea-salt sulfate in the marine boundary layer over the North Atlantic Ocean, *J. Geophys. Res.*, (submitted), 1995.

Schütz, L., and K. A. Rahn, Trace element concentrations in erodible soils, *Atmos. Environ., 16*, 171-176, 1982.

Turekian, K. K., W. C. Graustein, and J. K. Cochran, Lead-210 in the SEAREX program: an aerosol tracer across the Pacific, in *Chemical Oceanography, Vol. 10, SEAREX: The Sea/Air Exchange Program*, pp. 51-81, edited by J. P. Riley, R. Chester and R. A. Duce, Academic, San Diego, Calif., 1989.

Uematsu, M., R. A. Duce, J. M. Prospero, L. Chen, J. T. Merrill and R. L. McDonald, The transport of mineral aerosol from Asia over the North Pacific Ocean, *J. Geophys. Res., 88*, 5343-5352, 1983.

Watts, S. F., R. Yaaqub, and T. Davies, The use of Whatman 41 filter papers for high volume aerosol sampling: Comments, Atmos. Environ., 21, 2731-2732, 1987.

PRESENTATIONS AND PAPERS ARISING FROM NASA CONTRACT NAG8-841

Presentations using data acquired under this grant

The principal presentation of the data obtained under this grant was:

Savoie, D. L., J. M. Prospero, R. Arimoto, R. A. Duce, and B. Bodhaine, Concentrations of particulate nitrogen and sulfur species and mineral dust in the near-surface atmospheric boundary layer over the Pacific Ocean during the GLOBE Survey Flights, (Abstract) *Eos Trans. AGU, 71*, 1226, 1990. Fall Meeting of the American Geophysical Union, 3-7 December 1990 (DLS-Oral).

The results from this grant have provided a critical part of the data base of aerosol species concentrations over the Pacific Ocean. Consequently, many other presentations have included the data that were derived from this grant; these include:

Prospero, J. M., and D. L. Savoie, Temporal and spatial distribution of nitrogen and sulfur species in aerosols over the world ocean. CHEMRAWN VII, World Conference on the Chemistry of the Atmosphere: Its Impact on Global Change, Baltimore, Maryland, 2-6 December 1991.

Prospero, J. M., D. L. Savoie, Huang F., Huang T., M. A. Izaguirre, and T. H. Snowdon, Aerosol nitrate, non-sea-salt sulfate, methanesulfonate and ammonium in the marine boundary layer over the western North Pacific during PEM-West, (Abstract) *Eos Trans. AGU, 73*(25, Supplement), 28, 1992. Western Pacific Geophysics Meeting, Hong Kong, 17-21 August 1992.

Arimoto, R., Y. Gao, X. Zhang, M. Zhou, R. A. Duce, J. M. Prospero, D. L. Savoie, and L. Chen, Chemistry of aerosol particles over Asia and the North Pacific, First IGAC Scientific Conference, Eilat, Israel, 18-22 April 1993.

Arimoto, R., R. A. Duce, J. M. Prospero, and D. L. Savoie, Relationships among aerosol constituents from Asia and the North Pacific, (Abstract) *Eos Trans. AGU, 75*(25, Supplement), 16, 1994. Western Pacific Geophysics Meeting, Hong Kong, 25-29 July 1994.

Arimoto, R., Y. Gao, R. A. Duce, J. M. Prospero, and D. L. Savoie, Aerosol particles and global change, Colloquium on Global Change in Asia and the Pacific Regions (GCAP), Beijing, China, 8-10 August 1994.

Prospero, J. M., D. L. Savoie, R. Arimoto, and R. A. Duce, Spatial and temporal variability of aerosols over the North Pacific: Estimates of anthropogenic contributions, IGAC Meeting, 1994.

Jaffe, D., E. Pullman, Zhiyong Z., Lizhen Z., J. Merrill, W. Ellis, P. Novelli, J. Prospero, and D. Savoie, North Pacific atmosphere: Interpretation of data from Shemya, Guam, Midway, and Mauna Loa, To be presented at the IGAC/IGBP-WMO Meeting, Beijing, China, October 1995.

Arimoto, R., R. A. Duce, J. M. Prospero, D. L. Savoie, U. Tomza, N. F. Lewis, B. J. Ray, Y. Gao, M. Zhou, and X. Zhang, Coupling of the biogeochemical cycles of trace elements and major ions in the atmosphere over the Asia/Pacific region, To be presented at the IGAC/IGBP-WMO Meeting, Beijing, China, October 1995.

Publications using data acquired under this grant

Refereed Publications

Savoie, D. L., J. M. Prospero, R. Arimoto, and R. A. Duce, Nonsea-salt sulfate and methanesulfonate at American Samoa, *J. Geophys. Res., 99*(D2), 3587-3596, 1994.

Other Publications

Savoie, D. L., J. M. Prospero, R. Arimoto, and R. A. Duce, Aerosol constituents at American Samoa: November 1989, in *Climate Monitoring and Diagnostics Laboratory, No. 18, Summary Report 1989*, pp. 123-124, edited by W. D. Komhyr, CMDL, NOAA, Boulder, Colorado, 1990.

Savoie, D. L., J. M. Prospero, R. Arimoto, and R. A. Duce, Aerosol constituents at American Samoa: May-June 1990, in *Climate Monitoring and Diagnostics Laboratory, No. 19, Summary Report 1990*, pp. 109-111, edited by E. Ferguson, CMDL, NOAA, Boulder, Colorado, 1991.

Prospero, J. M., and D. L. Savoie, Nitrate and non-sea-salt sulfate aerosols at American Samoa: 1983-1990, in *Climate Monitoring and Diagnostics Laboratory, No. 20, Summary Report 1991*, pp. 117-118, edited by E. E. Ferguson, CMDL, NOAA, Boulder, Colorado, 1992.

Savoie, D. L., and J. M. Prospero, Nonsea-salt sulfate to methanesulfonate ratios at American Samoa, in *Climate Monitoring and Diagnostics Laboratory, No. 21, Summary Report 1992*, pp. 112-114, edited by J. T. Peterson and R. M. Rosson, CMDL, NOAA, Boulder, Colorado, 1993.

Publications Currently Submitted or in Preparation

Chin, M., D. J. Jacob, G. M. Gardner, M. Forman-Fowler, P. A. Spiro, and D. L. Savoie, A global three-dimensional model of tropospheric sulfate, *J. Geophys. Res.*, (submitted), 1995.

Arimoto, R.A., et al., Comparison of ground station and aircraft measurements during PEM-West (B), *J. Geophys. Res.*, (in preparation for PEM-West B Special Issue), 1995.

Prospero, J. M., et al., The relationship of aerosol light scattering properties to the physical and chemical characteristics of aerosols in the Hong Kong region, *J. Geophys. Res.*, (in preparation for PEM-West B Special Issue), 1995.

Savoie, D. L., R. Arimoto, J. M. Prospero, and R. A. Duce, Spatial and temporal variations of aerosol species in the marine boundary layer of the North Pacific, *J. Geophys. Res.*, (in preparation for PEM-West B Special Issue), 1995.

Other usages of data acquired under this grant

In addition to those cited above, the results that were obtained under this grant were supplied to other investigators and have been used for comparisons in several modeling efforts, specifically:

Penner, J. E., C. S. Atherton, J. Dignon, S. J. Ghan, and J. J. Wilson, Tropospheric nitrogen: A three dimensional study of sources, distributions, and deposition, *J. Geophys. Res., 96*, 959-990, 1991.

Kasibhatla, P. S., H. Levy II, and W. J. Moxim, Global NO_x, HNO_3, PAN, and NO_y distributions from fossil fuel combustion emissions: A model study, *J. Geophys. Res., 98*, 7165-7180, 1993.

We have most recently supplied all of the data that we obtained during the second GLOBE survey flight to Raif Majeed who is working with Marcia Baker and Dean Hegg at the University of Washington to model injections of particles from the free troposphere into the marine boundary layer by synoptic-scale subsidence.

We have also very recently supplied the Pacific dust data to Ina Tegen, a post doctoral associate at NASA Goddard Institute for Space Studies, who is working with the GISS General Circulation Model to develop a global model for dust generation and transport.

TABLE 1. SUMMARY STATISTICS FOR ATMOSPHERIC CONCENTRATIONS DURING GLOBE I, 1989

Statistic	Cl^- $\mu g\ m^{-3}$	NO_3^- $\mu g\ m^{-3}$	$SO_4^=$ $\mu g\ m^{-3}$	Na^+ $\mu g\ m^{-3}$	nss $SO_4^=$ $\mu g\ m^{-3}$	MSA $\mu g\ m^{-3}$	NH_4^+ $\mu g\ m^{-3}$	Dust† $ng\ m^{-3}$
				SHEMYA				
Number	4	4	4	4	4	0	4	3
Arith. Mean	48.47	0.112	7.599	26.971	0.810	*.****	0.0952	797.7
Std. Arith. Dev.	4.95	0.038	0.550	2.662	0.355	*.****	0.0255	197.1
Minimum	44.26	0.070	6.860	24.823	0.452	*.****	0.0762	672.3
Maximum	53.88	0.163	8.084	30.321	1.257	*.****	0.1328	1024.9
Geo. Mean	48.28	0.107	7.583	26.874	0.752	*.****	0.0930	782.7
Std. Geo. Dev.	1.107	1.412	1.077	1.102	1.568	*.***	1.278	1.264
				MIDWAY				
Number	26	26	26	26	26	26	26	26
Arith. Mean	7.28	0.217	1.662	4.199	0.605	0.0129	0.0958	396.6
Std. Arith. Dev.	3.37	0.082	0.697	1.893	0.415	0.0037	0.0529	415.8
Minimum	2.37	0.086	0.456	1.275	0.136	0.0071	0.0231	-46.7
Maximum	16.10	0.355	3.058	9.202	1.682	0.0225	0.2144	1686.1
Geo. Mean	6.54	0.200	1.500	3.782	0.484	0.0124	0.0822	*.*
Std. Geo. Dev.	1.631	1.527	1.640	1.626	1.999	1.323	1.785	*.***
				AMERICAN SAMOA				
Number	29	29	29	29	28	29	29	27
Arith. Mean	10.53	0.178	1.931	5.98	0.368	0.0177	0.0255	21.4
Std. Arith. Dev.	6.10	0.106	0.916	3.32	0.173	0.0075	0.0166	45.1
Minimum	4.73	0.043	1.087	2.90	0.138	0.0083	0.0083	-46.8
Maximum	28.95	0.379	4.503	15.92	0.688	0.0337	0.0673	152.7
Geo.Mean	9.41	0.146	1.773	5.39	0.327	0.0162	0.0211	*.*
Std. Geo. Dev.	1.564	1.938	1.490	1.539	1.664	1.514	1.878	*.***
				RAROTONGA				
Number	19	19	19	19	19	18	19	19
Arith. Mean	22.66	0.141	3.46	12.64	0.279	0.0182	0.0456	31.9
Std. Arith. Dev.	12.73	0.072	1.84	7.21	0.098	0.0045	0.0370	44.7
Minimum	11.75	0.042	1.92	6.58	0.081	0.0101	0.0016	-60.9
Maximum	67.06	0.291	9.93	38.05	0.455	0.0253	0.1446	133.8
Geo. Mean	20.45	0.124	3.16	11.39	0.261	0.0176	0.0322	*.*
Std. Geo. Dev.	1.538	1.720	1.502	1.543	1.505	1.301	2.678	*.***
				NORFOLK ISLAND				
Number	17	17	17	17	17	17	17	15
Arith. Mean	9.45	0.236	1.706	5.207	0.395	0.0366	0.1293	201.7
Std. Arith. Dev.	4.81	0.208	0.656	2.533	0.237	0.0098	0.0608	189.5
Minimum	4.24	0.042	1.141	2.532	0.092	0.0223	0.0486	1.6
Maximum	24.56	0.772	3.808	13.099	1.143	0.0543	0.2549	622.5
Geo. Mean	8.59	0.176	1.620	4.777	0.338	0.0353	0.1155	104.8
Std. Geo. Dev.	1.538	2.183	1.361	1.506	1.816	1.323	1.656	4.747
				KARAMEA				
Number	5	5	5	5	5	5	4	6
Arith. Mean	38.10	0.212	5.54	20.65	0.34	0.0437	0.1191	8641.5
Std. Arith. Dev.	6.77	0.055	0.97	3.68	0.16	0.0166	0.0622	6844.1
Minimum	29.72	0.161	4.18	16.16	0.11	0.0308	0.0323	3362.2
Maximum	48.63	0.302	6.90	26.41	0.53	0.0704	0.1794	21831.3
Geo. Mean	37.63	0.207	5.47	20.39	0.30	0.0416	0.1003	7055.9
Std. Geo. Dev.	1.191	1.273	1.196	1.190	1.881	1.413	2.16	1.93

†Dust is estimated as 12.5 times the measured Aluminum concentration
* indicates missing data or statistics that are not possible to calculate

TABLE 2. SUMMARY STATISTICS OF ATMOSPHERIC CONCENTRATIONS DURING GLOBE II, 1990

Statistic	Cl^- $\mu g\ m^{-3}$	NO_3^- $\mu g\ m^{-3}$	$SO_4^=$ $\mu g\ m^{-3}$	Na^+ $\mu g\ m^{-3}$	nss $SO_4^=$ $\mu g\ m^{-3}$	MSA $\mu g\ m^{-3}$	NH_4^+ $\mu g\ m^{-3}$	Dust† $ng\ m^{-3}$
				SHEMYA				
Number	3	3	3	3	3	0	3	5
Arith. Mean	20.93	0.246	3.911	12.078	0.871	*.****	0.1393	967.4
Std. Arith. Dev.	8.61	0.106	1.012	4.880	0.255	*.****	0.0283	436.5
Minimum	11.02	0.128	2.746	6.447	0.614	*.****	0.1118	630.9
Maximum	26.62	0.332	4.579	15.074	1.124	*.****	0.1683	1718.9
Geo. Mean	19.47	0.228	3.813	11.265	0.845	*.****	0.1374	904.5
Std. Geo. Dev.	1.638	1.659	1.330	1.622	1.355	*.***	1.227	1.478
				MIDWAY				
Number	24	24	24	24	24	24	24	24
Arith. Mean	7.191	0.474	2.044	4.14	1.002	0.0530	0.273	1626.1
Std. Arith. Dev.	4.209	0.226	0.688	2.35	0.537	0.0201	0.156	1313.5
Minimum	2.061	0.110	0.831	1.37	0.324	0.0228	0.045	198.1
Maximum	15.652	0.844	3.475	9.04	2.389	0.0876	0.636	4420.8
Geo. Mean	6.041	0.406	1.923	3.53	0.872	0.0490	0.228	1142.7
Std. Geo. Dev.	1.855	1.867	1.449	1.795	1.728	1.525	1.920	2.474
				OAHU				
Number	33	33	33	33	33	33	33	33
Arith. Mean	5.816	0.292	1.470	3.486	0.593	0.0306	0.0599	547.0
Std. Arith. Dev.	1.664	0.122	0.419	0.926	0.245	0.0102	0.0552	214.9.
Minimum	2.588	0.114	0.835	1.601	0.317	0.0186	-0.0082	150.8
Maximum	9.492	0.592	2.740	5.229	1.503	0.0626	0.2778	933.2
Geo. Mean	5.571	0.269	1.414	3.357	0.553	0.0293	*.****	497.7
Std. Geo. Dev.	1.358	1.527	1.325	1.333	1.447	1.347	*.***	1.610
				AMERICAN SAMOA				
Number	31	31	31	31	31	31	31	27
Arith. Mean	7.514	0.0940	1.566	4.416	0.454	0.0297	0.0172	14.4
Std. Arith. Dev.	2.209	0.0477	0.377	1.230	0.229	0.0159	0.0122	19.5
Minimum	3.343	0.0364	0.696	1.956	0.112	0.0087	0.0020	-13.4
Maximum	13.917	0.2067	2.399	7.878	0.868	0.0656	0.0582	68.9
Geo. Mean	7.200	0.0837	1.516	4.245	0.399	0.0256	0.0130	*.*
Std. Geo. Dev.	1.353	1.6242	1.309	1.340	1.698	1.778	2.285	*.***
				RAROTONGA				
Number	26	26	26	26	26	26	26	26
Arith. Mean	18.80	0.076	2.756	10.44	0.129	0.0144	0.0557	24.2
Std. Arith. Dev.	6.82	0.034	0.886	3.81	0.223	0.0044	0.0698	74.2
Minimum	10.30	0.018	1.563	5.91	-0.334	0.0084	-0.0106	-94.8
Maximum	36.73	0.143	4.842	20.56	0.841	0.0295	0.2722	234.8
Geo. Mean	17.74	0.068	2.627	9.85	*.***	0.0139	*.****	*.*
Std. Geo. Dev.	1.411	1.658	1.368	1.402	*.***	1.321	*.***	*.***
				NORFOLK ISLAND				
Number	17	17	17	17	17	17	17	17
Arith. Mean	11.19	0.109	1.697	6.15	0.149	0.0125	0.0505	40.5
Std. Arith. Dev.	7.45	0.140	1.078	3.93	0.135	0.0057	0.0411	71.7
Minimum	4.49	0.006	0.815	2.52	0.028	0.0074	0.0063	-67.5
Maximum	30.40	0.504	4.377	15.86	0.443	0.0293	0.1627	242.8
Geo. Mean	9.69	0.057	1.486	5.37	0.104	0.0116	0.0376	*.*
Std. Geo. Dev.	1.662	3.233	1.628	1.643	2.401	1.458	2.264	*.***

†Dust is estimated as 12.5 times the measured Aluminum concentration

* indicates missing data or statistics that are not possible to calculate

TABLE 3.

SHEMYA (52.92°N, 174.06°E)

20 May 1981 to 17 March 1994

Month of the Year	Nitrate µg/m3			Sodium µg/m3			Nonsea-Salt Sulfate µg/m3			Methanesulfonate ng/m3			Ammonium µg/m3			Aluminum ng/m3		
	Mean *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*
January	**0.080** *0.072*	**0.053** *0.029*	**9** *0.105*	**31.55** *32.23*	**18.74** *9.82*	**25** *53.72*	**0.510** *0.545*	**0.483** *0.017*	**9** *1.056*	**2.44** *2.10*	**1.66** *1.09*	**15** *3.92*	**0.032** *0.032*	**0.065** *-0.026*	**7** *0.096*	**132.1** *132.1*	**155.5** *57.3*	**2** *206.8*
February	**0.120** *0.098*	**0.073** *0.062*	**8** *0.162*	**26.57** *25.12*	**14.01** *14.55*	**28** *35.41*	**0.999** *1.145*	**0.666** *0.210*	**8** *1.572*	**3.41** *2.97*	**2.78** *1.11*	**17** *4.75*	**0.113** *0.132*	**0.074** *0.036*	**6** *0.177*	**112.7** *56.0*	**132.7** *27.7*	**7** *185.9*
March	**0.147** *0.118*	**0.129** *0.050*	**8** *0.227*	**32.06** *32.13*	**21.93** *13.42*	**25** *50.46*	**1.139** *0.960*	**1.038** *0.154*	**8** *1.804*	**5.57** *4.46*	**3.93** *2.67*	**15** *8.18*	**0.130** *0.122*	**0.110** *0.072*	**8** *0.223*	**111.9** *78.5*	**93.7** *38.6*	**8** *186.1*
April	**0.265** *0.212*	**0.185** *0.115*	**15** *0.372*	**20.25** *19.67*	**13.26** *8.52*	**30** *29.60*	**1.504** *1.061*	**1.412** *0.494*	**15** *2.695*	**21.46** *17.88*	**13.16** *9.10*	**20** *36.94*	**0.171** *0.148*	**0.120** *0.090*	**12** *0.268*	**468.0** *311.0*	**435.2** *213.7*	**6** *630.2*
May	**0.277** *0.254*	**0.158** *0.154*	**19** *0.458*	**13.04** *11.18*	**9.04** *5.17*	**22** *19.04*	**0.993** *0.653*	**1.819** *0.112*	**19** *1.023*	**93.02** *86.75*	**64.36** *47.17*	**20** *120.64*	**0.120** *0.116*	**0.085** *0.059*	**15** *0.147*	**108.9** *62.9*	**94.8** *50.2*	**6** *168.0*
June	**0.252** *0.250*	**0.092** *0.163*	**19** *0.324*	**7.71** *7.85*	**3.88** *4.10*	**19** *11.38*	**0.703** *0.773*	**0.821** *0.206*	**19** *1.420*	**161.88** *152.66*	**61.66** *107.31*	**19** *243.98*	**0.144** *0.143*	**0.085** *0.058*	**16** *0.232*	**62.0** *61.5*	**15.8** *48.4*	**4** *75.6*
July	**0.218** *0.181*	**0.132** *0.131*	**23** *0.264*	**8.02** *6.57*	**5.79** *4.68*	**25** *9.75*	**0.665** *0.588*	**0.404** *0.377*	**23** *1.084*	**196.96** *174.56*	**101.25** *98.73*	**24** *293.33*	**0.275** *0.186*	**0.319** *0.119*	**19** *0.321*	**21.3** *17.5*	**9.3** *16.0*	**4** *26.8*
August	**0.198** *0.184*	**0.081** *0.136*	**21** *0.294*	**13.76** *9.65*	**13.03** *5.56*	**25** *17.02*	**0.291** *0.426*	**0.696** *-0.410*	**21** *0.854*	**129.96** *103.40*	**76.21** *79.44*	**25** *172.96*	**0.142** *0.131*	**0.099** *0.066*	**17** *0.207*	**33.4** *16.0*	**28.2** *12.6*	**5** *61.1*
September	**0.267** *0.213*	**0.185** *0.108*	**22** *0.472*	**13.00** *13.47*	**5.63** *7.07*	**24** *18.44*	**0.420** *0.359*	**0.717** *0.183*	**22** *0.900*	**66.12** *49.79*	**61.47** *20.06*	**24** *100.12*	**0.187** *0.149*	**0.203** *0.090*	**18** *0.256*	**51.6** *55.0*	**24.9** *28.2*	**6** *68.3*
October	**0.230** *0.240*	**0.098** *0.109*	**11** *0.324*	**23.43** *21.51*	**10.32** *14.22*	**26** *29.27*	**0.398** *0.268*	**0.575** *-0.160*	**11** *0.909*	**15.07** *10.74*	**18.39** *4.77*	**25** *18.98*	**0.167** *0.135*	**0.085** *0.094*	**9** *0.265*	**35.3** *24.7*	**30.1** *14.8*	**7** *60.0*
November	**0.121** *0.110*	**0.074** *0.045*	**7** *0.163*	**29.62** *25.46*	**22.96** *10.05*	**25** *38.96*	**0.355** *0.302*	**0.329** *0.076*	**7** *0.675*	**4.00** *3.47*	**3.57** *1.17*	**22** *5.84*	**0.095** *0.093*	**0.031** *0.068*	**4** *0.122*	**58.2** *55.7*	**23.9** *36.6*	**7** *82.5*
December	**0.049** *0.036*	**0.026** *0.032*	**6** *0.082*	**29.67** *25.03*	**21.28** *14.44*	**22** *38.55*	**0.086** *0.233*	**0.626** *-0.557*	**6** *0.534*	**2.84** *1.96*	**1.90** *1.16*	**19** *4.67*	**0.030** *0.008*	**0.073** *-0.021*	**4** *0.083*	**83.5** *83.5*	**14.8** *76.4*	**2** *90.6*
Annual-Wkly	**0.212** *0.185*	**0.141** *0.086*	**168** *0.319*	**21.06** *17.02*	**16.97** *6.60*	**296** *34.75*	**0.682** *0.563*	**0.995** *0.088*	**168** *1.226*	**63.78** *17.98*	**85.17** *2.68*	**245** *134.83*	**0.157** *0.131*	**0.169** *0.040*	**134** *0.243*	**110.0** *55.9*	**183.4** *19.7*	**64** *180.2*
Annual-Mon	**0.185** *0.182*	**0.079** *0.092*	**12** *0.242*	**20.72** *20.59*	**9.27** *9.22*	**12** *27.06*	**0.672** *0.566*	**0.413** *0.294*	**12** *0.984*	**58.56** *14.31*	**70.40** *2.76*	**12** *115.22*	**0.134** *0.132*	**0.067** *0.078*	**12** *0.148*	**106.6** *58.8*	**119.4** *23.0*	**12** *95.2*

NOTE: Nitrate, Nonsea-salt Sulfate, and Ammonium values are for samples with Sodium concentrations less than 20 µg/m3

TABLE 4.

MIDWAY ISLAND (28.22°N, 177.35°W)

18 January 1981 to 7 April 1994

Month of the Year	Nitrate µg/m3			Sodium µg/m3			Nonsea-Salt Sulfate µg/m3			Methanesulfonate ng/m3			Ammonium µg/m3			Aluminum ng/m3		
	Mean *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*
January	**0.194** *0.193*	**0.099** *0.116*	**35** *0.284*	**4.53** *3.94*	**2.18** *2.75*	**35** *6.94*	**0.399** *0.344*	**0.324** *0.086*	**35** *0.668*	**6.97** *6.62*	**2.71** *3.95*	**14** *9.40*	**0.0806** *0.0663*	**0.0634** *0.0264*	**15** *0.1591*	**15.72** *18.60*	**12.31** *2.06*	**13** *27.15*
February	**0.257** *0.241*	**0.114** *0.145*	**35** *0.350*	**5.59** *4.88*	**3.59** *2.92*	**35** *7.55*	**0.379** *0.300*	**0.371** *0.227*	**35** *0.763*	**11.19** *8.09*	**7.22** *6.43*	**15** *18.89*	**0.0961** *0.0989*	**0.0559** *0.0330*	**18** *0.1588*	**71.01** *41.10*	**63.46** *17.92*	**22** *143.08*
March	**0.323** *0.339*	**0.138** *0.168*	**44** *0.469*	**4.65** *4.61*	**2.32** *2.24*	**44** *7.12*	**0.676** *0.622*	**0.372** *0.307*	**44** *1.097*	**14.09** *14.36*	**8.31** *4.52*	**19** *23.26*	**0.1169** *0.1036*	**0.0930** *0.0333*	**19** *0.1789*	**156.43** *133.19*	**113.70** *53.98*	**31** *290.46*
April	**0.411** *0.417*	**0.229** *0.155*	**49** *0.644*	**4.51** *4.16*	**2.80** *2.19*	**49** *6.29*	**0.887** *0.827*	**0.649** *0.209*	**48** *1.627*	**23.36** *24.00*	**14.16** *6.91*	**25** *36.45*	**0.1216** *0.0995*	**0.1072** *0.0376*	**22** *0.1932*	**135.90** *104.63*	**113.37** *43.80*	**31** *231.61*
May	**0.449** *0.437*	**0.215** *0.252*	**51** *0.693*	**3.44** *3.24*	**1.35** *2.26*	**51** *4.68*	**1.051** *0.929*	**0.802** *0.502*	**51** *1.614*	**46.11** *47.68*	**25.94** *17.45*	**23** *68.05*	**0.1421** *0.1197*	**0.1116** *0.0536*	**20** *0.2197*	**130.82** *.92.10*	**119.10** *45.74*	**37** *268.50*
June	**0.280** *0.271*	**0.098** *0.183*	**41** *0.372*	**3.17** *2.88*	**1.55** *1.83*	**41** *4.44*	**0.580** *0.550*	**0.221** *0.403*	**41** *0.783*	**29.07** *28.23*	**6.40** *22.69*	**18** *35.79*	**0.0533** *0.0435*	**0.0403** *0.0174*	**19** *0.0974*	**39.57** *21.47*	**44.81** *13.16*	**28** *60.86*
July	**0.187** *0.191*	**0.051** *0.139*	**46** *0.232*	**3.25** *3.01*	**1.31** *2.10*	**46** *4.55*	**0.383** *0.381*	**0.120** *0.299*	**46** *0.477*	**22.73** *21.81*	**6.43** *17.97*	**21** *27.19*	**0.0255** *0.0169*	**0.0271** *0.0030*	**23** *0.0557*	**8.16** *7.00*	**4.06** *5.28*	**25** *12.75*
August	**0.210** *0.207*	**0.076** *0.156*	**47** *0.273*	**3.35** *3.14*	**1.53** *2.13*	**47** *4.31*	**0.428** *0.379*	**0.230** *0.250*	**47** *0.605*	**26.85** *21.37*	**15.25** *16.34*	**21** *30.66*	**0.0303** *0.0170*	**0.0469** *0.0031*	**23** *0.0303*	**9.16** *5.82*	**8.80** *2.82*	**24** *13.40*
September	**0.224** *0.226*	**0.081** *0.139*	**46** *0.303*	**3.63** *3.16*	**2.00** *1.94*	**46** *5.06*	**0.386** *0.391*	**0.203** *0.258*	**46** *0.561*	**24.85** *20.63*	**13.31** *16.85*	**22** *33.49*	**0.0368** *0.0281*	**0.0349** *0.0048*	**20** *0.0768*	**16.91** *11.15*	**15.86** *4.17*	**24** *26.37*
October	**0.289** *0.275*	**0.100** *0.181*	**40** *0.386*	**4.63** *3.66*	**2.12** *3.00*	**40** *6.66*	**0.467** *0.490*	**0.292** *0.271*	**40** *0.732*	**17.19** *14.50*	**7.78** *9.75*	**21** *25.25*	**0.0309** *0.0260*	**0.0280** *0.0052*	**22** *0.0504*	**39.22** *25.50*	**40.84** *7.51*	**19** *57.09*
November	**0.255** *0.263*	**0.090** *0.183*	**38** *0.333*	**4.97** *4.58*	**2.35** *3.22*	**38** *6.82*	**0.429** *0.371*	**0.308** *0.239*	**37** *0.608*	**11.55** *11.48*	**3.82** *7.04*	**24** *14.52*	**0.0555** *0.0382*	**0.0506** *0.0115*	**20** *0.0891*	**51.22** *28.74*	**52.17** *16.04*	**23** *100.09*
December	**0.217** *0.190*	**0.108** *0.134*	**37** *0.304*	**5.01** *4.70*	**2.39** *3.45*	**37** *5.99*	**0.315** *0.334*	**0.312** *0.094*	**37** *0.583*	**9.93** *7.59*	**6.71** *6.05*	**18** *14.70*	**0.0500** *0.0346*	**0.0414** *0.0218*	**18** *0.0706*	**20.50** *16.77*	**17.69** *5.18*	**23** *37.30*
Annual-Wkly	**0.280** *0.242*	**0.155** *0.151*	**509** *0.411*	**4.16** *3.66*	**2.28** *2.26*	**509** *6.08*	**0.550** *0.449*	**0.467** *0.226*	**507** *0.866*	**21.19** *18.29*	**15.89** *7.01*	**241** *32.11*	**0.0686** *0.0412*	**0.0747** *0.0103*	**239** *0.1288*	**66.67** *26.76*	**90.11** *7.53*	**300** *129.01*
Annual-Mon	**0.275** *0.252*	**0.084** *0.192*	**12** *0.358*	**4.23** *3.80*	**0.82** *3.11*	**12** *4.63*	**0.532** *0.386*	**0.229** *0.341*	**12** *0.671*	**20.32** *17.56*	**10.93** *7.97*	**12** *25.02*	**0.0700** *0.0409*	**0.0404** *0.0239*	**12** *0.1005*	**57.88** *23.48*	**53.70** *10.15*	**12** *95.11*

TABLE 5.

OAHU, HAWAII (21.33°N, 157.70°W)

21 January 1981 to 17 March 1994

Month of the Year	Nitrate µg/m3			Sodium µg/m3			Nonsea-Salt Sulfate µg/m3			Methanesulfonate ng/m3			Ammonium µg/m3			Aluminum ng/m3		
	Mean *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*
January	**0.432** *0.347*	**0.279** *0.199*	**36** *0.668*	**5.68** *4.65*	**3.36** *3.19*	**36** *8.99*	**0.424** *0.393*	**0.318** *0.096*	**36** *0.693*	**12.95** *12.45*	**6.43** *7.05*	**16** *19.43*	**0.0756** *0.0312*	**0.1090** *-0.0005*	**17** *0.1357*	**48.14** *43.00*	**24.60** *22.08*	**9** *73.46*
February	**0.537** *0.411*	**0.424** *0.209*	**47** *0.806*	**5.29** *4.54*	**2.42** *3.30*	**47** *7.27*	**0.722** *0.531*	**0.717** *0.273*	**47** *1.064*	**14.87** *15.16*	**4.96** *8.78*	**20** *18.97*	**0.1169** *0.0292*	**0.1794** *0.0018*	**20** *0.2348*	**93.82** *74.04*	**80.35** *25.80*	**20** *129.37*
March	**0.394** *0.316*	**0.303** *0.213*	**51** *0.551*	**5.10** *4.69*	**1.96** *3.14*	**51** *7.03*	**0.623** *0.492*	**0.522** *0.288*	**51** *0.870*	**16.44** *17.60*	**5.89** *9.07*	**19** *20.07*	**0.0245** *0.0054*	**0.0451** *0.0009*	**21** *0.0446*	**119.91** *104.23*	**86.96** *43.43*	**21** *179.58*
April	**0.450** *0.383*	**0.262** *0.248*	**45** *0.555*	**4.87** *4.56*	**1.99** *3.34*	**45** *6.22*	**0.717** *0.593*	**0.449** *0.352*	**45** *1.004*	**23.93** *22.32*	**7.16** *17.54*	**17** *31.63*	**0.0851** *0.0089*	**0.1712** *0.0024*	**17** *0.1007*	**91.84** *66.09*	**80.29** *38.90*	**22** *136.34*
May	**0.418** *0.386*	**0.253** *0.241*	**44** *0.509*	**4.51** *4.03*	**2.40** *2.72*	**44** *5.85*	**0.714** *0.605*	**0.456** *0.369*	**44** *0.928*	**28.20** *29.24*	**5.81** *23.69*	**17** *33.84*	**0.0266** *0.0069*	**0.0312** *0.0010*	**17** *0.0604*	**110.47** *82.00*	**69.81** *46.90*	**23** *172.82*
June	**0.281** *0.274*	**0.100** *0.199*	**38** *0.353*	**3.85** *3.61*	**1.53** *2.73*	**38** *5.03*	**0.458** *0.436*	**0.231** *0.310*	**38** *0.585*	**23.12** *22.80*	**5.07** *18.89*	**17** *24.92*	**0.0073** *-0.0011*	**0.0289** *-0.0027*	**17** *0.0007*	**43.31** *42.51*	**20.85** *23.08*	**20** *69.31*
July	**0.240** *0.204*	**0.112** *0.159*	**39** *0.326*	**3.84** *3.86*	**1.13** *2.55*	**39** *5.10*	**0.407** *0.384*	**0.281** *0.229*	**39** *0.491*	**19.60** *19.31*	**4.85** *15.19*	**17** *25.52*	**0.0003** *-0.0009*	**0.0037** *-0.0026*	**17** *0.0028*	**15.41** *10.33*	**17.96** *5.02*	**16** *20.07*
August	**0.288** *0.257*	**0.167** *0.177*	**41** *0.371*	**4.00** *3.50*	**3.06** *2.67*	**41** *4.52*	**0.473** *0.417*	**0.253** *0.309*	**41** *0.565*	**21.49** *20.88*	**3.15** *19.22*	**17** *23.30*	**0.0011** *0.0002*	**0.0036** *-0.0016*	**17** *0.0027*	**14.07** *10.34*	**8.79** *6.49*	**16** *22.90*
September	**0.296** *0.273*	**0.105** *0.216*	**46** *0.401*	**3.52** *3.37*	**1.42** *2.09*	**46** *4.83*	**0.485** *0.449*	**0.227** *0.295*	**46** *0.625*	**20.54** *20.89*	**4.86** *15.66*	**17** *25.33*	**0.0169** *0.0040*	**0.0323** *-0.0009*	**17** *0.0304*	**18.29** *9.93*	**25.85** *5.44*	**20** *23.49*
October	**0.316** *0.272*	**0.239** *0.180*	**44** *0.396*	**3.82** *3.35*	**1.76** *2.57*	**42** *5.07*	**0.484** *0.392*	**0.298** *0.274*	**42** *0.669*	**18.24** *18.70*	**4.14** *13.60*	**17** *22.65*	**0.0314** *0.0038*	**0.0457** *-0.0022*	**17** *0.0918*	**21.67** *18.34*	**16.86** *8.28*	**18** *29.81*
November	**0.267** *0.213*	**0.172** *0.156*	**42** *0.368*	**5.82** *5.23*	**2.59** *3.49*	**39** *8.62*	**0.289** *0.273*	**0.251** *0.107*	**39** *0.463*	**12.02** *11.52*	**4.22** *8.71*	**18** *15.04*	**0.0103** *0.0012*	**0.0309** *-0.0005*	**18** *0.0075*	**19.03** *15.56*	**16.82** *9.26*	**12** *20.11*
December	**0.242** *0.179*	**0.133** *0.151*	**33** *0.355*	**5.48** *5.12*	**1.88** *3.68*	**33** *7.06*	**0.271** *0.249*	**0.156** *0.147*	**33** *0.467*	**9.28** *9.43*	**2.18** *7.25*	**17** *11.29*	**0.0117** *0.0008*	**0.0275** *-0.0041*	**17** *0.0218*	**34.30** *18.95*	**37.33** *8.95*	**8** *65.89*
Annual-Wkly	**0.352** *0.284*	**0.253** *0.184*	**506** *0.502*	**4.63** *4.10*	**2.31** *2.86*	**501** *6.31*	**0.519** *0.429*	**0.416** *0.251*	**501** *0.741*	**18.32** *18.34*	**7.20** *11.07*	**209** *25.30*	**0.0348** *0.0033*	**0.0899** *-0.0014*	**212** *0.0628*	**58.46** *35.22*	**66.56** *9.73*	**205** *110.42*
Annual-Mon	**0.347** *0.273*	**0.096** *0.211*	**12** *0.384*	**4.65** *4.29*	**0.82** *3.47*	**12** *4.79*	**0.506** *0.426*	**0.157** *0.358*	**12** *0.546*	**18.39** *19.00*	**5.51** *12.23*	**12** *22.44*	**0.0340** *0.0039*	**0.0377** *0.0000*	**12** *0.0138*	**52.51** *30.73*	**40.11** *10.33*	**12** *75.95*

TABLE 6.

AMERICAN SAMOA (14.25°S, 170.58°W)

19 March 1983 to 6 May 1992

Month of the Year	Nitrate µg/m3			Sodium µg/m3			Nonsea-Salt Sulfate µg/m3			Methanesulfonate ng/m3			Ammonium µg/m3			Aluminum ng/m3		
	Mean *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*
January	**0.113**	**0.064**	**27**	**5.33**	**2.20**	**27**	**0.407**	**0.164**	**26**	**28.38**	**7.01**	**8**	**0.0051**	**0.0100**	**9**	**2.35**	**1.57**	**6**
	0.092	*0.059*	*0.170*	*4.68*	*3.77*	*6.54*	*0.393*	*0.230*	*0.599*	*27.63*	*22.74*	*36.38*	*0.0016*	*-0.0004*	*0.0100*	*2.62*	*0.90*	*3.76*
February	**0.110**	**0.054**	**26**	**6.34**	**3.17**	**26**	**0.409**	**0.194**	**23**	**19.58**	**7.36**	**8**	**0.0166**	**0.0288**	**11**	**2.09**	**2.90**	**4**
	0.096	*0.066*	*0.151*	*5.43*	*3.73*	*8.43*	*0.408*	*0.194*	*0.581*	*18.28*	*12.59*	*27.04*	*0.0031*	*0.0001*	*0.0315*	*1.54*	*-0.15*	*4.36*
March	**0.093**	**0.038**	**35**	**4.69**	**1.50**	**35**	**0.398**	**0.137**	**34**	**20.40**	**9.10**	**12**	**0.0122**	**0.0230**	**12**	**1.40**	**1.03**	**14**
	0.089	*0.059*	*0.118*	*4.24*	*3.53*	*5.93*	*0.385*	*0.258*	*0.576*	*19.52*	*12.98*	*27.21*	*0.0044*	*0.0009*	*0.0156*	*1.02*	*0.41*	*2.61*
April	**0.076**	**0.023**	**33**	**4.79**	**1.81**	**33**	**0.291**	**0.140**	**32**	**20.03**	**11.22**	**14**	**0.0016**	**0.0027**	**11**	**1.41**	**2.95**	**14**
	0.082	*0.050*	*0.096*	*4.45*	*3.21*	*6.38*	*0.280*	*0.162*	*0.376*	*15.49*	*11.33*	*29.10*	*0.0004*	*-0.0004*	*0.0049*	*0.39*	*0.07*	*1.82*
May	**0.089**	**0.032**	**33**	**4.84**	**1.25**	**33**	**0.326**	**0.197**	**33**	**26.20**	**14.63**	**10**	**0.0153**	**0.0219**	**9**	**1.10**	**1.41**	**18**
	0.083	*0.062*	*0.122*	*5.25*	*3.40*	*6.05*	*0.290*	*0.194*	*0.414*	*23.45*	*13.78*	*39.12*	*0.0049*	*-0.0015*	*0.0272*	*0.70*	*0.08*	*2.26*
June	**0.095**	**0.034**	**36**	**4.68**	**1.59**	**36**	**0.335**	**0.108**	**35**	**23.27**	**12.55**	**12**	**0.0040**	**0.0065**	**9**	**0.72**	**0.96**	**19**
	0.094	*0.067*	*0.122*	*4.40*	*3.09*	*6.16*	*0.339*	*0.240*	*0.425*	*20.80*	*13.18*	*28.63*	*0.0022*	*-0.0010*	*0.0108*	*0.50*	*-0.11*	*1.81*
July	**0.102**	**0.040**	**37**	**5.13**	**1.48**	**37**	**0.316**	**0.134**	**37**	**23.68**	**14.42**	**11**	**0.0034**	**0.0087**	**11**	**0.96**	**0.93**	**17**
	0.093	*0.070*	*0.139*	*4.96*	*3.69*	*6.79*	*0.303*	*0.169*	*0.443*	*16.30*	*13.31*	*44.02*	*0.0005*	*-0.0032*	*0.0142*	*0.70*	*0.20*	*2.16*
August	**0.112**	**0.044**	**36**	**5.64**	**1.61**	**36**	**0.308**	**0.154**	**35**	**21.37**	**9.47**	**10**	**0.0016**	**0.0047**	**11**	**1.60**	**1.42**	**15**
	0.099	*0.063*	*0.154*	*5.44*	*4.43*	*7.15*	*0.298*	*0.154*	*0.476*	*24.71*	*10.73*	*30.62*	*0.0013*	*-0.0013*	*0.0045*	*1.50*	*0.20*	*2.94*
September	**0.152**	**0.058**	**38**	**5.06**	**1.35**	**38**	**0.458**	**0.154**	**38**	**28.90**	**12.20**	**13**	**0.0085**	**0.0064**	**13**	**1.24**	**0.92**	**16**
	0.132	*0.105*	*0.196*	*4.90*	*3.72*	*6.55*	*0.430*	*0.319*	*0.613*	*25.01*	*17.08*	*39.86*	*0.0066*	*0.0018*	*0.0168*	*1.13*	*0.51*	*2.19*
October	**0.139**	**0.054**	**35**	**4.53**	**1.19**	**34**	**0.456**	**0.161**	**34**	**24.47**	**9.30**	**10**	**0.0081**	**0.0083**	**12**	**2.10**	**1.59**	**14**
	0.138	*0.092*	*0.184*	*4.56*	*3.36*	*5.48*	*0.435*	*0.276*	*0.627*	*23.06*	*16.32*	*33.84*	*0.0061*	*0.0015*	*0.0129*	*1.86*	*1.06*	*3.50*
November	**0.132**	**0.053**	**37**	**4.75**	**1.24**	**37**	**0.351**	**0.100**	**37**	**19.05**	**5.37**	**15**	**0.0133**	**0.0178**	**13**	**2.04**	**1.90**	**17**
	0.129	*0.098*	*0.170*	*4.52*	*3.69*	*5.99*	*0.354*	*0.271*	*0.449*	*17.10*	*13.99*	*25.25*	*0.0039*	*0.0011*	*0.0271*	*1.53*	*0.52*	*3.45*
December	**0.146**	**0.061**	**29**	**5.95**	**1.78**	**29**	**0.416**	**0.173**	**29**	**19.53**	**6.84**	**5**	**0.0052**	**0.0041**	**9**	**2.58**	**2.88**	**8**
	0.130	*0.092*	*0.209*	*5.52*	*4.00*	*7.98*	*0.415*	*0.275*	*0.537*	*17.97*	*13.75*	*25.82*	*0.0037*	*0.0013*	*0.0102*	*2.85*	*0.99*	*4.42*
Annual-Wkly	**0.114**	**0.052**	**402**	**5.10**	**1.75**	**401**	**0.371**	**0.160**	**393**	**22.88**	**10.65**	**128**	**0.0081**	**0.0149**	**130**	**1.48**	**1.70**	**162**
	0.102	*0.067*	*0.164*	*4.84*	*3.54*	*6.63*	*0.356*	*0.224*	*0.509*	*21.32*	*12.81*	*30.98*	*0.0035*	*-0.0003*	*0.0145*	*1.06*	*0.20*	*2.80*
Annual-Mon	**0.113**	**0.024**	**12**	**5.14**	**0.57**	**12**	**0.373**	**0.058**	**12**	**22.90**	**3.49**	**12**	**0.0079**	**0.0053**	**12**	**1.63**	**0.59**	**12**
	0.095	*0.088*	*0.130*	*4.79*	*4.44*	*5.43*	*0.369*	*0.296*	*0.419*	*20.16*	*16.91*	*24.78*	*0.0034*	*0.0011*	*0.0052*	*1.32*	*0.65*	*2.04*

TABLE 7.

RAROTONGA (21.25°S, 159.75°W)

9 February 1989 to 6 January 1994

Month of the Year	Nitrate µg/m3			Sodium µg/m3			Nonsea-Salt Sulfate µg/m3			Methanesulfonate ng/m3			Ammonium µg/m3			Aluminum ng/m3		
	Mean *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*
January	**0.105** *0.108*	**0.039** *0.063*	**11** *0.147*	**17.66** *14.26*	**10.19** *8.72*	**11** *28.72*	**0.299** *0.335*	**0.205** *0.212*	**7** *0.454*	**29.75** *27.31*	**17.35** *11.07*	**11** *44.17*	**0.0088** *0.0067*	**0.0056** *0.0043*	**11** *0.0128*	**na** *na*	**na** *na*	**0** *na*
February	**0.101** *0.107*	**0.044** *0.056*	**12** *0.145*	**9.47** *8.88*	**3.25** *6.37*	**12** *11.95*	**0.202** *0.241*	**0.375** *-0.129*	**12** *0.453*	**29.67** *33.77*	**11.12** *20.18*	**9** *36.59*	**0.0135** *0.0080*	**0.0177** *0.0031*	**12** *0.0171*	**na** *na*	**na** *na*	**0** *na*
March	**0.101** *0.096*	**0.022** *0.087*	**17** *0.120*	**11.50** *9.33*	**6.89** *6.86*	**18** *14.30*	**0.176** *0.248*	**0.329** *0.087*	**16** *0.381*	**19.60** *21.09*	**7.18** *13.48*	**14** *25.49*	**0.0058** *0.0049*	**0.0044** *0.0016*	**18** *0.0103*	**na** *na*	**na** *na*	**0** *na*
April	**0.096** *0.077*	**0.051** *0.047*	**17** *0.156*	**10.48** *10.42*	**3.66** *7.53*	**17** *12.60*	**0.155** *0.190*	**0.189** *0.014*	**16** *0.342*	**11.45** *9.24*	**5.70** *6.61*	**12** *18.99*	**0.0082** *0.0024*	**0.0190** *0.0004*	**17** *0.0108*	**na** *na*	**na** *na*	**0** *na*
May	**0.090** *0.084*	**0.041** *0.084*	**18** *0.084*	**10.21** *8.71*	**4.99** *8.71*	**18** *8.71*	**0.118** *0.106*	**0.103** *0.106*	**17** *0.106*	**14.19** *13.97*	**2.84** *13.97*	**14** *13.97*	**0.0199** *0.0100*	**0.0219** *0.0100*	**18** *0.0100*	**1.75** *1.43*	**1.96** *1.43*	**4** *1.43*
June	**0.079** *0.073*	**0.026** *0.053*	**19** *0.111*	**12.27** *9.99*	**5.56** *8.16*	**19** *16.07*	**0.083** *0.121*	**0.179** *-0.066*	**16** *0.201*	**11.82** *10.43*	**4.67** *7.81*	**16** *17.71*	**0.0132** *0.0071*	**0.0208** *0.0005*	**18** *0.0229*	**4.34** *4.34*	**3.07** *2.86*	**2** *5.81*
July	**0.095** *0.089*	**0.040** *0.059*	**19** *0.137*	**11.62** *10.25*	**5.71** *6.04*	**19** *16.31*	**0.024** *0.134*	**0.303** *-0.274*	**18** *0.303*	**11.92** *9.55*	**7.49** *7.36*	**15** *19.10*	**0.0082** *0.0079*	**0.0109** *-0.0008*	**19** *0.0162*	**na** *na*	**na** *na*	**0** *na*
August	**0.116** *0.103*	**0.047** *0.078*	**21** *0.152*	**10.31** *9.22*	**3.58** *7.32*	**21** *12.48*	**0.133** *0.200*	**0.291** *-0.114*	**21** *0.366*	**13.89** *12.72*	**6.05** *9.00*	**18** *17.46*	**0.0143** *0.0101*	**0.0151** *0.0036*	**21** *0.0279*	**na** *na*	**na** *na*	**0** *na*
September	**0.154** *0.136*	**0.068** *0.091*	**21** *0.222*	**9.90** *9.19*	**2.98** *7.47*	**22** *12.78*	**0.263** *0.258*	**0.159** *0.148*	**22** *0.392*	**17.85** *16.49*	**6.42** *12.48*	**18** *23.70*	**0.0207** *0.0098*	**0.0242** *0.0042*	**22** *0.0376*	**na** *na*	**na** *na*	**0** *na*
October	**0.132** *0.119*	**0.054** *0.081*	**16** *0.196*	**10.93** *10.14*	**4.79** *7.53*	**16** *12.52*	**0.182** *0.137*	**0.332** *-0.184*	**15** *0.589*	**22.67** *22.31*	**7.21** *15.68*	**12** *30.69*	**0.0074** *0.0033*	**0.0079** *0.0020*	**16** *0.0137*	**4.63** *4.63*	**na** *4.63*	**1** *4.63*
November	**0.158** *0.141*	**0.078** *0.091*	**14** *0.212*	**10.88** *9.29*	**4.43** *6.50*	**14** *15.12*	**0.176** *0.310*	**0.442** *0.004*	**14** *0.454*	**22.89** *23.06*	**7.66** *16.06*	**13** *28.32*	**0.0166** *0.0064*	**0.0192** *0.0037*	**14** *0.0403*	**2.52** *2.79*	**1.96** *1.24*	**4** *3.79*
December	**0.112** *0.106*	**0.038** *0.076*	**20** *0.143*	**11.47** *8.95*	**6.69** *7.81*	**20** *15.84*	**0.121** *0.219*	**0.364** *-0.033*	**19** *0.326*	**23.92** *26.33*	**9.36** *12.40*	**10** *32.83*	**0.0132** *0.0073*	**0.0164** *0.0020*	**20** *0.0233*	**na** *na*	**na** *na*	**0** *na*
Annual-Wkly	**0.112** *0.104*	**0.052** *0.064*	**205** *0.155*	**11.22** *9.43*	**5.50** *7.10*	**207** *14.28*	**0.154** *0.202*	**0.286** *-0.072*	**193** *0.375*	**18.23** *15.83*	**9.82** *9.65*	**162** *27.49*	**0.0127** *0.0073*	**0.0171** *0.0018*	**206** *0.0227*	**2.76** *2.71*	**2.13** *0.79*	**11** *4.63*
Annual-Mon	**0.112** *0.105*	**0.025** *0.082*	**12** *0.123*	**11.39** *9.31*	**2.13** *8.93*	**12** *10.29*	**0.161** *0.209*	**0.074** *0.130*	**12** *0.270*	**19.14** *18.79*	**6.68** *10.22*	**12** *26.56*	**0.0125** *0.0072*	**0.0049** *0.0045*	**12** *0.0098*	**3.31** *3.56*	**1.40** *2.08*	**4** *4.49*

TABLE 8.

NORFOLK ISLAND (29.08°S, 167.98°E)

27 May 1983 to 7 January 1994

Month of the Year	Nitrate µg/m3			Sodium µg/m3			Nonsea-Salt Sulfate µg/m3			Methanesulfonate ng/m3			Ammonium µg/m3			Aluminum ng/m3		
	Mean *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*
January	**0.220** *0.204*	**0.134** *0.096*	**34** *0.302*	**6.20** *5.54*	**2.86** *4.03*	**34** *7.41*	**0.431** *0.431*	**0.173** *0.268*	**34** *0.582*	**46.14** *42.71*	**18.04** *29.03*	**15** *65.74*	**0.0787** *0.0731*	**0.0482** *0.0227*	**12** *0.1241*	**60.81** *43.95*	**57.60** *9.34*	**10** *136.00*
February	**0.190** *0.182*	**0.087** *0.115*	**37** *0.256*	**6.78** *5.51*	**4.19** *3.86*	**37** *9.70*	**0.411** *0.386*	**0.205** *0.259*	**36** *0.496*	**33.26** *30.65*	**10.84** *27.44*	**18** *37.76*	**0.0663** *0.0562*	**0.0548** *0.0095*	**13** *0.1339*	**68.26** *34.15*	**60.55** *19.02*	**12** *129.79*
March	**0.184** *0.149*	**0.100** *0.116*	**39** *0.266*	**7.18** *6.51*	**3.99** *3.69*	**39** *11.41*	**0.276** *0.284*	**0.178** *0.135*	**39** *0.407*	**23.72** *20.70*	**7.95** *16.90*	**17** *33.82*	**0.0499** *0.0449*	**0.0325** *0.0203*	**13** *0.0711*	**72.58** *21.20*	**127.33** *15.17*	**13** *94.54*
April	**0.167** *0.148*	**0.095** *0.086*	**39** *0.236*	**6.55** *5.27*	**3.71** *3.73*	**39** *10.26*	**0.250** *0.196*	**0.196** *0.103*	**39** *0.499*	**17.01** *14.92*	**9.28** *12.36*	**21** *22.44*	**0.0353** *0.0201*	**0.0337** *0.0097*	**16** *0.0532*	**22.82** *25.45*	**12.43** *6.82*	**12** *34.12*
May	**0.144** *0.114*	**0.112** *0.072*	**37** *0.199*	**7.21** *6.24*	**4.24** *3.88*	**37** *10.68*	**0.135** *0.135*	**0.185** *-0.011*	**37** *0.295*	**11.25** *10.62*	**4.38** *6.85*	**16** *16.21*	**0.0372** *0.0205*	**0.0382** *0.0125*	**17** *0.0542*	**74.03** *8.64*	**229.06** *2.98*	**12** *13.86*
June	**0.118** *0.105*	**0.084** *0.064*	**45** *0.137*	**9.03** *8.22*	**4.84** *5.06*	**45** *11.04*	**0.104** *0.128*	**0.179** *-0.005*	**44** *0.246*	**5.78** *5.87*	**2.43** *3.97*	**21** *8.07*	**0.0515** *0.0457*	**0.0363** *0.0189*	**21** *0.0868*	**7.38** *8.40*	**4.54** *2.63*	**19** *11.85*
July	**0.130** *0.095*	**0.109** *0.058*	**42** *0.183*	**9.53** *8.39*	**5.63** *4.53*	**42** *14.92*	**0.095** *0.088*	**0.186** *-0.054*	**42** *0.198*	**6.14** *5.15*	**2.64** *4.20*	**16** *8.53*	**0.0551** *0.0530*	**0.0302** *0.0252*	**18** *0.0840*	**9.85** *9.60*	**5.52** *5.26*	**17** *14.72*
August	**0.176** *0.133*	**0.138** *0.070*	**37** *0.280*	**8.10** *7.62*	**3.13** *5.14*	**37** *11.11*	**0.126** *0.107*	**0.205** *-0.048*	**36** *0.298*	**7.15** *6.88*	**1.91** *5.55*	**16** *9.20*	**0.0524** *0.0433*	**0.0295** *0.0280*	**14** *0.0836*	**9.30** *8.25*	**9.07** *3.06*	**16** *12.04*
September	**0.199** *0.160*	**0.137** *0.084*	**38** *0.295*	**10.66** *9.27*	**6.82** *5.42*	**38** *15.20*	**0.208** *0.203*	**0.209** *0.050*	**35** *0.379*	**13.99** *11.60*	**6.16** *9.81*	**14** *20.75*	**0.0653** *0.0509*	**0.0419** *0.0332*	**15** *0.0992*	**44.75** *9.30*	**110.45** *3.31*	**15** *30.36*
October	**0.236** *0.182*	**0.188** *0.116*	**38** *0.321*	**9.79** *8.03*	**6.37** *4.51*	**36** *13.89*	**0.268** *0.268*	**0.197** *0.118*	**31** *0.452*	**23.41** *19.05*	**12.63** *14.64*	**18** *28.96*	**0.0772** *0.0604*	**0.0975** *0.0307*	**17** *0.0784*	**17.95** *15.20*	**12.11** *8.29*	**12** *26.58*
November	**0.218** *0.168*	**0.141** *0.120*	**39** *0.332*	**7.32** *6.05*	**3.89** *4.34*	**37** *10.64*	**0.374** *0.339*	**0.273** *0.221*	**36** *0.610*	**41.80** *41.66*	**11.94** *28.79*	**23** *51.40*	**0.0831** *0.0760*	**0.0627** *0.0363*	**19** *0.1369*	**49.53** *17.80*	**79.45** *9.21*	**12** *68.24*
December	**0.239** *0.207*	**0.122** *0.137*	**34** *0.320*	**5.55** *4.95*	**2.35** *3.74*	**34** *8.11*	**0.451** *0.429*	**0.158** *0.315*	**34** *0.567*	**62.56** *61.27*	**21.92** *43.30*	**16** *83.04*	**0.0777** *0.0503*	**0.0866** *0.0299*	**16** *0.1056*	**55.00** *33.00*	**50.22** *23.68*	**9** *82.35*
Annual-Wkly	**0.183** *0.149*	**0.127** *0.081*	**459** *0.266*	**7.88** *6.65*	**4.76** *4.02*	**455** *11.28*	**0.254** *0.241*	**0.232** *0.056*	**443** *0.470*	**24.38** *17.70*	**20.12** *6.63*	**211** *42.97*	**0.0606** *0.0469*	**0.0550** *0.0196*	**191** *0.0940*	**37.52** *12.76*	**87.58** *5.16*	**159** *39.73*
Annual-Mon	**0.185** *0.187*	**0.040** *0.140*	**12** *0.224*	**7.82** *7.27*	**1.59** *6.47*	**12** *9.59*	**0.261** *0.259*	**0.131** *0.121*	**12** *0.415*	**24.35** *20.21*	**18.15** *6.91*	**12** *42.84*	**0.0608** *0.0602*	**0.0163** *0.0469*	**12** *0.0780*	**41.02** *47.14*	**26.07** *9.72*	**12** *69.29*

TABLE 9.

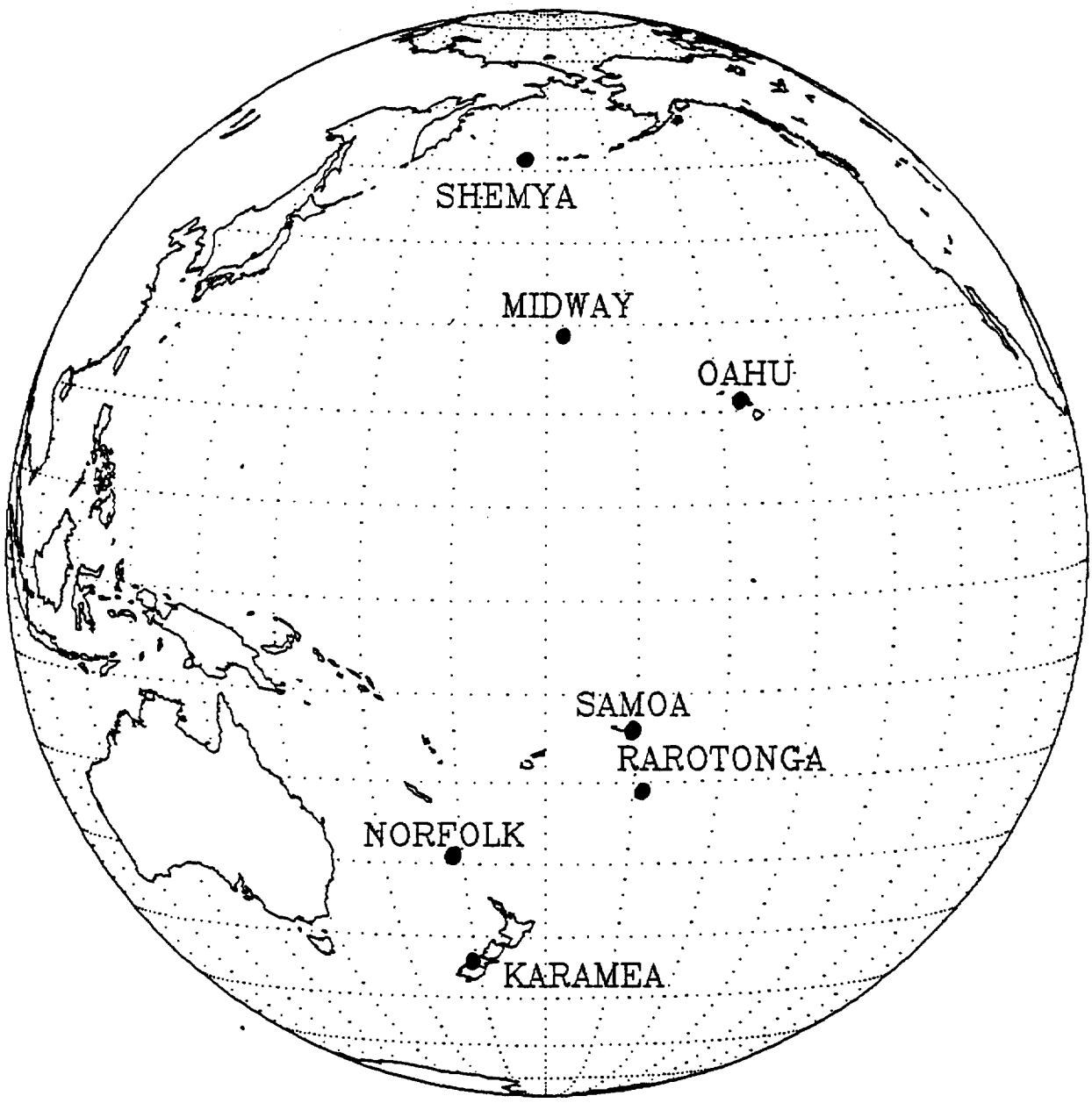
KARAMEA, NEW ZEALAND (41.25°S, 172.12°E)

4 July 1986 to 8 May 1990

Month of the Year	Nitrate µg/m3			Sodium µg/m3			Nonsea-Salt Sulfate µg/m3			Methanesulfonate ng/m3			Ammonium µg/m3			Aluminum ng/m3		
	Mean *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*	**Mean** *Median*	**Std** *16%*	**N** *84%*
January	**0.341** *0.311*	**0.227** *0.120*	**18** *0.591*	**18.68** *18.81*	**6.17** *12.62*	**18** *22.33*	**0.430** *0.502*	**0.246** *0.256*	**12** *0.617*	**na** *na*	**na** *na*	**0** *na*	**0.174** *0.142*	**0.085** *0.120*	**5** *0.229*	**na** *na*	**na** *na*	**0** *na*
February	**0.568** *0.543*	**0.460** *0.205*	**15** *1.010*	**19.96** *20.01*	**6.23** *14.04*	**15** *25.10*	**0.361** *0.310*	**0.230** *0.145*	**7** *0.648*	**50.11** *50.11*	**na** *50.11*	**1** *50.11*	**0.326** *0.306*	**0.237** *0.156*	**4** *0.498*	**na** *na*	**na** *na*	**0** *na*
March	**0.325** *0.369*	**0.169** *0.120*	**10** *0.462*	**18.51** *19.20*	**3.73** *14.39*	**10** *21.66*	**0.539** *0.555*	**0.285** *0.232*	**7** *0.622*	**na** *na*	**na** *na*	**0** *na*	**0.236** *0.229*	**0.094** *0.173*	**3** *0.300*	**na** *na*	**na** *na*	**0** *na*
April	**0.225** *0.210*	**0.094** *0.163*	**8** *0.330*	**24.18** *23.78*	**6.35** *17.27*	**8** *31.12*	**0.439** *0.439*	**0.216** *0.335*	**2** *0.543*	**na** *na*	**na** *na*	**0** *na*	**0.151** *0.106*	**0.108** *0.084*	**3** *0.221*	**na** *na*	**na** *na*	**0** *na*
May	**0.218** *0.203*	**0.119** *0.138*	**3** *0.299*	**28.98** *28.68*	**3.96** *26.30*	**3** *31.68*	**na** *na*	**na** *na*	**0** *na*	**na** *na*	**na** *na*	**0** *na*	**na** *na*	**na** *na*	**0** *na*	**na** *na*	**na** *na*	**0** *na*
June	**0.100** *0.065*	**0.076** *0.039*	**5** *0.179*	**17.84** *14.92*	**6.40** *12.99*	**5** *23.35*	**-0.028** *-0.022*	**0.099** *-0.095*	**3** *0.040*	**na** *na*	**na** *na*	**0** *na*	**0.195** *0.195*	**0.205** *0.097*	**2** *0.294*	**na** *na*	**na** *na*	**0** *na*
July	**0.118** *0.105*	**0.076** *0.051*	**10** *0.178*	**13.04** *13.13*	**7.66** *6.02*	**10** *18.24*	**0.145** *0.060*	**0.301** *0.023*	**8** *0.124*	**na** *na*	**na** *na*	**0** *na*	**0.304** *0.315*	**0.064** *0.261*	**3** *0.347*	**na** *na*	**na** *na*	**0** *na*
August	**0.181** *0.175*	**0.096** *0.087*	**12** *0.259*	**19.31** *19.25*	**7.64** *11.77*	**12** *26.56*	**0.210** *0.189*	**0.096** *0.116*	**7** *0.307*	**na** *na*	**na** *na*	**0** *na*	**0.178** *0.174*	**0.017** *0.167*	**3** *0.189*	**na** *na*	**na** *na*	**0** *na*
September	**0.232** *0.201*	**0.118** *0.126*	**16** *0.327*	**21.98** *21.05*	**6.90** *15.23*	**16** *29.39*	**0.208** *0.154*	**0.136** *0.078*	**7** *0.302*	**na** *na*	**na** *na*	**0** *na*	**0.240** *0.272*	**0.117** *0.152*	**4** *0.325*	**na** *na*	**na** *na*	**0** *na*
October	**0.180** *0.142*	**0.161** *0.082*	**17** *0.193*	**23.75** *22.94*	**10.33** *13.11*	**17** *33.65*	**0.347** *0.327*	**0.179** *0.194*	**6** *0.458*	**30.81** *30.81*	**na** *30.81*	**1** *30.81*	**0.112** *0.073*	**0.091** *0.050*	**5** *0.176*	**440.9** *440.9*	**na** *440.9*	**1** *440.9*
November	**0.264** *0.219*	**0.114** *0.180*	**14** *0.333*	**18.69** *19.44*	**3.69** *15.15*	**14** *20.88*	**0.379** *0.395*	**0.301** *0.128*	**9** *0.501*	**46.96** *42.32*	**17.21** *34.05*	**4** *60.25*	**0.117** *0.139*	**0.076** *0.067*	**3** *0.167*	**859.5** *636.0*	**617.7** *437.2*	**4** *1299.6*
December	**0.299** *0.262*	**0.214** *0.121*	**17** *0.426*	**16.43** *16.80*	**5.72** *10.19*	**17** *20.90*	**0.460** *0.340*	**0.491** *0.074*	**13** *1.035*	**na** *na*	**na** *na*	**0** *na*	**0.111** *0.122*	**0.065** *0.068*	**4** *0.154*	**269.0** *269.0*	**na** *269.0*	**1** *269.0*
Annual-Wkly	**0.274** *0.203*	**0.236** *0.100*	**145** *0.428*	**19.65** *19.46*	**7.24** *12.44*	**145** *26.44*	**0.343** *0.296*	**0.309** *0.075*	**81** *0.594*	**44.79** *42.32*	**15.04** *32.41*	**6** *54.17*	**0.192** *0.174*	**0.125** *0.073*	**39** *0.316*	**691.3** *448.7*	**547.5** *389.4*	**6** *1001.7*
Annual-Mon	**0.254** *0.207*	**0.124** *0.134*	**12** *0.325*	**20.11** *19.35*	**4.13** *16.35*	**12** *23.14*	**0.317** *0.327*	**0.166** *0.116*	**11** *0.464*	**42.63** *42.32*	**10.35** *34.49*	**3** *47.61*	**0.195** *0.174*	**0.075** *0.116*	**11** *0.285*	**523.1** *440.9*	**303.7** *324.0*	**3** *573.6*

FIGURE 1

UNIVERSITY OF MIAMI
PACIFIC AEROSOL NETWORK



NASA/GLOBE
GLOBAL BACKSCATTER EXPERIMENT

FIGURE 2

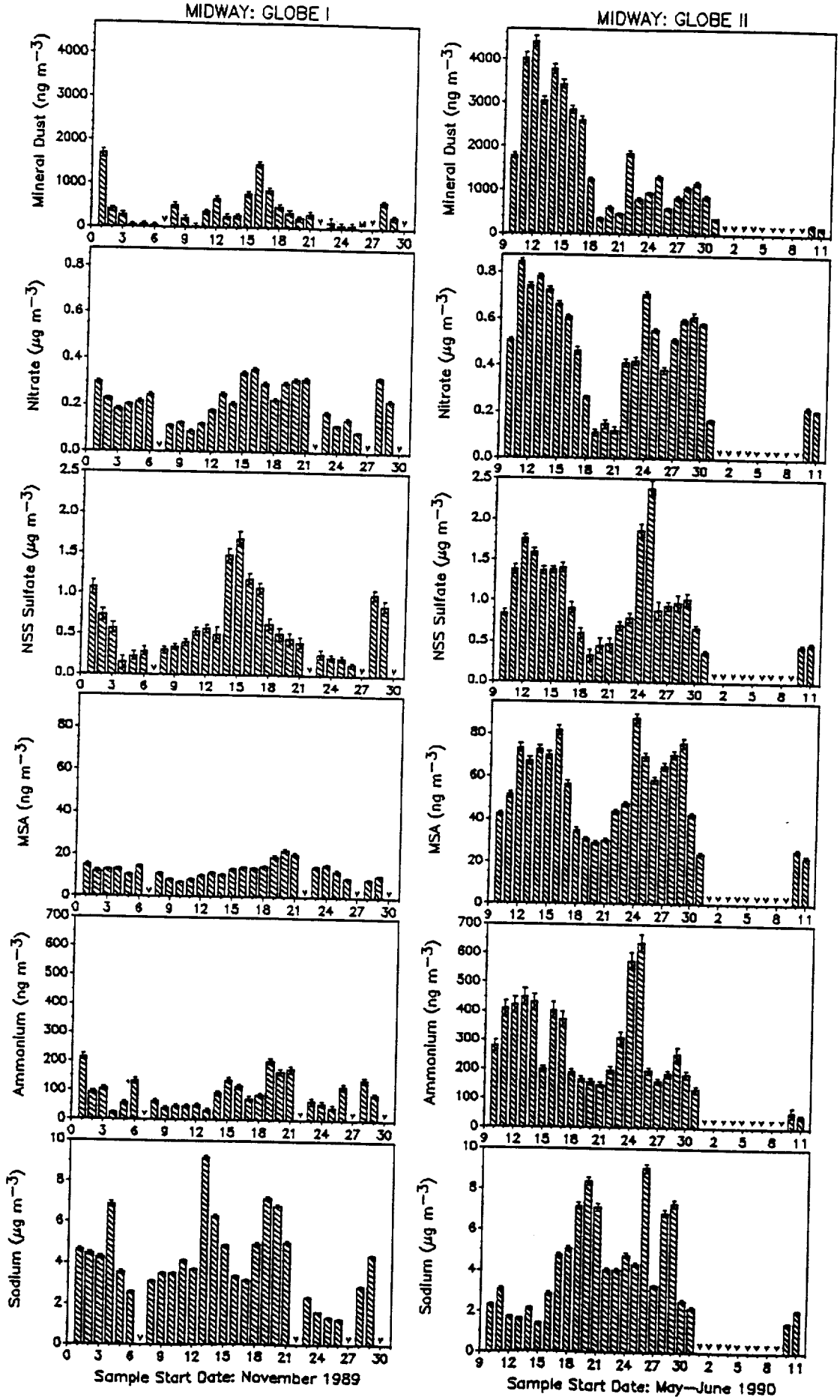

MIDWAY: GLOBE I
MIDWAY: GLOBE II
Mineral Dust (ng m^{-3})
Nitrate (μg m^{-3})
NSS Sulfate (μg m^{-3})
MSA (ng m^{-3})
Ammonium (ng m^{-3})
Sodium (μg m^{-3})
Sample Start Date: November 1989
Sample Start Date: May–June 1990

FIGURE 3

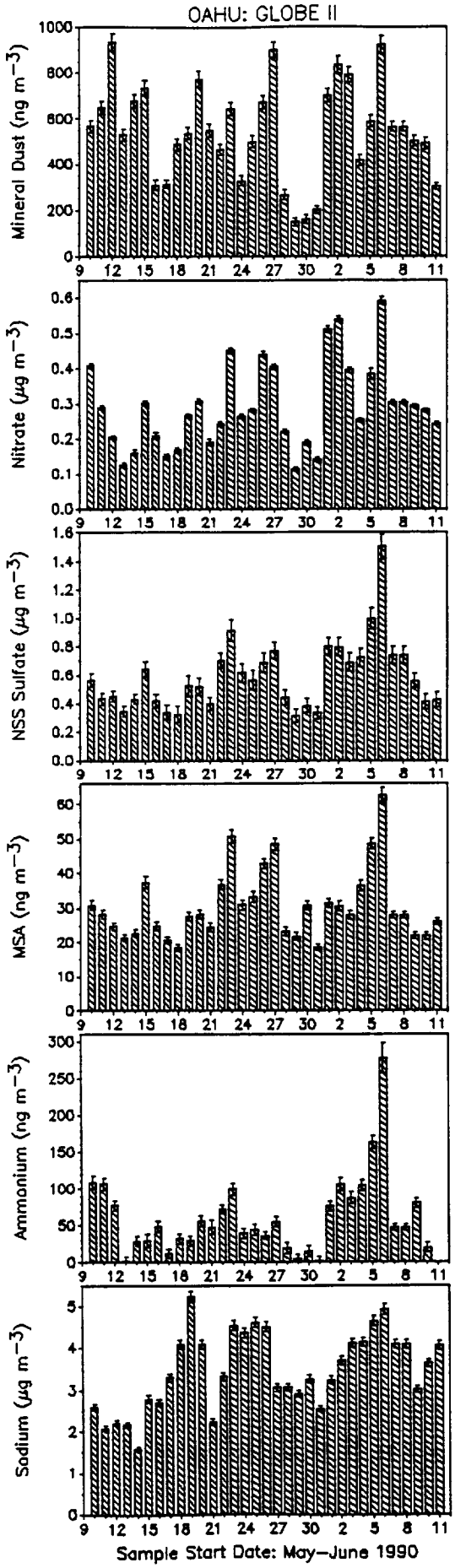

OAHU: GLOBE II
Mineral Dust (ng m^{-3})
Nitrate (μg m^{-3})
NSS Sulfate (μg m^{-3})
MSA (ng m^{-3})
Ammonium (ng m^{-3})
Sodium (μg m^{-3})
9 12 15 18 21 24 27 30 2 5 8 11
Sample Start Date: May–June 1990

FIGURE 4

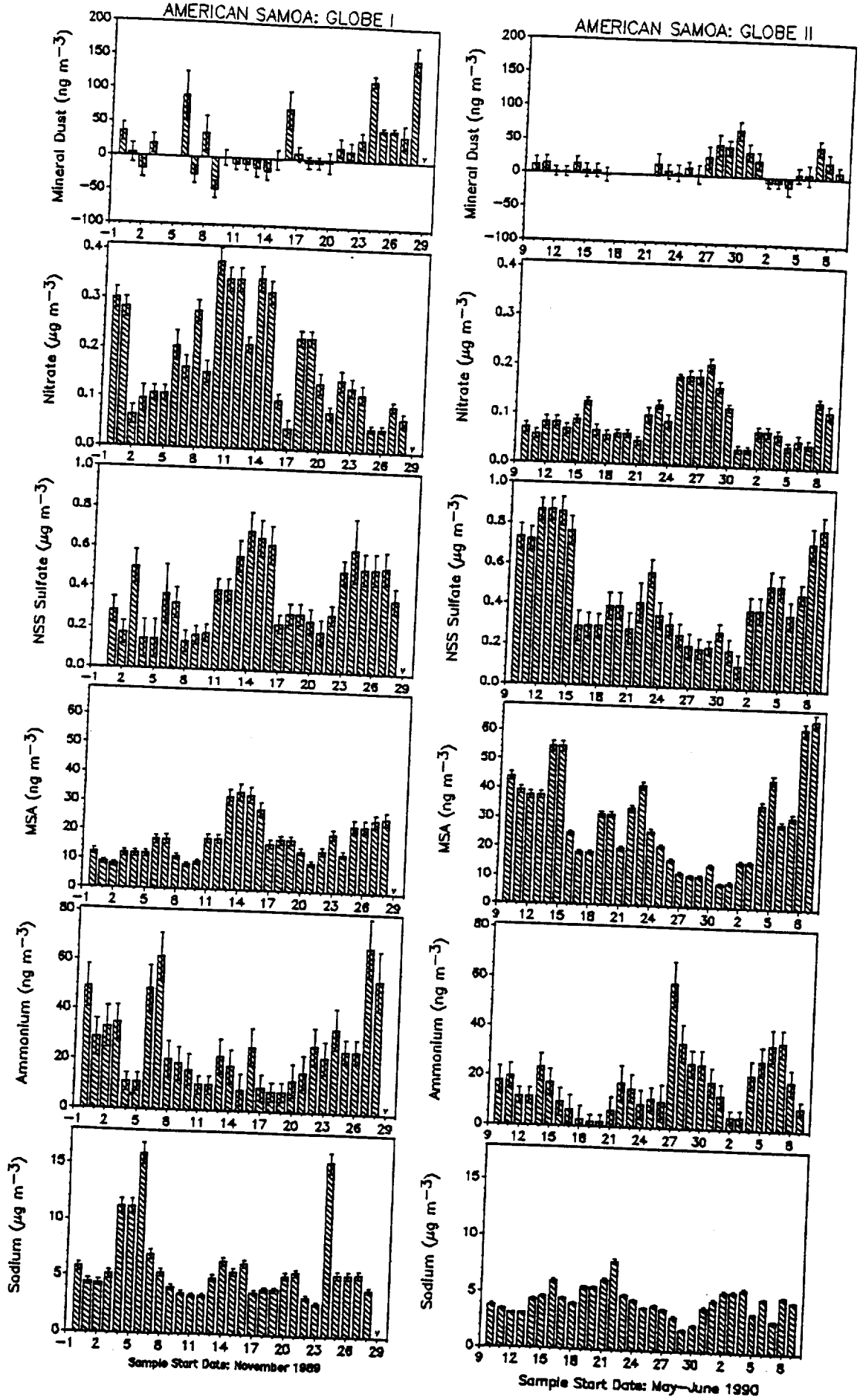

AMERICAN SAMOA: GLOBE I
AMERICAN SAMOA: GLOBE II
Mineral Dust (ng m−3)
Nitrate (μg m−3)
NSS Sulfate (μg m−3)
MSA (ng m−3)
Ammonium (ng m−3)
Sodium (μg m−3)
Sample Start Date: November 1989
Sample Start Date: May–June 1990

FIGURE 5

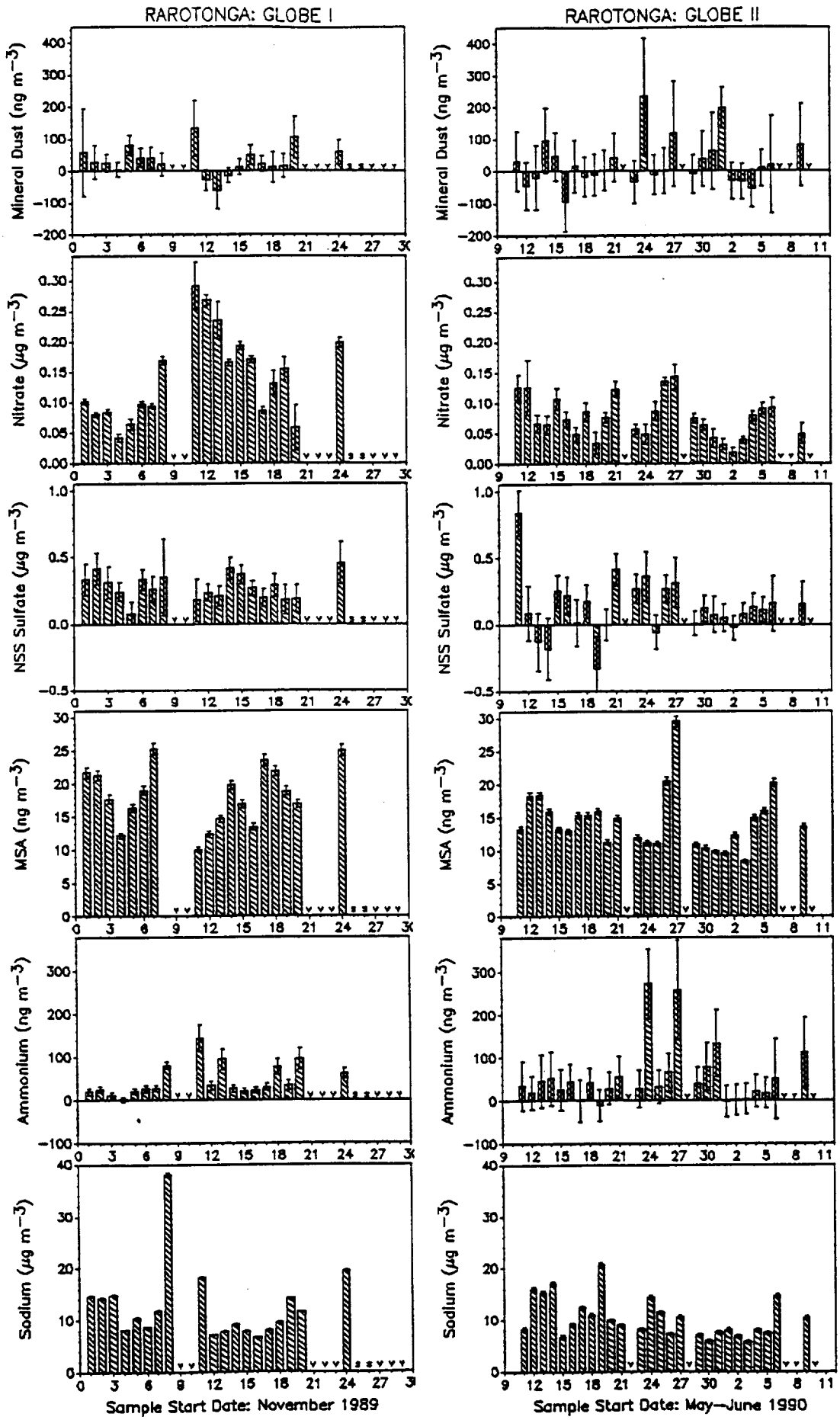

RAROTONGA: GLOBE I
RAROTONGA: GLOBE II
Mineral Dust (ng m^{-3})
Nitrate (μg m^{-3})
NSS Sulfate (μg m^{-3})
MSA (ng m^{-3})
Ammonium (ng m^{-3})
Sodium (μg m^{-3})
Sample Start Date: November 1989
Sample Start Date: May—June 1990

FIGURE 6

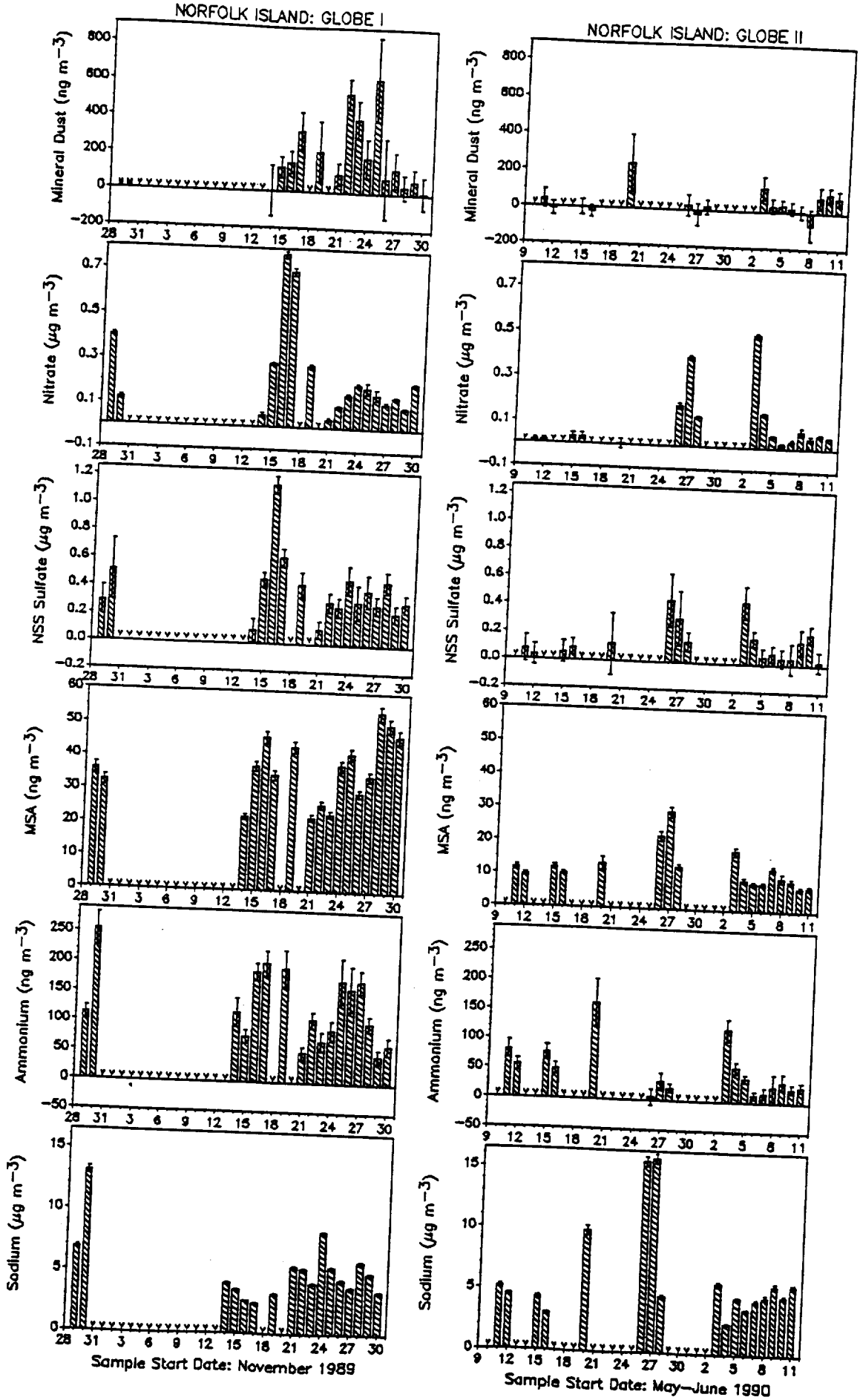

NORFOLK ISLAND: GLOBE I
NORFOLK ISLAND: GLOBE II
Mineral Dust (ng m−3)
Nitrate (μg m−3)
NSS Sulfate (μg m−3)
MSA (ng m−3)
Ammonium (ng m−3)
Sodium (μg m−3)
Sample Start Date: November 1989
Sample Start Date: May–June 1990

FIGURE 7

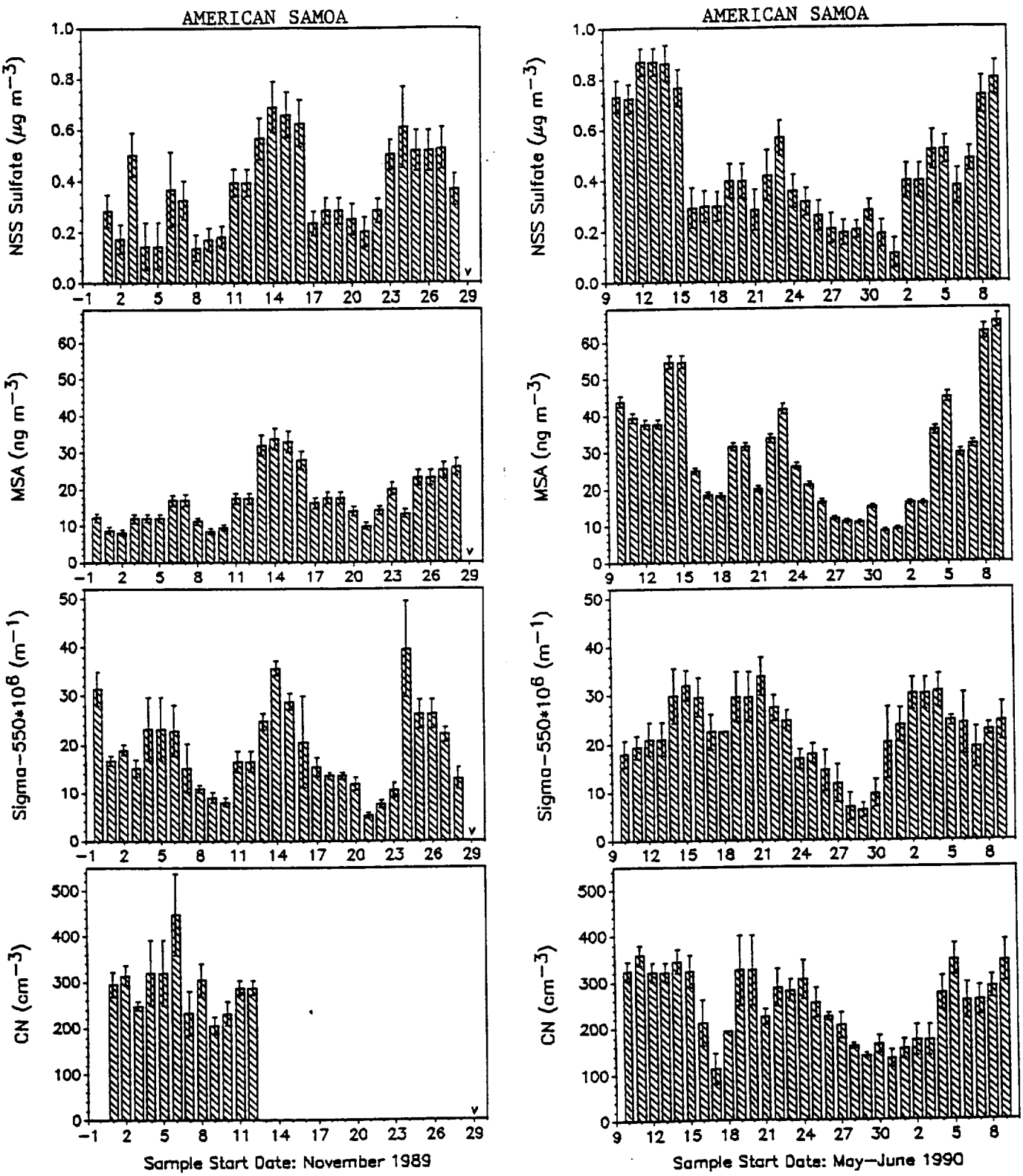

AMERICAN SAMOA
AMERICAN SAMOA
NSS Sulfate (μg m⁻³)
MSA (ng m⁻³)
Sigma-550*10⁶ (m⁻¹)
CN (cm⁻³)
Sample Start Date: November 1989
Sample Start Date: May–June 1990

FIGURE 8

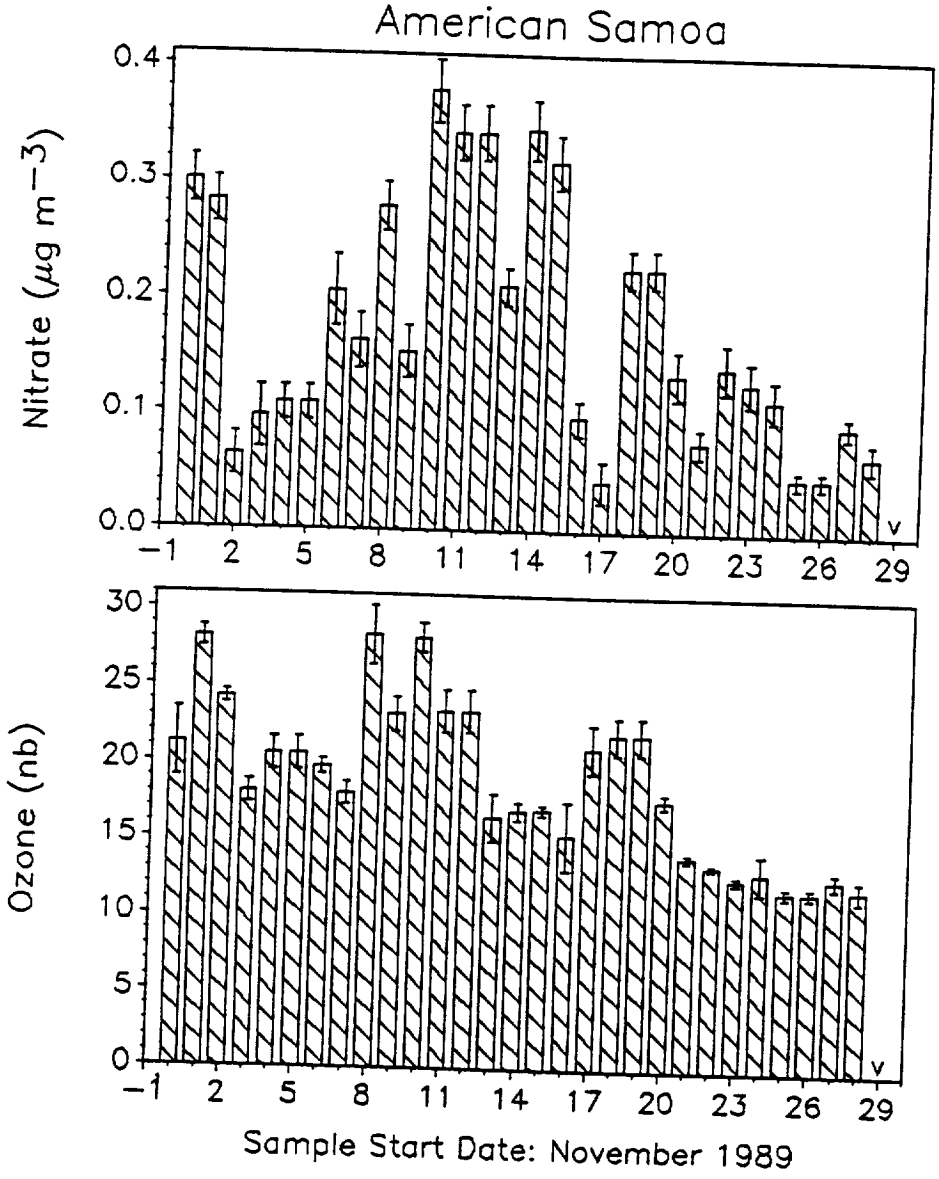

American Samoa
Nitrate ($\mu g\ m^{-3}$)
0.4
0.3
0.2
0.1
0.0
−1 2 5 8 11 14 17 20 23 26 29
V
Ozone (nb)
30
25
20
15
10
5
0
−1 2 5 8 11 14 17 20 23 26 29
V
Sample Start Date: November 1989

FIGURE 9

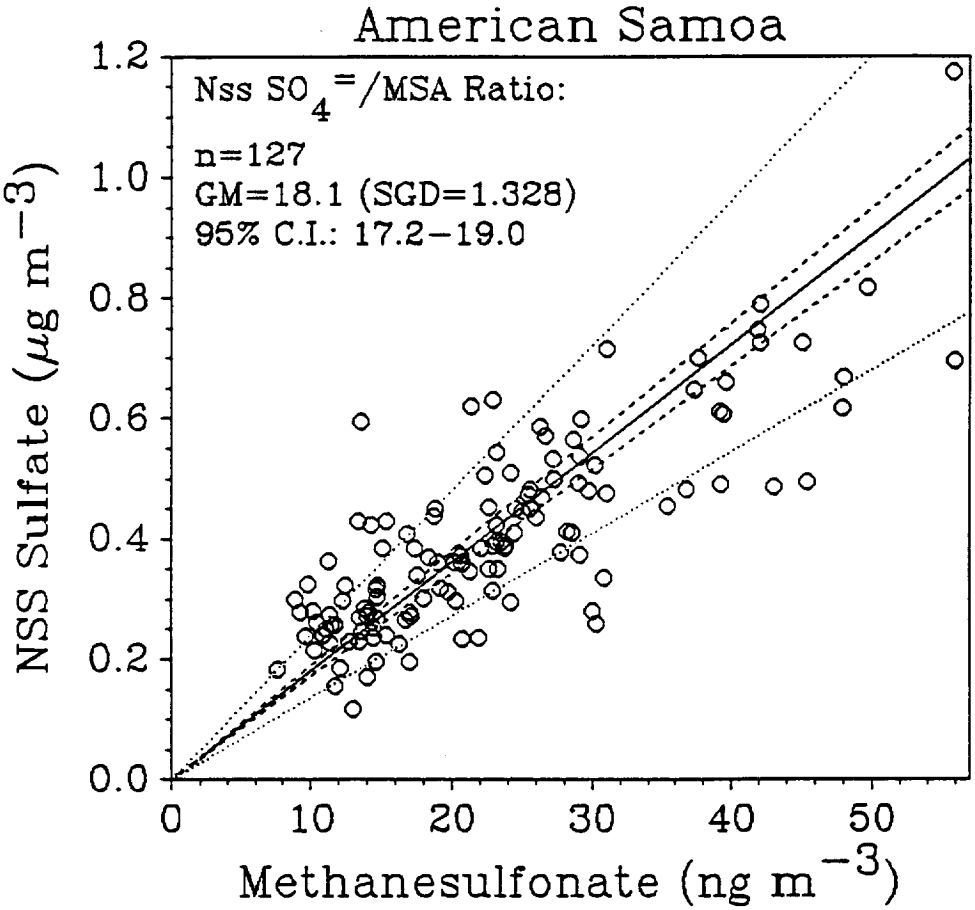

American Samoa
Nss $SO_4^=$/MSA Ratio:
n=127
GM=18.1 (SGD=1.328)
95% C.I.: 17.2–19.0
NSS Sulfate ($\mu g\ m^{-3}$)
Methanesulfonate ($ng\ m^{-3}$)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
10
20
30
40
50

FIGURE 10

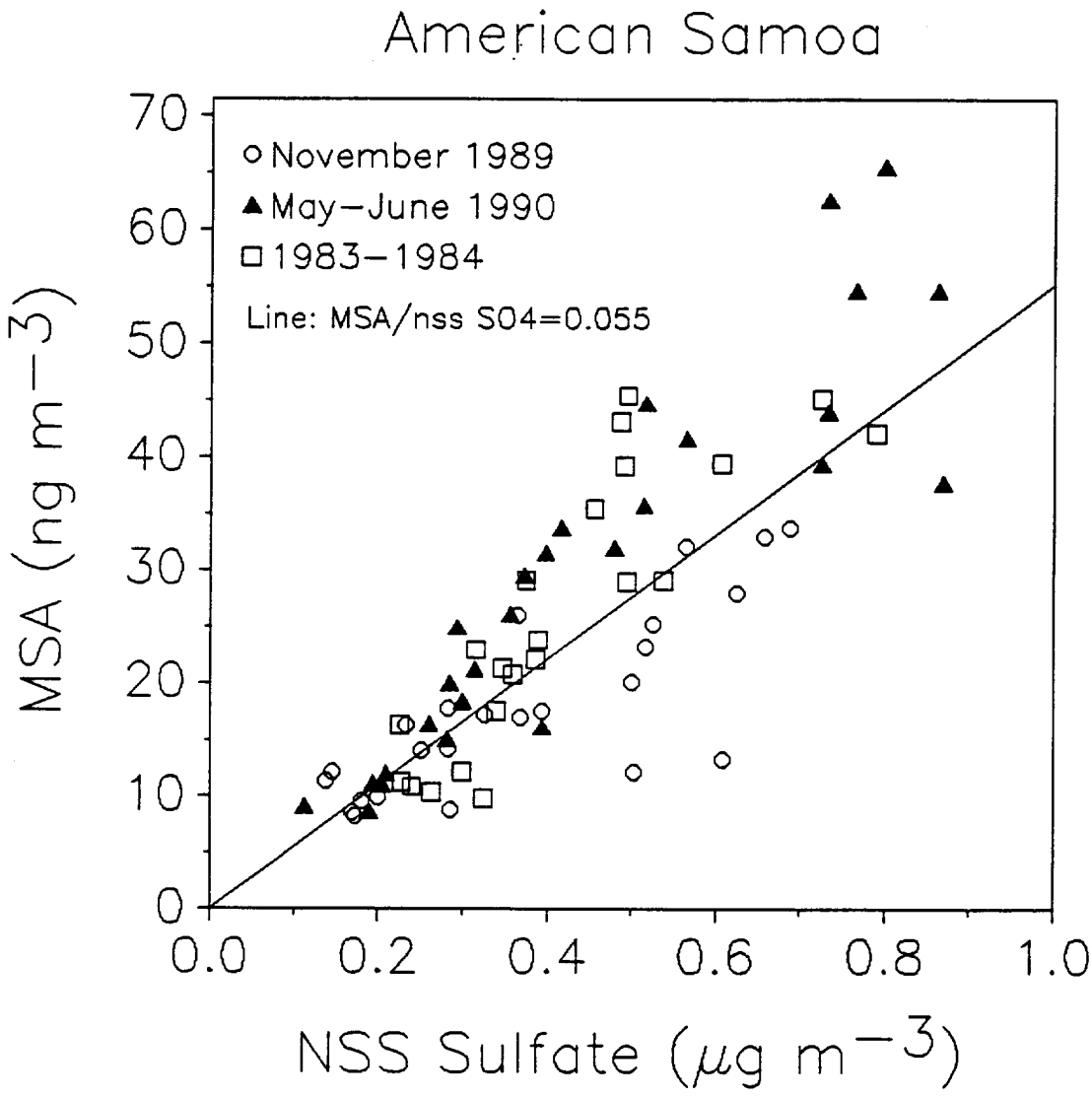

American Samoa
November 1989
May–June 1990
1983–1984
Line: MSA/nss SO4=0.055
MSA (ng m−3)
NSS Sulfate (μg m−3)
0
10
20
30
40
50
60
70
0.0
0.2
0.4
0.6
0.8
1.0

FIGURE 11

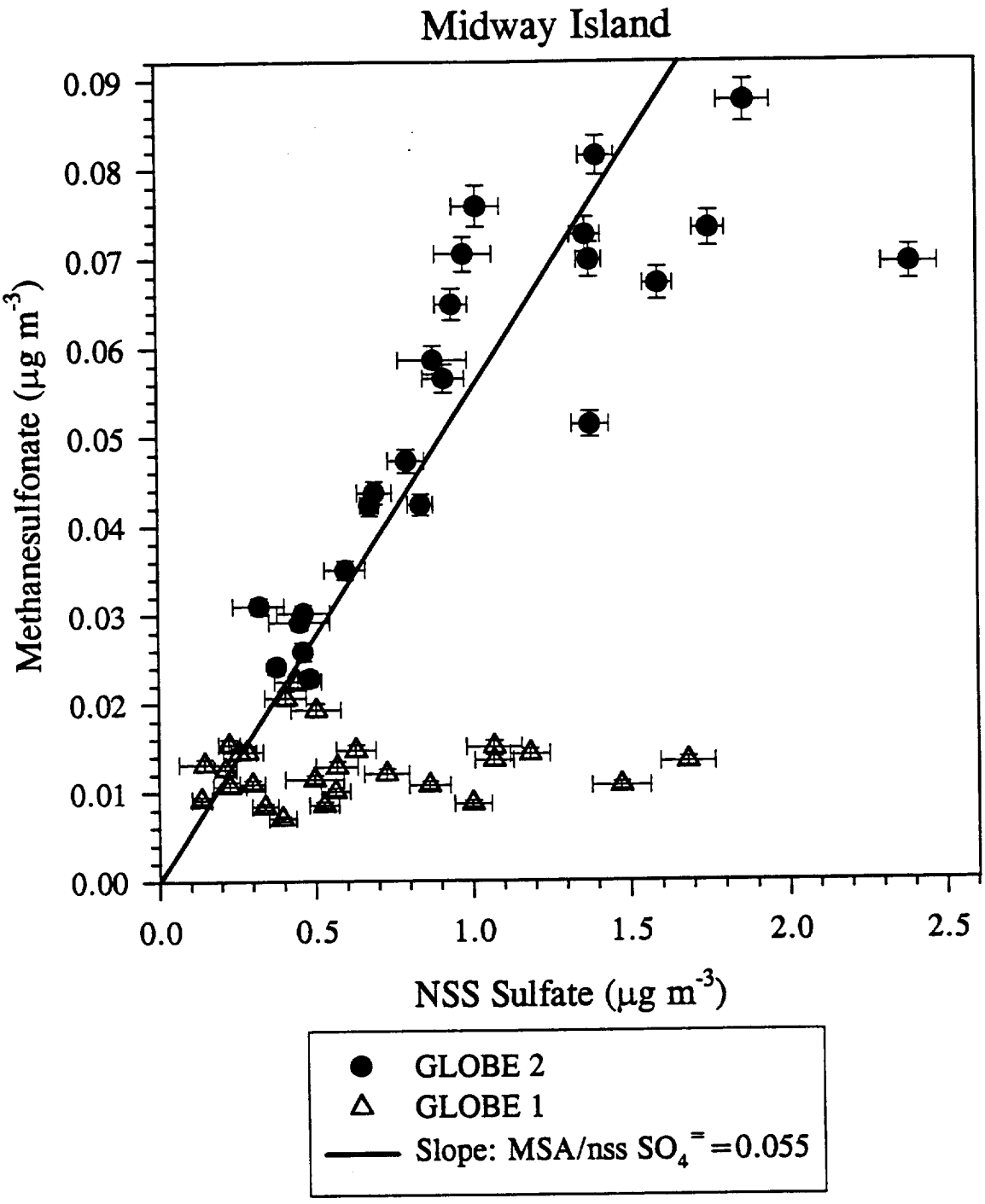

Midway Island
Methanesulfonate (μg m-3)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.0
0.5
1.0
1.5
2.0
2.5
NSS Sulfate (μg m-3)
GLOBE 2
GLOBE 1
Slope: MSA/nss SO4= =0.055

FIGURE 12

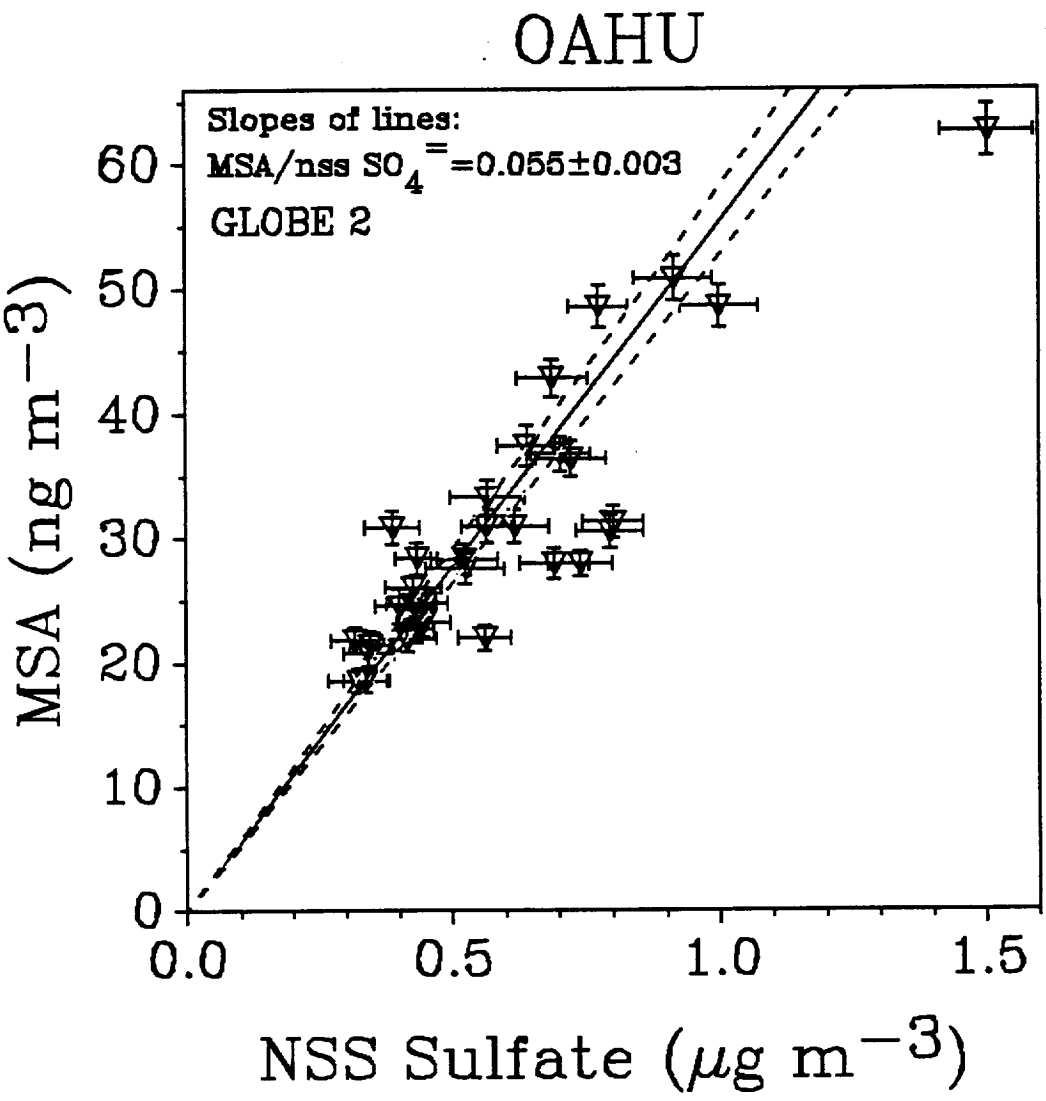

OAHU
Slopes of lines:
MSA/nss $SO_4^=$=0.055±0.003
GLOBE 2
MSA (ng m^{-3})
NSS Sulfate (μg m^{-3})
0
10
20
30
40
50
60
0.0
0.5
1.0
1.5

FIGURE 13

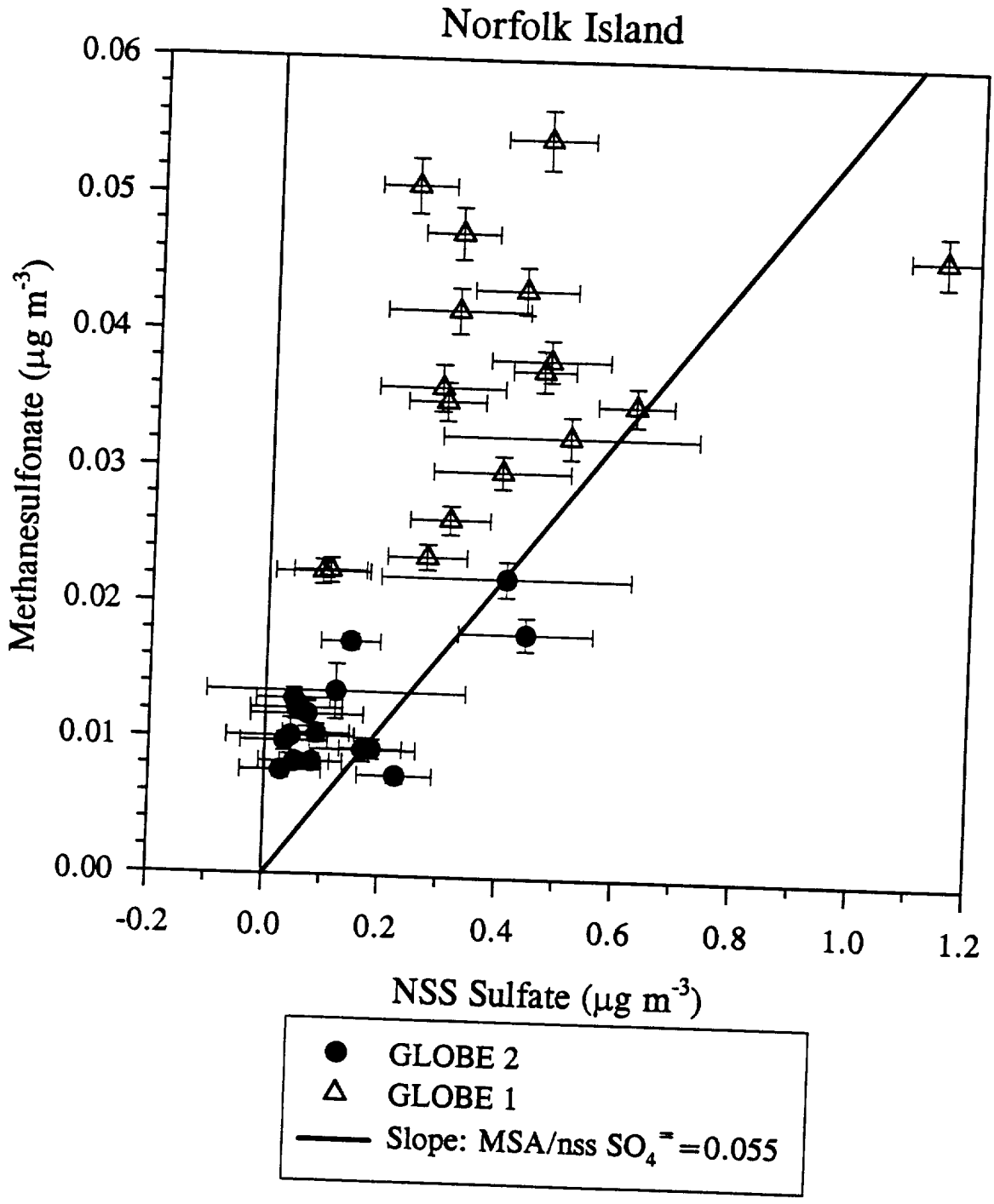

Norfolk Island
Methanesulfonate (μg m-3)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
NSS Sulfate (μg m-3)
GLOBE 2
GLOBE 1
Slope: MSA/nss SO4= =0.055

FIGURE 14

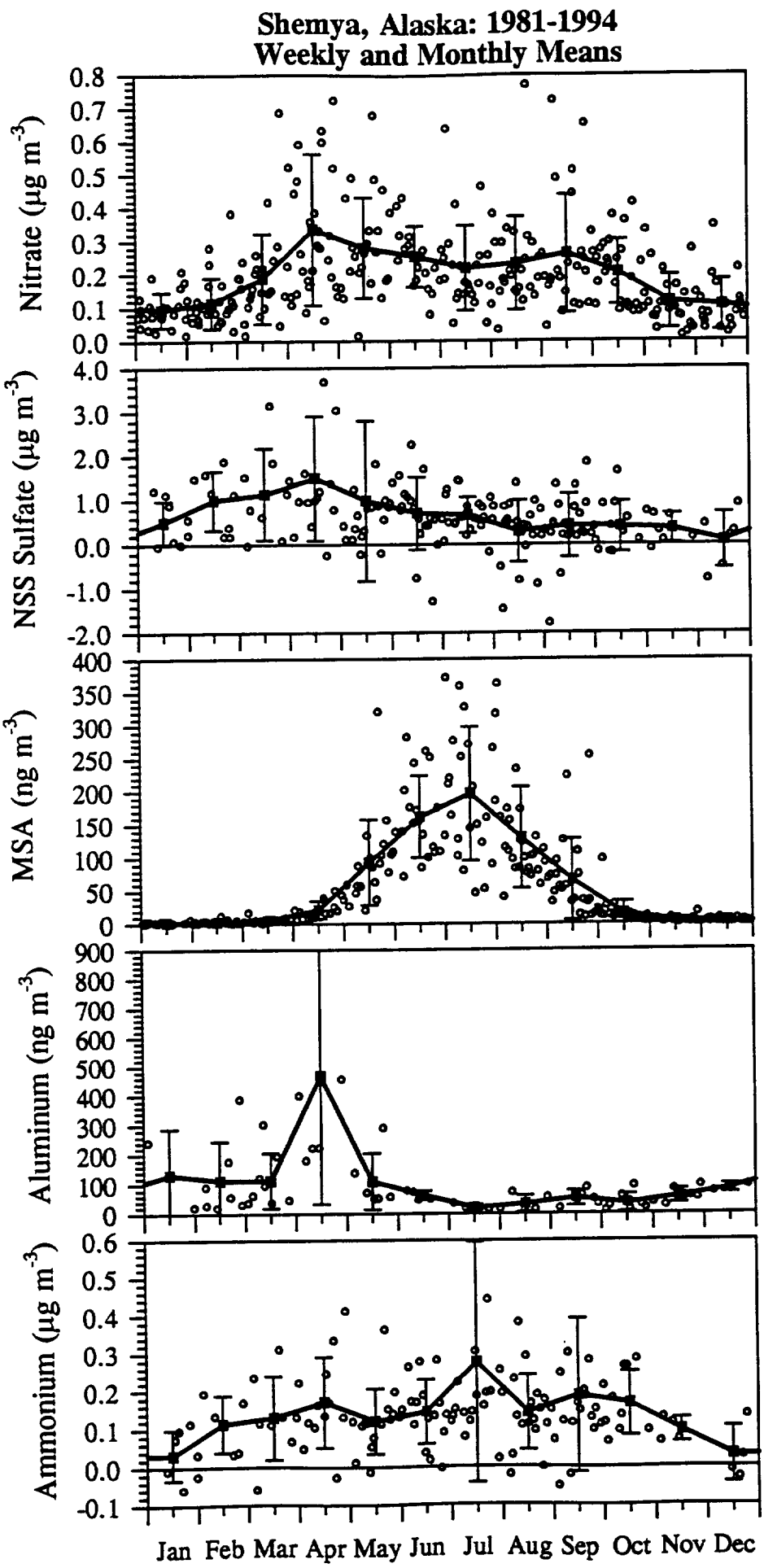

Shemya, Alaska: 1981-1994
Weekly and Monthly Means
Nitrate (μg m-3)
NSS Sulfate (μg m-3)
MSA (ng m-3)
Aluminum (ng m-3)
Ammonium (μg m-3)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

FIGURE 15

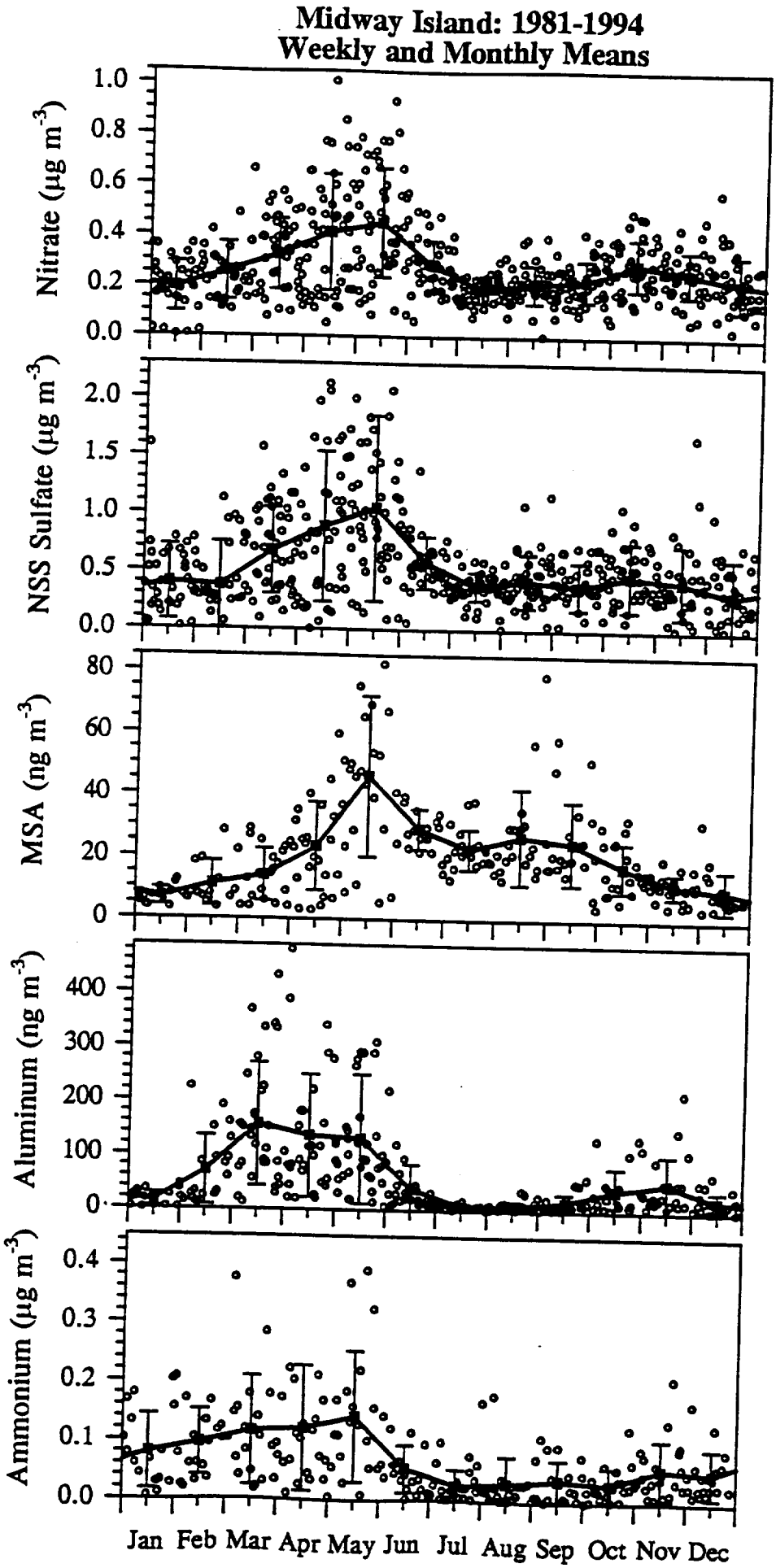

Midway Island: 1981-1994
Weekly and Monthly Means
Nitrate (μg m-3)
1.0
0.8
0.6
0.4
0.2
0.0
NSS Sulfate (μg m-3)
2.0
1.5
1.0
0.5
0.0
MSA (ng m-3)
80
60
40
20
0
Aluminum (ng m-3)
400
300
200
100
0
Ammonium (μg m-3)
0.4
0.3
0.2
0.1
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

FIGURE 16

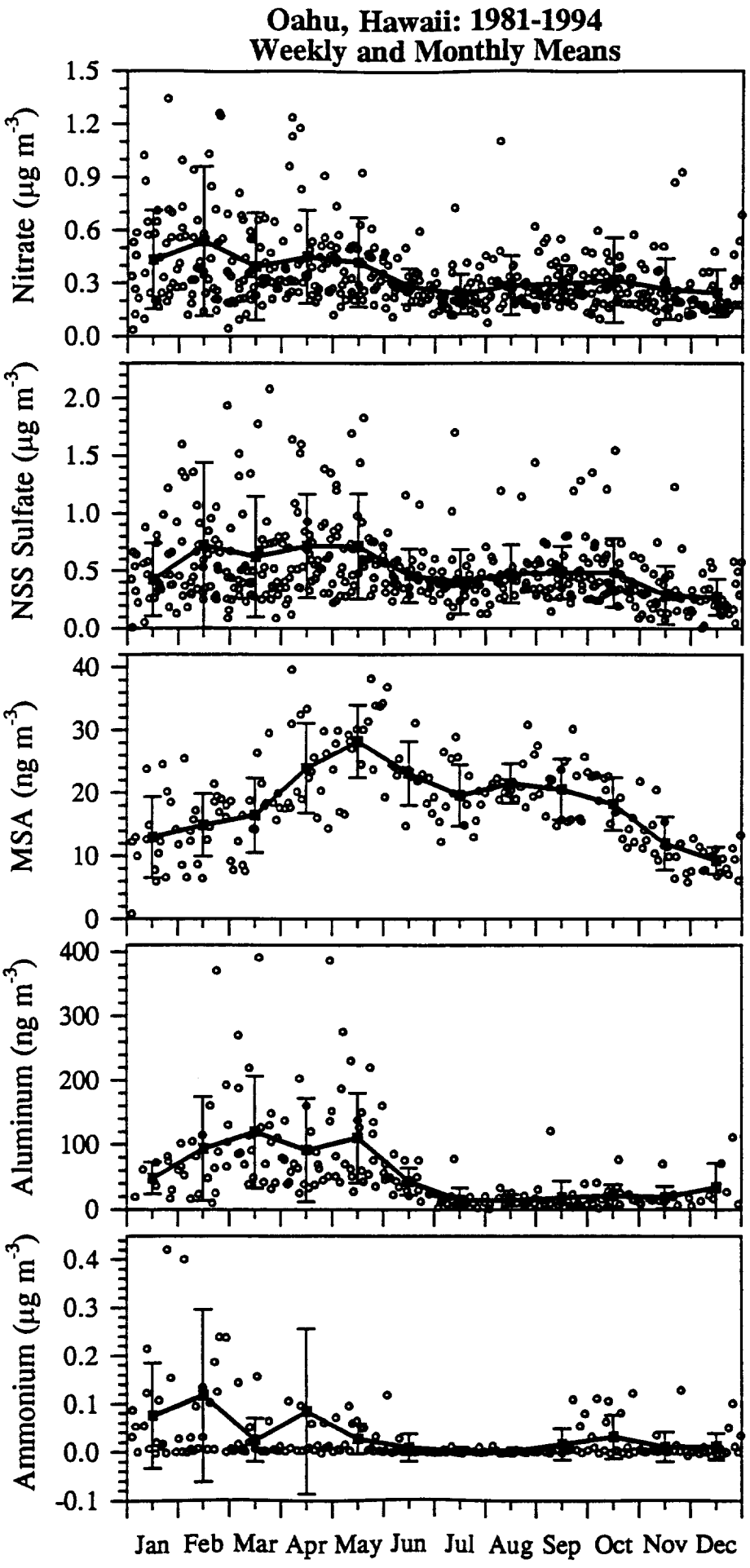

Oahu, Hawaii: 1981-1994
Weekly and Monthly Means
Nitrate (µg m-3)
1.5
1.2
0.9
0.6
0.3
0.0
NSS Sulfate (µg m-3)
2.0
1.5
1.0
0.5
0.0
MSA (ng m-3)
40
30
20
10
0
Aluminum (ng m-3)
400
300
200
100
0
Ammonium (µg m-3)
0.4
0.3
0.2
0.1
0.0
-0.1
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

FIGURE 18

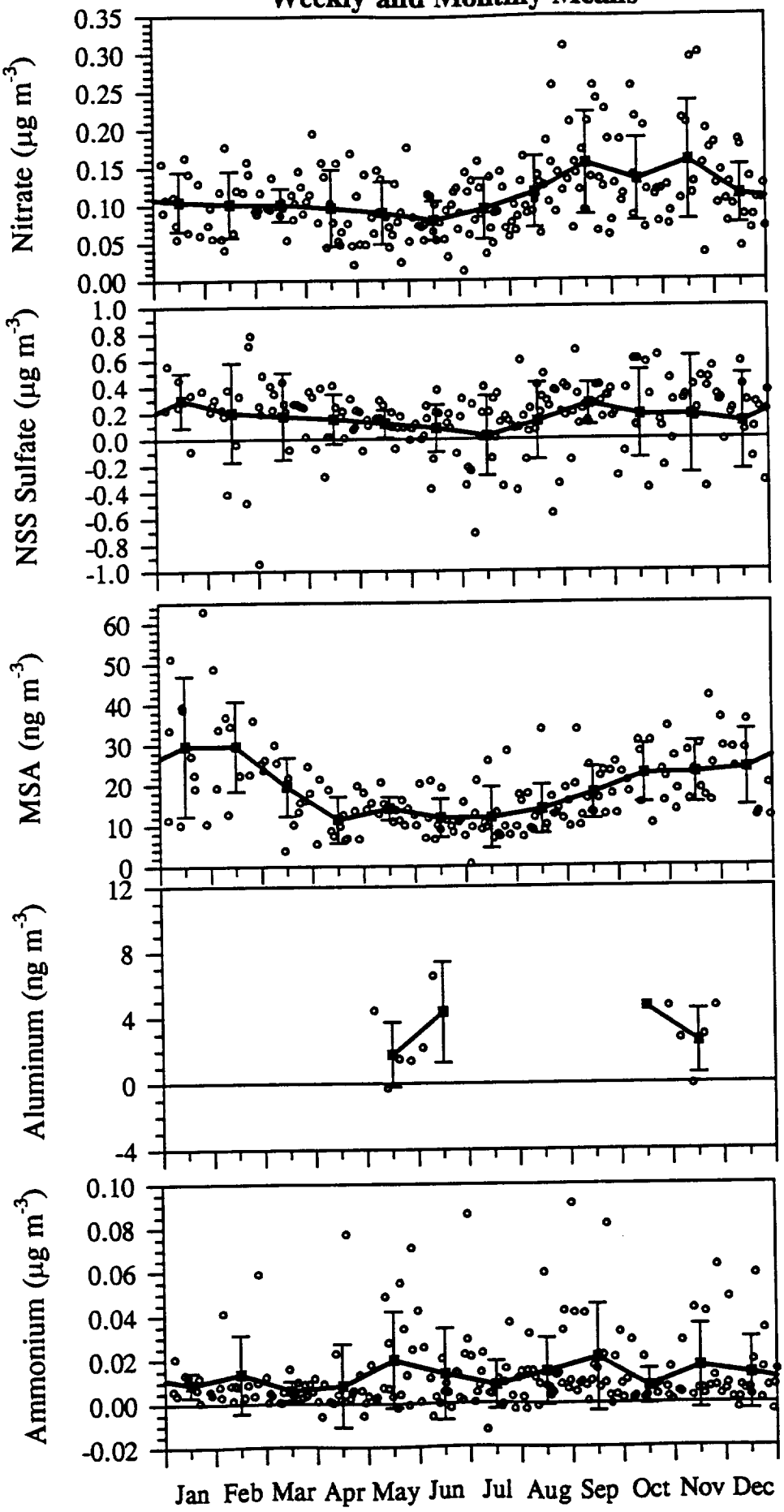


FIGURE 19

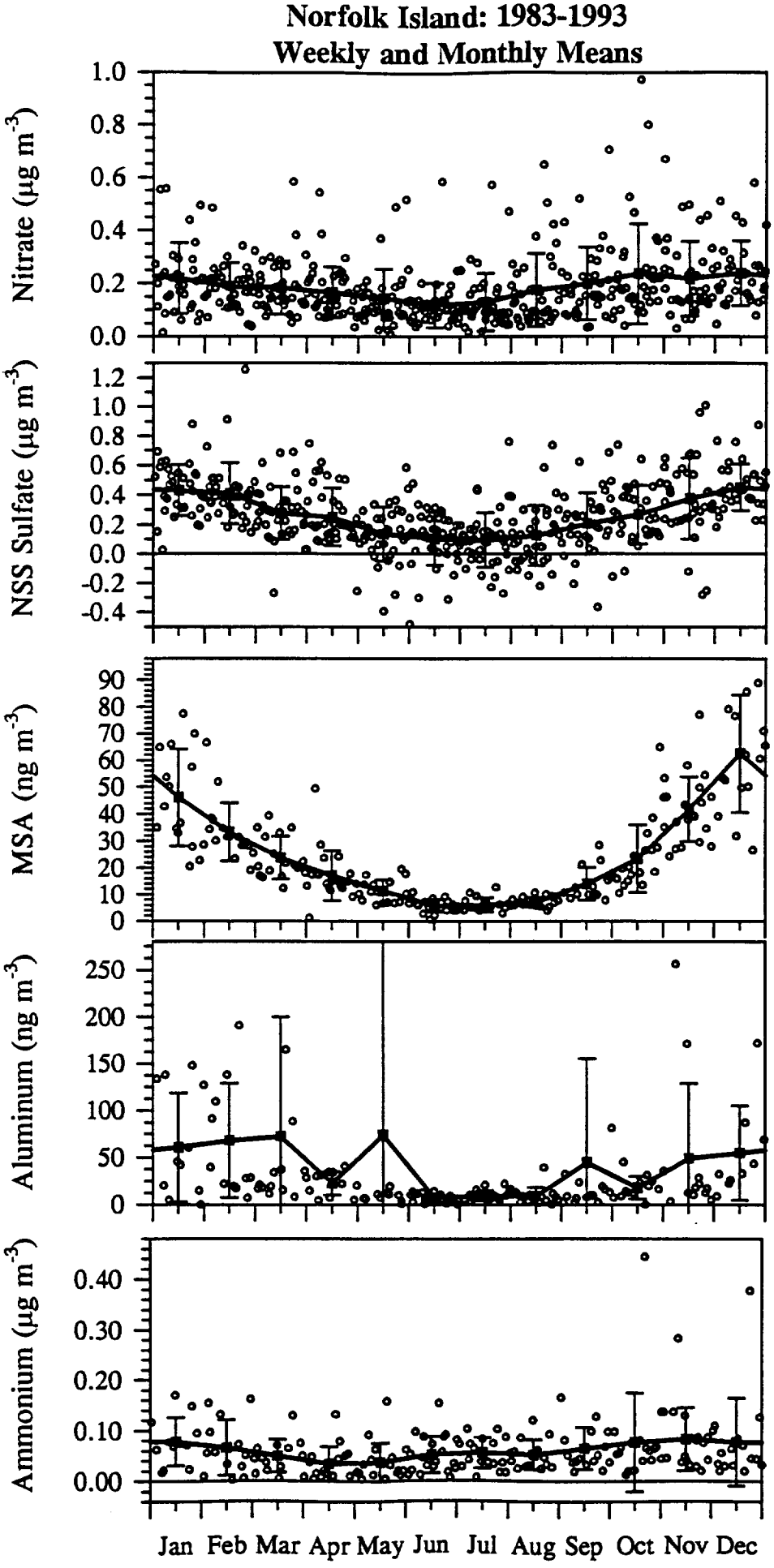
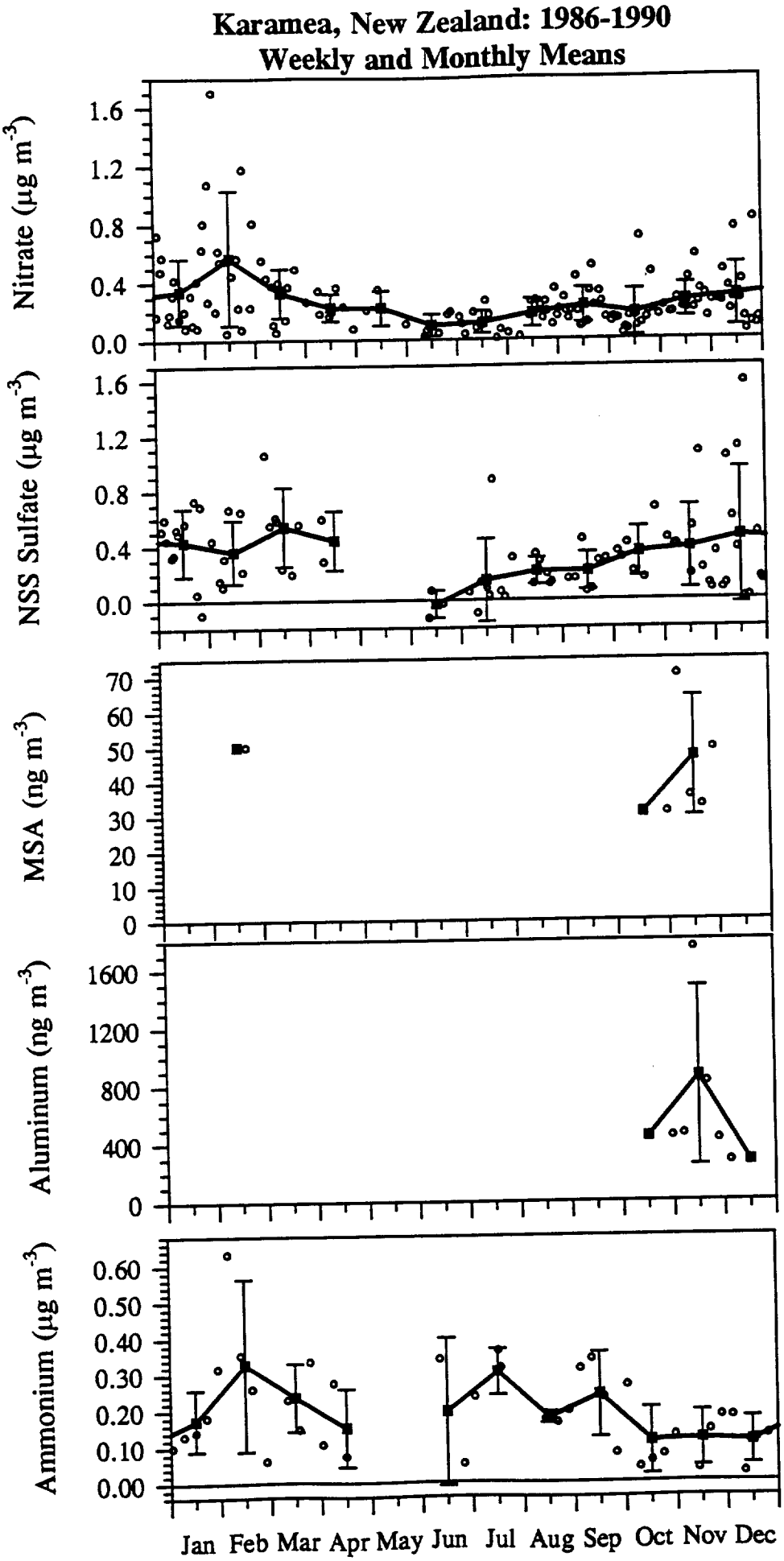

Norfolk Island: 1983-1993
Weekly and Monthly Means
Nitrate (μg m-3)
1.0
0.8
0.6
0.4
0.2
0.0
NSS Sulfate (μg m-3)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
MSA (ng m-3)
90
80
70
60
50
40
30
20
10
0
Aluminum (ng m-3)
250
200
150
100
50
0
Ammonium (μg m-3)
0.40
0.30
0.20
0.10
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

FIGURE 20


Karamea, New Zealand: 1986-1990
Weekly and Monthly Means
Nitrate (µg m-3)
1.6
1.2
0.8
0.4
0.0
NSS Sulfate (µg m-3)
1.6
1.2
0.8
0.4
0.0
MSA (ng m-3)
70
60
50
40
30
20
10
0
Aluminum (ng m-3)
1600
1200
800
400
0
Ammonium (µg m-3)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec