MINERAL AND SEA SALT AEROSOL CONCENTRATIONS OVER LOW LATITUDE TROPICAL ATLANTIC AND PACIFIC OCEANS DURING FGGE

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RESUMEN

Durante los meses de enero a marzo y de mayo a julio de 1979 se realizó muestreo de aerosol atmosférico a bordo de los buques mexicanos de investigación "Mariano Matamoros" y "DM 20" en el Océano Pacífico (7° N, 84° W) y Océano Atlántico (7°30' N, 42°30' W) respectivamente. Las componentes determinadas fueron: minerales y sales de mar. En el Océano Atlántico la media geométrica de la concentración de minerales fue de 7.27 $\mu g/m^3$ y la de sales de mar 21.38 $\mu g/m^3$. En el Océano Pacífico las concentraciones de estas componentes fueron 0.62 y 6.28 $\mu g/m^3$, respectivamente; en esta región son los primeros estudios que se desarrollan sobre aerosol mineral y sales de mar. En el análisis estadístico de estas dos componentes se utilizó el criterio de la χ^2 para la minimización del error. Para el Océano Atlántico se obtuvieron distribuciones log-normal bimodales; para el Pacífico distribuciones log-normales sencillas, lo cual estadísticamente indica la presencia de dos y un conjunto de fenómenos, respectivamente. Las concentraciones reportadas en el presente estudio para el Océano Atlántico están de acuerdo con las de otros autores. Las del Océano Pacífico son más altas que las reportadas en otras áreas de este océano.

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ABSTRACT

During the two periods of field observations of the First Garp Global Experiment (FGGE), from January to March and May to July, 1979, atmospheric aerosol samples were taken on board the Mexican R/V "Mariano Matamoros" and "DM 20", at two geographical points over the Pacific (7° N, 84° W) and Atlantic (7° 30'N, 42° 30'W) Oceans. The determined components were mineral and sea salt aerosol. On the Atlantic Ocean the geometric mean of the mineral aerosol was 7.27 $\mu g/m^3$, and for the sea salts 21.38 $\mu g/m^3$. On the Pacific ocean, the concentration of these components was 0.62 and 6.28 $\mu g/m^3$, respectively; these were the first extensive studies about mineral and sea salt aerosol in this region. A criterion of the minimization of the error given by χ^2 was used for the statistical analysis of mineral and sea salt concentrations. Bi-modal log-normal distributions were obtained for the Atlantic Ocean, and only simple log-normal distribution for the Pacific Ocean; these results show statistically the presence of two and one sets of physical phenomena related with the presence of aerosol. For the Atlantic Ocean, the concentrations reported in this work agree with those reported by other authors. For the Pacific Ocean, the values reported here are higher than those reported in the literature for other regions of this ocean.

INTRODUCTION

The observations upon which the present report is based were carried out during the periods of January to March and May to July, 1979, during the Special Observation Periods (SOP I and SOP II) of the First Global Experiment of GARP (FGGE). The observations were made on board the Mexican research vessels "Mariano Matamoros" and "DM 20", at points 7° N, 84° W over the Pacific Ocean, and 7°30'N, 42°30'W over the Atlantic Ocean (Figure 1). The presence of the Mexican ship "Mariano Matamoros" on the Eastern Equatorial North Pacific during FGGE gave us the opportunity to obtain extensive quantitative aerosol data from this region. Simultaneously, the Mexican R/V "DM 20" was located over the Equatorial Atlantic Ocean.

The present work is part of a research program on continental aerosol over the Oceans whose purpose is to detect its origins.

Atmospheric aerosol studies in the Northern Equatorial region of the Atlantic Ocean have demonstrated that the main component is mineral dust of Saharian origin (Delany *et al.*, 1967; Prospero *et al.*, 1970; Carlson and Prospero, 1972; Kondratyev *et al.*, 1976; Prospero and Nees, 1977; Prospero *et al.*, 1981). The presence of this component can be explained by dust storms in Northern Africa and by the wind patterns over the Tropical Atlantic (McDonald, 1938; McManus, 1970).

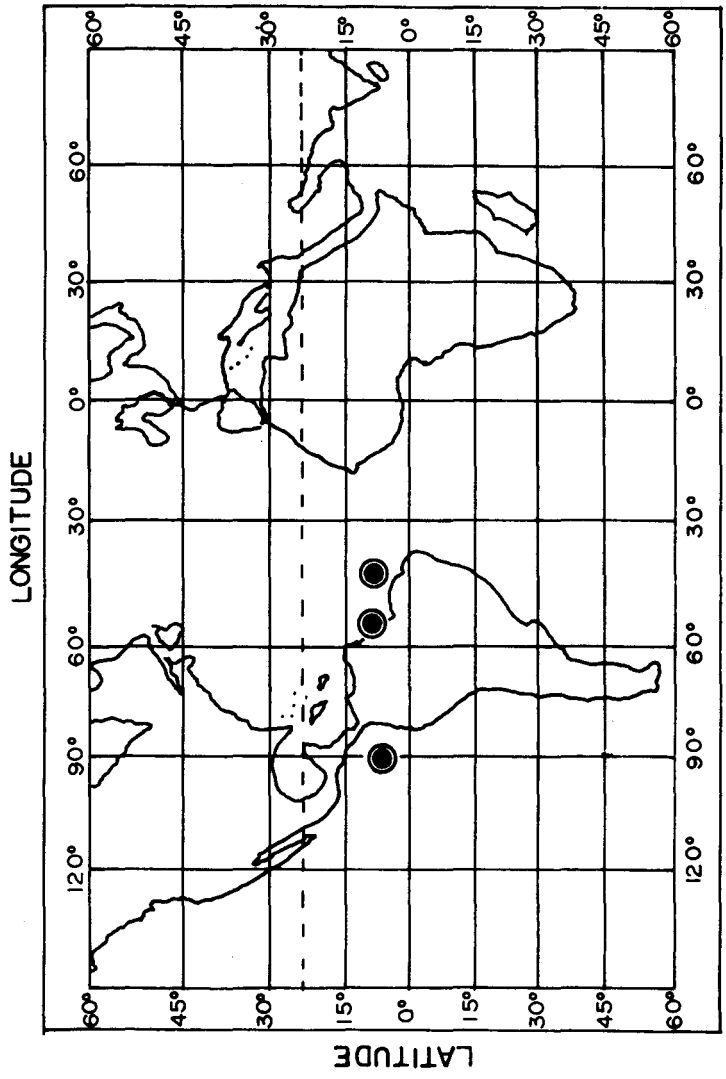

Fig. 1. Geographical locations of the Mexican Research Vessels "Mariano Matamoros", "DM 20" and French Guiana.

Other important components of maritime aerosol are sea salts, mainly originated by the break-up of bubbles on the water surface. Sea salt is confined to the mixed layer below the inversion. In the case of the North Equatorial Atlantic aerosol, one should also take into account that the layer of Saharian origin carries some soluble salts in its interior. However, soluble sodium is a very minor component (Savoie and Prospero, 1980).

To date, with respect to the Pacific Ocean, there are very few studies regarding atmospheric aerosol (Prospero and Bonatti, 1969; Duce *et al.*, 1980).

SAMPLING

The sampling periods of this study coincided with those in which the presence of Saharian aerosol had been reported, according to previous studies: In the spring, in the band of latitude 8°N – 17°N (Prospero and Bonatti, 1969). In the summer, in the band of latitude 15°N – 20°N (Savoie and Prospero, 1977). And during the winter, in the band of latitude 5°N – 10°N (Prospero and Ness, 1977).

Samples were collected with high volume samplers, located at a height of 10m over the flotation line. The filters used were Whatman Number 41, and the air flow through these was 1.2 m^3/min., approximately. The sampling time was 24 hours, starting at 0800 hours, (±15 minutes). Every seven days a blank filter (filters which were not exposed to sampling) was employed.

Sometimes the samples were contaminated by the vessel's engine exhaust, but this effect was eliminated during the calcination of the filter according to Prospero, 1979. The filters possible contamination during handling and insertion was eliminated, through analyzing the blank filters.

REMOVAL AND ANALYSIS

A quarter of a filter in small portions is placed in a special centrifuge tube, which incorporates a Gelman or Millipore filter in its base (pore size 0.45 μm and 25 mm diameter), previously washed with 0.05 M acetic acid. The same handling was used for both samples and blanks. The exposed filters were washed with three aliquots of distilled and dionized water (Savoie, 1978). Each washing was allowed to stand for 30 minutes, after which it was centrifuged at 1,500 RPM for five minutes. This action forces the wash water through the filter. The water solution was stored at 7°C, for later analysis by atomic absorption.

In the extract, the main cations are analyzed, including sodium, the concentration of which is converted to the equivalent concentrations of sea-salt, by multiplying by 3.252, the salinity-sodium ratio of sea water (Riley and Chester, 1971).

The quarter of the filter, washed together with the pre-filter, was placed in a crucible and then dried in a vacuum oven or dryer. After the moisture was eliminated, the crucible was placed in an oven, in order to calcinate the sample at 600°C. The residue weight, minus the ash weight of the blank filter is reported as mineral aerosol.

STATISTICAL ANALYSIS

The statistical procedure which was followed for the analysis of the two principal components-mineral aerosol and marine salts is the one established by Savoie and Prospero (1977), who propose that the best representation of these components, in some cases, is the normal logarithmic distribution. In the determination of the parameters which describe the distribution of the sampled aerosol concentration, some simplifications were made regarding the work of the aforementioned authors. The truncated gaussian method was not employed, but a criterion of minimization of the error given by χ^2 was used (Hoel, 1962).

RESULTS

Mineral aerosols

The average daily concentrations of mineral aerosols which were obtained during the experiment are shown in Figures 2a and 2b, together with the results from French Guiana (Prospero, 1980, personal communication; Prospero *et al.*, 1981). Note that the concentration of mineral aerosol is greatest over the Tropical Atlantic Ocean.

The meteorological data obtained from the radiosoundings made on board the ship on the Atlantic Ocean indicate the presence of a layer of air, which has the typical characteristics of the Saharian air mass, as reported by previous researchers (Carlson and Prospero, 1972; Prospero and Carlson, 1972). These characteristics were present only when the mineral aerosol concentrations were high. When the concentrations were low, a defined layer was not observed. Also, during the sampling period the winds were predominantly Easterly.

In Table 1, some statistical parameters are shown which are related to the concentration distribution. One can observe that the arithmetic mean of the mineral abundances at the Atlantic Ocean is 18 times greater than that of the Pacific Ocean. The order of magnitude of the arithmetic parameters obtained here, agrees with that obtained by Prospero (1979).

Following Savoie and Prospero (1977), the log-normal representation of the average daily distribution frequency of the mineral aerosol component was used, obtaining the results shown in Figures 3 and 4.

The statistical parameters of the distribution are shown in Table 1. For the Atlantic Ocean, the skewness is -0.3229, being the standard error of skewness 0.3333. Thus, the absolute value of the quotient of skewness/error is of -0.9688,

which implies that the value of the skewness is significant up to 68% confidence (Hoel, 1962). With this value, and by observing the histogram, one can infer that it is not a symmetrical curve, and thus a pair of log-normal distributions is adjusted to it. This adjustment is made by dividing the samples in two groups; the geometric average and the standard deviation are calculated in the usual manner. With these

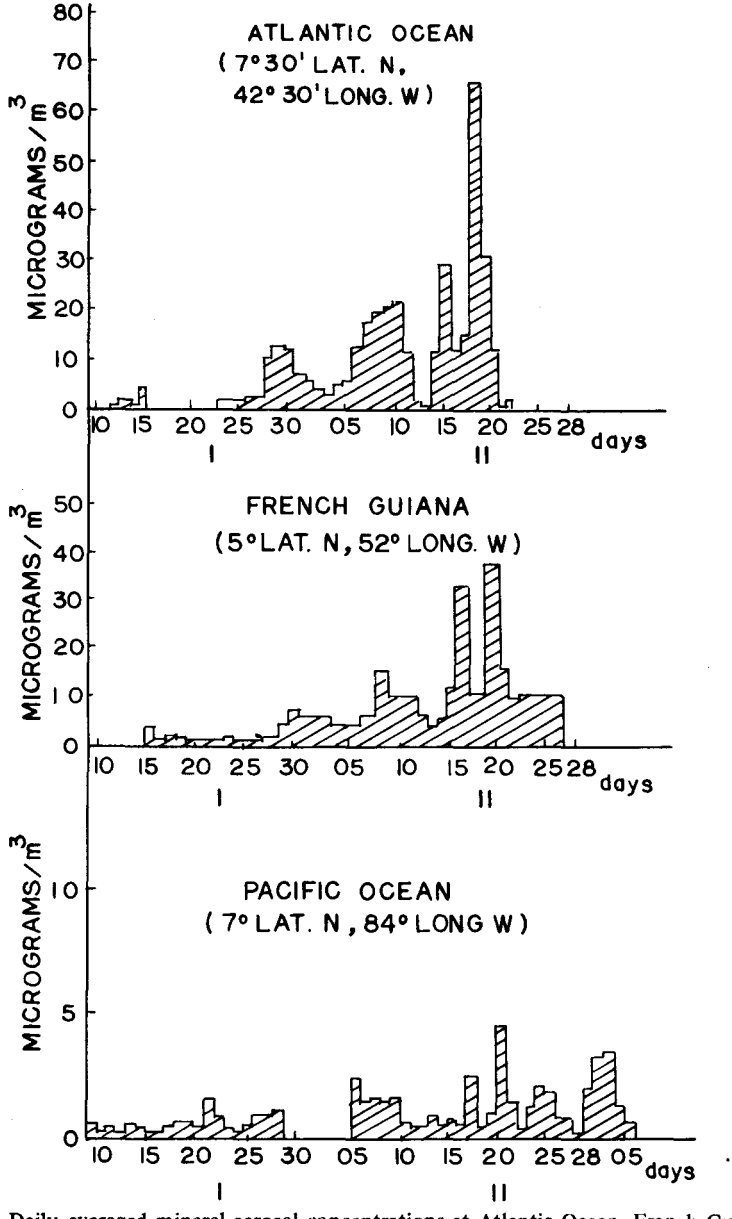

Fig. 2a. Daily averaged mineral aerosol concentrations at Atlantic Ocean, French Guiana and Pacific Ocean (SOP I).

parameters, a value of χ^2 is calculated, and the number of samples is varied in each group until the minimum value of χ^2 is obtained. In this case, from a group of 54 samples, the best division was obtained with $N_1 = 12$ and $N_2 = 42$. Once the best partition of the group is obtained, its statistical parameters are calculated; these are shown in Table 1.

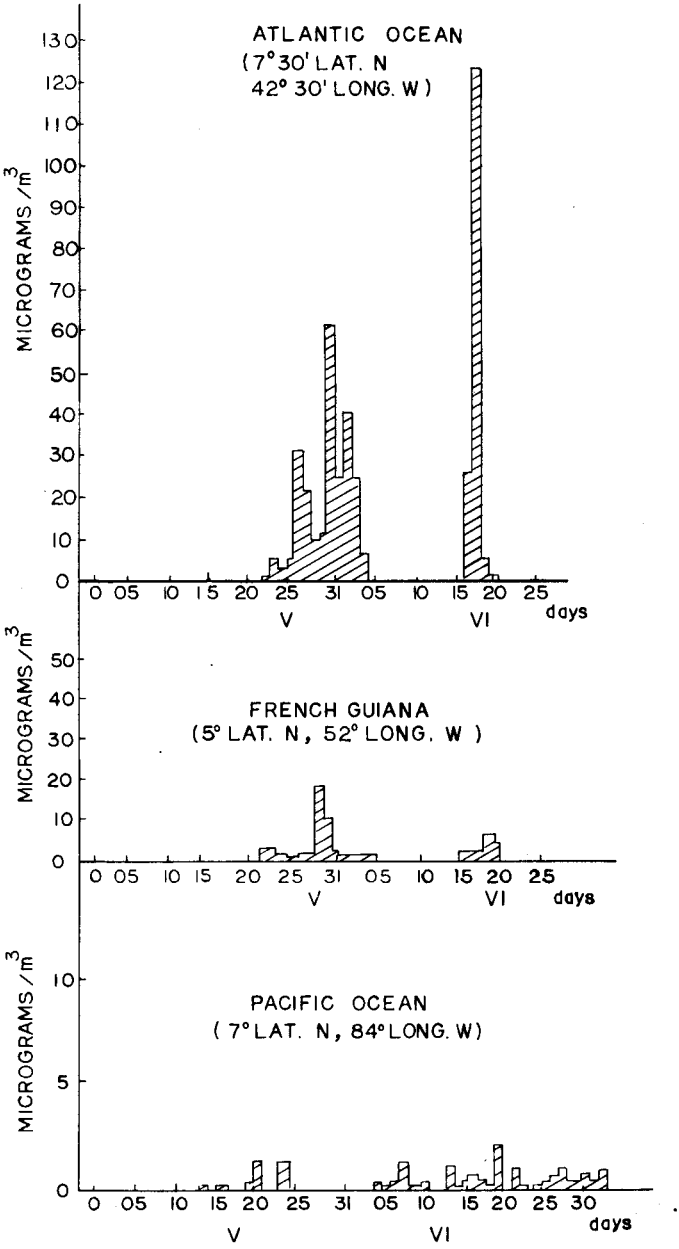

Fig. 2b. Daily averaged mineral aerosol concentrations at Atlantic Ocean, French Guiana and Pacific Ocean (SOP II).

Table 1

Statistical parameters of the frequency distribution: mineral and sea-salt aerosol concentrations ($\mu g/m^3$) on board the Mexican Research Vessels "Mariano Matamoros" and "DM 20" during FGGE.

	Atlantic Ocean		Pacific Ocean	
	Mineral aerosol	Sea-salt aerosol	Mineral aerosol	Sea-salt aerosol
n	54	45	82	80
Arithmetic mean	16.45	22.70	0.89	7.71
Arith.Std.Dev.	22.39	8.63	0.84	5.50
Geometric mean	7.27	21.38	0.62	6.28
Geo.Std.Dev.	4.10	1.40	2.39	1.88
Skewness (S)	–0.32	0.54	–0.03	0.15
Error Std.Skew. (E)	0.33	0.37	0.27	0.27
S/E	–0.97	1.47	–0.12	0.53

	$N_1 = 12$	$N_2 = 42$	$N_1 = 42$	$N_2 = 3$
Arithmetic mean	1.06	20.84	20.91	47.82
Arith.Std.Dev.	0.56	23.61	5.57	2.46
Geometric mean	0.91	13.17	20.19	47.75
Geo.Std.Dev.	1.78	2.56	1.31	1.05

For the Pacific Ocean, the distribution has the following parameters: Skewness -0.0315, standard error of the skewness 0.271, and skewness/error -0.1166. With the understanding that the skewness has a small value, not significantly different from zero, we can conclude that the curve is symmetrical and, therefore, the log-normal distribution was adjusted to it. The χ^2 test was applied to the mineral aerosol of the Pacific Ocean, and the value of 5.88 was obtained, representing a 66 % degree of confidence.

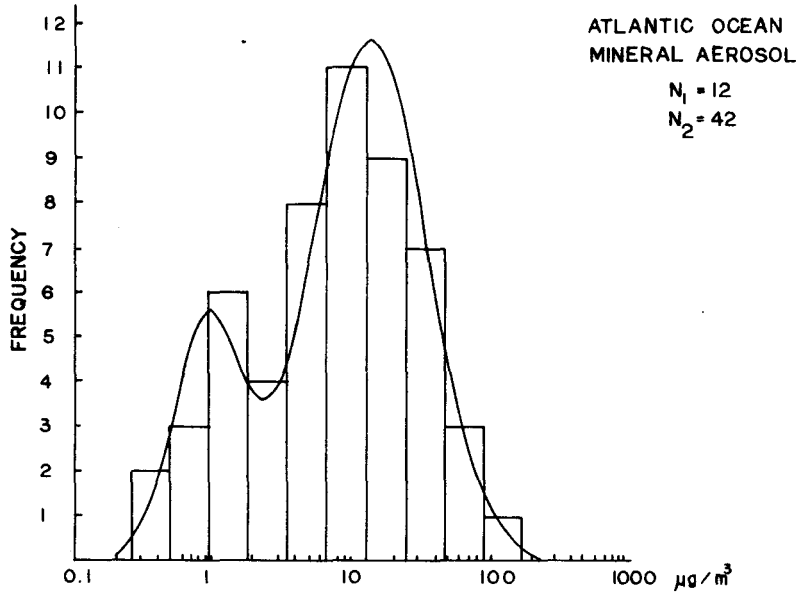

Fig. 3. Frequency distribution of the daily averaged mineral aerosol concentrations at Atlantic Ocean during FGGE.

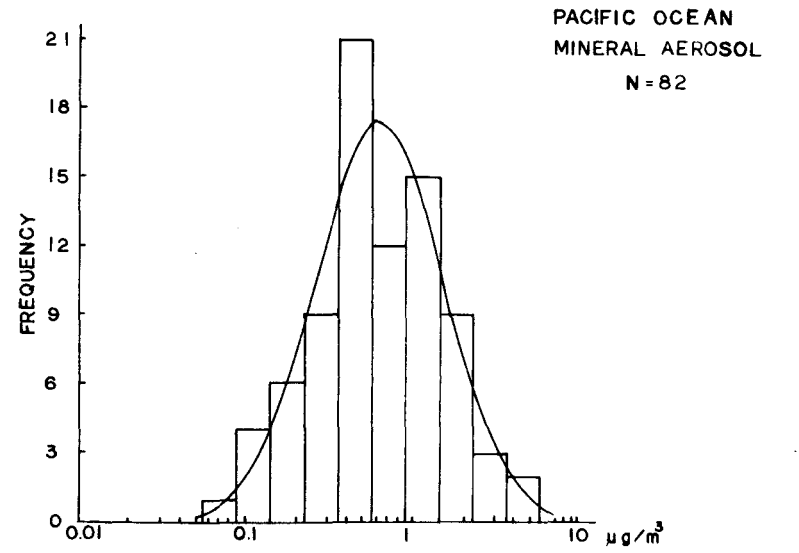

Fig. 4. Frequency distribution of the daily averaged mineral aerosol concentrations at Pacific Ocean during FGGE.

Sea salt

In Figure 5, the average daily concentration of sea salts obtained during the experiment is shown.

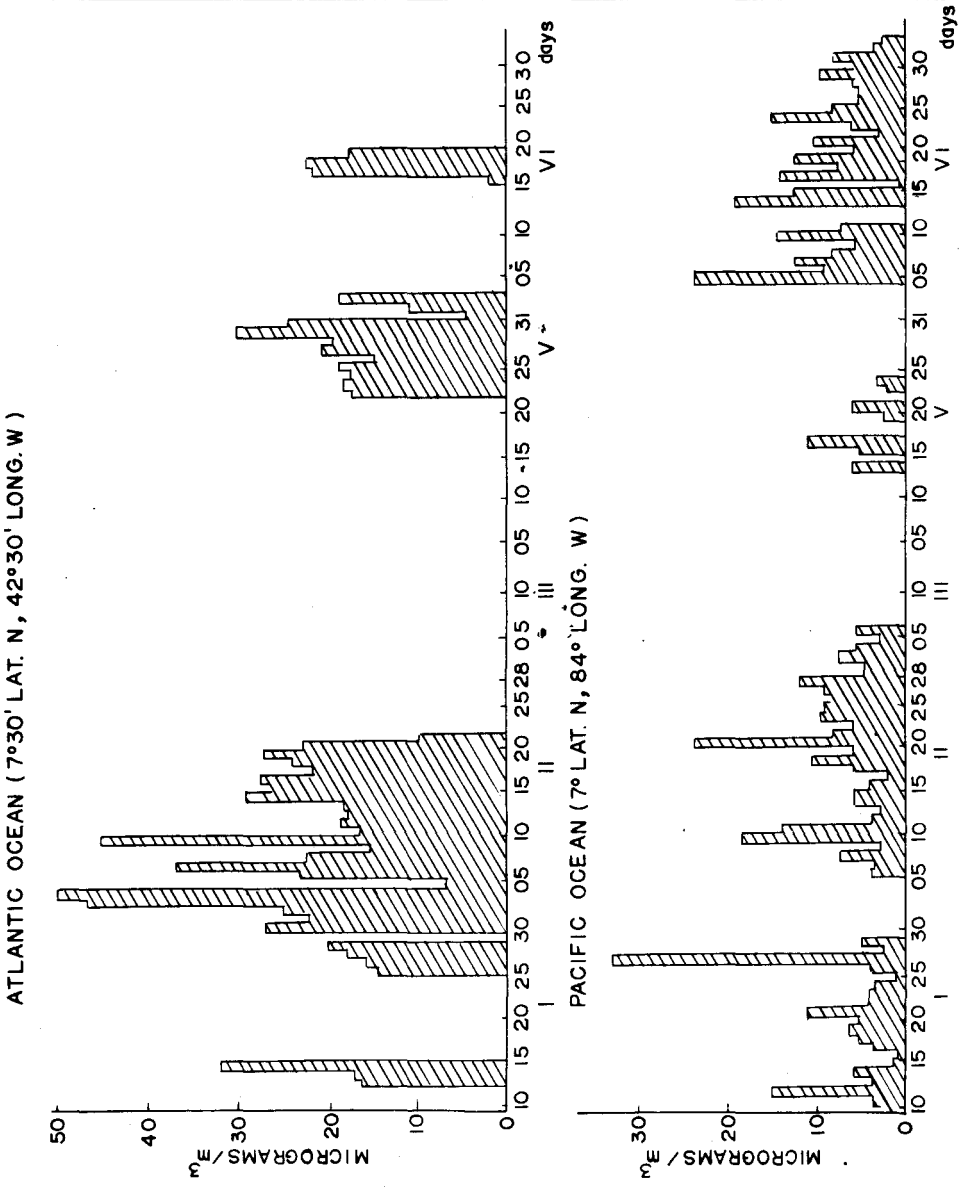

Fig. 5. Daily averaged sea salt concentration at Atlantic and Pacific Oceans during FGGE.

In Table 1, among other statistical parameters of sea salt concentrations, the arithmetic means of the concèntrations are shown. As in the case of the minerals, the arithmetic mean in the Atlantic Ocean exceeds that of the Pacific Ocean 2.9 times, which is within the order of magnitude reported by Prospero (1979). Also, the statistical parameters of the distribution of abundancy frequencies for sea salts in the Pacific Ocean are shown here. It can be observed that the skewness is not significantly different from zero; we therefore infer that the curve is symmetrical. Analyzing the histogram of Figure 6, log-normally built, we notice that its behavior is log-normal, for which a gaussian is adjusted to it.

The parameters of this gaussian can also be seen in the same Figure. The χ^2 test was used, obtaining a value of 2.98, which gives an 81% degree of confidence.

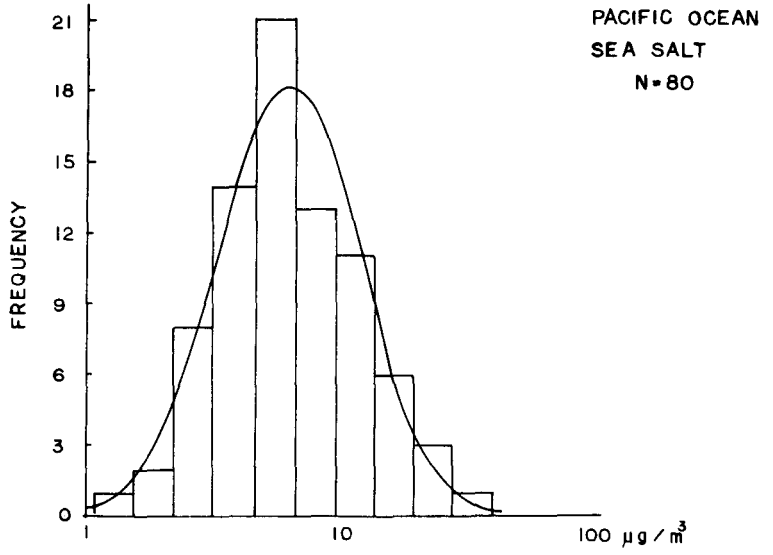

Fig. 6. Frequency distribution of the daily averaged sea salt concentration at Pacific Ocean during FGGE.

Finally, some of the statistical parameters obtained for the Atlantic Ocean are also shown. The skewness is 1.47 times its standard error, from which we deduce that the distribution is not a symmetrical curve (Figure 7). For this reason, the data were fitted with a couple of gaussian functions, using the same method which was applied to the Atlantic Ocean mineral aerosol. The best partition of the sea salts was found to be $N_1 = 42$ and $N_2 = 3$; the parameters for both gaussians are also shown in Table 1. The arithmetic mean for the aerosol concentrations over the Atlantic Ocean are larger than in the Pacific Ocean, regarding both sea salts and minerals.

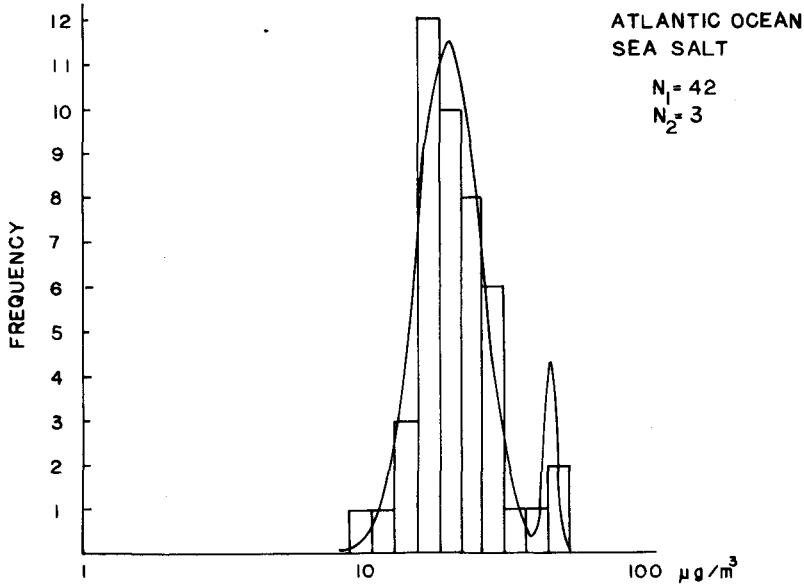

Fig. 7. Frequency distribution of the daily averaged sea salt concentration at Atlantic Ocean during FGGE.

We found a difference of approximately 24 hours (±12 hours), between the appearance of particle events in our observation point and French Guiana (Prospero, 1980, personal communication). This would happen if there were movement of continental dust from East to West. This result agrees with previously reported work by other researchers (Prospero and Bonatti, 1969; Prospero and Ness, 1977; Savoie and Prospero, 1977; Galindo, 1978), who state that, during this time of year, there is transport of dust from the northern coast of the Sahara along the Atlantic Equatorial Band, from 5°N to 20°N. This fact confirms that the aerosol sampled on the Atlantic Ocean contains an important contribution of continental origin.

The concentration distribution for the sea salts and the mineral aerosol of the Atlantic and Pacific Oceans are log-normal. For the Atlantic Ocean these present a bimodal distribution, indicating the participation of two sets of physical phenomena that inject aerosols into the atmosphere. One of these, the smaller mode (0.91 $\mu g/m^3$), is the background aerosol typical of the region; the other is the Saharian dust carried by Trade Winds.

For the Pacific Ocean, the obtained distribution was uni-modal, indicating the absence of Saharian dust, at least from our observation point.

Considering the climatic studies made in the sampled area of the Pacific Ocean (Rumney, 1968), and the radiosoundings (which include wind profiles) taken during our observation periods, two stages can be distinguished: The first of these, from January to March, in which the inter-tropical convergence zone was South of the Mexican vessel. During this stage, the predominant winds were northeasterly, suggesting that the mineral aerosol which was detected (and whose concentration is far lesser than in the Atlantic), came from the semi-desert areas of Southwestern Mexico and/or Central America (Prospero and Bonatti, 1969).

During the second stage of observation, from May to July, the inter-tropical convergence zone is slightly North of the sampling area. During this time the prevailing winds which were recorded on board were southwesterly, suggesting that the mineral aerosol came from the est coast of South America. This suggestion was reinforced by an analysis of the climatic maps of the region, in which one can observe the existence of a current which is related to the Semi-permanent Subtropical High that lies at all times West of Northern Chile, which could carry dust from the West coast of the continent, later turning East after hitting the inter-tropical convergence zone, in front of the coast of Central America.

The analysis of the radiosoundings taken on board the R/V located at the Equatorial Pacific Ocean during sampling periods do not show the physical characteristics of the profiles found for the Equatorial Atlantic Ocean during the presence of the Saharian dust layer, namely high potential temperature and low specific humidity, indicating the absence of Saharian aerosol. Comparing the concentrations of mineral and sea salts during the present experiment with other studies (Prospero, 1979; Duce *et al.*, 1980), one can observe that the concentrations reported here for the North-East Equatorial Pacific zone are, on average, higher but of the same magnitude.

CONCLUSIONS

The presence of aerosol of Saharian origin was confirmed during the SOP I and SOP II periods of the FGGE experiment over the Equatorial Atlantic Ocean.

The concentration of mineral aerosol is much lower in the Eastern Equatorial North Pacific than in the Western North Atlantic, however, there are indications of occasional dust episodes of some magnitude from nearly continental sources. These may play an important role in various atmospheric and geochemical processes.

The radiosoundings obtained on the Pacific Ocean do not show the thermodynamical characteristics of the Saharian dust layer seen on the atmosphere of the Equatorial Atlantic Ocean.

If we consider that the abundance distribution of mineral aerosol is uni-modal in the Northeast Equatorial Pacific Ocean, and that the radiosoundings do not present typical characteristics of the layers of air whose origin is Saharian, we can conclude that the aerosol which was sampled does not came from Africa. The authors consider that, should there be Saharian dust in this zone of the Pacific, it could be strongly masked by the presence of aerosol from the American continent. Therefore, it is necessary to concentrate on the chemical composition of the mineral aerosol, as well as making further studies with both land and ocean-going stations, in addition to the necessary meteorological and climatic information.

The method used in this paper, to obtain the parameter for the bi-modal gaussian distribution, is simpler than the method of truncated distribution and has a comparable accuracy.

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