TURBIDITY OVER THE INDIAN OCEAN

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Abstract: Atmospheric turbidity measurements were carried out over the Indian Ocean by a sunphotometer (λ=368, 500, 675, 778, 862 nm) during the voyage from Tokyo to Syowa Station, in the period of November through December 1979 and also from Syowa Station to Port Luis in the period of February through March 1981. In the region between 17°N and 67°S, the highest value of aerosol optical thickness (λ=500 nm) was 0.175 observed in the east end of the Indian Ocean close to the northwest coast of Australia, and the lowest value was in the region south of 20°S in the Indian Ocean.

The aerosol optical thickness in the low turbidity condition depends on the wind speed, whereas in the high turbidity condition the dependency is not clear.

The aerosol volume of large particles ($0.5 \leq r \leq 7$ μm) determined from the spectral extinction coefficient of the aerosol optical thickness gradually decreases from north to south. On the other hand, aerosol volume of small particles ($0.03 \leq r \leq 0.5$ μm) showed a maximum, contributing to the total volume appreciably, in the oceanic region between 10° and 20°S where the highest value of aerosol optical thickness was observed.

1. Introduction

Recent developments in man's activities have caused considerable changes of the atmospheric environment. An increase of particles in the atmosphere is one of the noticeable changes of the atmospheric environment. This causes a change of radiation field in the atmosphere, which necessarily leads to a change of the heat budget of the earth-atmosphere system (YAMAMOTO and TANAKA, 1972).

In order to obtain a better understanding of the characteristics of global air pollution, it is necessary not only to get a knowledge of the physical and chemical properties of aerosols in a clean atmosphere which is not directly affected by man made aerosols, but also to get a detailed knowledge of spatial distribution of aerosols from a polluted atmosphere.

Several studies have been carried out concerning the aerosols in the oceanic

atmosphere in the Southern Hemisphere (JUNGE and JAENICKE, 1971; MÉSZÁROS and VISSY, 1973; KOJIMA and SEKIKAWA, 1974; MÉSZÁROS, 1978; IWAI *et al.*, 1979; PATTERSON *et al.*, 1980).

Atmospheric turbidity gives useful information on atmospheric aerosol pollution. The observations of atmospheric turbidity have been carried out in central Europe (VOLZ, 1969), in eastern United States (PETERSON *et al.*, 1981), in polar regions (SHAW, 1982), and over the oceans in the Southern Hemisphere (FISHER, 1967).

By the 21st Japanese Antarctic Research Expedition (JARE) team, the observation of atmospheric turbidity with a sunphotometer (λ=368, 500, 675, 778, 862 nm) was carried out during the voyage from Tokyo to Syowa Station in Antarctica in the period of November through December 1979, and also from Syowa Station to Port Luis in the period of February through March 1981.

The aim of the present report is to give information on characteristics of turbidity distribution over the Indian Ocean. The measurements in the Southern Hemisphere, where the data are scarce, will be useful.

2. Measurements

Solar radiation was measured with the sunphotometer which can obtain the intensity of incident solar radiation in a narrow waveband.

These measurements give the aerosol optical thickness $\tau_A(\lambda)$ per unit air mass as defined by the relation;

$$\tau_A(\lambda)=\frac{\ln (J_0(\lambda)/(J(\lambda)\cdot S))}{M}-\left(\frac{P}{P_0}\cdot\tau_R(\lambda)+\tau_0(\lambda)\right),$$

where $J(\lambda)$ is the intensity of solar radiation incident upon the sunphotometer; $J_0(\lambda)$ an individual instrumental calibration constant which is numerically equivalent to the intensity of solar radiation at the top of the atmosphere when a solar distance is 1 AU (1 AU$=1.496\times10^8$ km). S is the correction factor for mean sun-earth distance, M the relative optical air mass (KASTEN, 1966), $\tau_R(\lambda)$ the Rayleigh scattering optical thickness of molecules (FLÖHLICH and SHAW, 1980), P the station pressure, P_0 the sea-level pressure, and $\tau_0(\lambda)$ the optical thickness for ozone absorption, *i.e.*, absorption coefficient multiplied by the amount of ozone.

The measurements were made by using an Eko MS-110 sunphotometer. The sunphotometer had an aperture angle of 2.5 degrees. A cover glass of fused quartz was on the aperture. The detector was silicon photo-diode. Spectral measurements were made with interference filters set on the rotating disk. Their nominal pass

Table 1. The accuracies of the extrapolation process at each wavelength.

	Wavelength				
	862 nm	778 nm	675 nm	500 nm	368 nm
$\Delta J_0/J_0$	0.005	0.005	0.006	0.007	0.014
$\Delta\tau_A$	0.003	0.003	0.003	0.004	0.007

$\Delta J_0/J_0$ means uncertainty (r.m.s) in the case of extrapolation by Langley method. $\Delta\tau_A$ means the error (r.m.s) of the optical thickness at M=2.

wavelengths were 368, 500, 675, 778 and 862 nm.

Eighteen determinations of $J_0(\lambda)$ values by Langley method were made thirteen times at Syowa Station and five times aboard (MATSUBARA and KAWAGUCHI, 1983). Through these determinations it was confirmed that the calibration constant $J_0(\lambda)$ did not change during the observation period. In our data $J_0(\lambda)$ is mean value of eighteen determinations. Table 1 shows the error expected in the determination of $\tau_A(\lambda)$ in our data.

3. Results and Discussion

JARE-21 team successfully obtained 64 individual data of the aerosol optical thickness at 5 wavelengths. Figure 1 shows the locations where observations were made.

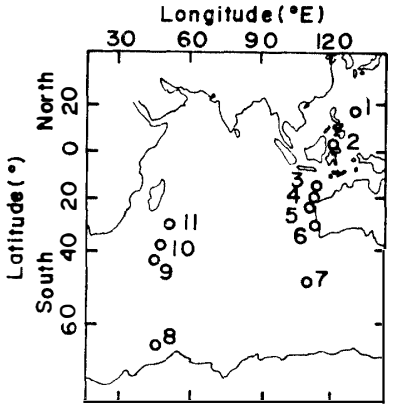

Fig. 1. Locations where observations were made.

3.1. Basic data

Table 2 shows the mean aerosol optical thickness at various locations. The highest value at $\lambda=500$ nm in the region between 17°N and 67°S was 0.175 observed in the east end of the Indian Ocean close to the northwest coast of Australia. The

Table 2. Summary of the measurement data.

Obs. No.	Date	Latitude	Longitude	Optical thickness 862 nm	778 nm	675 nm	500 nm	368 nm
1	25 Nov. '79	17°N	130°E	0.131	0.128	0.130	0.115	0.170
2	28 Nov.	3°N	122°E	0.104	0.100	0.102	0.099	0.158
3	2 Dec.	15°S	114°E	0.101	0.105	0.127	0.158	0.276
4	3 Dec.	20°S	114°E	0.113	0.117	0.139	0.175	0.293
5	4 Dec.	25°S	113°E	0.045	0.044	0.054	0.050	0.103
6	5 Dec.	30°S	114°E	0.029	0.026	0.031	0.027	0.074
7	17 Dec.	49°S	110°E	0.057	0.049	0.054	0.036	0.070
8	19 Feb. '81	67°S	47°E	0.037	0.031	0.032	0.036	0.058
9	5 Mar.	42°S	46°E	0.035	0.028	0.026	0.032	0.058
10	6 Mar.	37°S	49°E	0.092	0.083	0.077	0.079	0.101
11	7 Mar.	32°S	51°E	0.039	0.031	0.026	0.032	0.060

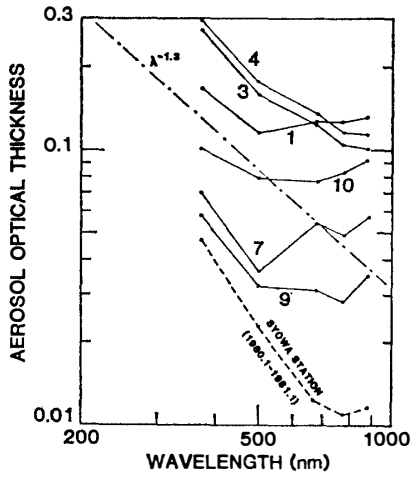

Fig. 2. Spectral extinctions of the aerosol optical thickness at various locations. Numbers mean Obs. No. in Table 1. A dash-line shows the mean spectral extinction at Syowa Station, Antarctica, in the period from January 1980 to January 1981 (MATSUBARA and KAWAGUCHI, 1983).

lowest value at $\lambda=500$ nm was 0.027 observed in the region south of 20°S in the Indian Ocean.

Spectral extinctions of the aerosol optical thickness are shown in Fig. 2. It can be seen from the figure that two spectral extinctions of observation number 3 and 4 can be approximated by the power law distribution of wavelength, whereas others deviate from the power law distribution as the wavelength increases, suggesting the appreciable contribution of larger particles to the total aerosol loading.

3.2. Relation between wind speed and aerosol optical thickness

It has been observed that the aerosol concentration over the ocean surface is a function of wind force, measured on Beaufort scale (WOODCOCK, 1953; KOJIMA and SEKIKAWA, 1974; PATTERSON *et al.*, 1980). This means that the emission of salt particles from sea surface increases as wind speed increases.

It has been also reported that aerosol optical thickness is rather sensitive to the surface aerosol concentration (KOBAYASHI and YANO, 1982).

From these investigations it may be expected that the optical thickness over the

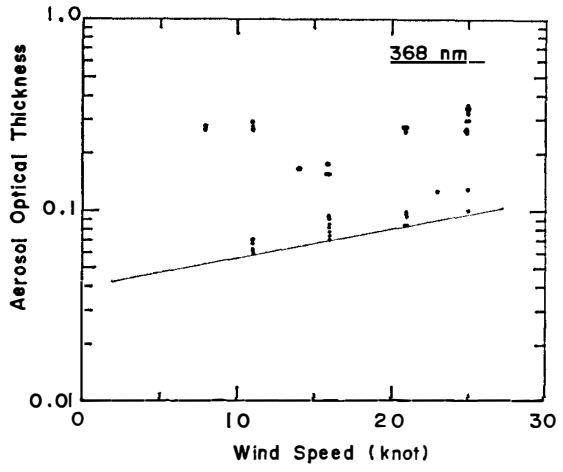

Fig. 3. An example of the dependence of the aerosol optical thickness at $\lambda=368$ nm on the wind speed.

ocean increases with the increase in the surface wind speed. Therefore in the case of measurement on board the influence of the wind speed on the turbidity measurements must be taken into account.

Figure 3 shows an example of the dependency of the aerosol optical thickness at $\lambda=368$ nm on the wind speed in the present observation. In the figure, all of optical thickness for 368 nm obtained during the voyage are plotted. In the figure, the aerosol optical thickness seems to depend on the wind speed in the low turbidity condition. In the high turbidity condition, however, the dependency is not clear. Thus as for the high value, turbidity obtained in the present observation is considered to give a representative value of entire columnar air of that oceanic region.

3.3. Relation between latitude and aerosol optical thickness

Figure 4 shows the aerosol optical thickness at $\lambda=500$ nm plotted against latitude. In the figure, relatively high aerosol optical thickness is seen in the region north of 20°S. The optical thickness in the region south of 20°S is low and constant. The high value seen for $\lambda=500$ nm in the region from 10° to 20°S becomes uncertain as wavelength increases, and the optical thickness at $\lambda=862$ nm rather shows a gradual decrease from north to south.

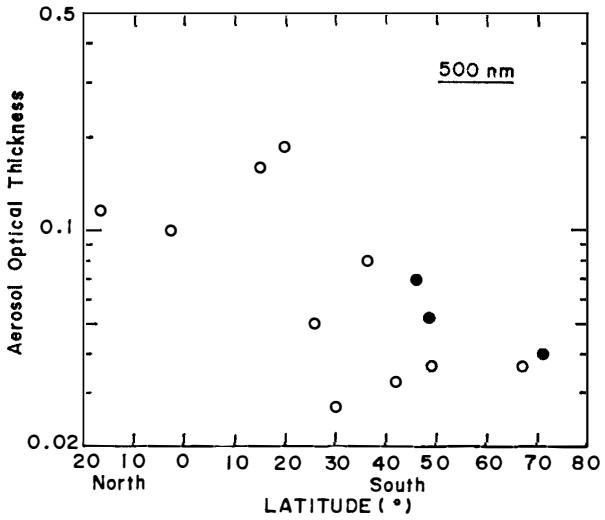

Fig. 4. Relation between latitude and aerosol optical thickness at $\lambda=500$ nm. Solid circles by FISHER *(1967).*

The present results in the Southern Hemisphere fairly agreed with the results obtained for $\lambda=500$ nm during the voyage from McMurdo Station to Duniden, New Zealand by FISHER (1967).

3.4. Relation between latitude and aerosol volume

Figure 5 shows the aerosol volume plotted against latitude. An aerosol volume was inferred from the measured spectral extinction by means of the inversion method (YAMAMOTO and TANAKA, 1969). In this inversion, the size range of radius is assumed to be from 0.03 μm to 7 μm and a refractive index of particle to be 1.49. The total aerosol volume is a nearly constant high value in the region north of 20°S, and very low value in the region south of 20°S. Volume of large particles ($0.5\leq r\leq 7$ μm),

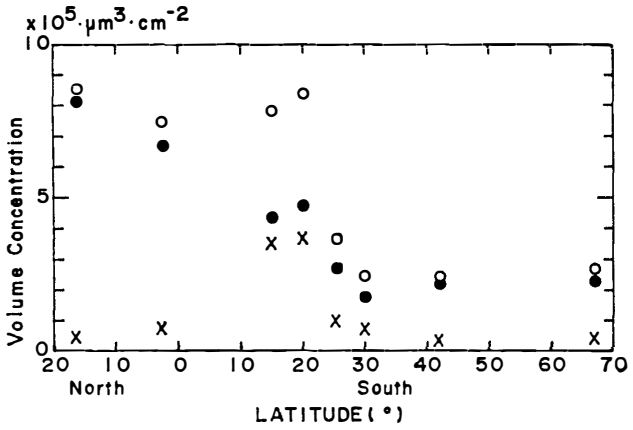

Fig. 5. Relation between latitude and aerosol volume. Open circles, solid circles and crosses denote the total volume ($0.03 \leq r \leq 7$ μm), volume of large particles ($0.5 \leq r \leq 7$ μm) and volume of small particles ($0.03 \leq r \leq 0.5$ μm), respectively.

however, decreases gradually toward south in the region north of 20°S, and becomes very low and constant in the region south of 20°S. On the other hand, volume of small particles ($0.03 \leq r \leq 0.5$ μm) shows high values in the region from 10° to 20°S, but in the other regions of both hemispheres it shows uniform low values.

PATTERSON *et al.* (1980) reported the results of the aircraft observation over the Pacific Ocean that total aerosol and crustal component concentrations showed a general decrease from north to south, and the lowest concentration was seen south of 20°S.

Their results show a similar tendency in the latitudinal distribution to our results, except the high volume in the region from 10° to 20°S. This high volume seems to have resulted from the circumstance where the volume of large particles gradually decrease from north to south, but the volume of small particles contributes largely to the total aerosol volume in the region between 10° and 20°S.

IWAI *et al.* (1979) reported by the observation of Aitken particles in the same season that high concentrations of 700–1200 cm^{-3} were observed in the region from 8.5° to 23.5°S. They quoted that high concentration in this oceanic region had been measured also by SHIRATORI (1934). Thus high concentration of small particles in this oceanic region seems to be a representative one in this region.

JUNGE and JAENICKE (1971) reported that high particle concentration which is due to mineral dust from the Sahara desert was detected in the oceanic region far from land.

Spectral extinction of aerosol optical thickness in the region between 10° and 20°S can be approximated by the power law distribution. According to the map of mean wind distribution over the Indian Ocean, it can be seen that the prevailing winds in the region, where the highest extinction was obtained, blow through the desert area in the Australian continent in austral summer, but the prevailing winds, especially in the region south of 20°S, blow from the Indian Ocean in the same season. Therefore, the high volume concentration in the region from 10° to 20°S in the present observation seems to be of particles of continental origin produced in the desert of the Australian continent.

4. Concluding Remarks

Atmospheric turbidity measurements were carried out during the voyage from Tokyo to Syowa Station, in the period of November through December 1979, and also from Syowa Station to Port Luis in the period of February through March 1981. Most observations were made south of 20°N.

(1) The highest value of aerosol optical thickness ($\lambda=500$ nm) was 0.175 observed in the east end of the Indian Ocean close to the northwest coast of Australia. The lowest value ($\lambda=500$ nm) was 0.027 observed in the region south of 20°S in the Indian Ocean.

(2) The aerosol optical thickness in low turbidity condition depends fairly on the wind speed, whereas in high turbidity condition the dependency is not clear. This result seems to suggest that in the case of turbidity measurement over the ocean, it is necessary to make corrections by measuring the concentration of aerosol close to the sea surface to obtain the correct information of dust loading in the free atmosphere.

(3) The aerosol volume was determined from the spectral extinction coefficient of the aerosol optical thickness. The total aerosol volume was high in the region north of 20°S, especially in the region from 10° to 20°S, and sharply decreased in the region south of 20°S. The volume of large particles ($0.5\leq r\leq 7\ \mu$m) gradually decreased from north to south. The volume of small particles ($0.03\leq r\leq 0.5\ \mu$m) was high in the region from 10° to 20°S. High value in the region from 10° to 20°S is brought by the contribution of small particles. Aerosols in this region seem to originate in the Australian continent.

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