Oceanology No. 12 (1980)
PL ISSN 0078-3234

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FLUCTUATIONS IN THE ATMOSPHERIC DUST CONTENT ABOVE THE CENTRAL ATLANTIC AND TRANSFER OF DUSTS FROM THE SAHARA *

Contents:

1. INTRODUCTION

Fluctuations in the dust content above the central Atlantic are interesting because of the removal of dusts from the Sahara [6, 8—11]. Many problems are connected with this phenomenon, especially the effect of optically active aerosols on the radiation budget of the atmosphere-ocean system. The exceptional cumulative properties of the sea as regards heat energy and the large inertia of processes of heat exchange with the atmosphere probably create a system which causes a „signal amplifier" effect with respect to the influence of dust content on long-term weather and climatic changes. However, the complexity of this system requires above all the investigation of the dynamic characteristics of atmospheric dust above the ocean.

These studies were undertaken during the international GARP Atlantic Tropical Experiment in 1974 (GATE-74). They were later continued, not only in order to explain the characteristics of the conditions obtaining over the central Atlantic during the measurement period, but also to check the methods used and to obtain reference dimensions which could be used in the development of similar studies in the Baltic.

2. METHOD

Measurements were made during GATE-74 on the Soviet research vessel Musson [7]. During the measurement period from June to September 1974, the ship was stationed north of the equator in the central

* This study was accomplished in Interdepartmental Programme I. 15.

Atlantic, mostly between 5° and 12° N and 21° and 23° W (Fig. 1). For collecting aerosol samples, a four stages cascade impactor of the author's own construction was used. The apparatus contained glass plates with a specially prepared sticky surface, and these were exposed to dust for from one to two hours by pumping on board an average of 20 m^3 of fresh air per sample. (The air was obtained from the outside of the ship at a height of about 10 m above sea level). Up to four measurements in 24 h were made.

The impactor, specially constructed for these experiments, was, for organizational reasons, not fully tried out before measurements began. Its merits and faults could be estimated only on the basis of materials collected during GATE-74. Particles of sea-salt, collected together with dust, acted as a kind of standard. The application of the impactor on the Atlantic showed, that the nuclei of sea-salt of radius $r \geqslant 1\ \mu m$ are almost all collected on the first cascade (gap width about 5 mm, distance from collecting surface 3 mm). On the second cascade from the inlet (gap 3 mm, distance 2 mm) no salt crystals could be found with a 1000-fold magnification.

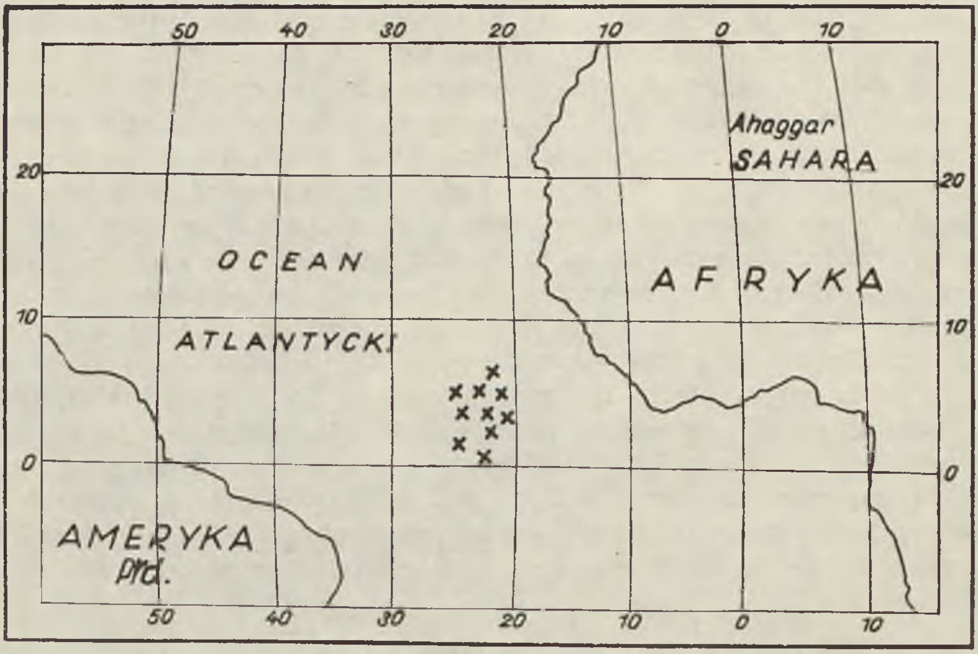

Fig. 1. Map of central Atlantic showing the areas studied
Stations where measurements were made on board r/v Musson are indicated by crosses

Ryc. 1. Mapa środkowej części Atlantyku z lokalizacją objętych badaniem obszarów
Krzyżykami oznaczono miejsca stacjonowania statku r/v Musson w okresie prowadzenia pomiarów

For the single-cascade impactor, the value η — the coefficient of capture on the plate surface, was established on the basis of autoradiographic measurements of Rn-222 and Po-214 in the air just above the water on the Baltic [3]. On average, it was 2×10^{-4} cm^{-2} for Po-214 and $2{,}6 \times 10^{-5}$ cm^{-2} for Rn-222. In the first case, the result refers to the collection of larger particles under the influence of inertia forces, in the second, to the capture by diffusion of much smaller particles in the thin layer of air in contact with the plate and their adsorption onto the surface of the plate. The value of η for radon refers rather to primary aerosol particles (if not to free atoms of this gas), for which the efficiency of capture in the impactor should not exactly depend on the geometry of the apparatus, though at least to the degree to which it is dependent in the case of tipical aerosol particles collected in the same way. Taking the above into consideration, the value of η could have been estimated from the analysis and the extrapolation shown in Fig. 2. By way of a basis, it was accepted that the natural radioactivity of the atmosphere is linked mainly with particles 0,015 — 0,5 μm in size and with the modal value of 0,1 μm for a spectrum of these magnitudes, also that Rn-222 corresponds to the lower limit of this interval, while Po-214 corresponds to the characteristic value of 0,1 μm [5].

The dushed line has been introduced into the figure 2 so as to compare the value of η which could have been obtained assuming a non-linear dependence of η on r. Although such a dependence results

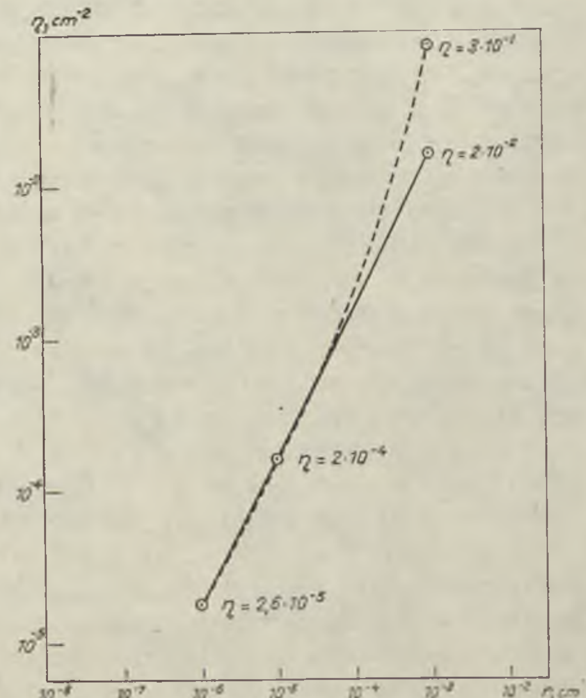

Fig. 2. Analysis of the dependence of the coefficient of capture (η) in the impactor on the radius (r) of aerosol particles

Ryc. 2. Analiza zależności współczynnika wychwytu (η) od wielkości promienia (r) cząstek aerozolu, pozwalająca oszacować efektywność działania zastosowanego w pracy impaktora from the analysis of one of the impactor examples described by Green and Lane [4], in our case, analysis of measurement materials confirmed a generally linear dependence within the limits of r covered by the present studies. In any case, that a linear dependence exists within the range of particle sizes from 10 to 18 μm is shown by the registration data of the impactor described by Green and Lane [4].

The low efficiency of particle capture in the impactor caused the collected samples to be far from saturated. The concentration of particles on the plates covered quite a wide range of extinction differences. The increase in capture efficiency with the increase in radius was sufficiently great to ensure the predominance of coarse — grained particles on the first cascade. The particles collected on the second cascade were at least one order of magnitude smaller than those on the first cascade; crystals of sea salt of radius $r \geqslant 1$ μm were not noted on the second cascade.

Traces of the dust samples collected on the glass plates, in the form of rectangular matt spots, were then analysed photometrically. This analysis was done by measuring the reduction of light intensity after having passed it through the dusty parts of the plates. A Pulfrich photometer with an Elpho photoelectric attachment and an S-53 filter were used. The background correction was carried out by measuring the light reduction through unexposed plates prepared in the same way. As a check for this, parallel light rays were passed through the non--dusty parts of the plates next to the spots of collected dust. Only samples collected on the first and second cascade were suitable for such analysis. The samples collected on the following two cascades appeared as very thin threads because of the narrow gaps. Since the beam of light in the Pulfrich photometer was relatively wide, it was impossible to take exact measurements of these samples.

The data obtained from the photometer readings enabled the light extinction value (E) for samples of opaque or semitransparent dusts to be determined. The sea salt particles, being relatively transparent, had practically no effect on these readings. This is confirmed by a comparision of the results of the photometric studies of the aerosol samples with those obtained from microscopic examination of the number and size of the sea salt crystals collected (Fig. 3). That the aerosol causing fluctuations in extinction is not derived from the sea is proved by the lack of any kind of dependence of these fluctuations on wind velocity. This is one of the differences between aerosols of marine and non--marine origin. The influence of wind velocity on the increase in sea salt concentration has already been confirmed [5]. Thus, we can say that the method applied here permitted the registration of concentration fluctuations of dusts of non-marine origin, mostly those removed from above land. The cosmic component is negligibly small.

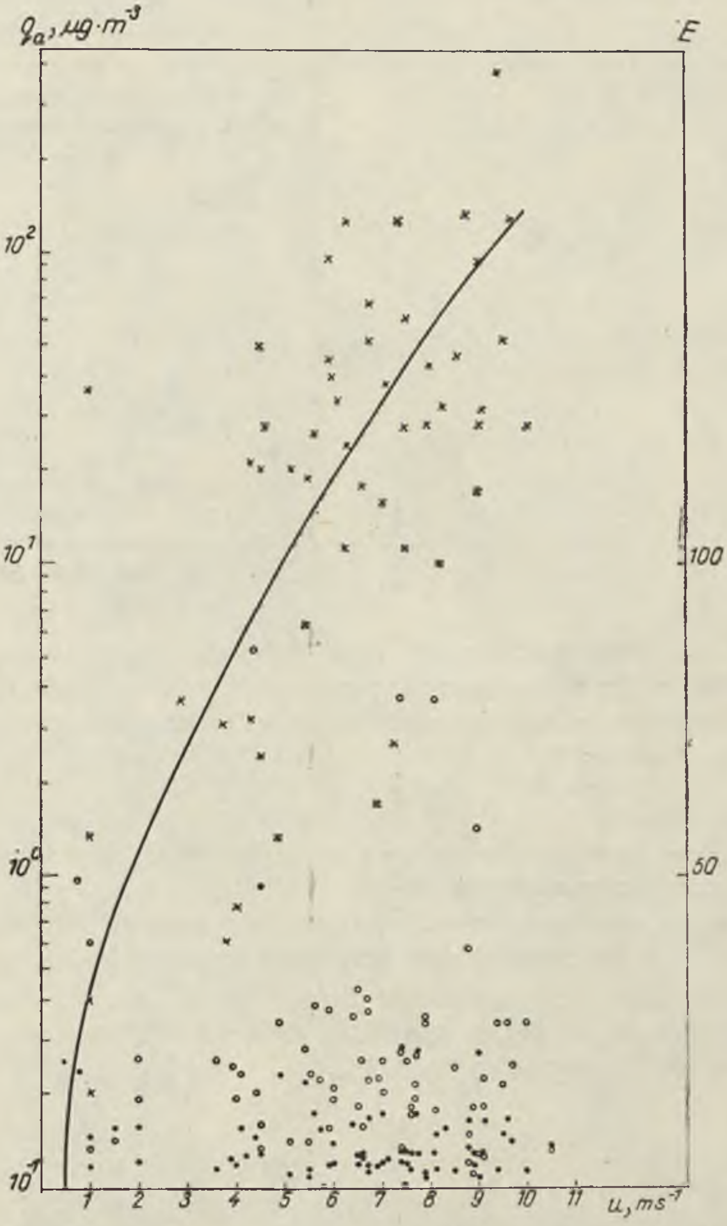

Fig. 3. Comparison of the dependence of the sea-salt particle concentration (q_a) in the near water air layer and of the reduction in light intensity (E) in aerosol samples on wind velocity u

Crosses indicate data on salt particles; circles indicate light extinction in samples collected on the first cascade, dots — light extinction in samples from the second cascade

Ryc. 3. Porównanie zależności koncentracji cząstek soli morskiej w powietrzu przywodnym i stopnia osłabienia wiązki światła w próbach aerozolu od prędkości wiatru

Krzyżyki odpowiadają danym uzyskanym dla cząstek soli, punkty puste — dla ekstynkcji światła w próbach zebranych na pierwszej kaskadzie, pełne — dla ekstynkcji w próbach z drugiej kaskady

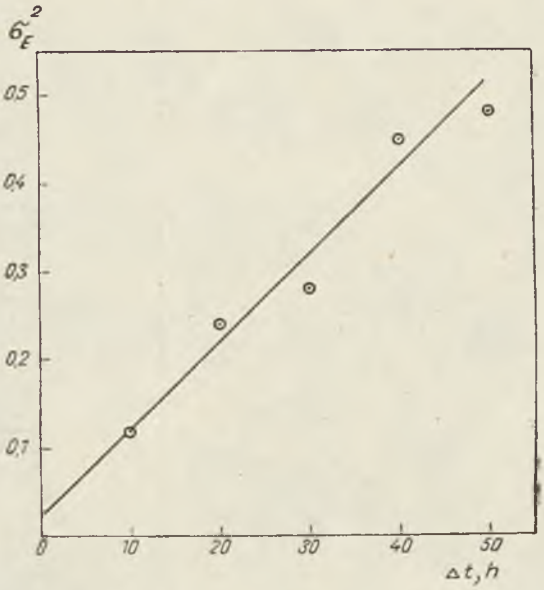

Fig. 4. Graphical analysis of accidental error on the basis of dispersion (σ_E) of measured values of ΔE for characteristic time intervals Δt

Ryc. 4. Graficzna analiza przypadkowego błędu na podstawie dyspersji (σ_E) zmierzonych wartości ΔE dla charakterystycznych przedziałów czasu Δt

Values of the reduction in light intensity (E) in aerosol samples were obtained from photometric readings in relative units. The effect of accidental error on the measured results has been defined by the following equation [9].

$$\sigma_E^2(\Delta t) = \sigma^2(\Delta t) + 2\,\sigma_o^2$$

where σ_E — the dispersion of measured differences in values of E for sections of time Δt,

σ and σ_O — the dispersion of real and apparent differences respectively, caused by the accidental error.

Graphical analysis of the dispersion σ_E (Fig. 4) for the characteristic variation of dust content in the study area showed, that the accidental error was small, no greater than 10%.

3. THE CIRCUMSTANCES OF THE EXPERIMENT

The aerosol conditions off the coast of Africa during GATE-74 cannot be taken as normal, not deviating from the average conditions obtaining in these areas. The drought, which lasted from 1968-9 to 1974 favoured a considerable increase in the atmospheric dust content; as the drought continued the atmospheric aerosol content increased three fold. According to Savoie and Prospero [10], during GATE-74 the average dust concentration going at tropical latitudes from the African Coast to the Sal Island and further, to the west of Barbados, i.e. in an area practically free from industrial pollution [1], amounted to 29.8, 20.5 and

8.1 $\mu g \cdot m^{-3}$. Timofiejev's findings [12] on the transparency of the atmosphere at such latitudes also agree with these results. In August and September 1974, the transparency of the atmosphere was below its average value. While the size and concentration of aerosol particles generally increased, there were also considerable variations in the transparency of the air in time. These variations were due to the removal of dust by the NE Trade Wind blowing from the African continent. However it has already been shown with the aid of satellite photographs [11], that clouds of dust carried by the NE Trade Wind from the Sahara bring about the greatest increase in atmospheric dust content above the Atlantic. The conditions described were reflected in the results presented in this paper, results obtained using an original photometric research method. It is difficult to equate them with results achieved using other methods, nevertheless such a comparison greatly helps to explain facts and can be important for the broadening of research into the dynamic of atmospheric dust content.

4. RESULTS

The material obtained from measurements of the reduction in light intensity for samples from the first cascade is distinguished by large differences in extinction. The graph (Fig. 5) of the measurements illustrates the wide range of variation of extinction. The graphical comparison of the data for the central Atlantic with those obtained in the same way for the Baltic during April — June 1971 serves as a check for the method. The mean amplitudes and periods of the day-to-day fluctuations in dust content for the two areas differ considerably, which is, of course, the result of different geographical and circulational conditions. Analysis of the periodicity of the day-to-day dust content fluctuations for the central Atlantic has shown, that a time interval of fluctuations predominates which is a period lasting about 40 hours. In the spectrum of variations of meteorological values, the maximum frequency is usually around 11.57 μHz, which corresponds to the 24 h period. The maximum in the energy spectrum falls on the frequency 2.78 μHz, which corresponds to a period of 4.2×24 h, i.e. approximately to the variations characteristic for natural synoptic periods. Analysis of the day-to day dust content fluctuations thus shows that such fluctuations of a frequency of approximately 6.9 μHz which corresponds to a period of about 1.7×24 h are characteristic for the central Atlantic.

If the extinction variations during measurements for the aerosol samples collected on the first cascade (Fig. 6) are followed, it may be seen that the maximum values are periodically repeated a few times each month. These values were compared with those of Martin [6] con-

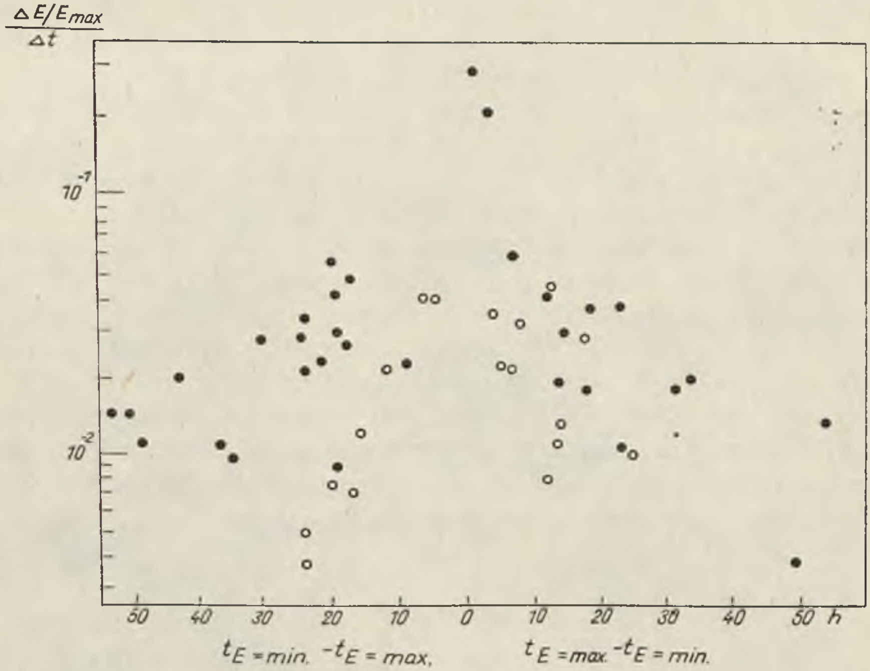

Fig. 5. Analysis of dust content fluctuations relative to periods Δt separating its extreme values

Dots indicate data for the central Atlantic, circles — data for the Baltic

Ryc. 5. Analiza wahań zapylenia w stosunku do okresów Δt dzielących jego wartości ekstremalne

Punkty pełne odpowiadają danym uzyskanym dla środkowej części Atlantyku, puste — dla Bałtyku

cerning the removal of dust from the Sahara to over the Atlantic. These investigations were carried out as part of GATE-74 on the basis of visible light and infrared photographs taken from a satellite. These measurements covered the period from 3rd to 8th August 1974. The occurence of a large dust cloud in the Sahara, to the west of the Ahaggar massif, and moving in a westerly direction, was confirmed.

According to the analysis, the first discharge of dust, which probably took place during the early hours of 3rd August, caused the cloud to cross the coastal zone of the Atlantic Ocean with the trade wind as a tongue extending towards the west. The cloud was particularly easily visible on the visible light photograph, when is was crossing the coastal zone on 6th August. The analysis of satellite data helped to establish, that by the following day the cloud had already spread out over a large area of the ocean, reaching its central part. The satellite photographs also confirmed, that a second discharge of dust had taken place in the same region of the Sahara during the morning of 5th August.

If the results of Martin's analysis are compared with the results of the direct measurements made in this study (Fig. 6a), the following conclusions may be drawn.

1. The two discharges of dust on the Sahara on 3rd and 5th August,

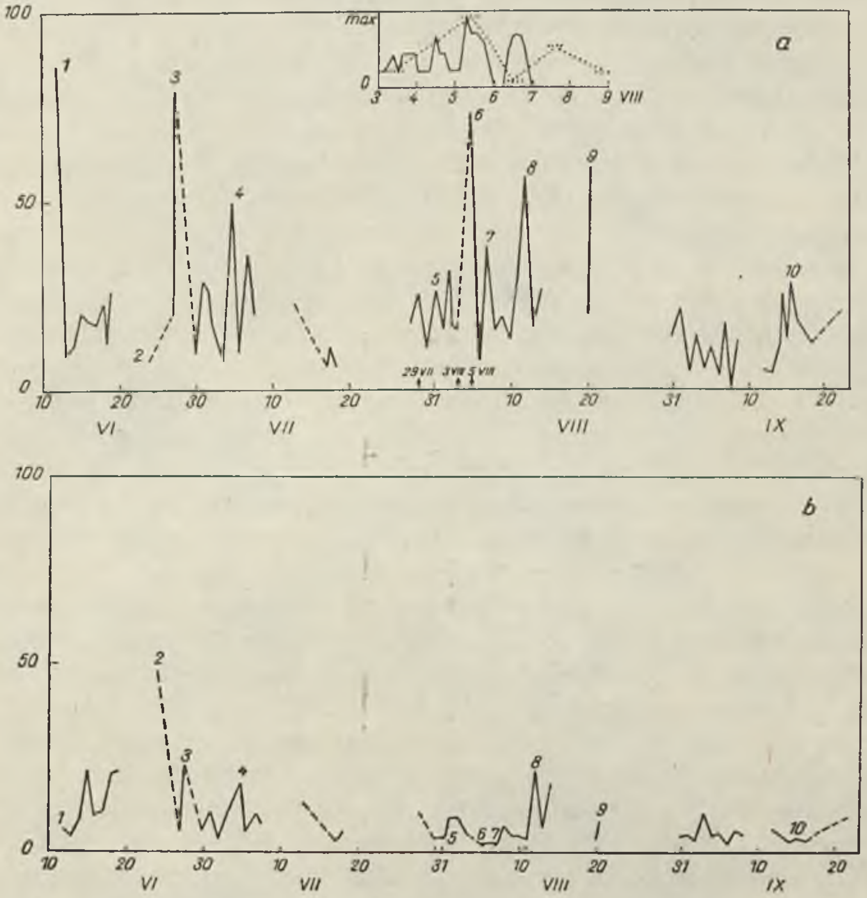

Fig. 6. Fluctuations in atmospheric dust content over the central Atlantic during the Atlantic Tropical Experiment GATE-74

Graphs represent the results of measurements made on the basis of light extinction values in samples from the first (a) and second (b) cascade. At the top of graph (a), on an enlarged time scale, data of Saharan dust discharges obtained by D.W. Martin (1975) during GATE-74 on the basis of satellite observations (salid line) compared with measurements made on the ocean with an impactor (dotted lines). The dates of observed discharges are marked by arrows

Ryc. 6. Wahania zapylenia powietrza nad obszarami środkowej części Atlantyku w okresie Atlantyckiego Eksperymentu Tropikalnego GATE-74

Na podstawie pomiarów ekstynkcji światła w próbach z pierwszej (a) oraz z drugiej (b) kaskady. U góry na wykresie (a) w zwiększonej skali czasu dane zrzutu pyłu saharyjskiego, uzyskane przez D. W. Martina (1975) podczas GATE-74 na podstawie obserwacji satelitarnych (łamana linia ciągła), porównano z danymi pomiarów dokonanych na oceanie za pomocą impaktora (kropkowane kreski poziome i łączące je proste). Daty obserwowanych zrzutów oznaczono strzałkami which were discovered after analysing the satellite photographs, may explain the extinction maxima (peaks No. 6 and 7 on Fig. 6a) in aerosol samples collected on 5^{th} and 7^{th} August in the Atlantic.

2. Analysis of visible light and infrared satellite photographs enables the boundary of the main body of the dust cloud to be drawn (where the dust is dense enough). On the other hand the peripheral parts of the cloud, where the dust concentration is less, are impossible to trace photographically, and may be for more extensive than the central part of the cloud observed on the photographs.

When analysing the variations of contrast of dust cloud spots on the satellite photographs (Fig. 6a, from 0 to max on the upper graph) alternation is drawn to the effect of cloudiness on the variations and on the reduction of that contrast during the day time, a link between the maximum contrast on 5^{th} August and the discharge of dust on the Sahara noted on the same day nonetheless probably exists. The extinction maximum corresponding to this (Fig. 6a, maximum 7) shows, that the increase in dust content over the central Atlantic followed two days after the discharge on 5^{th} August. The same applies to the discharge on 3^{rd} August, for which the extinction maximum over the central areas of ocean was noted on the 5^{th} August (Fig. 6a, maximum 6). Therefore, the result of photometric analysis has found definite confirmation. It characterises the rate at which the dust cloud spread under the influence of the trade wind. The distance from Ahaggar to the measuring station on board r/v Musson in the Atlantic (about 5° N, 23° W) was roughly 3500 km. Taking into account the average time of air filtration on the ocean (15^{00}h on 5^{th} and 11^{00}h on 7^{th} August) it is easy to calculate that in both cases the dust cloud moved with an approximate speed of 65 $km \cdot h^{-1}$. This is a speed characteristic for zonal winds in the free atmosphere, blowing in the northern part of the equatorial zone in the lower stratosphere from east to west. The duration and distance of spreading of the dust suggests the possibility that the equatorial jet had a hand in its movement.

It appears that somewhat smaller discharges of dust were noted by Martin [6] at two points in the Sahara on 29^{th} July. The author assumes that the smaller contrastive effect of the tongues and bands of dust was in this case caused by greater cloudiness. This is why it was impossible to carry out a more precise analysis of the dust clouds and to reach more certain conclusions about their characteristics. Nevertheless, our measurements showed a smaller dust content maximum relative to the situation described above (Fig. 6a, maximum 5). This identification is supported by the fact that, like the above two increases in dust concentration, the maximum also occured two days after the discharge registered on the satellite photographs. Some doubt has arisen over the presence of two other parallel dust content peaks beside this maximum. This is not satisfactorily explained by the analysis of satellite photographs for the dust discharge in the Sahara of 29th July.

Since we did not have any satellite photographs of the period and place investigated apart from those used in Martin's paper [6], we were unable to verify the remaining maxima. One can only assume that it was not so much the cloudiness as weaker discharges of dust that made a closer study of the event of 19th July impossible. It took place, apparently, not only in two parts of the desert, but also with differing intensity and during a relatively short time.

From a comparison of the results obtained for the first cascade of the impactor (Fig. 6a) with those for the second cascade (Fig. 6b) the following statements may be made:

— in the second case all peaks are distinctly smaller,

— the peaks of extinction identified for dust discharges in the Sahara in samples from the first cascade correspond to the minima in the samples from the second cascade.

From the above it can be concluded, that coarse-grained dust of eolitic and Saharan origin over the Atlantic was collected mainly on the first cascade. Thus, apart from maxima 5, 6 and 7, a desert origin may also be indicated by the other peaks in concentration marked 1 and 10, because minimum values on the second cascade correspond to them. At the same time, the possibility can not be excluded, that the maximum concentrations 3, 4, 8 and 9 shoving a distinct fall in extinction on the second cascade, are also linked with cases of dust discharge from the Sahara. The reverse case is interesting — the distinct maximum 2 on the second cascade corresponding to a minimum on the first one. This indicates an increase in concentration of particles of radius $r < 1\ \mu m$ in the second half of June. What connection this may have the removal of dust from the African continent and, possibly with the extreme northerly position of the intertropical convergence zone at this time of year, is at present difficult to say.

5. CONCLUSIONS

1. The use of a four-cascade impactor in the Atlantic has shown, that particles of sea salt of radius $r \geqslant 1\ \mu m$ are collected almost entirely on the first cascade. A 1000-fold magnification of the second cascade from the inlet did not reveal any sea-salt crystals of radius $r \geqslant 1\ \mu m$. By analysing photometrically the light extinction in aerosol samples it was possible to obtain results referring exclusively to dusts of non--marine origin for both the first and the second cascades.

2. During June and July the increase in extinction for dust discharges in the Sahara identified in samples from the first cascade

usually correspond to minimum values measured in samples from the second cascade; this confirms the presence of coarse-grained dusts of eolitic and Saharan origin in the sample composition. The inverse case, where the reduction in light intensity was due to particles of radius $r < 1\ \mu m$, was valid only for the second half of June.

3. During measurements above the central Atlantic, the most frequently occurring period of fluctuation was about 1.7×24 hours. Increases in dust content took place two days after stormy dust discharges in the Ahaggar area of the Sahara and had been recorded on satellite photographs. The dust cloud was carried to above the central Atlantic at a speed of 65 km per hour, which indicates the possibility of the equatorial jet helping in the movement of the cloud.

4. Analysis of the visible light and infra-red satellite photographs permits only the boundaries of the main body of the dust cloud to be drawn. A much more extensive part of the cloud, where the dust concentration is less, can not be discovered photographically using current techniques of satellite observation of the Earth's atmosphere.

The author wishes to express his thanks to Dr Henryka Berek and mgr Józef Kowalewski for their help with the measurements.

Oceanologia nr 12 (1980)
PL ISSN 0078-3234

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WAHANIA STOPNIA ZAPYLENIA ATMOSFERY NAD ŚRODKOWYM ATLANTYKIEM I PRZENOSZENIE PYŁÓW Z SAHARY

Streszczenie

Badano międzydobowe wahania stopnia zapylenia powietrza przywodnego w centralnej części Atlantyku. Pomiary przeprowadzono z radzieckiego statku r/v Musson w okresie Atlantyckiego Eksperymentu Tropikalnego GATE-74. Zastosowano czterokaskadowy impaktor oraz metodę fotometrycznej analizy zebranych próbek. Stwierdzono dominowanie okresu wahań zapylenia około 1,7 doby. Zanotowano wzrosty zapylenia następujące po upływie dwóch dni od obserwowanych na zdjęciach satelitarnych przypadków burzliwego zrzutu pyłu eolicznego w okolicy Ahaggar na Saharze. Obłoki pyłu były przenoszone na odległość około 3500 km do rejonu pomiarów z prędkością ($\sim$ 65 km h^{-1}) charakterystyczną dla wiatrów strefowych, wiejących w północnej części strefy równikowej na poziomie dolnej stratosfery.

Stwierdzono, że współczesna technika zdjęć satelitarnych w promieniowaniu widzialnym i podczerwonym pozwala na uzyskanie zarysu granic tylko głównej masy obłoku pyłowego. Część obłoku o mniejszych, choć mierzalnych, stężeniach pyłu przenoszonego nad ocean z Sahary jest znacznie bardziej rozległa.

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