

CHAPTER 12

Monitoring and Critical Review of the Estimated Source Strength of Mineral Dust from the Sahara

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ABSTRACT

A transport model is used to estimate from turbidity measurements at Sal, Cape Verde Islands, the source strength of the Sahara for mineral material. The estimated value of 260×10^9 t/yr is definitely larger than previously estimated. Because of the sea-land-circulation at Africa's west coast, fractions of this amount might return to Africa. Larger portions certainly settle out within the first thousand kilometres. Only particles in the range of $0.1 \mu\text{m}$ to $1 \mu\text{m}$ in radius are transported over longer distances. The evaluation of different types of measurements of the last decades showed no indication for a drastic increase in turbidity. Consequently, an increase in dust transport – as previously proposed – cannot be confirmed.

12.1 INTRODUCTION

The often referred to SMIC (1971) Report estimates that between 25% and 50% of natural particles production are of mineral (soil and rock debris) origin. This estimate is based mainly on the Goldberg (1971) model in which the mineral dust load in the Atlantic Ocean northeast trades enters with $2.5 \mu\text{g}/\text{m}^3$ – first published by Prospero (1968). According to more recent papers (Carlson and Prospero, 1972; Prospero and Carlson, 1972) this value seems to be very low. Based on their measurements and on observed sedimentation rates in the Atlantic Ocean the production rate for mineral particles was estimated to be around 60×10^6 t/yr.

This paper uses direct measurements in the surface air of the NE-trades, long term optical measurements, and a transport model to estimate the strength of the Sahara as a source for mineral particles. Since this new value seems to be considerably larger than that mentioned above it will be discussed whether observations really support the idea of an increase in source strength.

12.2 ESTIMATE OF THE STRENGTH OF THE SAHARA AS SOURCE FOR MINERAL PARTICLES

Measurements of physical and chemical properties of the surface aerosol in the NE-trade wind region were carried out in two field expeditions: July 1973 on Sal, Cape Verde Islands, and November 1973 aboard the German Research Vessel 'Meteor' on a cruise from the Caribbean Sea to the African continent. These measurements focused on the size distribution of mineral particles and are discussed by Schütz (1977) and Jaenicke and Kasten (1977). In addition, Schütz (1977, 1979) discussed a transport model for mineral dust from Africa over the North Atlantic Ocean. This model uses the transport pattern recently recalled by Carlson and Prospero (1972). The surface measurements on the Atlantic Ocean and direct measurements on the African continent (Schütz and Jaenicke, 1974), led to the conclusion that the mineral aerosol leaves the African continent with an aerosol size distribution of a concentration decrease proportional to r^{-2} — quite in contrast to other typical continental aerosols with -3 as exponent. This point is of special importance because the behaviour of the dust during transport is influenced by the shape of the starting size distribution.

To support our intensive but time-limited observations optical measurements were carried out on Sal, Cape Verde Islands, during the years 1973 until 1975. Figure 12.1 shows the results in form of Linke's turbidity factor T . These measurements indicate the seasonal variation of the dust transport with maximum in summer and minimum in winter. Compared to the Rayleigh atmosphere the comparatively large values of T in the months of minimum turbidity reveal the quasi continuous character of the dust transport on a monthly basis.

Especially for these measurements Prospero (1976) pointed out that measurements with the Volz-sunphotometer might be affected by changing calibration values. A careful investigation in fact showed such variations. For the calculations in Figure 12.1 adjusted calibration values were used, obtained several times during the whole observation period.

The average Linke turbidity factor T_{500} over the whole period of observation is $\bar{T}_{500} = 3.45$ ($\bar{B}_{500} = 0.166$, $\bar{a}_{D500} = 0.382$, $\bar{\tau}_{500} = 0.382$). This turbidity is caused mainly by particles in the range $0.1 \mu\text{m} - 1 \mu\text{m}$ in radius. Following Volz (1959) the mass of particles in a vertical column can be estimated and yield M ($0.1 - 1 \mu\text{m}$) = $9.1 \times 10^{-6} \text{ g cm}^{-2}$ for Sal. It could be shown (Jaenicke and Kasten, 1977) that this column contains practically only mineral particles. In surface air sea salt, organic material, and ammonium sulphate is of minor importance and consequently in the entire column extending up to 5000 m. Schütz (1979) model shows that particles in this size range are practically not removed from the column during transport. From the original extension in the vertical (1500 m to 5000 m altitude) at the starting point they spread over the entire column without considerable loss due to dry deposition. The above figure then is identical with the columnar mass in the source region.

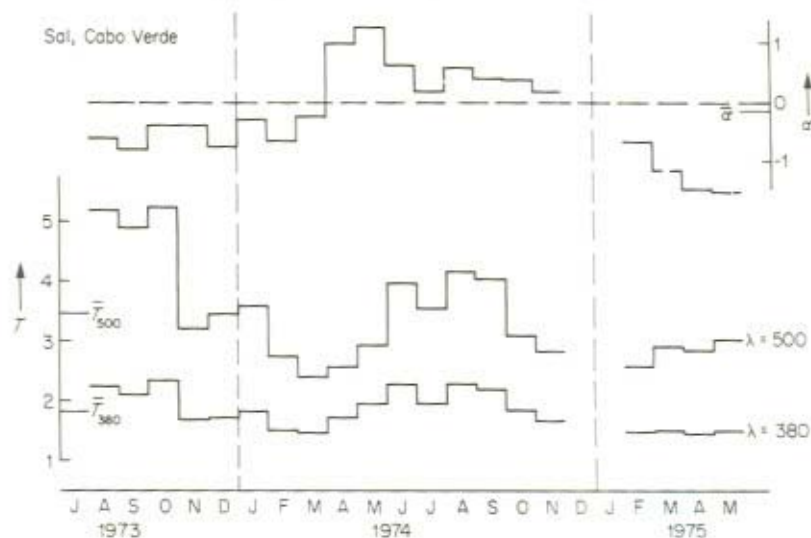


Figure 12.1 Linke's turbidity factor T for two wavelengths ($\lambda = 380$ nm, $\lambda = 500$ nm) at Sal, Cape Verde Islands. The calibration constants were monitored during the observation period and showed to be stable for $\lambda = 500$ nm, while fluctuations occurred for $\lambda = 380$ nm. Angström's exponent α , therefore, is given with all reservations

The discussion by Schütz (1979) indicated that the source aerosol exhibits a distribution with $\nu^* = 2$.^{*} In such an aerosol the $0.1 \mu\text{m} - 1 \mu\text{m}$ radius range covers 6.7% of the total mass, thus $1.35 \times 10^{-4} \text{ g cm}^{-2}$ can be expected as total columnar mass in the source area ($0.1 \mu\text{m}$ to $20 \mu\text{m}$ particle radius). If we assume a dust duct of 1000 km width [from 15°N (Dakar) to 24°N] and the average wind velocity of 6 m s^{-1} (Newell *et al.*, 1972) a total of $260 \times 10^6 \text{ t/yr}$ as source strength results. This figure, of course, is only valid within a factor of 2 if the uncertainties of the assumptions are considered.

Figure 12.2 shows how this dust spreads over the Atlantic Ocean, if we follow the Schütz (1977) model. During the first thousand kilometres a rapid dry fallout occurs from which we believe considerable fractions are returned to Africa. As can be seen from satellite photographs and weather maps a sea-land-circulation up to

^{*}Size distribution

$$\frac{dN}{d \log r} = n^*(r_0)(r/r_0)^{-\nu^*},$$

where

- r = particle radius in μm ;
- r_0 = arbitrary chosen reference radius;
- N = number of particles cm^{-3} larger than r ,
- $n^*(r)$ = differential number size distribution in cm^{-3} ;
- ν^* = exponent of the distribution.

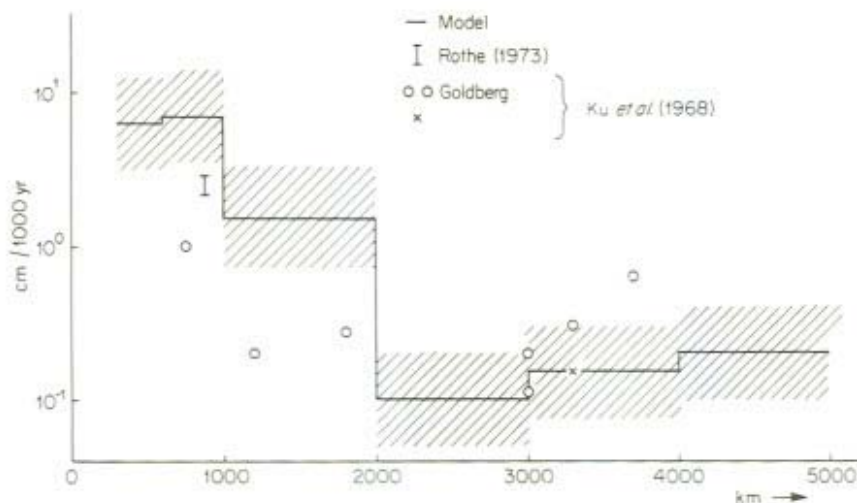


Figure 12.3 Estimate of ocean sedimentation rates due to eolian dry deposition. Measured values of Goldberg *et al.* (1963), Ku *et al.* (1968), Rothe (1973) are given for comparison. The area close to the continent is difficult to compare because of possible influences from effects within the continental shelf

Summarizing this comparison our budget calculation is not in disagreement with measured sedimentation rates at the ocean floor and with estimates of airborne material at 5000 km distance. At this distance, however, it is practically impossible to sense the rapid loss of airborne material during the first thousand kilometres of transport and, consequently, the source strength of the Sahara probably was underestimated.

The new estimate, of course, has consequences to the total world mineral production as mentioned above. The value of $100\text{--}500 \times 10^6$ t/yr should probably be corrected towards higher values.

12.3 RECENT VARIATION IN SOURCE STRENGTH

It was claimed recently that the transport of dust over the Atlantic Ocean has increased due to the severe drought in the Sahel zone since 1968. This is of special interest to all scientists concerned with the effects of deserts and desertification. Unsigned news reports (BAMS, 1974) disclose that Carlson and Prospero found a threefold increase in summertime dust levels at Barbados in 1973 compared to 1967. Since our estimates about source strength carried out above are based upon measurements in 1973–1975 it is necessary to ascertain whether these measurements were done in periods of increased dust transport and thus not representative for the situation in general. In this case, the comparisons made above for turbidity and sedimentation would be invalid as well.

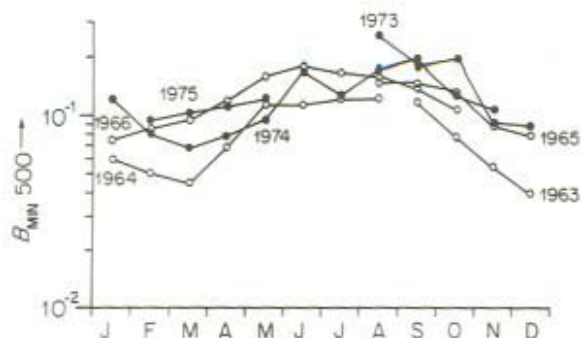


Figure 12.4 Turbidity data from the Cape Verde Islands during 1963–1966 (Volz, 1959) and 1973–1975 (Jaenicke and Kasten, 1977) $B_{\min 500}$ was calculated according to Volz

The following section will look for presumptive evidence for a change in dust transport between 1968 and 1973. Since meridional shifts of the dust plume might have caused the observed increase (see below) it is necessary to obtain observations from stations comparatively close to the source to find out if the source strength varied in the past.

From 1963 until 1966 Volz (un-published draft) carried out turbidity measurements in the Cape Verde Islands region. Figure 12.4 shows monthly averages from 1963 until 1966 compared to our measurements in 1973 until 1975. Our data were calculated according to Volz's procedure, thus they might be slightly different from the data in Figure 12.1. Both sets of data show the same annual cycle and agree quite nicely. The averages of both sets of data are

$$\bar{B}_{\min 500} (1963-1966) = 0.099$$

$$\bar{B}_{\min 500} (1973-1975) = 0.121$$

Since B is directly proportional to the mass of $0.1-1 \mu\text{m}$ particles in a vertical column it means an increase of 22% in particle columnar mass. The statistical accuracy of both sets of data, however, is not sufficient for the statement that the dust transport has increased.

There is further evidence that the dust transport has practically not changed in recent years. Jaenicke and Schütz (1977) proposed a method to derive the atmospheric turbidity from the time difference between the recorded end of sunshine in sunshine recorders and astronomical sunrise/sunset. The method seems to be rather sensitive and comparisons with measured turbidities are quite in favour with the proposed method. Sunshine records have been available since 1880 and thus can be used to establish a climatology of turbidity. From the Sahara, data are available from a less extended period summarized in Dubief (1959). A drawback of the proposed method is that the sunshine records have to be evaluated for cloudless

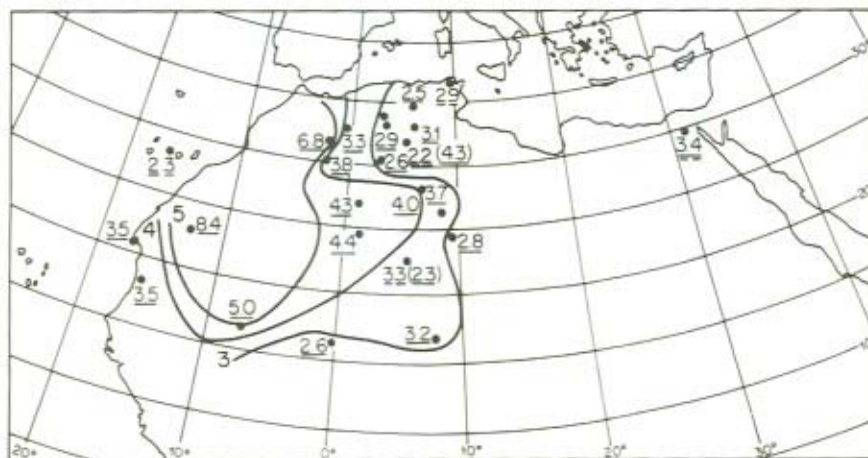


Figure 12.5 Isolines of Linke's turbidity factor calculated from suntraces (using data from Dubief, 1959) and direct measurements (Steinhauser, 1934; Dubief, 1959). The underlines indicate the source of the data
 — from suntraces Dubief (1959), $I_{cs} = 20 \text{ mW cm}^{-2}$
 - - - turbidity Dubief (1959), Steinhauser (1934)
 — Isolines of turbidity T_g

sunrise/sunset. At the present this has not been done for the Sahara. However, Lauscher (1957) offers a method to calculate the 'recorded' sunrise/sunset if the duration of sunshine and cloudiness is given. It would go beyond the scope of this paper to give details of this method.

I am aware of the uncertainty of this procedure, but the results obtained are surprising. Figure 12.5 shows isolines of Linke's turbidity factor T_g for the Sahara from observed data before 1959. The map shows a centre of turbidity in the West-Sahara which is practically identical to the region of increased dust storm activities, as compiled by Dubief (1953). Although the method of evaluation might give rise to objections the uniformity of the results is quite surprising. It seems to be more than coincidental that values $T_g = 3.5$ are calculated for Africa's West coast. Values equal to those were measured on Sal ($T = 3.45$).

It should certainly be permitted to summarize:

1. Evaluation of suntraces lead to turbidity values of $T_g = 3.5$ at Africa's Sahara west coast for some years before 1959
2. Turbidity measurements at Sal during 1973–1975 give $T_{500} = 3.45$ or $B_{\min 500} = 0.121$
3. Turbidity measurements in the Cape Verde Archipelago during 1963–1966 give $B_{\min 500} = 0.099$

These findings certainly do not support the idea of a drastically changed dust production and transport over the North Atlantic Ocean. This presumptive evi-

dence, however, is based exclusively on turbidity measurements. Thus the particles radius range of roughly $0.1 \mu\text{m}$ to $1 \mu\text{m}$ was considered only. It is, however, expected that the above conclusions are valid for all particle sizes. Measurements during dust storms in the Sahara (Schütz and Jaenicke, 1974) indicate that all particle sizes are activated and no particle size selection occurs.

In addition, the following should be considered. The Sahel zone certainly covers less than 50% of the total dust production area in North Africa. Should only the Sahel zone be responsible for a threefold increase in dust production of the whole area it would mean that a more than 6-fold output of the Sahel zone must be considered. It is beyond the limits of this paper to decide whether this can be regarded as realistic.

Carlson and Prospero (1972) report that the dust at Barbados during the winter months is of greyish or black colour with a possible origin from the semiarid grasslands south of the Sahara. An increased dust production in the Sahel zone should, therefore, affect the winter months, quite in contrast to the observations.

The increase in dust content in Barbados has probably other reasons than increased dust production in the Sahel zone. Hastenrath (1976) discusses the correlation between dry or wet years in the Sahel zone and modified pattern of the NE-trade winds. He reports about an increase of wind velocity, and a more southern location of the NE-trades during dry Sahel years as compared to wet years. It is recommended to investigate the influence of these large scale variations on the dust content in the West Indies.

12.4 MONITORING OF THE DUST PLUME

The above discussion indicated that two aspects of the mineral dust plume from the Sahara seem to be of interest: the radiational properties and the dry fallout. These properties then should be monitored in such a way that the whole dust plume is surveyed.

Carlson *et al.* (1977) showed the possible effects of increased dust amounts on the radiational cooling or heating of the atmosphere and its consequences on the dynamics of the troposphere. Since the particles causing optical effects are transported over long distances more or less unaffected, monitoring stations can be selected quite independently from the distance of the source so long as they are within the plume. Monitoring the turbidity of the atmosphere would give sufficient information about the radiational properties and would cover the dust plume in its entire vertical extension. A network of photometers would give quite reliable results but not sooner than some ten years from now. The same remains valid if monitoring from satellites is considered.

The use of the sunshine recorder network would give additional information for some decades in the past. It is, therefore, recommended to use a combination of a turbidity and sunshine recorder network for an optimum of information.

Optical measurements and even the determination of airborne particles mass will

give no information about dry deposition (Jaenicke, 1973). This is probably best done with simple deposition dust collectors positioned on the ground. Because of the large falling velocity of the giant particles the whole dust plume in its vertical extension contributes to the deposition. Dry deposition usually occurs in the 'vicinity' of the dust source. The giant particles are not carried over large distances as could be shown. Schütz and Jaenicke (1974) estimated that only one quarter of the giant particles which became airborne leaves the boundaries of the Sahara. Because dry deposition is observed close to the source it is affected by short time disturbances. To avoid blurring of any trend, time averaging methods are recommended. Dust deposition collectors exposed for roughly one month and weighed afterwards serve this purpose.

Summarizing this discussion:

Turbidity and dry deposition cover two different size classes of the airborne particles and two different effects of the dust plume. Both effects give information about the whole vertical extension of the plume. Sal, Cape Verde Islands, seems to be an ideal place for a ground based monitoring station. It is located at such a distance from the source that both effects, turbidity and dry-fallout, can be observed best.

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