Open access • Journal Article • DOI:10.1029/95GL03313

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Institutions: Centre national de la recherche scientifique

Published on: 01 Dec 1995 - Geophysical Research Letters (John Wiley & Sons, Ltd)

Topics: Mineral dust, Cape verde and Tropical Atlantic

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GEOPHYSICAL RESEARCH LETTERS, VOL. 22, NO. 23, PAGES 3191-3194, DECEMBER 1, 1995

An additional low layer transport of Sahelian and Saharan dust over the North-Eastern Tropical Atlantic

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Abstract. Mineral dust concentrations have been measured from a monitoring aerosol station set up at Sal, Cape Verde Island between December 1991 and December 1994 in order to assess the transport process of African dust over the North-eastern Tropical Atlantic. These measurements indicate a pronounced seasonal pattern, with maximum dust concentrations observed during winter. A meteorological analysis shows that the transport of dust occurs at low altitudes, in the trade winds layer, during this season. Large quantities of dust are carried out of North-western Africa, in particular from the Sahel at these altitudes. Such process could constitute the major supply of atmospheric mineral matter to the surface sea water of the Eastern Atlantic.

Introduction

Measurements show that in many oceanic regions the major aerosol constituent is mineral matter derived from continents. The greatest concentrations of soil aerosol particles are found over marine areas "downwind" of arid regions and deserts (D'Almeida, 1986). The Sahara desert is one of the major source areas for windblown dust in the Northern Hemisphere. It has been shown that large amounts of Saharan mineral dust experience long-range transport across the Northern Tropical Atlantic (Delany et al., 1967; Prospero and Nees, 1977; Schütz, 1980), providing material to the deep sea sediments (Sarnthein and Koopman, 1980) and soils of the Western Atlantic islands (Muhs et al., 1990), or nutrients to the Amazon forest (Swap et al., 1992) and sea surface-waters (Duce et al., 1991). Long-term aerosol studies have shown a seasonal pattern for the transatlantic transport of African dust, due to the seasonal shift of the InterTropical Convergence Zone (I.T.C.Z.); during summer, dust is transported above the trade winds atmospheric layer, in the so-called Saharan Air Layer (S.A.L.). This S.A.L. often reaches altitudes of 5-7 km, and extends as far as the Caribbean Sea and the south-eastern United States (Carlson and Prospero, 1972; Prospero and Carlson, 1972). During late winter and spring the dust transport shifts 10° south, allowing dust particles to reach South America (Prospero et al., 1981). In contrast, very little is known on the transport pattern and seasonality in the oceanic regions off the African coast, mainly because collections over this region have been performed for short periods only either at islands sites (Jaenicke and Schütz, 1978; Bergametti et al., 1989; Prospero et al., 1977; Savoie and Prospero, 1977) or aboard ships (Chester and Johnson, 1971; Chester et al., 1971; Buat-Ménard and Chesselet, 1979). We report here three years of monthly averaged mineral dust concentrations from a monitoring aerosol station set up at Sal island, Cape Verde. The seasonality of dust transport is discussed with light of meteorological data and airmass trajectories. Results provide a new insight to source regions and transport pathways of mineral dust in the North-Eastern Tropical Atlantic.

Paper number 95GL03313
0094-8534/95/95GL-03313$03.00

Data Set

To assess the transport process of dust over the North-eastern Tropical Atlantic, we operate since December 1991 a daily aerosol sampling station at Sal, the most north-eastern island of the Cape Verde Archipelago (16°45'N, 22°57'W), located 500 km west of the African coast. At the top of a 25-m high tower located at an altitude of 100 m, 5 km from the eastern coastline, we collect daily filter samples (0.4-μm-pore-size Nuclepore), with a flow rate of about 1m3/h. Daily elemental silicon concentrations are determined by X-Ray fluorescence spectrometry, following to the method described by Losno et al. (1987). Subsequently, the total mineral dust concentration is estimated considering that silicon represents about 33% of the mineral aerosol (Bowen, 1966).

In order to interpret these measurements, we selected vertical profiles of wind direction (from the ground level up to altitude of ten kilometers) and other meteorological data from the operational meteorological radiosoundings of the atmosphere performed at Sal island by the S.N.M.G. (Serviço Nacional de Meteorologia i Geofisica).

Furthermore, air mass trajectories, associated to major dust events, have been computed from the three dimensional atmospheric transport model (TM2Z) (Ramonet et al., in press) in order to trace back the transport of aerosol particles from their source-regions.

Results

At Sal Island, the highest monthly averaged mineral aerosol concentrations occur in December or January. The summer concentrations are found to be at least 5 times lower (Fig. 1). This is consistent with climatological horizontal visibility recorded at

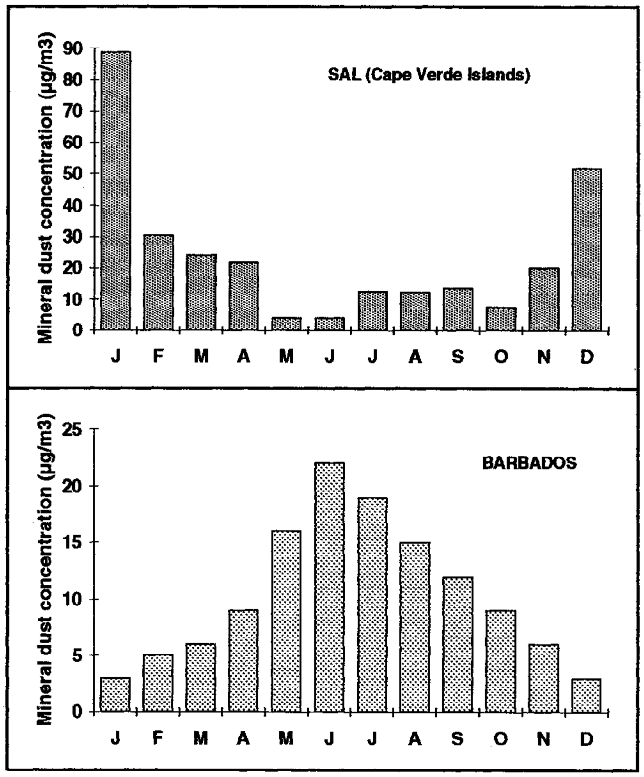

Figure 1. Monthly arithmetic mean of mineral dust concentrations at the surface level: (a) Sal, Cape Verde Island (1992-1994); (b) Barbados, Caribbean Sea (1973-1992).

Sal Island (Jaenicke and Schütz, 1978) which indicates that the highest visibilities (8 to 16 km) are most frequent during the summer months, whereas visibilities of less than 8 km are observed mainly in winter. As shown in Fig.1, this seasonal cycle of dust concentration is opposite to that observed at Barbados, West Indies (13°10'N, 59°30'W) where maximum concentrations occur in summer (June to August), the winter concentrations being 10-100 times lower (Prospero and Nees, 1977). The seasonal cycle observed at Sal also differs from that observed in Cayenne, French Guiana (4°50'N, 52°22'W) where the maximum is observed in March (Prospero et al., 1981). The maximum monthly mean concentrations at Sal (120, 95 and 70 µg/m3 respectively for 1992, 1993 and 1994 respectively) are 3-5 times higher than recorded at Barbados (about 25 µg/m3 for the 1965-1992 period) and Guiana (28 and 23 µg/m3, respectively for 1978 and 1979). Although these measurements were not taken over the same years, and interannual variability is to be expected, the higher concentration level observed at Sal than in western Atlantic stations is likely to be the result of the respective distances from the African coast (close to about 500 km for Cape Verde Islands as compared to several thousands for Barbados and Guiana).

Discussion

1. Transport pattern

As far as we know, the only descriptions of dust outbreaks over the Atlantic ocean are made for the summer meteorological situation. During this season, long-range dust transport occurs at high altitudes, within the so-called Saharan Air Layer (S.A.L.) above the trade winds inversion, located 1.5 km above sea level

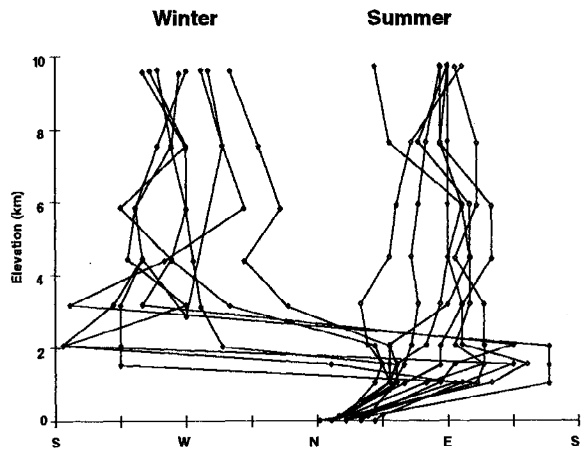

Figure 2. Typical winter (December 1991 and January 1992) and summer (July and August 1992) vertical wind direction profiles from radiosoundings performed at Sal (Cape Verde Islands).

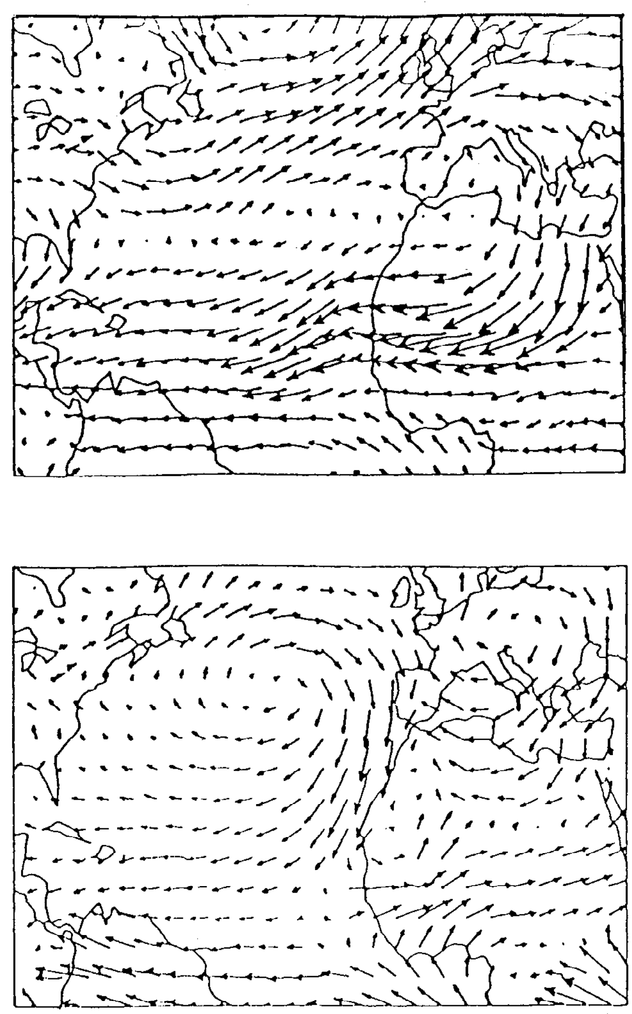

Figure 3. Average zonal wind fields in the layer 0-0.4 km over the Tropical North Atlantic for (a) January; (b) July (from M.S. Foreman-Fowler. GISS GCM diagnostics, monthly averages of winds for the 9 layers and geopotential heights at 700, 500, and 200 mb. *Internal Report*. Harvard University. April 1992.)

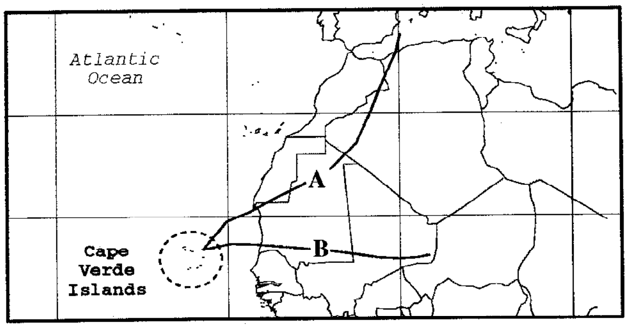

Figure 4. Air mass trajectories at 800 meter level corresponding to the two typical sources of dust events observed during winter in Cape Verde Islands. A: March 13, 1992; B: January 6, 1992.

(Prospero and Carlson, 1981). Indeed, considering the typical vertical profiles of wind direction in the Cape Verde Islands region (Fig. 2), easterly winds are dominant in summer throughout altitudes of up to 10 km. During winter, easterly winds are restricted to a more shallow layer below, 1.5 -3 km (850-700 mb), above, westerly "counter trade winds" prevail, setting the upper limit of the dust transport layer. This seasonal dependence is confirmed by the climatological vertical wind profiles established over the Atlantic (Schütz, 1980), and the African continent (Dubief, 1977).

Climatological zonal windfields in the north-eastern Tropical Atlantic are consistent with our observations of dust concentrations (Fig.3). Indeed, due to the seasonal meridional shift of the Azores anticyclone, the trade winds have an oceanic origin in summer, whereas in winter they move to a more continental origin. Consequently, during winter the region of Cape Verde Islands is localized across the main path of African dust transport in the north-east trade winds. Thus, the seasonal cycle of dust concentrations observed at ground level in Cape Verde Islands is dependent on a winter low layer transport in the trade winds. The low concentrations observed during summer at sea-level in Cape Verde are due to the fact that no mineral dust is carried by the trade winds at this time of the year. In fact, the African dust reaching Barbados during this season is transported over Cape Verde Islands, as shown by Meteosat images (Jankowiak and Tanré, 1992), but at high altitude and does not affect significantly the concentrations observed at Sal.

2. Source Regions involved

The backward trajectories, calculated for each dust event indicate two main origins for winter dust arriving at Cape Verde Islands (Fig.4). First, for a significant number of dust events, the trajectories indicate a northern origin, in western and central Sahara, involving similar source-regions than those previously shown to influence the summer transport (Mauritania, Northern Mali and Central Algeria) (Prospero and Carlson, 1981; Kalu, 1977; Bertrand et al, 1974). A second source region that is very active is located in the Sahelian zone, south of 20°N. This is confirmed by reports of a major center of dust storm production in western Niger and northern Chad, with a maximum activity during the dry season between December and February (Kalu, 1977; Bertrand et al., 1974). Thus, it seems that some Saharan source-regions may be active for dust events observed in both winter and summer, but our results strongly suggest that additional southerly source-regions enhance significantly the dust concentrations observed in winter over the Eastern Atlantic.

Conclusion

Our observations indicate that a winter time dust transport in the trade winds layer takes place together with the well-known high altitude transport pattern to deliver Sahelian and Saharan dust to the North Tropical Atlantic. Because of the lower altitude of the dust transport, it is likely that this additional pathway affects only the Eastern North Tropical Atlantic. This supply of dust to the eastern northern Atlantic could dominate the annual budget to that region since we report both high concentrations in Cape Verde Islands in winter for such events and low surface concentrations in other seasons. This could have strong implications for both, the impact of atmospheric desert dust on the biological productivity of sea surface-waters and on the interpretation of deep sea sediment records.

Acknowledgments. The authors wish to thank Y. Balkanski for useful comments, P. Bousquet for the computation of trajectories and E. Bon Guyen for illustration. This work is supported by the « Programme Environnement du CNRS » in the framework of the action « Erosion Eolienne en Régions Arides et Semi-Arides ». This is CFR contribution n° 1738.

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(Received July 7, 1995; revised October, 10 1995; accepted october, 22, 1995)