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Back-trajectory model of the Saharan dust flux and particle mass distribution in West Africa

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ABSTRACT

A back trajectory model of the Sahara dust flux toward the Gulf of Guinea has been studied. First, the atmospheric circulation over North and West Africa in winter is obtained by the backward trajectory plots with NOAA HYSPLIT to establish the winds responsible for the dust transport. The 'box' model derived by Resch et al. (2007) is used to develop the back trajectory model equations. The dust particle mass distributions at various locations traced back from Kumasi and Tamale to the Harmattan dust origin in the Chad basin can be obtained. The model is first tested with the particle mass concentrations at Tamale in Harmattan 2002 and 2005, which are easily deduced. Sample calculations are shown to illustrate the use of the model to estimate the particle mass concentration distributions at Kano and Maiduguri in Nigeria during the Harmattan 2002 and 2005.

1. Introduction

The seasonal influx of the Saharan dust particles into the countries near the Gulf of Guinea in West Africa during the northern winter months of November–March has been previously reported (e.g. McTainsh, 1980; d'Almeida, 1986; Tiessen et al., 1991; Afeti and Resch, 2000; Breuning-Madsen and Awadzi, 2005; Resch et al., 2007; Sunnu et al., 2008; Lyngsie et al., 2011). The dry and hazy dust, known locally as the Harmattan, has its source in the Bodélé Depression of the Chad Basin (e.g. Brooks and Legrand, 2000; Prospero et al., 2002; Tegen et al., 2006; Todd et al., 2007; Prospero, 2011). However, few studies of the dust physical characteristics, flux, deposition and their transport toward the Gulf of Guinea existed. Meanwhile, the transport of the African dust plume over the Atlantic Ocean to the Americas has been extensively studied using both satellite and ground observations as well as simulation models (e.g. Prospero, 1999; Prospero et al., 2002; Chiapello et al., 2005; Kaufman et al., 2005). The Saharan dust transport to the Mediterranean Basin and Europe is less pronounced, occurring in summer, sporadic but not negligible and has been observed (e.g. Romero et al., 1999; Schwikowski et al., 1995; Hamonou et al., 1999). The general circulation over the Sahara prevents the eastwards transport that only occurs occasionally. The dust transport towards the west including West Africa, the North Atlantic and the Caribbean is pervasive and attracts concerns of the dust researchers.

Because of the large extent of the dust sources in the Sahara Desert, satellite remote sensing provides a good opportunity to obtain information on the dust sources. Various optical techniques, used to monitor the earth's atmosphere for suspended dust, have been put on satellites to provide spatio-temporal information on the dust aerosol source including UV Aerosol Index (AI), Infrared Difference Dust Index (IDDI), Aerosol Optical Thickness (AOT) (e.g. Hsu et al., 2004). Dust clouds are visible in satellite photos as a gray shade as seen in Fig. 1. The N-E direction of the Harmattan winds can also be seen. While in Fig. 2, the arrow shows the direction of the winds which entrain the dust from the Bodèlè Depression (Faya-Largeau) across the countries traversed towards the Gulf of Guinea. The infrared difference dust index (IDDI) which is an Infrared Brightness Temperature (IRBT) depression caused by the presence of dust aerosols in the atmosphere of the dust sources in the Sahara Desert have been described by Legrand et al. (2001) and Deepshikha et al. (2006a,b). The major dust reserves in the Sahara desert have been observed around (a) the Spanish Sahara to North Mauritania, (b) the triangle formed by the Hoggar, Adrar des Iforhas and Air mountains i.e. northeast of Gao in Mali, (c) North to Northeast of Dirku, North of Bilma, Niger off the West side of the Tibesti mountains in Chad or what is currently known as the

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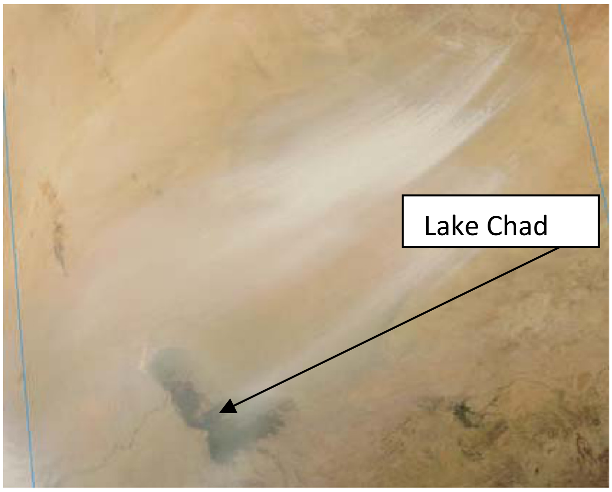

Fig. 1. Bodèlè depression and the Sahara dust plume (Lake Chad arrowed) (NASA image courtesy the rapidfire.sci.gsfc.nasa.gov MODIS rapid response team at NASA GSFC).

Fig. 2. Map of West Africa showing the N-E wind direction, the dust source Faya-Largeau in Bodèlè Depression and receptor sites of Kumasi, Tamale, Kano and Maiduguri.

Bodèlè Depression and (d) the Northern part of Sudan (Sunnu, 2006).

The production of dust in the desert has been related to variables of surface soil texture, wind speed, vegetation, vegetative residue, surface roughness, soil aggregate size distribution, soil moisture and rainfall. Increase in the dust source strength in the Sahara may also be significant and associated with the drought in the Sahel and agricultural use of the lands adjacent to the desert dust sources as noted by Mulitza et al. (2010). The Desert dust sources consist of soil particles (0.01–1000 μm in radius) which might be loosely packed to enable mobilization as dust storms. It is known that there is dust production and transport throughout the year from the Sahara Desert. However, the Saharan dust is not transported everywhere all year round but it is transported in discrete, concentrated, latitudinal and longitudinal corridors that vary in all directions throughout the year. The nature of the deflation, transport, and deposition of the aeolian dust material from the Sahara is episodic and has also been linked to seasonal and annual rainfall as well as large-scale weather features such as the Inter-Tropical Convergence Zone and the North Atlantic Oscillation (Sunnu, 2006). Indeed, the transport of Saharan dust over West Africa is a seasonal phenomenon with the migration of the ITCZ as an important parameter. During summer (May–October), the regime of the N-E winds with the dry dust load are restricted to above 20°N and the Saharan dust laden winds do not reach the Gulf of Guinea.

The dust mobilization from the Bodélé Depression in northern Chad basin is caused by density currents (in the afternoon) and the northeast trade winds embedded with the low-level jet (LLJ), which is a newly identified feature (Todd et al., 2008). Thus the daytime dust production is observed to be higher than the night time production by a factor of 2–4 as noted in Deepshikha and Srinivasan (2010). The emission of large quantity of mineral dust from the Bodèlè depression and its subsequent long-range transport to West Africa, the tropical Atlantic and beyond is effected mainly by the northeast trade winds (Schepanski et al., 2008; Deepshikha and Srinivasan, 2010). In Fig. 1, a characteristic dual-plume dust storm is shown blowing out of the Bodèlè Depression towards southwest on January 29, 2007 (modis.gsfc.nasa.gov MODIS). Consequently, the northeast trade winds which blow across the Sahara desert, towards the Gulf of Guinea, during northern winter is the most dynamic parameter responsible for the propagation of the dust particles.

The meeting points of the Saharan dust-laden northeast winds and the wet southwest monsoon winds form the Inter-Tropical Convergence Zone (ITCZ). Therefore, in West Africa, the Saharan dust affects those areas with latitudes north of the latitudinal position of the ITCZ, which separates the Saharan dust-laden northeast winds from the southwest monsoon winds (Sunnu, 2006). The Saharan dust aerosol however, hardly extends beyond the Gulf of Guinea because of the presence of the ITCZ barrier which is located between latitude 6.7°N and 5.7°N with respect to Kumasi (1.57°W). Most of the particles carried by the N-E trade winds are scavenged, washed-out or rained-out on meeting the S-W monsoon winds, which have high moisture content. Thus particle deposition are high on the countries along the West African coast. As a result, areas south of the ITCZ are shielded from direct Sahara dust invasion. However, on meeting, the dry Sahara dust plume is lifted over the heavier monsoon emerging from the Atlantic Ocean. The dust aloft feeds into the Saharan air layer (SAL) overlaying the monsoon where the dust travels beyond the Gulf of Guinea, towards Southern America and the Amazon forest.

The Saharan dust particles have been associated with changes in the earth's radiation balance (Tegen et al., 2004), precipitation in the Soudao–Sahel region (Prospero and Lamb, 2003), modifications in photolysis rates (Martin et al., 2003), air quality (Prospero, 1999), and reduction of visibility (Pinker et al., 2001). Saharan dust has also been identified as a source of ocean nutrients (Martin et al., 1991) and fertilizer for the Amazon forest (Swap et al., 1992). In West Africa, the Harmattan presence is associated with lower than normal temperatures in the night and early morning, hotter weather conditions during the day, hazy atmosphere and marked reduction in horizontal visibility as well as the deposition of thin layers of fine dust particles on exposed surfaces, including clothes and the skin. The reduction of visibility is often cited by local newspapers as the cause of many road accidents in the region during the Harmattan season. Poor visibility also frequently accounts for the disruption of aviation schedules, for example, the Kenya Airline that crushed in Abidjan on 30th January, 2000 was unable to land in Lagos because of the Harmattan dust that besieged the airport and flights were suspended (Sunnu, 2006).

Literature on the Saharan dust shows that measurements have been conducted in the principal regions affected by the dust transport. In West Africa, this kind of ground data on the dust deposition is scarce. What are the dust flux and deposition rates in the region and what quantity of Saharan dust is deposited every year on countries in the Gulf of Guinea? This paper reports the results of a study involving a back-trajectory mathematical model to estimate the dust particle concentration in some cities in West Africa.