A NEW INSIGHT OF TRANS-ATLANTIC AFRICAN DUST TRANSPORT WITH CALIPSO LIDAR MEASURMENTS

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ABSTRACT

A new overall picture of trans-Atlantic African dust transport is presented with CALIPSO lidar measurements. African dust is transported cross the Atlantic all year long with a strong seasonal variation in the pathways horizontally and vertically. Summer is more favorable season for African dust transport crossing Atlantic. In winter and spring, the trans-Atlantic dust transport pathway shifts southwards about 10º, which is controlled by the easterly trade wind along with the shift of dust production areas. The seasonal shift of dust production regions follows with the shift of strong updraft regions over the North African. The first seasonal vertical structure of trans-Atlantic dust transport is constructed. The height of dust lifted over land determines the vertical and horizontal range of dust transport. During summer, dust reaches the highest over land and mainly transported in free troposphere, while dust is mainly limited in the low altitudes over land and ocean during winter. The mean dust layer top decreases by 10 - 35 m/degree when dust transported cross the Atlantic depending on different seasons. Therefore, dust mainly concentrated in the boundary layer when reaching west coast of the Atlantic.

1. INTRODUCTION

North African has been regarded as the largest dust source in the world. Crossing Atlantic transport is one of most important African dust transport pathways. African dust and its transport have been documented by several passive remote sensors, e.g., the Advanced Vary High Resolution Radiometer (AVHRR) [1], Meteosat [2], Total Ozone Mapping Spectrometer (TOMS) [3] and Moderate Resolution Imaging Spectroradiometer (MODIS) [4]. But passive measurements are not able to provide vertical information.

The CALIPSO (The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) satellite launched on April 28, 2006 carries a two-wavelength, polarization-sensitive lidar which can accurately measure the vertical distribution of the clouds and aerosols globally [5]. The capability of CALIPSO lidar to measure depolarization ratio makes it possible to distinguish dust aerosol from other type aerosols [6]. Moreover, CALIPSO lidar can detect dust aerosol in any terrestrial surface condition and for both daytime and nighttime measurements [7]. The vertical information provided by CALIPSO lidar will greatly help us to refine dust aerosol radiative studies and better understand dust transport.

2. DATA AND ANALYSIS

To improve signal-to-noise ratio (SNR) and to match the level 2 5 km cloud layer products, the CALIPSO lidar level 1B nighttime data (June 2006- May 2007) are averaged to 5 km horizontally. The level 2 5 km cloud layer products are used here for cloud-screening. Thus, results presented in here are based on the nighttime data under cloud-free conditions. But, these results shouldn't impact the trans-Atlantic African dust transport study significantly.

2.1 Dust aerosol occurrences

One main characteristic of dust particles is the nonsphericity which can produce larger linear depolarization ratio (the ratio of perpendicular to parallel polarization components measured by a lidar) than other types of aerosols. Therefore, the linear depolarization ratio is an effective parameter for dust aerosol identification. For each 5 km cloud-free profile, six geometric height ranges, i.e., 0.2-1.0km, 1.0-2.0km, 2.0-3.0km, 3.0-4.0km, 4.0-5.0km and 5.0-6.0km, above ground level (AGL) are selected to calculate the layer mean volume depolarization ratio (VDR), respectively. Based on the VDR in each layer, by applying a threshold a dust layer can be identified [8]. The frequency of dust aerosol occurrence (OCC) is defined as:

$$OCC = N_{dust} / N_{cf} \tag{1}$$

where, the N_{dust} and N_{cf} are the number of dusty profiles (either of the six layers is identified as dust layer) and cloud-free profiles, respectively, in a map grid box (e.g., 1ºx1º).

2.2 Dust aerosol vertical structure

Dust aerosol vertical structure is explored in term of dust occurrence, depolarization ratio, 1064 nm attenuated backscattering coefficient and dust layer top and base height.

Dust layer top and base heights are determined based on the depolarization data at 60 m vertical resolution. First, the height of the maximum depolarization ratio in the highest 1 km dust layer is determined. Then the top of

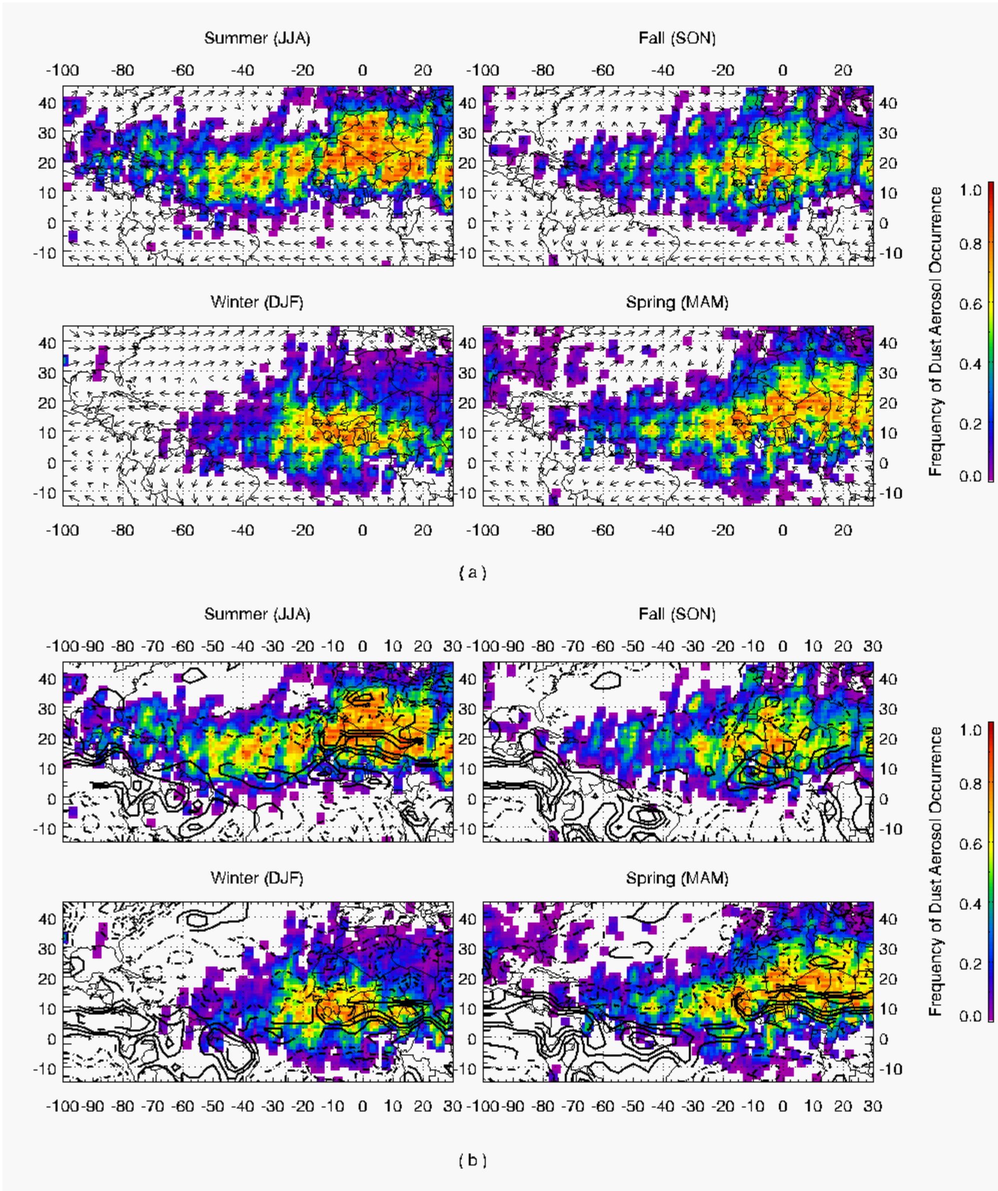

Figure 1. The seasonal map of dust aerosol occurrence along with 850mb horizontal wind (a) and vertical velocity (b). Note that in (a), the arrow indicates the wind direction and the length of the staff indicates the magnitude of wind speed; in (b), the solid contour line indicates updraft and the dash contour line indicates downdraft.

the dust layer is selected at a height where the depolarization ratio decreases below the VDR threshold searched from the maximum depolarization ratio height upward. Similarly, the dust base height is identified by starting at the lowest 1 km dust layer and analyzing the depolarization ratio downward. Data points between the dust layer top and base with 1064 nm attenuated backscattering coefficient lager than 0.0004 $km^{-1}sr^{-1}$ are used to calculate the dust occurrence (related to total dusty profiles), depolarization ratio and 1064nm attenuated backscattering coefficient at 60 m vertical resolution.

3. RESULTS AND DISCUSSION

3.1 Dust aerosol occurrences and their association with dynamics

Figure 1(a) shows the seasonal mean map of dust aerosol occurrences (in 1ºx1º grid box) in the North Africa and tropical Atlantic region (latitudes from 15ºS to 45ºN, longitudes from 100ºW to 30ºE). From this occurrence map, one can find the trans-Atlantic African dust happens all year long with a strong seasonal variation. Dust outbreaks are often in summer and spring over the Northern African. The high dust occurrence regions over the Atlantic indicate the dust

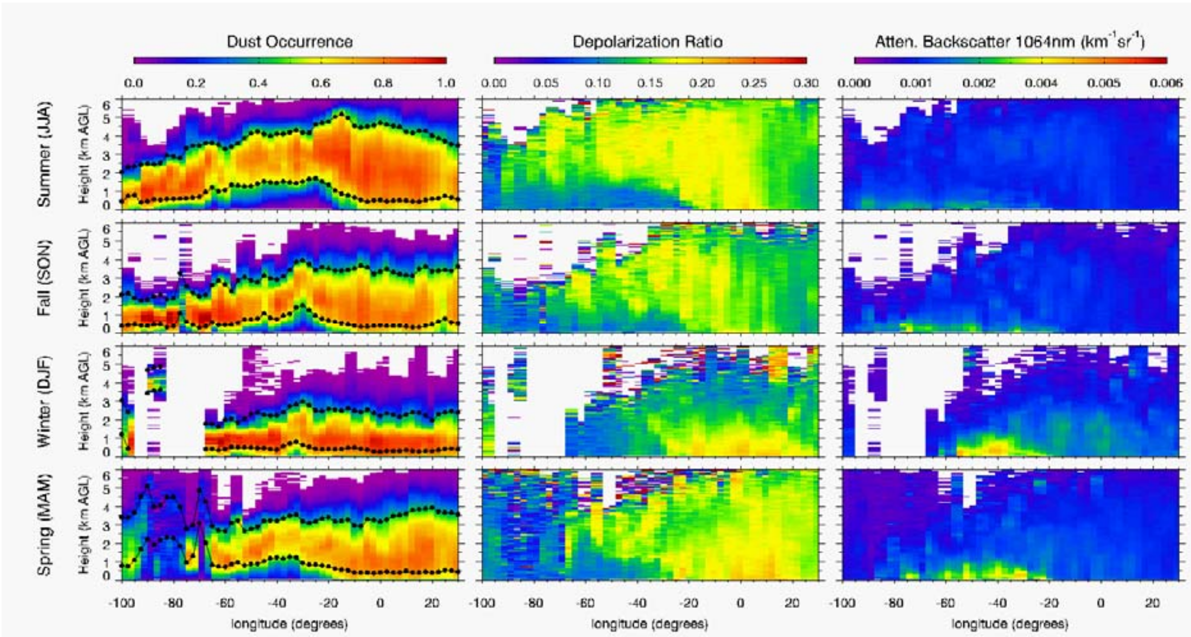

Figure 2. The seasonal variation of zonal mean vertical distribution of dust layer occurrence, depolarization ratio and 1064nm attenuated backscattering coefficient.

transport pathway. It is clear that dust aerosol is transported the furthest cross the Atlantic in summer. In winter only a limited dust storms are transported cross the Atlantic. Compared with summer and fall, the pathway shifts southwards about 10º in winter and spring.

The production and transport of dust aerosol is controlled by the meteorological conditions [8]. In figure 1(a), we also overplot the 850 mb horizontal wind (from NCEP/NCAR reanalysis data), which clearly show that the westward transport of African dust is strongly controlled by the prevailing easterlies.

Updraft is one of the important factors to control the dust aerosol production. In figure 1(b), we plot the corresponding seasonal 850 mb vertical velocity (from NCEP/NCAR reanalysis data), which show that dust source regions have weak updraft and strongest updraft regions indicate ITCZ locations over land. It is clear that most dust events are in the northern side of ITCZ and the ITCZ over Africa shifts southwards about 10º in winter and spring compared with the summer and fall. This may explain well the shift of the dust transport pathway under the trade wind.

3.2 Dust aerosol vertical structure

Taking the advantage of the vertical resolved measurements of CALIOP lidar, the zonal mean vertical structure of dust aerosol is shown in the figure 2. The latitude range for zonal mean is from 15ºS to 45ºN as shown in figure 1(a).The longitude is from 100ºW to 30ºE with a resolution of 2.5º.

The vertical structures also show a strong seasonal variation. The vertical dust occurrence indicates the dust aerosol height statistically. Over the land (longitude greater than -20º), summer has a distinguish higher dust top than the other seasons with an averaged value about 4 km followed by fall and spring with the value about 3.5 km. In winter, dust is often constrained below 2 km. From the depolarization ratio and 1064 nm attenuated backscatter plots, one can see there is a significant dust is lifted above 4 km except for winter. A case study on an extensive dust event occurred in August 2006 over the North Africa [10] has shown that the dust particles were lofted to ~6.6 km over the source.

Over the ocean (longitude less than -20º), summer has also a higher dust top and dust base heights than the other seasons. In summer, the mean dust layer top decreases by about 35 m/degree when dust transported cross the Atlantic. In fall and spring, the rate is about 25 m/degree while in winter the value decreases to about 10 m/degree. The dust top and base along the transport pathway outlines the vertical boundaries of the Sahara air layer (SAL) which forms an arc structure over the east tropical Atlantic. In winter, dust is mainly transported in the lower altitudes. From the depolarization ratio and 1064 nm attenuated backscatter plots, below the dust base height, it shows small depolarization ratios but large attenuated backscatters especially in winter and spring. This indicates the dust aerosol mixed with the marine boundary layer aerosols. Although dust aerosol is mainly transported cross the

Atlantic in free troposphere during summer, dust transport in the low altitudes is important all season, especially when dust transported further away from the source regions.

When Africa dust aerosol is transported off the land, the dust layer base rises at the coast even in the winter. The corresponding longitude of the maximum dust layer base height is about 25ºW, 30ºW and 35ºW, respectively, in summer, fall and spring.

4. CONCLUSION

Dust is one of the main aerosol types in the atmosphere and plays an important role in modulating climate. North Africa is the most prolific source of the dust aerosol and its westward transport can reach the American continent. CALIPSO lidar data reveals the transport pathways of trans-Atlantic Africa dust have a strong seasonal variation both horizontally and vertically which determined by the height of dust lifted over the source area. In summer, dust can be transport further than the other seasons. In winter and spring, the dust transport pathway shifts southwards about 10º along with the updraft regions in dust production area. This shift is controlled by the easterly trade wind and the updraft in the dust source area. Vertical structures show, in summer, the mean dust layer top height over land reaches it's maximum about 4km followed by the fall and spring when dust transport mainly happens in the free-troposphere in these three seasons. In winter, dust is constrained within 2km and mainly transports in lower altitudes. However, this low level transport is important all season, especially when dust transported further away from the source regions. The mean dust layer top decreases by 10 - 35 m/degree when dust transported cross the Atlantic. Therefore, dust mainly concentrated in the boundary layer when reaching west coast of the Atlantic.

New approaches to reliably detect dust layer above cloudy layer and/or under optical thin cloudy layer need to be explored in the future.

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