Dust altitude climatology based on CALIPSO observations

Christoforos Tsamalis, Sophie Peyridieu and Alain Chédin
Laboratoire de Météorologie Dynamique, CNRS/IPSL, Ecole Polytechnique, Palaiseau, France

This work has been supported in part by the European Community under the contract FP7/2007-2013 (MACC project).
We thank the ICARE Data and Services Center for providing access to the CALIPSO data (http://www.icare.univ-lille1.fr).

christoforos.tsamalis@lmd.polytechnique.fr

I. Introduction

Dust aerosols are important constituents of the earth climate as they influence many processes of the planet. Their deposition in the ocean supplies it with iron, which in turn affects the ocean biogeochemistry, they act as cloud condensation and ice nuclei and therefore have strong implications in the hydrological cycle, they impact the concentrations of trace gases, like ozone, via heterogeneous reactions, while they also affect the earth's radiative budget either via the direct effect though reflection and absorption of both the incoming solar radiation and the outgoing infrared radiation, or via the indirect effects by altering cloud properties. At the same time, they impede the retrieval of other atmospheric and surface parameters from space remote sensors, as they strongly interfere with the observed signal.

An important parameter of the dust aerosols is their altitude as it defines their impact on the aforementioned processes. But this parameter is not easily measurable except from lidars (Papayannis et al., 2008; Tesche et al., 2009) and more recently from passive remote sensors like AIRS or IASI (Pierangelo et al., 2004; Peyridieu et al., 2010). Nevertheless, ground based lidars are situated at specific locations and cannot offer a complete estimation of the dust altitude impact on the earth climate, while dedicated campaigns using lidars and in situ measurements are restricted in time. On the other hand, the passive instruments AIRS and IASI offer a very good spatial coverage, but their new established results, if they already show a satisfactory agreement with CALIOP, still need further validation. However, the space lidar CALIOP offers the possibility of accurate determination of the aerosols altitude on a global scale.

II. CALIOP data

The satellite CALIPSO with the on board two wavelength depolarisation lidar CALIOP was launched on 28 April 2006 (Winker et al., 2007; Winker et al., 2009). The depolarisation measurements at 532 nm allow the discrimination between the dust aerosols and the other types of aerosols, which by and large do not depolarize light (Mielonen et al., 2009). Nevertheless, the beam diameter of 70 m at the earth's surface makes it difficult to interpret statistically the results, as the 16 days repetition cycle of CALIPSO does not cover the whole earth. In order to overcome this difficulty, the L2 5 km aerosol layer product (version 3.01) is used here, and more specifically the two aerosol classes 'dust' and 'polluted dust', to calculate the seasonal climatology for all the available night time data (for a better signal to noise ratio) of almost 5 years (June 2006 – February 2011) with a horizontal resolution of 1 degree (Omar et al., 2009).

In the L2 aerosol product some layers may overlap due to the horizontal resolution of the detection algorithm (Scheme 1). In order to investigate the impact of the layer overlap, Figure 1 presents the seasonal difference of mean altitude and geometrical thickness between the results without overlap and with overlap for the 'dust' class. As it can be seen, the differences are rather important (greater than 300 m), especially during summer and for this reason the data with overlap, after the necessary corrections, will be used from now on. Table 1 presents the statistics of the number of layers detected by CALIPSO in a column and the percentage of overlaps realised by the CALIPSO layer detection algorithm. Also, it is known that the 'polluted dust' class may also contain biomass burning aerosols, but for the 0-30º N region, their impact is not so important as the desert dust is the dominant type of aerosol in this region in summer, when the peak of dust activity is observed. This is confirmed on Figure 2, which shows the seasonal percentage of each of the two classes versus the total number of aerosols layers detected by CALIPSO.

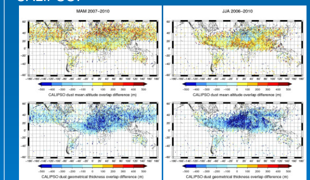


Figure 1: Differences for the 'dust' class between the data without overlap and with overlap for the mean altitude (top) and the geometrical thickness (bottom) during the spring (left) and the summer (right) season.

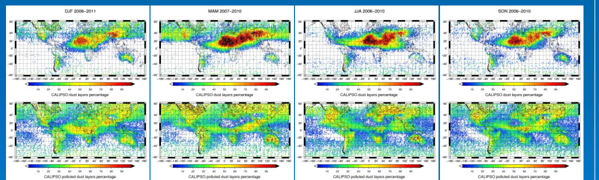
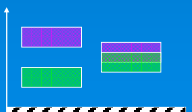


Figure 2: Seasonal layers percentage for the 'dust' class (top) and the 'polluted dust' class (bottom) versus the total number of layers detected by CALIOP.



Scheme 1: Example of two aerosol layers (left) without overlap and (right) with overlap.

Table 1: Seasonal percentage of layers' number per 5 km column and the percentage of overlaps among the layers.

Season/Layers	1	2	3	overlap
DJF (2006-2011)	83%	15%	2%	18%
MAM (2007-2010)	78%	18%	3%	22%
JJA (2006-2010)	81%	16%	2%	24%
SON (2006-2010)	84%	14%	2%	21%

III. Results

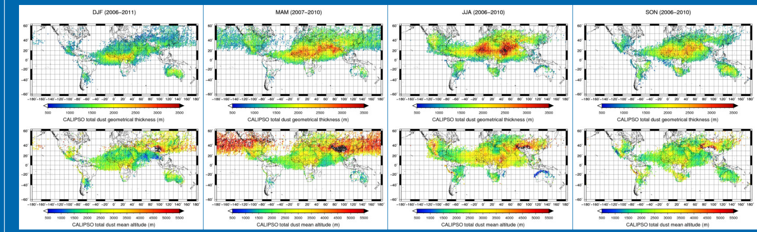


Figure 3: Dust geometrical thickness (top) and mean altitude (a.s.l.) (bottom) for the two classes and the four seasons: winter, spring, summer and fall. Only points with at least 180 layers detected by CALIPSO are plotted in order to represent statistical significant data.

As it can be seen from Figure 3 the dust geometrical thickness attains its maximum ~3.5 km above the Arabian Peninsula following by West Sahara ~3 km during the summer season. These is an obvious seasonal dependence with lower values during winter, when the dust layers are thick enough in the zone 0-10º N and intermediate and more homogeneous thicknesses for the whole dust belt during the spring and fall seasons. For the dust mean altitude (Figure 3), the seasonal dependence is similar to that of the thickness, except over the Tibetan Plateau, where the maximum of over 5.5 km (see Figure 6 for Earth's topography) is observed during spring, with the subsequent long-rage transport at about 5 km towards North America. Results show that although the export of dust from Sahara to Atlantic ocean during summer happens essentially between 10-20º N, as already known, the mean dust altitude is more elevated in the region 20-30º N than in the former region, due to more elevated plume bottom (Fig. 4), even if the dust geometrical thickness is more important in the 10-20º N region. For the mean bottom of the dust plume there is not strong variation with season and over the continents it follows generally the Earth's topography, while the mean top shows a significant seasonal change, which is more obvious above the Atlantic and Pacific oceans (Fig. 4).

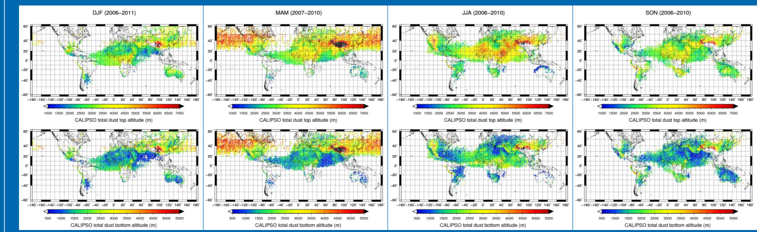


Figure 4: Dust mean top (top) and bottom (bottom) altitude (a.s.l.) for the two classes and the four seasons: winter, spring, summer and fall. The remark of Figure 3 applies also.

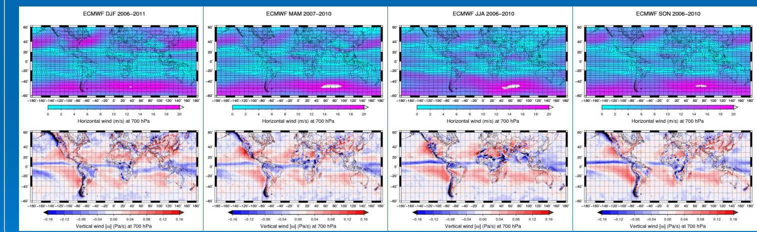


Figure 5: ERA-Interim ECMWF seasonal climatology at 700 hPa of (top) horizontal wind direction and speed (m/s) and (bottom) omega vertical wind velocity (Pa/s), for the same period as CALIPSO data.

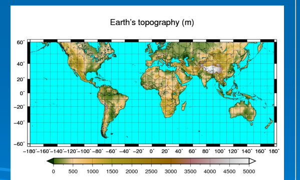


Figure 6: The Earth's topography in order to facilitate the interpretation of CALIPSO's climatology results.

IV. Discussion

During the transport of the dust plume from the Sahara to the Caribbean, the mean altitude and the geometrical thickness decrease slowly, confirming previous studies. The export of dust from its main sources can be explained by the wind direction based on ERA-Interim ECMWF results for the same period as for CALIPSO (Fig. 5). Moreover, the geometrical thickness of dust can be overall explained by the ECMWF vertical wind velocity, with regions like southwest Arabian Peninsula and south Sahara (Sahel), which present strong convection essentially during summer (Fig. 5) to display thicker dust plumes. Exception to this consists the region of the Atlantic ocean 20-35º N off the African coast, where there is subsidence according to ECMWF, but the dust plume remains thicker than in other southern regions.

Beyond the quantification of the dust plume geometrical characteristics (mean altitude, thickness, top and bottom), the CALIPSO data offer the possibility to localize the dust sources (Fig. 2), while they also denote that the majority (~80%) of dust layers are consisted of one single layer (Tab. 1), a fact that justifies the use of one dust layer in the inversion of remote sensing satellite data.

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