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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Transport of dust particles from the Bodélé region to the monsoon layer: AMMA case study of the 9–14 June 2006 period" *by* S. Crumeyrolle et al.

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We thank referee n°1 for his detailed and constructive comments on our manuscript. We have revised the manuscript attempting to take into account all the comments raised by both reviewers. We apologize for the delay due to the time required to perform the requested additional analysis.

Referee 1 : However, most of paper results are well known and I believe that they do not significantly contribute to the knowledge of the dust transport dynamics.

Author Comment : Vegetation heterogeneities affect properties such as albedo, roughness length, and leaf area index, which control surface fluxes of heat and water. Vari-

ations in these fluxes can then potentially impact the dynamics and growth of the BL. Many modelling studies are confirming the presence of these circulations for boundaries between different vegetation types (Hong et al., 1995; Pinty et al., 1989). Despite the considerable number of modelling studies that predict the presence of land surface induced mesoscale circulations, few observational studies have demonstrated their existence. Some studies, however, have measured a significant mean across-boundary wind anomaly between native vegetation and cropland (Doran et al., 1995; Smith et al., 1994; Souza et al., 2000) attributed to land surface impacts. In all these studies, the observations are attributed to PBL temperature differences caused by variations in the sensible heat flux over the different vegetation types. Taylor et al. (2003,2007) and Garcia-Carreras et al. (2010) investigate the impact of soil moisture on the dynamics within the planetary boundary layer in Africa using aircraft data. Garcia-Carreras et al. (2010) related the vegetation anomalies to the vertical transport of isoprene from the surface to the upper layers. This result highlights strong exchanges from the monsoon flux into the Harmattan layer. The goal of the present manuscript is to show the dynamical mechanism induced by vegetation heterogeneities which facilitates the sedimentation of dust particles from the Saharan Air Layer (SAL) into the Boundary Layer (BL).

The potential temperature and surface temperatures, observed with the ATR-42 on 13 June 2006, are closely linked to the surface temperature (Figure 1, herein). This relationship is particularly strong between 10.4°N and 11.4°N. In this area, observations show a relationship between temperature anomalies (shown on figure 1) and dust particle concentrations (shown on Figure 7 in the manuscript). As far as authors are aware, this manuscript is the first that highlights the strong relationship between the fraction of forest or shrub cover with the presence of high concentrations of dust particles in the monsoon flux.

Referee 1 : The authors . . . do not "determine the process that facilitates the sedimentation of dust particles from the Saharan Air Layer (SAL) to the boundary layer".

AC : The referee is correct to note that we do not determine the process that facilitates the sedimentation of particles. That's why this sentence has been removed from the abstract. Nevertheless, a dynamical mechanism induced by vegetation heterogeneities is shown in this study. This mechanism seems to be associated with high dust content in the boundary layer. As the observations as well as the simulation results show this strong relationship, we conclude that this dynamical mechanism should facilitate the sedimentation of dust particles from the SAL to the boundary layer.

In order to address the referees general comments within the revised manuscript we have added this discussion in the abstract and in the introduction.

REMARKS : In this manuscript we use a mesoscale model to investigate which process may explain the presence of high dust particle in the monsoon flux. Indeed, these particles cannot be generated at ground level because of the land surface cover (Figure 12, in the manuscript) but may sediment from the SAL into the BL (see figure 1). As the sedimentation of dust particles is clearly linked with the vegetation heterogeneities, no sensitivity tests have been done with the mesoscale model.

1/ How the authors define the Saharan Air Layer (SAL) ?

North of the ITD and above the ML is the SAL, which can be characterized by high dust content, consistent with low visibility (Karyampudi et al., 1999). The SAL is decoupled from the surface below and is more closely linked to the desert regions (Parker et al., 2005). The presence of aerosol in the SAL is connected to long range transport from Sahelian and Saharan regions. We have added this discussion to the revised manuscript to clarify this point.

2/ Par. 3.1- The simulation begins at 00:00UTC on 8 June 2006. Are model results affected by the simulation start time?

The reviewer is correct in saying that the simulation start time may have an impact on the modelled results. In our case, the simulation begins one day before the dust lifting

in the Bodélé region in order to well represent this event. As AOD is well reproduced compared to observations in the Bodele region on the same days (figure 3), we assume that the start time chosen is the good one. Moreover, a spin up time of one day has been used and tested in recent studies (Grini et al., 2006; Crumeyrolle, 2008, Tulet, 2008, 2010).

3/ Par. 3.2 –How the new dust size spectrum affect model results? Are model results quite sensitive to dust size spectrum?

A comparison with the previous size distribution would be interesting, but the objectives of this manuscript would not be improved with this comparison. This new size distribution has been established solely to represent the aerosol particle size spectra closer of what has been observed on board the ATR-42 during the event. A better representation of particle modes is needed to accurately represent the sedimentation of dust particles and the scavenged fraction of particles (see Tulet 2010).

Moreover, note that comparison of model results using two different dust parameterisations will be difficult. Indeed, since the size distribution is modified, the overall spatial distribution of dusts will be also modified due to sedimentation processes and dust radiative impacts.

4/ Par. 3.2- page 5059, line 9 Authors say: "As dust particles have a large impact on the radiative budget and thus on the atmospheric dynamics, . . . diffusion of dust particles have to be turned off: . . . Are SED and NOSED simulations meaningful if the dust radiative impact is turned off?

To better understand the processes that facilitate the sedimentation of dust particles into the boundary layer two couples of simulations are used: one for which the radiative impact of dust has been taken into account (RAD) and another one without this radiative impact (NORAD). Both couples of simulation are composed of two simulations: one for which the sedimentation of dust has been taken into account (SED) and another one without this process (NOSED). The RAD simulations are used to control if the dynamics of the situation, the localisation and the concentration of dust in the SAL are similar to the NORAD simulations.

To quantify the fraction of sedimented dust, the difference between SED and NOSED simulations has to be made. In this study, the sedimentation process is defined as the settling process due to gravity. Thus, to avoid turbulent entrainment effects due to direct effect of dust particles, the atmospheric dynamics of both simulations have to be exactly the same. So, we use the NORAD couple of simulations (SED and NOSED) to determine the localisation and the concentration of sedimented particles.

Furthermore, dust particle transport is currently treated using an off-line chemical transport model (Grini et al., 2002; Myhre et al., 2003; Berglen et al., 2004; Endresen et al., 2003; Gauss et al., 2003 ; Grini et al. 2004). As the CTM is run off-line, the radiative impact of dust particles on the dynamical parameters is not taken into account in these studies.

To assess the dynamical impact of dust particles, the differences between RAD and NORAD simulations were investigated. The results show that the surface level wind speed is underestimated as a function of latitude, when the diffusion of dust particles is turned off (NORAD). Indeed, the maximum surface level wind speed is underestimated by 51% and 17% in the Northern part of the domain (Agoufou) and in the southern part of the domain (Djougou), respectively. Consequently the aerosol optical depth is also underestimated (by a maximum of 25% over Djougou).

Despite these differences, the sedimentation process occurs exactly in the same area (between 6°N and 9°N) in the RAD or NORAD simulation. Thus, the dynamical mechanism due to vegetation heterogeneities may explain the favoured area of high dust content. To clarify this major point, a part of this discussion has been introduced into section 3.

5/ Par. 3.3.1- Scales of Fig. 3 are not clear. I suggest the authors to compare time evolution (from 8 to 14 June) of daily AODs by AERONET with corresponding values

by the model to better show the model performance at the three AERONET sites.

The figure has been amended in the revised manuscript. .

6/ Par. 3.3.2, pg. 5064, line 11:.."the aerosol particle depth": : :What does it means?

This has been changed in "The above results show that the aerosol optical depth and concentrations as well as the key dynamical and thermodynamic parameters are well represented in the simulation. "

7) Par. 4.1 – I believe that scattering coefficients of Fig. 7a are determined by all aerosol particles. Why the authors only show particle concentrations for particles with Dp>0.5 micron? Is the evolution with the latitude different if the concentration of all particles is considered? Significant changes of particle concentrations with latitude are generally observed during dust outbreaks.

A two-stage low-volume impactor with 50% aerodynamic cutoff diameters of 0.2 and 1.6μm was used to collect particles on electron microscope grids (Matsuki et al., 2003). The analysis distinguished between fine (0.2μm<Dp<1.6μm) and coarse fraction of particles (Dp>1.6μm) and the frequency of occurrence of the main elements was determined. This analysis shows that dust particle abundance is higher than 80% in the coarse fraction of particles and lower than 30% in the fine fraction of particles. If we take the concentration of particles with Dp>1.6μm, a large part of the dust number concentration will be missed. If we use the total number of particle, we probably overestimate the dust concentration. Thus, we assume that the dust population may be well represented by particles with Dp>0.5 micron.

In the northern part of the domain, the evolution of the total particle concentration with latitude is similar to that of the concentration of particles with Dp>0.5 micron. South of 9°N and close to the gulf of Guinea, the total concentration of particles increases due to the presence of a plume originating from anthropogenic activities near Cotonou. In the manuscript, a part of this discussion has been added to explain why we choose the particle concentration (Dp>0.5 micron) and a plot of the total particle concentration has been added to figure 7. Then, we have removed all the comments about the intensity of the scattering coefficient that is related to the total number of particles. Only a discussion about the spectral dependence of the scattering parameter (Angstrom coefficient) as a function of the latitude is maintained.

The Reviewer is correct in saying that significant changes in particle concentrations with latitude are generally observed during dust outbreaks in the SAL. Dust particles are uplifted when the surface wind speed exceeds a certain threshold. This threshold wind speed mainly depends on surface roughness elements, grain size and soil moisture. During the dust outbreak, the surface wind speed does not always exceed the wind speed threshold. Then, the dust outbreak may be compared to a sequence of dust events.

The dust outbreaks tended to occur in the Bodélé region, north of the ITD. These outbreaks of uplifted dust particles are then transported within the Saharan Air Layer by the Harmattan flux. In the boundary layer, the dust presence may be explained by the sedimentation process or by local generation. Observations by the ATR-42 in the boundary layer show two peaks in the particle (Dp>0.5μm) concentrations. The northern maximum occurs at 12.6°N where the Forest/shrub cover is lower than 0.1%. Thus, the northern maximum of particle (Dp>0.5μm) concentrations is due to local production of dust particles. The southern maximum occurs at 10.8°N where the Forest/shrub cover is higher than 0.2%. As the surface cover is sufficient to inhibit the local production of dust particles, the southern maximum is rather due to sedimentation of dust particles. This point has been clarified in the new version of the manuscript.

8) Which is the Meso-NH model temporal resolution? For which time intervals model results of Figs. 9-11 have been retrieved?

The temporal resolution varies with the spatial resolution of the domain. In the larger domain (36km), the temporal resolution is $\sim$20s and $\sim$5s in the smaller domain (5km).

These details have been added to the manuscript. Figures 9-11 respectively correspond to the cross-section of dust number concentration for the simulation including sedimentation and to the difference of dust mass concentration between the simulation without sedimentation and the simulation including sedimentation at the same time : 1200 UTC on 13 June 2006. This has been clarified in the captions of both figures.

9) Are model results shown in this paper dependent on the fraction of forest/shrub? (Fig. 8 and Fig. 12).

Several investigations have confirmed the strong coupling that exists between the tropospheric air mass circulation and the energy exchanges at the surface of the atmospheric boundary layer (Woodward 1987; Melillo et al. 1995). This confirms the need for a thorough and realistic description of the land surface characteristics in meteorological models in meso-scale research and Numerical Weather Prediction (NWP) models. In atmospheric models, surface exchanges are parameterised by Soil-Vegetation-Atmosphere-Transfer (SVAT) schemes. SVATs provide the right allocation of the land-water mask and of the soil-vegetation characteristics for the calculation of the surface fluxes of heat, moisture, and momentum (Masson et al, 2001). The SVAT scheme used in Meso-NH is called ISBA.

The ECOCLIMAP climatology is used to initialize the ISBA scheme. The vegetation parameters are deduced from satellite data for each month. Each cover of the map is converted as an association between 12 main vegetation types related to the ISBA surface scheme used in Meso-NH. Different surface parameters are then assigned to, for example, the desert surface, the bare soil and woody vegetation parts of the grid mesh, allowing the computation of several energy budgets in the same grid mesh.

The differences taken into account by the ISBA scheme between these two classes of vegetation are shown : The class forest is a mix between the Equatorian African Forest and Monsoon Forest class where these two classes are defined as follow: - Equatorian African Forest: Leaf Area Index (variable between 5.2 and 6.0 upon the sol type); Height of trees (30. meters); Roof depth (8 meters); Ground depth (8 meters). - Monsoon Forest : Leaf Area Index (variable between 5.0 et 6.0 upon the sol type); Height of trees (20. meters); Roof depth (5 meters); Ground depth (5 meters). The class shrub cover is defined as follows : Leaf Area Index (variable between 0 and 2 upon the sol type); Height of trees (2. meters); Roof depth (2 meters); Ground depth (2 meters).

Figure 8 presents the fraction of forest/shrub cover derived from the GlobCover Land Cover map (resolution 300m) and figure 12 shows the ECOCLIMAP climatology (resolution 1km) of the fraction of forest/shrub cover used in the simulation. In the model and as observed, the fraction of forest/shrub cover determines where sedimentation occurs. Thus if the fraction of forest/shrub cover is changed in the model, the dust distribution in the PBL is also changed.

The best way to measure the sensitivity of the model to the fraction Forest/shrub would be to run a simulation by replacing the class "shrub" with "forest" and make differences between both simulations to figure out dynamic impacts of “shrub”. It has not been done in this work and may possibly involve extra work if the reviewer considers it necessary to confirm the results. In light of feedback and drifts of forecasting models running on multiple consecutive days, it will not be easy to highlight a breeze circulation which is not affected by large scale feedback.

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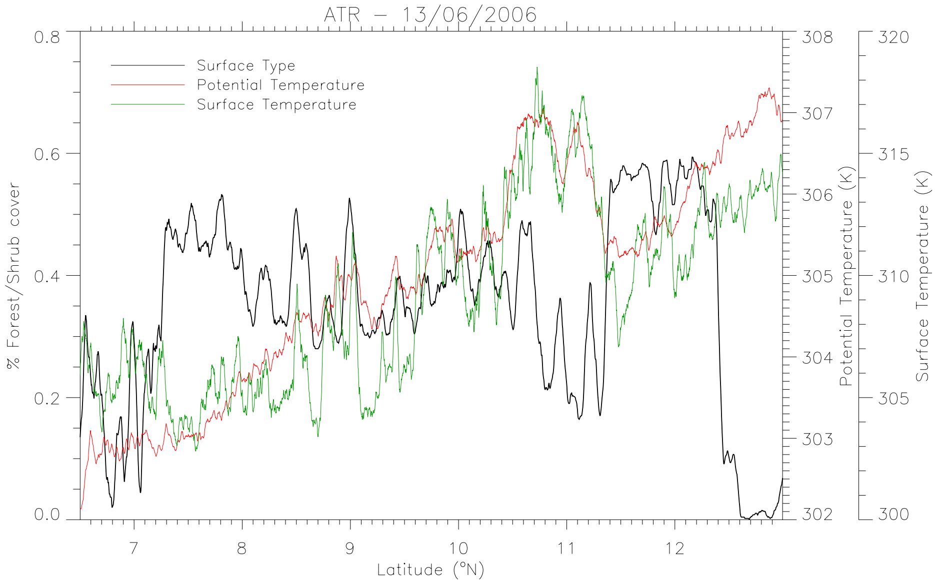

Fig. 1. Data along the flight path (800m) of the fraction of forest/shrub cover as derived from the GlobCover Land Cover map (black), the potential temperature (red), and the surface temperature (green).