Transport of dust particles from the Bodele region to the monsoon layer. Case study of the 9-14 june 2006 period.

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Within the framework of the AMMA field campaign, state-of-the-art aerosol in situ instrumentation has been deployed on the French ATR-42 research aircraft. In particular, measurements taken on-board allowed us to study aerosol concentrations, detailed size distributions, and the chemical and hygroscopic properties of aerosols. This present study is based on two different flight missions (SOP1) over source regions in Niger and along the meridian Niamey/Cotonou. The second mission was performed in coordination with the French-F20 (F-F20) which released twelve dropsondes. The first aim of this study is to improve the aerosol size distribution to take into account over West Africa during the long range transport of dust from its emission to its sedimentation. The second objective is to quantify the sedimentation process of coarse and accumulation modes of mineral dust aerosols from the sahelian layer to the boundary layer.

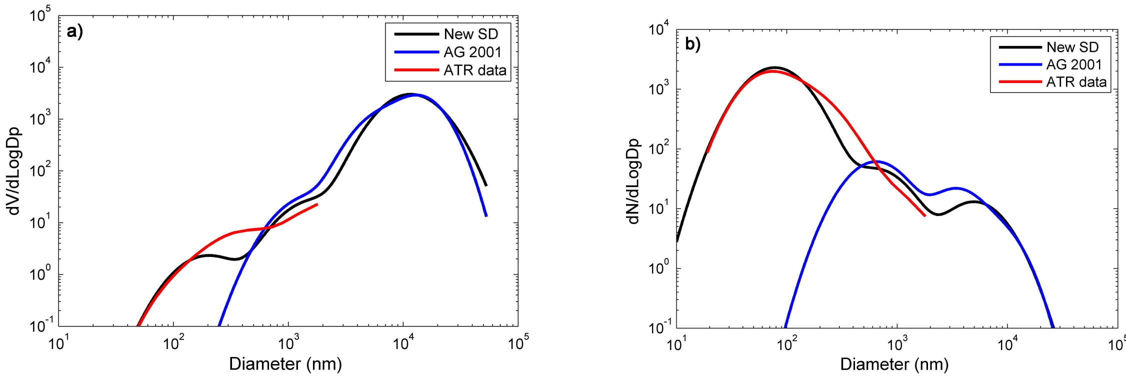

Figure 1 : Volume (a) and Number (b) size distribution of particles given by Alfaro and Gomes (2001) (blue line), by ATR-42 observations (red line) and the new size distribution (black line) proposed in this study and used in the Meso-NH parametrisation.

Based on the Alfaro and Gomes 2001 (AG01) parameterisation and on ATR-42 measurements, a new scheme of dust size distribution has been constructed by summing 3 modes (a coarse mode derived from AG01, a finer mode derived from observations and a mode in-between common to observations and AG01). This multimodal log-normal distribution has been developed and implemented to modelize an intense African dust event that has been observed over Niger from 9 to14 June 2006. The results indicate that the present modelled emission and transport yield a mass and number concentration distribution as well as an aerosol optical thickness much closer to observations.

Dust particles are emitted and lifted up in the source region and then transported by the Harmattan flow in the sahelian layer (Karyampudi et al., 1999). Figure 2 shows the evolution of the concentration of particles with diameter higher than 0.5 µm ($CN_{Dp>0.5\ \mu m}$) and of the aerosol scattering coefficients measured as a function of latitude. At 10.8°N, the $CN_{Dp>0.5\ \mu m}$ concentration reaches a maximum (17 cm^{-3}) associated with a maximum of scattering coefficient (90 Mm^{-1}) at all wavelengths. As the ATR-42 flew at a constant altitude (700m) which was located in the middle of the monsoon layer, the measurements were never sampled in the SAL and Figure 2 shows only the evolution of dust concentrations in the monsoon layer. In this area the vegetation cover (0.2, Figure 8) is still too important to allow local dust production. These measurements confirm that dust particles observed with the ATR-42 are not generated at the surface but their presence in this zone is only due to long range transport from the northern region.

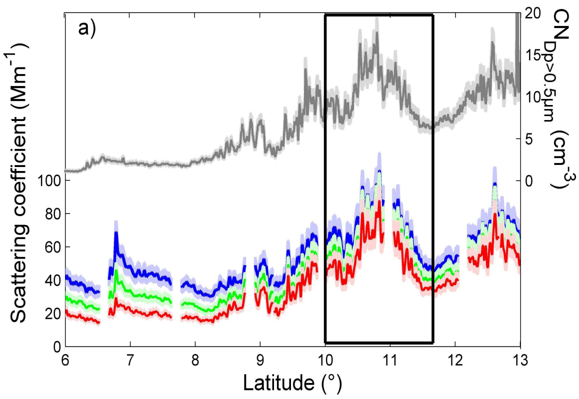

Figure 2 : Scattering coefficient observed on-board the ATR-42 for 3 different wavelengths are represented using blue (450nm), green (550nm) and red (700nm) lines as a function of latitude. Concentration of particles with diameter higher than 0.5 µm is plotted in grey as a function of latitude.

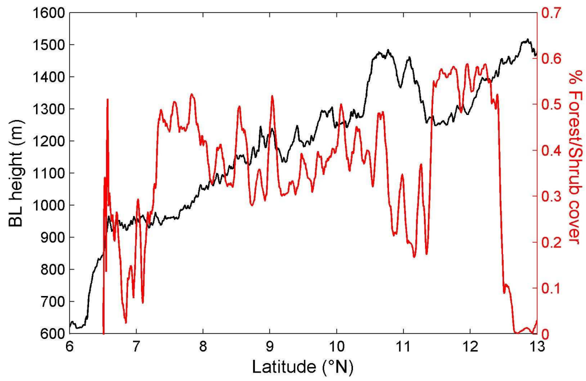

Figure 3 : Calculated boundary layer top (black line) and fraction of forest/shrub cover as derived from the GlobCover Land Cover map (red line) as a function of latitude.

Recent studies investigated the impact of vegetation heterogeneities on the dynamics within the planetary boundary layer (Taylor et al. 2003; Taylor et al. 2007; Garcia-Carreras et al., 2010). These studies highlighted a strong relationship between the boundary layer temperatures, the boundary layer top, the meridional wind velocity and the fraction of forest or shrub cover. Figure 3 shows the calculated boundary layer height and the amount of forest/shrub cover derived from the GlobCover Land Cover map, as in Garcia-Carreras et al. (2010), along the meridian from Niamey to Cotonou. Over the area running from 9.9°N to 12.3°N, the forest/shrub cover diminishes (15 %) from 9.9°N to 11.1°N, and as a consequence of an increase in Bowen ratio, the surface temperature increases. Thus, the BL height reaches maximum values (1500 m). These results show a strong relationship between surface cover and the height of the boundary layer (as inferred from BL temperature), consistent with the results of Garcia-Carreras et al (2010) from flights later in the season. This coupling between the surface and the boundary layer dynamics occurs exactly in the same area of high dust content.

To complement the observations and interpret the results, a simulation exercise was carried out. Two separate simulations have been done, one which takes into account the dust sedimentation (SED) and another one which does not take into account the dust sedimentation (NOSED). In order to have a general view of the dust particle sedimentation process, the difference of dust mass concentrations between the simulation without sedimentation and the simulation including sedimentation (NOSED - SED) is given in Figure 4. Negative mass concentrations correspond to sedimented particles and positive concentrations correspond to dust particles that are removed because of the sedimentation process. Between 6°N and 9°N, the difference of dust concentration is minimum (~ -1000 cm^{-3}) in both the monsoon layer and in the Harmattan layer. These particles are mainly coming from upper layers where the difference in dust concentrations is maximum (layer at 3500m). Furthermore, this sedimentation process leads to the presence of dust in the boundary layer down to 800 m, corresponding to the higher altitude of the ATR-42 flight plan, between 7.3°N and 8.8°N.

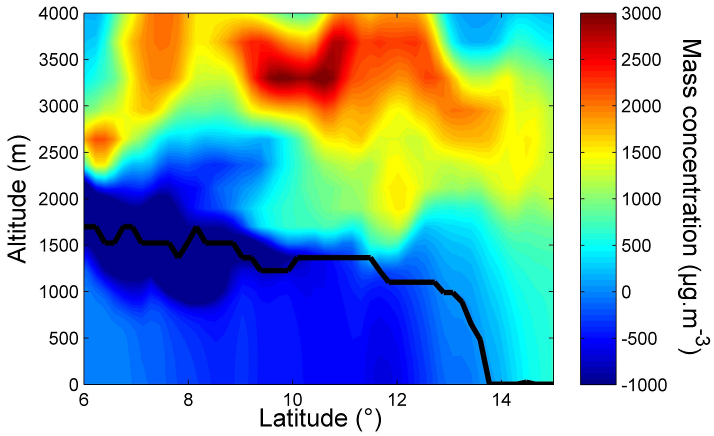

Figure 4 : Difference of dust mass concentration between the simulation without sedimentation (NOSED) and the simulation including sedimentation (SED; see text for more details). Negative mass concentrations correspond to sedimented particles. The black line illustrates the top of the monsoon flux.

As the fraction of forest/shrub cover used in the simulation is an ECOCLIMAP climatology with 1km of resolution (Figure 5), the comparison with another climatology, Globcover Land Cover map, with higher resolution (300m) highlights some inconsistencies. Indeed, the forest/shrub cover is much more important (30%) between 6°N and 7°N in ECOCLIMAP than the Globcover surface cover and weaker (20 %) between 7°N and 8°N (Figure 5). In the northern part of the domain, the ECOCLIMAP forest/shrub cover is always higher than 40 % and frequently exceeds 55 %. As a result, the surface cover anomalies are located in the southern part of the domain. Indeed, the forest/shrub cover in the simulation is more important at 10°N than in the observations, thus the heat flux is weaker and the top of the boundary layer is lower.

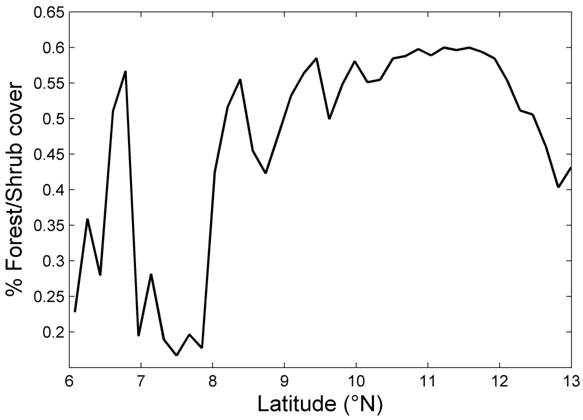

Figure 5 : Fraction of forest/shrub cover taken into account in Meso-NH (black line).

Finally, the comparison between observations and the simulation results shows that the presence of vegetation anomalies and dust are closely linked. Indeed, a reduction in forest or shrub cover lead to an increase in the BL height (inferred from BL temperature in the observations, and consistent with the model results) and leads to exchanges between the monsoon layer and the Harmattan layer via entrainment. Thus, aerosol particles and compounds produced in the monsoon layer are measured in the upper layer (Garcia-Carreras et al., 2010) while aerosol particles transported from desert regions by the Harmattan flux are observed in the monsoon layer. These mechanisms imply that we should infer a significant diurnal cycle in the mechanisms of dust sedimentation from the SAL to the monsoon layer. During the day, the sedimentation is modulated by the differing rates of BL entrainment over differing surfaces. At night, when the atmospheric profile is more stable (Parker et al. 2005b), sedimentation acts alone and is likely to be independent of the underlying surface.

Reference : *Crumeyrolle, S., Tulet, P., Garcia-Carreras, L., Flamant, C., Parker, D. J., Matsuki, A., Schwarzenboeck, A., Formenti, P., and Gomes, L.: Transport of dust particles from the Bodélé region to the monsoon layer: AMMA case study of the 9–14 June 2006 period, Atmos. Chem. Phys. Discuss., 10, 5051-5090, 2010.*

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