**Anonymous Referee #2**
**Received and published: 6 July 2012**

Review of manuscript by Yang et al.: CALIPSO observations of transatlantic dust: vertical stratification and effect of clouds

In this article the authors describe changes of Sahara dust microphysical properties during westward transport through three adjacent North Atlantic regions and in the vicinity of clouds, based on one month (two orbital cycles) nighttime CALIOP data. Observations also indicate shape-induced vertical segregation of dust. Quantities used are attenuated backscatter at 532 and 1064 nm (from which a colour ratio is deferred) and the volume depolarisation ratio at 532 nm, both at 5/0.27 km horizontal/vertical resolution. For the near-cloud impact study 0.333 km resolution lev 1 CALIOP data are used, cloud/aerosol discrimination algorithms use CALIOP lev2.

The change of particle characteristics in the vicinity of clouds is an important topic which is of interest to users of CALIOP products, but the depolarization part needs revision in order to draw robust conclusions.

General comments:
The main results critically depend on the performance of the operational CALIOP cloud/aerosol discrimination algorithm. Thus this would merit a more detailed discussion. E.g., whether different PDF are used for water and ice clouds since the latter could easily be confused with depolarizing aerosols. As far as I understand, the PDF discrimination uses no information on the vertical distribution of the scatterers. How does the misinterpretation rate depend on the distance from clouds? How large is, statistically, the influence of nearby off-track clouds?

The current Version 3 cloud-aerosol discrimination (CAD) uses a 5D PDF, and considers altitude, latitude, backscatter, depolarization ratio, and color ratio. The current version data should have a better discrimination between ice clouds and dust aerosols than earlier versions (which used only latitude, backscatter, and color ratio), because dust and ice cloud are mostly at different altitudes. As suggested by the reviewer, we address this issue in the revised manuscript (L7-8 and L15-20 on P4).

Regarding the dependence of misclassification rate on distance from clouds, our earlier results indicate that the misclassification rate increases near clouds in Version 2; in addition, a much better ability of discrimination can be found very close to clouds in Version 3 [Yang et al. 2012]). In this paper, regardless of the distance to clouds, we use the data with cloud aerosol discrimination (CAD) confidence levels 70-100, which means that the success rate is above 85%. (The success rate can be estimated from the CAD following Liu et al., 2009). Furthermore, our dataset is for summer, and our statistics is only for altitudes below 5 km, which helps reducing the contributions from misclassified ice.

The influence of nearby off-track clouds has been studied elsewhere by using co-located MODIS data (Várnai and Marshak, 2012). The results indicate that off-track clouds do not change drastically the aerosol property trends near clouds that are obtained from CALIOP data alone. They also show that off-track cloud contributions can be taken into account by a scaling factor. We thank the reviewer for pointing this out; we have included the issue of off-track cloud in the revised manuscript (L1-6 on P3).

The authors should more clearly demonstrate the novelty of their approach/results which to me seems only given for the investigations of particle modification in the vicinity of clouds. The latter is an important topic, which is of interest to all users of CALIOP products. The changes of dust characteristics in the course of long-range transport, as discussed here, in most aspects have already been demonstrated in the literature to ACE-ASIA, SAMUM, AMMA

We agree that large amount of field research has been conducted on the changes of dust characteristics during long-range transport. Our results complement to these studies. Besides the investigation of cloud influence, this work is based on datasets that are large in time and area and covers three consecutive regions along the typical dust transport path in summer. Another novelty is the use of CALIOP observations for statistics ***conditioned*** on the presence of dust, instead of entire atmospheric columns that may include non-dust segments as well. More importantly, the initial presentation of dust long-range transport observation also serves as a prelude to the study of cloud effects on dust, which is one of the main focuses of this paper. We have included references about the field experiments mentioned by the reviewer, and clarified our purpose and approach in L15-27 on P5 of the revised manuscript.

The data base of about 2 x 60 latitudinal tracks seems rather small to derive general statements about changing Saharan dust characteristics during transport – therefore this is more like a case study since SD may exhibit quite variable properties depending on its origin and mixing with other aerosols and quite different cases have been reported in the literature (and this should be mentioned here).

We agree that since the statistics is only for the time period selected, our study is indeed more of a case study than a study of long-term average behaviors. Our initial reason for limiting the time-duration to a month was to reduce variations in the origin of dust, changes in mixing with other aerosols, and other complicating factors. The dependence on origin, season and mixing will be further studied and presented elsewhere. As suggested, we rephrased the corresponding section in the revised manuscript for clarification (L14-16 on P3).

An error of up to 30% in cloud/aerosol discrimination sounds high. Moreover, I wonder why the PDF classes' separation should be better (the overlap smaller) with coarser (5 km instead of 0.33 km) resolution – is this due to limitations by SNR?

To clarify this issue, we have rephrased the description of cloud-aerosol discrimination (CAD) in the revised manuscript (L15 on P4). The error rate R can be estimated by using R=(1-CAD%)/2 (e.g., Liu et al., 2009). Therefore using data with CAD scores above 70% correspond to an error rate of less than 15%. Based on our understanding, the better SNR plays an important role in making cloud-aerosol discrimination more accurate at coarser resolutions than at 333 m.

Specific comments:
If the CAD (12055, 13-16) applies for discrimination of clouds from aerosols in general, i.e not specific for dust, the 'CALIOP aerosol product' should be explained more in detail. Otherwise, it is not self evident how the assignment of the number of samples to dust (and not any other type of particles) is justified.

Good suggestion. As described above, we added a few sentences (L15-20 on P4) to explain that current CAD scores consider even altitude and depolarization information, which help separating dust from clouds more accurately. Furthermore, as described in a separate paragraph (L25-32 on P4), dust is distinguished from other aerosols mostly by the depolarization ratio and is labeled as aerosol subtype "desert dust" or "polluted dust" in the aerosol product.

12058, 15-22: why does chi' increase to the west when there are more sea salt particles instead of SD particles? According to your definition on p. 12054, l23-25 larger chi' means larger particles, i.e. chi' =beta'1064/beta'532. They are not necessarily larger.

Thank you for pointing this out. We have changed/corrected the corresponding part in the revised manuscript. In particular, we expanded the paper by including an analysis of dust particulate properties in addition to its volume counterparts (see the Appendix of the revised paper). As shown in Fig A2 of the revised manuscript, the dust particulate color ratio decreases toward the west, which is opposite to the trend observed for the color ratio of dusty volumes. Since the particulate color-ratio has removed the contributions from molecular Rayleigh scattering and gas absorption, the westward decreasing trend in color ratio seems to reflect the impact of particle size-dependent sedimentation during transport and/or mixing with marine aerosol. However, our further results on volume or particulate properties under clear skies (section 3.2) show that color ratio varies insignificantly westward. Therefore, the westward increase or decrease of color ratio is likely due to the effects of clouds. We have updated the related issues on color ratio in the revised manuscript such as in L5-6 on P1, L3-6 on P7, L17-18 on P7, L21-26 on P8, L1-3 on P10 etc..

12058, 25 to 12059, 5 and section 3.3.2.: This is a plausible, hypothesis. Can you confirm it by estimating the segregation based on typical sizes, shape factors?

This is a good suggestion for deeper studies. Currently we can reference only theoretical studies. Simulations have shown that for 4-6 μm size particles, the expected atmospheric lifetime increases from 11 to 13 days if the aspect ratio changes from 1 to 5. For particles between 12 μm and 20 μm size, the expected lifetime increases from 2.5 to 6 days if the aspect ratio increases from 1 to 5 (Ginoux, 2003). We note, however, that reality could be more complicated, as larger particles of complex shapes cannot be fully characterized by the single parameter of aspect ratio.

12064, 3-17: The increase of delta' towards clouds is odd and may either indicate important effects, artefacts or detection limitations. Is it significant with respect to accuracy? How large is your minimum detectable delta' and how large is it in terms of aerosol depolarization delta_aerosol= R/(R-1)*(delta'-delta_molecular/R ) with
R=(beta_part+beta_mol)/beta_mol.

$\delta_a = \frac{R}{R-1} * (\delta' - \delta_m/R)$ where $R = (\beta_p + \beta_m)/\beta_m$

How do you calculate the error bars? Although I do not expect large difference using aerosol-depol instead of volume-depol it (as was previously commented) in this specific case, indeed it would be the better one to use.

We agree that the increase in depolarization near clouds is odd. The decreasing number of dust samples near clouds in Fig7a suggests that the increase in depolarization near clouds can be the results of CALIOP not identifying as dust near-cloud volumes where the particle population becomes more spherical (for example due to cloud contamination or humidification of aerosols). This is discussed in L16-end on P13 and L1-2 on P14. Since the error bars are much smaller than the increase in depolarization, we think this trend is significant. According to the CALIOP ATBD (see below), the median particulate depolarization ratio uncertainties in the aerosol layer product is typically ~0.04 for nighttime data. Since our results are statistics for large amounts of data, the median error should be much smaller than 0.04.

We did additional calculations for a quick estimation of the particulate depolarization ratio by using a formula (e.g. Omar, et al, 2009) similar to the one provided by the reviewer. As shown in Figure R3, the results display a near-cloud increase not unlike the one in Fig7d.

For simplicity, the error bar in Figure R3 is estimated using the error propagation formula

$$\Delta\delta = \sqrt{\left(\frac{\partial\delta}{\partial\delta'}\Delta\delta'\right)^2 + \left(\frac{\partial\delta}{\partial\beta'}\Delta\beta'\right)^2}$$

This equation uses the volume depolarization $\delta'$, volume backscatter $\beta'$ and their corresponding uncertainties ($\Delta\delta'$ and $\Delta\beta'$) shown in Fig.7b and 7d. At the same time, the molecular depolarization ratio and backscatter are set to 0.0036 and 0.0014 in the estimation of $\frac{\partial\delta}{\partial\delta'}$ and $\frac{\partial\delta}{\partial\beta'}$. The 0.0014 $km^{-1}sr^{-1}$ of backscatter is obtained by rough estimation based on molecular model curves around 1 km of altitude (CALIPSO ATBD).  This estimation has also been included in the revised manuscript (L18-19 on P13, L23-28 on P17 and L1-8 on P18).

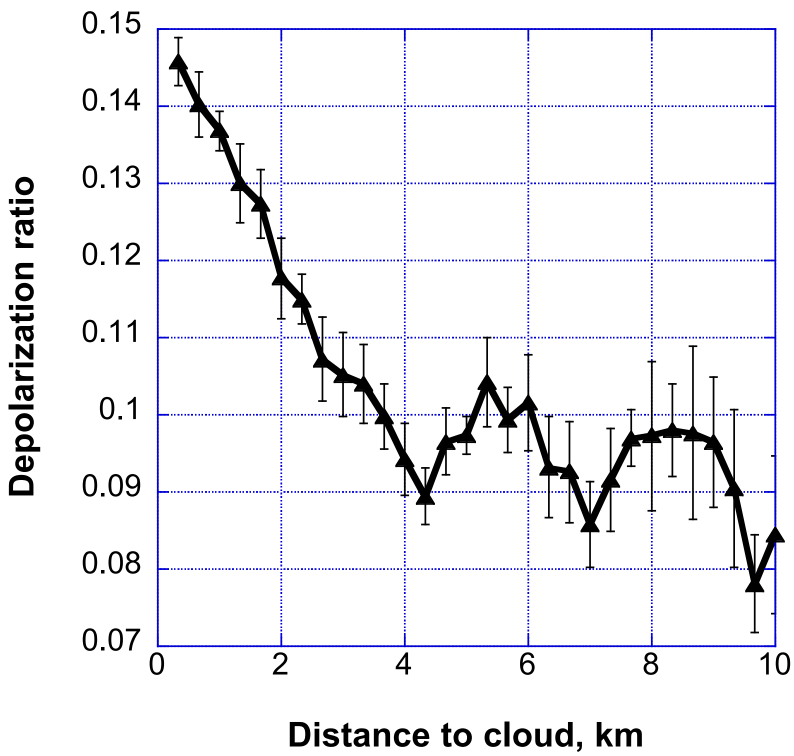

Figure R3. Estimated particulate depolarization ratio as a function of distance to clouds for low dust.

Section 3.1.1.: The profound different shape of the western sample profile may be a result of air-mass change rather than changing dust characteristics. Is there experimental or model evidence for there being the same air-mass (e.g. trajectories)?

Good point. We believe that the different behaviors in the western region arise from changes in dust characteristics during transport because the average wind speed is westward in all dust-containing parts of all three regions during the study period (see Figure R4), which indicates that dust in the western region is transported from the east, as opposed to coming from other directions inside different air masses.

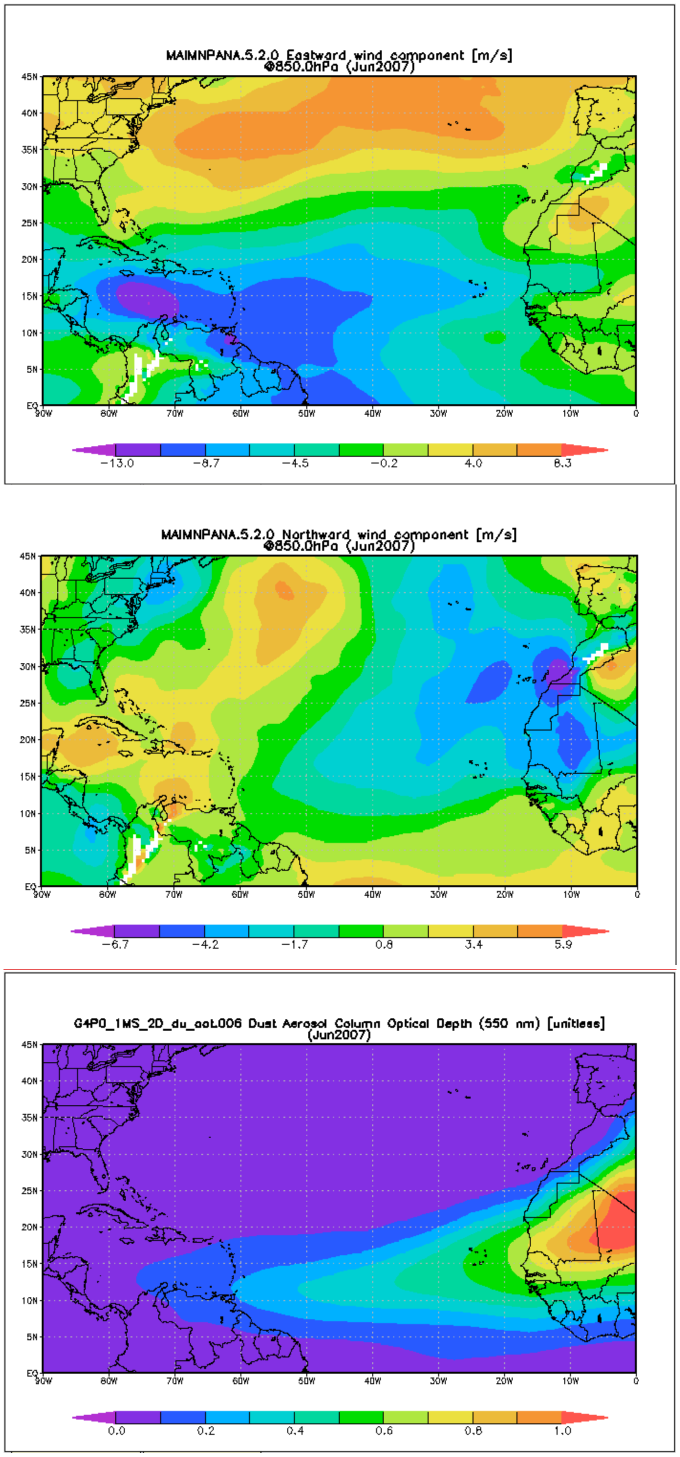


Figure R4. (Upper) Map of Eastward wind speed at 850.0hPa averaged for June, 2007. (Middle) Map of Northward wind speed at 850.0hPa averaged for June, 2007. (Lower) Map of dust column Optical Depth at 550nm averaged for June, 2007. It shows that average wind speed is mostly westward in all dust-containing parts of all three regions during the study period. In addition, the wind speed reached its maximum when entering Caribbean Sea.

Fig 7: The colours/symbols used for dust alt < 2km and dust alt > 2km are hardly distinguishable on a printout -> choose different

Thanks for pointing this out. We changed symbols for low dust.

**References:**

Ginoux, P., Effects of nonsphericity on mineral dust modeling, J. Geophys. Res., 108(D2), 4052, doi:10.1029/2002JD002516, 2003.

Liu, Zhaoyan, and Coauthors, 2009: The CALIPSO Lidar Cloud and Aerosol Discrimination: Version 2 Algorithm and Initial Assessment of Performance. *J. Atmos. Oceanic Technol.*, **26**, 1198–1213. doi: http://dx.doi.org/10.1175/2009JTECHA1229.1

W. Yang , Marshak, A., Várnai, T., Liu, Z.: Effect of CALIPSO cloud–aerosol discrimination (CAD) confidence levels on observations of aerosol properties near clouds. Atmospheric Research 116 (2012) 134–141

Z. Liu, M. Vaughan, D. Winker, C. Kittaka, B. Getzweich, R. Kuehn, A. Omar, K. Powell, C. Trepte, C. Hostetler.: The CALIPSO lidar cloud and aerosoldiscrimination: Version 2 algorithm and initial assessment of performance. J. Atmos. Oceanic Technol., 26 (2009), pp. 1198–1213

Omar, Ali H., and Coauthors, 2009: The CALIPSO Automated Aerosol Classification and Lidar Ratio Selection Algorithm. *J. Atmos. Oceanic Technol.*, **26**, 1994–2014. doi: http://dx.doi.org/10.1175/2009JTECHA1231.1

CALIPSO ATBD: CALIOP Algorithm Theoretical Basis Document Part 2: Feature Detection and Layer Properties Algorithms. http://www-calipso.larc.nasa.gov/resources/pdfs/PC-SCI-202_Part2_rev1x01.pdf