Atmos. Chem. Phys. Discuss., 9, C11289–C11295, 2010
www.atmos-chem-phys-discuss.net/9/C11289/2010/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Effects of absorbing aerosols in cloudy skies: a satellite study over the Atlantic Ocean" *by* K. Peters et al.

K. Peters et al.

karsten.peters@zmaw.de

Received and published: 5 March 2010

The aim of this paper is to quantify the aerosol radiative forcing above clouds. Absorbing aerosols located above clouds may reduce the amount of light reflected back into space by the clouds, causing a local positive radiative forcing that is not currently well understood (Forster et al., 2007). The subject of the paper is then relevant for publication in ACP [...]
The short-wave local planetary albedo α in case of aerosols above clouds depends on:
(1) the cloud albedo : Cloud Optical Thickness (COT) and microphysical properties.
(2) the properties of the aerosol located above the cloud : Aerosol Optical Thickness (AOT) and micro-physical properties.
(3) the vertical structure of the atmosphere: the respective locations of cloud and

aerosol layers along the vertical.
The authors use a combination of satellite observations in order to derive a statistical relationship between the short-wave local planetary albedo α, the liquid water path (LWP) and the aerosol optical thickness (AOT) in cases when aerosols are located above clouds.
The relation is
*α = a0 + a1*ln(LWP) +a2*ln(AOT) (Eq. 1)*
The α is derived using the CERES TOA shortwave flux, the LWP form AMSR-R and the AOT from MODIS, with the 3 intruments onboard the AQUA satellite. This is the most important relation of the paper and all the results come from this equation.
Thank you, we appreciate the reviewers' short summary of our work, although we do not attempt to specificly analyse situations with aerosol residing above clouds, since the OMI aerosol index cannot distinguish where in cloudy scenes the aerosol is located vertically with respect to the cloud. This will further be addressed in the following responses.

Response to major issues:

The AOT used to perform the calculations is not the one retrieved above the clouds but the AOT retrieved close to the clouds for non-cloudy pixels. Without information on the vertical structure of the atmosphere (the authors deliberately choose not to use lidar observations), we cannot be sure that the AOT retrieved close to the clouds over ocean is the same that the one above the clouds. In case of aerosols in cloudy scenes, the aerosols may be inside the clouds or even below the clouds and the AOT assumed above the clouds for such cases is clearly wrong.
In this study, we try to avoid stating this as an analysis of absorbing aerosols above clouds. By deliberately not using data from CALIPSO, we are indeed not able to sample the vertical structure of the atmosphere. We are able to sample for absorbing aerosols in cloudy skies, though. This is done by assuming the aerosol optical depth (AOD)

being homogeneously distributed in a 1x1 degree grid box, with the cloud properties prone to much higher spatial variability.
We attempt to be consistent with the notation throughout the manuscript, meaning we try to avoid stating to have identified the radiative effect of absorbing aerosols above clouds. Checking the manuscript, we found several instances where we state to have quantified the radiative effect of "absorbing aerosols above clouds". These instances have been changed to "absorbing aerosols in cloudy scenes" in the revised manuscript. We would like to thank the reviewer for pointing us to this deficiency and helping us making the manuscript more clear.

The authors use the aerosol index (AI) provided by OMI to check the presence of absorbing aerosols in cloudy pixels. I agree that the OMI AI allows detecting (qualitatively) the presence of absorbing aerosols in cloudy skies however the OMI AI cannot quantify how much aerosols are above or inside the clouds.
This is indeed correct. We use the UV-AI to check for the presence of absorbing aerosols in cloudy scenes. But we do not attempt to quantify absorbing aerosol amount from the UV-AI, as this is simply not possible with the information at hand in this study. We go into detail on this issue in section 3 in the old and in section 3 of the revised manuscript.

To my point of view, the only valid approach to derive the aerosol radiative forcing above clouds is to start from an estimate of the aerosol optical thickness retrieved above the clouds.
Thank you for this comment. We agree that if one was to explicitly attempt quantifying the aerosol radiative forcing of absorbing aerosols above clouds, an estimate of the aerosol optical thickness retrieved above the clouds is essential. But as already stated above, we do not explicitly attempt to quantify the radiative effect of absorbing aerosols above clouds, but the one of absorbing aerosols in cloudy skies. This may also include

aerosol indirect effects, as explained in the next reply. We added clarifications to abstract and pertinent parts of the manuscript describing this more clearly.

The cloud albedo is the parameter that primarily drives the short-wave local planetary albedo α in case of scenes with aerosols above clouds. In Eq. 1, the effect of the clouds properties on α comes from the second term (a1ln(LWP)). The LWP is not suitable to represent the effect of the cloud albedo on α and equation 1 does not account for cloud microphysics.
*A well know simple expression of LWP is LWP = 23 * CODvis *reffc * w*
(COD : cloud optical thickness, reffc : cloud particles effective radius, w : density of liquid water) LWP mixes the information on the cloud optical thickness and the cloud microphysical properties (i.e. effective radius). Same LWP value is obtained for COD=16, reffc=16μm and for COD=8, reffc=32μm. But the cloud albedo in the first case is significantly larger than in the second case (the cloud albedo integrated over the solar spectrum increases with increasing CODvis values and de-creasing reffc values).
It means that a given LWP value can result in different cloud albedo values. So, LWP is not a suitable quantity to represent the effect of the cloud albedo on α.
We very much appreciate this very detailed comment of the reviewer. We are sorry that we did not describe our method clear enough in the previous version of the manuscript. We improved the formulations in the revised manuscript accordingly. We chose to characterize the contribution of the clouds to the local planetary albedo (LPA) in terms of cloud macro- and microphysics. Macrophysical cloud properties are introduced by means of the liquid water path (LWP), as this quantity may be largely influenced by local meteorological conditions (Stevens and Feingold, 2009). Microphysical cloud properties as cloud droplet number concentration or cloud droplet effective radius (reffc) (the latter also being affected by cloud liquid water content), are dependent on the ambient aerosol population. Therefore, microphysical properties are introduced into equation 1 of the manuscript by means of the measured AOD. By doing this, we include both, direct as well as indirect, aerosol effects in the term (a2 ln(AOD)). As we attempt to

derive the bulk radiative effect of the observed aerosol mixture in cloudy scenes, this is a valid approach. In terms of cloud parameters, we agree that cloud optical depth is the main parameter affecting albedo. COD, in turn, is a function of LWP and reffc. In place of the latter, we better use cloud droplet number concentration (CDNC), since it is, in contrast to reffc, independent of LWP. CDNC is essentially a function of AOD. Thus, the two functionalities we include, namely dependence on LWP and AOD, are pertinent to explain the variability in albedo.
We have added additional information on this in the manuscript to make this approach clearer.
Furthermore, another reason for not using measurements of COD and reffc in this study is that these can be strongly affected when being measured in the presence of absorbing aerosols (Haywood et al., 2004; Wilcox et al., 2009). Measurements in the microwave spectral region, such as those provided from the AMSR-E instrument, are not affected by the presence of absorbing aerosols.

In Eq. 1, the effect of the aerosol properties on α comes from the third term (a2ln(AOT)). Impact of the aerosol layer on the TOA shortwave flux is depending on the cloud albedo below (see for instance Chylek and Wong, GRL, 1995). Are the a2 values reflecting the effect ?
Thank you for this valuable comment. In our analysis, the a2 values do not depend on cloud macrophysical properties. But as mentioned above, we include cloud microphysical effects in the third term of the equation. This is especially important, when the observed aerosol mixes with the cloud.
If aerosols above clouds are observed (which we, again, cannot determine explicitly), the albedo of the underlying cloud is crucial. In the revised version of the analysis, we have now constrained the cloud albedo at the lower end: We do not use scenes in the analysis which have a LWP of less than 20 g m^{-2}. Furthermore, the cloud albedo is also constrained to the higher end: We do not use scenes having cloud top temperatures lower than 273.15K and limit the analysis to "single layer liquid water clouds",

as determined by the MODIS Cloud Quality Assurance flag. A certain range of cloud reflectances is sampled for each region, though. Thus, as we attempt to quantify the bulk radiative effect of observed aerosol mixtures in cloudy skies on long time scales, our approach is valid.
Furthermore, an attempt to quantify the TOA radiative effect of aerosols in cloudy skies with respect to cloud reflectance would significantly reduce the amount of measurements available for the statistical analysis. At the moment, we do not have more data at hand, making this not feasible.

It seems to me that Eq. 1 does not account for aerosol microphysics. α is the TOA shortwave flux at TOA integrated over the solar spectrum and then Eq. 1 should account for the spectral variability of the AOT or the aerosol microphysics. Are the a0 values accounting for the aerosol microphysics? Also, the authors did not say if the AOT in Eq. 1 was dependent on the wavelength or not.
Thank you for this remark. Indeed, we do not account for the spectral dependence of aerosol-radiation interactions. We are interested in characterising the bulk absorption effect of an observed aerosol mixture in the broadband shortwave part of the solar spectrum, though. As the predominantly sampled absorbing aerosol species are either dust- or biomass burning aerosols, our method implies derivation of the radiative effect of both aerosol species in the visible part of the spectrum. In this part of the spectrum, the radiative effects may differ significantly between both species.
We included some phrases on the spectral absorption characteristics in the manuscript. For further justification of our method concerning spectral dependence of aerosol absorption, please see the detailed reply to the second comment of reviewer 1.
The AOD in Eq.1 is measured at 550 nm. We have included this in the manuscript.

Comment on the restructuring of some parts of the paper

From February 22-26, the first author took part in the workshop "Advanced Scientific Writing", held by Dallas Murphy and Jochem Marotzke, at the Max Planck Institute for Meteorology in Hamburg. The input received there lead to the need of rewriting and restructuring some parts of the paper in order to improve readibility. These modifications included (1) a shortening of the "abstract", (2) restructuring of the "introduction", (3) giving the description of the UV-AI it's own section, (4) restructuring of the "methods", (5) restructuring and refinement of the "summary and conclusions" as well as (6) rewriting of several sentences to enhance clarity.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 20853, 2009.