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REMOTE SENSING OF AEROSOLS ABOVE CLOUD USING POLARIZATION MEASUREMENTS FROM POLDER/PARASOL: COMPARISON WITH LIDAR CALIOP

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ABSTRACT. Most of the current aerosol retrievals from passive sensors are restricted to cloud-free scenes, which strongly reduces our ability to monitor the aerosol properties at a global scale. The presence of aerosols above clouds affect the polarized radiation reflected by the clouds, as shown by the measurements provided by the POlarization and Directionality of Earth Reflectances (POLDER) instrument. An approximate model of the polarized signal was developed and used to retrieve the Aerosol Optical Thickness (AOT) above clouds. Results obtained with this method in various regions of the world are presented. In the second part, we present additional results obtained with an improved method that allows the retrieval of a detailed microphysical model of the observed particles. The retrieved POLDER AOTs are compared to AOTs retrieved by a space-borne lidar in the case of a dust layer transported above clouds. The advantages and limitations of the different methods are discussed.

1. Introduction

Current aerosol retrievals from passive sensors are limited over cloud free pixels, which can bias the estimate of the direct aerosol effect on Earths climate [1] as well as the retrieval of cloud properties from satellites [2]. We recently developed a method that allows to retrieve the Aerosol Optical Thickness (AOT) above clouds [3]. The method mainly relies on the use of passive polarized measurements provided by the POLDER instrument onboard the PARASOL space platform. As a part of the constellation of satellites called A-train, POLDER/PARASOL acquired data in conjunction with multiple other passives and active sensors, as for instance the MODIS instrument and the lidar CALIOP [3]. In the first part, we recall the theoretical basis of the method and present results obtained for various situations and regions. In the second part, we present an improved version of the method that allows the simultaneous retrieval of the aerosols and clouds properties. The POLDER retrieved AOTs are compared with AOTs retrieved by the lidar CALIOP. Finally, we briefly discuss the advantages and limitations of each method and conclude.

2. Retrieval of AOT above clouds with polarization

The quantity used to derive the aerosol and cloud properties is the polarized normalized radiance (unitless) defined as:

$$L_p = \pm\sqrt{(Q^2 + U^2)}$$

Q and U are respectively the first and second normalized Stokes parameters [3]. The sign of the polarized radiance is positive when the direction of the scattered electric field is normal to the plan of scattering and negative when it is parallel. The POLDER instrument measures the angular and spectral properties of the polarized radiance at the top of the atmosphere. Figure 1 shows the angular polarized features typically observed for liquid clouds. We observe small level of polarization at side scattering angles $(80 - 130°)$ and a strong peak of polarization around $140°$ corresponding to the primary cloud-bow. The presence of aerosols above the cloud significantly affects the polarized light reflected by the cloud. One can note an additional polarization signal at side scattering angles and an attenuation of the cloud-bow. For the retrieval of the AOT, we restrict observations to scattering

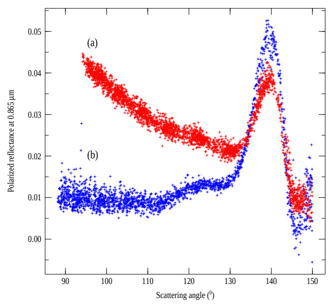


Figure 1. Polarized radiances measured by POLDER at 0.865μm as a function of the scattering angle when only liquid clouds are present (blue symbols) and when a significant load of biomass burning aerosols is located above the clouds (red symbols).

angle smaller than 130^o where polarization measurements are highly sensitive to scattering by fine mode particles and almost insensitive to cloud microphysics. We consider 15 aerosol models, which consists of a single lognormal size distribution of small spherical particles with effective radius varying between 0.089 and 0.54μm and an effective variance of 0.173. We assume that the refractive index is $1.47 - 0.01i$. The optical properties are calculated using the Mie theory. We use an approximate model of the aerosol-cloud interactions to simulate the polarization signal [3]. The model and AOT that provide the best fit between data and simulation is the best solution. The variability of cloud properties within each POLDER pixel $(6 \times 6\text{km}^2)$ is evaluated from MODIS retrievals at higher resolution (1 x 1 km^2 at nadir) and only homogeneous pixels are kept for the inversion. We also restrict the inversion to optically thick clouds (optical thickness $> 3.$) since the polarized light reflected by the cloud located below the aerosol layer is then saturated which

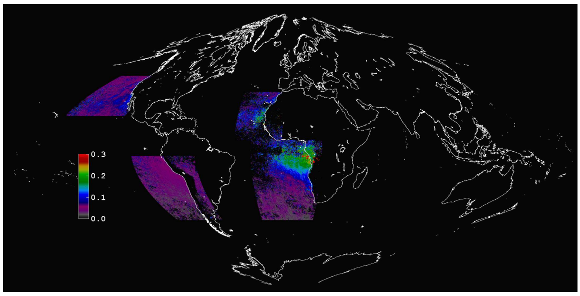
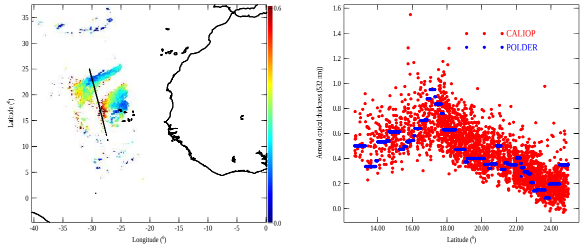


Figure 2. AOT retrieved above clouds at 0.865μm. Mean values calculated over 3 months (JJA) of 2008 and for four areas.

means that it does not depend on the cloud optical thickness. As shown in Figure 2, the method retrieves large AOT values associated with small particles size (effective radius of 0.15μm) for the tropical southeast Atlantic region. At the time period considered here (June-August), fires in South East Africa are frequent and meteorological processes favor biomass burning aerosols transport to the west. These particles mainly contribute to fine mode AOT. Our method also detects aerosols above clouds in the tropical North East Atlantic region close to Sahara. These particles are very likely to be desert dust aerosols. The two other selected regions do not show many events of aerosols above clouds.

3. Simultaneous retrieval of aerosol and clouds properties

Polarization measurements acquired at scattering angles larger than 130^o are sensitive to cloud microphysics and are now included in the retrieval scheme. A spatial aggregation of the POLDER data is performed, allowing a homogenous sampling of the scattering angle, which helps for the retrieval of the cloud microphysics. We then retrieved the particles properties at a coarse resolution (pixel of 200 x 200 km^2). The polarized radiances are accurately calculated using the Successive Orders of Scattering (SOS) code [4]. The simultaneous retrieval of the aerosol and cloud properties is driven using an optimal method estimate [5]. The main retrieve parameters are : AOT, particles size, complex refractive index and cloud-droplet size. We consider spheroid models [6] and the fraction of non-sphericity is included in the retrieval scheme. Lidar data are typically used to depict the vertical structure of the atmosphere along the orbit track and are used here to model the vertical distribution of the aerosol and cloud properties in the SOS code. The retrieved aerosol microphysics is finally used to constrain the retrieval of the AOT at $865\,\mathrm{nm}$ above clouds at a fine resolution $(18 \times 18\,\mathrm{km}^2)$. The spatial variability of the AOT of a dust layer transported above low-level clouds is shown in Figure 3a. The contribution of the coarse mode to the total AOT at 865 nm is about 90 % and it is associated with 100 % of non-spherical particles. The effective radius for the coarse mode is equal to 1.9μm and the complex refractive index is equal to $1.40 - 0.009i$. The cloud-droplet effective radius is about 12μm. Lidar system can also provide estimates of AOT above clouds. The comparison of the POLDER and CALIOP AOTs is shown in Figure 3b. The CALIOP AOT is retrieved at 0.532μm using the method described in [7]. Note that the CALIOP data



(a) (b)

Figure 3. (a) AOT retrieved above clouds at 0.865μm by POLDER and lidar CALIOP trace (black line). Observations performed on the 26^{th} of July 2008. (b) AOT retrieved by the lidar CALIOP at 0.532μm and POLDER AOT retrieved along the CALIOP trace.

are not averaged (i.e. single shot) and that the POLDER AOT is extrapolated at 0.532μm using the retrieved aerosol microphysics. We observe a good coherence between the AOTs retrieved by POLDER and the ones retrieved by CALIOP.

4. Conclusions

Passive sensors that provide multi-angular spectral polarized measurements have the ability to retrieve aerosol properties above liquid clouds. The method based on an approximate model appears to be robust on global scale and allows retrieving AOT when the optical thickness of the cloud located below the aerosol layer is larger than 3. This method is primarily sensitive to fine mode AOT. We developed a new method that allows the simultaneous retrieval of both the aerosol and cloud microphysical parameters. The retrieved POLDER AOTs is in good agreement with the ones retrieved by CALIOP using the method developed by [7] in case of a difficult case study (i.e. non-spherical coarse particles). Our improved method requires an exact modeling of the signal and the use of a sophisticated algorithm, which is time consuming. Future efforts will then focus on the development of an operational version of this algorithm that will be used for the treatment of the 5 years of data acquired by POLDER/PARASOL. The main perspective of this work is the estimate of the aerosol above clouds forcing at a global scale.

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