AEROSOL OPTICAL DEPTH RETRIEVALS IN LOW CLOUD AREAS USING CALIPSO OBSERVATIONS : TOWARDS A REGIONAL ANALYSIS OVER THE GULF OF GUINEA

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ABSTRACT

The quantification of aerosol optical depth of is of high importance for climate change analysis. Space-borne radiometric observations have long been used for this purpose despite inherent problems linked to their horizontal resolution for cloud and aerosol differentiation and the lack of information on the vertical. Difficulties may arise in regions where aerosol types are mixed and clouds are present. Backscatter lidar observations such as those provided by the new CALIPSO mission [1] are expected to give complementary information to reduce uncertainties in such conditions. In the operational retrieval (version 2.01), the aerosol optical depth is performed using a standard inversion procedure to the backscatter lidar measurements, using a tabulated backscatter-to-extinction ratio. This first step may however induce biases in the analysis in the aerosol optical depth (AOD). The objective of this study is to analyze the potential of newly proposed methods [2, 3] to quantify AODs from space over the ocean in regions of multiple aerosol types and broken liquid water clouds. The Gulf of Guinea has been chosen to perform tests for a one month period. First comparisons with MODIS data show an overall bias of 5%, and a standard deviation smaller than 0.09 in the retrieved AOD. Discrepancies between results on AODs retrieved in clear air and over liquid water clouds with the various methods are however observed. Preliminary results are shown and discussed.

1. INTRODUCTION

In order to improve our knowledge on climate change, accurate measurements of the aerosol radiative properties must be performed at regional and global scale, namely to better understand their interactions with clouds. The African continent is a source of different types of aerosols, mainly Saharan dust and black carbon from biomass burning. During summertime, biomass burning aerosols are advected from fire regions in Central Africa over the Gulf of Guinea area where they can interact with the stratocumulus cloud layer created by the subsidence in this region (the subsiding branch of the Hadley cell). This region is important since aerosol and cloud distribution may lead here to a significant forcing [4]. Aerosol properties are usually derived from space radiometry, but recently, first observations have been made available from the lidar CALIOP [5] on the CALIPSO platform. CALIPSO and CLOUDSAT platforms are now part of the AQUA-train, allowing the use of new methods to directly retrieve the aerosol optical depth (AOD), without an a priori knowledge of the lidar ratio [2, 3]. This study aims at comparing results from several methods to retrieve aerosol optical depth in a complex area. Comparisons can be performed over the ocean in regions of clear air using results from surface echo [3], [6] and MODIS retrievals. Results obtained from the CALIPSO-CLOUDSAT surface reflectance method (CCSRM) [3] at 0.532 µm during daytime are here compared to MODIS retrievals at 0.550 µm for a one month period over the Gulf of Guinea area. First comparisons between AODs obtained with CCSRM, the water cloud method (WCM) and MODIS are made in areas above and close to dense liquid water clouds.

2. THE STUDIED AREA

We analyzed the A-Train data on the Guinea Gulf area from the 1st to 31st august 2006, corresponding to AMMA 2nd Special Observation Period. We delimitated the studied zone by the coordinates (30S, 5N, 20W, 10E). Fig. 1 is showing the boundaries of the selected region and the CALIPSO/CloudSat tracks inside.

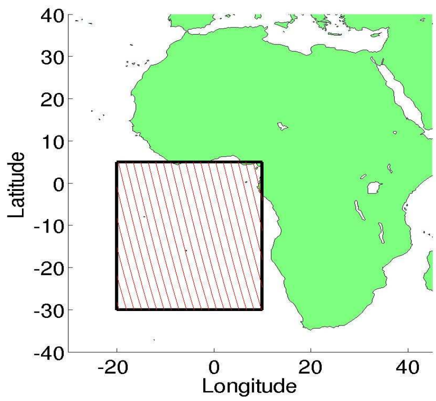

Figure 1. The oceanic region where the regional study has been performed is delimited by the solid rectangle. The diagonal lines are the different tracks of the footprint of the CALIPSO lidar.

Level 1 CloudSat release 4.0, CALIPSO version 2.01 data and MODIS Level 2 collection 5 have been used in the present study.

3. METHODOLOGY DESCRIPTION

3.1 CALIPSO-CloudSat-MODIS principle

The analysis of the lidar and radar echo from the ocean surface has been the subject of many studies [7-11]. They allow to link the lidar and radar normalized scattering cross section $\sigma_{SR,L}$ (subscripts S, R and L used for surface, radar and lidar observations, respectively) to wave slope and observation angle. Assuming nadir measurements, a linear relationship can be obtained between the normalized lidar and radar scattering cross-sections, including atmospheric transmission due to integrated water vapor path (IWVP) at radar wavelength, and to aerosol columnar content at lidar wavelength. The calibration factor Ct, mostly depending on instrumental characteristics (but also on capillary waves and foam contribution), can be accurately obtained for clear and dry atmospheres. This is shown in Fig. 2 for mid-latitude observations. We found here a constant value of Ct = 0.8 (this was 0.7 on data version 1.20).

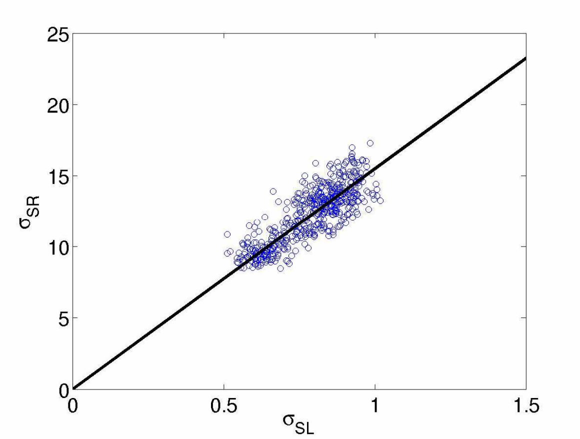

Figure 2. Normalized radar cross section as a function of the lidar one. The solid black line indicates the theoretical linear relationship. Saturation effects for the highest value (σ_{SR} higher than 20) and apparition of foam (σ_R smaller than 7) would both imply a departure from this linear relationship.

In the studied area, radar data were corrected using MODIS MYDO5_L2 infrared (IR) product. Using subscript att for attenuation due to water vapour for the radar, the AOD at lidar wavelength τ_{AL} can be written as

$$\tau_{AL} = \frac{1}{2}\ln\left(\frac{\rho_{0L}\sigma_{SR,att}}{4\pi\rho_{0R}\gamma_{SL,att}}\right) + \tau_{AR} + \frac{1}{2}\ln C_t \quad (2)$$

$\rho_{0R,L}$ is the Fresnel reflectance coefficient (ρ_{0R} = 0.41 for 3.1 mm radar measurements, and ρ_{0L} = 0.020 for lidar observations at 0.53 µm). $\gamma_{SL,att}$ is the lidar attenuated backscattering coefficient integrated on the surface echo. τ_{AR} is the atmospheric "optical" depth at radar wavelength. C_t is the calibration factor. The accuracy on Ct is estimated to 10% for wind speed values between 3 and 10 m/s, this domain being defined to minimize the overall error. According to (2) such an error on Ct corresponds to an error of 0.05 on the aerosol optical depth. In the tropics, a large fraction of the total uncertainty is due to the correction of the water vapour absorption at radar wavelength.

3.2 Water Cloud Method (WCM) principle

Transmission analysis can be performed using hard target return. Using dense clouds to this purpose requires to correct multiple scattering impact. This can be done taking advantage of the measurement of depolarization and the link between the multiple scattering and depolarization in liquid water clouds. This potential has been recently demonstrated for space lidar measurements [12]. This method can be used for elevated aerosol layers above dense liquid water clouds. [2]. The two-way transmittance being written as $T^2=\exp(-2(\tau_{mL} + \tau_{AL}))$, where τ_{AL} and τ_{mL} are the AOD and molecular optical depth of the overlying layer, the AOD with this method is obtained as

$$\tau_{AL} = -\frac{1}{2}\ln\left(2S_C\gamma_{CL,att}\left(\frac{1-\delta}{1+\delta}\right)^2\right) - \tau_{mL} \quad (3)$$

$\gamma_{CL,att}$ is the attenuated backscattering coefficient integrated on the cloud layer and δ the depolarization ratio [12]. For water clouds observed at 532 nm, a constant value of the lidar ratio S_c equal to 19.2 sr was used as in [4] in the following analysis. The main source of error comes from signal noise and calibration error that would directly impact the retrievals.

4. AOD RETRIEVALS

Fig. 3. shows an example of observations and retrieved AODs for a single orbit in the selected area. The structure observed in Fig 3a corresponds to a broken stratocumulus layer at about 2 km with aerosols above. Results obtained with the CCSRM and WCM are compared to MODIS observations in Fig. 3b. In the large clear air area between 0 and 6S, the CCSRM AOD was forced to coincide with MODIS one, leading to a calibration factor this time equal to 0.7. It is seen that AODs significantly differ in smaller clear air areas around 10S and 18-23S. In the application of the WCM approach, the analysis is only made over dense clouds where lidar surface return is not observed. More generally, some differences appear for the lowest AOD values (below 0.2), in the shattered part of the stratocumulus layer where CCSRM AODs are much smaller than MODIS ones.

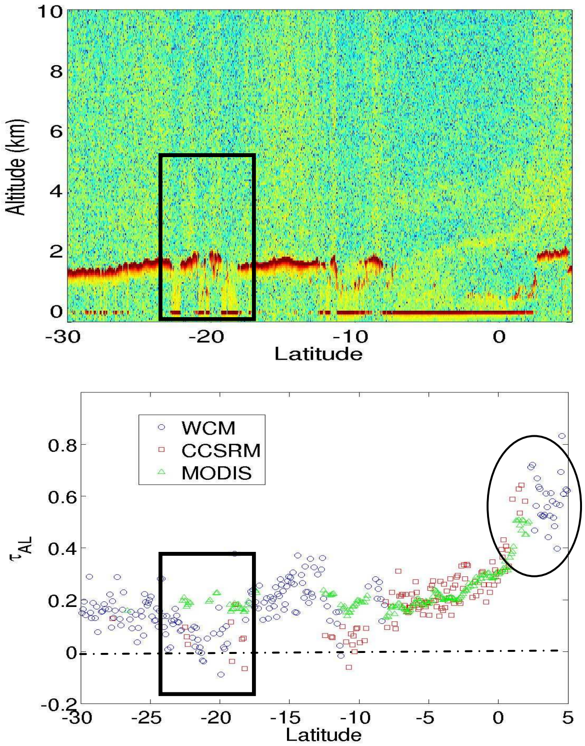

Figure 3. a) 2D cross-section of the CALIPSO signal on the 14 August 2006 and b) the corresponding AOD retrievals by WCM, CCSRM and MODIS (bottom).

A good continuity is observed between WCM and CCSRM AODs at 3N, in a large aerosol load. MODIS AOD is however smaller here than the AODs retrieved by the two other methods, showing the possibility of a bias of MODIS near this cloud. It is seen in Figure 2 that the aerosol backscattering decreases at southern latitudes and fairly clean air should be observed between 20 to 30S. Continuity between CCSRM and WCM values is good near 19S and 22S in much smaller aerosol loads. This is surprising as the main contribution to the AOD should come from the boundary layer, below the cloud, which is only detectable with CCSRM. Furthermore, the increase in values of WCM AODs at 22-25S are surprising for a weak aerosol load above a dense stratocumulus. The AODs retrieved by these two alternative methods are however much smaller than for MODIS in both 10 S and 20S areas. Figure 4 is showing a zoom on observations in the rectangle reported in Figure 3). Backscattering appears weak above the cloud layer, and almost no aerosol load appears detectable.

The calculation of the integrated backscatter coefficient, in the region, shows overall weak values. Taking MODIS AOD as reference (about 0.2), this would correspond to an average lidar ratio larger than 40. Referring to smaller AODs from CCSRM (0.1) as given in Figure 4 would reduce lidar ratio by a factor 2, which in this case could be more in adequation with a contribution of sea salt in this area.

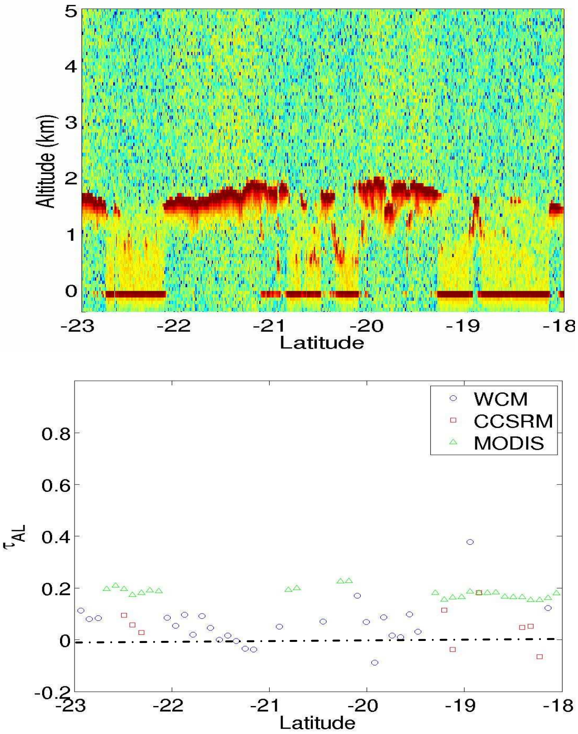

Figure 4. same as Fig. 3 but zoomed in latitude in the rectangle shown in Fig. 3 and filtered to MODIS resolution.

According to (2), the CCSRM may underestimate the AOD if the correction due to water vapor absorption is too large. It may be the case, but AODs may be then too large. In between clouds, aerosol properties may mix moistened sea salt, biomass burning particles, and small clouds. This may introduce a bias in the MODIS aerosol retrievals, but also in visible or IR water vapor products, or Cloudsat. Possible changes in cloud lidar ratio may occurr as well. To further look into possible biases, a statistical results of CCSRM and the comparison with the closest MODIS pixel (Aqua aerosol 550 nm MYD_04_L2 product) are reported in Figs 5. Keeping the calibration determined in Figure 3, The overall mean slope for AODs larger than 0.2 shows a bias smaller than 5%. The standard deviation is rather high, about 0.09, but is quite encouraging considering the possible sources of errors. However for low AODs a bias is observed. This corresponds to clear air areas mostly in between clouds. A comparable also smaller bias is also shown from the analysis made in clear air at mid-latitudes as reported in Figure 1 (a larger calibration factor was indeed found and used in this first figure). This last case clearly corresponds to a change in calibration constant, leading to a bias in AOD equal to 0.05. However for observations at the same latitude, the calibration constant is not expected to change, and this bias could be attributed to errors in the retrieved water vapor (no saturation effect is expected on lidar signal as large surface echoes are filtered out), aerosol mixed properties, or cloud contamination.

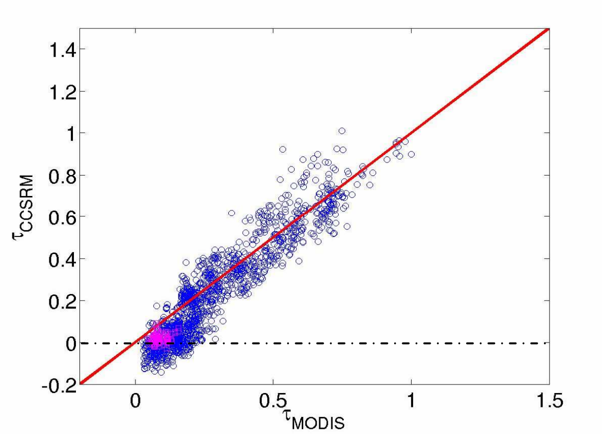

Figure 5. AOD CCSRM retrievals as a function of MODIS ones. The solid line refers to the 1:1 relationship.

5. CONCLUSION

Several methods for retrieving AODs have been tested for a monthly regional study at tropical latitudes, and allowed to get a good overall agreement with the MODIS AOD retrieval. The CCSRM method proves to be robust, and shows consistency with WCM. Those methods are promising but further research is needed to understand the differences with MODIS and to better quantify the different sources of errors. No a priori conclusion can be made, and several tracks need to be explored. The comparative analysis offers such a possibility. Analysis will be extended using other methods as for example using the surface wind analysis [6].

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