COMPARISONS OF CLOUD MICROPHYSICAL PROPERTIES RETRIEVED FROM DIFFERENT ALGORITHMS DURING AEROSOL TRANSPORT EVENTS

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ABSTRACT

Multi-spectral data from the MODerate resolution Imaging Spectroradiometer (MODIS) onboard the Terra spacecraft are used to derive cloud optical thickness and effective particle radius using the algorithm of Nakajima and Nakajima (1995). Microphysical cloud properties are retrieved during strong aerosol events from biomass burning to better understand the actual effects of cloud-aerosol interactions. Rosenfeld (1999) observations have shown not only that cloud microphysical properties are affected by the presence of smoke aerosols from burning vegetation but also that precipitation can be consequently suppressed.

A key step for the understanding of these effects is the comparison of the retrieved cloud parameters with independent sources. In the present work the retrieved quantities (Costa et al., 2004) are compared with space and time coincident cloud optical thickness and effective particle radius from the MODIS official cloud product (King et al., 1998) and intensive measurement campaigns.

Low Earth Orbit (LEO) satellite sensors are normally targeted for these studies, as it is in the present work, since they were the only ones that supplied the necessary multi-spectral measurements. The launch of Geostationary Earth Orbit (GEO) platforms with sensors like the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on METEOSAT Second Generation (MSG) opens up the possibility of extending cloud and aerosol retrievals to the GEO orbit. This will greatly improve the frequency of measurements, allowing for global monitoring of cloud properties. An extension of the study in view of the upcoming availability of MSG-SEVIRI multi-spectral data is conceived.

1. INTRODUCTION

Clouds are a major driving force behind climate mechanisms so that the global monitoring of their optical and microphysical properties retrieved from multi-spectral satellite sensor data becomes a main task/necessity. Recent studies on this topic have evidenced that aerosol can affect cloud microphysical properties (first indirect effect) and cloud lifetime (second indirect effect) (Albrecht, 1989; Bréon et al., 2002; Kawamoto and Nakajima, 2003). The first indirect effect consists in a decrease of droplet size due to an increase in droplet concentration (assuming a constant liquid water content), when a cloud is polluted with anthropogenic aerosol particles serving as additional cloud condensation nuclei (Twomey, 1974). The second effect is the reduction

of the efficiency of precipitation forming processes due to the decrease of cloud particle size, tending to increase the liquid water content, cloud lifetime and thickness (Rosenfeld, 1999, 2000). The biomass burning aerosol is considered one of the main responsible of this kind of cloud properties modification: many regions of the Earth are characterized by the emission of biomass burning aerosol connected to the agricultural practises and forest fires, but the quantification of the effects of the aerosol-cloud interaction is not yet completely achieved.

Cloud parameters such as visible optical thickness (t), effective radius (r_e) and cloud top temperature (T_c) have been retrieved by applying a retrieval algorithm (Nakajima and Nakajima, 1995; Kawamoto et al. 2001) to MODIS (MODerate resolution Imaging Spectroradiometer) radiance data in the occasion of clouds forming during intense biomass burning aerosol transports in Southern Africa and Portugal in summer 2000 and 2003, respectively (Costa et al., 2004). Comparisons between the retrieved parameters and space and time coincident MODIS cloud official products (King et al., 1998) have been carried out in order to test the performances of the adopted retrieval algorithm and the cloudy pixel selection against a state of the art retrieval algorithm. Moreover, for the case study over Southern Africa comparisons are presented with *in situ* measurements of the Southern African Fire-Atmosphere Research Initiative 2000 (SAFARI 2000) (http://mercury.ornl.gov/safari2k/) field campaign in the attempt to further improve the understanding of the interactions between clouds and aerosol.

Low Earth Orbit (LEO) satellite sensor data are normally used for this kind of studies because of the availability of the necessary multispectral measurements and the high spatial resolution. The geostationary perspective of Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board METEOSAT Second Generation (MSG) will allow for a better monitoring of the temporal evolution of the cloud properties and help in comparisons with *in situ* measurements.

2. CASE STUDIES

An intense fire season occurred in Southern Africa during summer 2000 with a peak in late August and early September, and reaching the highest levels of biomass burning in the world. The present analysis focused on the African coasts between Southern Angola and Northern Namibia on 2, 7, 11, 13, 14, 16 and 18 September. During these days a large aerosol transport took place, as shown in Fig. 1a for 13 September, where the presence of absorbing aerosol off the Namibian and Angolan coasts is evidenced by positive Total Ozone Mapping Spectrometer (TOMS) aerosol index values (Torres et al., 1998) (see the greyish spots over the Atlantic Ocean). This oceanic area is normally characterized by the presence of semi permanent stratiform clouds, so it provides a good opportunity to increase the understanding of cloud microphysics and cloud-aerosol interactions. Aerosol transport phenomena did not happen on 16 and 18 September, but the two days were analysed to evaluate background cloud characteristics in absence of smoke particles.

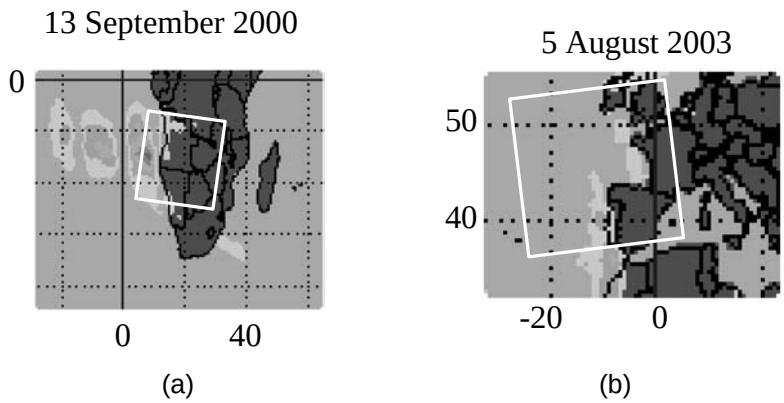

Figure 1 - *TOMS aerosol index maps of the aerosol transport events in Southern Africa (a) and Portugal (b). The greyish spots locate the absorbing aerosol. The white boxes delimit the location of the MODIS granule data used for retrieving the cloud top properties.*

Very similar conditions occurred in Portugal in August 2003, the worst fire season that Portugal faced in the last two decades, if not ever. Numerous wildfires and the corresponding smoke plumes were easily detectable from satellite images. The study concentrated on 5 August and the corresponding aerosol index map is shown in Fig. 1b. On this day most of the absorbing aerosols were located over the Bay of Biscay, reaching the U.K. and Ireland southern coasts.

3. DATA AND METODOLOGY

The cloud optical and microphysical characterization the case study regions is described by Costa et al. (2004) in this volume. MODIS radiance data in the spectral channels centred at 0.65 (visible, VIS), 3.75 (near infrared, NIR) and 11.03 (thermal infrared, IR) μm were selected and processed to retrieve t, r_e and T_c.

Comparisons between the retrieval results and time and space collocated MODIS official product data sets of optical thickness, effective radius and top temperature were carried out. The idea was to validate the present retrievals against a state of the art retrieval algorithm, in particular as regards to the set up of the algorithm and the selection of cloudy pixel.

Data sets from the SAFARI 2000 campaign in Southern Africa (Swap et al., 2003) were used as a further source of validation data for the African case study. The campaign explored, studied and addressed the linkages between land-atmosphere processes, the relationship between biogenic, pyrogenic or anthropogenic emissions and the mechanisms of the biogeophysical and biogeochemical systems, and the consequences of deposition. The intensive SAFARI 2000 six-week field campaign was conducted from 13 August to 25 September and included satellite (TERRA and Landsat 7) observations, numerous flights over surface AEROSOL Robotic NETwork (AERONET, Holben et al., 1998) sites, deployment of flux towers in South Africa, Botswana and Zambia, and *in situ* aircraft measurements of the University of Washington CV-580, South African Weather Service Aerocommander 690As and the UK MetOffice C-130.

The SAFARI 2000 data sets used in this work are the cloud effective radius measurements made by the UK Met Office C-130 aircraft (Keil and Haywood, 2003), and the cloud and aerosol layers bottom and top heights as a part of the cloud and aerosol measurements from the ER-2 Cloud Physics Lidar (CPL) (McGill et al., 2003). For comparison sake the SAFARI 2000 data are always attributed to the retrieved cloud parameters of the nearest MODIS pixel. Due to the availability of only one MODIS granule data per day over the regions of the case studies the time coincidence between the aircraft measurements and our cloud retrieved parameters is not every time optimal, but always within the 2-3 hours time frame. Note that data from a geostationary satellite sensor like SEVIRI with a frequency of measurement of 15 minutes would greatly improve the comparisons and this is the goal of future studies.

4. RESULTS AND DISCUSSION

First, the results of the retrieval (r_e, t and T_c) are compared with the corresponding cloud retrieval products of the MODIS team for both case studies. The results of the comparisons for the African case study are shown in Fig. 2. The frequency of occurrence is plotted as a function of the relative differences between the cloud parameters of the MODIS official products and our retrieved cloud parameters. 13 September was selected as representative of a typical scenario containing biomass burning aerosol and clouds, but similar results are

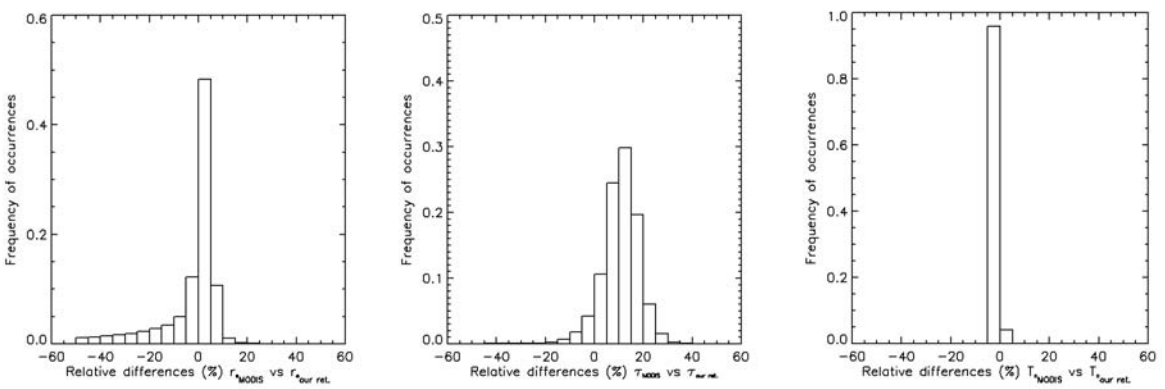

Figure 2 - *African case study, 13 September 2000. Results of the comparisons between the MODIS cloud retrieval official products and the cloud parameters retrieved according to our methodology (r_e, t and T_c) from the same MODIS radiance data. Relative differences with respect the MODIS official products are shown. Only the MODIS pixels over ocean classified as covered by water clouds (stratocumulus or cumulus) enter the histogram construction.*

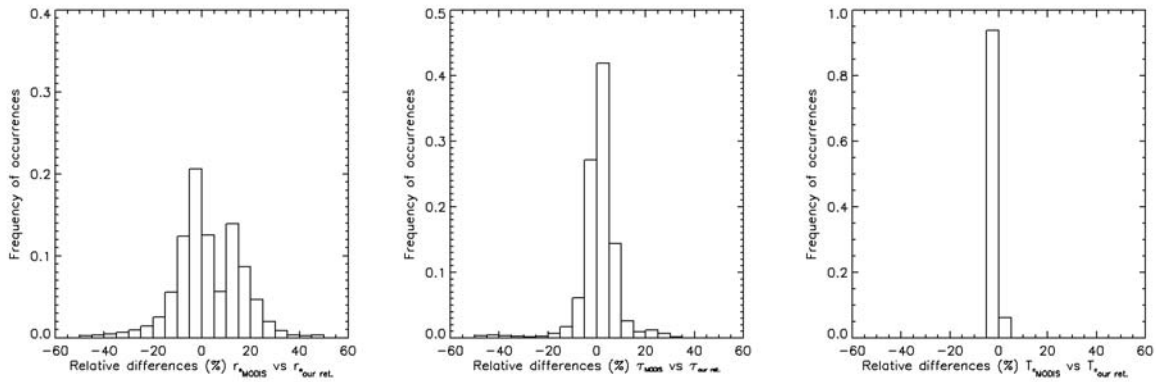

Figure 3 - *Same as in Fig. 2 but for the case study of the Portugal, 5 August 2003.*

obtained for the other days (not shown). The results reported in these graphs are relative to the MODIS pixels over ocean classified as covered by water clouds (stratocumulus or cumulus) by the threshold bispectral technique described by Costa et al. (2004). The agreement between the MODIS official product parameters and the retrieved ones according to our methodology is encouraging since for all three cloud parameters the frequency of occurrence distributions are sharp and peaked near zero. Only the t histogram is peaked near the 15 % relative difference, pointing out a slight overestimation of τ by our retrieval method. However, more than 50% of cases show relative differences lower than 15%. The same analysis was conducted for the Portugal case study, whose results are reported in Fig. 3 for the 5 August, 2003. Also in this case the comparisons confirmed an agreement between the two retrieval procedures. In this case the histogram of r_e differences is the broadest, but 50% of the examined cases show differences lower than 10%. It is conceivable that a better agreement can be obtained by refining the selection technique of the cloud covered pixels and the cloud thermodynamic phase determination.

Further comparisons were carried out for the Southern Africa case study to validate the present retrieved cloud parameters using data sets of the SAFARI 2000 measurements campaign. Results of the comparisons between our retrieved cloud particle effective radius values and the corresponding measurements made by the Met Office C-130 aircraft for 2, 7, 11, 14 and 18 September are displayed in Fig. 4 (different symbols refer

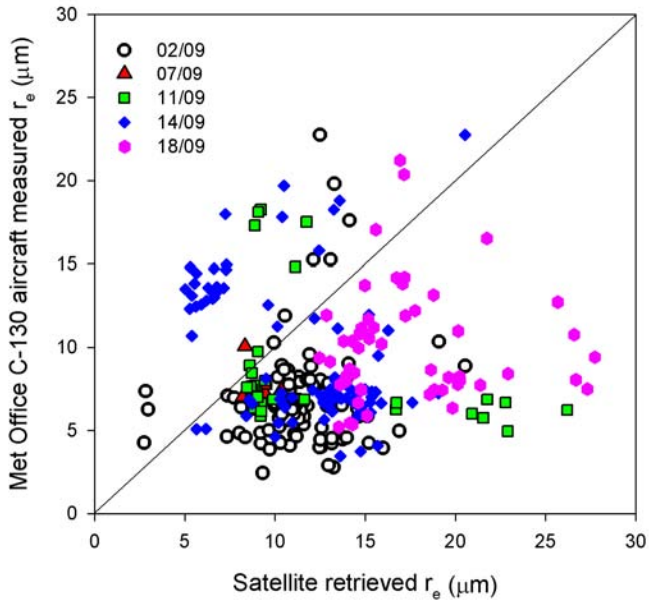

Figure 4 - *Results of the comparisons between our retrieved cloud particle effective radius values and the corresponding measurements made by the UK Met Office C-130 aircraft on 2, 7, 11, 14 and 18 September. Due to the different spatial resolution of the data each aircraft measurement was referred to the nearest MODIS pixel and then, considering all the aircraft measurements attributed at the same satellite pixel, the average value of the aircraft effective radius was computed.*

to the different days). Average values of the aircraft-measured effective radius are plotted against the our satellite-retrieved r_e. Due to the different spatial resolution of the data each aircraft measurement was referred to the nearest MODIS pixel and then, considering all the aircraft measurements attributed to the same satellite pixel, the average value of the aircraft effective radius was computed. The satellite retrieved r_e values are in general larger than those measured by the C-130, even if the differences are moderate. For example, on 2 September most of the retrieved r_e values fall within the range of 10-15 μm and the measured ones are in the range 5-10 μm. A good agreement between the two data sets is found on 7 September although very few coincident satellite-aircraft data were available on this day. The reasons for these findings could be twofold:

1) Aircraft measurements were carried out during straight and level runs and profiles, so that they refer to different altitudes into the cloud from bottom to top, whereas the satellite retrieved r_e belong only to the uppermost cloud layers.
2) On the other hand the typical scenario observed during the 4 days showed an elevated biomass aerosol layer and low-level stratiform clouds located below it (Keil and Haywood, 2003; Haywood et al., 2003). The present retrieval algorithm does not consider the presence of an aerosol layer in the atmosphere.

The above two reasons could partially justify the differences between measured and retrieved r_e in Fig. 4. This remains to be verified by means of for example radiative transfer simulations of the near infrared radiance data (usually employed for the r_e retrieval, as in the present work), where the aerosol load is properly described with respect to the scattering properties.

On 18 September the aerosol load was greatly diminished off coast of Namibia and Angola. The analysis of the cloud parameters, in particular r_e, was performed to evaluate the possible influence of aerosol transport on cloud properties. Note from the scatter plot in Fig. 4 that this day was characterized by the largest r_e for both the data sets with respect to the previous days, e.g. 2 or 7 September. This can be considered as a signal of the influence of the aerosol on cloud microphysical properties.

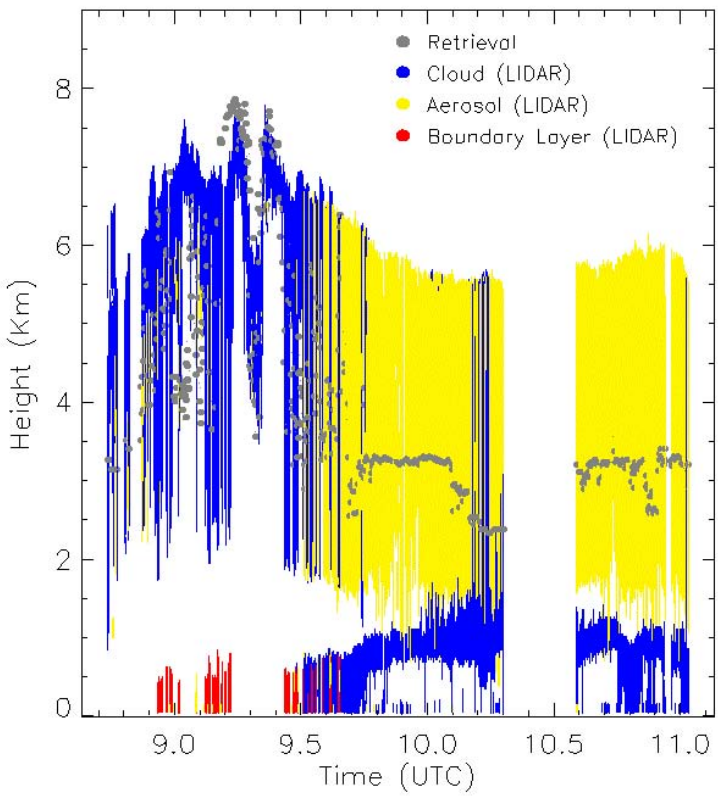

Figure 5 - *Case study of Southern Africa, 13 September. Comparisons between the retrieved cloud top height H_c and that measured by the Cloud Physics Lidar (CPL) onboard the NASA ER-2 aircraft. The vertical lines identify the different layers retrieved by the CPL: cloud layer (blue), presence of an aerosol layer (yellow), and planetary boundary layer (red). The overplotted grey dots represent the cloud top height as retrieved from the MODIS data using the present algorithm.*

For 13 September one more comparison was done between the satellite retrieved cloud top height (H_c) and the one measured by the Cloud Physics Lidar (CPL) onboard the NASA ER-2 aircraft. In Fig. 5 the vertical lines identify the different layers retrieved by the CPL. The bottom and top heights of the various layers detected by the CPL are plotted as a function of flight time. The cloud top height as retrieved from the MODIS data using the present algorithm are also plotted. Note that a large portion of the flight was characterized by the presence of a thick aerosol layer located above the cloud top. The agreement between the CPL and MODIS cloud top height is good enough when the aerosol layer is absent, whereas there is a clear overestimation of the cloud top height computed by the retrieval algorithm in the other case. This confirms what was found in the previous comparisons, that is that the presence of an absorbing aerosol layer above the cloud damages the quality of the cloud top parameter retrieval from satellite sensors.

5. CONCLUSIONS

The cloud optical and microphysical characterization (r_e, t and T_c) during two strong biomass burning events were obtained from MODIS VIS, NIR and IR radiance data according to Costa et al. (2004). The retrieved parameters were compared with the MODIS cloud retrieval official products and data sets of r_e and H_c from aircraft measurements of the SAFARI 2000 campaign, in order to evaluate the performances of the present retrieval procedure and the possible effects of the aerosol-cloud interactions.

The comparisons have pointed out an acceptable agreement with MODIS cloud parameters, whereas more complicated is the interpretation of the comparisons with the SAFARI 2000 data. It will be necessary to undertake an investigation of other case studies similar to those examined in this work together with a sensitivity analysis of the variations of the microphysical cloud properties in presence of biomass burning aerosol layers. These are necessary steps towards a better understanding of the aerosol-cloud interactions. Moreover, similar studies using MSG-SEVIRI data are planned, taking advantage of the high image frequency for the global monitoring of the cloud properties.

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