CLOUDS AND AEROSOL RADIATIVE INTERACTION AND FORCING INITIATIVE

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ABSTRACT

The CLouds and Aerosol Radiative Interaction and Forcing Investigation (CLARIFI) project is part of ESA's Changing Earth Science Network Initiative and aims at quantifying the radiative effect of UV-absorbing aerosol layers above cloud layers, using space-based instruments and radiative transfer modelling. We focus on clouds and smoke from biomass burning in Southern Africa. It appears that clouds that exist in the presence of smoke aerosols have a typical reflectance spectrum, with a lower reflectance in the UV and visible than clouds without smoke. This lower reflectance is caused by the light absorption by smoke aerosols above the clouds, which is strongly wavelength-dependent. From integration of the measured reflectance spectrum of these smoke-polluted clouds over the SCIAMACHY wavelength range, we obtain a direct estimate of the shortwave absorption of polluted clouds. In this paper the first results of project are presented.

Key words: SCIAMACHY; CALIPSO; aerosols; clouds; radiative forcing.

1. INTRODUCTION

Aerosols affect the Earth's albedo and shortwave radiation balance by scattering and absorption of sunlight. It appears that the radiative effect of aerosols strongly depends on the underlying scene, whether it is dark or bright. For example, absorbing aerosols above a bright cloud can lower the albedo of the cloud and thereby perform a strong heating effect. However, it is difficult to obtain quantitative information from satellites on this direct aerosol effect. The reason is that most aerosol detection algorithms fail in the presence of clouds, because cloudy scenes are considered to be too bright to allow aerosol retrieval. This detection problem can be avoided by use of the absorbing aerosol index (AAI) to detect absorbing aerosols. The AAI is a differential spectral index to identify UV-absorbing aerosols, like desert dust and smoke. The strength of the AAI aerosol detection method is that it works equally well for land and sea surfaces, and that it works even in the presence of clouds.

Furthermore, SCIAMACHY measures the Earth's reflectance from 240 to 1750 nm, i.e. the major part of the shortwave spectrum, which can be used to directly integrate the spectral difference of clean cloud and polluted cloud scenes, to derive a radiative forcing. This feature of SCIAMACHY provides a unique opportunity to esti-

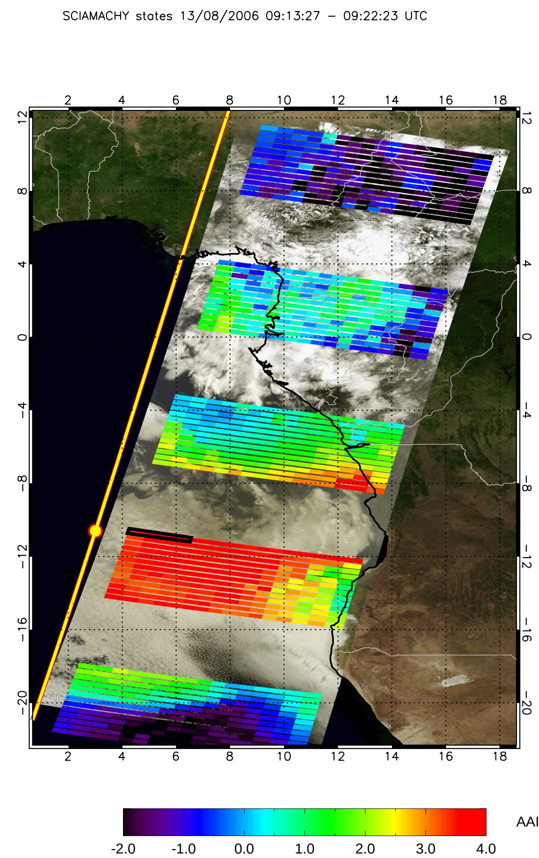

Figure 1. Composite of NASA Blue Marble images, ENVISAT/MERIS reflectances and ENVISAT/SCIAMACHY AAI on 13 August 2006. The ENVISAT data shown in the figure was acquired between 09:13 and 09:22 UTC. The yellow line shows the Calipso track from 01:19 and 01:28 UTC on 13 August 2006. The dot in the track matches with the arrow in Fig. 2. The black rectangle in the SCIAMACHY data are the pixels from which the reflectance spectrum is constructed, shown in Fig. 3.

mate local and global aerosol radiative forcing, without assumptions of the aerosol microphysical properties.

Radiative transfer model (RTM) calculations will be needed to understand the processes involved in the scene. For example, the relative position of the clouds and aerosol layers determine the strength and the sign of the resultant radiative forcing [1]. This information can be obtained using Calipso, from which the vertical structure of the atmosphere can be determined. A case study is presented in section 2 of nearly simultaneous SCIAMACHY and Calipso measurement, to show the impact of the absorbing aerosols in a cloudy scene.

Global information on absorbing aerosols over clouds has been obtained with the AAI from SCIAMACHY, combined with the FRESCO+ cloud fraction product, also from SCIAMACHY, and presented in section 3.

2. AEROSOL - CLOUD INTERACTION

In August 2006 a intense biomass burning aerosol plume was detected over southern Africa using the AAI from several satellite instruments, which could be followed for almost two weeks as it travelled from Angola and Namibia over the Southern Atlantic Ocean before it dissipated. Figure 1 shows a composite of NASA Blue Marble images, ENVISAT/MERIS reflectances and ENVISAT/SCIAMACHY AAI on 13 August 2006. The ENVISAT data shown in the figure was acquired between 09:13 and 09:22 UTC. The Meris image shows the extensive cloud cover over the Atlantic Ocean south of 8°S and also a brown grayish haze over the cloudy and clear sky scenes between about 8° and 12°S. This is the biomass burning aerosol plume, which is present over the cloud layer. The SCIAMACHY AAI information overlaid over the image shows very high values of AAI between 10° and 16°S, which indicates that the aerosols are UV-absorbing and present above the cloud layer. This is confirmed by Calipso data shown in Fig. 2, the track of which is also plotted in Fig. 1 as the yellow line. The Calipso data shown in this figure was acquired between 01:19 and 01:28 UTC, so about 8 hours before the ENVISAT data. However, a day time pass of Calipso at around 13:00 UTC showed a similar structure, even if it was much more spatially distant from the ENVISAT track. The arrow in Fig. 2 shows the location of the yellow dot in Fig.1. The Calipso data clearly shows a extensive cloud layer at around one kilometre altitude between 22° and 1°S and a very large plume of aerosols between one and 5 kilometres altitude, from 20°S to almost 5°N. The aerosol layer extends all the way down to the cloud layer, although this cannot be seen clearly from Fig. 2. In this figure the backscatter at 532 nm is shown, which doesn't penetrate the entire aerosol layer. However, the 1064 nm backscatter data penetrates much further and in this data (not shown) the layer is visible all the way down to the cloud layer. The Calipso clearly shows that the aerosol is present above the cloud layer. degrtaaf [2] showed that this is the most effective way for UV-absorbing aerosols to affect the spectrum in the UV and produce a high AAI, but no Calipso data were present at that moment.

The SCIAMACHY spectrum from the area indicated by the black rectangle in Fig.1 is shown in Fig.3. The reflectance is clearly much lower in the UV than in the visible and near infrared. A unpolluted cloud scene has a much flatter spectrum [2] (not shown). By integrating the difference between the polluted cloud spectrum and a reference clean cloud spectrum the radiative forcing of the aerosols may be obtained directly.

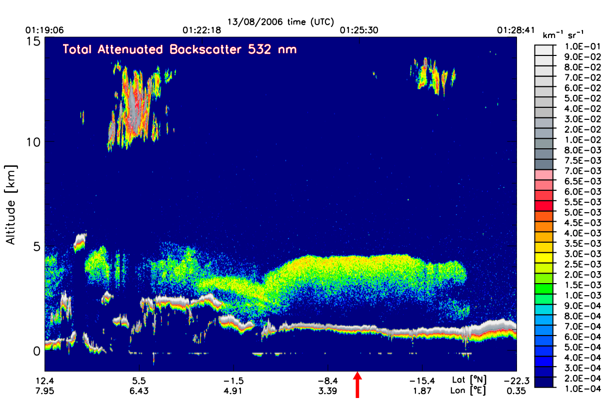

Figure 2. Calipso 532 nm backscatter signal on 13 August 2006 from 01:19 to 01:28 UTC. The red arrow corresponds to the yellow dot in Fig.1. The colour scale is constructed so that blue areas correspond roughly to background (clear sky) areas, green/yellow to red areas to aerosol layers and green/yellow to grey areas correspond to cloud layers.

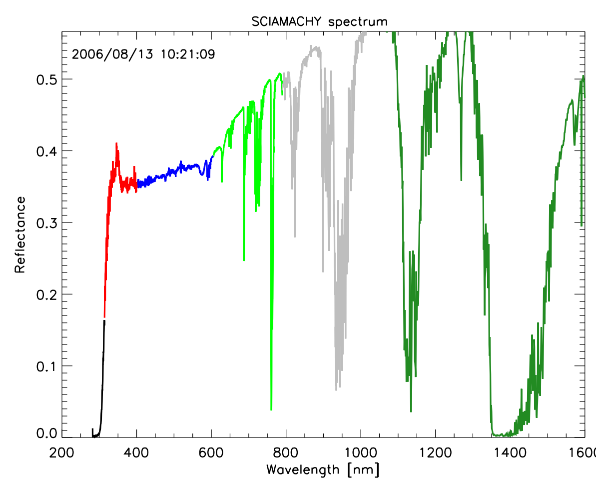

Figure 3. SCIAMACHY 1-s reflectance spectrum on 13 August 2006, 10:21:09. The location of the spectrum is shown in Fig. 1 as the black rectangle. The colours refer to the different SCIAMACHY clusters from which the spectrum is constructed, but this is not relevant here.

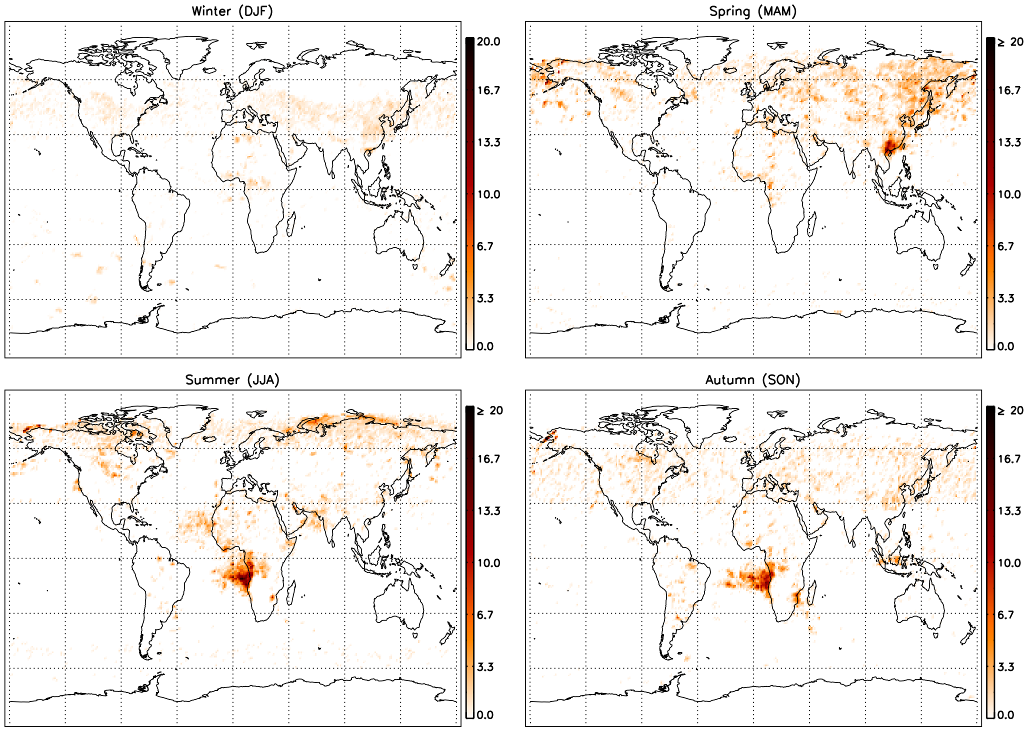

Figure 4. Global view of events having a SCIAMACHY AAI greater than 1 and a FRESCO+ cloud fraction greater than 0.5, between 2006 and 2008, as a function of season (top-left panel: (boreal) winter (Dec., Jan. and Feb.); top-right panel: spring (Mar., Apr. and May); lower-left panel: summer (Jun., Jul. and Aug.); lower-right panel: Autumn (Sep., Oct. and Nov.)

3. GLOBAL VIEW OF ABSORBING AEROSOLS AND CLOUDS EVENTS

In order to find the global occurrence of events like the one presented in section 2, SCIAMACHY AAI and SCIAMACHY/FRESCO cloud fractions (CF) were combined to find cloudy pixels with enough UV-absorbing aerosols in the scene to cause a high AAI. In Figure 4 the seasonal averages are shown of events having an AAI > 1 and a CF > 0.5 for the years 2006-2008. Two regions clearly stand out in this figure. In the boreal spring time a high number of events occur of south-east China, which originate from anthropogenic rice straw burning in the months March and April. And west of southern Africa a high number of events are found in the months June - September, which originate from agricultural biomass burning. In both regions the events are yearly recurring.

4. CONCLUSIONS

The combination of space-based instruments provides unique opportunities for the quantification of aerosol direct radiative forcing, in order to further understand the climatic impact of anthropogenic and natural aerosols on climate. From SCIAMACHY/FRESCO+ data cloudy scenes can be determined and combining them with SCIAMACHY/AAI the global events of UV-absorbing aerosols over clouds becomes apparent. Furthermore, the entire radiance and irradiance spectrum in the UV, visible and near infrared is available from SCIAMACHY, providing the possibility to directly quantify the absorption and radiative forcing from the aerosols. From Calipso the vertical structure of the scene can be determined, which is essential for modelling and understanding the processes involved.

In order to successfully determine the radiative forcing of UV-absorbing aerosols, the clean cloud spectra should be determined for the entire range of scenes encountered with the SCIAMACHY geometry. This will be done using a suit of SCIAMACHY clean cloud spectra and radiative transfer modelling.

ACKNOWLEDGMENTS

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