P1.17 AEROSOLS AND CLOUDS: IMPROVED KNOWLEDGE THROUGH SPACE BORNE LIDAR MEASUREMENTS

Dulce Lajas[1♣], Paul Ingmann[1], Tobias Wehr[1] and Albert Ansmann[2]
[1]European Space Agency, Science and Applications Department, ESA/Estec, Keplerlaan 1, 2200 AG Noordwijk, The Netherlands
[2]Leibniz Institute for Tropospheric Research, Permoserstrasse 15, 04318 Leipzig, Germany

1. INTRODUCTION

The role of aerosols and clouds in the Earth's climate system needs to be better understood due to their complexity on interacting with the atmospheric components and controlling the atmospheric dynamics. The characterization of aerosols and clouds requires improvement given the diversity of their microphysical and macrophysical characteristics, both in space and time. Clouds play a fundamental role in the balance of the Earth Radiation Budget (ERB) and in the hydrological cycle. Aerosol, in turn, behaves in a more complex manner as they can have a *direct* and *indirect* effect in the atmosphere. The *direct* effect is related with the chemical composition of the aerosol and does not interact with any other substances to modulate solar radiation. On the other hand, it can regulate to a great extent the development and evolution of clouds systems, via the so-called *indirect effect*. With the aim of ameliorating and understanding the role of aerosols and clouds in the global climate scenario, as single components and/or as a system, an extended database can be built taking advantage of a new set of space borne missions based on active and passive sensors. As such the global data of aerosols and clouds optical properties generated from CALIPSO, ADM-Aeolus and EarthCARE are envisaged to be part of a long term data base (2006-2016) to better qualify and quantify their role in the global climate.

CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) is a joint mission NASA/CNES launched on the 28th April 2006. The mission goal is to provide a new insight into the role that clouds and atmospheric aerosols have in modulating the global climate and atmospheric chemistry. ADM-Aeolus (Atmospheric Dynamics Mission - Aeolus) is a space-borne Doppler wind Lidar ESA mission focused on the retrieval of accurate wind profiles as a main geophysical product. From this mission there are additional geophysical products expected to be retrieved such as the cloud profile and cloud cover, aerosols extinction, etc. The launch is scheduled for the end of 2008. EarthCARE (Earth Clouds, Aerosol and Radiation Explorer) is implemented as one of ESA's Earth Explorer Core Missions (joint mission ESA/JAXA/NICT) to demonstrate the feasibility and usefulness of instrument synergy for cloud-aerosol-radiation interactions. The launch is scheduled for the end of 2012.

The usefulness of combining the data of these three missions would be enormous regarding the current insufficient understanding of the role of aerosols and clouds in the current climate and also crucial for improvement of NWP (Numerical Weather Prediction) models, *via* data assimilation, for global and regional applications.

2. SPACE BORNE ATMOSPHERIC LIDARS

2.1 *CALIPSO*

CALIPSO is a Lidar mission developed by NASA and CNES (Winker, 2003), part of the A-Train constellation which gathers sensors like CloudSat. The latter, takes on board a radar instrument focused on the study of cloud properties, such as their radiative properties. CALIPSO on the other hand is mainly concentrated on investigating the role of aerosols (*direct* or *indirect* forcing) on clouds and analyse of clouds that do not attenuate the Lidar signal, like thin cirrus. In a more general context, this mission will also provide long wave surface and atmospheric fluxes and a more comprehensive analysis of the cloud radiative feedbacks. This mission proposes to give a new insight into the role that clouds and atmospheric aerosols play in regulating Earth's weather, climate, and air quality. By measuring the vertical structure and properties of thin clouds and aerosols over the globe, this mission will provide new information that will help to improve weather and climate forecast models. More information on the properties of aerosols that are not currently operating observational satellites can be determined such as the altitude of aerosols layer in the atmosphere. In Figure 1 (top panel) is shown the first data obtained by CALIPSO corresponding to the 7th of June 2006. We see the cloud boundaries clearly defined, the Lidar signal attenuated by the thicker clouds and a good definition of the planetary boundary layer. Similar characteristics can be seen on a more recent image acquired on the 17th of September 2006 (Figure 1, bottom panel). CALIPSO Level 2 Products (Vaughan, 2004) expected regarding aerosols are the height and thickness of aerosols in the boundary layer (with a minimum detection threshold of $\beta > 2.5 \times 10^{-4} km^{-1} sr^{-1}$), optical depth ($\tau$), particle backscatter (β_a (z)) and extinction

♣*Corresponding author address*: Dulce Lajas, European Space Agency, Science and Applications Department, ESA/Estec, Keplerlaan 1, 2200 AG, The Netherlands, +31 (0)71 56 53094, e-mail: dulce.lajas@esa.int

coefficient (σ_a). In what respects the cloud products, CALIPSO is expected to provide their height, thickness, optical depth (σ), backscatter (β_c (z)), extinction (σ_c), ice/water phase, ice cloud emissivity (ε) and ice particle size. The height, thickness and optical depth (σ) of aerosols have an horizontal resolution of 5km (σ with a vertical resolution of 60m), the β_a (z) and σ_a have an horizontal resolution of 40km and vertical resolution of 120m up to 20km and 360m above 20km.

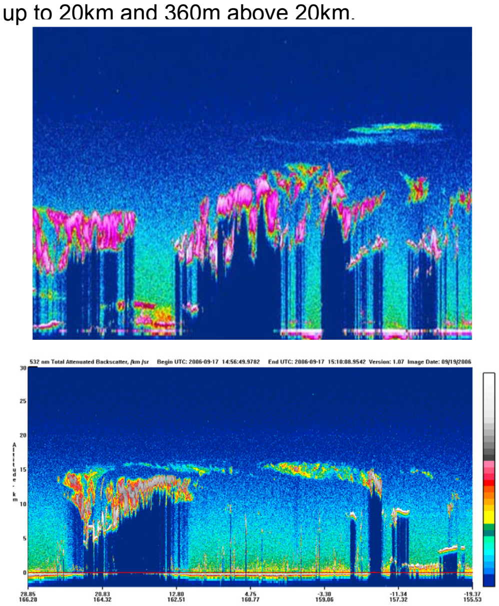

Figure1: First image of CALIPSO from the 7th of June 2006 (top panel). On the bottom panel is CALIPSO data from the 17th of September 2006 (NASA/CNES).

Regarding the cloud products the horizontal resolution varies between 1/3 and 5 km and the vertical resolution varies between 30 and 60m. The high horizontal resolution in the case of the cloud products is recommended due to the high spatial variability of clouds.

The CALIPSO payload consists of three co-aligned nadir-viewing instruments: CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization), IIR (Imaging Infrared Radiometer) and WFC (Wide Field Camera (Winker, 2003). CALIOP is a two-wavelength polarization-sensitive lidar providing high-resolution vertical profiles of clouds and aerosols and it three receiver channels: one measuring the 1064 nm backscatter intensity and the other two measuring orthogonally polarized components of the 532 nm backscattered signal. The wavelengths in the radiometer were selected to optimize the retrievals of CALIOP and the camera is used to match the band 1 of MODIS (Moderate Resolution Imaging Spectroradiometer), instrument on board of Aqua.

2.2 *ADM-Aeolus*

The ADM-Aeolus mission (ESA, 1999; Stofellen 2005) aims at improving the understanding of atmospheric dynamics and global atmospheric transport and global cycling of energy, water, aerosols and chemicals. The improved analysis of atmospheric dynamical state can be made through the assimilation of ADM-Aeolus' wind profile measurements. Therefore better initial conditions for weather forecasting and an improvement on the parameterisation of atmospheric processes in models are expected. Within this mission, taking into advantage the physical characteristics of Lidar retrievals it is also envisaged to derive additional geophysical products characterizing aerosols and clouds. The vertical resolution is 500 m in the boundary layer (0-2km), 1km in the troposphere (2-16km) and 2km in the stratosphere (16-20km).

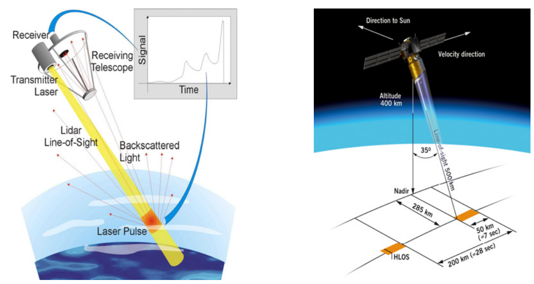

Figure 2: Winds are derived from the backscattered laser light, Doppler shifted by the movement of the scattering aerosols and molecules along the Lidar line-of-sight. Lidar altitude: 408 km; lidar wavelength 355 nm, laser pulse energy: 120 mJ; pulse repetition rate: 100 Hz; primary mirror diameter: 1.5 m and vertical resolution: 500 m – 2000 m.

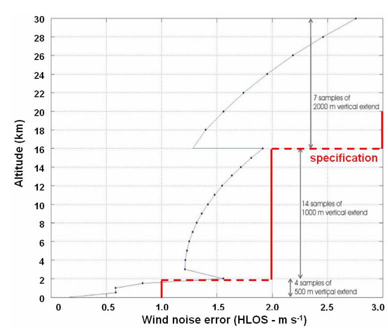

Figure 3: Expected performance of the ALADIN instrument with direct impact on the wind noise error.

By means of the High Spectral Resolution Lidar (HSRL) technique (Eloranta, 2005), it is possible the retrieval of geophysical optical properties of aerosols and clouds, such as cloud fraction and cloud top height, particle optical depths (*e.g.,* aerosols and cirrus layers), particle backscatter ratio profile (total-to-molecular backscatter ratio), particle backscatter coefficients profiles, particle extinction coefficient profiles and particle backscatter-to-extinction (Lidar) ratio. The calculation of the Lidar ratio can provide useful information on the estimation of the radiative forcing by aerosols.

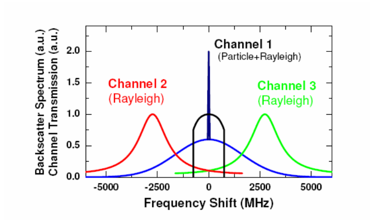

Figure 4: The HSRL has 2 molecular channels (Rayleigh) and a Mie channel (Ansmann, 2005).

The measurements with this instrument are based on the analysis of Doppler shift of back-scattered Doppler Wind Lidar signal. For the application of the HRSL method the two Rayleigh signals are used in the retrieval of the geophysical optical properties. In case of cross talk (contamination of the Rayleigh signal by the Mie signal), then the Mie signal is used to correct the Rayleigh signal for this contamination. With the HSRL method (backscatter and extinction) the particle backscatter and extinction coefficients can be retrieved independently. In Table 1 are shown the expected total uncertainties of the derived aerosols and cloud properties using the HSRL methodology.

Table 1: Expected total uncertainties in the backscatter (β_a) and extinction coefficients (σ_a), and Lidar ratio (S_a) for 140 (cirrus, CI) and 700–shot averages (aerosol, PSC), and vertical resolutions of 500 m (PBL aerosol), 1000 m (FT aerosol, CI), and 2000 m (stratospheric aerosol, PSC). Planetary boundary layer (PBL), lofted aerosol layers (FTA), cirrus (CI), stratospheric aerosol layer (SA), and polar stratospheric clouds (PSC) (Ansmann, 2005).

Layer (extinction value)	$\delta\beta_a/\beta_a$	$\delta\sigma_a/\sigma_a$	$\delta S_a/S_a$
PBL (σ_a=200 Mm^{-1})	5%–10%	10%–25%	15%–30%
FTA (σ_a=50 Mm^{-1})	5%–15%	25%–40%	30%–50%
CI (σ_a=200 Mm^{-1})	10%–15%	20%–25%	25%–35%
SA (σ_a=10 Mm^{-1})	5%–15%	>100%	>100%
PSC (σ_a=20 Mm^{-1})	10%–15%	50%–70%	50%–70%

The ADM-Aeolus lidar instrument ALADIN (Atmospheric Lidar Doppler Instrument) is based on a direct-detection Doppler lidar operating in the ultraviolet (UV) spectral region at 355 nm.

2.3 *EarthCARE*

The EarthCARE mission (ESA, 2004) has the objective to quantify the cloud-aerosol-radiation interactions by an improvement on the understanding of atmospheric dynamics, global atmospheric transport, and global cycle of energy, water, aerosols and chemicals. The retrieved data can be used to initialize NWP model forecasts and provide an off-line evaluation of the representation of clouds. Furthermore the knowledge of the small-scale physical processes within clouds and aerosols layers is expected to improve. Within this mission the impact of aerosols and clouds in climate and numerical weather forecasting was investigated via a data assimilation study (Janisková, 2001). Other geophysical properties are investigated such as the vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds, the vertical distribution of atmospheric liquid water and ice on a global scale, their transport by clouds and radiative impact; the cloud overlap in the vertical, cloud-precipitation interactions and the characteristics of vertical motion within clouds; the profiles of atmospheric radiative heating and cooling through a combination of retrieved aerosol and cloud properties.

The outcome of this mission would be beneficial for the improvement on the characterization of the macro and microphysical characteristics of aerosols and clouds and how these interact with radiation fields hoping for a better improvement of climate and NWP models. This mission has as scientific requirement to measure vertical cloud and aerosol profiles to derive instantaneous radiative fluxes with an accuracy of 10 Wm^{-2}.

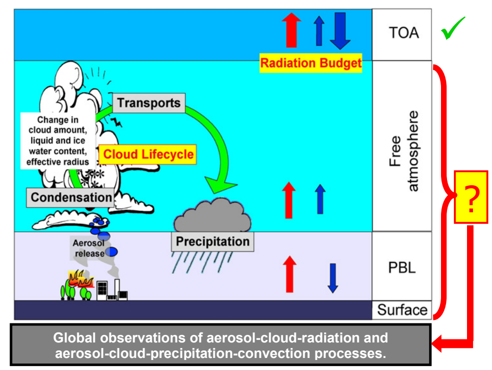

Figure 5: EarthCARE has the potential to retrieve global observations of aerosol-cloud-radiation and aerosol-cloud-precipitation-convection processes (PBL: planetary boundary layer, TOA: Top-of-Atmosphere).

The payload will be a Broad Band Radiometer (BBR), a Multi Spectral Imager (MSI), a Cloud Profiling Radar (CPR) and an Atmospheric Backscatter Lidar (ATLID). It is expected measurements from the single instruments and with a synergistic approach of the appropriate instruments combination.

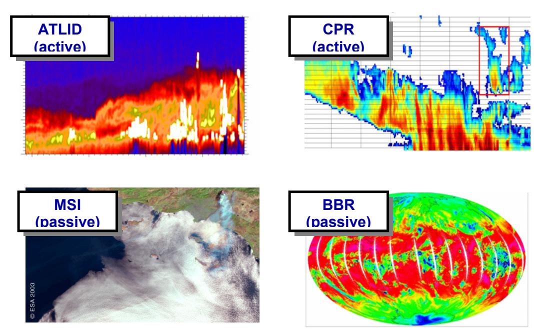

Figure 6: Instruments part of the EarthCARE mission. The ATLID (Lidar) and CPR (Radar) are active instruments and the MSI (Imager) and BBR (Radiometer) are passive instruments.

In particular, with the ATLID (high spectral resolution and depolarisation lidar) it is possible the retrieval of vertical profiles of extinction and characteristics of aerosols ,vertical profiles of liquid, super cooled and ice water, cloud overlap, particle size and extinction.

Furthermore, within the preparatory studies for EarthCARE, the EarthCARE simulator (Donovan, 2001) has been developed where simple and complex scenes with detailed cloud and aerosol microphysics can be modelled (appropriate retrieval algorithms have been implemented) and where the instrument characteristics like the noise, sampling and footprints can be included.

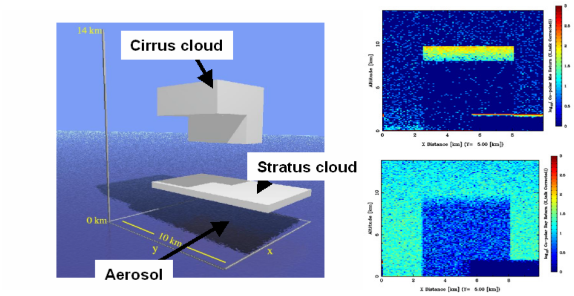

Figure 7: Example of a 'simple' scene created with the KNMI simulator (left panel). Example of scene Lidar results (full 3-D Lidar Monte-Carlo treatment; top right panel: Mie return; right panel: Rayleigh (molecular) return) (Donovan, 2001).

The simulator includes a 3-D Monte-Carlo radiative transfer code for long and short wave radiation calculation and also includes a multiple scattering module embedded, for the Lidar simulation tool.

3. CONCLUSIONS

The global data of aerosol and clouds optical properties generated from CALIPSO, ADM-Aeolus and EarthCARE missions are envisaged to be part of a long term data base (2006-2016), crucial for climate studies and NWP applications. Given the different spatial and temporal resolution of the aerosols and cloud products derived from these three missions a very well defined strategy needs to be in place to take advantage synergistic use of these data sets. Furthermore it is of fundamental importance that the assembling of this geophysical data can be made in such a way that it could be made operational for usage in regional and climate modelling. Within the context of a long data base one must not forget the *in situ* measurements network that would need to be adequately gathered in order to complete or complement the global space borne data base.

4. REFERENCES

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