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EarthCARE
Towards a Quantification of Cloud-Aerosol-Radiation Interactions

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1. INTRODUCTION

The *Earth Clouds, Aerosols and Radiation Explorer*, EarthCARE, has been selected for implementation as the sixth Earth Explorer Mission of the European Space Agency's Living Planet Programme [1]. The mission will measure three-dimensional structures of clouds and aerosols simultaneously with the respective outgoing broad band flux. These measurements would significantly contribute to the understanding of key parameters in the Earth radiation budget and quantify the impact of clouds and aerosols on radiation and flux. With this, EarthCARE would provide crucial data for the improvement of clouds and aerosols parameterisation in climate models and would furthermore contribute to improvements of numerical weather prediction [4]. With a target launch date in 2012, the mission would also provide data similar to A-Train missions CloudSAT and CALIPSO, thus supplementing and continuing their respective data sets of lidar and radar observations.

The mission is being implemented in cooperation with the Japanese Aerospace Exploration Agency, JAXA, which will provide one of the mission core instruments, the Doppler radar.

2. Mission Objectives and Observational Requirements

The primary mission objective is to improve the understanding of cloud-aerosol-radiation interactions. This shall be achieved through

- Global observations of vertical distributions of ice and liquid water in clouds, cloud overlaps, cloud-precipitation interactions and the characterisation of vertical motions within clouds;
- Global observations of vertical profiles of natural and anthropogenic aerosols, their radiative properties and interactions with clouds;
- The retrieval of atmospheric radiative heating and cooling through the combination of retrieved aerosol and cloud properties;
- The measurements of TOA radiances and retrieval of fluxes in relation of the observed clouds and aerosols.

The key parameters to be addressed are cloud and aerosol extinction and absorption properties, large-scale cloud structure (including cloud fraction and overlap) and cloud condensate content, particle size, shape and small scale cloud structures. Furthermore, EarthCARE will measure simultaneously measure TOA broad-band radiances and fluxes in order to relate them to the observed cloud and aerosol properties.

These mission objectives will be address through the measurements of

- Cloud properties: Cloud top and base height (including multi-layer clouds), fractional cloud cover and overlap (height resolved), occurrence of ice and liquid and super-cooled layers, vertical profiles of ice and liquid water content and effective ice, respectively droplet, sizes and ice particle shapes, small scale (around 1km) fluctuations of these properties;
- Aerosol properties: extinction profile, boundary layer height, presence of anthropogenic and natural aerosols;
- Vertical velocities inside clouds to characterise convection and ice sedimentation;
- Drizzle rain rates and estimates of heavier rainfall rates;
- Narrow-band and broad-band reflected solar and emitted thermal TOA radiances to retrieve fluxes.

3. Instruments Overview

The EarthCARE payload consists of four instruments, a high spectral resolution lidar, a Doppler radar, an imager and a broad-band radiometer. The Doppler radar will be provided by JAXA and NiCT, the other instruments and

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the satellite will be developed under ESA contracts.

One of the particular advantages of EarthCARE is the deployment of the four instruments on the same platform. Strict collocation requirements of their fields-of-view have been established in order to ensure the observation of the same atmospheric scene and enable synergistic retrievals of cloud and aerosol properties. The four instruments footprints (centres of the footprints of lidar, radar, radiometer and the imager's nadir pixel) will be collocated to an RMS accuracy of 350m (1000m for radiometer).

3.1 *Active Instruments: ATLID*

The *Atmospheric Lidar*, ATLID, is a single wavelength lidar operating in the UV with a high spectral resolution receiver that will separate the back-scattered particle (Mie) signal and molecular (Rayleigh) signal. A small laser beam footprint of around 6 m combined with a small telescope footprint (around 30m) is favoured to minimise multiple scattering effects and reduce solar background.

The laser transmitter operates at the 3rd harmonic of an Nd-YAG laser around 355 nm. This wavelength allows relatively high pulse energy to be used without exceeding eye safety constraints. A conventional design made of a low power oscillator and a power amplifier is proposed. The laser will benefit from the development activities of the ALADIN Doppler wind lidar of the ADM-Aeolus Earth Explorer, and in particular for the reference laser head the same design will be used.

The Mie-Rayleigh separation is performed by high resolution Fabry-Pérot étalons, a second unit of which is also used for the suppression of background radiation. This 'High-Spectral Resolution' technique uses the reduction in the molecular return to directly determine the extinction of aerosols and thin clouds, which is then used to correct the backscatter coefficient in the Mie channel for attenuation, and find the extinction to backscatter ratio of the lidar signal. Low Light Level CCD's (L3CCD) and Photo-Multiplier Tubes (PMT) are considered as candidate detectors.

Wavelength tunability is needed to ensure in-flight relative calibration of the aerosol channel and of the molecular channel and possibly, for Earth Doppler compensation. This can be achieved either with a wavelength tunable laser or wavelength tunable Fabry-Pérot étalon. A cross-polar channel will be implemented in order to support the cloud phase discrimination by using the depolarisation ratio.

The instrument performance is presented in Figure 1. The signal to noise ratio (SNR) is displayed as a function of altitude for both the Mie and Rayleigh signals. Two geophysical simulations have been simulated: (1) daytime conditions over a dense cloud deck; (2) nighttime conditions. The cirrus backscatter and extinction coefficients are $\beta=8\times10^{-7}$ $m^{-1}sr^{-1}$ and $\alpha=4\times10^{-5}$ m^{-1}, respectively. The full vertical resolution of 100m is considered for the Mie channel, while data are accumulated in the vertical direction over 300 m for the Rayleigh channel. A horizontal integration length of 10 km is assumed for both channels, in order to achieve the required performance. However, a pulse repetition frequency of 70 to 100Hz would lead to an approximate spacing of single measurements (i.e. single lidar shots) on ground of 100m or less, of which every measurement will be individually available for scientific analysis.

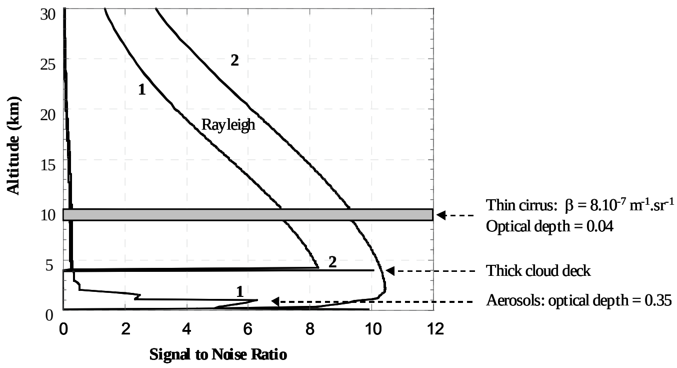

Figure 1: ATLID SNR as a function of altitude.

3.2 *Active Instruments: CPR*

The *Cloud Profiling Radar*, CPR, is a highly sensitive 94GHz cloud radar with Doppler capability.

The CPR measurements will provide profiles of ice and liquid water content throughout the cloud, in particular in regions where the lidar or passive optical sensors could not penetrate. The CPR will be designed to achieve a radar reflectivity sensitivity of -35dBZ (Z defined at 94GHz and 10°C) at TOA, for a 10 km along-track horizontal integration and -30dBZ over 1km horizontal integration, with a vertical resolution of 400m (sampling 100m). This would enable the radar to detect over 98% of radiatively significant ice clouds and 40% of all stratocumulus, for the 10km horizontal integration case [2].

CPR will have the capability to measure the Doppler signal from the vertical motion of cloud particles to an accuracy of 1m/s (for a horizontal signal integration over 10km, or possibly even shorter), in order to measure convection and ice sedimentation rates. A principle of pulse-pair Doppler radar measurements is based on the detection of the phase difference between echo signals from two consecutive radar pulses provided that the correlation between them is sufficiently high.

The radar will operate at a frequency of 94.05±0.0035GHz, and cover the atmosphere in the vertical domain from -0.5km up to 20km. Since the Doppler performance will very strongly depend on the correlation of consecutive pulses (i.e., the density of vertical sampling within a given vertical range), a limitation of the vertical observation range will have a large impact on the Doppler performance. Therefore, the vertical measurement range will have to be traded against the Doppler performance. While in tropical regions, frequent occurrence of high clouds can be expected, the upper altitude should be at 20km, while outside the tropics, this upper altitude limit can be lower in order to improve the Doppler performance. In polar regions, the altitude range will not extend above 12km, in mid-latitudes an intermediate value will be used. Thin high clouds, for example PSCs, would still be seen by ATLID, while they would be hardly or not at all visible for CPR anyway.

The radar has a fully redundant configuration of transmitter, receiver, and signal processor. The transmitter consists of a millimeter-wave klystron-tube unit and its high-voltage power supply. A quasi-optical (QO) technique is used for the antenna feeder to achieve high-performance antenna radiation characteristics and sufficient isolation between transmitted and received signals with low insertion loss. The QO feeder sub-system is located in the centre of the radar box.

The transmitter peak power will be 1800W. The polarization will be either linear or circular. The CPR main reflector will have a diameter of 2.5m necessary to achieve the required sensitivity and Doppler performance. The accuracy in pointing alignment is one of the critical design items, because EarthCARE relies on synergistic measurements among on-board sensors. The co-alignment between CPR and ATLID footprints is given the highest priority.

3.3 *Passive Instruments: MSI*

The *Multi-Spectral Imager*, MSI, is designed to provide images in the visible and infra-red spectral regions in support of the active instruments. It will provide scientific products for clouds and aerosols as well as the information of the cloud and aerosol layers. The MSI will also be used for the calibration of the BBR (broad-band radiometer, see below) and for supporting the conversion of BBR measured broad-band radiances into fluxes. The instrument will look at nadir with a spatial resolution of 500m and a swath width of 150km. The swath will be tilted in across-track direction in order to minimize the number of pixels affected by sun glint. The across-track coverage will be -35km to 115km relative to nadir.

The instrument makes use of the push-broom concept, with three independent cameras, operating in the visible and NIR, SWIR and TIR bands. The bands are listed in Table 1 together with the required radiometric resolution.

Band	Center µm	Width µm	SNR @ ρ=1.0	NEDT@ 293 K
VIS	0.659	0.02	500	
NIR	0.865	0.02	500	
SWIR 1	1.61	0.06	250	
SWIR 2	2.2	0.1	250	
TIR 1	8.8	0.9		0.25 K
TIR 2	10.8	0.9		0.25 K
TIR 3	12.0	0.9		0.25 K

Table 1: MSI spectral bands; ρ=reflectivity

Calibration is essential to meet the radiometric performance requirements. For the VIS/NIR and SWIR this will be done by means of a solar diffuser and a dark signal provided by the inside of the calibration mechanism. For the TIR bands this will be achieved by means of a cold space view and a blackbody.

MSI will at least provide horizontal structures of clouds, like cloud cover and specifically cloud type, cloud optical and microphysical properties over sea and land surfaces. As a goal requirement, MSI shall furthermore be able to provide measurements of aerosol optical properties and aerosol type over ocean to supplement the ATLID aerosol measurements in the across-track dimension. Furthermore, it should be able to retrieve accurately thin cloud optical thickness variation, water droplet and ice particles sizes, surface temperatures and thin cirrus measurements.

The combination of ATLID, CPR and MSI measurements shall enable synergistic retrievals of three dimensional cloud and aerosol fields with the highest vertical profile information content along the nadir track, where ATLID and CPR will measure.

3.4 *Passive Instruments: BBR*

The fourth instrument onboard EarthCARE is the *Broad-Band Radiometer*, BBR, which will measure the outgoing TOA radiances in a short wave (0.2-4µm) channel and a total wave (4-50µm) channel, from which the long wave contribution can be deduced. BBR will have three telescope, one pointing at nadir with a pixel size of 10km x 10km, while the other two telescopes point in fore- and aft-direction, respectively, under a 55° nadir angle, in order to enable a reconstruction of radiative fluxes from the radiance measurements. The nadir footprint will be centred at nadir and collocated with the MSI nadir pixel and the ATLID and CPR footprints to an RMS accuracy of 1km. The fore- and aft-view will also have a footprint pixel size of 10km x 10km and will cover the same ground scene with an across-track collocation accuracy of better than 1km. The along-track sampling will be 1km.

An on-board black body simulator will be used for calibration. Fluxes will be retrieved from the BBR radiance measurements using angular dependency models selected through scene identifiers provided by the measurements of the MSI and the active instruments. The goal requirement is to achieve a flux retrievals with an error of up to $10Wm^{-2}$, which will be composed of three statistically independent error sources, namely the instrument performance error (estimated at around $7Wm^{-2}$), an unfiltering error (removal of instrument filter functions from measured flux, estimated at around $2.6Wm^{-2}$) and radiance to flux conversion error, which will be very strongly scene dependent and could range from below $1Wm^{-2}$ to more than $10Wm^{-2}$.

The retrieval of BBR measurements and exploitations of the synergies with the MSI will benefit from CERES and ScaRaB experience of combining narrow- and broadband data to improve radiance-to-flux conversion and estimates of in-atmosphere and surface as well as TOA longwave and shortwave fluxes.

The synergistic analysis of the BBR and MSI will enable us to compare measured TOA broad-band radiances and retrieved fluxes with radiances and fluxes modelled from the three-dimensional cloud and aerosol fields synergistically retrieved from ATLID, CPR and MSI measurements.

4. Summary

The synergistic use of EarthCARE instruments will be essential for the full exploitation of their observations in order to address the mission objectives. Figures 2 and 3 summarise the science questions posed that led to the instruments configurations (above) and sketches how the synergistic exploitation of the measurements will enable science studies.

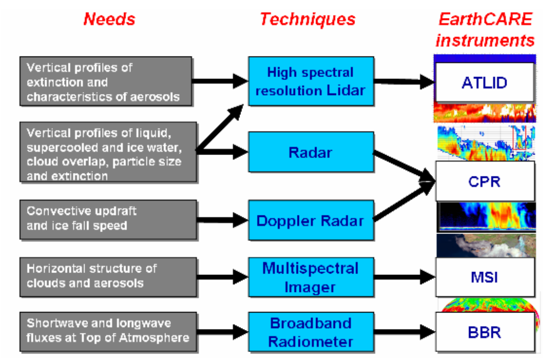

Figure 2: Science requirements leading to EarthCARE's payload configuration

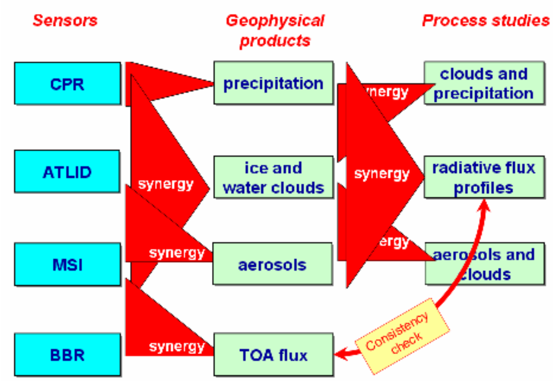

Figure 3: Synergistic use of the instruments' measurements will enable required science studies.

The experiences which are now being gained with the A-Train, in particular CloudSAT and CALIPSO, will be most valuable for the preparation of EarthCARE exploitation. In turn, the EarthCARE data set will provide a continuation in time of data sets similar to CloudSAT and CALIPSO, as well as broad-band radiance and flux measurements.

The start of the mission Phase B in 2007 will mark the beginning of ESA's satellite procurement activities. Technology pre-development activities as well as scientific preparatory studies are well underway, in particular the development of an end-to-end mission simulator [3], including a basic set of geophysical retrieval algorithms. Our preparatory science activities will now focus on the preparation of synergistic geophysical retrieval algorithms and the scientific exploitation of EarthCARE.

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