EarthCARE – The Earth Cloud, Aerosol and Radiation Explorer mission

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ABSTRACT

EarthCARE, the Earth Cloud, Aerosol and Radiation Explorer, is a joint European-Japanese mission which has been defined with the objective of improving the understanding of cloud-aerosol-radiation interactions so as to include them correctly and reliably in climate and numerical weather prediction models. The EarthCARE Mission has been approved for implementation as ESA's third Earth Explorer Core Mission. It is currently at the end of its Preliminary Design Phase (phase B). Launch is planned for the end of 2013.

This paper presents the EarthCARE programmatic status and the current mission design and performance. Furthermore, the mission end-to-end simulator and data processing up to level 2 (geophysical products) and related science activities will be outlined.

1. INTRODUCTION

1.1 Motivation

Radiation and climate are closely coupled, solar radiation being the source and thermal infrared radiation to space the ultimate sink of energy in the Earth-atmosphere system. While the radiative forcing due to anthropogenic greenhouse gases is relatively well known, significant uncertainties remain regarding the radiative forcing by aerosols, in particular concerning indirect aerosol effects on cloud radiative properties and the ability of clouds to produce precipitation. Radiative feedbacks by clouds (which change the climate sensitivity to radiative forcing) are poorly understood and a primary source of inter-model differences in equilibrium climate sensitivity [1]. Aerosols and clouds therefore provide the largest source of uncertainty in both the radiative forcing and in the climate response. The EarthCARE mission is motivated in part by the need to reduce these uncertainties and thereby to provide a more secure foundation for predictions of future climate change.

1.2 EarthCARE science objectives

EarthCARE has the overall objective of improving the understanding of cloud-aerosol-radiation interactions in the Earth atmosphere so as to include them correctly and reliably in climate and numerical weather prediction models.

Specifically, the scientific objectives of EarthCARE are [2], [3]:

• The observation of the vertical distributions of atmospheric liquid water and ice on a global scale, their transport by clouds and their radiative impact.

• The observation of cloud distribution (“cloud overlap”), cloud-precipitation interactions and the characteristics of vertical motions (convection and sedimentation) within clouds.

• The observation of the vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds.

• The retrieval of profiles of atmospheric radiative heating and cooling through the combination of the retrieved aerosol and cloud properties.

1.3 Overall requirements

EarthCARE will meet its science objectives by measuring globally and simultaneously the vertical structure and horizontal distribution of cloud and aerosol fields together with outgoing radiation. Cloud and aerosol properties relevant to atmospheric radiative transfer have to be measured. The goal is to reconstruct top-of-atmosphere (TOA) short and long-wave fluxes from the measured cloud and aerosol profiles to an accuracy of about 10 W/m^2 for a footprint of 10 km^2 [3]. Accuracy requirements for cloud and aerosol parameters have been derived from this requirement and further translated into instrument requirements.

2. THE EARTHCARE SYSTEM

2.1 Programmatic status and related missions

EarthCARE is a research mission within ESA’s Living Planet Program. It is being implemented as ESA’s third Earth Explorer Core mission. EarthCARE is a joint European-Japanese mission where JAXA provides the Cloud Profiling Radar and will operate its own Payload Data Ground Segment (PDGS). ESA is responsible for the system including the spacecraft, three European instruments, the launcher and the European Ground Segment, including Flight Operations Segment (FOS) and PDGS. Prime contractor for the EarthCARE satellite (including Level 1 processor development and satellite in-orbit verification) is Astrium GmbH (Germany). EarthCARE is currently (autumn 2009) at the end of its Preliminary Design Phase (phase B). This will be followed by the implementation phase (phase C/D) with a target launch date at the end of 2013. EarthCARE is being designed for an in-orbit lifetime of 3 years, with a margin of one additional year of operations.

The synergistic use of space-borne lidar and radar for cloud and aerosol studies is presently being pioneered by the Calipso [4] and CloudSat [5] missions launched 2006 into NASA’s ‘A-train’ (see, e.g., [6], [7], and references therein).

2.2 System overview

EarthCARE will acquire the required measurements in a synergistic way using a combination of two active and two passive instruments on a single satellite platform. The EarthCARE payload consists of the high spectral resolution backscatter cloud/aerosol lidar (ATLID) operating at 355 nm, the 94 GHz Doppler cloud profiling radar (CPR) provided by JAXA/NICT,

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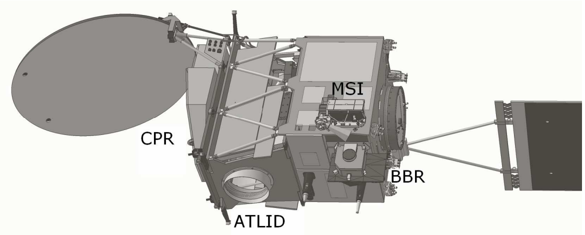
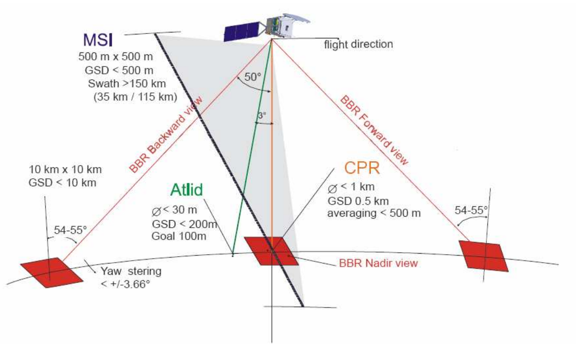
the multi-channel spectral imager (MSI), and the total-wave and short-wave broad-band radiometer (BBR). The two active instruments ATLID and CPR provide vertical profiles of cloud and aerosol parameters along the satellite track (2D, YZ). MSI measures horizontal fields of cloud and aerosol (2D, XY), thereby providing the scene context for the two active instruments. The BBR provides broadband radiances at the top of the atmosphere.

Figure 1: *The EarthCARE satellite*



ATLID, CPR, and MSI measurements together can be used in models to reconstruct the (3D, XYZ) cloud-aerosol-radiation field. Model derived TOA radiances or fluxes can be compared to radiances or fluxes derived from BBR measurements. Synergistic use of instruments necessitates stringent requirements on co-registration between instruments. The required thermo-mechanical stability will be ensured by the use of a Carbon fiber reinforced polymer (CFRP) structure for the satellite platform. EarthCARE will have an overall size of about 3.2x2.5x4.0 m in stowed configuration and a total launch mass (including propellant) of 2.0 tons.

Figure 2: *Observation geometry*



EarthCARE will fly on a near-circular sun-synchronous retrograde polar orbit at a mean local solar time of 1400h at descending node equator crossing. The current baseline selection is a 389 orbits/25 days nominal orbit at a mean geodetic altitude of 408 km, and a 140 orbits/9 days calibration orbit at a mean geodetic altitude of 410 km. This relatively low altitude has been chosen to optimise the performance of the active instruments. The nominal orbit achieves global coverage with the MSI swath within one repeat cycle of 25 days. The calibration orbit shortens the repeatability of overpasses to 9 days which is advantageous when regular passes over dedicated calibration sites are required.

3. INSTRUMENTS

3.1 ATLID

The Atmospheric Lidar (ATLID) is a high spectral resolution (HSRL) lidar operating at 355 nm, the tripled frequency of a Nd:YAG laser. A HSRL lidar differentiates contributions from particles (Mie scattering) and molecules (Rayleigh scattering) in the backscattered signal using the fact that the Doppler broadening of (fast) molecules is much wider than that of (slow) particles. A narrow bandwidth Fabry-Perot Etalon around the central wavelength is used to separate Mie and Rayleigh signals. This separation allows backscatter and extinction to be measured independently. In addition, the two polarisation directions of the Mie signal are measured separately.

The optical instrument units are: the transmitter including the reference laser head and power laser head (and a second set of laser heads for full redundancy), an afocal Cassegrain telescope for collecting the back-scattered light, and a receiver containing the focal plane optics and CCD detectors coupled via fibre optics. ATLID characteristics and instrument budgets are summarised in Table 1. Budgets for mass and data rate in the tables below include margins.

Table 1: *ATLID characteristics and budgets.*

Wavelength	355 nm
Channels	Rayleigh, Mie co-polar, Mie cross-polar
Lidar sensitivity (minimum detectable backscattering coefficient)	$8 \cdot 10^{-7}$/m·sr (#)
Cloud optical depth sensitivity and range	0.05 – 2 (#)
Aerosol optical depth sensitivity and range	0.05 – 2 (##)
Vertical range	-0.5 to 40 km
Vertical sampling	100 m up to 20 km, 200 m above
Horizontal sampling	100 m raw 200 m effective (*)
Receiver footprint on ground	< 30 m
Pulse energy	30 mJ
Pulse repetition rate (corresponding to the horizontal sampling above)	74 Hz
Pulse duration	< 35 ns
Depointing from nadir	3° (backwards)
Mass	389 kg
Data Rate	642 kbit/s

(#) For 10 km along-track integration, 1km thick cirrus
(##) For 100 km along-track integration, 1km layer in planetary boundary layer
(*) Two pulses will be co-added resulting in an effective horizontal sampling of 200 m.

3.2 CPR

The Cloud Profiling Radar (CPR) is a high power W - band Doppler radar. Its pulses penetrate deep into lower cloud layers where optical radiation is already attenuated. Its sensitivity has been chosen such that it will detect 98% of radiatively significant ice clouds. CPR will be the first space-borne Doppler radar. Doppler measurements employ the phase shift between pulses (pulse-pair method) rather than frequency shifts (which are too small to be directly measured) to derive vertical motion of cloud particles.

The CPR will operate with a variable pulse repetition frequency (PRF) adapted to the varying satellite altitude and maximum observation altitude (12/16/20 km depending on latitude). The strategy is to maximise the PRF in order to improve the quality of the Doppler signal while still keeping the PRF low enough to avoid range ambiguities. The CPR will be calibrated once per month using a number of calibration modes. In one of them the satellite performs a ±10° roll manoeuvre while the CPR sweeps the sea surface. Another one uses return echoes of ground transponders.

Table 2: *CPR characteristics and budgets.*

Operating frequency	94.05 GHz
Antenna subtended aperture	2.5 m
Antenna gain	65.3 dB
Peak transmit power at antenna input port (beginning of life)	1430 W
Pulse repetition frequency	6100 – 7500 Hz
Transmit pulse width	3.3 µs
Dynamic range	-36 to +20 dBZ
Doppler accuracy	1.0 m/s (##)
Vertical range	-1 to 20 km
Vertical sampling	100 m
Vertical resolution	500 m
Horizontal sampling	500 m (*)
Beam footprint on ground	< 800 m
Mass	245 kg
Data Rate	270 kbit/s

(#) For 10 km along-track integration at top of atmosphere
(##) For 10 km along-track and minimum reflectivity -19 dBZ
(*) This means, about 500 pulse echoes (depending on PRF) have to be co-added on board

3.3 MSI

The multi-spectral imager (MSI) is a pushbroom imager measuring TOA radiances in seven spectral bands from the visible to the thermal infrared. The 150 km wide swath is tilted towards the anti-sun direction (East) in order to minimise sunglint. Two separate units are mounted on the optical bench, one comprising the 4 VIS/NIR/SWIR (VNS) channels, the other one the 3 thermal infrared (TIR) channels. Linear (1D) Si and InGaAs detector arrays are used in the VNS channels while the TIR channels are equipped with 2D microbolometer arrays.

Table 3: *MSI characteristics and budgets.*

Swath (relative to nadir)	-35 to + 115 km
Horizontal sampling at nadir	500 m
Radiometric accuracy	
VIS/NIR/SWIR channels	5 %
TIR channels	1 K
Spectral band	**Centre (width)**
Visible (VIS)	670 nm (20 nm)
Near-infrared (NIR)	865 nm (20 nm)
Shortwave infrared (SWIR) 1	1.65 µm (0.05 µm)
Shortwave infrared (SWIR) 2	2.21 µm (0.1 µm)
Thermal infrared (TIR) 1	8.80 µm (0.9 µm)
Thermal infrared (TIR) 2	10.8 µm (0.9 µm)
Thermal infrared (TIR) 3	12.0 µm (0.9 µm)
Mass	48 kg
Data Rate (day/night)	772/386 kbit/s

3.4 BBR

The broad-band radiometer (BBR) measures TOA radiances in 2 broad spectral bands, total wave (solar+earth) and short wave (solar). The long wave (earth) radiance can then be derived as the difference of the two. Short wave measurements are performed inserting a quartz filter into the optical path. BBR measures in three viewing directions (rear/nadir/forward) thereby enabling reconstruction of fluxes from the measured readiances. It uses linear microbolometer array detectors creating pushbroom images at a ground sampling distance of approximately 5/6km along track. From this, 10x10 km^2 footprints are reconstructed in ground processing.

Table 4: *BBR characteristics and budgets.*

Viewing angles (at satellite, rear/nadir/forward)	-50.27°, 0, +50.27°
Spectral band	**Spectral range**
Short wave	0.25 – 4 µm
Total wave	0.25 – 50 µm
Radiometric accuracy	
Short wave	2.5 $W/m^2.sr$
Long wave	1.5 $W/m^2.sr$
Mass	41 kg
Data Rate (nominal)	131 kbit/s

4. DATA PROCESSING AND PRODUCTS

Level 1 (L1) and level 2 (L2) algorithms and products are being developed in Europe and Japan. CPR L1 development and operational processing is under JAXA responsibility while L2 development and processing is a joint European-Japanese activity. For the European processors gradual evolution of the software from engineering (L1) / scientific (L2) processors to operational processors is foreseen. European instrument simulators and L1 processors are being developed within the main industrial contract. L2 algorithms are being prepared in dedicated scientific studies. All products will be delivered together with geolocation, error estimates, and quality flags.

4.1 Level 1 processing and products

The primary level 1b products are: attenuated backscatter profiles for the ATLID, reflectivity and Doppler profiles for the CPR, radiometrically calibrated radiances and brightness temperatures for the MSI, and radiometrically calibrated and spatially integrated broadband radiances (short wave and long wave) for the BBR. Special efforts will be made during L1 development to facilitate synergistic use of the L1 products.

4.2 Level 2 processing and products

A tentative list of EarthCARE L2 products based on inputs from the Mission Advisory Group is given in Table 5. Standard spatial grids foresee 1 and 10 km resolutions horizontally and 100 m and 500 m vertically. In addition to vertical profiles, layer integrated products and layer boundary products (e.g., cloud base height) are being considered.

Table 5: *EarthCARE level 2 products (preliminary)*

Single instrument products (level 2a)	
ATLID	Feature mask (significant returns) Extinction, backscatter, depolarisation Target classification Aerosol extinction, backscatter, type Ice water content (empirical)
CPR (*)	Feature mask (significant returns) Target classification (hydrometeor types) Ice water content / effective radius Liquid water content / effective radius Vertical motion Precipitation/snow
MSI	Cloud flag/cloud type Cloud phase Cloud top temperature/height Effective cloud particle radius Aerosol optical thickness (ocean/land)
BBR	Unfiltered radiances (#)
Synergistic products (level 2b) (##)	
BBR/MSI	Unfiltered radiances
ATLID/MSI	Cloud top height Aerosol optical thickness, aerosol type
ATLID/CPR /MSI	Target classification Ice water content / effective radius Liquid water content / effective radius Aerosol extinction / type Rain water content / rain rates Cloud fraction and overlap Reconstructed TOA radiances Flux and heating rate profiles

(*) For a number of parameters, there could be two types of CPR products, one based solely on reflectivity, the other one using Doppler signals in addition.

(#) To be confirmed. Usually, unfiltering requires scene identification from the MSI which make unfiltered radiances a level 2b BBR/MSI product, however, a new algorithm has been proposed using only BBR L1 data.
(##) More instrument combinations are conceivable. Only the most important are listed here.

4.3 End-to-end mission simulator

European L1 and L2 processor developments make use of an existing end-to-end mission performance simulator for EarthCARE, ECSIM [8]. In this simulator, a sequence of models from scene generation via radiative transfer, instrument model, L1 and L2 processor can be run in a unified framework. New developments provide “plug-in” modules for this framework. Prescribing the development environment and a number of interfaces by the mandatory use of the ECSIM facilitates a harmonisation of EarthCARE processor developments across the multitude of providers. Furthermore, it allows L1 and L2 algorithm developers to share a common set of test scenarios created by ECSIM models and enables them to perform end-to-end performance tests.

REFERENCES

[1] IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[2] Reports for Mission Selection. The Six Candidate Earth Explorer Missions. Vol. 1: EarthCARE – Earth Clouds, Aerosols and Radiation Explorer. ESA SP-1279(1), 2004.

[3] EarthCARE Mission Requirements Document. ESA-RS-ESA-SY-012. Prepared by the EarthCARE Mission Advisory Group and T. Wehr (ed.).

[4] Winker, D. M., W. H. Hunt, and M. J. McGill (2007), Initial performance assessment of CALIOP, Geophys. Res. Lett., 34, L19803, doi:10.1029/2007GL030135.

[5] Stephens, G. L., *et al.* (2008), CloudSat mission: Performance and early science after the first year of operation, J. Geophys. Res., 113, D00A18, doi:10.1029/2008JD009982.

[6] Mace, G., *et al.* (2009), A description of hydrometeor layer occurrence statistics derived from the first year of merged Cloudsat and CALIPSO data, J. Geophys. Res., 114, D00A26, doi:10.1029/2007JD009755.

[7] Sato, K., *et al.* (2009), 95-GHz Doppler radar and lidar synergy for simultaneous ice microphysics and in-cloud vertical air motion retrieval, J. Geophys. Res., 114, D03203, doi:10.1029/2008JD010222

[8] Donovan, D., *et al.* (2008), ECSIM Model and Algorithms Document. KNMI, De Bilt and Deimos Space, Madrid.