THE ESA EARTHCARE MISSION: MISSION CONCEPT AND LIDAR INSTRUMENT PRE-DEVELOPMENT

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1. INTRODUCTION

The EarthCARE (Earth Clouds, Aerosols, and Radiation Explorer) mission has been selected as the 6th Earth Explorer missions of ESA's Living Planet programme [1]. Understanding both natural and anthropogenic climate change is of paramount importance in the 21st century. The predictions of future climate rely on global numerical models, all of which have limitations arising from the parameterisation of sub-grid scale processes. Clouds are a key feature of weather and play a crucial role in both the hydrological cycle and the energy budget of the Earth. Despite their importance there are still large deficiencies in the representation of clouds, aerosols and radiative transfer in atmospheric models and these are the source of large uncertainties in the predictions of climate change. Advances in the representation of the radiative effects of clouds and aerosols will be made possible with EarthCARE.

2. MISSION OBJECTIVES

The EarthCARE mission has been specifically defined with the basic objective of improving the understanding of cloud-aerosol-radiation interactions in order to include them correctly and reliably in climate and numerical weather prediction models. The goals are to retrieve vertical profiles of clouds and aerosols, and the characteristics of their radiative and micro-physical properties to determine flux gradients within the atmosphere and fluxes at the Earth's surface, as well as to measure directly the fluxes at the top of the atmosphere and also to clarify the processes involved in aerosol-cloud and cloud-precipitation-convection interactions. Specifically, the scientific objectives are:

1. The observation of the vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interactions with clouds.
2. The observation of the vertical distributions of atmospheric liquid water and ice on a global scale, their transport by clouds and their radiative impact.
3. The observation of cloud distribution ('cloud overlap'), cloud-precipitation interactions and the characteristics of vertical motions within clouds.
4. The retrieval of profiles of atmospheric radiative heating and cooling through the combination of the retrieved aerosol and cloud properties.

EarthCARE will meet these objectives by measuring simultaneously the vertical structure and the horizontal distribution of cloud and aerosol fields together with the outgoing radiation over all climate zones.

The EarthCARE payload is thus composed of four instruments: an ATmospheric backscatter LIDar (ATLID), a Cloud Profiling Radar (CPR), a Multi-Spectral Imager (MSI) and a Broad Band Radiometer (BBR).

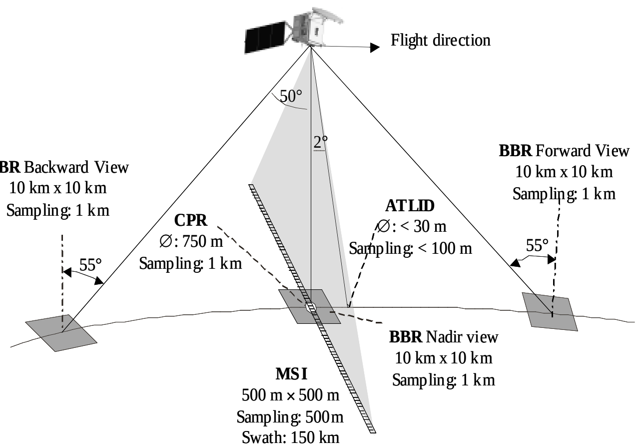

Figure 1: EarthCARE observation geometry

This instrument suite has been optimised to provide co-located samples of the state of the atmosphere along track. To this end, the centres of the instrument footprints will be located as close as possible to ensure good co-registration. The observation geometry is depicted in Figure 1.

3. PAYLOAD

3.1 Atmospheric Lidar

A single wavelength lidar with a High-Spectral Resolution receiver separating Rayleigh (molecular) and Mie (cloud and aerosol particles) backscatter returns has been selected. Table 1 summarizes the observation requirements applicable to ATLID. A telescope footprint smaller than 30 m is favored to minimise the multiple scattering effects and to reduce the solar background noise by reducing the telescope field of view. An additional cross-polarisation channel is implemented.

Table 1: ATLID observation requirements

	Mie co-polar channel	Rayleigh channel	Mie cross-polar channel
Cirrus optical depth	0.04		
Backscatter sr^{-1} m^{-1}	8 10^{-7}		2.6 10^{-5}
Vertical resolution	100 m	300 m	100 m
Horizontal resolution	10 km		
Required Accuracy	50%	15%	50%

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.

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.

The main characteristics of the instrument are given in Table 2.

Parameter	Unit	Value
Laser pulse energy @ 355 nm	mJ	19 …25
Pulse Repetition Frequency	Hz	70 …100
Spectral line width (FWHM)	MHz	50
Telescope diameter	m	~ 0.6
HSR etalon bandwidth	pm	0.3 to 0.5
Detector		PMT, L3CCD

Table 2: ATLID design parameters

Figure 2 illustrates the mechanical configuration of the monostatic concept.

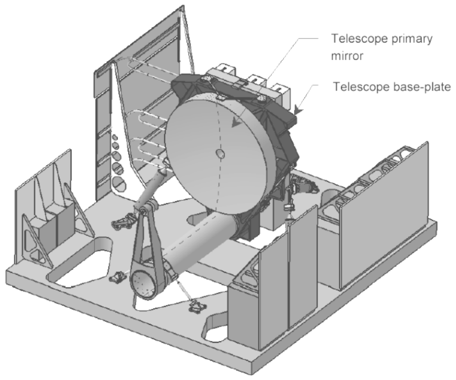

Figure 2: ATLID mechanical architecture

3.2 Cloud Profiling Radar

The objective of the CPR is to provide vertical profiles of cloud structure along the sub-satellite track. A unique feature of the CPR is the emission of microwave pulses that penetrate deep into lower cloud layers, which cannot be viewed by passive optical sensors or reached by the lidar. The CPR is designed to attain a high sensitivity. In addition, a unique concept of Doppler measurement of cloud particles is newly introduced in this programme. A principle of pulse-pair Doppler radar measurement 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 accuracy in Doppler velocity in the radial direction expected here is better than 1 ms^{-1}. A correction technique is proposed which uses the Doppler velocity estimate of the surface back-scatter as a zero-Doppler reference in order to cancel biases caused by variation in satellite attitude and altitude.

Table 3 presents a summary of the CPR parameters.

Parameter	Value
Frequency	94.05 GHz ± 3.5 MHz
Polarisation	Linear or circular
Transmitter power	1800 W (peak)
Radar beam pointing	Fixed vertical (nadir)
Vertical range	-0.5 to 20 km (-0.5 to 12 km at high latitude beyond ± 60°)
Vertical resolution	400 m (sampling 100 m)
Instantaneous footprint	~ 750 m
Sensitivity	≤ -36 dBZ at TOA (over 10 km)
Antenna aperture size	≤ 2.5 m diameter
Doppler velocity accuracy Doppler measurement range	≤ 1 ms^{-1} for cloud vertical motion ± 10 ms^{-1}

Table 3: CPR design parameters

An overall view of the CPR configuration with an antenna main reflector of 2.5 m in aperture diameter is shown in Figure 3. The reflector size is particularly important for the performance in Doppler measurement as well as for sensitivity. The large, lightweight antenna reflector, with high surface accuracy, is integrated with an accurate deployment mechanism.

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.

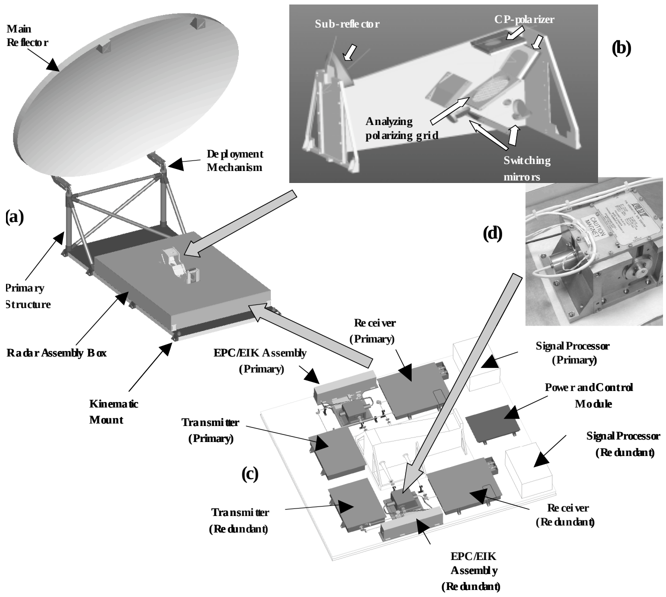

Figure 3: (a) Overall CPR view, deployed; (b) Quasi-optical feeder consisting of grids and mirrors; (c) instrument modules within the radar assembly box; (d) High power amplifier (Extended Inter-action Klystron, EIK)

3.3 Multi-Spectral Imager

The MSI is designed to provide images in the visible and infrared spectral regions in support of the active instruments. It will provide scientific products for clouds and aerosols as well as the contextual information of the cloud and aerosol layers. The MSI will also be used for the calibration of the BBR. The instrument will look at nadir with a spatial resolution of 500 m and a swath width of 150 km.

The instrument makes use of the push-broom concept, with three independent cameras, operating in the VNIR, SWIR and TIR bands. The bands are listed in Table 4 together with the required radiometric resolution. The VIS/NIR detectors are of Si CCD type, whereas a cooled MCT array will be used for the SWIR bands. Uncooled micro-bolometers will be employed as TIR detectors. The detectors will be complemented by front-end electronics containing the read-out electronics, pre-amplifiers and analogue to digital converters.

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 4: MSI spectral bands

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. For the TIR bands this will be achieved by means of a cold space view and a blackbody. The configuration of the instrument concepts is shown in Figure 4 where the VNIR/SWIR and TIR optical heads are visible on either side of the optical bench.

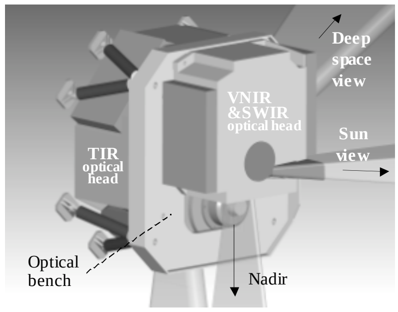

Figure 4: MSI mechanical configuration

3.4 Broad Band Radiometer

The BBR will provide an estimate of the reflected (short-wave, 0.2–4 µm) and emitted (longwave, 4–50 µm) fluxes at the top of the atmosphere. As the instrument can only measure radiance, the conversion to flux will be performed analytically by means of angular dependence models (ADM). Therefore three views in the along track direction are used, namely nadir, forward and backward with observation zenith angles (OZA) of 55 degrees. The size of the three footprints will be 10 km by 10 km. Co-registration to 10% of the foot-print size of all views is required.

The instrument is a two-channel radiometer, in which the LW channel is obtained by subtracting the SW component from a channel covering the complete spectral range. Dedicated telescopes are used for all views. Instrument performance is presented in table 5 and configuration is shown in Figure 5.

Error Contribution	Flux $W.m^{-2}$
Instrument	7.2
Unfiltering	2.6
Flux conversion	4.0
Total (1σ)	8.7

Table 5: BBR performance

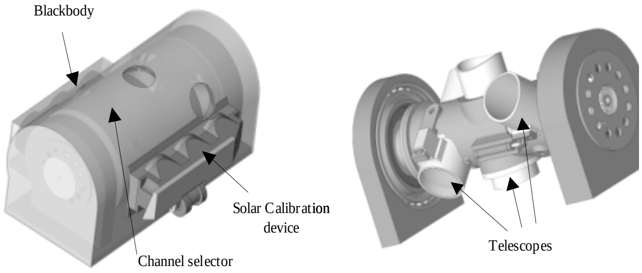

Figure 5: BBR configuration. The three telescopes view the Earth in three different along-track directions: nadir, forward and backward. The channel selector is used to modulate the input flux of the pyro-electric detectors.

4. SATELLITE

The satellite configuration is constrained by the accommodation of the instruments, which all require an unobstructed Earth view. In some cases, deep space and occasional sun views are also necessary for instrument calibration. The two active instruments with their rather high mass and volume clearly drive the concept. Furthermore, sufficiently large areas need to be made available for the radiators to dissipate instrument heat.

A stacked configuration has been selected as a result of trade-offs covering mass, instrument accommodation and also assembly/integration considerations. Structural deformations resulting from manufacturing tolerances and in-orbit environment are minimised, as the load paths between the instruments are rather short. This will result in the co-registration requirements to be met without resorting to complex design and manufacturing techniques. Two satellite concepts have been investigated for which the overall deployed configuration is shown in Figure 6. The active instruments are accommodated on top of the service module, the passive ones on the nadir panels of the lidar and the service module.

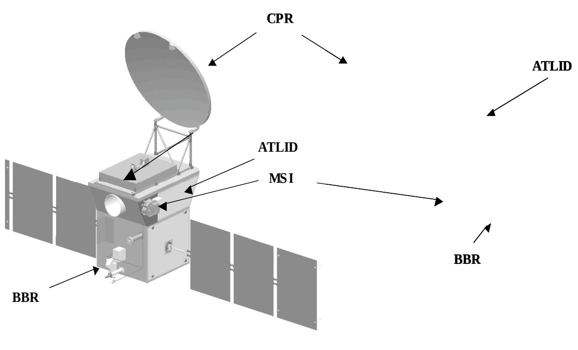

Figure 6: EarthCARE two possible configurations.

5. INSTRUMENT PRE-DEVELOPMENT

Following the selection for implementation of the EarthCARE mission and the development risk analysis performed during phase A, a pre-development programme for instruments was undertaken to reduce the technical and programmatic risks of the mission. The objectives of this pre-development programme are to validate the technologies used in the flight design, evaluate the flight-worthiness of its major equipment and critical component and verify the overall instrument performance. The pre-development programme is mainly focussing on the ATLID instrument and encompasses:

- Developments of the laser head of a frequency tripled Nd:YAG laser providing 25-30 mJ per pulse at 355 nm, operating at 70-100 Hz PRF.
- Developments and assessment of pulsed laser diode bars and stacks used for pumping the laser transmitter.
- Developments of the lidar receiver, consisting of the critical sub-systems as the filtering stage, the detector and the acquisition chain, verification of the receiver functions and performance.
- Demonstration of electron-multiplication CCDs devices (so-called L3CCD) optimised for fast sampling of lidar signals at very low noise.
- Testing of the Multi-Spectral Imager and BroadBand Radiometer infra-red detectors

6. CONCLUSIONS

EarthCARE, planned for launch in 2012, will be realised through an extensive cooperation between ESA, JAXA and NiCT covering both technical and scientific areas. ESA will contribute the platform, the ground segment, the launcher and three instruments, namely the Atmospheric backscatter Lidar (ATLID), the Broad Band Radiometer (BBR) and the Multi-Spectral Imager (MSI), while JAXA and NiCT will contribute the Cloud Profiling Radar (CPR). The instruments embarked on EarthCARE are all expected to have an operational potential in future weather and climate monitoring missions.

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REFERENCES

1. EarthCARE Mission, Report for selection, ESA-SP-1279 (1).
2. The ESA Earth Explorer EarthCARE Mission, SPIE vol. 5882, Sept.2005.