EarthCARE Project

System Requirements Document

for Phases B, C/D, E1

Prepared by EarthCARE Team

Checked by D. Maeusli

Approved by A. Lefebvre

ESTEC
Noordwijk
The Netherlands

DOCUMENT CHANGE RECORD

ISSUE/REV.	DATE	CHANGE
1	02 February 2007	EarthCARE ITT Release
1A	20 May 2008	§ 2.1 correction of AD-27 title § 2.2 ND-26 (PSS-04-253 replaced by ECSS-E-50-14), ND-27 (title correction) and ND-99 (refered in § 7.2.6.1.2 req MEC-FC-13) § 2.1 addition of ECSIM ID-13 & ID-14 § 4.1.1 OBS-OR2 (requirement locat time limited to 13:45-14:00 range and removal of morning option); OBS-OR-4 (Table 4-1 (descending node & local time & addition of a Design Case orbit column plus a note explaining Design Case range limits); OBS-OR-5 (ATLID margin revised); OBS-OR-6 (geometric parameters vs Design-case orbits & MSI swath) § 4.1.3: OBS-RO2 (reduced MLST range to 13:45-14:00 plus replacement of TBD in req. plus table 4-2; second part of req. listed as a note) § 4.1.4: OBS-RO4 (reduced MLST range to 13:45-14:00 plus replacement of TBD in req. plus table 4-3; second part of req. listed as a note) § 4.2 (req. renumbering to remove duplication of OBS-SP4 ref.) § 5.2.1 Depolarisation Ratio definition § 5.3.10 CPR-DR-22 (TBD replaced by figure with explanative note); CPR-DR-54 (correction of pitch pointing value plus inclusion of a goal); CPR-DR-62 (TBD replaced by TBC STEP) § 5.3.12 (CPR-SP-1 is linked to CPR-FO12, and not to -11) § 5.5.6.2 BBR-SR-2 Table 5.5-2 (max value of λ-axis in graph corrected to 5 for being in line with underlying table values) § 5.5.7 (BBR-LW-1: LW channel range value – correction of lower value) § 6.7 OPS-IC-5 (req. wording changed/clarified) § 7.2.5 (correction of wrong reference § 7.2.4 into § 7.2.5) § 7.2.6.1.2 (req MEC-FC-13 refers to ND-99) § 7.3.5.6 DHS-MM-25 (note extended to address packet interleaving on X-band) § 7.3.6.3 COM-HR-6 deletion (requirement applying to COM HR terminal on ground only); COM-HR-8 (deletion of smaller antenna reference) § 7.3.7.2 & Annex 4 (correction of requirement references changed from HAR-DE-xx into HAR-FU-xx) § 7.4.1 AIT-GS-17&18 (EGSE equipment initially referred as SEIS is renamed into PISA) § 8.2 (edito) § 8.3 DPR-SI-11 (addition of ID-13)

		§ 8.4 DPR-GP-7 (addition of ID-13) and DPR-GP-14 (use of a separate ECGP module for CCDB updates) Annex 2 ARDL (added); CDB (removed as duplicating CCDB); PISA (renaming of former EGSE SEIS equipment); SEIS (deletion) Annex 3 (HAR-FU)

Table of Contents

1 Introduction and Scope of Document

Earth Explorer Missions are part of the Earth Observation Envelope Programme (EOEP). They are missions led by the European Space Agency to cover primary research objectives. The EarthCARE Mission has been approved for implementation as the third Earth Explorer Core Mission. The mission will be implemented in collaboration with Japanese Aerospace Exploration Agency who will provide one of the core Instruments.

The EarthCARE mission has been specifically defined with the basic 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. Specifically, the scientific objectives are:

- The observation of the vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds.
- 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 within clouds, and
- 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 horizontal distribution of cloud and aerosol fields together with outgoing radiation over all climate zones. More specifically, EarthCARE will measure:

- Properties of aerosol layers:
  - (a) The occurrence of aerosol layers, their profile of extinction coefficient and boundary layer height, and
  - (b) The presence of absorbing and non-absorbing aerosols from anthropogenic or natural sources.
- Properties of cloud fields:
  - (a) Cloud boundaries (top and base height) including multi-layer clouds.
  - (b) Height resolved fractional cloud cover and cloud overlap.
  - (c) The occurrence of ice liquid and super-cooled cloud layers.
  - (d) Vertical profiles of ice water content and effective ice particle size and shape.
  - (e) Vertical profiles of liquid water content and effective droplet size.
  - (f) Small scale (1 km or less) fluctuations in these cloud properties.
- Vertical velocities to characterise cloud convective motions and ice sedimentation.
- Drizzle rain rates and estimates of heavier rainfall rates.
- Narrow-band and broad-band reflected solar and emitted thermal radiances at the top of the atmosphere.

This document provides the requirements for the EarthCARE system for the phases B, C/D and E. All numbered requirements shall be verified and tracked.

2 Documents

2.1 Applicable Documents

The following documents are considered as expansions of this document, providing more details of the requirements, to the extent specified herein. This System Requirements Document takes precedence over any other technical requirement.

The process for defining and agreeing new technical requirements, is defined in the Statement of Work.

In case of conflicts between this document and the applicable documents, the conflict shall be brought to the attention of ESA for resolution.

AD-7	EC-RS-ESA-SY-0002	EarthCARE Product Assurance and Safety Requirements Document
AD-8	EC-RS-ESA-SY-0008	CPR Instrument Interface Requirements Document
AD-10	EC-RS-ESA-SY-0010	EarthCARE Operations Interface Requirements Document
AD-17	No reference	Dnepr User's Manual
AD-19	EHB0003	Rockot User's Manual
AD-21	No reference	Soyuz CSG User's Manual
AD-23	TBD	VEGA User's Manual
AD-25	PE-TN-ESA-GS-0001	Earth Explorer File Format Standards
AD-27	TBD	Generic PDS- IPF Interface Guidelines

Other EarthCARE Applicable Documents (and associated references) are not used within the present SRD document.

2.2 Normative Documents

ECSS (European Co-operation for Space Standardisation) documents are available on the Internet at: www.ecss.nl.

In the case of conflicts between this document and the applicable documents, the conflict shall be brought to the attention of the agency for resolution.

The applicability of Level 1 ECSS Standards (Policy and Principles) extends implicitly to the lower level standards. In some cases, the applicable document refers explicitly to lower level standards.

ND-1	ECSS-E-10-04A	Space environment
ND-2	ECSS-E-10-Part 6A	System engineering-functional and technical specifications
ND-3	ECSS-E-20A	Electrical and electronic
ND-4	ECSS-E-20-08A	Photovoltaic Assemblies and Components
ND-5	ECSS-E-20-01A	Multipaction design and test
ND-6	ECSS-E-30-Part 1A	Thermal control
ND-7	ECSS-E-30-Part 2A	Structural
ND-8	ECSS-E-30-Part 3A	Mechanism
ND-9	ECSS-E-30-Part 5.1A	Propulsion
ND-10	ECSS-E-30-Part 6A	Pyrotechnics
ND-11	ECSS-E-30-Part 7A	Mechanical parts

ND-12	ECSS-E-30-Part 8A	Materials
ND-13	ECSS-E-30-01A	Fracture control
ND-14	ANSI/AIAA S-080-1998	Space Systems- metallic pressure vessels, pressurized Structures, and Pressure Components
ND-15	ECSS-E-40-Part 1B	Software – Part 1: Principles and requirements
ND-16	ECSS-E-50-Part 1A	Communications – Part 1: Principles and requirements
ND-17	ECSS-E-50-05A	Radio frequency and modulation
ND-18	ECSS-E-50-12A	Space Wire – Links, Nodes, Routers and Networks
ND-19	CCSDS 101.0-B-6-S	Telemetry Channel Coding (ISO 11754)
ND-20	ECSS-E-50-02A	Ranging and Doppler Tracking
ND-21	CCSDS 102.0-B-5-S	Packet Telemetry (ISO 13419)
ND-22	CCSDS 201.0-B-3-S	Telecommand Part 1 – Channel Service (ISO 12171)
ND-23	CCSDS 202.0-B-3-S	Telecommand Part 2 – Data Routing Service (ISO 12172)
ND-24	CCSDS 202.1-B-2-S	Telecommand Part 2.1 – Command Operation Procedures (ISO 12173)
ND-25	CCSDS 203.0-B-2-S	Telecommand Part 3 – Data Management Service (ISO 12174)
ND-26	ECSS-E-50-14	Spacecraft Discrete Interfaces
ND-27	MIL-STD 1553-B-Notice 4	Digital Time Division Command / Response Multiplex Data Bus
ND-28	CCSDS 301.0-B-3	Time Code Formats (ISO 11104)
ND-29	CCSDS 121.0-B-1	Lossless compression
ND-30	CCSDS 727.0-B-3	File Delivery Protocol (CFDP) (ISO17355)
ND-31	ECSS-E-70 Part 1A	Ground systems and operations – Part 1: Principles and requirements
ND-32	ECSS-E-70 Part 2A	Ground systems and operations – Part 2: Document Requirements Definitions (DRD)
ND-33	ECSS-E-70-41A	Ground systems and operations - Telemetry and telecommand packet utilisation (PUS)
ND-34	ECSS-E-70-11A	Space Engineering – Space Segment Operability
ND-35	CCSDS 911.1-B-2	Space Link Extension – return all frames service specification
ND-36	CCSDS 912.1-B-2	Space Link Extension – forward CLTU service specification
ND-37	ANSI/IEEE Std 754-1985	IEEE Standard for Binary Floating-Point Arithmetic
ND-38	IEC standard 825-1	Safety of Laser Products
ND-39	EHB.DRG.Rep.002	ESA Pointing Error Handbook
ND-40	No Reference	The Solar Spectral Irradiance (ND-40-A for < 2400nm, ND-40-B for >2400nm)
ND-42	No Reference	European Code of Conduct for Space Debris Mitigation
ND-45	ECSS-Q-70-01A	Space Product Assurance: Cleanliness and Contamination Control
ND-56	ECSS-P-001B	Glossary of Terms
ND-62	ECSS-Q-40B	Safety
ND-71	ECSS-Q-70B	Materials, Mechanical Parts and Processes
ND-99	ECSS-E-30-02	Structural Design of Pressurised Hardware
ND-112	ECSS-E-70-32A	Space Engineering: Test and Operations Procedure Language

Other EarthCARE Normative Documents (and associated references) are not used within the present SRD document.

2.3 Informative Documents

The following EarthCARE Informative Documents (and associated references) are used within the present SRD document.

ID-13	ECSIM-DMS-TEC-ICD-01-R	ECSIM Simulator ICD
ID-14	ECSIM-DMS-TEC-SUM-01-R	ECSIM System User Manual (for SW version 1.2)

3 EarthCARE Mission

3.1 Mission Objectives Overview

EarthCARE responds to the need to provide an as complete as possible picture of the 3-dimensional spatial and the temporal structure of the radiative flux field at the top of the atmosphere (TOA), within the atmosphere and at the Earth's surface. These properties are to a large extent determined by the distribution of water vapour, clouds and aerosols. The underlying processes are driven by the radiative energy exchange between the Sun, the Earth and its atmosphere. To this end, the mission will provide input data for numerical modelling and global studies of:

- the divergence of radiative energy,
- the aerosol-cloud-radiation interaction,
- the distribution of water in its different physical states and its transport by clouds,
- the distribution of aerosols, and
- the cloud field overlap and cloud-precipitation interactions.

The geophysical products to be generated by the mission will be used in addition for constraining global and regional circulation models. This will support the evaluation of the Earth's climate variability. In addition, improvements in short- and medium term weather forecasts are expected.

The EarthCARE observations will be performed in a synergistic manner to make maximum use of the instruments flying on the same satellite.

3.2 EarthCARE System and Interfaces

The EarthCARE system consists of the Space Segment, the Launcher Segment and the Ground Segment.

The EarthCARE Space Segment is the satellite composed of a platform and a payload with the following instruments:

- **A Backscatter LIDar (ATLID):** to determine vertical profiles of aerosol physical parameters and, in synergy with the cloud profiling radar, vertical profiles of cloud physical parameters.

- **A Cloud Profiling Radar (CPR):** for the retrieval of the micro- and macroscopic properties of clouds, as well as the vertical velocity of cloud particles.

- **A Multi-Spectral Imager (MSI):** to provide information of the horizontal structure of cloud fields in support of the vertical profiles measured by the active instruments.

- **A BroadBand Radiometer (BBR):** to measure short-wave (SW) and long-wave (LW) fluxes at the TOA as a cross-check of the radiative flux derived from the cloud-aerosol profiles measured by the active instruments.

With the exception of the CPR, all EarthCARE instruments are considered as Contractor Procured Instruments (CPI) and are developed or procured under the Contractor's own responsibility.

The CPR is developed and procured by JAXA and delivered to ESA in the context of the ESA/JAXA cooperation for EarthCARE. As a Customer Furnished Equipment, the CPR will be delivered to the EarthCARE contractor which will assume the responsibility to accommodate – and verify compatibility of -

the CPR instrument within the EarthCARE system in all respects (Satellite, Ground segment, end-to-end performance simulator and level 1b processing).

The EarthCARE platform has to be developed by the contractor to embark all the necessary utilities and sub-systems needed to accommodate and operate the instruments in the space environment.

The Launcher Segment of the EarthCARE system consists of the launcher, to be procured by ESA. The launch vehicle will be used to place the EarthCARE satellite onto the proper orbit.

The Ground Segment of the EarthCARE system is composed of two elements:

- The Flight Operation Segment (FOS) is responsible for spacecraft commanding, spacecraft health monitoring, orbit control and on-board software configuration and maintenance. The FOS will be provided by the Agency according to interface requirements and operations manuals provided by the Contractor.

-The Payload Data Ground Segment (PDGS) is responsible for science data acquisition, processing, archiving and distribution, as well as mission planning. The PDGS will be provided and operated by the Agency and will include interfaces to the JAXA data-segment. The PDGS will include an operational version of the L1 processors defined and prototyped by the Contractor and a version of the CPR prototype processor delivered by JAXA.

Finally, it is highlighted that the Agency will develop an EarthCARE End-to-End mission Simulator (ECEESIM). The ECEESIM will be composed of separate modules representing individual elements in the overall EarthCARE 'observations to science products' chain. The Contractor is responsible for the elements of the ECEESIM representing the Flight Segment as well as the Level 0 to 1 processing and the Contractor shall support the Agency in defining the relevant data interface.

The main elements of the ECEESIM are:

(a) An EarthCARE scenery simulator

(b) An EarthCARE Satellite System Simulator (ESSS) including Instruments Models and auxiliary modules such as AOCS, orbit propagator, datation etc

(c) An EarthCARE Ground Processor (ECGP): raw/Level 0 to Level 1 data products

(d) A higher level products processor

The EarthCARE scenery simulator (a) and the higher level products processor (d) are not under the responsibility of the Contractor but interfaces from/to these modules will need to be agreed. The ESSS (b) is under the responsibility of the Contractor. It is composed of a series of individual modules (ATLID, BBR, CPR, MSI models and auxiliary modules such as AOCS, orbit propagator, datation etc). For the CPR, the Contractor responsibility covers integration and final testing of the CFI CPR instrument model. The ESSS output shall be compatible with the input of the ECGP (c) which is as well under the responsibility of the Contractor. For the CPR, the Contractor responsibility covers integration and final testing of the CFI CPR processor.

A number of ground support equipment to support development and AIT activities as well as the launch campaign will have also to be developed or procured by the Contractor.

The present SRD document specifies the main functionality and performance required from the part of the EarthCARE system which falls under the contractor direct responsibility. In addition, the SRD lists a set of requirements in order to give a (first) definition of the external interfaces, typically the EarthCARE satellite external interfaces to the launcher, to the FOS and to the PDGS. In each case, the Contractor will be responsible for defining and controlling these interfaces.

From the above, note that any requirement related to the satellite has to be considered as applicable for both the platform and the instruments.

3.3 Mission Assumptions

3.3.1 Launcher

The EarthCARE satellite will be compatible with at least two different launchers.

The selection process for the launcher is defined in the Statement of Work.

3.3.2 Environment

The environment encountered during the launch preparation activity, launch and ascent will be defined in accordance to the Launcher User Manual until specific launcher/EarthCARE ICD are available and approved by the Agency.

The applicable environment encountered in orbit, including the solar and earth electromagnetic radiation, high-energy particles, meteorite and debris environment, is defined in [ND-1].

3.3.3 Operational concept

The EarthCARE satellite will be operated by ESA. The Mission operations commence at separation of the satellite from the launcher and continue until disposal at the end of the mission. Mission operations include the following tasks:

- <u>Mission Planning</u> will operate the satellite according to a High Level Operations Plan to be provided by ESA. ESA will detail mission operations in a Flight Operations Plan.
- <u>Satellite status monitoring</u> by means of processing the housekeeping telemetry such that the status of all satellite sub-systems can be monitored. Monitoring includes attitude monitoring.
- <u>Satellite control</u> taking control actions by means of immediate or time-/orbit position- tagged telecommands following the Flight Operations Plan, and responding to monitoring anomalies.
- <u>Orbit determination and control</u> using tracking data both provided by the sensors of the attitude and orbit control system and by ground tracking and implementing orbit maneuvers to change the satellite velocity such that required orbital conditions are achieved.
- <u>Attitude determination</u> based on the processed attitude sensor data in the satellite monitoring.
- <u>On-board software maintenance</u>
- <u>Acquisition , processing, archiving and distribution of scientific data products.</u>

The operations support activities for EarthCARE will be conducted according to the following concept:

- All Satellite operations will be conducted by ESA according to procedures laid down in the Flight Operations Plan.
- Satellite control during the operational phase will be 'off-line'. Real time operations will be reduced to a minimum. For command and control, only one Ground Station will be used. The contacts between the Mission Operations Control Centre and the satellite will primarily be used for pre-programming of those autonomous operations functions on the spacecraft, and for housekeeping and payload data collection for off-line status assessment and anomalies detection
  The scheduling of the ground station passes will be coordinated with other Earth Explorer missions. Satellite compatibility with the ESA stations is ascertained by the Satellite to Ground Interface Document

During the operational phase, a dedicated ground station will be used to acquire the instrument science data stream. The current operational scenario baseline relies on the use of all the passes over the ground station in order to be able to dump all the science data generated on-board the satellite while minimizing the time between sensing the data on-board and their availability at the ground segment level. Other operational scenarios are also considered for enhancing science data dissemination via the use of additional ground stations and the use of multi-dumps (i.e. dump of same data to several ground stations) and/or near real time downlink transmission (i.e. without intermediate on-board storage). The EarthCARE satellite will have to be designed accordingly towards supporting both the scenario baseline and alternatives.

3.4 Mission Phases

On the basis of the previous assumptions the mission will be broken into the following operational phases:

- Launch and Early Orbit Phase
- Commissioning Phase
- Operational Phase
- End of Life Phase

The phases are specified under para. 6.1.

3.5 Definitions

Acronym list and definitions are given in ANNEX-2.

Refer also to sections 5.2.1 (ATLID), 5.3.1 (CPR), 5.4.1 (MSI) and 5.5.1 (BBR) for definitions which are specific to each individual instrument.

3.5.1 Altitude Definitions

ALT-DF-1 Geodetic altitude is the distance above the reference earth ellipsoid WGS-84, measured along the local normal to the ellipsoid.
The geodetic altitude of EarthCARE is changing along the orbit, the frozen orbit concept preserves an identical geodetic altitude as a function of latitude.

ALT-DF-2 Spherical altitude is the mean Kepler semi-major axis of the spacecraft orbit minus the equatorial radius of the Earth.
The spherical altitude of EarthCARE is a constant value, several km smaller than the minimum geodetic altitude.

ALT-DF-3 Surface altitude is the distance above the Earth surface, measured along the local normal to the ellipsoid.

ALT-DF-4 Surface height is the geodetic altitude of the surface of the Earth.
Please note that Surface altitude = Geodetic altitude – Surface height.

3.6 Reference Frames

For the definition of the EarthCARE satellite attitude along its orbit, the following Reference Frames shall be used.

The reference frames are defined using the following basic vectors:

REF-RF-1 Local Nadir is a Unit vector with:

Origin O_{YS}: Centre of Mass of the complete satellite in operational conditions (in-orbit deployed configuration);
Direction: perpendicular to the earth's reference ellipsoid, in the direction towards the Earth.

REF-RF-2 Earth rotation compensated velocity vector (Vel^{sc}_{earth}) is a Vector with:

Origin O_{YS}: Centre of Mass of the complete satellite in operational conditions (in-orbit deployed configuration);
Direction: Inertial satellite velocity vector, corrected for (minus) the (latitude dependent) earth-rotation velocity vector at the origin of the vector.

Note: The following approximations may be considered for Local Nadir and Vel^{sc}_{earth}:

$$Vel^{sc}_{earth} = Vel^{sc} + \begin{bmatrix} 0 & \omega & 0 \\ -\omega & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} Pos \ ,$$

$$Local \ \ Nadir = -Pos \ - \begin{bmatrix} 0 \\ 0 \\ \beta \end{bmatrix} .Pos$$

Where ω *= 0.729211585 x* 10^{-4}

β *= 0.0063 (TBC)*

Pos = Inertial position vector

Vel^{sc} *= Inertial velocity vector*

The above approximations are derived for the inertial reference frame: True of Date but may also be considered when using the Mean_of_2000 coordinate frame.

3.6.1 Yaw Steering Reference Frame (index YS)

The Yaw-Steering Reference Frame aligns the Z-axis with the local nadir, and delivers rectangular images, provided the instrument scan is in the YZ-plane.

REF-YS-1 The Yaw Steering Reference Frame is a right-handed orthogonal frame defined by:

Origin O_{YS}: Centre of Mass of the complete satellite in operational conditions (in-orbit deployed configuration).

$+X_{YS}$: Roll Axis: Equal to the vector product of Y_{YS} x Z_{YS}

$+Y_{YS}$: Pitch Axis: Equal to the normalised vector product of Local Nadir x Vel^{sc}_{earth}

$+Z_{YS}$: Yaw Axis: Local Nadir

Note: same attitude as the historical definitions used in ERS and Envisat.

3.6.2 Zero-Doppler Reference Frame (Index 0D)

The Zero-Doppler Reference Frame offers Zero Doppler for a reflected signal from the active instruments, provided the reflector is rotating with the Earth, and is in the YZ-plane.

REF-0D-1 The Zero-Doppler Reference Frame is a right-handed orthogonal frame defined by:

Origin O_{0D}: Centre of Mass of the complete satellite in operational conditions (in-orbit deployed configuration).

$+X_{0D}$: Roll Axis: In the direction of Vel^{sc}_{earth}

$+Y_{0D}$: Pitch Axis: Equal to the normalised vector product of Local Nadir x Vel^{sc}_{earth}

$+Z_{0D}$: Yaw Axis: Equal to the vector product of X_{0D} x Y_{0D}

3.6.3 International Celestial Reference Frame (ICRF)

REF-IR-1 The ICRF is a Cartesian inertial reference frame based on the precise coordinates of extragalactic radio sources. The origin of the frame is the Earth's center of mass. The x-axis is pointing towards the Vernal Equinox at J2000.0.The z-axis is the vertical on the Mean Equator at J2000.0, pointing North. The y-axis completes a right-hand system.

The ICRF is the Earth Centered Inertial (ECI) reference system employed in the EarthCARE mission.

This reference system is used for the attitude quaternion output from the Star Tracker.

3.6.4 International Terrestrial Reference Frame (ITRF)

REF-TR-1 The ITRF is an Earth-fixed Cartesian system. The origin of the frame is the Earth's center of mass. The x-axis points towards the IERS Reference Meridian. The z-axis points to the Reference North Pole. The y-axis completes a right-handed system. The ITRF is the Earth Centered Earth Fixed (ECEF) reference system employed in the EarthCARE mission.

This reference system is used for the orbit model, the input models and the GNSS model.

3.6.5 Spacecraft Frame (SCF)

REF-SF-1 The SCF is a right-handed orthogonal body-fixed system.

Origin $_{SCF}$: the origin is located in the plane of attachment to the launcher and in the centre of the attachment ring.

$+X_{SCF}$: is perpendicular to the Satellite/Launcher separation plane, pointing positively from the separation plane towards the Satellite

$+Z_{SCF}$: is pointing towards nadir

$+Y_{SCF}$: completes the right-handed orthogonal Spacecraft frame.

3.7 Measurement Units

REF-UM-2 Measurement units shall be in the SI system

4 Observation Requirements

OBS-GE-1 All orbital and attitude parameters shall be defined with reference to the EGM96 model as per ND-1.

4.1 Orbit Requirements

4.1.1 General

OBS-OR-1 The orbit shall be frozen and sun-synchronous (FSS).

Note: A frozen orbit is such that the altitude at specific latitude is constant. It has an eccentricity vector, (e_x, e_y) = e (cos ω , sin ω), without secular perturbations. For a low spacecraft orbit like EarthCARE the largest part of the perturbations of this vector are due to the gravitational field of the Earth, especially the J_2 and the J_3 terms. The frozen orbit solution requires a mean argument of perigee, ω, equal to 90.0 deg. The required eccentricity depends on the semi-major axis and inclination.

A sun-synchronous orbit has an orbital plane precession equal to the mean angular rotation of the Earth around the Sun. This will result in a constant angle between the orbital plane and the mean Sun. The sun-synchronous orbit requires an inclination, i , larger than 90.0 deg, depending on the semi-major axis.

OBS-OR-2 The satellite shall be designed to be compatible with the FSS orbit at a mean local solar time (MLST) selected within the range [13:45 to 14:00] at descending node.

OBS-OR-3 The system shall be dimensioned such that the altitude maintenance will be ± 2500m (TBC) with respect to the reference orbit all along the orbit.

With such value, preliminary simulations indicate that orbit maintenance maneuver will be required once every 2-4 weeks.

OBS-OR-4 The mean semi-major axis of the orbit shall be selectable, and agreed by the Agency, between 6750 km and 6804 km.

Note: The corresponding elements of the lowest and highest orbits are given in the following table:

Parameter	Low Orbit Values (mean kepler)	Design-Case Orbit Range	High Orbit Values (mean kepler)
Semi-major axis	*A = 6750.040 km*	*A =TBD*	*a = 6803.451 km*
Eccentricity	*E = 0.001293*	*E = TBD*	*e = 0.001274*
Inclination (sun-synchronous)	*i = 96.951°*	*i = TBD*	*I = 97.146°*
Argument of perigee	ω *= 90°*	ω *= 90°*	ω *= 90°*
Mean Local Solar Time Descending Node	*MLST = 13:45 -14:00*	*MLST = 13:45 -14:00*	*MLST = 13:45 – 14:00*
Repeat cycle / cycle length	*30 days, 469 orbits*	*TBD days, TBD orbits*	*20 days, 309 orbits*
Orbital duration	*5526.652 s*	*TBD*	*5592.233 s*
Mean Spherical Altitude	*371.903 km*	*385.5 to 402 km*	*425.314 km*
Minimum Geodetic Altitude	*377.113 km*	*TBD*	*430.478 km*
Maximum Geodetic Altitude	*404.760 km*	*TBD*	*458.055 km*
Average Geodetic Altitude	*387.130 km*	*TBD*	*440.483 km*

Table 4-1 EarthCARE Low / High Orbit Values & Design-Case Orbit Range

The above Design-Case orbit range is derived from the range covering the two reference orbits (OBS-RO-2, OBS-RO-4), extended by a 2.5 km for orbit maintenance (OBS-OR-3) and a 5-km margin, leading to a low Design-Case orbit with a mean spherical altitude of 385.5 km (393-2.5-5 km) and to a high Design-Case orbit with a mean spherical altitude of 402 km (394.5+2.5+5 km) respectively.

OBS-OR-5 The full performance of the spacecraft and its instruments shall be met over the mission at a to-be-specified MLST within above range ±5 minutes and at the agreed altitudes (see OBS-OR-4, OBS-CO-2 and OBS-CO-3). For each instrument, a margin shall be established:

- CPR: lower orbit sensitivity margin is 1dB (worst case); higher orbit margin is TBD.
- MSI: TBD by Industry
- ATLID: 17% for the High Orbit and 25% margin for the Design-case Orbit range with respect to the thresholds values listed in ATL-PR-2 to ATL-PR-5.
- BBR: TBD by Industry

Yearly sun illumination variation has to be accounted for.

OBS-OR-6 Geometric parameters such as ground pixel size, geo-location shall be met as specified in this document for the high Design-case orbit value (see OBS-OR-4) with the exception of MSI for which coverage shall be met at low Design-case orbit value

4.1.2 Coverage & Re-visit Cycle

OBS-CO-1 Spatial coverage: The system shall be designed to produce products within the performance requirements specified in this SRD along the selected orbit, including extreme latitudes.

OBS-CO-2 Global coverage: it shall be possible to achieve global coverage between the extreme latitudes, using the MSI swath, at any time during the mission in no longer than 30 days, under the assumption that only observations obtained on the sun illuminated part of the orbit are used.

The global coverage refers to the time required for systematic acquisition of a given area disregarding cloud cover and sun glint and possibly under different OZA conditions.

OBS-CO-3 Optimised re-visit cycle: it shall be possible, during the CAL/VAL period, to optimise the local re-visit time down to less than 10 days at the expense of global observation.

4.1.3 Reference Orbit for CAL/VAL Phase

OBS-RO-1 The orbit repeat period shall be selected, and agreed with the Agency, to meet the spatial coverage (OBS-CO-1) and optimized revisit cycle (OBS-CO-3) requirements.

OBS-RO-2 The CAL/VAL repeat cycle shall be 9 (TBC) days, 140 (TBC) orbits. The longitude of ascending node of relative orbit 1 is assumed to be 0.0 deg.

Relative orbit 1 within the CAL/VAL repeat cycle is defined as the orbit with a longitude of ascending node between 0.0 and (360°/cycle length) East.

Note: the corresponding elements of a TBC CAL/VAL orbit candidate are given by the following table:

Parameter	***Mean Kepler***
Semi-major axis	*a = 6772.57 km*
Eccentricity	*e = 0.001283*
Inclination (sun-synchronous)	*i = 97.055°*
Argument of perigee	ω *= 90°*
Mean Local Solar Time, Descending Node	*MLST = 13:45-14:00*
Repeat cycle / cycle length	*9 days, 140 orbits*
Orbital duration	*5554.3 s*
Mean Spherical Altitude	*394.43 km*
Minimum Geodetic Altitude	*399.6 km*
Maximum Geodetic Altitude	*427.3 km*
Average Geodetic Altitude	*409.7 km*

Table 4-2 EarthCARE CAL/VAL Orbit

4.1.4 Reference Orbit for Routine Phase

OBS-RO-3 The orbit repeat period shall be selected, and agreed with the Agency, to meet the spatial coverage (OBS-CO-1) and global coverage (OBS-CO-2) requirements.

OBS-RO-4 The routine repeat cycle shall be 25 (TBC) days, 389 (TBC) orbits. The longitude of ascending node of relative orbit 1 is assumed to be 0.0 deg.

Relative orbit 1 within the routine repeat cycle is defined as the orbit with a longitude of ascending node between 0.0 and (360°/cycle length) East.

Note: the corresponding elements of a TBC routine orbit candidate are given by the following table:

Parameter	***Mean Kepler***
Semi-major axis	*a = 6771.28 km*
Eccentricity	*e = 0.001283*
Inclination (sun-synchronous)	*i = 97.050°*
Argument of perigee	ω *= 90°*
Mean Local Solar Time, Descending Node	*MLST = 13:45-14:00*
Repeat cycle / cycle length	*25 days, 389 orbits*

Orbital duration	*5552.7 s*
Mean Spherical Altitude	*393.14 km*
Minimum Geodetic Altitude	*398.4 km*
Maximum Geodetic Altitude	*426.0 km*
Average Geodetic Altitude	*408.3 km*

Table 4-3 EarthCARE Routine Orbit

4.1.5 Orbit Maintenance

OBS-MO-1 During the nominal lifetime of the mission, it shall be possible to change the repeat cycle three times. For fuel budget calculations it shall be assumed that the semi-major axis difference is 10 km for each repeat cycle change (total $\Delta v \approx 33$ m/s (TBC) for 3 repeat cycle changes of 10km each).

OBS-MO-2 Ground-track maintenance: To allow long-term predictability of the measurements, and to facilitate planning, the accuracy of the sub-satellite ground track repeats shall be better than 25 km. The ground-track accuracy shall be maintained all along the orbit. The reference ground-track shall be defined for a drag-free, perfectly sun-synchronous orbit.

OBS-MO-3 Ground-track maintenance during specific CAL/VAL phase: the accuracy with which the sub-satellite ground track repeats shall be better than 1 km for TBD specific locations along the orbit. The reference ground-track shall be defined for a drag-free, perfectly sun-synchronous orbit.

4.1.6 Orbit Determination and Prediction

OBS-PO-1 EarthCARE satellite shall autonomously be capable to determine and predict its orbit with accuracy and rate sufficient to satisfy the related needs coming from all the on-board payloads, equipment and operations.

I.e. information generated by suitably selected GPS receiver and on-board orbit propagator (see AOS-FU-11) shall be sufficient to cope with the on-board users demand (e.g. CPR, ATLID,) without ground intervention.

OBS-PO-2 Any ground support for orbit determination and prediction on-board EarthCARE satellite shall be minimized, duly justified and identified for Agency approval.

Associated uploads will, in any case, have to comply to the same requirements applicable to any other telecommand, in particular vis-à-vis EarthCARE operation autonomy.

OBS-PO-3 EarthCARE satellite shall downlink suitable housekeeping telemetry in order to support the Flight Operation Segment on ground in order to reconstitute and predict EarthCARE satellite orbits accurately as well as to monitor, and control if necessary, the on-board orbit determination and propagator.

4.1.7 Space Debris Avoidance

OBS-SD-1 To protect the EarthCARE mission and to avoid the generation of more debris, the EarthCARE system shall predict regularly the collision risk with objects listed in the debris database (USSpaceCom Catalog).

OBS-SD-2 The EarthCARE system shall implement a strategy which reduces the risk of collision with a single space debris part to less than 1 / 10,000.

The strategy will nominally start with a request for additional measurements on the collision object, followed by analysing the effect of applying small manoeuvres to EarthCARE.

OBS-SD-3 For budget calculations, a single large manoeuvre raising the orbit by 2 km, followed by manoeuvres to return to the nominal orbit, with identical phasing shall be assumed occurring once during the mission (total $\Delta v \approx 2.2$ m/s).

4.1.8 End of Mission - Deorbiting

OBS-EM-1 An end of mission strategy shall be defined in accordance to ND-42 and implemented.

4.2 System-level Pointing Requirements

The requirements below address the inter instruments alignment performance. The instrument absolute pointing requirements and intra-instrument pointing requirements are specified in the relevant instrument sections. All requirements are given as RMS values along the orbit.

OBS-SP-1 All requirements shall be met over the full mission life time with the exception of the calibration mode listed in OBS-SP-13.

OBS-SP-2 Pointing budget shall be derived in accordance to ND-39

OBS-SP-3 The distance in the across track direction between the footprint centres of the CPR and the ATLID laser beam shall be smaller than 350 m with a goal of 200 m.

OBS-SP-4 The distance in the across track direction between the footprint centres of the BBR and the CPR shall be smaller than 1000m.

OBS-SP-5 The distance in the across track direction between the footprint centres of the BBR and the ATLID laser beam shall be smaller than 1000m.

OBS-SP-6 The knowledge of the distance in both the across track and the along track direction between the centres of all MSI pixels and the CPR footprint center shall be better than 350 m. with a goal of 200 m.

OBS-SP-7 The knowledge of the distance in both the across track and the along track direction between the centres of all MSI pixels and the ATLID laser beam footprint center shall be better than 350 m with a goal of 200 m.

OBS-SP-8 The knowledge of the distance in both the across track and the along track direction between the centres of all MSI pixels and the BBR footprint center shall be better than 1000m.

OBS-SP-9 The knowledge of the distance in the along track direction between the footprint centres of the CPR and the ATLID laser beam shall be better than 350 m with a goal of 200 m.

OBS-SP-10 The knowledge of the distance in the along track direction between the footprint centres of the BBR and the CPR shall be better than 1000 m.

OBS-SP-11 The knowledge of the distance in the along track direction between the footprint centres of the BBR and the ATLID laser beam shall be better than 1000 m.

OBS-SP-12 The instrument pointing stability requirements shall be derived from the observation and performance requirements as applicable.

OBS-SP-13 In fulfilling the required roll manoeuvre for CPR calibration (CPR-FO-12), it shall be ensured that the overall spacecraft roll angle does not exceed the range -15 to +15 degrees and the overall time required for the complete manoeuvre does not exceed 2 (TBC) minutes.

OBS-SP-14 Telemetry related to pointing shall be available in all operational modes in housekeeping and science data and compatible with the geo-location requirements specified in OBS-GR-1.

4.3 Geo-location Requirements

OBS-GR-1 The geo-location accuracy of the EarthCARE Level 1b and, for MSI Level 1c, data shall be better than 500 m RMS, accounting for all errors introduced by satellite pointing, navigation, and timing. This requirement shall apply to the full mission lifetime and shall cover all operation modes associated with the nominal operation of the instruments and their calibration.

5 Instruments Requirements

This section lists a set of generic and specific requirements which shall apply during the design and development of respectively all (section 5.1) or individual (sections 5.2 to 5.5) EarthCARE instruments.

In addition, system requirements defined in other SRD sections will have to be propagated to derive complete requirement specifications for each Instrument.

5.1 General Requirements

PAY-GE-1 The instruments shall be autonomous with respect to their internal operations.

PAY-GE-2 The instruments shall be operated via the (packet utilisation) services defined in ND-33 and further detailed in AD-10 while they shall provide their data in standard CCSDS packets in accordance to ND-21.

Note that APIDs should be used in accordance to requirement OPS-SC-3.

PAY-GE-3 The housekeeping and science packets – and data if necessary - from all instruments shall be time stamped in accordance to mechanism defined under section 6.6.

PAY-GE-4 After instrument switch-on (IOV phase excepted), recovery from safe mode and after over-illumination by the sun (within the limits specified per instrument), nominal operational performance shall be achieved/resumed within a period of less than 1 day [TBC].

Tolerance/limits for direct viewing of the sun are specified in: ATL-OP-6 (ATLID), CPR-FO-15 (CPR), MSI-SA-4 (MSI) and BBR-FO-13 (BBR).

PAY-GE-5 All instrument mode changes (including sudden removal of primary power) shall be possible at any point in time without any damage or performance degradation at sub-sequent switch-on.

PAY-GE-6 All instruments shall be considered as non-essential loads. In case of EPS power contingency, they shall be switched off in accordance to EPS-GE-4; EPS warnings (via DHS or TBC DNEL) will be supplied to initiate a controlled instrument switch off.

Despite EPS warnings, the occurrence of sudden removal of primary power can not be totally discarded (due to fast power drop at system/EPS level or due to the detection of under- or over-voltage at instrument input level).

PAY-GE-7 Each instrument shall provide suitable standard interface(s) in order to support the DHS sub-system for routing the data according to the following scheme:

- Scientific data: to dedicated Instrument Packet Store(s) as part of the DHS on-board data storage and nominal transmission via High Rate Telemetry Data Downlink (X-band)
- Ancillary/HK data: to a common Ancillary/HK Satellite Packet Store as part of the DHS on-board data storage and nominal transmission via TTC Data Downlink (S-band) and, in parallel, upto a complete replica via the High Rate Telemetry Data Downlink (X-band)

This requirement does not necessarily imply different physical interfaces as long as there is a mechanism to differentiate the two types of data. A set of standard I/F is listed in section 2.2 as preferred candidates: Spacewire (ND-18), Mil-1553B (ND-27) and discrete interfaces (ND-26).

PAY-GE-8 The instrument science data stream shall include (in a dedicated ancillary field), a replica of the housekeeping information sent by S-band. The TM structure, at word level, shall be identical in housekeeping and science stream and the same encoding shall be used (analogue or digital).

PAY-GE-9 Each instrument shall interface the spacecraft with a redundant set of electrical interfaces (i.e. all the interfaces used for powering, commanding, synchronizing, monitoring the instrument as well as for transferring its instrument science data) and shall be able to operate independently from either set.

PAY-GE-10 In case the instrument will be in charge of selecting which interface to use, the selection scheme shall be deterministic vis-à-vis the status of the nom./red. interfaces. In addition, such interface selected/used by the instrument shall be duly reported in the instrument telemetry.

PAY-GE-11 Each instrument shall be nominally operated in cold redundancy. Hot redundancy from interface point-of-view shall be possible to an extent subject to Agency's approval.

PAY-GE-12 Each instrument shall be designed in order to avoid any instrument failure propagation to the platform either by mechanical, thermal, electrical or electromagnetic effect. Instrument software failures shall also be isolated at Instrument level.

PAY-GE-13 Each instrument shall be designed to avoid any failure propagation from one electrical interface to another one.

PAY-GE-14 Each instrument shall be designed to accept, from platform level, separate sources to be powered during instrument nominal operational modes and to power instrument (survival) heaters during non-operative and contingency situations.

PAY-GE-15 Each instrument shall be designed to achieve full functionality and performance independently of the operational status of the other EarthCARE instruments.

PAY-GE-16 Each instrument shall have at least one alignment cube to reference to satellite AOCS and to support instrument co-registration.

PAY-GE-17 Each instrument science acquisition chain shall be designed in order to remain within specification over the full dynamic range [lowest expected in-orbit signal, highest expected in-orbit signal] with an adequate margin on both sides. Exceptions shall be identified and agreed with the Agency.

In case lowest expected signal is zero, the margin will only be applied at the upper range side.

5.2 Atmospheric Backscatter Lidar (Atlid)

ATLID shall provide vertical profiles of the physical aerosol parameters (e.g. backscatter and optical depth), altitude of the highest cloud top and in synergy with the Cloud Profiling Radar, vertical profiles of the physical cloud parameters.

5.2.1 Terms and Definitions

Altitude

is defined with respect to the Earth ellipsoid model as defined in section 3.5.1. The altitude of a given echo sample shall correspond to the vertical distance between the centre of the atmospheric target and the reference Earth ellipsoid at the point where the LOS intersects the ellipsoid.

Altitude estimation accuracy

is the rms error of the vertical samples altitude knowledge. This shall include instrument and platform induced errors.

Centre of the laser beam footprint

is defined as the barycentre of the laser beam footprint

Depolarisation ratio

is defined as the ratio of the right-handed polarisation to the left-handed polarisation backscattered intensities of the scene, assuming a right-handed polarised emission at the instrument output.

Diameter of the laser beam footprint

is defined as the full width (99% encircled energy) of an assumed gaussian laser beam shape projected at the ground surface.

Diameter of the receiver footprint

is defined as the full width of the projected receiver field of view at the ground surface.

Horizontal sampling interval

is the distance in the along track satellite velocity vector direction between two consecutive laser beams footprint's centre.

Impulse response

F(t) of the lidar is the echo profile of the current emitted laser pulse low-pass filtered to the required vertical sampling when the target is an ideal scattering plane, with a perfectly transparent atmosphere between the instrument and the target.

Integration length

for a given atmospheric target corresponds to the distance over which echoes reflected by the target can be averaged on ground to enhance the SNR.

Lidar echo

of a scattering atmosphere in the single scattering approximation is given by:

$$V(t) = [K.\frac{\beta(R)}{R^2}.T_{atm}^2] * F(t)$$

where β(R) is the backscatter coefficient at range R from the lidar, T_{atm} is the one way atmospheric transmission from the instrument to the target, F(t) is the impulse response of the lidar, * is the convolution operator, V(t) is the sampled output signal at time $t = 2.R.c^{-1}$, c is the speed of light and K is the lidar constant.

Lidar constant (K)

is the transfer calibration constant relating each receiving channel measured data to level 1 b data. The lidar constant allows retrieving absolute attenuated backscatter signals at the entrance of the instrument from the measured signals. There shall be a lidar constant per channel

Line-Of-Sight (LOS)

is defined by the laser pulse propagation direction. It corresponds to the line drawn between the laser beam at ATLID output and the centre of the laser beam footprint.

Measurement accuracy

is related to the retrieved L1b signals. The accuracy shall include both random and systematic errors. This shall encompass among others, the temporal SNR, the relative drifts and accuracy, the background/offset correction, the spectral and polarisation cross-talk corrections.

Mie co-polar (respectively Mie cross-polar, Rayleigh) input signal - $MieCop_{inp}$ (respectively $MieCross_{inp}$, Ray_{inp})

is the pure and range corrected attenuated aerosol and cloud co-polar backscattered signal, respectively pure and range corrected attenuated aerosol and cloud cross-polar backscattered signal, respectively pure and range corrected attenuated molecular backscattered signal, as expressed at the entrance of ATLID instrument. This is defining the L1B products and is expressed in $sr^{-1}m^{-1}$.

The combination of 2 or more receiver channels might be used to retrieve the Input signals.

$$MieCop_{inp}(z) = \beta cop_{aersol+cloud}(z) \times T_{atm}^2(z) = \frac{V(t) \times R^2}{K \times F(t)}$$

where V(t) is the measured Mie co-polar backscatter signal in the corresponding Mie co-polar channel once cross-talks have been corrected.

z is the altitude of the measured layer.

$$MieCross_{inp}(z) = \beta cross_{aersol+cloud}(z) \times T_{atm}^2(z) = \frac{V(t) \times R^2}{K \times F(t)}$$

where V(t) is the measured Mie cross-polar backscatter signal in the corresponding Mie cross-polar channel once cross-talks have been corrected.

$$Ray_{inp}(z) = \beta_{molecular}(z) \times T^2_{atm}(z) = \frac{V(t) \times R^2}{K \times F(t)}$$

where V(t) is the measured molecular backscatter signal in the corresponding Rayleigh channel once cross-talks have been corrected.

Mie co-polarisation channel (respectively Mie cross-polarisation channel, Rayleigh channel)

A receiver channel is referring to the raw data as measured at the output of the receiver. The Mie co-polarisation channel (respectively Mie cross-polarisation channel, Rayleigh channel) is the receiver channel dedicated to the measurement of the Mie backscatter component with opposite polarisation rotation direction to the emitted polarisation, (respectively of the Mie backscatter component with same polarisation direction as the emitted polarisation of the Rayleigh backscatter component)

Optical depth

of a cloud (or an aerosol layer) is the integral of the cloud (or aerosol layer) extinction coefficient over the geometrical vertical extent of the cloud.

$$\tau = \int_{\Delta R} \alpha(z) dz$$

where τ is the optical depth

α [m^{-1}] is the extinction coefficient of the cloud (aerosol)

ΔR is the geometrical vertical extent of the cloud (aerosol)

Polarisation cross-talk in the Mie co-polar channel

Assuming a pure “Mie scattering target”, i.e. with zero Rayleigh scattering, depolarisation ratio infinite and no background, the Polarisation cross-talk in the Mie co-polar channel is the ratio of the measured signal on the Mie co-polar channel to the measured signal on the Mie cross-polar channel, after subtraction of detection offset and correction of the linearity.

Polarisation cross-talk in the Mie cross-polar channel

Assuming a pure “Mie scattering target”, i.e. with zero Rayleigh scattering, depolarisation ratio nul and no background, the Polarisation cross-talk in the Mie cross-polar channel is the ratio of the measured signal on the Mie cross-polar channel to the measured signal on the Mie co-polar channel, after subtraction of detection offset and correction of the linearity.

Polarisation impurity of the emitted laser light at the output of ATLID

Is defined as the ratio of the left to the right handed emitted polarisation intensities, assuming a right-handed polarised emission.

Radiometric stability

The radiometric stability [%] over one orbit is defined as follows: $2 * \frac{\sqrt{\overline{S}_1^2 - \overline{S}_2^2}}{\overline{S}_1 + \overline{S}_2}$

where $\overline{S}_1 and \overline{S}_2$ are the pure and range corrected attenuated backscattered signal estimates derived from the lidar for any two arbitrarily chosen integration periods of 2000 km (TBC: this assumes that the measurement noise is reduced by averaging over the 2000km length so that it is negligible) length within an orbit, for a spatially and temporally constant scene.

Receiver

Is the part of instrument dedicated to the collection of the backscatter signal up to the digitisation of the signal.

Spectral cross-talk in the Rayleigh channel

Assuming a pure “Mie scattering target”, i.e. with zero Rayleigh scattering, depolarisation ratio null and no background, the Spectral cross-talk in the Rayleigh channel is the ratio of the measured raw signal on the Rayleigh channel to the measured raw signal on the Mie co-polar channel, after subtraction of detection offset and correction of the linearity.

Spectral cross-talk in the Mie co-polar channel

Assuming a pure “Molecular scattering target”, i.e. with zero Mie scattering, depolarisation ratio null and no background, the Spectral cross-talk in the Mie co-polar channel is the ratio of the measured raw signal on the Mie co-polar channel to the measured raw signal on the Rayleigh channel, after subtraction of detection offset and correction of the linearity.

Specular reflection signal

the specular reflection signal characteristics can be inferred from any internal or external reflection within a dynamic range from the highest level specified in ATL-PR-6 to an equivalent ground specular return when ATLID is pointing to nadir with a clear atmosphere (lower decile aerosol model) and a ground albedo of 0.03.

Signal to noise ratio (SNR)

is the ratio of the value of the noiseless (ideal) output signal, obtained after perfect compensation of instrument and background offsets, to the noise. The noise is the root-mean-square deviation of the output signal with respect to the ideal output signal. According to this definition, the noise contains contributions of random noise phenomena and any uncompensated bias. The SNR is defined either on single echoes or on averaged echoes within a specified integration distance and for a specified vertical resolution.

Vertical profile

is a continuous sequence of consecutive samples of the temporal profile of the echo.

Vertical resolution

is the full-width (90% TBC enclosed energy) of the instrument response to a rectangular window backscatter function with a width equal to the vertical sampling interval.

Vertical sampling

is the distance in the Line of Sight direction between two consecutive samples of the temporal profile of the echo.

5.2.2 Functional Requirements

ATL-FR-1 The instrument concept shall be a single wavelength lidar with a high-spectral resolution (HSR) receiver allowing the separation of the Rayleigh (molecular) and Mie (cloud and aerosol particles) backscatter returns.

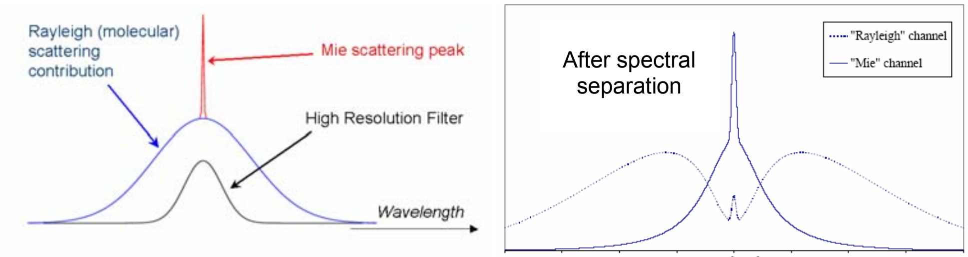


Figure 5.2-1: High Spectral Resolution separation principle (for illustration only) in the right figure after spectral separation

ATL-FR-2 ATLID shall provide 3 receiving channels:

- a Mie co-polarisation channel dedicated to the measurement of the Mie backscattering with a polarisation rotation direction opposite to the emitted polarisation
- a Mie cross-polarisation channel dedicated to the measurement of the Mie backscattering with same polarisation rotation direction as the emitted polarisation
- a Rayleigh channel dedicated to the measurement of the molecular backscattering

ATL-FR-3 The signal acquisition in all channels shall be simultaneous to better than 5% (0-peak value) of the vertical temporal sampling, with a goal of 1% (0-peak value).

ATL-FR-4 ATLID shall provide a continuous sequence of samples of the temporal profile of the echo within the altitude range [-0.5km, 40km].

ATL-FR-5 Interruption of the nominal measurement mode for calibration shall be limited as much as possible and in agreement with GSR-LR-5. The use of the calibration mode shall not entail the systematic loss of imaging capability in specific geographic locations.

ATL-FR-6 All raw data acquired during on-board calibration shall be transmitted to ground.

ATL-FR-7 ATLID shall transmit all parameters applied on-board that modify the measurement data and can be changed by command.

ATL-FR-8 ATLID shall be capable of transmitting unprocessed data to allow for testing and verification of the on-board correction functions.

5.2.3 Operational Requirements

ATL-OP-1 Unless otherwise stated the requirements shall be met

- for the full signal dynamic range;
- over the full orbit altitude range defined in table 4.1
- for level 1b data;
- over the specified mission duration.

ATL-OP-2 The instrument operational availability, as defined in GSR-LR-4, shall be better than 99 % during the operation phase.

ATL-OP-3 The optical fluence generated by ATLID shall meet the eye safety criteria [ND-38] for an observer who tracks EarthCARE with an 80 mm diameter telescope from the ground and is located in the centre of the laser beam footprint from ATLID. High optical fluence and potential eye damage casualties shall also be considered for defining safety measures for all ground operations of the laser.

ATL-OP-4 The number of operational modes and on board correction functions shall be kept to the strict minimum required to meet the requirements.

ATL-OP-5 As baseline, the operational modes used for ground testing shall be the same as the modes used in flight. Deviations shall be identified and agreed with the Agency.

ATL-OP-6 The instrument shall not be damaged by direct viewing of the sun during 60 (TBC) seconds.

Full instrument performance as specified in this document should then be resumed in accordance to req. PAY-GE-4. Longer sun illumination shall be prevented at system level via AOCS req. AOS-FU-3.

ATL-OP-7 The instrument shall not be damaged by over illumination due to internal or external specular reflections.

In flight this should be typically ensured by design or satellite operations, on ground by definition of appropriate AIV procedures.

ATL-OP-8 In case of specular reflections, the instrument performance, as specified in 5.2.8, shall be recovered after less than 0.1 (TBC) seconds.

5.2.4 Spectral Requirements

ATL-SR-1 ATLID shall operate at a fixed wavelength in the range 354.8 nm ± 0.5 nm.

5.2.5 Polarisation Requirements

ATL-PO-1 The Mie co-polarisation channel shall measure the component of the Mie backscattering with a polarisation rotation direction opposite to the emitted polarisation.

ATL-PO-2 The Mie cross-polarisation channel shall measure the component of the Mie backscattering with same polarisation rotation direction as the emitted polarisation.

ATL-PO-3 The polarisation state of the emitted laser light at the output of ATLID shall be circular.

ATL-PO-4 The polarisation impurity of the emitted laser light at the output of ATLID shall be less than 1 % (TBC).

5.2.6 Design Requirements

ATL-DE-1 The ATLID instrument shall be designed to intrinsically meet its performance requirements. Exceptions shall be handled by provision of characterisation data such that its performance requirements are met.

ATL-DE-2 The baseline for the ATLID shall be a pressurised design that minimises the number of critical elements exposed to vacuum and, as a minimum, shall incorporate a transmitter power laser head that is integrated in a sealed and pressurized enclosure.

ATL-DE-3 Use of organic or non-metallic materials shall be minimised as far as possible in the design of the ATLID instrument and, in particular, in those areas containing critical (as defined in ECSS-P001B, ND-56) and contamination sensitive units. All organic materials in the vicinity of critical components shall be demonstrated by test to be compliant with the operational requirements of the instrument.

The few organic and non-metallic materials should be duly identified and subject to Agency's approval.

ATL-DE-4 ATLID design shall avoid (minimise) the contamination sources and contaminating paths to critical elements and the related consequences on the instrument performance so that the compliance to the instrument performance is not compromised by contamination of optical surfaces. This shall account for laser-induced contamination and laser induced damage effects.

ATL-DE-5 The outgassing properties of all materials in vicinity of optical surfaces and detectors shall be evaluated and demonstrated compliant with the Cleanliness and Contamination Control Plan required to meet the instrument performance requirements.

ATL-DE-6 Measures such as component bake-out or use of molecular absorber shall be considered in the design phase to reduce contamination sources for any identified critical element.

ATL-DE-7 ATLID shall be designed such that protective measures such as purging, covers, can be implemented during all instrument and satellite phases, avoiding (minimising) the exposure of critical elements to contaminants, and it shall be demonstrated that these measures will be sufficient to meet the instrument operational requirements.

It should be traded whether protective windows or covers should be used during all the satellite AIV activities, to protect ATLID from sources of contamination.

ATL-DE-8 Protective measures to limit contamination sources and outgassing coming from other parts of the satellite during launch and in the early in-orbit operations shall be defined and implemented. Implementation of dedicated contamination monitoring of ATLID during early in-orbit operations shall be investigated.

ATL-DE-9 The ATLID design shall allow for decontamination of the instrument in orbit by outgassing, and shall enable the temperature of critical elements to be such as to prevent condensation of outgassing contaminants from non- critical areas of the instrument and the rest of the satellite.

ATL-DE-10 There shall be no direct view from any critical unit (with respect to the contamination) to the spacecraft.

ATL-DE-11 The following minimum cleanliness levels shall be maintained for ATLID:

	in vicinity of critical units		Away from critical units	
	in laser beam vicinity	out of laser beam vicinity	other optical components	non optical components
Molecular cleanliness level	$1x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$
Particulate cleanliness level	$10mm^2/m^2$	$10mm^2/m^2$	$50mm^2/m^2$	$300mm^2/m^2$

Table 5.2-1 Minimum cleanliness levels for ATLID

5.2.7 Geometrical Requirements

ATL-GR-1 ATLID shall have a single fixed LOS with respect to satellite axes. The LOS shall be at an angle of absolute value comprised within the range 2±0.2 (TBC) degrees with respect to the nadir of the satellite (Z_s axis) and within the XZ plane.

ATL-GR-2 The instrument LOS shall not point to the nadir (0±0.3 degrees) in any of the operational mode.

ATL-GR-3 Vertical profiles shall be measured in an altitude range extending from - 0.5 km up to 40 km with respect to the reference ellipsoid.

ATL-GR-4 The vertical sampling interval shall be constant and smaller than or equal to 100 m from -0.5 km to 20 km and smaller than or equal to 500 m with a target of 100m from 20 km to 40 km altitude.

ATL-GR-5 The knowledge of the vertical sampling interval shall be better than 5% of ATL-GR-4 value (TBC).

ATL-GR-6 The vertical resolution shall be constant and smaller than or equal to 100 m from -0.5 km to 20 km and smaller than or equal to 500 m with a target of 100 m from 20 km to 40 km altitude.

ATL-GR-7 The knowledge of the vertical resolution shall be better than 5% of ATL-GR-6 value (TBC).

ATL-GR-8 The altitude geo-location accuracy shall be better than 100 m rms.

ATL-GR-9 The horizontal sampling interval shall be smaller than or equal to 200 m. 100 m horizontal sampling interval is considered as ideal from science point of view.

ATL-GR-10 The knowledge of the horizontal sampling shall be better than 5% of ATL-GR-9 (TBC).

ATL-GR-11 Onboard summation of vertical samples may be applied for both backscattered echo and calibration measurements over a distance not exceeding the values specified in Table 5.2-2.

	Horizontal	Vertical
Backscattered echo	Maximum: 200m (*)	Specified vertical sampling
Calibration	Same as backscattered echo	No requirement

Table 5.2-2 Maximum onboard sample summation equivalent distance

(*) the transmission to ground of all the vertical profiles (not summed) is however preferred.

ATL-GR-12 The diameter of the receiver footprint shall be less than 30 metres.

ATL-GR-13 The laser beam and receiver footprints centre shall be and stay co-aligned to an accuracy allowing to meet the performance requirements ATL-PR-2, ATL-PR-3, ATL-PR-4, and ATL-PR-5.

5.2.8 Performance Requirements

ATL-PR-1 The ATLID Reference Model of the Atmosphere (ARMA) defined in ANNEX-1 shall be used for all performance assessment and instrument sizing.

ATL-PR-2 The accuracy of the derived Mie input co-polar shall be better than the values specified in Table 5.2-3 in the cloud and for the reference atmospheric scene specified in Table 5.2-4. This shall not take into account the lidar constant knowledge.

Cloud backscatter coefficient m^{-1} sr^{-1}	Mie co-polar signal accuracy	Rayleigh signal accuracy	
	10 km horizontal integration length	10 km horizontal integration length	200 km horizontal integration length
8×10^{-7}	48%	15% with a goal of 10%	5%
1.4×10^{-5}	10%		
1.6×10^{-4}	5%		
10^{-3}	5%		

Table 5.2-3: Mie co-polar signal required accuracy in the cloud and Rayleigh signal required accuracy above and below the cloud

	Target characteristics	
	Cirrus cloud	Molecular scattering
Backscatter coefficient, m^{-1} sr^{-1}	8×10^{-7} to 10^{-3}	As per ARMA
Extinction coefficient, m^{-1}	5.0×10^{-5}	As per ARMA
Depolarisation ratio	0	As per ARMA
Altitude range, m	9000 to 10000	
Background	Daytime: dense cloud deck with an albedo of 1 at an altitude of 4 km	
Vertical integration length, m	100	300
Horizontal integration length, km	As per Table 5.2-3	

Table 5.2-4 Atmospheric scene characteristics and integration length requirements for Mie co-polarisation and Rayleigh signals radiometric performance

ATL-PR-3 The accuracy of the derived Rayleigh input signal shall be better than the values specified in Table 5.2-3 below and above the cirrus cloud and for the reference atmospheric scene specified in Table 5.2-4. This shall not take into account the lidar constant knowledge.

ATL-PR-4 The accuracy of the derived Mie input cross-polar signal shall be better than 45% in the cirrus cloud and for the reference atmospheric scene specified in *Table 5.2-5*. This shall not take into account the lidar constant knowledge.

	Target characteristics
Backscatter coefficient, m^{-1} sr^{-1}	2.6×10^{-5} (*)
Extinction coefficient, m^{-1}	5.0×10^{-5}
Cloud depolarisation ratio	10 % (*)
Altitude range, m	9000 to 10000
Background	Daytime: dense cloud deck with an albedo of 1 at an altitude of 4 km
Vertical integration length, m	100
Horizontal integration length, km	10

Table 5.2-5. Atmospheric scene characteristics and integration length requirements for Mie cross-polarisation signal radiometric performance

(*) This means an equivalent backscatter coefficient of $2.6 \ 10^{-6}$ sr^{-1} m^{-1} in the cross-polarized signal.

ATL-PR-5 The accuracy of the derived Rayleigh input signal shall be better than the values specified in Table 5.2-6 for the reference atmospheric scene specified in Table 5.2-7. This shall not take into account the lidar constant knowledge.

Aerosol backscatter coefficient m^{-1} sr^{-1}	Required accuracy
8 x 10^{-7} to 7 10^{-6}	10%
7 x 10^{-6} to 1.7 10^{-5}	20%

Table 5.2-6 Rayleigh required accuracy in the aerosol layer

	Target characteristics	
	Aerosol layer	Molecular scattering
Aerosol backscatter coefficient, m^{-1} sr^{-1}	Constant backscatter from 0 to 1 km as given in Table 5.2-6	As per ARMA
Lidar ratio, sr	60	As per ARMA
Altitude range, m	0 to1 km (*)	
Background	Daytime: dry snow ground	
Vertical integration length, m	1000	
Horizontal integration length, km	10	

Table 5.2-7: Atmospheric scene characteristics and integration length requirements for Rayleigh signal radiometric performance when used for aerosol optical depth retrieval

(*) It is then assumed that 10 vertical samples are averaged. The ground echo shall not be accounted for.

ATL-PR-6 The receiver shall perform measurements with a linearity performance better than 3% (TBC) in the following dynamic range:

- from the smallest signal corresponding to a cirrus backscatter coefficient of $10^{-7}m^{-1}sr^{-1}$ at an altitude of 10 km and in night time conditions.
- to the highest signal return corresponding to a cloud deck with an albedo of 1.5 at an altitude of 4 km in daytime: this is equivalent to a cloud backscatter coefficient of 9.6 10^{-3} $m^{-1}sr^{-1}$ with depolarisation ratio equal to 100 % at an altitude of 4 km.

ATL-PR-7 The radiometric stability for each channel shall be better than 1% (TBC).

ATL-PR-8 The accuracy of the Mie co-polar signal L1B product shall be better than 50% in the cloud of backscatter coefficient $8.10^{-7}sr^{-1}m^{-1}$, for 10 km horizontal integration length and the reference atmospheric scene specified in Table 5.2-4.

ATL-PR-9 The accuracy of the Rayleigh signal L1B product shall be better than 15% below and above the cirrus cloud, for 10km horizontal integration length and the reference atmospheric scene specified in Table 5.2-4

ATL-PR-10 The accuracy of the Mie cross-polar signal L1B product shall be better than 50% in the cirrus cloud and for the reference atmospheric scene specified in *Table 5.2-5*.

5.2.9 In-flight Calibration Requirements

ATL-CA-1 Absolute in-flight calibration accuracy of the lidar constant shall better than 10% (TBC) in the Mie co-polar and Rayleigh channels. The lidar constant in the Mie cross-polar channel shall be calibrated relatively to the Mie co-polar channel to an accuracy better than 15% with a target of 10% (TBC).

ATL-CA-2 Absolute calibration of the lidar constant in the Rayleigh channel shall be performed above an altitude of 30km.

ATL-CA-3 Absolute calibration of the solar background and detection offsets in all receiving channels shall be performed above an altitude of 100km and below the ground surface, for a horizontal integration length not larger than specified in Table 5.2-3.

ATL-CA-4 The Spectral cross-talk in the Rayleigh channel shall be known to better than 20 % of its value or 0.05 whichever is greatest, with a target of 10 % of its value or 0.025 whichever is greatest.

ATL-CA-5 The Spectral cross-talk in the Mie co-polar channel shall be known to better than 10 % of its value or 0.03 whichever is greatest.

ATL-CA-6 The Polarisation cross-talk in the Mie co-polar channel shall be known to better than 10 % of its value or 0.01 whichever is greatest.

ATL-CA-7 The Polarisation cross-talk in the Mie cross-polar channel shall be known to better than 10 % of its value or 0.01 whichever is greatest.

ATL-CA-8 The instrument shall transmit all ancillary data required for the on-ground data processing. As a minimum the instrument shall provide the data specified in Table 5.2-8

Name	Units	Definition
Laser energy monitoring	J or W	Energy monitoring at different stages of the Laser transmitter allowing a health continuous monitoring: laser diodes relative power, laser seeder power, power laser head oscillator and amplifier(s) energy, frequency doubler and tripler output energy.
Laser critical elements temperature	K	Temperature of the LDA, Active material, optical bench,
Laser voltage and supplied power	V	
Optical bench and sensitive optical units temperature	K	
Detector and Video electronics voltages	V	
Video electronics temperature	K	Temperature of the video processing unit
Detector temperature	K	Temperature of the detectors

Table 5.2-8 In-flight instrument ancillary data

5.2.10 Atlid Specific Data Product Requirements

This section is limited to data product requirement specific to Atlid instrument. Other generic requirements, i.e. applicable to all instruments are listed under chapter 8 and hence also apply to Atlid instrument.

ATL-DP-1 The Level 1b product shall consist of pure and range corrected attenuated backscatter profiles ($sr^{-1}m^{-1}$) for each of the three channels, as measured and expressed at the entrance of the instrument. The product shall be fully geo-located, as well as error estimates and reliability data for each data set.

ATL-DP-2 The Level 1b product data shall meet the ATL-PR-8, ATL-PR-9 and ATL-PR-10 performance requirements of section 5.2.8.

5.3 Cloud Profiling Radar (CPR)

The CPR is a millimetre-wave pulsed radar with a fixed downwards looking pencil-beam antenna. It transmits microwave pulses which are able to penetrate lower cloud layers and includes a unique Doppler function for retrieval of vertical particle velocity.

Its objective is to provide vertical profiles of cloud structures and vertical velocity of cloud/precipitation particles along the satellite track. This information is deduced from the measured radar backscatter signals and the Doppler-shift induced on these signals by the motion of cloud particles.

Nota Bene: With the exception of those requirements beginning with the identifier' CPR-SP-xx' the requirements given in sections 5.3 are given as indication of the present CPR configuration and are applicable to the supplier of the CPR instrument. Those requirements beginning with the identifier' CPR-SP-xx' are applicable to the satellite contractor.

5.3.1 Terms and Definitions

Altitude

is defined with respect to the reference Earth ellipsoid model. The altitude of a given echo sample shall correspond to the centre of the volume in space which contributes to that sample (the so-called radar resolution cell) measured from the ellipsoid along its normal.

Altitude knowledge,

Δh_{pos} includes the satellite altitude and attitude knowledge uncertainty, instrument timing measurement errors and uncertainty in propagation delay knowledge:

$$\Delta h_{pos} = (\Delta h_{alt}^2 + \Delta h_{tim}^2 + \Delta h_{prop}^2)^{1/2} \quad \text{(m)}$$

Δh_{alt} : rms uncertainty in satellite altitude and attitude knowledge
Δh_{tim} : rms instrument timing measurement error
Δh_{prop} : rms uncertainty in propagation delay knowledge

Cross-polarisation

is the one-way antenna cross-polarisation gain level with respect to the peak copolar gain.

External Calibration error

Calibration error is the uncertainty in the calibration applied to the CPR at the time of calibration. It consists of two parts, the uncertainty in the scattering coefficient of the target employed in the calibration and the uncertainty in the overall radiometric stability at the time of calibration.

Impulse response function

is defined for the nominal measurement mode and is a two-dimensional function representing the response of the radar as it passes over an ideal point target of a unit reflectivity, contained within the plane defined by the sub-satellite track and local vertical, neglecting all noise contributions and when the signal is integrated over the specified distance.

Instantaneous radar footprint

is defined by the one-way –3 dB antenna contour projected onto the reference Earth ellipsoid model.

Per-unit-volume radar reflectivity

η, is the radar cross section of the scattering medium per unit volume.

Radar reflectivity factor

Z, is a term related to the size and spatial density of cloud particles. A direct relationship exists between Radar reflectivity factor and Per unit-volume-radar reflectivity.

Radiometric Stability

The radiometric stability over one orbit is defined as follows:

$$K_{orbit} = 10 \times \log(1 + \frac{\sqrt{(\hat{\eta}_{app1} - \hat{\eta}_{app2})^2}}{E[\hat{\eta}_{app1} + \hat{\eta}_{app2}]}) \quad [dB]$$

where $\hat{\eta}_{app1}$ and $\hat{\eta}_{app2}$ are the apparent radar reflectivity estimates derived from the radar for any two arbitrarily chosen integration periods of 1000 km length within an orbit, for a spatially and temporally constant scene.

The orbit-to-orbit radiometric stability is defined by the same formula, but for any two arbitrarily chosen integration periods of 1000 km length over two arbitrarily selected orbits within a maximum period of 3 months, for a spatially and temporally constant scene.

Radiometric resolution

Radiometric resolution is the error in the reflectivity estimate which arises due to the finite signal to noise ratio of the instrument and the limited number of data samples integrated to derive the estimate. For the CPR, incoherent integration of the samples is performed in along track, and noise subtraction is performed using an accumulation of noise samples. The radiometric resolution, γ, is given by:

$$\gamma = \sqrt{(1 + 1/\mathrm{SNR}_{pp})^{2}/\mathrm{N} + 1/(\mathrm{M}.\mathrm{SNR}_{pp}^{2})} \quad \text{[dimensionless quantity]}$$

Where:

SNR_{pp} is the signal to noise ratio per pulse
N is the effective number of integrated pulses allowing for inter-pulse correlation
M is the number of noise samples used

Total radiometric accuracy

K_{tot} is defined as:

$$K_{tot} = 10 \times \log(1 + \frac{\sqrt{E[(\hat{\eta}_{app} - \eta_{app})^2]}}{\eta_{app}}) \quad [dB]$$

where E denotes an expectation (or average), η_{app} is the error free (ideal) mean apparent per-unit-volume radar reflectivity for a spatially and temporally constant scene, and $\hat{\eta}_{app}$ is the corresponding quantity estimate derived from the radar for the specified integration distance. The estimate includes all errors due to target speckle, all forms of noise and all instrument related errors including the External Calibration error.

Specifically excluded from the total radiometric accuracy budget are the contributions from ground clutter which are controlled by means of an independent budget.

Vertical resolution

is defined for the nominal measurement by the -3 dB width of the radar impulse response function along the nadir direction (central cut).

5.3.2 CPR Functional and Operational Requirements

CPR-FO-1 The CPR shall be designed to be compatible with the range of orbits defined in 4.1 of this document.

CPR-FO-2 The cloud radar shall perform measurements continuously in orbit.

5.3.2.1 Measurement Modes

CPR-FO-3 There shall be two nominal measurement sub-modes: a Doppler sub-mode and a non-Doppler sub-mode.

CPR-FO-4 Nominal modes shall be designed to include short periods of internal calibration which is performed without causing interruption to the measurements.

CPR-FO-5 The CPR operation shall be switchable from one mode to the other at any pre-programmed time or upon command from the ground.

CPR-FO-6 The switching between the Doppler and non-Doppler sub-modes shall be synchronised to the integration cell length.

CPR-FO-7 Switching between the two sub-modes shall not take more than 1 s.

CPR-FO-8 During the measurement mode, the satellite-ground range variation in combination with the high instrument PRF will necessitate that updates of the PRF are performed around the orbit in order to maintain the return signal within the echo window. The time to perform such a PRF update shall not take more than 1 s (TBC).

5.3.2.2 Silent State Mode

CPR-FO-9 In addition, there shall also be a Silent State mode which is entered at a pre-programmed point in the orbit and lasts between 10 seconds and 15 minutes (TBC). During Silent State mode, no radar pulses are transmitted.

For availability computation purposes, the CPR instrument can be considered as available during Silent state.

CPR-FO-10 Up to 10 (TBC) such interruptions of measurement per orbit shall be possible with selectable intervals.

This mode will be used to protect ground-based instruments, e.g. radiofrequency telescopes operating in the same frequency band in compliance with applicable ITU recommendations.

CPR-FO-11 If an interruption of the measurement modes is necessary for switching between the nominal and Silent State, it shall be arranged such, that the transition shall occur at the end of integration cell.

5.3.2.3 Calibration Mode

CPR-FO-12 An external Calibration mode operation shall be foreseen, if it is judged necessary to meet the performance requirements. Presently, there are two different approaches foreseen for performing such an end-to-end absolute calibration. The approach which results in the minimum operational complexity is preferred.

The spacecraft will be able to perform both approaches.

- Approach 1: The CPR is operated in its nominal measurement mode (nadir pointing) over a set of specific land areas with well-characterised radar backscatter properties;
- Approach 2: The use of ocean surface for external calibration involves operation of the CPR at reduced PRF with the spacecraft rotating about its roll axis with an angular velocity in the range of 0.6 – 0.68 degrees/s between an inclination 10 degrees from one side of the satellite ground track to 10 degrees to the other side of the ground track.

This approach currently foresees two such sweeps, one closely after the other, followed by a return to nominal attitude and operation.

In implementing such an approach, periods of acceleration and deceleration have to be built into the manoeuvre to reach the constant velocity phases – the instrument operates continuously throughout the manoeuvre.

Such manoeuvres are foreseen at weekly intervals during the commissioning phase and monthly thereafter.

Operation of the mode described in Approach 2 may not entail interruption of the measurement mode for more than TBD s per orbit.

CPR-FO-13 If an external calibration mode of operation is implemented and if an interruption of the measurement mode is necessary for switching purposes, transition periods between the modes shall not exceed 1.0s (TBC)

5.3.2.4 Test Mode

CPR-FO-14 If it is necessary to perform in-flight characterisation of on-board parameters not determined in the routine operation of the instrument, the instrument provider may consider the provision of the test mode to establish these parameters.

5.3.2.5 Sun Viewing

CPR-FO-15 The CPR instrument shall not be damaged by direct alignment of the antenna with the sun for a period of up to 60 seconds (TBC).

Full instrument performance as specified in this document should then be resumed in accordance to req. PAY-GE-4. Longer sun illumination shall be prevented at system level via AOCS req. AOS-FU-3.

5.3.3 CPR Frequency Requirements

CPR-FR-1 The radar shall perform measurements at the frequency centred at 94.05 GHz +/- 3.5 MHz (TBC).

5.3.4 CPR Polarisation Requirements

CPR-PO-1 The polarisation of the transmitted signal shall be linear or circular. In the case of linear polarisation, the orientation of the polarisation may be arbitrary but must remain fixed.

CPR-PO-2 Cross-polarisation shall be better than -20 dB.

5.3.5 Geometrical Requirements

CPR-GR-1 Measurements shall cover the altitude range between –0.5 km and 20 km with respect to the reference ellipsoid surface. The altitude range may be reduced to either – 0.5 km and 16 km or – 0.5 km and 12 km over TBD latitude regions.

CPR-GR-2 The above ranges and latitude regions shall be selectable by ground command.

CPR-GR-3 The emitted pulse shall have a duration of 3.3 µs +/- TBD µs. The resulting vertical resolution, defined as the half-power width of the impulse response function, shall be less than or equal to 400 ± TBD m (exact value depends on the receiver impulse response).

CPR-GR-4 The vertical sampling interval shall be 100 m +/- TBD m.

CPR-GR-5 Knowledge of the absolute altitude of the samples with respect to the reference ellipsoid shall be better than 50 m RMS including all instrument and platform induced errors.

CPR-GR-6 The nominal instantaneous radar footprint shall have a diameter less than or equal to 1 km.

CPR-GR-7 Overall pointing of the CPR bore-sight (including satellite effects) shall be maintained to within 2 mrad (1 sigma) of the Earth local normal.

CPR-GR-8 This overall pointing shall be ensured at instrument level by designing the instrument to take into account the satellite pointing assumptions set out in 5.3.10

CPR-GR-9 Effects originating from the orbital altitude variation of the satellite shall be removed from the cloud Doppler measurement. The rate of altitude variation will be known to an accuracy of 0.2 m/s

5.3.6 Data Requirements

CPR-DA-1 The radar echo and Doppler-shift profiles shall be averaged on board for transmission to ground over an along track distance on ground of 500m.

CPR-DA-2 The maximum data rate of the instrument including all auxiliary data shall be 270 (TBC) kbits/s

5.3.7 Radiometric Requirements

CPR-RA-1 The radar shall perform power measurements of the back-scattered signal from cloud particles, along the sub-satellite track.

CPR-RA-2 After correction for spacecraft vertical speed and non-ideal antenna pointing, the Doppler function shall provide an unambiguous estimate of the vertical velocity of cloud particles/droplets with respect to the reference ellipsoid.

CPR-RA-3 For an along track integration distance of 10 km it shall be possible to determine this velocity over the range of –10 m/s to +10 m/s with an accuracy of 1 m/s (threshold) at any PRF at a minimum reflectivity factor of -19 dBZ.

CPR-RA-4 The total radiometric accuracy of the derived apparent per-unit-volume radar reflectivity, shall at all times be better (i.e. less) than or equal to 2.7 dB for an along-track signal integration distance of 10 km

CPR-RA-5 The total radiometric accuracy budget shall be formed from the arithmetic sum of two components, the External Calibration error, K_{extcal} and all other relevant terms, K_{other} viz:

$$K_{tot} = K_{extcal} + K_{other} \quad \text{(dB)}$$

CPR-RA-6 The dynamic range shall cover the range between Z_{min} and Z_{max} at the top of the atmosphere (20 km) as specified below. All geometrical and radiometric requirements shall be met within this dynamic range.

Z_{min} shall be less than or equal to -35 dBZ and Z_{max} shall be higher than or equal to 21 dBZ.

Z_{max} shall be sufficient to cover the dynamic range of surface-returns which are used for the absolute radiometric calibrations and as zero-Doppler reference.

CPR-RA-7 The radiometric resolution of the instrument shall be less than 0.46 at the lower end of its dynamic range.

CPR-RA-8 For the Doppler measurements, the vertical velocity estimation range as defined in CPR-RA-3 the following measurement goals shall be applied for a minimum reflectivity factor of -14 dBZ: 1 m/s accuracy for 1 km along track integration at all PRFs and 0.2 m/s for 10 km along track integration at 7200 Hz PRF.

CPR-RA-9 The spurious response at 1 km altitude due to the ground clutter shall not exceed the level returned from cloud at 1 km altitude having a reflectivity factor of –33 dBZ.

CPR-RA-10 The radiometric stability over one orbit shall be better (less) than or equal to 0.3 dB.

CPR-RA-11 The orbit-to-orbit radiometric stability shall be better (less) than or equal to 0.5 dB.

CPR-RA-12 The External Calibration error shall be better (less) than or equal to 1 dB.

5.3.8 CPR Performance Modelling Requirements

CPR-PM-1 For the purposes of instrument design and performance assessment, the radar cross section product shall be assumed to be the apparent per-unit-volume radar cross-section as a function of altitude integrated over an along track distance of 10 km.

CPR-PM-2 Similarly, for the Doppler function, the product shall be assumed to be the bulk vertical velocity of the particles/droplets and the spectral width of velocity as a function of altitude, integrated over an along track distance of 10 km.

CPR-PM-3 The Earth and orbit models defined in the CPR IRD [AD-8] shall be used in the modelling.

CPR-PM-4 A clear air atmospheric attenuation shall be taken into account both within and outside clouds using the data of Paragraph 5.3.8.1

CPR-PM-5 The particle size distribution of clouds and their associated radar characteristics shall be represented as defined in Paragraph 5.3.8.2

CPR-PM-6 The surface reflectivity model given in Paragraph 5.3.8.3 shall be used for calculating the ground clutter spurious response.

CPR-PM-7 The background brightness temperature of the Earth surface shall be taken to lie between 120 K and 300 K.

5.3.8.1 Clear Air Atmospheric Attenuation

The clear air atmospheric attenuation, A, is defined as follows:

$$A = \int_{h}^{h_{max}} k_g(z)dz \quad \text{dB}$$

where: $k_g(z)$: specific attenuation (clear atmosphere)

$\int_{h}^{h_{max}} k_g(z)dz$: one-way total zenith attenuation in [dB] from altitude h to the top of the atmosphere, which is given in the table below.

CPR-PM-8 The attenuation for any intermediate altitude shall be calculated by a linear interpolation in dB of the values tabulated below.

CPR-PM-9 The values for the "Annual Tropic atmosphere" shall be used for the performance evaluation. The "Summer Mid-Latitude" values are given for information only.

Altitude, km	One-way total zenith attenuation [dB]	
	Annual Tropic	Summer Mid-Latitude
0	2.17	1.45
0.25	1.89	1.26
0.50	1.64	1.10
0.75	1.41	0.95
1.0	1.21	0.83
1.5	0.88	0.62
2.0	0.64	0.47
4.0	0.20	0.17
6.0	0.080	0.076
8.0	0.042	0.041
12.0	0.015	0.014
16.0	0.005	0.004
20.0	0.001	0.001
25.0	0.000	0.000

5.3.8.2 Cloud Particle Size Distributions and Associated Radar Characteristics

The particle distribution is represented by the modified Gamma function as follows:

$$N(D) = 0.5 \times A(\frac{D}{2})^{\alpha} \times e^{-B(\frac{D}{2})^{\gamma}} \quad [\mu m^{-1} cm^{-3}]$$

where D is the particle diameter in [μm] and A, B, α and γ are parameters of the modified Gamma function.

Assuming Rayleigh region scattering, the radar reflectivity factor is defined as:

$$z = \int_0^{\infty} D^6 N(D) dD = 10^{-12} \times \frac{A}{2^{\alpha+1}} [\gamma(\frac{B^{1/\gamma}}{2})^{\alpha+7}]^{-1} \times \Gamma(\frac{\alpha+7}{\gamma}) \quad [mm^6 m^{-3}]$$

where Γ( ) is the Gamma function. This reflectivity factor is commonly expressed in [dBZ]:

$$Z = 10 \times \log z \quad [dBz]$$

The per-unit-volume radar reflectivity η is expressed as:

$$\eta = 10^{-6} \times \frac{\pi^5}{\lambda^4} \times |K|^2 \times z \quad [m^{-1}]$$

where λ is the wavelength in [mm] and K is the complex dielectric factor of the droplets.

CPR-PM-10 For all calculations, a normalising value of $|K|^2 = 0.75$ shall be used.

CPR-PM-11 For the estimation of attenuation due to water cloud droplets, Im(-K) = 0.2 shall be assumed. The apparent radar reflectivity η_{app} takes account of the attenuation due to the clear atmosphere and clouds.

CPR-PM-12 The specific attenuation k [dB/km] due to the cloud droplets shall be derived using:

$$k = 0.434 \times 10^{-5} \times \frac{\pi^2}{\lambda} \times Im(-K) \times \frac{A}{2^{\alpha+1}} [\gamma(\frac{B^{1/\gamma}}{2})^{\alpha+4}]^{-1} \times \Gamma(\frac{\alpha+4}{\gamma}) \quad [dB/km]$$

where only the absorption term has been taken into account (attenuation due to the scattering term is negligible). This assumption is valid only in the case of Rayleigh regime scattering.

5.3.8.3 Surface reflectivity model

CPR-PM-13 The estimation of the ground clutter shall be made using the following per-unit-surface reflectivity model:

$$\sigma^0(\theta) = 15 \times \cos^{-4}\theta \times \exp(-\frac{\tan^2\theta}{s^2}) \quad [dB], \quad 0° \le \theta \le 20°$$

$$\sigma^0(\theta) = 9 - \frac{\theta}{10} \quad [dB], \quad 20° < \theta \le 40°$$

$$\sigma^0(\theta) = 11 - \frac{3\theta}{20} \quad [dB], \quad 40° < \theta \le 60°$$

where θ is the incidence angle (with respect to the local normal) in degrees and s = 0.361993737

5.3.9 CPR Specific Data Product Requirements

This section is limited to data product requirement specific to CPR instrument.

CPR-DP-1 The echo and noise samples, averaged on board over an along-track ground distance as specified above (500 m) shall be transmitted to the ground segment to enable the Level 1b product to be generated.

CPR-DP-2 The Level 1b product shall comprise estimates of apparent per unit volume radar cross section and Doppler derived estimates of cloud particle/droplet velocities.

CPR-DP-3 The apparent per-unit-volume radar cross-section as a function of altitude integrated over an along track distance of 10 km shall be derived from the measured back-scattered signal power.

CPR-DP-4 For the Doppler function, the bulk vertical velocity of the particles/droplets and spectral width of velocity integrated over along track distance of 10 km and 1 km shall be derived as a function of altitude.

CPR-DP-5 The barycentre of the Level 1b product shall be localized to an accuracy of 500 m.

5.3.10 CPR Design Requirements

Design standards applicable for CPR industry are Japanese standards, except for the S/C interface parts or characteristics.

Reliability

CPR-DR-1 The probability that the CPR meets its performance requirements after 2 years on-ground testing, 2 years storage, 6 months commissioning and 30 months in-flight operation shall be assessed and shall be greater than TBD.

CPR-DR-2 The reliability of the instrument shall also be calculated for an extra 1 year in orbit.

Single point failures

Single point failures are defined as the failure of any element of the instrument which would result in the irrevocable degradation of instrument performance below the levels specified.

Multiple failures, which result from common-cause or common-mode failure mechanisms shall be considered as single failures for determining failure tolerance.

CPR-DR-3 Single point failures shall be avoided by use of redundancy. Deviations shall be identified and agreed with ESA.

CPR-DR-4 Single point failures which are considered to be unavoidable shall be identified in the FMECA under agreement with ESA.

Availability

CPR-DR-5 During the routine operations phase it is intended to operate the instrument almost continuously in orbit. Loss of availability due to external calibration activities and origins internal to the instrument shall be less than 5 %.

Failsafe

CPR-DR-6 In the event that the power supplies to the CPR fall below the undervoltage limit (TBD) or above the overvoltage limit (TBD), the instrument shall detect this condition and switch off.

CPR-DR-7 In the event that communication is lost between the satellite and instrument controller, the instrument shall detect this condition and CPR shall be designed to be in a safe condition.

Control

CPR-DR-8 The CPR shall be controlled and monitored by control electronics located within its Signal Processor. This unit shall be commanded from the satellite by macrocommands. The format of the macrocommands is described in TBD.

CPR-DR-9 The satellite will be responsible for powering up the Signal Processor which shall establish a state from which macrocommands may be received and executed.

CPR-DR-10 Mode transitions requested by macrocommand shall be under the control of the CPR Signal Processor.

CPR-DR-11 Macrocommands shall be executed according to their time tag or immediately in the event that they are not time tagged.

CPR-DR-12 In the event of CPR failure or severe anomaly, the CPR shall be designed to enter a safe mode autonomously.

CPR-DR-13 The Signal Processor shall monitor the instrument and provide housekeeping telemetry. The content and format of this telemetry is described in AD-8.

CPR-DR-14 All commands executed by the Signal Processor shall undergo status verification of their execution.

CPR-DR-15 The above status verification shall be reported in the housekeeping data.

CPR-DR-16 Monitoring of parameters indicative of the instrument's health (e.g. temperatures supplies to the EIK etc.) shall be included as part of the housekeeping data set.

CPR-DR-17 It shall be possible to dump any part of the memory of the Signal Processor control electronics.

CPR-DR-18 It shall be possible to patch any part of the memory of the Signal Processor control electronics.

Science data generation

CPR-DR-19 CPR shall generate instrument science data packets for transmission to ground within CCSDS packets via the satellite science data subsystem.

CPR-DR-20 The downlinked packets shall contain all on-board data necessary to generate the CPR level 1B product.

CPR-DR-21 The need for any on-board data necessary for level 1B processing which is not generated directly by the CPR shall be identified at an early stage of the programme and notified to higher level.

CPR-DR-22 The maximum data generated per orbit by the CPR shall not exceed 187.5 Mbytes (TBC).

Note: the above amount of CPR data is derived from an average data rate of 270 kbps and the orbit duration identified by OBS-RO-2 requirement.

Datation

CPR-DR-23 The CPR Signal Processor shall maintain a time reference which is synchronised to the satellite time standard.

CPR-DR-24 This time reference shall be employed to time stamp the instrument science data to an accuracy of better than 0.015 ms with respect to the satellite time standard.

Mass

CPR-DR-25 The CPR mass is the mass of all CPR flight hardware provided to ESA and is specified in the IRD.

Power

CPR-DR-26 Input power to the CPR (excluding heaters) in any mode is specified in the IRD.

CPR-DR-27 An assessment of the mean orbital power consumption of the instrument based on each mode shall be provided to ESA. In measurement mode the orbital power consumption shall be assessed on the basis of the nominal orbital PRF profile.

CPR-DR-28 Heater power availability is defined in the IRD and shall be available under TBD conditions.

Materials

CPR-DR-29 The CPR baseplate and spacecraft CPR-accommodation structure shall be manufactured using materials or a technology which are mutually compatible.

CPR-DR-30 The use of magnetic materials shall be avoided. Exception shall be subject to Agency's approval.

CPR-DR-31 Magnetic components shall be identified in the Interface Control Drawing (ICD)

Grounding

TBD

Outgassing and contamination

With the understanding that EarthCARE embarks very sensitive optical elements, specific measures in terms of design and implementation will have to be taken towards avoiding (minimizing) contamination. Detailed requirements shall be released during phase B.

CPR-DR-32 The outgassing properties of all materials shall be evaluated and demonstrated compliant with the contamination plan so as to meet the instrument performance requirements and the satellite requirements.

CPR-DR-33 The CPR design shall ensure that the CPR does not compromise the performance of other instruments on EarthCARE.

CPR-DR-34 All CPR elements shall be subjected to TV test including bakeout phase details to be agreed.

CPR-DR-35 Preferred venting hole shall be on –Z direction.

CPR-DR-36 In case of sensitivity to ATOX, exposed surfaces shall be protected by suitable materials.

CPR-DR-37 The following minimum cleanliness levels shall be maintained for CPR:

- Molecular Cleanliness Level: $5x10^{-7}gcm^{-2}$
- Particulate Cleanliness Level: $300mm^2/m^2$

Multipaction

CPR-DR-38 The instrument shall be multipaction free.

CPR-DR-39 The standards defined in ND-5 (E-20-01 A) shall apply subject to the following CPR specific caveats:

- Paragraph 4.2 – append "for the CPR the VSWR and reflection phase of load connected to component shall be considered in multipaction design and test."
- Paragraph 4.4 – verification shall be performed by test of the CPR protoflight model only
- Tables 2 and 3 – the applicable test margin for the CPR protoflight unit shall be 3 dB
- Paragraph 4.6.2 – append "for the CPR, the minimum design margin shall be 6 dB, verification testing shall be conducted with 3 dB margin.
- Paragraph 6.3 – append "e. For CPR, testing should at least be performed at the upper qualification temperature limit."

Arc discharge

CPR-DR-40 No malfunction shall occur when the CPR is submitted to a direct repetitive arc discharge of at least TBD mJ energy.

CPR-DR-41 No malfunction shall occur when the CPR is submitted to a indirect repetitive arc discharge of at least TBD mJ energy.

Atmospheric oxygen

CPR-DR-42 The CPR will be exposed to an atomic oxygen environment as indicated in ND-1. Material selection shall take account of this environment

Hold-down and Deployment mechanisms

CPR-DR-43 During the launch phase, the antenna reflector shall be constrained against the satellite +X face by use of a suitable hold-down mechanism.

CPR-DR-44 The hold-down mechanism shall be capable of being released during the early orbit phase in response to a command from the satellite.

CPR-DR-45 The reflector shall be capable of moving from its stowed position to the deployed position (at which it meets the pointing specification) under the control of a deployment mechanism.

CPR-DR-46 This hold down and deployment mechanisms shall be designed with consideration to the effects of shock on the satellite and final antenna pointing.

CPR-DR-47 Unless absolutely necessary, the deployment mechanism may not be electrically powered. Any need for an electrically powered deployment shall be identified at an early stage and communicated to the Agency for approval.

CPR-DR-48 Telemetry signals shall be provided to indicate successful release of the hold-down mechanism and successful deployment of the reflector.

CPR-DR-49 In the event that there is a need to mount a third-party cable harness on the reflector, the prime contractor is responsible for provision of the harness in the area of the deployment hinge. The CPR supplier and prime contractor are jointly responsible for ensuring that adequate torque margin exists during the deployment. CPR supplier is responsible for verification.

Mechanical requirements

CPR-DR-50 The CPR shall be equipped with suitable lifting points (or if necessary a suitable lifting device) to allow the instrument to be integrated onto the satellite.

CPR-DR-51 The CPR reflector shall be equipped with suitable suspension points (or if necessary a suitable supporting device) to allow its deployment during satellite testing on ground.

CPR-DR-52 The lifting arrangement may also be employed to off-load the instrument from the satellite panel during instrument alignment.

Pointing assumptions

CPR-DR-53 In meeting the CPR overall pointing requirement, the instrument designer shall assume the following contributions as originating from the satellite in case of local normal pointing:

	Roll (+/- mrad)	Pitch (+/-mrad)	Yaw (+/- mrad)
Total Error (RMS)	0.7	0.7	N/A

Note: N/A = Yaw value will vary along the orbit as a function of the yaw steering law.

CPR-DR-54 In evaluating the instrument measurement performance, the following data shall be assumed regarding satellite pointing knowledge:

	Roll (+/- mrad)	Pitch (+/-mrad)	Yaw (+/- mrad)
Total Error (RMS)	TBD	0.2 (goal: 0.043)	TBD

Alignment

CPR-DR-55 Integration and alignment of the CPR on the satellite is a Satellite Contractor responsibility. However, provision of a CPR design which is compatible with the required alignment accuracy shall be the responsibility of the CPR supplier.

CPR-DR-56 A description of the method to be applied to align the instrument on the satellite shall be provided under agreement with ESA.

CPR-DR-57 The instrument shall be equipped with mirror cubes which are accessible when the instrument is in stowed configuration. The direction of the antenna bore sight in the deployed configuration shall be made known with respect to the orientation of the mirror cube faces.

CPR-DR-58 The mirror cubes shall fulfil the following requirements TBD.

CPR-DR-59 The uncertainty in the deployed antenna bore sight to mirror cube characterisation shall be less than TBD.

CPR-DR-60 Correct along track pointing of the CPR shall be achieved when the instrument interface plane is coincident with the instrument mounting surface of the satellite. This may imply the provision of some type of preselected alignment device (possibly baseplane shims) for inclusion by the satellite contractor.

CPR-DR-61 Co-alignment of the CPR with respect to ATLID in the across track direction shall be adjustable by rotation of the CPR orientation using the mirror cube as a reference. The CPR shall therefore include a facility by means of which the orientation of its antenna bore sight may be rotated about the satellite X-axis by +/- 0.25 degrees.

Mathematical Models

Mathematical modelling will be part of the satellite design and verification process. This will be based on standard modelling packages. There will be an exchange of data between the instrument developer and the satellite design authority and vice-versa which will be controlled by direct file transfer of the modelling tools used.

CPR-DR-62 The three-dimensional CAD package type shall be STEP compatible (TBC).

CPR-DR-63 The structural analysis used in the mechanical design shall be NASTRAN.

CPR-DR-64 A thermal mathematical model (ESARAD/ESATAN TBC) shall be provided for integration into the satellite level model to allow validation of the thermal control interface and coupled system analyses.

CPR-DR-65 Details of the model specifications shall be provided with the model deliveries.

Verification

CPR-DR-66 CPR functionality and performance shall be established at instrument level before, after thermal, thermal vacuum testing, mechanical and EMC testing.

CPR-DR-67 In the case of thermal, thermal vacuum and EMC environments, functionality and performance shall also be confirmed under these environments.

CPR-DR-68 Exceptions in the scope of the above testing shall be made in agreement with ESA.

CPR-DR-69 Unless qualification has been achieved elsewhere, environmental levels and durations applied shall be based on a proto-flight philosophy with qualification levels and acceptance durations.

CPR-DR-70 In case qualification is achieved on a non-PFM item, environmental levels and durations shall be qualification levels and qualification durations.

CPR-DR-71 An adequate subset of instrument test procedures for use during testing of the instrument at integration and higher levels shall be delivered with the instrument.

CPR-DR-72 The tests referred to in CPR-DR-71 shall minimise the use of the antenna reflector as part of the test configuration and be subject to Agency approval.

CPR-DR-73 The reflector shall be capable of being opened with the CPR uppermost on the satellite and, if necessary, supported with a simple jig.

CPR-DR-74 Testing of the CPR during and after satellite integration shall be possible in an orientation such that the CPR is uppermost on the satellite (with its interface plane horizontal); this orientation will be employed both for clean room and vacuum.

CPR-DR-75 In addition, automatic, unassisted deployment tests of the CPR antenna shall be performed with the satellite oriented such that the CPR hinge axis is vertical.

CPR-DR-76 As part of the satellite test programme, there will be a need for a Radio Frequency Compatibility test to confirm that the payload may be operated as an ensemble of instruments without mutual interference. To this end, the design shall incorporate features which allow the reflector to be deployed, adequately supported and operable whilst in an anechoic environment.

Ground support equipment

CPR-DR-77 Electrical Ground Support Equipment developed for instrument level testing shall be compatible with the Satellite check-out equipment.

CPR-DR-78 Such EGSE shall be made available to the integration team at the instrument delivery to allow testing at higher level.

CPR-DR-79 Any special adapters required to interface the EGSE to the instrument for higher level testing shall be provided with the EGSE delivery.

CPR-DR-80 Any special Mechanical Ground Support Equipment necessary to allow the CPR to be integrated with the satellite shall be provided by the contractor.

CPR-DR-81 The CPR shall be tested for its compatibility with the satellite before shipping, using the Satellite Interface Simulator, provided by the prime contractor.

5.3.11 CPR Environmental Requirements

CPR-DR-82 The CPR shall be thermally isolated from the satellite.

CPR-DR-83 During normal operation, the CPR shall provide its own thermal control.

CPR-DR-84 In designing and verifying the CPR, the manufacturer shall take into account assumptions on the thermal, launch, space and electromagnetic environments.

CPR-DR-85 These environments will be declared in the CPR Instrument Interface Requirements document which may evolve with factors such as launcher selection.

5.3.12 CPR Requirements on Spacecraft

The above CPR requirements in some cases imply requirements which have to be fulfilled by the spacecraft. The following table cross references the implied satellite requirement number to the CPR requirement number and description from which it stems.

The implied spacecraft level requirements are stated thereafter.

Spacecraft requirement Number	CPR requirement number	CPR requirement description
CPR-SP-1	CPR-FO-12	Calibration mode
CPR-SP-2	CPR-GR-5	Altitude knowledge
CPR-SP-3	CPR-DR-8	Commanding
CPR-SP-4	CPR-DR-9	CPR power up
CPR-SP-5	CPR-DR-19	Science data transmission
CPR-SP-6	CPR-DR-20, CPR-DR-21	On-board data
CPR-SP-7	CPR-DR-23	Time synchronisation
CPR-SP-8	CPR-DR-26, CPR-DR-28	Power provision
CPR-SP-9	CPR-DR-41	Antenna release
CPR-SP-10	CPR-DR-42, CPR-DR-44	Deployment mechanism
CPR-SP-11	CPR-DR-44	Shock
CPR-SP-12	CPR-DR-48	Deployment telemetry
CPR-SP-13	CPR-DR-53	Satellite pointing
CPR-SP-14	CPR-DR-54	Satellite pointing knowledge

CPR-SP-15	CPR-GR-9	Satellite altitude rate knowledge
CPR-SP-16	CPR-DR-49	Reflector Third-party harness

CPR-SP-1 The spacecraft shall be capable of fulfilling the manoeuvre described in approach 2 of CPR-FO-12.

CPR-SP-2 The spacecraft shall provide data at 1 second intervals representing its altitude with the reference ellipsoid with an accuracy of 50m TBC.

CPR-SP-3 The spacecraft shall control the CPR by issuing macrocommands to the CPR Signal Processor.

CPR-SP-4 The spacecraft shall be responsible for initial power-up the CPR Signal Processor to allow the instrument to respond to macrocommands.

CPR-SP-5 The spacecraft shall accept science data from the CPR, stored them on-board when required and then transmit to ground.

CPR-SP-6 The spacecraft shall provide on-board data necessary for CPR data processing to the CPR for inclusion in the science data packets.

CPR-SP-7 The spacecraft shall make the satellite time standard available to synchronise its internal time standard with that of the satellite.

CPR-SP-8 The spacecraft shall provide separate resources to power the instrument in routine modes and to power instrument heaters during non- nominal situations.

CPR-SP-9 The spacecraft shall control the release of the antenna hold-down mechanism.

CPR-SP-10 In the event that the CPR deployment mechanism is not autonomous, the spacecraft shall control the operation of the deployment mechanism.

CPR-SP-11 The spacecraft shall tolerate shock associated with release and deployment of the CPR antenna.

CPR-SP-12 The spacecraft shall monitor the telemetry associated with the antenna deployment.

CPR-SP-13 The spacecraft pointing shall be within the limits specified for requirement CPR-DR-53.

CPR-SP-14 The satellite pointing data shall be known to the accuracy specified in requirement CPR-DR-54.

CPR-SP-15 The satellite shall provide data allowing the satellite altitude rate to be derived to, within the limits specified for requirement CPR-GR-9.

CPR-SP-16 The prime contractor shall fulfil the obligations induced by CPR-DR-49.

5.4 Multi-Spectral Imager (MSI)

The MSI shall provide measurements giving the context of the measurements of the active instruments and the BBR. The MSI is intended to provide information on the horizontal variability of the atmospheric conditions and to identify e.g. cloud type, textures, and temperature.

5.4.1 MSI Terms and definitions

Absolute localisation accuracy

Difference between the estimated position of any spatial sample and its true position on the reference Earth geoid.

Absolute radiometric accuracy

Unknown bias error (difference between measured value and true value) of the values associated to the samples in an image when a stable and spatially uniform scene is imaged. The absolute accuracy shall be demonstrated by averaging a sufficiently large number of samples such that the residual temporal variation does not dominate the calculation.

Day light condition

Part of the orbit where the sun zenith angle at satellite ground track is lower than 85º (TBC).

Defect

A spatial sample is considered as a defect spatial sample if,

- For solar channels, at reference TOA radiance its SNR is less than half (TBC) of the specified SNR value or if it is completely blind or saturated
- For thermal infrared channels, at reference brightness temperature its NEDT is larger than twice (TBC) of the specified NEDT value or if it is completely blind or saturated

Image

Ensemble of data acquired over a two-dimensional scene with equal number of spatial samples in the cross- and along-track direction. The number of spatial samples in cross-track is defined by the instrument swath and spatial sampling interval. The image of the two-dimensional scene is made of rows (cross-track direction) and columns (along-track direction).

Image swath

Maximum distance on ground between the positions of two spatial samples belonging to the same row when the image centre is viewed in the nadir or oblique direction.

Image length

Maximum distance on ground between the positions of two spatial samples belonging to the same column when the image centre is viewed in the nadir or oblique direction.

Inter-channel spatial co-registration

Maximum equivalent ground distance between the positions of all pairs of spatial samples acquired in two spectral channels and related to the same target.

Inter-channel temporal co-registration

Maximum time interval between the acquisitions of spectral channels related to the same target on Earth

Linearity

$$\left| \frac{S(L_a)}{L_a} x \frac{L_b}{S(L_b)} - 1 \right|$$

where:

S(L) is the instrument response to the entrance radiance L

L_a and L_b are any two radiance levels comprised within the signal dynamic range

The linearity shall be demonstrated by considering a sufficiently large number of radiance data within the dynamic range. Each radiance shall be measured over a sufficiently large number of samples such that the residual temporal variation does not dominate the calculation.

Mapping law

Angular mapping in the object space of the line of sight of individual detector elements. The mapping law can be either f. θ or f.tan(θ) law, where f is the instrument focal length.

Modulation Transfer Function (MTF)

Ratio of the modulation in the image to the modulation in the object as a function of spatial frequency of a sine wave object.

Suppose a radiance signal at the entrance of the instrument, constant in the along track direction and varying in the across track direction according to:

$$L(f,u) : \frac{L_{\max} + L_{\min}}{2} + \frac{L_{\max} - L_{\min}}{2} . \sin(2\pi fy + u)$$

Where f is the spatial frequency (cycles per unit distance)

y is the distance across track

u is the sample scene phase parameter

Then the across track modulation transfer function $MTF_{act}(f)$ is defined as

$$MTF_{act}(f) = \frac{\max[\frac{x_{\max}(f,u) - x_{\min}(f,u)}{x_{\max}(f,u) + x_{\min}(f,u)}]}{\frac{L_{\max}(f,u) - L_{\min}(f,u)}{L_{\max}(f,u) + L_{\min}(f,u)}}$$

Where $x_{max}(f,u)$ and $x_{min}(f,u)$ are respectively the maximum and minimum instrument response to the sinusoidal radiance, after detector equalisation

The along track modulation transfer function $MTF_{alt}(f)$ is similarly defined.

The system MTF includes all the perturbations induced by the image acquisition process (e.g. instrument, platform, etc.) and shall include as a minimum the effect of the optics, detector, integration time, straylight.

Out-Of-Band (OOB) rejection

The out-of-band rejection (OOB) is defined as:

$$OOB = 1 - \frac{\int_{\lambda_{center}-\Delta\lambda}^{\lambda_{center}+\Delta\lambda} L(\lambda)R(\lambda)d\lambda}{\int_{0.3\mu m}^{20\mu m} L(\lambda)R(\lambda)d\lambda}$$

where:

- $R(\lambda)$ is the instrument spectral response
- $L(\lambda)$ is:
  – the spectral radiance of a source which simulates the solar spectral energy distribution (5820 K) for the solar channels
  – the spectral radiance of a 293 K blackbody source for the TIR channels

Point Spread Function (PSF) of a spatial sample

For a spatial sample i observing in channel j with centroid ν_o a stable scene of spectrally integrated radiance $L_{ij}(\nu_o, x, y)$, the measured spectral radiance L'_{ij} is given by:

$$L'_{ij} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} PSF_{ij}(x,y)L_{ij}(\nu_o, x, y)dxdy$$

where: $PSF_{ij}(x,y)$ is the system Point Spread Function for spatial sample i in a channel j. The system PSF is the integral over dwell time of the instantaneous PSF, including optics, detectors, electronics and nominal pointing variation during dwell time. The spatial integral of the $PSF_{ij}(x,y)$ is normalised to 1.

Polarization sensitivity

Assuming measurement of a stable, spatially uniform, linearly polarized scene, the polarization sensitivity is defined as

$$P = \frac{S_{max} - S_{min}}{S_{max} + S_{min}}$$

where S_{max} and S_{min} are the maximum and minimum sample values obtained when the polarization is gradually rotated over 180 deg.

Position of sample

Geographic location of the barycenter of the system PSF.

Radiometric resolution

Radiometric resolution is expressed in Signal-to-Noise ratio (SNR) or Noise Equivalent Differential Radiance (NEDL) for the solar channels and Noise Equivalent Differential Temperature (NEDT) for the thermal infra-red channels, where

$$NEDL = \frac{L}{SNR}$$

And

$$NEDT = \frac{NEDL}{\frac{dL}{dT}}$$

For thermal infra-red channels the radiance L is given by the Planck function.

The Noise Equivalent Differential Radiance (NEDL) is the RMS deviation of the retrieved radiance associated to the samples of an image acquired over a stable and spatially uniform scene.

Radiometric stability

The radiometric stability defines the range of variability of the measured radiances L(t) for the solar channels, and brightness temperatures $T_b(t)$ for the thermal channels, over a stable with time not changing scene taken at any two times t_j , t_k within a specified time period τ:

$$\left|\frac{L(t_k) - L(t_j)}{L(t_k)}\right| * 100 <$$ Relative Accuracy in [%] for the solar channels

or

$$\left|T_b(t_k) - T_b(t_j)\right| <$$ Relative Accuracy in [K] for the thermal infra-red channels

Solar channels

Channels with center wavelength lower than 3.0 μm.

Spatial Sample

The spatial sample is associated with system PSF. The centre of the spatial sample is the system PSF barycentre.

Spatial Sampling Distance (SSD)

The barycenter-to-barycenter distance between adjacent spatial samples on the Earth's surface

Spectral channel center wavelength

Wavelength of the centroid of the spectral response.

Spectral channel width:

Full-Width-at-Half-Maximum of the spectral response of a sample.

Spectral response of a sample

The spectral response R(λ) relates the radiometrically calibrated, spectrally integrated radiance $L'(\lambda_o)$ measured in a spectral channel with the spectral radiance L(λ) emanating from a spatially homogeneous scene. The spectral response is normalised such that its spectral integral yields 1. The spectral response R(λ) is defined by:

$$L'(\lambda_o) = \int_{-\infty}^{\infty} R(\lambda, \lambda_o).L(\lambda)d\lambda$$

$\Delta\lambda_{50\%}$ is the spectral width at 50% spectral response.

$\Delta\lambda_{5\%}$ is the spectral width at 5% spectral response.

The wavelengths where the spectral response equals 50% define the channel edges.

Sun Zenith Angle (SZA)

Angle between the sun direction and the local zenith at target level (i.e., zenith – target – sun)

Thermal Infra-red (TIR) channels

Channels with center wavelength larger than 3.0 μm.

TOA spectral radiance, spectral reflectance

The relationship between TOA spectral radiance and TOA spectral reflectance is defined as follows:

$$L^{TOA} = \frac{\rho^{TOA}.E_s.\cos(\theta_s)}{\pi}$$

where:

- L^{TOA} is the top-of-atmosphere spectral radiance
- r^{TOA} is the top-of-atmosphere spectral reflectance
- θ_s is sun zenith angle.

5.4.2 MSI Geophysical Assumptions

5.4.2.1 Signal Levels

Typical levels of signals at the entrance of MSI are specified hereafter

For the solar channels

- L_{min} Minimum radiance of the dynamic range
- L_{ref} Reference radiance
- L_{max} Maximum radiance of the dynamic range
- L_{sg} Sun-glint radiance
- L_{sun} Sun radiance

For the TIR channels

- T_{min} Minimum brightness temperature
- T_{ref} Reference brightness temperature
- T_{max} Maximum brightness temperature

The sun-glint and sun radiance of the solar channels are defined by:

$$L_{sg} = 0.02 \frac{Max_j[E_s(j)]}{2\pi(1-\cos(\alpha_s))}$$

$$L_{sun} = \frac{Max_j[E_s(j)]}{2\pi(1-\cos(\alpha_s))}$$

Where E_s is the extraterrestrial solar irradiance

j is the julian day

α_s is half the angle subtended by the sun (16 arcmin)

The maximum radiance of the dynamic range is defined by:

$$L_{max} = \frac{E_s.\cos(\theta_s)}{\pi}$$

Where E_s is the extraterrestrial solar irradiance

θ_s is sun zenith angle

5.4.2.2 Extraterrestrial solar irradiance

The reference solar spectral irradiance data are provided in ND-40. The data are for a distance Earth-Sun of 1 astronomical unit (AU).

5.4.3 MSI Functional and Operational Requirements

MSI-FO-1 Unless otherwise stated the instrument requirements shall be met

- for the full signal dynamic range;
- for each spectral channel;
- for each spatial sample acquired within an image, excluding defects;
- for Level 1b and Level 1c data;
- over the specified mission duration including degradation resulting from molecular and particulate contamination.

MSI-FO-2 MSI shall perform measurements of the Earth scenes continuously in orbit.

MSI-FO-3 Acquisition in the solar channels is only mandatory in the daytime part of the orbit.

MSI-FO-4 Interruption of the imaging mode for calibration shall be limited as much as possible and shall be in agreement with the Satellite Operational Availability and the Time Allocation for in-orbit calibration requirements (resp. GSR-LR-4 and GSR-LR-5. The use of the calibration mode shall not entail the systematic loss of imaging capability in specific geographic locations.

MSI-FO-5 All raw data acquired during on-board calibration shall be transmitted to ground.

MSI-FO-6 The radiometric calibration shall be performed on ground.

The radiometric calibration is here referred to as the process of converting the digital data into TOA spectral radiance or brightness temperature through the correction of all radiometric errors introduced by the instrument (e.g. gain and offset correction).

MSI-FO-7 Unless duly justified all processing of the data performed on-board, if any, shall be reversible.

Processing is here referred to as functions altering the scientific content of the measurement data

MSI-FO-8 MSI shall transmit all gain and offset parameters applied on-board that modify the measurement data.

MSI-FO-9 MSI shall be capable of transmitting unprocessed data to allow testing and verification of the on-board correction functions.

MSI-FO-10 The number of MSI modes and on-board correction functions shall be kept to the strict minimum required to meet the requirements.

MSI-FO-11 The MSI shall have on-board end-to-end response calibration for the spectral channels. The calibration shall be a full optical system, full aperture.

MSI-FO-12 The on-board calibration sources shall be protected from ageing (contamination, UV exposure, ..) when non operated for instrument calibration.

MSI-FO-13 MSI shall have view baffles to keep out all direct sunlight from its interior during normal instrument operation.

MSI-FO-14 MSI shall have an alignment cube to reference to satellite AOCS.

5.4.4 Contamination

MSI-CO-1 MSI design (venting and other measures) shall avoid (minimise) the contamination sources and contamination pathways and the related consequences on the instrument performance so that the compliance to the instrument performance is not compromised by contamination.

MSI-CO-2 The outgassing properties of all materials in vicinity of optical surfaces and detectors shall be evaluated and demonstrated compliant with the contamination plan so as to meet the instrument performance requirements.

MSI-CO-3 Purging and other contamination protection measures shall be implemented during all instrument and satellite phases whenever needed.

MSI-CO-4 The MSI design shall ensure that the MSI does not compromise the performance of other instruments on EarthCARE.

MSI-CO-5 The following minimum cleanliness levels shall be maintained for MSI:

	optical components	non optical components
Molecular cleanliness level	$5x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$
Particulate cleanliness level	$50mm^2/m^2$	$300mm^2/m^2$

Table 5.4-1 Minimum cleanliness levels for MSI

5.4.5 MSI Design Requirements

MSI-DS-1 The MSI instrument shall be designed to intrinsically meet its performance requirements. Exceptions shall be handled by provision of characterisation data such that its performance requirements are met.

MSI-DS-2 All design requirements in section 5.4.5 (Design Requirements) shall be met for level 0 and higher level data unless otherwise specified.

5.4.5.1 Spectral Requirements

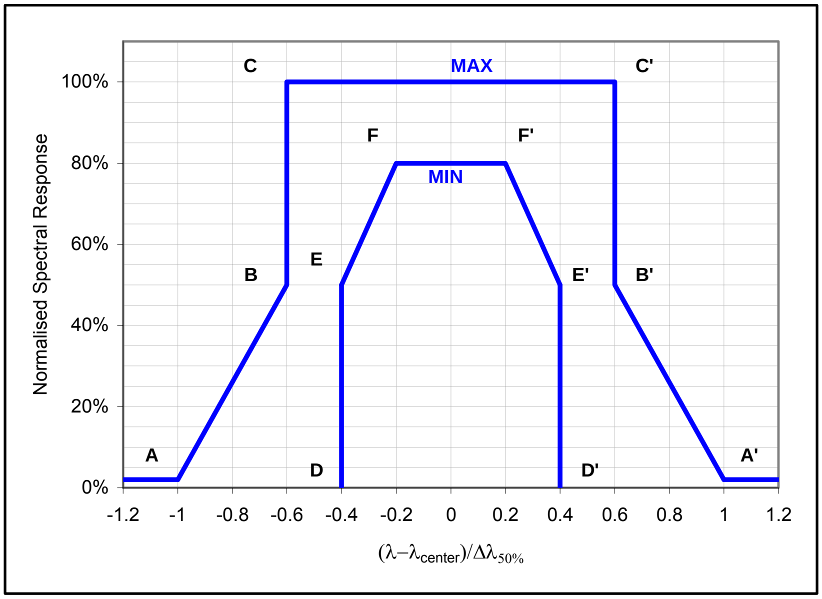
5.4.5.1.1 Spectral Channels

MSI-SR-1 MSI shall measure scene radiance in 7 spectral channels. The channels shall have the characteristics specified in Table 5.4-2

Spectral Channel			Center λ_{center}	Tolerance on λ_{center}	Spectral width $\Delta\lambda_{50\%}$	Spectral width $\Delta\lambda_{5\%}$
			µm	µm	µm	µm
B	1	VIS	0.67	±0.01	0.02	0.03
B	2	NIR	0.865	±0.01	0.02	0.03
B	3	SWIR 1	1.65	±0.015	0.05	0.08
B	4	SWIR 2	2.21	±0.015	0.1	0.15
B	7	TIR 1	8.80	±0.05	0.9	1.1 (goal)
B	8	TIR 2	10.80	±0.05	0.9	1.1 (goal)
B	9	TIR 3	12.00	±0.05	0.9	1.1 (goal)

Table 5.4-2 MSI spectral channels

MSI-SR-2 The MSI spectral response normalised by its maximum shall meet the spectral template plotted in Table 5.4-3:



	A/A'	B/B'	C/C'	D/D'	E/E'	F/F'
$(\lambda-\lambda_{center})/\Delta\lambda$	±1	±0.6	±0.6	±0.4	±0.4	±0.2
NSR	0.02	0.5	1	0	0.5	0.8

Table 5.4-3 MSI Spectral Response Template

MSI-SR-3 For any spectral channel, the out-of-band (OOB) rejection shall be less than 3% (TBC) (1% goal).

5.4.5.2 Geometrical Requirements

5.4.5.2.1 Field-of-View

MSI-GR-1 MSI shall image the Earth in nadir view for all spectral channels

MSI-GR-2 The MSI swath shall cover a distance from the sub-satellite point larger than or equal to

i. 35 km along the $-Y_{YS}$ direction

ii. 115 km along the Y_{YS} direction

Note: The FOV is tilted in the anti-sun direction to minimize the sunglint influence.

5.4.5.2.2 Spatial Sampling Distance

MSI-GR-3 The spatial sampling at SSP shall be smaller than or equal to 500 m.

MSI-GR-4 The spatial sampling distance at SSP in the along-track direction shall be constant within ± 1%.

MSI-GR-5 The angular sampling interval across track shall be regular and shall follow a f.tan(θ) or f. θ mapping law within ±1%.

5.4.5.2.3 Inter-channel Spatial Co-registration

MSI-GR-6 The inter-channel spatial co-registration shall be smaller than 0.15 SSD (goal: 0.1 SSD) for a target located anywhere in the altitude range 0 – 20 km. For VIS/NIR pair of spectral channels the requirement is applicable at level 0 and higher level. For any other pair of spectral channels the requirement is applicable at level 1c (goal: level 0 and higher level).

5.4.5.2.4 Inter-channel Temporal Co-registration

MSI-GR-7 The inter-channel temporal co-registration shall be smaller than 2.5 sec.

5.4.5.3 Modulation Transfer Function

MSI-MT-1 The system modulation transfer function (MTF) shall be larger than 0.25 for all frequencies between 0 km^{-1} and Nyquist frequency.

5.4.5.4 Polarisation Sensitivity

MSI-PO-1 The MSI polarization sensitivity shall be less than

- 0.01 in the solar channels
- 0.1 (0.04 goal) in the TIR channels.

5.4.5.5 Saturation

5.4.5.5.1 Sun-glint Scene

MSI-SA-1 The specified MSI requirements shall be achieved within 5 spatial sampling distances after observation of sun glint radiances L_{sg} .

MSI-SA-2 The data acquired in the solar channels polluted by sun-glint signal with equivalent surface reflectance exceeding 0.005 shall be flagged.

5.4.5.5.2 Hot Scenes

MSI-SA-3 The specified MSI requirements shall be achieved within 5 spatial sampling distances after observation of a hot scene of 10x10 km^2 with a brightness temperature of 500 K

5.4.5.5.3 Direct View of Sun

MSI-SA-4 MSI shall not be damaged by direct sun exposure for a period of up to 60 seconds (TBC).

In non-nominal operation of the satellite the MSI might be exposed to the sun with the sun entering in the instrument FOV for such periods. Full instrument performance as specified in this document should then be resumed in accordance to req. PAY-GE-4. Longer sun illumination shall be prevented at system level via AOCS req. AOS-FU-3.

5.4.5.6 Straylight

MSI-ST-1 Let assume:

- An image is composed of two uniform parts of infinite size and of different radiance,
- The radiance in one part is the L_{max} radiance defined in section 5.4.2.1 for the solar channels and the maximum signal specified in Table 5.4-5 for the TIR channels.
- The radiance in the other part is comprised between the low reference signal and the maximum signal specified in Table 5.4-4 and Table 5.4-5
- The step transition between the two uniform parts is located between two adjacent columns or rows

then,

the specified MSI requirements shall be achieved for spatial samples located at a distance larger than 2 SSD on each side of the step transition.

Stray-light performance is specified for non-uniform scenes to control pollution of low radiance parts of an image by stray optical and electrical originating from high-radiance parts.

5.4.6 Image Quality Requirements

5.4.6.1 Geometric Image Quality

All requirements in this section are to be met with a probability of 90%.

5.4.6.1.1 Absolute Localisation Accuracy

MSI-IQ-1 The absolute localization accuracy shall be such as to ensure meeting OBS-GR-1. Goal figure for the MSI shall be 0.5 goal spatial sampling distance.

5.4.6.2 Radiometric Image Quality

All requirements in this section are RMS values.

5.4.6.2.1 Radiometric Resolution

MSI-RI-1 The signal to noise ratio (SNR) of the solar channels shall be higher than the values specified in Table 5.4-4

Note: the SNR of the MSI solar channels shall be estimated over the full dynamic range.

Band			Min Signal(1)	Reference Signal(1)		Max Signal(1)	SNR @ Reference Signal	
				Low	High		Low	High
							Goal	Threshold
			$W.m^{-2}.sr^{-1}.\mu m^{-1}$					
B	1	VIS	3.85	30	444.6	489.1	75	500
B	2	NIR	0.95	17	282.7	311.0	65	500
B	3	SWIR 1	0.016	1.5	67.9	69.3	18	250
B	4	SWIR 2	0.0015	0.5	24.6	24.6	21	250
(1)	TOA spectral radiance							

Table 5.4-4 MSI signal level and SNR requirements of the solar channels

MSI-RI-2 The Noise Equivalent Differential Temperature (NEDT) of the IR channels shall be smaller than the values specified in Table 5.4-5.

Note: The NEDT of the MSI TIR channels shall be estimated over the full dynamic range.

Band			Min Signal(1)	Reference Signal(1)		Max Signal(1)	NEDT @ Reference Signal			
				Low	High		Low		High	
							Threshold	Goal	Threshold	Goal
			K	K	K	K	K	K	K	K
B	7	TIR 1	170	220	293	350	0.80	0.60	0.25	0.10
B	8	TIR 2	170	220	293	350	0.80	0.70	0.25	0.15
B	9	TIR 3	170	220	293	350	0.80	0.80	0.25	0.15

(1) TOA brightness temperature

Table 5.4-5 MSI signal level and NEDT requirements for the TIR channels

MSI-RI-3 The level 0 data Least Significant Bit (LSB) shall be smaller than the achieved Noise Equivalent Differential Radiance (NEDL).

5.4.6.2.2 Signal Dynamic Range

MSI-SD-1 The minimum and maximum signal of Table 5.4-4 and Table 5.4-5 specify the instrument full dynamic range. The low reference and maximum signal of Table 5.4-4 and Table 5.4-5 specify the instrument reduced dynamic range.

5.4.6.2.3 Absolute Radiometric Accuracy

MSI-AR-1 The absolute radiometric accuracy of the data acquired in the solar channels shall be smaller than 10% (5% goal) over the reduced dynamic range, traceable to the SI units.

MSI-AR-2 The absolute radiometric accuracy of the data acquired in the TIR channels shall be smaller than 1 K over the reduced dynamic range, traceable to SI units.

5.4.6.2.4 Inter channel Radiometric Accuracy

MSI-IR-1 The inter-channel relative reflectance difference between all solar channels looking at a spectrally constant reflectance reference target shall be less than 1% (TBC) of the estimated reflectance value.

MSI-IR-2 The inter-channel measured brightness temperature difference between all TIR channels looking at the same black body scene shall be less than 0.25K (goal: 0.1 K).

5.4.6.2.5 Linearity

MSI-LI-1 The instrument linearity shall be better than 0.01. i.e.

$$\left| \frac{S(L_a)}{L_a} x \frac{L_b}{S(L_b)} - 1 \right| \leq 0.01$$

where S(L) is the instrument response to the spectrally integrated radiance L

La and Lb are any two radiance levels comprised within the signal dynamic range

This requirement ensures a constant absolute gain calibration coefficient over the instrument signal dynamic range.

5.4.6.2.6 Radiometric Stability

MSI-RR-1 Assuming a stable and spatially uniform scene, the Level 1b data acquired in the solar channels shall be constant to better than 1 % over one year.

MSI-RR-2 Assuming a stable and spatially uniform blackbody scene, the Level 1b data acquired in the TIR channels shall be constant to better than 0.3 K over one year.

5.4.6.3 Spectrometric Image Quality

All requirements in this section are RMS values.

MSI-SI-1 The position of the solar channels centre wavelength and channel edges shall not vary by more than ± 0.002 µm.

MSI-SI-2 The position of the TIR channels centre wavelength and channel edges shall not vary by more than ± 0.05 µm.

5.4.7 Defects

MSI-DE-1 The number of defects in an image swath shall be less than 1 % for each spectral channel.

Defects may be removed from any performance average or standard deviations for determining compliance to performance specifications.

MSI-DE-2 Two defects must be separated by at least one spatial sample.

MSI-DE-3 There shall be no defect in the part of the MSI FOV that covers a swath of 40 km centred on the BBR spatial sample position.

5.4.8 In-flight Ancillary Data / Characterisation

MSI-IC-1 The instrument shall transmit all ancillary data required for the on-ground image data processing. As a minimum the instrument shall provide the data specified in Table 5.4-6.

Name	Units	Definition	Instrument Mode
Detector blank pixels	Counts	Signal generated from pixels that are shielded from scene/instrument signal. Data to be provided for TBD pixels at each image row.	Earth observation
Blackbody temperature	K	Temperature of the blackbody	Earth observation & Calibration
Optical and structural elements temperature	K	Optical and structural elements that influence the radiometric response of the spectral channels shall be temperature monitored and down-linked for calibration ground processing.	Earth observation & Calibration
Video electronics temperature	K	Temperature of the video processing unit	Earth observation & Calibration
Detector temperature	K	Temperature of the detectors	Earth observation & Calibration
TBS			

Table 5.4-6 In-flight instrument ancillary data

5.4.9 MSI Specific Data Product Requirements

This section is limited to data product requirement specific to MSI instrument. Other generic requirements, i.e. applicable to all instruments are listed under chapter 8 and hence also apply to MSI instrument.

Performance to be met by MSI data products, up to Level 1c, are specified in requirement MSI-FO-1.

MSI-DP-1 The Level 1b product shall consist of Top of Atmosphere (TOA) radiance ($W.m^{-2}.sr^{-1}.\mu m^{-1}$) in the solar channels and brightness temperatures (K) in the infra-red channels. The product shall be radiometrically calibrated, spectrally characterised, ortho-rectified, geo-located, annotated with satellite position and pointing, landmarks and preliminary pixel classification (cloud, water, vegetation, sun-glint,..).

MSI-DP-2 The Level 1c product shall be created through re-sampling of the Level 1b product using a selectable re-sampling method (e.g. bi-cubic convolution interpolation, nearest neighbour)

5.5 Broad-Band Radiometer (BBR)

The Broad-Band Radiometer (BBR) shall provide an estimate of the Top Of the Atmosphere (TOA) solar reflected radiance and the Earth emitted radiance along the satellite track. The radiances measured by the BBR are filtered by the spectral response of the instrument. The TOA unfiltered radiances are obtained by correlating both the BBR and MSI filtered radiances.

The BBR shall measure the solar reflected radiance and the total radiance in the Short Wave (SW) and Total Wave (TW) channels respectively. The Earth emitted radiance, also referred to as Long-Wave (LW) radiance, shall be estimated from the measurements in the SW and TW channels.

5.5.1 BBR Terms and definition

Absolute localisation accuracy

Difference between the estimated position of any spatial sample and its true position on the reference Earth geoid.

Absolute radiometric accuracy

The absolute radiometric accuracy is the difference between the real input radiance and the estimated radiance associated to a spatial sample. It includes all systematic errors after calibration and the instrument noise error (random error). It is the instantaneous error applicable for each spatial sample acquired by the instrument.

Channel to channel Cross-Talk

The channel to channel cross talk is defined as the cross-talk resulting from a relative change in any channel output when all other channel's illumination is changed from the minimum to the maximum signal of the dynamic range.

Integrated Energy (IE)

The Integrated Energy (IE) is the ratio of the radiance measured by the instrument in a directional view i and a spectral channel j over a squared area of size d centred around a position (x_o,y_o) on Earth to the radiance measured by the instrument from the entire large and spatially uniform scene.

$$IE_{ij}(d) = \frac{\int_0^{\infty} \int_{y_o-\frac{d}{2}}^{y_o+\frac{d}{2}} \int_{x_o-\frac{d}{2}}^{x_o+\frac{d}{2}} PSF_{ij}(x,y,\lambda).L_i(\lambda).R_{ij}(\lambda).dx.dy.d\lambda}{\int_0^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} PSF_{ij}(x,y,\lambda).L_i(\lambda).R_{ij}(\lambda).dx.dy.d\lambda}$$

Where i stands for the instrument along track directional view: nadir, forward, backward

j stands for the spectral channel: SW and TW

$R_{ij}(\lambda)$ is the instrument spectral response function in directional view i and spectral channel j

PSF_{ij} is the instrument Point Spread Function in directional view i and spectral channel j.

By definition the spatial integrated energy IE(d) and angular integrated energy IE(θ) are equal in case θ is the angle subtended by the distance d as seen from the instrument.

Linearity

$$\left| \frac{S(L_a)}{L_a} \cdot \frac{L_b}{S(L_b)} - 1 \right|$$

where S(L) is the instrument response to the entrance radiance L

L_a and L_b are any two radiance levels comprised within the signal dynamic range

The linearity shall be demonstrated by considering a sufficiently large number radiance data within the dynamic range. Each radiance data shall shall be measured over a sufficiently large number of samples such that the residual temporal variation does not dominate the calculation.

Observation Zenith Angle (OZA)

Angle between the satellite viewing direction and the local zenith defined in the target reference frame (i.e., zenith – target – satellite)

Point Spread Function (PSF) of a spatial sample

For a spatial sample i observing in channel j with wavelength λ_0 a stable scene of spectrally integrated radiance L_{ij}(x, y, λ_0) the measured spectral radiance L'_{ij} is given by:

$$L'_{ij}(\lambda_0) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} PSF_{ij}(x,y,\lambda_0) L_{ij}(x,y,\lambda_0)\,dxdy$$

where: $PSF_{ij}(x,y)$ is the system Point Spread Function for spatial sample i in a channel j. The system PSF is the integral over dwell time of the instantaneous PSF, including optics, detectors, electronics and pointing variation during dwell time. The spatial integral of the $PSF_{ij}(x,y)$ is normalised to 1.

Polarization sensitivity

Assuming measurement of a stable, spatially uniform, linearly polarized scene, the polarization sensitivity is defined as

$$P = \frac{S_{max} - S_{min}}{S_{max} + S_{min}}$$

where S_{max} and S_{min} are the maximum and minimum sample values obtained when the polarization is gradually rotated over 180 deg.

Position of sample

Geographic location of the barycenter of the system PSF.

Radiometric resolution

Radiometric resolution is expressed in Signal-to-Noise ratio (SNR) or Noise Equivalent Differential Radiance (NEDL), where

$$NEDL = \frac{L}{SNR}$$

The Noise Equivalent Differential Radiance (NEDL) is the RMS deviation of the retrieved radiance associated to a large number of samples acquired over a stable and spatially uniform scene.

Radiometric stability

The radiometric stability defines the range of variability of the measured radiances L(t) over a stable with time not changing scene taken at any two times t_j , t_k within a specified time period τ:

$$\left| \frac{L(t_k) - L(t_j)}{L(t_k)} \right|$$

Spatial co-registration

Maximum equivalent ground distance between the centers of the SW and TW spatial samples acquired in the three views and related to the same target.

Spatial Resolution

The spatial resolution ΔX is defined as the dimension of a squared area centred at the system PSF barycentre position of the nadir directional view that contains 80% of the spatial energy integrated (IE).

Spatial Sample

A spatial sample is a Level 1b measurement meeting all instrument requirements. The spatial sample is associated with system PSF. The centre of the spatial sample is the system PSF barycentre.

Solar Reflected Radiance

Solar radiance that has been reflected/scattered by the Earth-Atmosphere system.

The solar reflected radiance is estimated from the measurements of the Short-Wave (SW) channel.

Earth Emitted Radiance

Thermal radiance emitted by the Earth-Atmosphere system.

The Earth emitted radiance, also referred to as the Long-Wave (LW) radiance, is estimated from the measurements of the SW and TW channels.

Total Radiance

Total radiance exiting the Earth-Atmosphere system.

The total radiance is estimated from the measurements of the Total-Wave (TW) channel.

Spatial Sampling Distance (SSD)

The barycenter-to-barycenter distance between adjacent spatial samples on the Earth's surface acquired in the same directional view.

Spectral response of a sample

The spectral response R(λ) of a spectral channel relates the radiometrically calibrated, spectrally integrated radiance L' measured in a spectral channel with the spectral radiance L(λ) emanating from a spatially homogeneous scene. The spectral response is normalised such that its spectral integral yields 1. The spectral response R(λ) is defined by:

$$L' = \int_{-\infty}^{\infty} R(\lambda).L(\lambda) d\lambda$$

5.5.2 Geophysical Assumptions

5.5.2.1 Reference Scenes

The scenes to be considered for the assessment of the instrument performance are:

1. Maximum short wave radiation,
2. Minimum short wave radiation,
3. Maximum long wave radiation,
4. Minimum long wave radiation.

For each reference scene, the spectral radiances are provided in ANNEX-3.

The reference scenes are identical for all three directional views of the BBR.

5.5.2.2 Extraterrestrial Solar Irradiance

The reference solar spectral irradiance data are provided in ND-40. The data are for a distance Earth-Sun of 1 astronomical unit (AU).

5.5.3 BBR functional and operational requirements

BBR-FO-1 Unless otherwise stated the instrument requirements shall be met

- for the full signal dynamic range;
- for the reference scenes
- for the SW and TW channels;
- for each spatial sample acquired;
- for each directional view;
- for Level 1b data;
- over the specified mission duration, including degradation resulting from molecular and particulate contamination.

BBR-FO-2 The instrument shall perform measurements continuously in orbit.

BBR-FO-3 Interruption of the measurement mode shall be limited as much as possible and shall be in agreement with the Satellite Operational Availability and the time allocation for in-orbit calibration requirements (resp. GSR-LR-4 and GSR-LR-5) The use of the calibration mode shall not entail the systematic loss of imaging capability in specific geographical locations.

BBR-FO-4 All raw data acquired during on-board calibration shall be transmitted to ground.

BBR-FO-5 The radiometric calibration shall be performed on ground.

The radiometric calibration is here referred to as the process of converting the digital data into TOA spectral radiance or brightness temperature through the correction of all radiometric errors introduced by the instrument (e.g. gain and offset correction).

BBR-FO-6 Unless duly justified all processing of the data performed on-board, if any, shall be reversible.

Processing is here referred to as functions altering the scientific content of the measurement data

BBR-FO-7 BBR shall transmit all gain and offset parameters applied on-board that modify the measurement data.

BBR-FO-8 BBR shall be capable of transmitting unprocessed data to allow testing and verification of the on-board processing functions.

BBR-FO-9 The number of BBR modes and on-board correction functions shall be kept to the strict minimum required to meet the requirements.

BBR-FO-10 The BBR shall implement on board sources for calibrating the spectral response comprising as, a minimum, a solar illuminated diffuser and blackbody reference sources.

BBR-FO-11 The on-board calibration sources shall be protected from ageing (contamination, UV exposure, ..) when non operated for instrument calibration.

BBR-FO-12 BBR shall have view baffles to keep out all direct sunlight from its interior during normal instrument operation.

BBR-FO-13 BBR instrument shall not be damaged by direct sun illumination for a period of up to 60 seconds (TBC).

Full instrument performance as specified in this document should then be resumed in accordance to req. PAY-GE-4. Longer sun illumination shall be prevented at system level via AOCS req. AOS-FU-3.

5.5.4 Contamination

BBR-CO-1 BBR design (venting and other measures) shall avoid (minimise) the contamination sources and contamination pathways and the related consequences on the instrument performance so that the compliance to the instrument performance is not compromised by contamination.

BBR-CO-2 The outgassing properties of all materials in vicinity of optical surfaces and detectors shall be evaluated and demonstrated compliant with the contamination plan so as to meet the instrument performance requirements.

BBR-CO-3 Purging and other protection measures shall be implemented during all instrument and satellite phases whenever needed.

BBR-CO-4 The BBR design shall ensure that the BBR does not compromise the performance of other instruments on EarthCARE.

BBR-CO-5 The following minimum cleanliness levels shall be maintained for BBR:

	optical components	non optical components
Molecular cleanliness level	$5x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$
Particulate cleanliness level	$50mm^2/m^2$	$300mm^2/m^2$

Table 5.5-1 Minimum cleanliness levels for BBR

5.5.5 Procurement Requirements

BBR-PR-1 The optical elements and detectors of the SW and TW channels and for the three directional views shall be procured from the same manufacturing batch, to ensure as much as possible identical spectral response.

5.5.6 Design Requirements

BBR-DS-1 The BBR instrument shall be designed to intrinsically meet its performance requirements. Exceptions shall be handled by provision of characterisation data such that its performance requirements are met.

BBR-DS-2 All requirements in section 5.5.6 (Design Requirements) shall be met for Level 0 data and higher level data unless otherwise specified.

5.5.6.1 Spectral Requirements

5.5.6.1.1 Spectral channels

BBR-SR-1 BBR shall measure Earth radiance in two spectral channels:

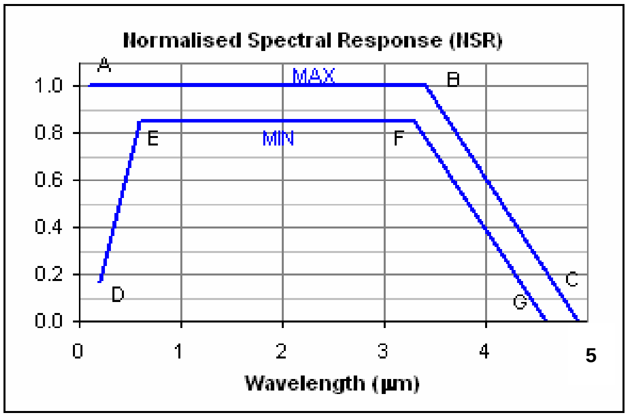
- the short wave (SW) channel [< 0.2 μm , 4 μm] and
- the total wave (TW) channel [< 0.2 μm , > 50 μm]

Unless otherwise stated all performance requirements are given for the radiance calculated in the SW and LW channels. The performance of the LW channels shall be estimated from the performance of the instrument SW and TW channels.

5.5.6.1.2 Spectral Response

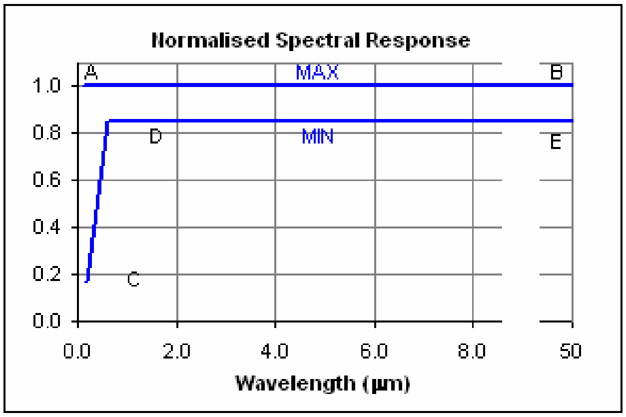
BBR-SR-2 The normalised spectral response of the SW and TW channels shall be “as flat as possible” and shall meet the spectral response envelope plotted in Table 5.5-2 and Table 5.5-3 respectively.

The normalised spectral response is specified so that the amplitude of the actual spectral response after normalisation with respect to the actual peak value shall be within the template given in Table 5.5-2 and Table 5.5-3.



		A	B	C	D	E	F	G
λ	µm	0.1	3.4	4.9	0.2	0.6	3.3	4.6
NSR		1	1	0	0.17	0.85	0.85	0

Table 5.5-2 SW- spectral channel template



		A	B	C	D	E
λ	µm	0.1	50	0.2	0.6	50
NSR		1	1	0.17	0.85	0.85

Table 5.5-3 TW spectral channel template

5.5.6.2 Geometrical Requirements

5.5.6.2.1 Angular Sampling

BBR-GR-1 BBR shall measure Earth radiance along-track with a sampling along the satellite's flight direction in three angularly fixed directional views and for both the SW and TW channels:

- Nadir view, i.e. an observation zenith angle (OZA) of 0 degrees
- Forward view, with an OZA of 55 degrees and
- Backward view with an OZA of 55 degrees

The OZA values are specified for a spatial sample located on the Earth at equator

5.5.6.2.2 Spatial resolution

BBR-GR-2 The spatial resolution ΔX shall be smaller than or equal to 10 km

5.5.6.2.3 Spatial Sampling Distance

BBR-GR-3 The spatial sampling distance along track shall be constant within ±1% and smaller than or equal to 1km.

Over-sampling of the individual views will be used to improve the spatial registration performance

5.5.6.3 Integrated Energy

BBR-IE-1 The energy integrated in the SW (resp. TW) channel over a square target,

- of size ΔX,
- centred around the system PSF barycentre of the nadir view,
- located at any altitude between 0 and 20 km
- considering the total radiance of the reference scenes

shall be identical within 2% for the three directional views

$$\frac{\left|IE_{nadir,j} - IE_{k,j}\right|}{IE_{nadir,j}} \leq 0.02$$

where k stands for the forward and the backward view

The error resulting from a spatial mis-registration between the 3 views is included.

BBR-IE-2 The energy integrated in the nadir (resp. forward, backward) directional view over a square target,

- of size ΔX,
- centred around the system PSF barycentre of the SW channel,
- located at any altitude between 0 and 20 km
- considering the solar reflected radiance of the reference scenes

shall be identical within 2% in the SW channel and TW channel

$$\frac{\left|IE_{i,SW} - IE_{i,TW}\right|}{IE_{i,SW}} \leq 0.02$$

The error resulting from a spatial mis-registration between the SW and TW channels is included.

BBR-IE-3 The integrated energy over a square target of size 1.5 x ΔX shall be at least 99%.

5.5.6.4 Polarisation Sensitivity

BBR-PS-1 The instrument polarisation sensitivity shall be less than 0.01 in the spectral range 0.2µm – 4.0µm.

BBR-PS-2 The instrument polarisation sensitivity beyond 4.0 µm shall be minimised.

5.5.6.5 Bright Scenes

BBR-BS-1 The specified observational requirements shall be achieved within 5 (TBC) spatial sampling distances after observation of a hot scene of 10x10 km^2 with a brightness temperature of 500 K

BBR-BS-2 BBR shall be able to recover from direct sun exposure, capable of observing the sun during 60 seconds TBC and maintain full compliance to the instrument requirements after such event.

In non-nominal operation of the satellite the BBR might be exposed to the sun with the sun entering in the instrument FOV.

5.5.7 LW Requirements

BBR-LW-1 BBR shall estimate the Earth spectral radiance in a Long-Wave (LW) channel from the measurement in the Short-Wave and Total-Wave channels:

Long-Wave (LW) channel: [4 µm , > 50.0 µm]

Note: The performance of the LW channel shall be estimated from the performance of the instrument SW and TW channels.

5.5.8 Data Quality Requirements

5.5.8.1 Geometric Data Quality

All requirements in this section shall be met with a probability of 90%.

5.5.8.1.1 Absolute Localisation Accuracy

BBR-GD-1 The absolute localisation accuracy shall be such as to ensure meeting OBS-GR-1.

5.5.8.2 Radiometric Data Quality

All requirements in this section are RMS values.

5.5.8.2.1 Signal Dynamic range

BBR-RD-1 The minimum and maximum signals defining the signal dynamic range are TBC:

- short-wave channel: 0 - 450 W m^{-2} sr^{-1}
- long-wave channel: 0 - 130 W m^{-2} sr^{-1}
- total channel: 0 - 550 W m^{-2} sr^{-1}

5.5.8.2.2 Absolute Radiometric Accuracy

BBR-RD-2 The absolute radiometric accuracy of the measured radiance shall be less than

- o 2.5 W m^{-2} sr^{-1} (2.0 W m^{-2} sr^{-1} goal) in the SW channel
- o 1.5 W m^{-2} sr^{-1} in the LW channel.

Traceable to SI units

The absolute radiometric accuracy includes all systematic errors after calibration (see definition of Absolute Radiometric Accuracy)

5.5.8.2.3 Linearity

BBR-RD-3 The instrument linearity shall be better than 0.005. i.e.

$$\left| \frac{S(L_a)}{L_a} x \frac{L_b}{S(L_b)} - 1 \right| \leq 0.005$$

where S(L) is the instrument response to the spectrally integrated radiance L

La and Lb are any two radiance levels comprised within the signal dynamic range

This requirement ensures a constant absolute gain calibration coefficient over the instrument signal dynamic range.

5.5.8.2.4 Radiometric Stability

BBR-RD-4 Assuming a stable and spatially uniform scene, the level 1b data acquired in the SW and TW channels shall be constant to better than 0.5 % (goal: 0.1 %) over the orbit.

5.5.9 In-flight Characterisation

BBR-IC-1 The instrument shall transmit all ancillary data required for the on-ground image data processing. As a minimum the instrument shall provide the data specified in Table 5.5-4

Name	Units	Definition	Instrument Mode
Detector blank pixels	Counts	Signal generated from pixels that are shielded from scene/instrument signal. Data to be provided for TBD pixels at each image row.	Earth observation
Blackbody temperature	K	Temperature of the blackbody and its surrounding environment	Earth observation & Calibration
Optical and structural elements temperature	K	Optical and structural elements that influence the radiometric response of the spectral channels shall be temperature monitored and telemetered for calibration ground processing.	Earth observation & Calibration
Video electronics temperature	K	Temperature of the video processing unit	Earth observation & Calibration
Detector temperature	K	Temperature of the detectors	Earth observation & Calibration
TBS			

Table 5.5-4 In-flight instrument ancillary data

5.5.10 BBR Specific Data Product Requirements

This section is limited to data product requirement specific to BBR instrument. Other generic requirements, i.e. applicable to all instruments are listed under chapter 8 and hence also apply to BBR instrument.

Performance to be met by BBR data products, up to Level 1b, are specified in requirement BBR-FO-1.

BBR-DP-1 The Level 1b product shall consist of Top of Atmosphere (TOA) radiance ($W.m^{-2}.sr^{-1}$) in the short wave and long wave channels and for the three observation views (nadir, forward and backward). The product shall be radiometrically calibrated, spectrally characterised, orthorectified, geo-located annotated with satellite position and pointing.

6 Mission Requirements

6.1 Definition of Mission Phases

OPS-MP-1 The mission shall be broken down into operational phases as follows:

- Launch and Early Orbit Phase (LEOP)
- Commissioning Phase (COP)
- Measurement/Operational Phase (MOP)
- End of Life Phase (EOP)

Duration of the respective mission phases is given under section 7.1/Lifetime requirement.

6.1.1 Launch and Early Operations Phase (LEOP)

OPS-MP-2 The LEOP shall start at switchover from ground-supplied power to the space segment internal batteries. The aim of this phase is to perform the initial acquisition of the satellite. The LEOP shall include the following events:

- Internally powered pre-launch phase, during the count-down.
- Launch phase, from the launch until separation of the satellite from the launcher;
- Collision Avoidance from upper stage of launcher, if required
- Attitude rate reduction, coarse and nominal attitude acquisition
- Deployment of solar panels (incl. start of panel rotation) and delivery of power
- COM TTC Terminal S-band link acquisition of the satellite
- Any other required appendage deployments such as CPR antenna
- Initial spacecraft check-out (incl. GPS activation)

6.1.2 Commisioning Phase (COP)

OPS-MP-3 The aim of the COP phase is to make ready the spacecraft and instruments for nominal operations. The COP shall include the following operations:

- Platform functional checkout, in which the satellite basic functions and health are verified
- Instruments switch on and functional checkout to verify the health of the instruments
- EarthCARE initial performance characterisation/calibration in which the various performance parameters of the system (i.e. platform and payloads) are determined
- Ground segment data acquisition, processing and final commissioning (including COM High Rate TM Terminal X-band link acquisition)
- In orbit verification of level 1b performances and performances stability
- Specific operations to ensure a proper CAL/VAL campaign

6.1.3 Measurement/Operational Phase (MOP)

OPS-MP-4 The aim of the MOP phase is to operate the payload continuously in nominal mode such as to produce the mission scientific output. MOP starts once the satellite is commissioned, satellite and instrument are calibrated and all subsystems are operating continuously in nominal mode. The MOP shall include the following operations:

- Nominal operation where the instruments operate continuously or perform internal characterization and calibration measurements which are needed to achieve the specified performances.
- Processing of raw data and production of level 1B data with data acquisition, processing, archiving and data product distribution.
- Orbit control, to maintain the selected orbit of the satellite
- Specific routine calibrations

6.1.4 End of Life Phase (EOP)

OPS-MP-5 The EOP phase marks the end of the mission. At end of life, EarthCARE shall either allow controlled de-orbiting to avoid that harmful debris could reach populated areas, or it shall be designed such that no harmful debris will be generated when entering the atmosphere, as specified in the European Code of Conduct for Space Debris Mitigation (ND-42)

This paragraph is a statement of the way in which ESA intends to proceed to the End of Life, assuming that it is possible to control the satellite at this time. Recognising that loss of command and control functions is a common loss of mission, ESA does not require that the system design be driven by de-orbiting at End of Life.
Note also that the use of a controlled de-orbiting should also been done towards avoiding generation of harmful debris as an uncontrolled re-entry can never be totally excluded in reality due to e.g. a major satellite malfunctioning.

6.2 Operational Requirements

6.2.1 General Operational Requirements

OPS-GE-1 The EarthCARE satellite shall comply to the operational design requirements as defined in the Operations Interface Requirement Document [AD-10] as well as to the operability requirements listed in ND-34.

OPS-GE-2 The EarthCARE satellite shall be designed in order to operationally cope with no ground station contact for a period of at least 72 hours.

OPS-GE-3 All HK data generated during a max. 72-hour ground station outage shall be duly accumulated, stored on-board EarthCARE and downloaded to ground (via COM TTC, S-band) at the end of the outage without any data loss during and after GS outage.

I.e. the nominal throughput on S-band downlink should identify extra margin in order to resorb the accumulation of data (which occurred during the outage) in parallel to the downlink of the new data which continue to be nominally generated once the GS contacts have resumed. As back-up, it should also be possible to use X-band downlink.

OPS-GE-4 For Instrument science data and associated HK/ancillary data, the on-board storage shall be sized to cope with a max. 72-hour ground station outage while the COM subsystem to downlink the accumulated science data shall be limited to cope with an equivalent max. 24-hour GS outage without any data loss during that equivalent outage and as soon as GS contacts are resumed.

Other more severe autonomy requirements are listed in this SRD but address survivability and/or dimensioning of extra data storage.

6.2.2 Nominal Operations

6.2.2.1 Launch and Early Operations Phase (LEOP)

OPS-NO-1 The spacecraft design shall allow to support all LEOP operations via an ESA ground station network composed of: Kiruna, Svalbard, Troll and Vilspa (all GS TBC).

OPS-NO-2 The satellite shall be capable of running an automatic sequence without ground intervention during the whole LEOP. The sequence shall be able to cope with a single anomaly event while ground commanded switch-on shall be possible as back-up.

OPS-NO-3 The spacecraft design shall allow to nominally schedule all critical events as e.g. deployments so that they happen within the visibility of one of the LEOP ground stations.

OPS-NO-4 During LEOP, the satellite shall be compatible with any solar aspect angle. Any exception due to instrument and sensor limitations shall be identified, minimized and be subject of approval by the Agency.

OPS-NO-5 After launch without ground contacts in nominal and one-failure situations, the satellite shall survive, without subsequent loss of mission, for a duration of:

- at least 5 [TBC] orbits prior solar array deployment
- at least 5 days after solar array deployment.

6.2.2.2 Commissioning Phase (COP)

OPS-NO-6 The spacecraft design shall allow to support all COP operations via a single, dedicated ground station located at Kiruna, Sweden (TBC)

6.2.2.3 Measurement/Operational Phase (MOP)

OPS-NO-7 The spacecraft design shall allow to support all MOP operations via a single, dedicated Master ground station located at Kiruna, Sweden (TBC)

OPS-NO-8 The spacecraft design shall provide the necessary features in order to support instrument data dissemination (multi-dumps) to other secondary ground stations.

From satellite point-of-view, this requirement is not considered as a dimensioning requirement. Typically the on-board storage will continue to be sized according to a one GS scenario. It should be used while making design choices as e.g. the management of the recorder read pointers.

OPS-NO-9 MOP shall include three operational modes:

- Nominal Operation Mode
- External Calibration Mode
- Orbit Control Mode

OPS-NO-8 EarthCARE shall be able to perform continuous operations (i.e. measurements or internal calibration).

OPS-NO-9 If relevant, the on-board ephemeris tables (eg Earth, Sun) shall not require an update from ground more frequently than once every 72 hours in all critical phases of the mission. In routine phases this frequency shall not be more than once per week.

6.2.2.3.1 Nominal Operation Mode

OPS-NO-10 The Nominal Operation Mode and Sequence shall include all necessary on-board control for achieving the Level 1B products performances.

OPS-NO-11 The Nominal Operation Mode and Sequence shall include the routine operations for the satellite maintenance (incl. internal calibrations), at the exception of the ones related to the orbit maintenance.

Satellite maintenance includes all operations towards monitoring/updating on-board parameters, software and (re-)configuration as long as the associated severity did not lead to a transition into Safety Mode (with dedicated emergency operations).

OPS-NO-12 Although few satellite routine maintenances may lead to the disruption of L1B production, EarthCARE shall be designed towards maximizing measurement operation time.

This requirement implies the possibility to operate all the EarthCARE instruments simultaneously in parallel.

6.2.2.3.2 External Calibration Mode

OPS-NO-13 The External Calibration Mode shall include all operations required by the EartCARE instrument which may require an externally calibration, i.e. a calibration process which can not be handled at the Instrument level only but which needs a specific support from the satellite/system level.

Refer to section 5 for further details about the external calibration required by the respective EarthCARE instrument. A typical example of external calibration is the one related to the CPR instrument based on a +/- 10 degree S/C roll manoeuvre (CPR-FO-12, approach 2).

OPS-NO-14 Because the operations performed during the External Calibration Mode may disrupt measurements by other Instruments, the design of the EarthCARE satellite and of its operation timeline shall be made towards minimizing the External Calibration Mode duration.

Via this requirement, the External Calibration operations should also avoid to affect other instruments which have been already calibrated.

6.2.2.3.3 Orbit Control Mode

OPS-NO-15 The Orbit Control Mode (OCM) shall be used to perform orbit maintenance manoeuvres. The manoeuvres include any necessary corrections for injection dispersion.

In OCM, the instruments may continue to be operated but their performance may be temporarily degraded but minimizing the unavailability duration (due to absence of instrument disactivation/activation transitions). However, power consideration will also have to be taken into account prior final OCM definition.

OPS-NO-16 Orbit maintenance shall be commanded by ground.

OPS-NO-17 Orbit Control Mode shall be possible at any solar aspect angle.

OPS-NO-18 During the Orbit Control Mode, the power generated by the solar array shall be guaranteed to supply all the power needed by the EarthCARE satellite including margins.

This will be achieved via suitable solar array sizing and illumination maintenance/control.

6.2.2.4 End of Life Phase (EOP)

OPS-NO-19 At EOP, the satellite shall dispose of all remaining fuel, if it can be demonstrated that it will burn up during re-entry in the atmosphere and does not pose any hazard, or the satellite de-orbiting shall commence and a controlled re-entry in the atmosphere shall be allowed.

OPS-NO-20 The end of life requirement shall be met in nominal and one-failure situations.

OPS-NO-21 The end of life requirement shall be met without the use of mechanical gyroscopes.

6.2.3 Emergency Operations

OPS-EO-1 EarthCARE shall have a Safe Mode. That mode shall place the satellite in a safe attitude control mode; its design shall minimize the usage of on-board resources (non-essential H/W loads, SW/CPU processing, power consumption, …)

OPS-EO-2 The Safe Mode shall either be initiated automatically on-board in the case of detection of a failure which affects the satellite safety, or by ground command.

OPS-EO-3 EarthCARE shall be able to survive in a Safe Mode for at least 8 days without the need of ground intervention, provided there is no further failure.

OPS-EO-4 The capability to enter Safe Mode autonomously shall be present during all mission phases and modes.

OPS-EO-5 The Safe Mode shall maintain a safe attitude within the constraints allowing a continuous supply of power to essential loads, maintaining a stable (thermal, sun blinding, ATOX) environment compatible with the satellite survival.

OPS-EO-6 The Safe Mode shall ensure a two-way communication link via COM TTC S-band link with the ground station when coverage is available for at least housekeeping telemetry data and commanding (i.e. providing suitable link margins with omni-directional coverage).

OPS-EO-7 No nominal operations shall require the inhibition of the Safe Mode or associated monitoring, or a forced entry into Safe Mode.

OPS-EO-8 In case of Safe Mode the spacecraft shall generate the required set of telemetry packets that allow unambiguous and rapid identification of the Safe Mode and its correct operation. All data and history of on-board events required to determine the reason for triggering Safe Mode shall be accessible in TM either as real-time TM or stored in safeguard memory areas that can be dumped and cleared/ reset by ground.

OPS-EO-9 Essential on-board autonomous functions, including fault management, shall be available in Safe Mode.

OPS-EO-10 In Safe Mode hardware and software that is independent from the hardware and software operated in nominal modes shall be used as far as possible. Exceptions shall be identified, justified and submitted for Agency's approval.

6.3 Commandability

OPS-CO-1 The satellite shall be fully commanded via the S-Band COM TTC Terminal uplink.

This means that on-board operations as well as S-band and X-band COM Terminals will be operated by ground through S-band uplink.

OPS-CO-2 The spacecraft shall be able to receive and process a continuous uplink of any sequence of telecommand packets (with any combination of APID's) at the nominal uplink rate in all of its operational modes (including Safe Mode).

This requirement includes the case that all commands are destined to the same APID and are of the same type (e.g. Memory Patch commands).

OPS-CO-3 Situations in which the control centre is expected to react shall be unambiguously recognisable in the available telemetry by means of a down-linked identifier.

OPS-CO-4 Commanding of hazardous/vital functions shall be implemented by means of two independent telecommands. Hazardous/vital functions shall only be executed after successful reception and validation of both independent telecommands.

Hazardous/vital functions are those which - when executed at the incorrect time - could cause mission degradation or damage to equipment, facilities or personnel. This requirement is in addition to any derived from launch site safety requirements.

OPS-CO-5 All commands, with the exception of High Priority commands as defined in AD-10, shall have the capability of being scheduled for future execution.

OPS-CO-6 Two ways of command scheduling shall be possible, using either on-board reference time information or orbit position information.

Most suitable set of parameters to specify the Orbit Position has to be identified by the Contractor and agreed with the Agency. Among possible options are: orbit number & orbit angle relative to ascending node, (coarse) time & orbit angle relative to ascending node, GPS position. Possibility to repeat a same command at regular time-/position-intervals should also be considered towards reducing amount of telecommands.

OPS-CO-7 During nominal operation including incidence of a single failure, there shall be no requirement for the control centre to send telecommands more often than once every 5 days and the on-board Mission Schedule buffer shall be sized accordingly.

OPS-CO-8 A telecommand packet shall contain a single telecommand function only.

A telecommand function is an operationally self-contained control action. A telecommand function may comprise or invoke one or more low-level control actions.

OPS-CO-9 It shall be possible to individually command all on-board equipment directly from the ground.

I.e. even elements (such as e.g. thrusters) which are not normally commanded directly since they are part of a sub-system (i.e. AOCS/propulsion subsystem in the thruster example) should be commandable.

OPS-CO-10 It shall be possible to command the spacecraft or any subsystem or the instruments into each of their operational modes by means of a single telecommand function (including e.g. the initiation of a high level On-Board Control Procedure via telecommand).

This requirement also means that no set-up is required prior commanding the target into an operational mode. Furthermore, as the requirement does not explicitly specify the entity issuing the telecommands, it means that both ground station and on-board computer should have such a capability. The sole exception is at spacecraft level where the TC can be issued by ground only.

OPS-CO-11 The telecommand history of commands issued on-board shall be kept on-board for interrogation until deletion by ground.

OPS-CO-12 Changes to on-board data or software parameters shall be implemented via dedicated telecommand(s). In particular, all parameters used for autonomous operations (e.g. thresholds for limit checking and biases for attitude control) including fault management, orbit and attitude control etc., shall be updateable by telecommand.

The general-purpose memory load telecommand shall not be used for the above. Use of this telecommand to fulfil specific instances of the above requirement may be permissible if the data and software parameter locations remain fixed, independent of the software version (i.e. if it can be defined as a dedicated command in the ground database, where the addresses are fixed in the command structure).

OPS-CO-13 Readouts of loaded on-board data or software parameters shall be requested via dedicated telecommand(s) and then made available in telemetry.

The general-purpose memory dump telecommand shall not be used for the above. Use of this telecommand to fulfil specific instances of the above requirements may be permissible under the same conditions as in OPS-CO-12.

OPS-CO-14 It shall be possible to alleviate the uploading of large patches by preparing and storing them first in a dedicated uplink memory area into the on-board data storage, prior performing the patch of the final/targeted equipment.

That buffer intends to introduce flexibility to upload large software patches despite the limited duration of the ground station passes and the limited uplink bandwidth. Routine operations do not need to be halted till the availability of the complete patch on-board; at that moment, ground can request on-board transfer of the complete patch to the targeted equipment memory.

OPS-CO-15 The uplink memory area(s) of the on-board storage capacity (End-of-Life) shall be sufficient to simultaneously store a copy of each on-board software. These uploaded copies shall be stored in separate area(s), i.e. in addition to the areas used for the storage of the TM Science and Housekeeping/Ancillary data.

6.4 Observability

OPS-OB-1 The satellite status shall be fully monitored via the S-band COM TTC Terminal downlink. I.e. all housekeeping telemetry shall be primarily routed to ground via S-band downlink. As back-up, it shall also be possible to route a copy of the stored HK/ancillary data via X-band.

This requirement does not preclude the downlink of payload scientific data via S-band but this use should be limited for e.g. failure diagnosis. All scientific data will however be primarily routed to ground *via X-band COM High Rate Terminal.*

OPS-OB-2 The satellite shall provide in its housekeeping telemetry all data required for the monitoring of all parameters of the flight configuration and execution of all nominal and foreseen contingency operations throughout the entire mission.

OPS-OB-3 It shall be possible for the ground to determine the status of the hardware and software of each on-board sub-system and instruments unambiguously from real-time housekeeping telemetry without knowing the history of the telecommands, the history of autonomous on-board actions or information delivered in previous telemetry.

OPS-OB-4 The downlink telemetry shall be adequately split in physical and/or virtual channels such that the real-time housekeeping telemetry can be transmitted on ground and processed independently from any other type of telemetry (i.e. idle transfer frames, housekeeping telemetry played back from the on-board storage and measurement data).

The above requirement allows the use of a same VC ID on the two S- and X-bands. This should typically be done for Idle frames, i.e. a same VCID should be used on both downlinks. For other meaningful VCs, the use of the complete set of available VCID should be considered first.

OPS-OB-5 In order to maintain a constant bit rate on the S-band downlink physical channel used for housekeeping TM, a dedicated virtual channel with idle frames shall be used.

A constant bit rate should not be maintained by means of idle packets introduction in housekeeping TM VC. Idle packets shall be reserved for the cases to complete a frame already containing a meaningful packet which, otherwise, would not be down-linked in an acceptable time (e.g. last packet of a dump in a dedicated VC, scarce packet production by the on-board software, etc).

OPS-OB-6 Essential (high-priority) telemetry enabling a reliable determination of the current status of the on-board vital equipment under all circumstances shall always be available for real-time downlink in any spacecraft mode (including Safe Mode).

OPS-OB-7 The availability of telemetry information shall be compatible with the required response for any control loops implemented on ground. These responses times shall be reported in the User Manual.

OPS-OB-8 A 'system log' of the satellite anomalies, autonomous switch-downs, command failure reports, etc., shall be maintained on-board and available for downlink on request from the ground (as part of the real-time housekeeping TM virtual channel).

It is not required that the 'system log' contains the nominal events generated on-board.

OPS-OB-9 The system log shall be able to cover at least 8 days.

OPS-OB-10 It shall be possible to clear the current content of the system log on ground request.

Because non-volatile memory is considered as implementation baseline, and in absence of over-writing, the data storage period in the system log will be solely driven by the reception of such ground request.

OPS-OB-11 The system log shall be regularly saved on-board such that its content is available for downlink also after a reconfiguration and/or cold restart of the DHS main equipment.

OPS-OB-12 Telemetry shall always be provided to unambiguously identify the conditions required for execution of all possible configuration dependant telecommands.

A configuration dependant telecommand is defined as a telecommand that should only be executed if a particular subsystem or instrument condition is satisfied.

OPS-OB-13 Status information in telemetry shall be provided from direct measurements from operating units rather than from secondary effects. This is particularly essential for the status of all on-board relays.

OPS-OB-14 All mission critical functions shall be observable by at least two independently obtained measurements. These critical functions shall be duly identified in the EarthCARE User Manual

OPS-OB-15 All inputs to on-board autonomous processes shall be accessible to the ground via telemetry.

OPS-OB-16 Information to indicate all actions of operational significance taken by on-board software shall be available in telemetry.

A list will have to be submitted for Agency's approval and then duly documented in the EarthCARE User Manual.

OPS-OB-17 Software status telemetry shall include all commandable parameters such as monitoring and control thresholds, software tables and flags as well as any global variables.

OPS-OB-18 The value of a telemetry parameter shall be transmitted in contiguous bits within one packet.

OPS-OB-19 Telemetry generated on-board and selected for down-link shall be stored on-board in order to keep track of on-board operations which occurred outside ground station visibility as well as to allow retransmission in case of loss/problem during the initial TM transmission attempt while in ground station visibility.

OPS-OB-20 Telemetry shall always be available to determine the health/selection status of all units that manage the generation and routing of (other) telemetry data.

I.e. it should also include the identification of nominal or redundant units presently selected.

OPS-OB-21 The handling of on-board telemetry shall be hierarchically structured such that the on/off status of a unit is available and valid in telemetry data that are not managed by the unit itself. This allows the monitoring and assessment of the status of a unit even if it is switched off.

OPS-OB-22 The effect of high-priority command shall be observable on the ground using high-priority telemetry data without software involvement.

OPS-OB-23 The ground segment shall be provided with all telemetry data required to verify reception, acceptance and execution of each telecommand unambiguously. This shall include any telecommand sent from ground for immediate, delayed (time-/orbit position tagged) execution, or sent from an on-board application.

OPS-OB-24 Housekeeping Telemetry packets, which during nominal operations are only to be routed to the relevant Mass Memory Storage, should have a different APID from packets that are to be sent on the real-time downlink. This is to prevent discontinuities in the Source Sequence Counter for packets that arrive on the real-time downlink.

OPS-OB-25 The on-board storage capacity (End-of-Life) shall be sufficient to store all housekeeping packets generated on-board for all phases of the mission during at least the maximum specified period of spacecraft autonomy (defined under section 6.2.1) plus one day (for downlink).

This requirement implicitly specifies that it should be possible to downlink the housekeeping telemetry recorded over the autonomy (black-out) period within a period of 24 hours. If not achievable due to downlink limitation, the on-board data storage capacity will have to be increased accordingly.

OPS-OB-26 All timing information used for on-board functions like time tagging of telecommands and running of application software and for telemetry and measurement data time stamping shall be synchronised with a single on-board time reference.

OPS-OB-27 All recorded housekeeping platform and instrument telemetry shall be downlinked using a specific Virtual Channel different to the real-time housekeeping telemetry and science data streams.

OPS-OB-28 It shall be possible to activate any provided diagnostic mode of a non-operating unit without interfereing with the nominal operation of the spacecraft.

6.5 Science Data Retrieval

OPS-SC-1 The scientific data generated by the instruments on-board EarthCARE plus the relevant set of HK/ancillary data necessary to support ground for (preliminary) science data validity checks and processing shall be routed to ground through the on-board data storage and the X-band COM High Rate Terminal downlink.

The associated set of housekeeping telemetry/ancillary will be down-loaded via X-band in order to provide an overview of the satellite health status and to support preliminary science data validity checks and processing, All HK data will be nominally routed to ground via S-band COM TTC Terminal but the requirement does not preclude the use of X-band as back-up.

OPS-SC-2 Although the operational scenario baseline is to temporarily store science data on-board, it shall also be possible to selectively transmit in real-time scientific data (incl. relevant set of HK/ancillary data). Real-time and recorded scientific data shall be routed to ground via different virtual channels.

The possibility to transmit real-time scientific data on the X-band allows to support: near-real-time applications/users on ground (implying also the need of extra ground X-band receiver terminals) as well *as failure diagnosis (e.g. allowing to compare real-time and stored/retrieved scientific data).*

OPS-SC-3 Different APIDs shall be used per instrument mode for science packets while science packets with a same/given APID shall have an identical format and size.

Such requirement will lead to a significant simplification of the processing of the science data on ground.

OPS-SC-4 The downlink science packet and other HK/ancillary data packet streams shall be adequately split in virtual channels. It shall be possible to dump each instrument and different HK/ancillary packet stream(s) via a different virtual channel.

OPS-SC-5 Via telecommands, it shall be possible to reconfigure the allocation of the Virtual Channels.

This should allow to dump the science packets generated by one, a sub-set or all instruments via a single VC.

OPS-SC-6 In order to maintain a constant bit rate and to keep lock on the X-band downlink physical channel used for science data stream TM, a dedicated virtual channel with idle frames shall be used.

The same idle VCID may be used for both S- and X-band downlink.

OPS-SC-7 All science packets shall be stored on-board in order to be dumped during ground station passes, to allow retransmission in case of downlink transmission errors and/or to disseminate science packets to other ground stations.

OPS-SC-8 The on-board storage capacity (End-of-Life) shall be sufficient to store all science packets and associated HK/ancillary data generated on-board during COP and MOP phases of the mission during at least the maximum specified period of spacecraft autonomy (defined under section 6.2.1).

A larger outage value is used for the storage capacity compared to the one used for the X-band downlink; rationales are to allow to spread the accumulated data on a number of orbits following the end of the outage while authorising some latency (see section 6.7, OPSIC-7) to support selective re-dumps, when required.

OPS-SC-9 The X-band COM HR downlink shall be sized to cope with equivalent max. 24-hour GS outage during COP and MOP phases of mission as defined under section 6.2.1, i.e. it shall be possible to download all science data and associated HK/ancillary data via X-band without any loss for an equivalent max 24-hour GS outage period under the assumption that the next GS outage is separated by at least 48 hours from the previous GS outage ending.

6.6 On-board Time

OPS-TI-1 EarthCARE shall use an elapsed time based on the CCSDS-CUC format (in accordance to ND-28) as On-Board Time (OBT) reference. That OBT shall be used for stamping all the measurement and housekeeping TM packets (and data when necessary) as well as for all the time-tagged telecommands.

OPS-TI-2 Timing information provided in Housekeeping telemetry shall allow the ground to perform the correlation from on-board time to UTC with the accuracy necessary for command & control operations and compliant with any instrument absolute datation requirements: 1 msec [TBC] during whole nominal operations.

OPS-TI-3 The OBT distribution across EarthCARE shall guarantee that the different on-board sub-systems and instruments are maintained synchronized with a relative accuracy better than 16 microseconds [TBC].

This requirement includes all the delays (harness, logic inside equipment) in the distribution of the OBT and during the maintenance of local OBT copies. It also assumes that, by keeping all on-board equipment synchronized with central OBT at such above accuracy, no direct inter-instrument link/connection will be required. If necessary, increase of above accuracy should be preferred to the use of dedicated inter-instrument links.

OPS-TI-4 The execution accuracy for time-tagged telecommands, under on-board software control, shall be better than 50 ms (TBC).

If more severe requirements exist, then a hardware-based may have to be considered with performance capability equivalent to those listed under OPS-TI-2 and OPS-TI-3 requirements.

OPS-TI-5 As a GPS/GNSS receiver is intended to be used on-board EarthCARE (e.g. to support AOCS), the GPS time can then be used in complement to the primary OBT for time-stamping science data. In such case, an on-board GPS/OBT correlation mechanism shall be implemented on-board EarthCARE and periodic TM packets shall report the correlation results.

Availability of GPS time on-board EarthCARE may also significantly increase the UTC/OBT correlation accuracy. In case of GPS time, its use on-board EarthCARE will have to be defined and agreed with the Agency. Note that limitations already exist via OPS-OB-26 and OPS-TI-1. These requirements clearly specify the use of OBT for all HK TM data and for all TC and TM packets respectively.

OPS-TI-6 If an on-board subsystem or instrument has operationally not been (yet) synchronized to the OBT reference after a power reset or switch-on this shall be indicated within the time field of its telemetry packets.

I.e. it should be possible to derive at any time the validity of the supplied time information.

OPS-TI-7 The packet time-stamp shall correspond to the end of the actual sampling of the data within that packet.

OPS-TI-8 The sampling time of the data placed in the packet data field with respect to the packet time stamp shall be deterministic. If such determinism can not be guaranteed and/or an higher time accuracy is necessary, data shall be individually time-stamped.

For simplicity and data throughput minimisation, the deterministic solution should be preferred as far as possible.

OPS-TI-9 With the exceptions of a complete satellite power down, nom/red. OBT reconfiguration or the reception of an OBT maintenance telecommand, under no circumstance shall the OBT experience a discontinuity. In the case of a nom./red. reconfiguration, the discontinuity shall not exceed 1 second.

OPS-TI-10 The OBT shall be designed in order not to require any ground intervention for in-orbit OBT time maintenance. The DHS and its OBT reference shall however be designed in order to support the possibility to set an absolute value or to add/subtract a delta-value to the current OBT counter value.

The OBT maintenance telecommands implying time discontinuities on users side, such telecommands should be essentially limited to support AIT/AIV activities.

OPS-TI-11 The TM Time source packet shall include the on-orbit position to allow the verification of the time/position as used by the OPS/MTL schedulers as well as auxiliary flags to report the on-board time synchronization status.

6.7 Space-Ground Interface Compatibility Requirements

OPS-IC-1 EarthCARE shall be compatible with the ESA Earth Observation Ground Segment.

This will have to be defined and consolidated in frame of Phase B with the Agency and duly tracked and specified in an EarthCARE Space/Ground Interface Control Documents (D-ES-11, D-ES-12) to be generated by the Contractor.

OPS-IC-2 EarthCARE telecommunications system shall be compatible with the ESA LEOP networks and with the selected launchers during the early operations from separation to the end of the commissioning phase.

OPS-IC-3 EarthCARE design shall allow to be fully operated during MOP via a single Master Ground Station (Kiruna, TBC) for nominal command and control (via S-band).

OPS-IC-4 EarthCARE design shall allow to dump all science data during MOP via a single Ground Station (Kiruna, TBC) using X-band downlink.

OPS-IC-5 EarthCARE shall be designed to allow nominally the dump of all data generated on-board within 90% of the number and duration of passes accumulated along a GS visibility cycle of TBD days. Remaining 10% passes and duration shall be reserved for unplanned (dump) operations to be performed during working days only.

From the Master GS point-of-view, a repetitive pattern/cycle will be observable although the distribution and duration of the S/C passes will vary from one orbit to the others. Assuming that a S/C pass will be *dedicated to planned or (exclusive) unplanned dumps, this requirement indicates that 10% of the S/C passes should be reserved for unplanned dumps; selection of passes for unplanned dumps should be adequately selected to correspond to 10% of the overall downlink bandwith as well as to be spaced to fall during working days.*

OPS-IC-6 In the case of nominal ground station unavailability, it shall be possible to dump all the data (science, HK) later towards a contingency ground station.

OPS-IC-7 In the case of (transient) downlink transmission problems, subsequent passes reserved for unplanned operations shall be used and it shall be possible to selectively command a retransmission of the missing TM packets within the next 2 days after occurrence of the TM packet loss.

OPS-IC-8 The packet service definition shall implement the functionality required in chapter 3 of the EarthCARE Operations Interface Requirements Document [AD-10], which are derived from the packet utilisation standard ND-33.

OPS-IC-9 The telemetry shall be in accordance with the Packet Telemetry Standard ND-21 and the Telemetry Channel Coding Standard ND-19.

OPS-IC-10 The telecommand format shall be in accordance with the Packet Telecommand Standard ND-22 to ND-25

OPS-IC-11 The ranging signal for up and downlink shall be in accordance with the Ranging Standard ND-20

6.8 Fault Detection and Recovery

OPS-FD-1 EarthCARE shall automatically detect any fault, failure and error that makes it deviate from its nominal configuration and operating mode. This includes both hardware and software.

OPS-FD-2 EarthCARE shall detect single faults, failures and errors. Where such events affect only instrument, but not platform operation, the instrument may be switched to a non-operational state. Where such events affect platform operations, all of the instruments may be switched to non-operational state, but the platform shall be reconfigured to continue its commanded mode. Switch down of the instruments to non-operational states should not occur for inessential reasons.
In exceptional cases it shall be permissible for the satellite to enter safe mode as a result of a single anomaly event.

I.e. autonomy/FDIR at instrument level in case of failure may be significantly limited if compared to the one at platform level. All cases leading to several instruments in non-operational state, or even to enter into safe mode will have to be identified by the contractor and approved by the agency.

OPS-FD-3 The management of anomalies within a unit, subsystem or instrument shall be handled in a hierarchical manner such that the resolution is sought on the lowest level possible to preserve the spacecraft health. I.e. the reconfigurations which are not necessary to preserve the health of the spacecraft, shall be avoided.

OPS-FD-4 Configuration and health status data shall be stored in protected resources /safeguard memory.

OPS-FD-5 Failure detection algorithms shall avoid continuous production of the same anomaly report packet if the same failure is detected with a specified number of monitoring cycles.

OPS-FD-6 All units that perform regular self-checks shall report them.

OPS-FD-7 Anomalies and the actions taken to recover from them shall be reported in event driven packets. This shall be duly identified in the EarthCARE User Manual.

OPS-FD-8 The fault management functions at all levels shall be able to access lower level telemetry data produced by subsystems and instruments, with the exception of science data. This includes in particular non-periodic event packets that can be used to trigger recovery actions at system or subsystem level as a result of an anomaly occurred (and detected) in another subsystem.

OPS-FD-9 The fault management functions at all levels shall carry out consistency verification checks on independent or redundant sensor readings whenever available before starting the recovery actions.

OPS-FD-10 It shall be possible for the ground to enable / disable and override each individual fault management function implemented in software. This shall be possible parameter by parameter.

OPS-FD-11 As design goal, it shall be possible for the ground to enable / disable and override each individual fault management function implemented by hardware. However it shall not be possible to disable/inhibit a protection feature that in case of a single failure at spacecraft level could lead to the loss of the main primary power bus. Any non-overridable function shall be defined and agreed by ESA.

OPS-FD-12 Spare capacity (25% at launch time) for additional monitoring and autonomy actions shall be available.

This implies spare on-board acquisition/processing/actuation resources as well as spare commanding and monitoring capabilities and bandwidth between ground and satellite.

OPS-FD-13 All parameters used for autonomous operations (e.g. thresholds for limit checking or thresholds and biases for attitude control), including fault management, orbit and attitude control etc., shall be updateable by telecommand and available in telemetry.

OPS-FD-14 Initialisation of a mode (at spacecraft, subsystem, instrument or unit level) shall include configuration of the necessary hardware (e.g. sensors, actuators), activation of a default periodic telemetry configuration, and all of the automatic processes (e.g. automatic control of attitude slews) required to achieve the objective of the mode.

OPS-FD-15 The spacecraft shall have the knowledge of the actual health status of all the hardware units required for any mode start that is potentially hazardous (e.g. attitude control modes). It shall be possible to override this information by telecommand, and it shall be available in telemetry.

OPS-FD-16 An on-board logic shall be available to prevent incorrect commanding of forbidden software based mode transitions. The allowed and forbidden mode transitions between all possible pairs of modes shall be implemented in software and thus updateable by means of memory patch or table update commands.

6.9 Space Debris Prevention

The following requirements from ECSS-Q-40 (ND-62) shall apply:

OPS-DE-1 Normal operations shall not result in the creation of orbital space debris through the jettison or release of items, or the ejection of fragments. (para 5.2.8 d of ND-62).

OPS-DE-2 Propellant, pressurized fluids, and stored electrical and mechanical energy that remains in orbital systems and elements at the end of mission shall be safely dissipated. It should be ensured that released liquids do not form droplets. (para 5.2.8 e of ND-62).

7 Design Requirements

This section lists a set of requirements which shall apply during the design and development of the complete EarthCARE spacecraft, i.e. including every subsystem and instrument. I.e. even if each EarthCARE instrument is specified under a dedicated section 5.i, the here below design requirements complement those of section 5.i.

In addition, because no clear boundary exists in-between the platform sub-systems while these sub-systems also have ramifications within the Instruments, the requirements which are listed here below in accordance to a sub-system classification also apply to each unit of the EarthCARE satellite design in order to achieve a uniform design quality standard.

7.1 Lifetime, Reliability, Availability and Product Assurance

GSR-LR-1 **In-orbit Lifetime:**
EarthCARE shall be designed for a duration in-orbit of:

- LEOP: 5 days
- commissioning phase: 6 months, and
- operational phase at least 30 months.

With allocation of consumables to allow the above plus an extension of 1 year in-orbit operations

GSR-LR-2 **On ground Lifetime:**
The EarthCARE shall be designed for 5 years on-ground activities in controlled conditions or storage time if needed

GSR-LR-3 **Reliability** is defined as the probability that the satellite (platform + payload) will perform as specified in its operational environment over the period defined in GSR-LR-1. The satellite shall be designed to have a reliability greater than 0.8 (TBC) over the nominal design lifetime.

Above satellite calculation shall assume a reliability figure of 0.95 for the CFI CPR instrument.

GSR-LR-4 **Operational Availability** is defined as the probability that the space segment (platform + payload) and the link to the ground segment are able to provide the required data at the specified time (and assuming the necessary resources are provided). EarthCARE shall be designed to provide an availability during the operation phase greater than 0.95 (TBC).

Above satellite calculation can assume an intrinsic availability figure of 0.98 for the CFI CPR instrument.

GSR-LR-5 **Time Allocation for in-orbit calibration:** the time required for internal calibration and characterization measurements shall not exceed 6 % of the total time of operation. This time is not counted as unavailability.

GSR-LR-6 **Single-point failures** are defined as any failure which causes the service to be permanently discontinued without possibility of recovery. This can be a hardware failure or an irrecoverable software error. Single-point failures shall not permitted except where specifically agreed by ESA.

GSR-LR-7 **Single Failure Tolerance**
The satellite shall be able to sustain a single failure or operator error without critical or catastrophic consequences. Multiple Failures, which results from common-cause or common-mode failure mechanisms shall also be considered as single failure for determining failure tolerance.

GSR-LR-8 **Product Assurance**
EarthCARE shall comply to AD-7.

7.2 Design and Engineering Requirements

7.2.1 General

DER-GE-1 The EarthCARE spacecraft shall be designed to embark the instruments, ensuring that their requirements in terms of mechanical, thermal and electrical accommodation, functionality, operations, performance, testing, verification, availability, reliability and contamination are met.

7.2.2 Environment and Contamination Control

DER-EN-1 EarthCARE shall be designed to operate in the space environment as specified in ND-1, and to survive the environment and handling during assembly, integration and testing, transport and the launch.

DER-EN-2 Earth CARE shall be designed to limit the effect of internal and external contamination of its instruments to a level which guarantees the required performance during on-ground and in-orbit operations.

This may encompass the appropriate selection of materials and the use of e.g. venting, purging, separation of enclosures, on-ground and in-orbit de-contamination provision.

DER-EN-3 The satellite and its GSE shall be designed to minimize the areas of settling and accumulation of molecular and particulate contamination. If elimination is not possible, such areas shall be designed for easy access for cleaning.

DER-EN-4 The satellite, excepting the instruments which have specific cleanliness requirements, shall be, as a minimum, visibly clean at all times during integration and testing and at the time of the integration with the launcher in accordance with ECSS-Q-70-01A, ND-45.

DER-EN-5 Ground covers shall be provided to protect the ingress of contamination into apertures except when such apertures are specifically required to be open. The environments in which the satellite resides shall minimize contamination during AIT campaign, to a level that guarantees operational requirements for the instruments.

DER-EN-6 Provisions for purging of contamination sensitive subsystems (e.g. receiver optics, laser heads) shall be implemented in the satellite.

DER-EN-7 The maximum expected contamination levels shall be compatible with the instrument contamination budget.

DER-EN-8 The out-gassing of materials and in particular their interaction with the ATLID laser beam, shall not compromise the instrument performance. For potential sources of contamination (e.g. solar arrays, thermal control paints, harness), the out-gassing shall be defined and minimized by conditioning (e.g. vacuum bake-out).

DER-EN-9 The satellite shall be designed to avoid (minimize) organic and other outgassing materials in the vicinity of critical optical surfaces and shall ensure that electrical subsystems are isolated from the instrument optics. If this is not possible, these items shall be subject to a mandatory vacuum bake-out to reduce outgassing to an acceptable level for instrument operation.

DER-EN-10 Where mechanisms are used in the area of critical items (in particular laser optics), these mechanisms shall be designed to minimize the generation of metallic particles (ECSS-P001B, ND-56, for definition of Critical).

DER-EN-11 The design shall incorporate provision for monitoring of actual particulate and molecular contamination levels during the whole AIT campaign up to launch.

DER-EN-12 The minimum cleanliness levels shall be maintained for the spacecraft:

	in vicinity of critical units		Away from critical units	
	in laser beam vicinity	out of laser beam vicinity	other optical components	non optical components
Molecular cleanliness level	$1x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$	$5x10^{-7}gcm^{-2}$
Particulate cleanliness level	$10mm^2/m^2$	$10mm^2/m^2$	$50mm^2/m^2$	$300mm^2/m^2$

Table 7.2-1 Minimum cleanliness level for EarthCARE spacecraft

7.2.3 Launcher and Launch Environment Compatibility

DER-LL-1 The EarthCARE satellite shall be compatible with 2 launchers (potential candidiates: VEGA, Soyuz in CSG, Rockot, Dnepr). Compatibility shall cover at least: envelope, mass, mechanical and electrical interfaces, environment.

See EarthCARE SoW for further details about the selection process

DER-LL-2 EarthCARE shall be qualified to the two ESA selected launchers.

DER-LL-3 EarthCARE shall be acceptance tested to the final launcher.

DER-LL-4 EarthCARE mass budget shall incorporate adequate margins at satellite and unit level.

DER-LL-5 EarthCARE physical envelope shall include its dynamic envelope.

DER-LL-6 The satellite design and its GSE shall provide the capability for pre-launch operational checkout, functional and performance checkout and launch readiness verification of the integrated launch configuration including the instruments at the launch site. The checkout capability at the launch site shall be provided without disassembly of the integrated launch configuration.

DER-LL-7 The satellite and its GSE shall for all launch site operations comply with the launch site facilities and the launch vehicle interfaces.

DER-LL-8 EarthCARE shall comply with the Launcher ICDs. At the beginning, In absence of ICD, EarthCARE satellite shall comply with the Launcher User's Manuals at their latest issues.

DER-LL-9 The EarthCARE satellite shall be designed to cope with the rapid depressurisation during the ascent.

7.2.4 EMC and Magnetic Cleanliness

7.2.4.1 Electromagnetic Compatibility Requirements

EMC-EC-1 Electromagnetic compatibility shall be achieved in accordance with chapter 6 of ND-3 with the modifications as identified in the present chapter 7.2.4

EMC-EC-2 The satellite electromagnetic emission and susceptibility shall comply with the launchers requirements.

EMC-EC-3 The differential charging potential of the spacecraft external surfaces shall not generate high voltage levels which would affect the performances of sensitive equipment.

EMC-EC-4 The spacecraft shall operate with nominal performance when exposed to conducted electrostatic discharges (current injected into structure) or radiated electrostatic discharges having characteristics of: magnitude / energy commensurate with the orbital or on ground environment.

EMC-EC-5 The electrical architecture shall be based on a suitable grounding / isolation philosophy for power and signal lines. Differential receivers and transmitters should be used for data transmission lines. The performance of the differential transmission lines shall not be affected by common mode noise.

7.2.4.2 Protection of Other Radio Frequency Services

EMC-EC-6 EarthCARE wanted and unwanted emissions shall comply to ND-17 in order to protect other radio frequency services such as in the frequency bands of the Deep Space Network (ITU-R.SA-1157) and of the Radio Astronomy Service (ITU-R.RA-769-1).

EMC-EC-7 Wanted and unwanted emissions from the EarthCARE spacecraft falling into frequency bands of the Radio Location Service shall comply with Recommendation ITU-R. RS-1281. (TBC)

It concerns the sensors on board and therefore is not applicable to ECSS-E50-05A and this particular recommendation relates to the frequency band 13.4-13.75 GHz

7.2.5 On-Board Software

Requirements listed under section 7.2.5 are applicable for each software embarked on-board EarthCARE (i.e. platform & instruments). Some requirements related to the DHS (platform) software are listed under section 7.3.5 and complement the here below requirements for that specific software.

7.2.5.1 General Requirements

OSW-GE-1 On-board software shall implement functions and services, which are necessary to fulfil the mission objectives under the specific EarthCARE operational conditions.

Exactly which functions and services to implement in software will have to be documented in the Requirement Baseline and justified in the Design Justification File as the results of a hardware/software trade-off and system partitioning.

OSW-GE-2 On-board software shall ensure:

- High level of autonomy both under nominal and non-nominal conditions
- The support of all operational modes, including ground testing, pre-launch, launch and nominal operations, and
- A robustness against malfunctions at software and hardware level

Depending on the on-board software, the above should be ensured at system, sub-system or equipment level. At system level, this will typically fall under DHS software responsibility.

OSW-GE-3 On-board software shall implement the necessary functions and services to monitor and control the satellite (including instruments and sub-systems) by the ground in accordance with the operational principles detailed in the ECSS Packet Utilisation Standard [ND-33] and as further detailed in the EarthCARE Operations Interface Requirements Document [AD-10].

OSW-GE-4 On-board software shall implement a subset of the standard PUS-services to be agreed with the Agency. Non-implemented services shall not be present as code.

OSW-GE-5 Non-standard PUS-service definitions shall not be used.

OSW-GE-6 On-board software images/patches shall be delivered in line with requirements listed in EC-OIRD [AD-10], On-board software section.

7.2.5.2 Memory Management

OSW-MM-1 Fixed areas of the on-board memory(-ies) shall be dedicated to each constituent of the on-board software: a) code, b) constant data, c) variable data.

It is important to highlight here that constant and variable data are considered as part of the on-board software for reading and interpreting the following requirements.

OSW-MM-2 Each on-board software shall reside on a non-volatile memory and load from that memory into working memory at time of boot-up.

OSW-MM-3 It shall be possible for ground to start the boot-up process from the on-board memory by means of a telecommand. Note that this requirement covers both warm and cold start.

OSW-MM-4 It shall be possible for ground to dump any part of the on-board software, including boot-up parts.

OSW-MM-5 It shall be possible for ground to patch any part of the on-board software, excepted boot-up parts.

OSW-MM-6 It shall be possible for ground to load software patches to a non-volatile on-board memory, so that they are not lost on a power cycle of the relevant unit. Hence, on-board storage of software in non-modifiable ROM memories shall be limited such that software corrections/updates can be made when the satellite is in orbit. An exception to this shall be the code and data needed for bringing the unit to a state such that it is able to accept load memory telecommands (e.g. boot software, emergency software).

Because on-board software includes constant and variable data parts (in accordance to OBS-MM-1), the present requirement also means that it should be possible to save some actual values for equipment/instrument operations (e.g. calibration parameters) in non-volatile memory.

OSW-MM-7 It shall be possible for ground to load software patches into RAM memory, so that re-loading the software from the non-volatile memory of the relevant unit reverts to the previous software version.

OSW-MM-8 For critical software, storage of more than one software version in non volatile memories on-board, together with the possibility of selecting the one at boot up by ground command shall be provided. Exceptions shall be reviewed and agreed with the Agency.

OSW-MM-9 At initialisation, the various software checksum shall be computed and made available in the satellite telemetry.

OSW-MM-10 It shall be possible for ground to request a checksum of specified areas of memory. I.e. on-board software shall provide the capability to calculate the checksum of the memory area selected by TC.

OSW-MM-11 It shall be possible, from nominal chain, to patch and dump on-board software in the redundant chain.

This should allow to maintain the redundant equipment by making the necessary corrective patches and latest parameter updates. If not possible, then a copy should be at least stored on-board by the higher hierarchical entity towards speeding up the reconfiguration process.

7.2.5.3 Design Requirements

OSW-DE-1 On-board software shall be designed in accordance with ND-15.

OSW-DE-2 On-board software shall be written in a high-level language to be approved by the Agency. Use of a low-level language must be strictly limited and justified.

OSW-DE-3 On-board software shall support software modification and inspection during flight. The design of the on-board software shall allow the controlled generation and uplink of small memory areas without requiring all on-board software to be modified.

OSW-DE-4 On-board software shall be modular, minimising the interdependency between software modules in order to allow independent development, testing, and modification of software modules.

OSW-DE-5 On-board software shall perform error detection and error handling. In case of EDAC usage, a memory scrubbing shall be performed to avoid accumulation of single bit errors due to SEU.

OSW-DE-6 On-board software shall be designed with a specific margin philosophy in place.

The requirements below give margins for key metrics at launch time. During the software development process, the margins should be higher in order to ensure the minimum margins at launch time. Other margins are listed under section 7.3.5.6 and may also apply.

OSW-DE-7 On-board software shall maintain a 25% margin on CPU load for an agreed set of references scenarios at launch time.

Because the notion of CPU load depends heavily on the software design and the operational scenarios, the margin philosophy will have to be detailed in the specification and design phases of the software development.

OSW-DE-8 On-board software shall have a 25% margin on memory usage at launch time on all memory (volatile and non-volatile).

This requirement ensures that memory will be available for after-launch software modifications. Margins should be useful margins: e,g. having 25% margin that can only be used for constants is not useful. That margin should be distributed among the modules to allow local patching and introduction of new functions.

OSW-DE-9 Under all load conditions (permitted by the flight operation manual), the software shall complete its functions within the required time. I.e. there shall be no schedule overruns leading to uncompleted tasks.

OSW-DE-10 In case of unexpected interruptions or exceptions, the on-board software handler shall report within TM (or save) the full details of errors. Then the handler will apply the treatment defined by the FDIR requirements.

OSW-DE-11 Flight software shall not contain any code still running in-flight needed only for on-ground testing.

7.2.6 Mechanical Requirements

7.2.6.1 General Mechanical Requirements

7.2.6.1.1 Applicability of Normative Documents

MEC-AP-1 The following normative documents shall apply to the extent defined in section 7.2.6:

ND-7	ECSS-E-30-Part 2A	Structural
ND-8	ECSS-E-30-Part 3A	Mechanism
ND-11	ECSS-E-30-Part 7A	Mechanical parts
ND-13	ECSS-E-30-01A	Fracture control

Note: the source of some requirements is identified as a footnote.

MEC-AP-2 Chapter 3 of ECSS-E-30 Part 2A and Chapter 3 of ECSS-E-30 01A shall apply.

7.2.6.1.2 General

MEC-GE-1 The satellite and all its units shall withstand applied loads due to the mechanical environments to which they are exposed during the service-life. The satellite and all its units shall be able, in operation, to fulfill the mission objectives for the mission lifetime defined taking into account all ground operations (including at least transportation, handling, testing and storage), and all phases of pre-launch, launch and operation.

In particular the following failure modes, for the satellite and all equipment at all level of integration shall be prevented:

- Permanent deformation, yield,
- Rupture,
- Instability, buckling,
- Gapping, of bolted joints, of storage devices,
- Degradation of bonded joints,
- Vibration induced mounting interface slip,
- Loss of alignment of equipment and instruments subject to alignment stability requirements,
- Distortion violating any specified envelope,
- Distortion causing functional failure or short circuit.

MEC-GE-2 The satellite and all its units shall be able to withstand the worst combinations of loads. As a minimum the following load events shall be considered:

1) Ground loads due to:
   - i) handling, transportation (incl. launch specific transportation) and storage loads,
   - ii) manufacturing, assembly and integration loads, and
   - iii) test loads.
2) Launch loads as defined by the Launcher Authority and including:
   - i) quasi-static loads,
   - ii) sinusoidal loads
   - iii) random and acoustic loads,
   - iv) shock loads,
   - v) depressurization.
3) In-orbit loads:
   - i) operational pressures,
   - ii) static and dynamic loads induced by thrusters,
   - iii) shocks due to pyrotechnical operation and deployment of appendages,
   - iv) thermo-elastic loads induced by temperature variations,
   - v) hygroscopic-induced load due to variations in moisture content,

<u>Combined Loads</u>

MEC-GE-3 For combined loads where L(P) is the load due to maximum expected operating pressure and L(M) is the non-pressure limit load, the combined limit load shall be: L(M) + L(P). The design factor of MEC-GE-7 and Factors of Safety defined in MEC-DS-8 shall apply.

MEC-GE-4 For load cases involving thermal and/or moisture desorption loads, the thermal/moisture desorption stress at the applicable temperature shall be added to the non-pressure load and/or the pressure load. The design factor of MEC-GE-7 and Factors of Safety defined in MEC-DS-8 shall apply.

MEC-GE-5 Where pressure and/or temperature and/or moisture desorption relieve the non-pressure load a Factor of Safety of 1.0 shall be used for the pressure and/or thermal and/or moisture desorption loads to derive the combined load. In this case the pressure load shall be based on the minimum operating pressure.

Limit Loads

MEC-GE-6 a) The limit loads shall be derived as follows:

1) For cases where a representative statistical distribution of the loads is known, the limit load shall be defined as the load level not being exceeded with a probability of 99 % and a confidence level of 90 % during the service-life.

2) For cases where a statistical distribution of the loads is not known the limit loads shall be based on conservative assumptions.

3) For pressurised systems, the maximum expected operating pressure (MEOP) shall be part of the limit loads.

b) For Gaussian distributed random loads for verification, with a zero mean value, the limit load contribution shall be derived as standard deviation multiplied by three, i.e. 3 × root-mean-square (r.m.s.).

Design Loads

MEC-GE-7 Design Loads shall be derived by multiplication of the Limit Loads by a design factor equal to 1.25 (i.e., DL= 1.25 x LL)

NOTE 1: The mechanical part of the LL shall be derived from the launcher manual either directly or indirectly via adequate analysis.

NOTE 2: As a result of the spacecraft-launcher coupled dynamic analysis (LCDA) performed during the project design and verification phases, the knowledge of the LL might be modified in the course of the project.

MEC-GE-8 An additional factor of equal to 1.25 shall be added in addition to the above design factor of 1.25 for those units without heritage or with large uncertainty in the loads definition.

7.2.6.1.3 Mechanical Functional Requirements

Strength

MEC-FC-1 The structure shall withstand the worst design loads without failing or exhibiting permanent deformations.

Buckling

MEC-FC-2 Buckling is not allowed.

Dynamic behavior

MEC-FC-3 The natural frequencies of the structure shall be within adequate bandwidths to prevent dynamic coupling with major excitation frequencies. In particular:

a) The lowest frequencies with a significant effective masses of the spacecraft in launch configuration, hard mounted to the launch vehicle interface, shall be in accordance with the applicable Launch Vehicle User's Manual and provide a minimum margin of +15% over the specified frequencies before verification of the spacecraft dynamic properties by test.

b) The stiffness of the spacecraft in-orbit configuration shall preclude the interaction of the spacecraft flexible modes with the attitude control system

MEC-FC-4 Secondary structures and all equipment shall not dynamically couple with the spacecraft structural modes. Whenever this requirement cannot be met equipment shall withstand the effects of dynamic amplification caused by coupling with the spacecraft modes.

MEC-FC-5 The satellite shall comply with the dynamic envelope requirements in the Launch Vehicle User's Manual, or ICD, applicable to ground handling, transportation and launch when subject to the worst case combination of limit loads and considering root-mean-square manufacturing tolerances.

Damage tolerance

MEC-FC-6 Damage tolerance design principles, e.g. fail-safe design (redundancy) of attachment points, or safe-life design and damage tolerant materials, shall be applied.

A structure is considered tolerant to damage if the amount of general degradation or the size and distribution of local defects expected during operation does not lead to structural degradation below limit-specified performance.

MEC-FC-7 Redundancy concepts (fail-safe) shall be implemented whenever possible to minimize single-point failures. Where a single-point failure mode is identified and redundancy cannot be provided the required strength and lifetime (safe-life design) shall be demonstrated.

MEC-FC-8 Interfaces within the primary structure, between primary and secondary structures, and to all units above 0.5 kg shall be fail-safe. In particular any bolted interface holding more than 0.5 kg shall survive with any bolt missing with safety factors for ultimate and yield equal to one.

Fracture control

MEC-FC-9 A reduced fracture control programme in accordance with clause 11 of ECSS-E-30-01A shall be established and integrated in the design and verification process

Tolerances and alignments

MEC-FC-10 a) The accuracy of the system of tolerances applied to the mechanical design shall guarantee conformance to geometrical interface requirements.

b) The angular and position tolerances shall be consistent with the requirements for alignment or pointing accuracy of the assembly to achieve the mission objectives.

c) Provision for alignment adjustability, both at assembly level and at spacecraft level, shall be included in the mechanical design together with the devices (e.g. alignment cubes) for measurement or checking of the alignment.

MEC-FC-11 The spacecraft structure shall allow all necessary alignments of equipment and instruments minimizing as much as possible the need for disassembling parts after the spacecraft integration. Note that this should be achieved keeping the compliance with MEC-GE-1, in particular vibration induced mounting interface slip shall be avoided.

Dimensional stability

MEC-FC-12 a) The mechanical design of the satellite shall ensure that no loss of alignment which jeopardises or degrades the mission objectives can be caused by the action of applied loads (e.g. launch loads, deployment loads, thermal and moisture release).

b) Materials selected shall take into account the stability of the material under the expected environment during the complete lifetime of EarthCARE.

Pressurized hardware

MEC-FC-13 For design, manufacturing, verification, operation and maintenance of metallic and non-metallic pressurized hardware the requirements of ND-99 shall apply

7.2.6.1.4 Mechanical Interface Requirements

MEC-IF-1 The spacecraft structure shall provide the mounting interface to the launch vehicle and comply with the launcher interface requirements.

MEC-IF-2 The spacecraft structure shall provide physical interfaces to all the equipment and instruments, including CPR, in accordance with the corresponding interface requirements

7.2.6.1.5 Mechanical Design Requirements

Accessibility and Maintainability

MEC-DS-1 The design shall allow access, maintenance, removal and replacement of all secondary structures, payload, equipment and connectors.

MEC-DS-2 a) The mechanical design shall be performed in such a way that assembly, integration and repair and maintenance activities can be carried out with a minimum of special tools and test equipment

b) The design shall minimize the maintenance during storage and ground life.

Materials Selection

MEC-DS-3 For materials selection ECSS-Q-70, ND-71, and ECSS-E-30 Part 8, ND-12, shall apply.

Corrosion effects

MEC-DS-4 a) Structural materials shall be corrosion resistant in their specific environment, to contained fluid and contacting materials. Materials shall be compatible with dissimilar materials. Materials shall be resistant to fretting and crack initiation.

NOTE: Corrosion shall be regarded as any deterioration in the physical and chemical properties of a material due to the environment.

b) Materials for which the corrosion is not known shall not be used.

c) Metals, their alloys and weldments, when used in structural applications shall be selected from subclause 6.1, Table I of ECSS-Q-70-36A.

Material design allowables

MEC-DS-5 a) For all structural material design allowables shall be statistically derived

b) All design allowables for metals, composites and any structural material other than glass and ceramics shall be defined by their A-values.

c) Design allowables for glass and ceramics shall be derived through a probabilistic approach

Venting

MEC-DS-6 a) All units in the satellite shall be properly vented to prevent build-up of excess pressure and to reduce the time to evacuate the unit.

b) The openings for venting (e.g. to prevent contamination or risk of explosion) shall be compatible with the purging system gas supply pressure and flow rate, if any.

c) The venting routing shall not contaminate critical units, for example optics or mechanism.

Margins of safety (MOS)

MEC-DS-7 a) Margins of safety (MOS) shall be calculated by the following formula:

$$MOS = \frac{design\ allowable\ load}{design\ limit\ load \times FOS} - 1$$

where:

- design allowable load is the allowable load under specific failure mode (e.g. yield, buckling or rupture);

- FOS is the applicable factor of safety (e.g. yield factor of safety, ultimate factor of safety)

NOTE Loads can be replaced by stresses if the load- stress relationship is linear.

b) All margins of safety shall be positive.

c) The margins of safety for combined loads shall be computed by the following procedure:

1) define the load combination applied at a certain design level (limit, yield or ultimate), according to the specified FOS for combined loads;

2) calculate the margin of safety as

$$MOS = \lambda - 1.$$

Where λ, called reserve factor, is the ratio between design allowable and design load

d) MOS shall be computed by accounting for interactions of different types of failures (e.g. failure of a bolt due to shear and tension)

NOTE: The following “interaction equation” is normally used to compute λ for interacting failure types:

$$\lambda^{\alpha}\mathbf{R}_1^{\alpha} + \lambda^{\beta}\mathbf{R}_2^{\beta} + \lambda^{\gamma}\mathbf{R}_3^{\gamma} + \lambda^{\delta}\mathbf{R}_4^{\delta} .... = \mathbf{1}$$

where α , β , γ , and δ are experimental exponents and **Ri** are the ratios between the i-th Design Load multipled by applicable Factors of Safety and the allowable load (which causes the failure if the i-th load is applied alone).

Factors of safety (FOS)

MEC-DS-8 a) The Factors of Safety of Table 7.2.5.1.5-1 shall be applied to the Design Loads (DL) as defined in MEC-GE-7

b) Special factors, also called “additional factors”, specified in Table 1 (e.g. for joints and inserts), shall be applied in addition to other factors of safety

Table 7.2.5.1.5-1: Minimum Factors of Safety

Structure type and sizing case	FOSY [a] for tested structures	FOSU [b] for tested structures	FOSY for verification by analysis only	FOSU for verification by analysis only	Additional factors [c]
Metallic structures	1.1	1.25	1.25	2.0	
Composite structures, Uniform material, brittle		1.25		2.0	
Sandwich structures:					
- Face wrinkling		1.25		2.0	1.2
- Intracell buckling		1.25		2.0	1.2
- Honeycomb shear		1.25		2.0	1.2
Glass structures		2.5		5.0	
Composite structures discontinuities		1.25		2.0	1.2
Joints and inserts		1.25		2.0	1.2
Global buckling		1.25[d]		2.0	

[a] Factor of Safety to Yield

[b] Factor of Safety to Ultimate

[c] These factors shall be applied in addition to other factors of safety

[d] For structures qualified by static test that covers also buckling loads

MEC-DS-9 Minimum Burst Factors to be applied to the maximum design pressure (MDP), to obtain the design burst pressure for pressure vessels, lines, fittings and other pressurized components are as follows:

Pressure Vessels 1.5

Lines and Fittings smaller than 38 mm diameter 4.0

Lines and Fittings 38 mm diameter or greater 2.5

Valves, Filters, Regulators, Other Pressurised Components 2.5

NOTE: burst pressure is the pressure level at which collapse, rupture or unstable fracture of the pressurized hardware occurs

Scatter Factors

MEC-DS-10 A scatter factor of 4 shall be used in fatigue analysis

NOTE1: The scatter factor is applied to the number of cycles of a certain load level in order to cover the uncertainties of loads and material properties. Usually for metallic materials a scatter factor of 4 is applied. However, for specific applications (e.g. pressure vessels and low cycle fatigue) higher values are commonly used (e.g. 5 for pressure vessels)

NOTE 2: for composite materials in some cases a factor on the stress (e.g. 1.15) is defined instead of a scatter factor on the load cycles

NOTE 3: The number of cycles can be based on the number of possible repetitions of

tests (e.g. 1 qualification vibration plus 3 possible repetitions) specified by the project.

7.2.6.1.6 Mechanical Verification Requirements

Verification by analysis

MEC-VF-1 All the Finite Element Models (FEM) prepared to support the mechanical verification activities at sub-system and satellite level shall be delivered in NASTRAN format

MEC-VF-2 The FEM of the spacecraft in its launch configuration shall be detailed enough to ensure an appropriate derivation and verification of the design loads and of the modal response of the various structural elements of the satellite up to 140 Hz

MEC-VF-3 A reduced FEM of the entire spacecraft correlated with the detailed FEM shall be delivered for the Launcher Coupled Loads Analysis (CLA). The reduced FEM shall comply with the quality criteria detailed in Table 4 given in chapter 5.8 of ECSS-E-30-11 and with the requirements specified by the launch authorities

MEC-VF-4 The analysis of adhesive joints shall be performed in accordance with ECSS-HB-305

MEC-VF-5 The analysis of standard insert connections shall be performed in accordance with ECSS-HB-306

Verification by test

MEC-VF-6 The satellite FEMs shall be verified and correlated against the results of modal survey tests carried out at complete spacecraft level, and at component level for units above 50 kg., The test versus analysis correlation requirements defined in chapter 5.8 of ECSS-E-30-11, with the quality criteria as given in Table 3 of the same standard shall be applied.

MEC-VF-7 Notching

Primary notching, i.e. notching to keep the accelerations of the centre of mass of EarthCARE at the design loads, is allowed.

MEC-VF-8 Secondary notching, i.e.: notching to protect internal equipment or notching to achieve accelerations at the centre of mass of EarthCARE lower than the design loads is not allowed.

MEC-VF-9 Flight, acceptance, qualification factors for tests

The minimum factors in Table 7.2.5.1.6-1 shall be applied. If larger factors are requested by the launcher user manual or the launcher authority, these larger factors shall be applied.

Table 7.2.5.1.6-1. Factors for flight, acceptance and qualification testing

Test	Unit	Flight	Acceptance	Qualification
Sine vibration	g	given by launcher authority	x 1	x 1.25
Acoustic	DBPa	given by launcher authority	+ 0 dB	+ 4 dB
Random (1)	g^2/Hz		x 1	x 1.25^2
Shock	g	given by launcher authority	not required	x 1.25

(1) not for satellite, for equipment only

MEC-VF-10 The structural model of the satellite shall pass successfully qualification static test.

MEC-VF-11 The structural model of the satellite shall pass successfully qualification sine vibration Test.

MEC-VF-12 The structural model of the satellite shall pass successfully qualification acoustic test.

MEC-VF-13 The structural model of the satellite shall pass successfully qualification shock tests.

MEC-VF-14 The flight satellite shall pass successfully acceptance sine vibration test.

MEC-VF-15 The flight satellite shall pass successfully acceptance acoustic test.

MEC-VF-16 The flight satellite shall pass successfully acceptance shock tests.

MEC-VF-17 The structural model of the satellite shall be able to survive 4 times all mechanical qualification tests, i.e. static, sine, acoustic and shock.

MEC-VF-18 The satellite Flight Model shall be able to survive 4 times all mechanical acceptance tests, i.e. sine, acoustic, shock plus one launch.

7.2.6.2 Mechanisms and Pyrotechnics

7.2.6.2.1 Mechanism General Requirements

MEP-GE-1 Reliability

a. All mechanisms shall demonstrate conformance to the required reliability figure.

NOTE: The method to achieve by design, derive by analysis, and demonstrate the required reliability figure can be found in ECSS-Q-30B.

Derived from ECSS-E-30 Part 3A – Section 4.2.3.2 a

MEP-GE-2 Redundancy

a. During the design of the mechanism all single point failure modes shall be identified.

b. All single points of failure shall be eliminated by redundant components where practicable.

c. Unless redundancy is achieved by the provision of a complete redundant mechanism, active elements of mechanisms such as sensors, motor windings (and brushes where applicable), actuators, switches and electronics shall be redundant.

d. Failure of one element or part shall not prevent the other redundant element or part from performing its intended function, nor the equipment from meeting its performance requirements.

Derived from ECSS-E-30 Part 3A – Section 4.2.3.4 b, c, f, g

MEP-GE-3 Factors of safety (FOS)

a. In the computation of safety margins the following minimum factors of safety shall be used for standard metallic materials:
- yield stress factor of safety 1,25
- ultimate stress factor of safety 1,5
- minimum fatigue factor (cycles) 4

b. Other materials shall require customer approval of required factors of safety on a case by case basis.

c. The following specific factors of safety shall apply on the components identified below :
- cables, stress factor of safety against rupture 3
- stops, shaft shoulders and recesses, against yield 2

Derived from ECSS-E-30 Part 3A – Section 4.7.4.2.8

MEP-GE-4 Functional dimensioning (motorization)

1 General

The mechanisms engineering shall conform to the motorization factor requirements on quasi-static torque (or force) ratio and where applicable on dynamic torque (or force) ratio as defined in the following sub-clauses.

ECSS-E-30 Part 3A – Section 4.7.4.3.1

MEP-GE-5 2 Quasi-static torque applicability

The quasi-static torque (or force) ratio is applicable to mechanisms where the moving function is performed without imposing design driving requirements on the functional performance due to time constraints. (e.g. deployment systems, unfolding devices).

NOTE the quasi-static torque (or force) ratio is defined as the actuation torque (or force) divided by the sum of the factored worst case resistive components opposing the movement of the mechanism plus any required deliverable output torque or force.

ECSS-E-30 Part 3A – Section 4.7.4.3.2

MEP-GE-6 3 Dynamic torque applicability

The dynamic torque (or force) ratio requirement is applicable to mechanisms which have to fulfil a specified acceleration requirement or for which an indirect acceleration requirement can be deduced from speed/time or other (dynamic) requirements.

NOTE The ratio is defined as the dynamic actuation torques (or forces) divided by the sum of the factored dynamic worst case resistive components and the additional factored inertial torque (or force) induced by the acceleration of the mechanism moving assembly plus any required deliverable output torque or force.

ECSS-E-30 Part 3A – Section 4.7.4.3.3

MEP-GE-7 4 Motorization factor - “quasi-static” torque (or force) ratio

a. Actuators (electrical, mechanical, thermal and others) shall be sized to provide throughout the operational lifetime and over the full range of travel actuation torques (or forces) which exceed at least two times the combined factored worst case resistive torque or forces in addition to any required deliverable output torque or force. The following minimum uncertainty factors shall be applied to the resistance components when deriving the worst case resistive torques (or forces) :

In order to derive the factored worst case quasi-static resistive torques (or forces), the components of resistance, considering worst case conditions, shall be multiplied by the following minimum uncertainty factors (see Table 2).

Table 2: Minimum uncertainty factors

Component of resistance	Symbol	Factor	
Inertia	I_T (or I_F)	1,1	
Spring	S	1,2	
Friction	F_R	3 #	(1,5)
Hysteresis	H_Y	3 #	(1,5)
Others (harness)	H_A	3 #	(1,5)
Adhesion	H_D	3	

b. The minimum required actuation torque (or force) is defined by the equations:

Minimum required actuation torque (Tmin)
Tmin =2,0×(1,1IT +1,2S +3 FR +3 HY +3 HA +3 HD)+TL

c. Minimum required actuation force (Fmin)
Fmin =2,0×(1,1IF +1,2S +3 FR +3 HY +3 HA +3 HD)+FL

The deliverable output torque or force is only applicable if specified by the customer.

d. When a function of the mechanism is to deliver an output torques or forces TL /FL , for further actuation, the output torque or force shall be derived ac-cording to the above torque or force requirements considering the specified uncertainty factors on the individual components of resistance as appropriate and the motorization factor of two shall also be applied to TL /FL .

e. The inertia resistance term (IT or IF) in the required minimum actuation torque (or force) equation is applicable to mechanisms being mounted in an accelerating frame of reference (e.g. spinning spacecraft, payload or other) and shall be derived considering the imposed inertial resistance load.

f. The specified uncertainty factors marked by # in Table 2 may be reduced to 1,5 providing that the worst case measured torque or force resistive components to which they refer are determined by measurement according to a test procedure approved by the customer and demonstrate the adequacy of the uncertainty factor with respect to the dispersions of the resistive component functional performances.

g. The kinetic energy of the moving components shall not be considered in the provision of actuation torques (or forces).

h. Environmental effects shall be accounted for separately in addition to the use of the above uncertainty factors when deriving the worst case resistive torques (or forces).

ECSS-E-30 Part 3A – Section 4.7.4.3.4

MEP-GE-8 5 Motorization factor - dynamic torque (or force) ratio

a. Actuators (electrical, mechanical, thermal and others) shall be sized to provide throughout the operational lifetime and over the full range of travel actuation torques (or forces) which exceed the sum of at least two times the combined worst case dynamic resistive torque (or forces) and 1,25 times the inertial resistance torque (or force) caused by the required worst case acceleration function. The minimum uncertainty factors (see Table 2) shall be applied to the resistance components when deriving the worst case resistive dynamic torques (or forces).

In order to derive the worst case dynamic resistive torques (or forces), the components of resistance considering the worst case conditions shall be multiplied by the minimum uncertainty factors (see Table 2).

b. The minimum required actuation torque *(Tmin)* to meet the dynamic torque ratio requirements is given by the formula:
Tmin =2,0×(1,1IT +1,2S +3 FR +3 HY +3 HA +3 HD) + 1,25 TD
where
TD is the dynamic torque.

c. The minimum required actuation force *(Fmin)* to meet the dynamic force ratio requirements is given by the formula:
Fmin =2,0×(1,1IF +1,2S +3 FR +3 HY +3 HA +3 HD) + 1,25 FD
where
FD is the dynamic force.

d. The inertia resistance term *(IT or IF*) in the required minimum actuation torque (or force) equation is applicable to mechanisms being mounted in an accelerating frame of reference (e.g. spinning spacecraft, payload or other) and shall be derived considering the imposed inertial resistance load.

e. The specified uncertainty factors marked by # in table 2 may be reduced to 1,5 providing that the worst case measured torque or force resistive components to which they refer are determined by measurement according to a test procedure approved by the customer and demonstrating adequacy of the uncertainty factor with respect to the dispersions of the resistive component functional performances.

f. The kinetic energy of the moving components shall not be considered in the provision of actuation torques (or forces).

g. Environmental effects shall be accounted for separately in addition to the use of the above uncertainty factors when deriving the worst case resistive torques (or forces).

ECSS-E-30 Part 3A – Section 4.7.4.3.5

MEP-GE-9 6 Actuation torque (or force) dimensioning

a. When the actuation torque (or force) is supplied by a spring actuator, the worst case actuation torque required in the equations in MEP-GE-7 and MEP-GE-8, shall be derived considering worst case conditions and shall be multiplied by the maximum uncertainty factor of 0,8.

b. Spring actuators shall be redundant unless agreed by the customer, and unless it is demonstrated by analysis and test that appropriately conservative spring sizing and functional performance characteristics guarantee the required reliability of the mission. The appropriate spring sizing shall demonstrate that a spring failure can be excluded as potential failure mode.

c. Actuating torques or forces based on hysteresis, harness generated, or any item whose primary function is not to provide torques or forces, shall not be used as a motorization source.

d. If torques (or forces) from harness or other above excluded actuator sources are relied upon to meet the motorization requirements their use shall be justified, agreed with the customer and the adequacy of the uncertainly factor with respect to the dispersion of the component actuation functional performances shall be demonstrated.

ECSS-E-30 Part 3A – Section 4.7.4.3.6

MEP-GE-10 Status monitoring

Unless monitored at spacecraft system level, the design of mechanisms shall include appropriate means to monitor the execution of its main functions. Mission critical mechanisms shall be designed in such way that monitoring information of its critical function(s) is accessible to the spacecraft telemetry.

ECSS-E-30 Part 3A – Section 4.7.4.4.2

MEP-GE-11 The mechanism design shall be compatible with operation on ground in ambient and thermal vacuum conditions. The permissible operations and the constraints for the operations in ambient shall be defined.
ECSS-E-30 Part 3A – Section 4.8.3.1 b

MEP-GE-12 Life test duration

The lifetime qualification shall be demonstrated using the factored sum of the predicted nominal ground test cycles and the in-orbit operation cycles. For the test demonstration, the number of predicted cycles shall be multiplied by the following factors in Table 3:

Table 3: Life test duration factors

Type	Number of predicted cycles	Factor
Ground testing	Number of on-ground test cycles (minimum 10)	4
In-orbit	1 to 10 cycles	10
	11 to 1000 cycles	4
	1001 to 100000 cycles	2
	> 100000 cycles	1,25

The cycle definition is subject to agreement with the customer and shall consider as a minimum, the number of motions over the same location, motion amplitude and number of reversals. In order to determine the lifetime to be demonstrated by test, an accumulation of cycles multiplied by their individual factors shall be used.

Derived ECSS-E-30 Part 3A – Section 4.8.3.3.11

MEP-GE-13 Life test of the mechanisms shall be successfully completed prior to flight.

MEP-GE-14 All mechanisms shall be able to perform nominally after a storage period of one year at spacecraft level. The mechanisms shall not request any additional tests during or after this period to confirm the performance of the mechanisms. Storage configuration needs not be flight configuration.

7.2.6.2.2 Mechanism Functional Requirements

MEP-FU-1 Deployment mechanism shall allow contingency operations to correct deployment anomalies (e.g. possibility to power up redundant winding of deployment motors, reverse operation of motors) by design features which do not introduce significant additional complexity.

MEP-FU-2 It shall be possible to command all mechanisms from ground.

MEP-FU-3 It shall be possible to activate all mechanisms during the AIT campaign. This functionality shall be available for the deployment tests

7.2.6.2.3 Pyrotechnics Requirements

MEP-PY-1 Pyrotechnics application and design shall be approved by ESA.

MEP-PY-2 All pyrotechnics shall be initiated via a spacecraft dedicated unit. This unit shall incorporate the safety inhibits and the possibility to test the functionality without activating the devices.

MEP-PY-3 All pyrotechnics shall be initiated via a dedicated module which is mechanically segregated, electrically independent and screened, and thermally decoupled from the rest of the unit that houses it. This module shall incorporate the safety inhibits.

MEP-PY-4 The unit initiating thermal knives, if any, shall incorporate inhibits.

MEP-PY-5 All pyrotechnic devices shall be redundant.

MEP-PY-6 All leads and electronics associated with pyrotechnics shall ensure high reliability and safety (including suitable screening).

MEP-PY-7 Use of pyrotechnic devices shall be compatible with the cleanliness requirements of the spacecraft.

7.2.7 Ground Handling Capabilities

7.2.7.1 Ground Testing

GHC-GT-1 The complete satellite shall be able to operate and be testable in at least one orientation under 1g. This specifically includes fully representative thermal testing.

GHC-GT-2 It shall be possible to perform all deployment tests at spacecraft level. Deviations shall be agreed with the Agency.

7.2.7.2 Modularity

GHC-MO-1 The satellite shall be constructed in modules, which allow parallel manufacturing and test on each module. These modules shall be at least:

- The Atlid instrument including laser and telescope
- The CPR instrument including antenna
- The satellite bus
- The solar array.

GHC-MO-2 Mechanical and electrical disassembly and re-integration shall be possible in no more than two shifts of AIT activity.

This covers mating/demating of both flight and other non-flight EarthCARE items.

GHC-MO-3 The satellite shall be transportable to the launch site in a fully integrated configuration.

7.2.7.3 Maintainability

GHC-MN-1 It shall be possible to mate and de-mate all electrical connectors of the instrument, when the instrument is standing alone, without further disassembly. A permissible exception is the interface between the detector and its front-end electronics.

GHC-MN-2 It shall be possible to remove and replace any electrical box from the instrument after disassembly of only the instrument core from the remote electrical panel. A permissible exception is the detector front-end electronics.

GHC-MN-3 It shall be possible to mate and de-mate all electrical connectors on the satellite bus, whether the bus is standing alone or integrated to the instrument, after the removal of no more than two access panels. These access panels shall not themselves have electrical units mounted on them.

GHC-MN-4 It shall be possible to remove and replace any electrical box from the satellite bus after disassembly of a single panel from the bus. This panel may have electrical units mounted to it.

GHC-MN-5 It shall be possible to access any PROM containing flight software without removing the corresponding electronics box from the satellite.

GHC-MN-6 Pyro safe/arm and fill/drain connections shall be accessible on the skin of the satellite when the satellite is in a fully integrated configuration.

GHC-MN-7 Pyro installation and replacement shall be possible when the satellite is in an otherwise fully integrated configuration.

7.2.8 Safety Requirements

GHC-SR-1 All elements of the system shall be designed to avoid (minimize) hazards to personnel and property.

Any potential hazard will have to be duly identified and agreed with Agency.

GHC-SR-2 The safety requirements of the launcher authority as well as the requirements in force for facilities to be used in the execution of the AIV programme shall be fully complied with.

GHC-SR-3 Design choices likely to create safety concerns shall be identified and submitted to the Agency for approval.

7.3 Subsystems Requirements

7.3.1 Attitude and Orbit Control Subsystem (AOCS)

7.3.1.1 AOCS General Requirements

AOS-GE-1 The spacecraft shall provide an Attitude and Orbit Control Subsystem (AOCS) that include:

- An autonomous capability to determine and to maintain the required spacecraft attitude pointing, rate and acceleration around three orthogonal axes during all the mission phases.
- A capability to perform orbit corrections to maintain the orbital parameters within the required range during the mission life. It shall provide an autonomous capability to command and control the actuators used to support orbit maintenance.
- An autonomous capability to place the spacecraft in a safe attitude in case of loss of nominal attitude. It shall provide the capability to recover the nominal pointing within the allowed outage requirements.

AOS-GE-2 The AOCS shall provide all on-board hardware and software to satisfy the attitude and orbit control required performances, and measurement requirements for all mission phases and operational modes.

AOS-GE-3 The detailed requirements on the AOCS system (e.g. attitude pointing, rate, acceleration maximum value and stability requirements) shall be derived from the mission performance requirements associated to the functions entrusted to the system (e.g. attitude and orbit control, as well as instrument calibration).

7.3.1.2 AOCS Functional Requirements

AOS-FU-1 The AOCS shall not introduce disturbances that invalidate the scientific observations.

AOS-FU-2 The spacecraft shall provide an AOCS that shall be able to maintain the spacecraft and payload in a safe attitude at all times

AOS-FU-3 The spacecraft shall provide an AOCS that shall be able to protect the sensitive spacecraft components from sun intrusion with a safety factor of 2 over the sun illumination survivability of each sensitive spacecraft component.

AOS-FU-4 The AOCS shall protect against direct impact of atomic oxygen on sensitive surfaces at all times (This will especially include the period between separation and initial attitude acquisition, or the period following an AOCS anomaly, i.e the Safe Mode transition and Safe Mode steady state operation)

AOS-FU-5 The AOCS control shall not generate internal mechanical disturbances that can endanger the deployment sequence of any appendages (solar panel or antenna)

AOS-FU-6 The AOCS shall be able to acquire the nominal Earth pointing attitude and rates from any initial attitude and rates limited only by the physical integrity of the satellite

AOS-FU-7 After separation from the launch vehicle, the AOCS shall:

- Damp out the residual angular rates as specified by the launcher specification,
- Bring the spacecraft into a power safe pointing attitude within a time compatible with the spacecraft internal power,
- Maintain the spacecraft in this pointing attitude ready to receive ground commands.

AOS-FU-8 The AOCS shall acquire and maintain a three-axis stabilised Earth pointing control throughout its orbital life in the presence of environmental/internal perturbation torques, spacecraft flexible modes and propellant slosh during all mission phases and nominal operational modes.

AOS-FU-9 The AOCS shall provide the spacecraft slewing capability that is required in the different mission phases

AOS-FU-10 The AOCS shall include an autonomous capability to measure the satellite position with an accuracy sufficient to satisfy all localisation and pointing requirements

AOS-FU-11 The AOCS shall be able to propagate on-board orbit & navigation information provided either on-board or by the ground segment. It shall be possible to synchronise the on-board orbit propagator with orbit measurement information determined either on-board or on-ground.

AOS-FU-12 The GPS receiver shall be able to function with full accuracy in the presence of a constellation of up to 32 GPS satellites.

AOS-FU-13 The AOCS shall provide the Data Handling Subsystem with all the necessary inputs to allow an on-ground attitude and orbit determination within the accuracy required by the mission needs at all times

AOS-FU-14 All AOCS functions shall be maintained with full performance after any single failure.

AOS-FU-15 In case of anomalies not resolved by autonomous on-board redundancy, reconfigurations, compensations or back-up actions, the satellite shall enter an autonomous Safe Mode that shall:

- bring the spacecraft into a safe power, thermal and Ground Communication condition which permits satellite survival
- bring/keep the spacecraft into a stable pointing mode which minimizes fuel consumption and which is compatible with an altitude recovery (minimizes altitude loss).

AOS-FU-16 The safe mode shall be capable of being entered either by ground command or without ground intervention by an on-board logic that has recognised that all other means of maintaining the nominal AOCS control mode have failed.

AOS-FU-17 In safe mode, the AOCS shall use:

- hardware equipment (for critical sensors and actuators) different from those used for nominal AOCS mode.
- software modules different from those used in operational modes (specific or different channels).

AOS-FU-18 The AOCS shall allow to recover autonomously a three-axis stabilised Earth pointing upon safe mode exit.

7.3.1.3 AOCS Performance Requirements

AOS-PE-1 After separation, the AOCS shall be able to acquire nominal Earth pointing attitude and rates from any initial attitude and, as a minimum, 1.5 times the launchers specified worst case rates at separation. *The pointing performance at this time may be degraded with respect to Operational Phase requirements, but should be good enough to satisfy the satellite power and thermal safety requirements.*

AOS-PE-2 The spacecraft shall provide an AOCS that shall be able to correct for worst case launcher injection errors

AOS-PE-3 The AOCS shall provide the attitude and pointing/rate stability required by the payload during the execution of the nominal mission phase

AOS-PE-4 The accuracy, data latency and update rate of the onboard position and velocity estimation shall be compliant with the payloads requirements, the mission localisation requirements and the satellite operation needs

AOS-PE-5 A propagator in the on-board position and velocity estimation shall be implemented to provide the required accuracy in case of missing orbital measurements, and to cover (when applicable) the needs for an higher update rate than supplied by the GPS receiver and/or compensate for measurement delays.

AOS-PE-6 A propagator in the attitude errors estimation shall be implemented to provide the required accuracy in case of missing attitude measurements, and to cover (when applicable) the needs for an higher update rate than supplied by the attitude sensor measurement system and/or compensate for measurement delays

AOS-PE-7 In Nominal Operation Mode and End-to-End Calibration Mode, the AOCS performance (absolute pointing error (APE), absolute measurement error (AME), absolute rate error (ARE), etc..) shall comply with the System Pointing requirements and with the Level 1B product performances requirements.

AOS-PE-8 The AOCS performances shall be made robust against the transient loss of measurements from nominal sensors (e.g. number of consecutive missing measurements TBC)

AOS-PE-9 The AOCS shall be able to function and meet its performance requirements for any day of launch.

7.3.1.4 AOCS Operational Requirements

AOS-OP-1 All nominal AOCS operations shall be fully automatic and autonomous. Ground intervention shall be limited to support for recovery operations after multiple failures.

AOS-OP-2 Adjustments of AOCS control loop parameters by telecommand shall be possible.

AOS-OP-3 The AOCS shall:

- accept immediate or time tagged telecommands to perform attitude and orbit manoeuvres,
- allow reconfiguration and parameter updating upon ground command.

AOS-OP-4 In all modes except Safe Mode, it shall be possible to command an attitude bias on the sensor measurements in order to compensate for payload misalignments and AOCS attitude errors.

AOS-OP-5 The AOCS shall provide the ground with sufficient measurement information without the need for telemetry reprogramming, to permit the spacecraft position and instrument pointing reconstitution with the accuracy required by the mission, system and operational requirements, throughout the relevant mission phases

AOS-OP-6 In each of the AOCS modes, sufficient data shall be available in telemetry to allow the ground to determine the satellite attitude independently of the on-board estimation process.

AOS-OP-7 The AOCS shall permit in-orbit reprogramming of its software (including the software embedded in equipments used by the AOCS).

AOS-OP-8 The AOCS shall provide all the necessary means in order to effectively support the EarthCARE Failure Detection, Isolation and Recovery (FDIR) as defined under section 6.8.

AOS-OP-9 The primary objective of the AOCS FDIR shall be to detect any s/c condition (attitude, rates, orbit changes) that present a potential threat to the safety of the mission and to correct any such condition and isolate the cause by means of transition to Safe Mode.

AOS-OP-10 The secondary objective of the AOCS FDIR shall be to maintain the Operational condition of the spacecraft by the correct, timely and unambiguous detection of equipment and software failures, errors and anomalies and the recovery of such failures, errors and anomalies by automatic software action and/or hardware reconfiguration.

AOS-OP-11 The mechanisms implementing the two objectives of the AOCS FDIR shall be kept as separate as possible and meeting the primary objective shall always have priority.

AOS-OP-12 The AOCS FDIR design shall incorporate provisions to inhibit thruster firings during loss of attitude conditions, and to inhibit anomalously long thruster firings.

AOS-OP-13 The AOCS shall provide sufficient information to ground to allow diagnosis of on-board failures. This may be by ground command or specific diagnostic telemetry packets.

E.g. dump of STR image.

AOS-OP-14 AOCS reconfigurations by ground shall not require a “Ground Intervention Mode”. It shall be possible for ground to uplink and store on-board all required reconfiguration commands (H/W change commands, acquisition table, etc.) in advance and then request the software to undertake the reconfiguration by sending a single command without affecting the mission.

AOS-OP-15 In all modes, the AOCS shall provide to the ground sufficient housekeeping data to perform:

- Failure detection and isolation,
- Monitoring of Switch-over to the redundant resources,
- Shutdown and isolation of malfunctioning parts.
- In-orbit calibration/characterisation

AOS-OP-16 Via telecommand, it shall be possible to select which pointing reference frame has to be used by the AOCS as in-between Yaw-Steering baseline (see 3.6.1) and TBC Zero-Doppler (see 3.6.2) pointing.

As a reminder (see above a.m. sections), the Yaw-Steering Reference Frame aligns the Z-axis with the local normal, and delivers rectangular images (provided the instrument scan is in the YZ-plane), while the Zero-Doppler Reference Frame offers Zero Doppler for a reflected signal from the active instruments (provided the reflector is rotating with the Earth, and is in the YZ-plane). Effectiveness of Zero-Doppler in frame of the EarthCARE application still needs to be confirmed, i.e. Yaw-Steering should be considered as baseline today in any cases.

7.3.2 Propulsion Subsystem

7.3.2.1 Propulsion General Requirements

PRO-GE-1 The Propulsion Subsystem shall be able to:

- Provide attitude control around three orthogonal axes during all mission phases
- Perform orbit acquisition and corrections to maintain the orbital parameters within the required range during the mission life

PRO-GE-2 The detailed requirements on the Propulsion Subsystem (e.g thrust, propellant loading) shall be derived from the mission and system performance requirements associated to the functions entrusted to the system (e.g. attitude and orbit control, instrument calibration).

7.3.2.2 Propulsion Functional Requirements

PRO-FU-1 The Propulsion Subsystem shall perform nominally for a period including:

- o the pre-launch lifetime,
- o the satellite storage requirement,
- o the mission lifetime.

PRO-FU-2 Two independent thruster branches shall be employed for redundancy, each capable of meeting the full mission requirements.

PRO-FU-3 The characteristics of the thrusters and their accommodation on the satellite shall not cause any deleterious effects (e.g contamination) on the spacecraft (on the optical sensors and on any other sensitive equipment) during the mission.

PRO-FU-4 Thruster directions and locations shall be selected to minimize generation of disturbing forces and torques (plume impingement) and fuel consumption.

PRO-FU-5 The propulsion subsystem shall provide means for determination of the remaining propellant quantities.

PRO-FU-6 Propellant gauging accuracy shall be such as to maximise the propellant available for use in the Operational Phase:

- to ensure that sufficient fuel is available to terminate Routine Operations and undertake a controlled re-entry, if this design option is retained,
- in the Operational Phase, to predict the end of the mission with an accuracy of three months.

PRO-FU-7 The Propulsion subsystem shall provide the Data Handling Subsystem with all the necessary inputs to allow propellant gauging within the required accuracy at all times during the operational life of the satellite.

PRO-FU-8 The Propulsion subsystem shall provide the Data Handling Subsystem with all the necessary inputs to allow the valves status and the tank pressure status to be monitored during ground operations and in-flight.

PRO-FU-9 All propulsion functions shall be maintained with full performance after any single failure.

PRO-FU-10 The redundant branch shall be protected such that any event that causes the loss of the nominal branch does not result in the loss of the redundant branch.

PRO-FU-11 For all ground operations and on the launch vehicle the propulsion system and its GSE shall comply with applicable safety regulations and constraints of the relevant ground facilities (with respect to failure tolerance levels).

PRO-FU-12 The propulsion sub-system design shall be defined in order to adequately support on-ground acceptance testing.

7.3.2.3 Propulsion Performance Requirements

PRO-PE-1 The Propulsion Subsystem shall have a filling capacity compliant with the propellant mass requirement.

PRO-PE-2 For the estimate of the propellant requirements, at least the following assumptions shall be used:

- manoeuvres for orbit acquisition and maintenance
- manoeuvres as needed for calibration
- collision risk avoidance
- de-orbiting at EOL (TBC)
- attitude control in all nominal mission phases
- a sufficient number of safe Mode fall-back and safe mode duration (to cover the contingency cases),
- residuals
- an additional margin of 20 %.

PRO-PE-3 The Thruster system shall be sized to be compliant with the required orbital range and with the worst case environmental conditions that will be experienced during the mission with worst case launch date.

PRO-PE-4 Three sigma values of dispersion errors and perturbation shall be considered in the determination of propellant budgets.

PRO-PE-5 The Propulsion Subsystem shall provide a thrust force and a thrust accuracy (e.g thrust repeatability, thrust vector stability) that are compliant with the mission requirements.

7.3.2.4 Propulsion Operational Requirements

PRO-OP-1 The propulsion subsystem shall provide all the necessary means in order to effectively support the EarthCARE Failure Detection, Isolation and Recovery (FDIR) as defined in section 6.8.

PRO-OP-2 The propulsion subsystem shall provide sufficient information to ground to allow diagnosis of on-board failures. This may be by ground command or specific diagnostic telemetry packets. The Propulsion Subsystem shall provide to the ground sufficient data to perform:

- Failure detection and isolation
- Switch-over to the redundant resources
- Shut-down and isolation of malfunctioning parts

PRO-OP-3 Fill and drain valve locations shall be chosen to facilitate loading and unloading of propellants and purging fluids.

7.3.3 Thermal Control Subsystem (TCS)

7.3.3.1 General

The requirements of this chapter are derived from a tailoring of ND-6.

Applicable terms and definitions relevant to the platform and payload thermal control are defined in para 3.1, 3.2 and 3.3 of ND-6.

TCS-GE-1 The Thermal control shall provide the platform and payload thermal environment (temperatures, gradients, stability, heat fluxes) required to ensure full performance of the satellite as required in all mission phases and operational modes and for the complete duration of the mission.

TCS-GE-2 Permanent operations for testing on ground and operation in flight shall be assumed for the design of the thermal control

7.3.3.2 Mission Phases

TCS-MP-1 a) The thermal control of the platform and payload shall withstand, operate and perform as specified, taking into account the natural and induced environmental conditions which they will experience throughout their lifetime, both on ground and on orbit. A reference list of mission phases environmental conditions is defined in para. 4.1 of ND-6
b) para 4.2.1 of ND-6 is applicable.

7.3.3.3 Design Requirements

TCS-DR-1 The thermal control design of the platform and payload shall be achieved, in principle, by passive means (conductively and radiatively controlled) with limited use of heaters where proven to be necessary to maintain specified operational or minimum survival, switch-on temperatures.

TCS-DR-2 To allow separate development and verification, the thermal control of the platform and payload shall be independent from each other to the maximum extent.

TCS-DR-3 The thermal control design of the platform and payload shall be verifiable by ground testing, by use of the correlated thermal mathematical models and by analysis.
Para. 4.5 of ND-6 provide an informative approach to verification. Major deviations between ND-6 and contractor preferred approach shall be highlighted for discussion and shall be agreed with the agency.

TCS-DR-4 The extreme design conditions to be applied for the thermal design shall consider the variation associated to the following parameters:

i) environment parameters (solar flux, albedo, earthshine)

ii) degradation of thermal properties over lifetime

iii) variations in internal power dissipation (e.g. for different operating modes)

iv) transient effects (orbital variations, duty cycles)

v) orbital attitude (phases and modes)

vi) failure modes

TCS-DR-5 Predictability and testability: Para. 4.4.6 of ND-6 is applicable. (NB: this refers to 4.2 of ND-6).

TCS-DR-6 Flexibility: para. 4.4.7 of ND-6 is applicable.

TCS-DR-7 Accessibility: para. 4.4.8 of ND-6 is applicable.

TCS-DR-8 Maintenance : para. 4.4.12 of ND-6 is applicable.

TCS-DR-9 Launcher interface : para 4.3.7 of ND-6 is applicable.

TCS-DR-10 The thermal control design of the platform and payload shall conform to the defined interface requirements and shall avoid/minimise constraints on other subsystems or system. Para 4.3 of ND-6 provide an informative approach on this topic. Major deviations between ND-6 and contractor preferred approach shall be highlighted for discussion and agreement with the agency.

TCS-DR-11 In co-operation with the unit manufacturers Thermal Control shall define temperature reference points (TRP) which are representative of the thermal status of the units. Temperatures at the TRP shall be guaranteed by Thermal Control for all mission phases.

TCS-DR-12 Temperatures at the TRP shall be used to drive the temperatures during acceptance and qualification thermal vacuum tests.

TCS-DR-13 Thermal Control of the platform and payload shall comprise sufficient temperature sensors, specifically at TRPs, to enable adequate temperature monitoring and control during nominal and non-nominal mission phases.

Control units will also deserve a particular attention.

TCS-DR-14 Thermal Control design of the platform and payload shall be optimised to achieve the required performances with the minimum resources i.e. lowest power consumption, mass.

TCS-DR-15 The platform/payload shall have the capability of detecting and overcoming/isolating failures of Thermal Control for continuation of nominal flight operations. As a minimum the following failures shall be considered:

i) thermistors and thermostats

ii) heater mats/lines

iii) violation of temperature limits

TCS-DR-16 Thermal Control design of the platform and payload shall allow easy repair and as a minimum :

i) adjustment of radiator size

ii) removal and/or replacement of insulation blankets , foils

iii) in place refurbishment of thermal control coatings and surface treatments.

7.3.3.4 Analysis and Verification Requirements

TCS-AV-1 Final flight temperature predictions shall be performed by use of revised thermal mathematical models correlated to the test temperatures within the deviation agreed with the Agency.

TCS-AV-2 Temperatures:

a) para 4.2.2 of ND-6 is applicable

b) the qualification temperature limits are equal to the acceptance limits extended at both ends by the qualification margin of 10 [C].

c) the acceptance temperature limits are equal to the design limits extended at both ends by the acceptance margin of 0 to 5 [C].

TCS-AV-3 Uncertainties associated to the thermal parameters involved in the design shall be calculated by means of sensitivity analysis, added to the analytically predicted temperatures and to the systematic errors (i.e. modelling error, typically 3 [C]) to define the design temperature range. Annex A1 of ND-6 provide an informative approach to uncertainties and sensitivity analysis. Major deviations between ND-6 and contractor preferred approach shall be highlighted for discussion and agreed with the agency.

TCS-AV-4 The Thermal Balance (TB) test configuration shall be representative of the (worst) case environment and mission flight conditions.

TCS-AV-5 The Thermal Balance (TB) test(s) shall follow test approach and test success criteria unambiguously defined and agreed with the Agency. Annex A3 of ND-6 provide an informative approach on this topic. Major deviations between ND-6 and contractor preferred approach shall be highlighted for discussion and agreed with the agency.

TCS-AV-6 The correlation success criteria shall be agreed with the Agency. Annex A4 of ND-6 provide an informative approach and guidelines on this topic. Major deviations between ND-6 and contractor preferred approach shall be highlighted for discussion and agreement with the agency.

TCS-AV-7 The platform and the payload Geometrical and Thermal Mathematical Models (GMM and TMM) shall be resp. established in ESARAD or Thermica and ESATAN. Other S/W codes can be used but need to be agreed with the Agency.

TCS-AV-8 The platform and the payload Geometrical and Thermal Mathematical Models (GMM and TMM) shall allow to perform separate as well as combined thermal analysis by mating the individual GMMs and TMMs. Annex 5 of ND-6 provide an informative approach on thermal analysis. Major deviations between ND-6 and contractor preferred approach shall be highlighted for discussion and agreement with the agency.

TCS-AV-9 Reduced GMM and TMM of the platform and the payload assembly shall be established (following the requirements of the Launcher Authorities) to enable the Launcher Authorities to perform coupled launcher/spacecraft thermal analysis.

TCS-AV-10 Whenever simplified/reduced models are used, correlation criteria between the detailed and simplified/reduced models shall be specified and agreed with the Agency.

TCS-AV-11 Temperature inputs for the structure thermo-elastic analysis shall consider the requirements of the structural mathematical models.

7.3.3.5 Additional Requirements

TCS-AD-1 During nominal operations the Thermal Control of platform and payload shall be able to recover from failure situations by autonomously selecting a redundant functional path.

TCS-AD-2 Storage: para. 4.6.11 of ND-6 is applicable.

TCS-AD-3 Thermal Control shall allow manual override and inhibition/enabling of all automated functions individually from ground.

TCS-AD-4 Repair: para. 4.6.12 of ND-6 is applicable.

TCS-AD-5 The thermal control of the payload and spacecraft shall be able to continue working with independent failures (thermistors, heaters, thermostats) providing the failures occurred in different areas.

7.3.4 Electrical Power Subsystem (EPS)

7.3.4.1 EPS General Requirements

EPS-GE-1 The power sub-system shall be designed in accordance with ND-3 and ND-4, including the solar spectrum specified in Annex A of ND-4.

EPS-GE-2 The power sub-system shall provide all power required by the spacecraft for all mission phases and all operational modes under the defined environmental conditions and shall also support test, pre-launch and launch activities.

EPS-GE-3 The power sub-system shall be provided by means of both solar array and batteries in accordance with the EarthCARE mission profile.

EPS-GE-4 In case of power contingency mode (e.g. battery under-voltages), all the Non Essential Loads (including instruments) shall be autonomously switched off on-board. The EPS shall however issue advanced warnings to DHS or via TBC dedicated Disconnect Non Essential Loads (DNEL) lines towards achieving a controlled switch-off of the non-essential loads within TBD seconds.

EPS-GE-5 At equipment level and for any EarthCARE units, the following design maturity power margins shall be applied:

- 5% for Off-The-Shelf (OTS) equipment (ECSS category A/B)
- 10% for OTS items requiring minor modifications (ECSS category C);
- 20% for new designed/developed items, or items requiring major modifications or re-design (ECSS category D).

EPS-GE-6 The power sub-system resources shall be dimensioned with adequate margin providing power to EarthCARE satellite up to the end of the mission as defined in ND-3. However the system margin at EOL for the most critical phase shall be at least 10% including one string failure and one cell failure for the solar array and battery respectively.

7.3.4.2 EPS Functional Requirements

EPS-FU-1 The power sub-system shall generate, store, condition, control, and protect/distribute electrical power on board of the spacecraft.

EPS-FU-2 The power sub-system shall provide adequate status monitoring and telecommand interfaces necessary for operation (including possibility of modifying EPS operation parameters), evaluation of its performance and failure detection and recovery during ground testing and in space operations.

EPS-FU-3 Telemetry shall be implemented to monitor the evolution of the power-energy resources and the sources temperature during the mission. The battery monitoring shall allow the determination of the battery state of charge from ground with the battery state of charge prediction model to an accuracy of better than 10%.

EPS-FU-4 The power sub-system shall autonomously perform mode transition operations of the protection without support from other spacecraft subsystems and under all operational conditions of the mission including contingency situations. No damage or degradation shall result from intermittent or cycled operation.

EPS-FU-5 The power sub-system shall autonomously perform the energy management and bus regulation without support from other spacecraft subsystems under all operational conditions of the mission including contingency situations.

EPS-FU-6 The power sub-system shall support the connection of external power sources during ground operation.

EPS-FU-7 The power outlets shall be switchable by ground command, with the exception of the power outlets supplying the TC reception chain and other essential equipment.

EPS-FU-8 All protection latch not having autonomous reset capability shall be at least resettable from ground command.

EPS-FU-9 In the case of hot redundant essential functions (e.g. TC reception), latching protection shall not be used, or if applied shall have an autonomous periodic reset. Override of critical on-board autonomous functions shall be implemented only if a safety interlock is implemented, preventing the activation of the override feature on both hot and redundant functions.

EPS-FU-10 The power outlets shall be equipped with suitable protection devices preventing failure propagation from any user to the power bus or to any other power outlet. The protection features of the other power outlets shall also remain fully functional.

EPS-FU-11 The power sub-system shall be equipped with suitable protection devices preventing failure propagation from the power bus to any user during both on-ground activities and in-orbit operations.

I.e. required protections should not only be designed for coping with in-orbit configurations (and possible failure modes) but as well with non-flight configuration (and failure modes) which can happen on ground (e.g. inadvertent disconnection of battery and/or solar simulators).

EPS-FU-12 The power sub-system shall be capable to restart automatically and autonomously after the occurrence of a power interruption as soon as the solar array power reappears.

EPS-FU-13 The power sub-system shall be able to start-up and operate from either of its power source inputs, solar array or battery, independently from the status of the other one (i.e. connected or not).

EPS-FU-14 At power up, restart and upon recovery from any power loss, the power sub-system shall set the spacecraft electrical configuration into a known deterministic and reproducible state. This state shall be safe (full battery charging capability and minimum power bus loading) and shall allow a predefined recovery of the spacecraft and of its sub-systems

EPS-FU-15 The power sub-system protection shall be tested at system level, simulating a worst case power degradation and its recovery.

EPS-FU-16 The EPS shall provide all resources needed for the operation of release of deployable items for payload as well as for spacecraft functions.

7.3.4.3 Solar Array Requirements

EPS-SA-1 The solar array design shall be one-string failure tolerant as per requested power margin philosophy.

EPS-SA-2 Protections shall be placed on the solar cells against shadowing and hot spot phenomena.

An analysis will have to be run first to identify the necessary protections.

EPS-SA-3 A short between a solar cell string and a conductive panel shall not produce any solar array power loss.

EPS-SA-4 In case of two shorts on the same panel, the power loss shall not be more than the power of two strings.

EPS-SA-5 The PVA layout shall be designed to meet the solar array magnetic moment requirements.

EPS-SA-6 The solar array shall be designed to survive the atomic-oxygen orbit environment without degrading the satellite performance and operations.

EPS-SA-7 The solar array design shall be based on I-V solar cells characteristics computed in BOL and EOL conditions at maximum and minimum foreseen temperatures according to mission profile.

EPS-SA-8 The solar array design shall take into account the leakage losses of bypass diodes if they represent more than 0.1% of the overall power to be provided.

EPS-SA-9 The design of the insulation barriers between adjacent slip rings shall be such that no occurrence of ESD or discharge phenomena will take place.

7.3.4.4 Energy Storage Requirements

EPS-BA-1 Batteries shall be designed to support powering the spacecraft through the launch sequence, including all anticipated contingencies and though all foreseen losses of solar energy during the mission, including those resulting from failures (e.g. de-pointing due to loss of pointing sensors, attitude control).

EPS-BA-2 Transient currents occurring when two or more separate strings of series-connected cells are connected together in parallel or when a cell fails short-circuit in a battery composed of parallel strings shall not result in exceeding the peak cell current rating.

EPS-BA-3 Procured battery cells shall be issued from the same production lot, with the same operational history.

This will avoid to have unbalanced cells in a same battery.

EPS-BA-4 When individual batteries are discharges in parallel, voltage imbalance between the batteries shall not result in current and temperature exceeding the limits imposed by the adopted technology.

EPS-BA-5 Conducting cases of battery cells in a battery package shall be double-isolated from each other and from battery structure, with an isolation between any cell and the structure greater than 10MΩ (measured at 500V DC).

EPS-BA-6 The battery charge current and end of charge voltage shall be autonomous and one fault tolerant.

EPS-BA-7 The switching between main and redundant charging management devices shall be completely autonomous and independent from on-board computer control.

EPS-BA-8 Any special in-flight measures to ensure that the batteries meet their performance requirements (e.g. in orbit reconditioning, cell state of charge balancing) that impose operational constraints shall be early (i.e. during phase B) identified at system level and be subject to Agency approval prior implementation.

EPS-BA-9 Flight batteries shall in principle not be used for ground operations to prevent any possible damage and subsequent degradation of life performance. If this approach is not respected, the flight worthiness of the batteries shall be re-verified (e.g. by capacity measurements) after the ground operations are completed, and in time for a possible replacement.

Use of Flight Model, and Flight Spare if applicable, will have to be duly identified in the relevant EarthCARE development and AIT/AIV plans.

EPS-BA-10 Any test equipment interfacing with the battery shall include an associated under-voltage, over-voltage, over-current and over-temperature activated isolation switch. Such test equipment shall also allow monitoring of the individual cells and to verify their matching.

7.3.4.5 Design Requirements

EPS-DE-1 All current limiting devices and automatic switch-off circuits shall be monitored by telemetry. The failure of the monitoring function shall not cause the protection elements to fail.

EPS-DE-2 Voltage of the main bus shall be carefully selected and justified considering the different drivers (e.g. power losses, solar array technology, COTS hardware, bus impedance and regulation accuracy).

EPS-DE-3 Any power line available from the power subsystem shall be protected against short circuit or overload appearing at user's side. The overload and short circuit protection shall be achieved by current limiters provided with trip-off capability. Use of fuses shall be avoided.

EPS-DE-4 Redundancy of essential functions and protection features shall be verified by test at system level, simulating in particular a worst case power degradation and its recovery.

EPS-DE-5 Whenever two or more blocks are interfaced, the compatibility of the source with the load shall be specified and verified to ensure stability of the cascade. The overall block (cascade of source and load block) shall meet the stability margins specified in ND-3 section 5.6.3 and the source/load impedances shall respect adequate constraints (to be specified by the contractor and submitted to the Agency for approval).

EPS-DE-6 The electrical power interface between the solar array(s) and the power control unit(s) and between battery(ies) and power control unit(s) shall be defined and shall result in the specification of the input impedance seen by the power conditioning unit(s).

EPS-DE-7 The availability of the specified solar array power to the power conditioning should be predicted and verified by a representative end-to-end test at spacecraft level.

EPS-DE-8 The stability of current limiters shall be ensured for the actual loads characteristics, verified by analysis under worst case conditions, and tested under a set of cases agreed with the Agency.

EPS-DE-9 When the distribution lines are protected by latching, or periodically reset current limiters, it shall be ensured that the inrush energy demanded by the load in normal switch-on and/or in automatic re-triggering does not cause the trip-off of the latching protection with a 20% margin. This requirement will be verified by electrical/thermal analysis under worst case conditions, and tested under most representative set of cases.

EPS-DE-10 When indefinitely re-settable current limiters are used instead of fold-back current limiters, the periodicity of resets after a fault condition shall be such that:

- no system EMC requirement is violated,
- the thermal stress resulting from the failed load current does not compromise the limiter operation i.e. components remain within their deratings.

EPS-DE-11 In case the distribution lines are protected by latching, foldback or periodically reset current limiters, the transient current peaks at current limiter intervention shall remain within the rated stress limits of the components used, for the worst case condition (minimum series impedance case).

EPS-DE-12 In case of an MPPT based concept, the MPPT architecture shall be modular ensuring that the mission success is not affected by the loss of any module caused by any internal single point failure.

EPS-DE-13 All DC/DC converters shall be over-voltage protected.

This requirement is not addressing power sub-system DC/DC converters but as well those used by other subsystems and instruments.

7.3.5 Data Handling Subsystem (DHS)

7.3.5.1 DHS General Requirements

DHS-GE-1 The spacecraft shall embark an on-board Data Handling Subsystem (DHS) which provides all the necessary data communication, processing and computing services and resources for the fulfillment of the EarthCARE system requirements and mission objectives. Main DHS functionality shall be split into:

- Decode, validate, process and distribute telecommands sent by the ground
- Provide adequate I/O as well as data link/bus connections for interfacing with all equipments and instruments on board the satellite (including I/O with launcher/ground test/support facilities),
- Generate and distribute timing data and signals according to the equipments and instruments accuracy requirements,
- Collect and store payload and satellite telemetry data for subsequent conditioning, digitalisation, encoding and transmission to ground,
- Provide all the means to execute the monitor and control services requested by the ground or autonomously (e.g. AOCS, FDIR functions).

In most implementations, the DHS will provide the computing processing and I/O resources to support other sub-systems such as AOCS and Thermal Control sub-systems. Most of the requirements listed under section 6 directly apply to the definition of the DHS design but are not repeated here.

DHS-GE-2 An end-to-end test capability shall be implemented which allows to verify the correct function of the DHS under ground control.
Note: One example of a possible implementation is the addressing of a free RTU-output by ground-TC, which is configured such that verification telemetry is generated at each step of the command execution chain (TC verification, data handling bus, execution of the command at RTU output level).

DHS-GE-3 The DHS design shall comply to ND-3 (chapters 4 & 6) and ND-34.

7.3.5.2 DHS TC Requirements

DHS-TC-1 The DHS shall be able to process telecommands from ground in accordance with the ECSS Packet Telecommand Standard and the ESA Telecommand Decoder Specification, ND-22 to ND-25.

DHS-TC-2 The DHS shall be able to distribute telecommands to the relevant application in accordance with the Application Process IDentifier.

DHS-TC-3 Redundant telecommands shall be separately routed from their corresponding nominal telecommands.

DHS-TC-4 The DHS shall provide the capability of direct commanding essential satellite equipments without software intervention.

DHS-TC-5 A telecommand that does not conform to the packet telecommand standard and/or is not recognized as a valid EarthCARE telecommand shall be rejected at the earliest possible stage in the on-board reception, acceptance and execution process.

DHS-TC-6 The on-board reception, processing and execution of telecommands to a unit shall not affect the performance of other on-going processes.

DHS-TC-7 The software shall allow spacing of time-tagged telecommands as close as 100 ms (TBC) while the execution instant of these time-tagged telecommands will be in line with the accuracy specified under OPS-TI-5.

DHS-TC-8 The orbit-position-tagged telecommands and their sequence spacing shall be in line with the predicted orbit accuracy (defined in section 4.1.6)

DHS-TC-9 The DHS shall provide a reliable capability to receive large data transfers via the uplink and to store these large data structures into the central on-board data storage. In addition, the DHS shall implement the necessary on-board transfer capability to move, on request, these data from the data storage till the targeted equipment (memory).

This should be used to upload new on-board software and/or OBCPs, providing a greater uploading and retransmission flexibility without affecting the operations of the targeted equipment till a complete availability of the set of data on-board. It should also be possible to handle/store several of these large data block simultaneously.

7.3.5.3 DHS I/O Interfaces Requirements

DHS-IO-1 The DHS shall support data exchange with other subsystems and instruments via implementing dedicated standard discrete interfaces, standard high rate data links and/or a standard spacecraft data handling bus. I/O interfaces shall be selected towards minimizing their number and types.

As such, the preferred solution shall be multiplexing control, monitoring and payload data on a same communication network. A list of preferred standard I/F is identified in section 2.2.

DHS-IO-2 The DHS shall provide the necessary interfaces to synchronise other spacecraft subsystems and instruments with the necessary relative accuracy. This shall also include interfaces to monitor the synchronization status and to support correlation mechanisms.

Preferably, it should be taken advantage of the other I/F already used for data exchanges.

DHS-IO-3 The DHS shall provide the necessary separation switches - and associated circuitry in order to detect the satellite separation from the launcher in a reliable way. That circuitry shall also embed extensive verification capability to test and detect any anomaly (prior separation).

A reliable separation detection typically relies on a set of switches with majority voting scheme while verification of the separation circuitry health could be achieved by e.g. the use of auxiliary Open/Close voltage references in connection with the required multiplexers/comparators.

DHS-IO-4 The DHS and its associated software shall provide the necessary functions for the management and the handling of the on-board communication network/bus and protocols.

DHS-IO-5 The DHS shall provide the necessary interfaces to support all the integration, test, verification and launch preparation activities.

7.3.5.4 DHS Datation Requirements

DHS-TI-1 The DHS shall implement the OBT reference with the performance as specified under section 6.6.

DHS-TI-2 The OBT counter shall not wrap-around for the entire duration of the mission including any conceivable mission extension.

DHS-TI-3 The DHS shall generate the necessary periodic Time Source Packets to support the correlation of OBT - and GPS if available on-board EarthCARE – with UTC on ground.

DHS-TI-4 The scheme used by DHS to distribute OBT to the other on-board sub-systems and instruments shall also allow a (re-)synchronisation of an equipment without disrupting other synchronized equipment.

This is usually achieved via a periodic broadcasting of suitable synchronization information across DHS towards allowing the DHS datation users to maintain a local OBT copy in their equipment; periodic emission will allow to cancel any error accumulated since the last synchronization event. Selected OBT distribution scheme should be subject to Agency approval.

DHS-TI-5 DHS datation function locally implemented in the various on-board sub-systems and instruments (DHS datation users) shall allow reception of the on-board re-synchronisation signals distributed on the DHS in order to maintain a local copy of the OBT reference. That local DHS datation function shall also cover error detection/quality checks (and maintenance of associated TM flags) on the incoming synchronization information and the capability to maintain the local OBT copy in free-wheeling mode in case of (temporary) disruption of synchronization signal reception.

DHS-TI-6 The DHS shall report in its housekeeping TM the status of the OBT distribution and synchronization. In addition, if the GPS time is available on-board EarthCARE, then a periodic TM packet should be provided allowing ground to derive a precise correlation between OBT and GPS times.

7.3.5.5 DHS TM Requirements

DHS-TM-1 Telemetry formatting shall be according to the ECSS Packet Telemetry Standard, ND-21, and the ESA Telemetry Channel Coding Standard, ND-19

DHS-TM-2 The DHS shall collect, format and store TM data (including both science and housekeeping data) and distribute them to the COM subsystem Terminals for downlink

DHS-TM-3 The sampling rates of periodic telemetry shall be sufficiently high to avoid data loss due to under sampling. Inversely, the sampling rate should not be selected too high towards unnecessarily occupying bandwidth and ground segment operation workload.

Such requirement is particularly relevant for selecting HPTM and time packet generation rates which will have to be ultimately selected in agreement with the Agency.

DHS-TM-4 Events Packets shall be the mechanism to unambiguously report events and anomalies.

DHS-TM-5 It shall be possible to determine the acquisition time or the time of the occurrence of an event using timing information in the telemetry.

7.3.5.6 DHS Data Storage Requirements

DHS-MM-1 The DHS shall provide a central on-board data storage for recording all TM packets (science and housekeeping) payload and spacecraft data (HK TM and instrument science data) as well as to support the uploading of large software patches. The sizing of this data storage shall satisfy the requirements listed under sections 6.2.1, 6.3, 6.4 and 6.5.

DHS-MM-2 Storage shall be organised in virtual storages called Packet Stores. The selection of which telemetry packets shall be stored in which Packet Store shall be maintainable by means of dedicated telecommands. Any number of packets can be assigned to a specific Packet Store.

DHS-MM-3 The on-board telemetry storage shall support at least one Packet Store for each TM virtual channel used to down-link the stored telemetry (excluding the possible virtual channels generated by the hardware, e.g. VC-7 for the idle frames) plus one PS for supporting the uplink of memory patches. In addition it shall be possible for the ground to modify the PS-VC/Downlink mapping.

The need of at least 16 PS has been currently estimated as follows: 3 PS in relation to S-band: 2 for HK TM downlink and 1 for Patch Uplink; 10 PS in relation to X-band: minimum 2 per instrument (8) and 2 for HK/ancillary data; 3 spare PS.

DHS-MM-4 Each PS shall be reconfigurable in terms of size and access right (including overwriting).

This requirement does not refer to input stream selection (based on type/sub-type and APID filtering) and to output stream routing (VC, COM Terminal selection) due to other existing SRD requirements. I.e. each PS will also have that configuration capability.

DHS-MM-5 It shall be possible to request a report of the current storage selection definitions.

DHS-MM-6 It shall be possible to assign a specific telemetry packet to more than one single Packet Store provided that they are down-linked in different TM virtual channels.

DHS-MM-7 It shall be possible to individually configure each Packet Store in order to select which packet types/ sub-types and APIDs shall be stored per Packet Store.

DHS-MM-8 Packets shall be stored cyclically. Packet Stores shall be individually configurable such that either old data are overwritten or recording is stopped once the store is full.

The management of the PS dedicated to the uplink of patches may differ; in such case, a solution shall be agreed with the agency.

DHS-MM-9 For Packet Stores with disabled overwrite, only stored data which have already been down-linked and are not protected via the Read Marker shall be overwritten by new data to be stored. Old data which have not been down-linked yet or are protected via the Read Marker shall not be overwritten.

The Read Marker is a mechanism to support multi-dump, i.e. to dump data several times. Use of the Read Marker will prevent data to be over-written after their first dump. It memorises an initial/previous read pointer location. The PS is then considered full as soon as the write pointer reaches either the Read Pointer or, if enabled and set, the Read Marker.

DHS-MM-10 For Packet Stores with enabled overwrite, oldest data shall be overwritten when the PS capacity has been exhausted. This means that the Write Pointer shall start to push the Nominal Read Pointer when necessary.

The Nominal Read Pointer is the read pointer associated to the suspend/resume dump operations (baseline) and differentiates it from a second read pointer to be used for selective playback (see DHS-MM-16).

DHS-MM-11 Each PS shall have its own set of pointers and Read Marker to record, to suspend/resume play back and to support selective playbacks and multi-dumps.

DHS-MM-12 For PS with disabled overwrite, the control of the Read Marker (RM) shall be performed in conjunction to any command used for PS playback (e.g. resume, set read pointer, etc) via relevant RM flags to disable/enable and set/unchange that marker. For each received playback command with enabled and set RM flags, then the PS shall memorize in its own RM register either the (Nominal) Read Pointer value at the time of the command reception or the (Nominal) Read Pointer value which is part of the received play-back command. The Read Marker register shall not be updated until reception of next play-back command with enabled and set RM flags or with disabled RM.

PS with disabled overwrite only precludes that the Write pointer pushes the Nominal Read Pointer. As that pointer will move to support the on-going dump, there would be the risk that the Write pointer overwrites the data already dumped a first time: the use of the Read Marker prevents such situation.

DHS-MM-13 It shall be possible for the ground to suspend/resume the down-link of the stored telemetry packets from a selected Packet Store.

Dump will resume from last (i.e. when previous dump was suspended) Nominal Read Pointer position except if, in the meantime, the Nominal Read Pointer has been pushed by the Write Pointer or has been reprogrammed. Suspend/resume should be used as baseline for mass memory operations.

DHS-MM-14 It shall be possible for the ground to suspend/resume the down-link of the stored telemetry packets for all Packet Stores using a single telecommand.

DHS-MM-15 It shall be possible for the ground to set the Nominal Read Pointer to a specified point (identified by a packet) in a selected Packet Store.

DHS-MM-16 It shall be possible for the ground to request the down-link of all telemetry packets within a specified packet range (identified by a Start and End Packet) from a selected Packet Store.

This mechanism allows recovering telemetry data that have already been dumped but not received on ground for any reason. The Nominal Read Pointer shall not be affected by the execution of this extra dump operation (i.e. an independent Read Pointer shall be maintained for the two dump mechanisms). The packets to be down-linked shall not include the Start and End Packets used to identify the packet range (since these packets are the last one received before the gap, and the first one after the gap respectively).

DHS-MM-17 The PS down-link shall be stopped as soon as the specified End Packet is reached, or in case the Nominal Write Pointer is reached (i.e. the PS is empty).

DHS-MM-18 Housekeeping information shall be provided on the state of the on-board storage, retrieval function and pointers/marker positions.

Such HK information should allow to retrieve pointer/marker information at both logical and physical address level.

DHS-MM-19 Information on the used and available space on the on-board storage shall be included in the housekeeping telemetry.

This should include periodic HK information to monitor the fill status/available capacity of each PS.

DHS-MM-20 Information on the most recent down-linked packet (Packet APID, SSC and time) shall be available in the housekeeping telemetry.

DHS-MM-21 It shall be possible for the ground to enable and disable the storage function for a selected Packet Store.

DHS-MM-22 The storage of packets shall not be interrupted during the dump or the deletion operations of the current content of the on-board storage.

DHS-MM-23 It shall be possible to dump Packet Stores on S-band and X-band independently.

A same PS can not be simultaneously dumped on S- and X-band links. But to start/stop dump on one down-link should not affect/limit transmission and throughput.

DHS-MM-24 It shall be possible to dump several Packet Stores simultaneously, in accordance to a VC/PS priority scheme, on a same S-, X-link, and in parallel to real time TM downlink. This shall even be possible while a patch is uploaded via S-band uplink.

This could be achieved by either interleaving the packets read from different stores in the down-link according to a programmable bandwidth allocation, or reading a single Packet Store at any time, but configuring the downlink operation by providing an ordered list of Packet Stores to be dumped when the downlink is resumed. Due to the significantly higher rates, it may not be feasible to support packet interleaving on the X-band downlink.

DHS-MM-25 It shall be possible for the ground to change by telecommand the downlink priority assigned to a VC/PS. If two or more PS have the same priority on a same VC, the packets shall be extracted for downlink from each PS one packet at the time. Real-time VC shall always have highest priority.

DHS-MM-26 It shall be possible to dump selected Packet Store(s) without having to interleave idle frames and/or idle packets.

Idle frames may only be generated to establish/maintain the downlink prior and after commanded dump while generation of idle packets should be limited to ensure the transmission of the last packet which is part of the requested dump.

DHS-MM-27 When a PS is open for dumping, it shall remain open even after all packets contained in it have been dumped. If a new packet is received and stored in that PS, the packet shall be dumped to ground as soon as possible in accordance to the priority scheme of the open PS.

DHS-MM-28 It shall be possible for the ground to request the downlink of the telemetry packets stored within a specified time range of a selected Packet Store from the on-board storage.

DHS-MM-29 The DHS data storage shall include the necessary means for error detection and correction to minimise the loss or corruption of transmitted and stored payload and platform data upon the occurrence of DHS and SW anomalies as well as SEUs.

Scrubbing should be used in connection to EDAC in order to avoid error accumulation.

DHS-MM-30 Stored HK/ancillary data shall not be lost in the event of a Safe Mode or on-board computer reconfiguration. It is however acceptable that data stored in the mass memory are lost in the event of a mass memory failure or a system power loss.

While it is understood that the Safeguard recorder is used to maintain a record in the event of catastrophic failure it might be simpler operationally if the data stored in the mass memory are not automatically lost even when the satellite is not in danger.

DHS-MM-31 The DHS data storage shall be based on a modular solid state mass memory allowing to:

a. switch on/off the memory and I/O modules in order to adjust to the required resources according to the actual satellite phase/mode and/or the selected PS configuration;
b. extend the memory size without impact on interfaces and functionality.

DHS-MM-32 The DHS shall implement the protected memory resources/Safeguard recorder with the capacity as required by sections 6.4/observability and 6.8/FDIR to store spacecraft and equipment configuration, health status, anomalies.

If relevant, the above Safeguard recorder may be extended to maintain copies/versions of critical software or parameter tables as well as for the storage of OBCP and MTL/OPS schedules.

DHS-MM-33 As a key tool for failure diagnosis - and isolation - in all EarthCARE modes and operations, the Safeguard recorder shall be designed to ensure/maximize the integrity and perenniality of the stored information. As baseline, a non-volatile memory technology shall be used to cope with failures, including power outages.

Because both the data volume and criticality significantly differ from other TM HK and science data, the Safeguard recorder may be developed as a separate entity to the (centralized) on-board storage resources. Because reliability is paramount, it is also accepted that operations of the Safeguard recorder are more basic (and implemented by e.g. PUS Service 6).

Perenniality is equivalent to mission lifetime.

7.3.5.7 DHS Processing, Monitor and Control Requirements

DHS-PC-1 The DHS shall support the closed-loop control functions implemented in the EarthCARE (platform) DHS on-board software. This includes the provision of the necessary processing resources and the availability of adequate sensor acquisition and actuator distribution channels.

DHS-PC-2 Adequate margins of DHS resources shall be available. Until launch time, these margins shall be at least 25% for:

a. CPU load / processing power (for an agreed set of representative worst-case scenarios).
b. Memory (volatile and non-volatile)
c. Telecommand channel (throughput, VCs)
d. Telemetry channels (within the 90% TM/pass throughput allocated to nominal/routine dump, VCs)
e. On-board communication network (for an agreed set of worst-case traffic scenarios)
f. Data storage (EOL capacity, number of PS).
g. Spare capacity for additional on-board monitoring

A margin philosophy should be put in place at the beginning of the EarthCARE development in order to use higher margins during the development process towards ultimately ensuring the minimum margins at the launch time.

DHS-PC-3 The DHS on board software shall implement functions and services that are necessary to fulfill the nominal and safe mode mission requirements described in the relevant requirements sections (i.e. Operational, Data Handling, FDIR, AOCS, Thermal control, Power management…).

DHS-PC-4 The safe mode software shall permit to download the nominal software image for investigation and to patch or upload a new nominal version.

DHS-PC-5 The nominal and the safe mode software of the platform shall be considered as two independent software items.

DHS-PC-6 The DHS software shall be able to schedule on board process (tasks) both cyclically at a predefined task-activation frequency, and event-driven (asynchronously).

DHS-PC-7 The DHS software shall support an On-board Scheduling Service in charge to execute a sequence of time-tagged TCs from a Mission Time Line (MTL) and a sequence of Orbit Position dependent TC from an Orbit Position Sequence (OPS). The DHS software shall store these commands in a dedicated memory area, which shall be sufficiently large for the storage of an MTL/OPS for a duration as specified under OPS-CO-7 (section 6.3).

DHS-PC-8 The DHS software shall provide all necessary capability to support and use On-board Control Procedures (OBCP).

DHS-PC-9 It shall be possible to request Diagnostic Reports as well as to define, modify, and remove definitions of Diagnostic Reports.
Diagnostic Reports will be used to support the download of additional parameters or existing parameters more frequently than down-linked in nominal telemetry.

DHS-PC-10 The software shall make use of Telemetry and Telecommand parameters description recorded in the Satellite Data Base. If this use is not direct, any translation shall be automatic using a validated tool.

7.3.5.8 DHS FDIR Requirements

DHS-FD-1 The DHS shall support all the onboard Failure Detection, Isolation and Recovery (FDIR) functions.

DHS-FD-2 The DHS shall be autonomous in line with the mission objectives. This shall include an autonomous start-up and initialisation capability upon availability of spacecraft power or upon DHS-reset.

DHS-FD-3 The DHS shall ensure the safety of the spacecraft and the minimisation of mission-interruptions without the need for ground intervention.

DHS-FD-4 The DHS shall include functions to detect software malfunctions, using e.g. watchdog timers to detect SW lockout situations at SW functional level and at the level of HW/SW interfaces.

DHS-FD-5 The DHS shall insure that no single failure lead to the loss of spacecraft commanding capability. The TC-reception chain shall be hot redundant.

DHS-FD-6 The DHS shall insure that no single failure shall cause unpredictable behaviour (i.e. unwanted activation of outputs or automatic sequences).

DHS-FD-7 The failure on the acceptance and/or in the execution of on-board issued commands shall be notified to ground by means of an anomaly event packet. Definition of these anomaly event packet shall be duly identified in the EarthCARE User Manual

Commands issued on-board are all commands which do not directly originate from the ground (for immediate or time-\position-tagged execution) and addressed to packet terminals or another function within the same terminal or to a hardware device.

DHS-FD-8 The DHS shall implement a safeguard recorder which shall provide non-volatile protected memory resources. Information to be stored in the safeguard memory shall include, among others:

- Configuration information (prior failure reconfiguration, current configuration)
- System health status (health/availability of nom./red. Units)
- HK and failure reporting events (to support failure diagnosis)
- Other TBD critical mission parameters

7.3.6 Communications Subsystem (COM)

7.3.6.1 COM General Requirements

COM-GE-1 The Communication Subsystem (COM) shall consist of all RF equipment and associated communication services to ensure satellite commanding from the ground station, telemetry data (science + HK) transmission to the ground and satellite ranging. The COM subsystem includes two terminals:

- The COM TTC Terminal: operating in both uplink/downlink directions in S-band
- The COM High Rate TM Terminal: operating in X-band for downlink direction only

COM-GE-2 The COM subsystem shall be compliant with the following ESA standards:

- Radio Frequency and Modulation Standard (ND-17)
- Ranging and Doppler Tracking (ND-20)
- TM Synchronization and Channel Coding Standard (CCSDS 131.0-B-1) (This standard is in the ESA approved standard list and only applicable if not superseded by ECSS equivalent document).

COM-GE-3 The COM subsystem shall be able to simultaneously receive and demodulate commands and modulate and transmit telemetry (incl. simultaneous S- and X-band transmissions) while doing ranging.

COM-GE-4 The COM TTC Terminal (i.e. S-band) shall be available during all mission phases, including pre-launch, launch and safe mode.

COM-GE-5 The COM High Rate TM Terminal shall be available during COP and MOP phases only.

COM-GE-6 The COM subsystem shall interface with the ESA ground segment and the NASA Deep Space Network (DSN, TBC). The applicable requirements for this interface are defined in AD-7.

COM-GE-7 Unwanted COM RF emissions shall be kept at a level such that they do not interfere with users of other bands. (Section 5.5.1 ECSS-E-50-05A, ND-17)

COM-GE-8 The COM output power shall be selected in order that the Power Flux Density limits on the Earth's surface is not be exceeded during all mission phases except launch. (Section 5.5.3 ECSS-E-50-05A, ND-17)

COM-GE-9 The COM subsystem shall be compliant with the requirement on RF emissions imposed by the launcher. (Section 5.5.1.4 ECSS-E-50-05A, ND-17)

COM-GE-10 The Frequency bands for the COM subsystem shall be selected from the bands allocated for the required service. (Sections 4.1 and 4.2 ECSS-E-50-05A, ND-17)

COM-GE-11 The COM subsystem modulation schemes shall be selected according to the guidelines provided in the ECSS-E-50-05A, ND-17,whilst trying to minimise the occupied bandwidth of the transmitted signals.

COM-GE-12 The link budget calculations and associated margins shall be according to ECSS-E-50-05A, ND-17, Annex D for any elevation angle >= 5 degrees above the ground station horizon:

- Nominal margin >3dB
- RSS worst-case margin >0dB
- Mean -3σ margin >0dB

COM-GE-13 The COM subsystem shall be designed to ensure ease of testability and to provide sufficient failure monitoring information.

COM-GE-14 To ensure full compatibility between the spacecraft and the ground segment, compatibility tests shall be accomplished by means of a spacecraft COM RF-suitcase. The COM RF-suitcase shall contain flight representative hardware to test the COM subsystem functional and performance characteristics for both the COM TTC terminal (S-band) and the COM High Rate TM Terminal (X-band).

7.3.6.2 COM TTC Terminal Requirements

COM-FU-1 The COM TTC Terminal shall support the following modes for the uplink:

- Carrier only;
- Telecommand;
- Ranging;
- Simultaneous Telecommand and Ranging.

COM-FU-2 The COM TTC Terminal shall support the following modes for the downlink:

- Carrier only;
- Telemetry;
- Ranging;
- Simultaneous Telemetry and Ranging.

COM-FU-3 The COM TTC Terminal shall receive and process the uplink telecommand signal from ground for subsequent transmission to the DHS subsystem.

COM-FU-4 The COM TTC Terminal shall receive a telemetry data stream from the DHS subsystem and transmit these data to the ground.

COM-FU-5 The COM TTC Terminal shall support range and range rate measurements in accordance with the Ranging and Doppler Tracking Standard (ND-20).

COM-FU-6 The COM TTC Terminal shall implement hot redundancy for the receive function and cold redundancy for the transmit function.

COM-FU-7 The COM TTC Terminal configuration shall be such that both receivers can receive and both decoders can decode simultaneously. Both nominal and contingency antennae shall feed signals to both COM TTC Terminal receiver (typically through a combiner and attenuator).

COM-FU-8 The topology used to interconnect the redundant S-band antennas / receivers / TC decoders shall avoid failure propagation while ensuring the ground control to select the RF/TC signal path unambiguously.

The above requirement may waive ND-34 req. 5.9.3.1 asking specifically for a cross-strapping between the redundant receivers and TC decoders without taking into account the overall Rf and DHS front-end assembly topology.

COM-FU-9 The active COM TTC transmitter shall be able to receive the telemetry stream from both nominal and redundant chains of the DHS subsystem.

COM-FU-10 Each COM TTC transponder shall be able to operate either in non-coherent or in coherent mode. This functionality shall be selectable via telecommand.

COM-FU-11 The COM TTC Terminal shall be designed so that the transmitters can be switched ON and OFF at any time by telecommand. (Section 5.5.2 ECSS-E-50-05A, ND-17)

COM-FU-12 The COM TTC receivers shall provide indication of the received signal quality to the DHS subsystem.

COM-FU-13 The COM TTC Terminal shall provide the required telecommand and ranging capabilities at maximum distance from the Earth and in any spacecraft attitude.

COM-FU-14 The COM TTC Terminal shall ensure that essential spacecraft telemetry can be transmitted to ground during all mission phases and at all spacecraft attitudes.

COM-FU-15 The COM TTC Terminal antenna configuration shall ensure omni-directional coverage of the spacecraft from the ground network, whilst ensuring compliance with all other COM subsystem requirements, for all mission phases and at all spacecraft attitudes.

COM-FU-16 The COM TTC Terminal antenna polarisation shall be the same for the uplink and the downlink.

COM-FU-17 The COM TTC Terminal antennas for nominal (nadir-pointing) and back-up (zenith-pointing) links shall have opposite (TBC) polarisation.

COM-FU-18 The COM TTC Terminal communication links shall be capable of operating within specification during all expected Doppler shift and Doppler rate conditions, experienced during the different EarthCARE mission phases.

COM-FU-19 The COM TTC Terminal shall be capable of recovering from a failure autonomously (with possible DHS support). It shall be possible to override the autonomous recovery action by use of ground commands.

COM-FU-20 The COM TTC Terminal shall be designed to ensure ease of testability and to provide sufficient failure indication.

COM-FU-21 The COM TTC Terminal shall support the following date rates:

- Up to 8 kbps (baseline) / up to 64 kbps TBC for telecommand (final max. data rate selection to comply with GS facilities, bandwidth occupancy and operational impacts/constraints related to S/W & memory patches, data rate margin specified in DHS-PC-2 and ranging)
- Up to 356 kbps (TBC) for telemetry and ranging (TM data rate to comply with the GS facilities. with ranging and data transmission requirements for all mission phases and with the data rate margin specified in DHS-PC-2 while minimizing the bandwidth occupancy)

COM-FU-22 The following quality requirements shall be met by the COM TTC Terminal uplink:

- Probability of frame rejection: $< 10^{-5}$
- Probability of undetected frame error: $< 10^{-19}$
- BER on physical channel: $< 10^{-5}$

COM-FU-23 The following quality requirements shall be met by the COM TTC Terminal downlink:

- Probability of frame loss: $< 10^{-7}$

COM-FU-24 The following characteristics shall be assumed for the COM TTC S-band max. 13-m antenna at Master ground station and for LEOP stations:

EIRP	63 dBW	(TBC)
G/T figure of merit (@ 5^0 elevation)	22.5+/-0.3 dB/K	(TBC)
Implementation loss	0.5+/-0.1 dB	(TBC)
Rx PLL Bandwidth	>=300 Hz	(TBC)

7.3.6.3 COM High Rate TM Terminal Requirements

COM-HR-1 The COM HR TM Terminal shall receive a telemetry data stream from the on-board data storage (part of the DHS subsystem) and transmit these data to the ground. It will consequently support Telemetry mode only.

COM-HR-2 The COM HR TM Terminal shall operate in cold redundancy and it will be controlled /monitored from DHS either autonomously or by ground via COM TTC Terminal (i.e. S-band link).

COM-HR-3 The active COM HR TM transmitter shall be able to receive the telemetry stream from both nominal and redundant DHS chains.

COM-HR-4 The COM HR TM Terminal shall be designed so that the transmitters can be switched ON and OFF at any time by COM TTC / DHS telecommand. (Section 5.5.2 ECSS-E-50-05A)

COM-HR-5 The COM HR TM Terminal antenna shall point in nadir direction and the antenna gain (isoflux type antenna) shall ensure that the link budget margins are met for all ground station elevation angles greater than 5 degrees, whilst respecting the power flux density requirements on the Earth surface and all other COM subsystem requirements for COP and MOP mission phases.

COM-HR-6 Deleted

COM-HR-7 The COM HR TM Terminal shall be capable of recovering from a failure autonomously (with possible DHS support). It shall be possible to override the autonomous recovery action by use of ground commands.

COM-HR-8 The COM HR TM Terminal shall interface with the selected ground stations. The applicable requirements for this interface will be consolidated in the mission Space/Ground RF Interface Control Document. The following characteristics shall be assumed for the COM HR TM X-band max. 13-m antenna Master ground station:

- G/T figure of merit (@ 5^0 elevation) 32 dB/K (TBC)
- Implementation loss 0.5+/-0.1 dB (TBC)
- Rx PLL Bandwidth >=300 Hz (TBC)

In accordance to OPS-SC-7, it should also be possible to transmit science packets to other X-band ground stations; such ground stations are assumed to be equipped with antennas of similar characteristics..

COM-HR-9 The COM HR TM Terminal frame rejection rate should be less than 10^{-7}.

COM-HR-10 The downlink data rates shall be selected to be compatible with the data transmission requirements, the data rate margin specified in DHS-PC-2 and the GS facilities capabilities.

7.3.7 Electrical Distribution, Harness and Connectors Requirements

7.3.7.1 General Requirements

The harness provides electrical connections between all electrical equipment. It includes harnesses for power supplies, analogue/digital signals and pyrotechnic pulses. It also includes also harnesses for connections with the umbilicals and skin/test connectors.

The harness includes also all fixation plates, bond straps, clamps support bracketry, metallic brackets used for interface connectors grommets, edge protection, connector savers, and thermal insulation.

HAR-GE-1 The harness shall provide adequate distribution and separation of all power supply, analogue and digital lines, command and actuation pulse and stimuli lines between all units, the test/skin connectors, the safe/arm brackets and connectors and the umbilical connectors.

HAR-GE-2 The harness shall be designed in accordance with ND-3 and ND-16.

7.3.7.2 Functional Requirements

HAR-FU-1 The harness shall transmit all electrical currents in a manner compatible with the requirements of the source and destination unit/interface.

HAR-FU-2 The signal deterioration due to resistive, inductive and capacitive behaviour of the interconnection lines or coax cables shall be such that all the relevant applicable sub-system specifications are met in the integrated satellite.

HAR-FU-3 The isolation requirements between leads, which are not connected together and between shield and centre conductor and shield to shield shall be at least 10MΩ under 500V DC at both polarities.

HAR-FU-4 In a minimum mass, the mechanical design and construction of the harness shall assure the reliable operation of the spacecraft under all environmental conditions. The stress, which occurs during manufacturing, integration, test, transport, launch preparation, launch and in-orbit operation shall cause no changes in the harness which might affect the correct functioning of the satellite. No piece of harness shall be used as a mechanical support.

7.3.7.3 Design Requirements

HAR-DE-1 Physical separation along common lines of the categories listed below (power, signals and lines for the mechanisms, if applicable) shall be retained between these categories up to and inclusive of the module interface connectors. Exceptions can be only the routing of harnesses down to connectors in the satellite separation plane.

- Category 1: All supply lines from power sources to users
- Category 2: All signal lines with the exception of the sensitive analogue signals
- Category 3: Lines for the mechanisms/pyrotechnics
- Category 4: Sensitive analogue signal

HAR-DE-2 All equipment shall use a separate connector dedicated to its functional interface, according to the categories listed above.

HAR-DE-3 Wiring of redundant systems, sub-systems or units of subsystems shall be routed through separate connectors and wire bundles. When not applied, this shall be tracked in the Critical Item List. This requirement can not be waived for redundant essential functions, both for unit internal and external routing.

HAR-DE-4 Cross strapping of redundant paths and circuits shall not be carried out in the harness.

HAR-DE-5 The pyrotechnic harness shall consist of twisted pairs of wires with an overall shield being continuous and connected to the conductive connector shells at all interfaces and grounded to the structure at all intermediate attachment points.

HAR-DE-6 All harness and all box and bracket mounted connectors supplying power shall have socket contacts.

HAR-DE-7 Where a shield connection through a connector is necessary, separate pins shall be used.

HAR-DE-8 All individual wire-to-pin interfaces shall be covered with transparent heat shrink sleeves.

HAR-DE-9 The harness shall be fixed onto the structure in order to avoid any damage during the launch phase. As a general rule it will be fixed:

- At equipment level: the harness connectors shall be fitted onto the equipment connectors by appropriate locking systems
- At the structure level
- At interface level: the connectors shall be fixed on metallic brackets themselves fixed onto the structure

HAR-DE-10 The harness restraining systems on the structure shall not bring any stress at connector level.

HAR-DE-11 Permanent connections installed for purposes of test at integrated satellite level shall be routed to skin connectors of the modules concerned (module interface connectors are no longer accessible at that level).

HAR-DE-12 Skin connectors shall also be provided to make-or-break power circuits.

HAR-DE-13 Caps, bridging connectors, and thermal insulation for flight shall close all these skin connectors. During testing activities these connectors shall be protected by connector savers.

HAR-DE-14 There shall be umbilical and test connectors to provide electrical interfaces respectively with the launcher and with the EGSE. Functions provided shall include all those necessary for supporting AIT and launch site activities.

HAR-DE-15 Skin test connectors shall be provided to support AIT activities in order to:

- monitor spacecraft operation
- maintain synchronisation between satellite, EGSE and real time simulators
- put the satellite in a defined operation scenario (e.g. quick upload of SW or mass memory images)

HAR-DE-16 Umbilical test connectors shall be provided in order to support pre-launch activities in order to:

- power the satellite (including switching to satellite own batteries)
- monitor the spacecraft health status
- upload SW and flight parameters

HAR-DE-17 Test harness shall be provided so that the satellite can be stimulated and monitored during functional testing. Test harness end connectors shall be located at the skin of the spacecraft so that they are accessible also when the spacecraft is fully equipped with MLI. Design of the test harness shall take into account critical lengths. Wherever possible the test harness shall be removed for the flight configuration.

HAR-DE-18 Safe and arming plugs shall be provided for disabling of hazard functions.

HAR-DE-19 For new equipment development, when the connection is not aligned to a defined standard, 10% spare contacts at unit PDR and at least 5% at CDR shall be achieved with, in any case, a minimum of two spare contacts at CDR.

7.4 Assembly, Integration and Testing (AIT)

7.4.1 Ground Support Equipment (GSE)

AIT-GS-1 GSE shall be designed for the execution of assembly, integration, verification, transportation, launch preparation and launch support and maintenance of satellite items and spares.

As a reminder the satellite includes both the platform and the instruments.

AIT-GS-2 GSE shall consist of all ground support equipment required from development until acceptance of flight items (unit up to satellite level) and spares and for the launch phase and shall include as a minimum MGSE, EGSE, OGSE and FGSE.

AIT-GS-3 GSE shall provide necessary stimuli to perform instrument performance tests.

AIT-GS-4 GSE shall be transportable.

AIT-GS-5 The MGSE shall include all mechanical ground equipment necessary for transportation, ground handling, testing and storing of the satellite.

AIT-GS-6 The EGSE shall include all electrical ground equipment necessary for unit and subsystem development and testing, satellite integration testing, satellite environmental testing, system testing (incl. e.g. AOCS Closed Loop testing), GS compatibility tests (incl. eg. SVTs, RF compatibility, X-band acquisition tests) and launch operations.

AIT-GS-7 The OGSE shall include all optical ground equipment necessary for unit, and subsystem development and testing, satellite integration testing, satellite environmental testing and launch campaign operations.

AIT-GS-8 The FGSE shall include all ground equipment necessary for propellant loading/unloading, pressurisation and satellite purging.

AIT-GS-9 The GSE shall comply with requirements and safety standard imposed by the facilities in which it has to operate.

E.g. GSEs supplied for use in Europe or at the launch site shall be certified to comply with the safety requirements applicable to the spacecraft prime contractor. A safety certificate is required for this (CE mark). Specific MGSE load certificates are also required.

AIT-GS-10 Satellite design features and appropriate GSE shall ensure eye safety of all test personnel during all phases of AIT.

AIT-GS-11 The GSE hardware and software developed for testing at unit, assembly, instrument and subsystem level shall be designed to allow maximum re-use at higher level tests.

AIT-GS-12 Handling tools and MGSE shall prevent accidental damages to all units and at all level of integration, including satellite level.

AIT-GS-13 All equipment MGSE to be used at satellite level, including the solar array and CPR deployment rigs, shall have been used and validated at equipment level.

AIT-GS-14 The GSE system shall be based on commercially available and supported hardware and software.

AIT-GS-15 No GSE fault shall propagate through the interface with flight or other hardware.

AIT-GS-16 The GSE shall provide the capability for all functional interfaces to be verified before connection to flight hardware.

AIT-GS-17 The EGSE Platform Interface Simulator Assembly (PISA) shall provide the complete set of flight representative electrical interfaces in order to validate the instrument interfaces with the satellite platform.

AIT-GS-18 The Core EGSE shall allow commanding and monitoring of the instrument(s) via the PISA.

AIT-GS-19 The Core EGSE shall support Automatic test Procedures (AP) and reference data bases.

AIT-GS-20 EGSE shall be able to process and archive all data, both measurement data and housekeeping telemetry, in real time. In particular, the EGSE shall be able to acquire and process the stored data dumped via both S- and X-band links.

AIT-GS-21 EGSE shall be able to export data as VCDU files (1 file per VCID), as ISP files (1 file per APID) and as TBD files. Extra files and all formats shall be agreed with the Agency in order to effectively support the GS compatibility tests.

AIT-GS-22 The EGSE design shall allow fast operations for servicing, inspections, confidence testing, fault detection and calibration and shall include features for fast and easy disconnect, removal and replacement of its components.

AIT-GS-23 The EGSE shall allow accommodation of ESOC NDIU equipment for interface testing such as ESOC System Validation Tests (SVT).

AIT-GS-24 The EGSE shall support the utilisation of the Satellite Reference Data Base, and its export to the Flight Operation Center.

AIT-GS-25 An RF suitcase for ground segment verification tests shall be part of the EGSE.

AIT-GS-26 MGSE shall be proof tested to 2 times the maximum expected load.

AIT-GS-27 The EGSE shall support to record and analyse all the satellite on-board communication traffic

AIT-GS-28 All sensitive surfaces for contamination shall be protected by TB/TV compatible covers (or windows).

AIT-GS-29 All RF antennas shall have RF caps compatible with the intended testing at both unit, sub-system and system levels. As baseline, RF caps shall be TB/TV compatible.

AIT-GS-30 A flight like scenario should be included as part of the system testing. Any limitation due to sensors (platform and instruments) stimuli's shall be agreed with the Agency.

AIT-GS-31 The EGSE shall allow accommodation of ESRIN XSVE equipment for interface testing of the science data link.

AIT-GS-32 The GSE shall allow for a quick assessment of instrument data in less than 10 minute to ensure near-real time performance evaluation during testing.

AIT-GS-33 The EGSE shall be capable of loading, dumping, and patching the flight software within 1 hour.

AIT-GS-34 The EGSE shall support the development and testing of operational procedures.

AIT-GS-35 The EGSE shall allow the loading of partial/complete memory images in the on-board DHS data storage in order to speed up test preparation of operation scenario or to check health status of the on-board data storage plus its associated error detection and correction features. The uploading of the complete on-board DHS data storage shall be possible within 2 hours (TBC) and for that purpose, a dedicated skin test interface may be required at satellite level.

AIT-GS-36 The EGSE shall be designed - and duly verified - in order not to modify the performance of the satellite when EGSE is connected.

E.g. during environmental test, the on-board DHS bus is commonly extended/instrumented via skin connector and long EGSE harness and this can significantly alter the performance of the DHS bus under test.

7.4.2 Software Development and Verification Environment (SDVE)

AIT-SD-1 For all on-board software, the relevant SDVE shall support on-board software development and testing prior to integration with the flight hardware and shall support flight software maintenance.

AIT-SD-2 The SDVE shall support unit (white and black box), modules, IT, functional and validation test of the flight software.

AIT-SD-3 The SDVE shall include software simulation of the environment in which the software operates (e.g. AOCS, data bus, TM/TC-interfaces, etc.) to present a flight-representative environment.

AIT-SD-4 The SDVE shall be transportable.

AIT-SD-5 All on-board SW elements shall use a SW Validation Facility (SVF) running on an instruction-level simulator for testing. HW, interfaces and environment shall be implemented via simulation models.

AIT-SD-6 The SDVE shall include and support tests of AOCS dynamic models.

AIT-SD-7 The operational interface to the SVF shall be achieved via the satellite reference database (SRDB).

AIT-SD-8 For SW-level testing of AOCS functions, the SVDE shall ensure the possibility that such AOCS SW can be tested in closed loop.

8 On Ground Instruments Data Processing Requirements

8.1 Data Product Definitions

To serve the scientific community, the measurement data from EarthCARE must be down-linked, processed, archived and delivered off line. The data downlink is performed on a dedicated separate channel. Data are transmitted from the receiving stations to a processing centre, and there processed to Level 1B (corrected and fully calibrated engineering data with all ancillary data required for further processing) and possibly up to level 1c - see [DPR-DP-4].

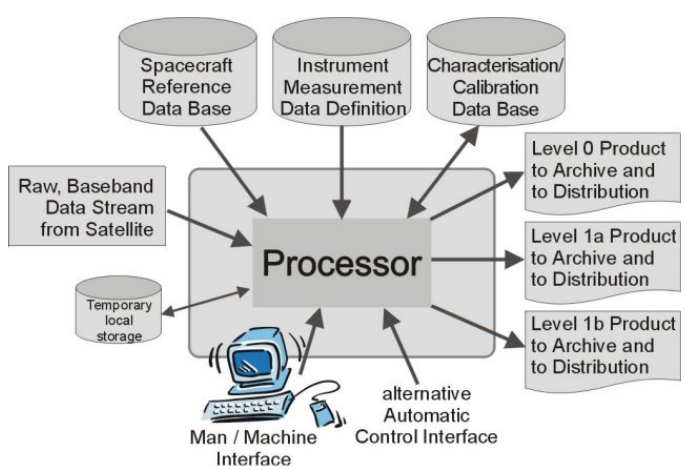
The raw, baseband data stream will be as received at the ground stations. The data will be a sequential mixture of real time and recorder dumps. It will consist of data packets transmitted as Virtual Channel Data Units (VCDU). VCDU's may be corrupt, packets may be incomplete and VCDU's and packets may be out of sequence.

DPR-DP-1 Level 0 products shall consist in raw telemetry source packets, time ordered, error free (e.g duplicated ISP removed) with time and quality annotation. Invalid or suspects packets shall be marked as such. Level 0 products will include both science and auxiliary products, if any (e.g. auxiliary products that contain information extracted from HK telemetry or from FOS, as necessary for the Level-1 processing).

DPR-DP-2 The level 1a products shall consist of Level 0 product contents with corresponding radiometric, spectral and geometric (i.e. Earth location) correction and calibration computed and appended, but not applied.

DPR-DP-3 For level 0 and level 1a products a separation into calibration products (for measurements in calibration mode) and observation products (for measurements in observation mode) may be required. This has to be decided and agreed with the Agency per instrument.

Fig. 8-1 Level 1 b Processor Interfaces



DPR-DP-4 The Level 1b products - and 1c products for MSI (sect. 5.4.9) - shall be fully geo-localised products, as well as error estimates and reliability data for each data set.
The Level 1b product data (Level 1c for MSI) shall meet the performance requirements of this document. The data shall be calibrated to engineering units using the best possible characterisation data available. At launch this will be the Satellite Characterisation & Calibration Data Base (CCDB). In orbit, this data base will be supplemented by in-orbit characterisation and calibration data.

Instrument specific Level 1b/c requirements for Atlid, CPR, MSI and BBR are given in sections 5.2.10, 5.3.9, 5.4.9 and 5.5.10 respectively.

DPR-DP-5 A complete set of Level 0 and Level 1 products shall be generated for each EarthCARE instrument

DPR-DP-6 The Level 1 products shall include the measurement and auxiliary data covering a sub-set, one or a multiple of orbits.

8.2 General Ground Software Requirements

These requirements pertain to all ground SW to be developed, in particular in the frame of the ESSS and Level 0 to 1 ECGPs.

DPR-GS-1 The Unix operating system shall be used. The actual hardware/operating system configuration shall be PC (multi-core/multi-processor system if needed)/Linux.

DPR-GS-2 Coding shall be performed in an high-level programming language such as C/C++.

DPR-GS-3 All files (including configuration and intermediate input/output files) shall be in XML or a format to be agreed with the Agency (e.g. HDF5, NetCDF) . The default format shall be XML while the other format shall be used for large files only (i.e., where using XML would significantly degrade performance).

DPR-GS-4 All processing parameters shall be configurable in external XML files (without code updates and/or recompilation).

DPR-GS-5 Test entry points shall be defined to facilitate testing and debugging. They shall allow running selected parts of the processing chain by providing breakpoints for reading intermediate input data and writing intermediate output data.

DPR-GS-6 Quick look visualisation and data extraction tools shall be implemented for all product levels and intermediate (debugging) input and output. These tools shall be used during SW development and testing.

DPR-GS-7 The functions of the Earth Explorer mission CFI software shall be used wherever possible.

DPR-GS-8 A man/machine interface shall be provided to allow operational control of the software. This shall include initialisation and re-initialisation.

DPR-GS-9 An alternative automatic command and control interface shall be provided with similar functionality of the man/machine interface.

8.3 EarthCARE Satellite System Simulator (ESSS) Requirements

DPR-SI-1 The ESSS shall simulate, from the signals received at aperture entrance level, the measurement data stream as produced by the space borne EarthCARE mission for all operational and calibration phases.

DPR-SI-2 This simulated data stream shall be identical to the one generated in-orbit and transmitted to ground, including the annotation data. Annotation data includes orbit, attitude and instruments housekeeping data.

DPR-SI-3 The simulated data stream shall cover (but not be limited to) all telemetry points required by the Level 0 to 1 processor. The ESSS is not required to cover satellite command and control or satellite housekeeping, except in so far as it directly affects measurement data or is required on input by the Level 0 to 1 processor.

DPR-SI-4 The ESSS shall model all EarthCARE payload instruments, including the CPR.

DPR-SI-5 Nominally, ESSS shall generate the data stream for at least two orbits. However, it shall be possible to generate data streams from shorter periods down to single observations as well.

DPR-SI-6 The ESSS shall consist of software to be installed by the Contractor on a host computer to be mutually agreed with the Agency.

DPR-SI-7 The ESSS shall consist of individual instrument modules, each one creating the measurement data stream for the respective instrument.

DPR-SI-8 It shall be possible to operate individual instrument modules stand-alone.

DPR-SI-9 It shall be possible to operate any combination of instrument modules using the same scene(s) on input generating consistent output (synchronisation, datation, geo-location).

DPR-SI-10 Each instrument module shall be able to process as well the scenes which are used as sizing scenes for other instruments.

DPR-SI-11 The ESSS shall comply to AD-27 and ID-13.

DPR-SI-12 The ESSS shall allow the entry of all relevant engineering parameters that have an influence on the measurement data output. All configuration data shall be easily modifiable by the users. ESSS shall allow performance and sensitivity analyses of instrument subsystems and components as required.

8.4 EarthCARE Ground Processor (ECGP) Requirements

DPR-GP-1 The ECGP shall have interfaces as indicated in Fig. 8-1.

Details of the interfaces with the PDGS will be agreed with the Contractor.

DPR-GP-2 The ECGP shall be able to produce Level 0, Level 1a, Level 1b and Level 1c (for MSI) products for every dump on an orbital basis.

DPR-GP-3 The ECGP shall consist of individual modules, each one performing the Level 0 to 1 processing for the respective instrument.

DPR-GP-4 It shall be possible to operate individual instrument modules stand-alone.

DPR-GP-5 It shall be possible to operate any combination of instrument modules.

DPR-GP-6 The conversion from raw CCSDS instrument science packets to Level 0 shall be performed by a separate module (ECGP front-end). This module shall perform consistency checks on the input data stream (completeness, duplicates, time order, fixed fields, etc.).

DPR-GP-7 The ECGP shall comply to AD-27 and ID-13.

DPR-GP-8 The ECGP shall be robust to degraded input data.

DPR-GP-9 Redundant calculations in the Level 0 to 1b processing chain shall be avoided wherever possible.

Redundant calculation cases will have to be presented to Agency for approval.

DPR-GP-10 The ECGP processors shall perform online product quality control. This function shall create Product Confidence Data (PCD) on all product levels and additional information for offline quality evaluation.

DPR-GP-11 It shall be possible to reprocess data of an orbit or less at a time without interfering with the operational flow and timing of regular products.

DPR-GP-12 The ECGP shall make systematic use of the Instrument Measurement Data Definition (IMDD) when processing data. A copy of this data base shall reside in the processor.

DPR-GP-13 The ECGP shall make systematic use of the Satellite Characterisation Calibration Data Base (CCDB), which shall initially contain the organised results of all on-ground characterisation activity. A copy of the data base shall reside in the processor.

DPR-GP-14 The CCDB shall be updateable in flight as a result of operations experience with the satellite, and of validation campaigns. Such updates shall be possible and convenient through a dedicated ECGP module (i.e. separate from the L0 to L1 processing core module).

DPR-GP-15 ECGP shall be completed by a set of visualisation tools (e.g. IDL or Matlab) to support the validation of data during on-ground validation, and later during in-flight validation

8.5 Data Product Format Specifications

DPR-PF-1 EarthCARE data products shall have a format compliant with AD-25.

Any deviation and details will have to be agreed with the Agency in the frame of the preparation of the Processor specification to be issued by the contractor.

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ANNEX-1 ATLID Reference Model of the Atmosphere (ARMA)

1 Introduction

The ATLID Reference Model of the Atmosphere (ARMA) is a simplified model of the Earth's atmosphere and surface, which includes the features listed below. It shall be used for the evaluation of instrument performance.

- Clear air aerosol backscatter and extinction,
- Aerosol depolarisation,
- Molecular backscatter and extinction,
- Typical cloud backscatter and extinction,
- Ground and cloud deck reflectance,
- Background radiance.

2 Clear-Air Characteristics

2.1 Aerosols

The ARMA aerosol backscatter model is derived from a climatological database of atmospheric backscatter at a wavelength of 10.6 µm in $m^{-1}sr^{-}1$ for regions of the Atlantic during the relatively clean atmospheric period 1988-1990. Five backscatter profiles are given in Table Annex 1-1 for the median, higher/lower quartile values and higher/lower decile values in each 1 km altitude bin from the ground up to an altitude of 16 km.

The **nominal backscatter profile to be considered in the sizing of the instrument is the median value profile**. Instrument performance assessment for the four other profiles is required.

> It must be noted that the backscatter coefficient is prone to variations by several orders of magnitude over a few 10s of meters as a result of aerosol stratification. This effect is not represented in the table, but could render the instrument performance estimates less representative.

Altitude	Lower decile	Lower quartile	Median	Higher quartile	Higher decile
0-1 km	9.3 E-09	4.1 E-08	2.8 E-07	1.6 E-06	5.1 E-06
1-2 km	1.9 E-10	1.8 E-09	2.2 E-0.8	1.6 E-07	1.6 E-06
2-3 km	4.6 E-11	1.4 E-10	7.2 E-10	6.6 E-09	1.1 E-07
3-4 km	2.6 E-11	7.1 E-11	1.9 E-10	9.7 E-10	9.5 E-08
4-5 km	1.5 E-11	3.8 E-11	8.5 E-11	5.6 E-10	1.1 E-07
5-6 km	9.0 E-12	2.5 E-11	5.7 E-11	3.6 E-10	8.1 E-09
6-7 km	6.5 E-12	2.0 E-11	4.4 E-11	2.0 E-10	2.5 E-09
7-8 km	6.3 E-12	1.9 E-11	4.4 E-11	2.0 E-10	2.6 E-09
8-9 km	6.2 E-12	1.7 E-11	4.3 E-11	2.0 E-10	8.0 E-09
9-10 km	6.2 E-12	1.7 E-11	3.5 E-11	1.7 E-10	3.0 E-08
10-11 km	6.2 E-12	1.4 E-11	3.2 E-11	1.3 E-10	4.3 E-08
11-12 km	~ 5.0 E-12	1.1 E-11	2.7 E-11	6.2 E-11	4.5 E-10
12-13 km	~ 5.0 E-12	1.3 E-11	2.5 E-11	4.9 E-11	2.9 E-10
13-14 km	~ 5.0 E-12	1.1 E-11	2.3 E-11	4.2 E-11	1.8 E-10
14-15 km	< 4.0 E-12	6.8 E-12	1.8 E-11	3.2 E-11	1.3 E-10
15-16 km	< 4.0 E-12	7.6 E-12	1.7 E-11	2.5 E-11	6.8 E-11

Table Annex1-1: ARMA backscatter coefficients

Note: between the defined levels, the back scatter coefficient shall be linearly interpolated.

A classical Lorentzian law shall be assumed to model the stratospheric aerosol backscatter coefficient In the altitude range from 15.5 km to 30 km:

$$\beta_{str}(z\,km) = \frac{\beta(15.5\,km)}{1 + (\frac{z - 15.5.km}{z_0})^2}$$

with the following boundary conditions:

1. Pure molecular backscatter coefficient at 30 km; β(30 km) = 2.35 E-13 $m^{-1}.sr^{-1}$
2. Aerosol backscatter coefficient β at 15.5 km as taken from the above table.

In general, the backscatter coefficient increases with decreasing wavelength with a wavelength dependence that is given roughly by $\lambda^{-\alpha}$. Moreover, the factor α depends on the strength of the backscatter coefficient. Roughly speaking, “high” backscatter at 10.6 µm will have a weaker dependence on wavelength than “low” backscatter. For trade-off of the instrument wavelength(s) (i.e. 1 µm or 355 nm), the backscatter coefficient shall be modelled by the following simplified scaling law:

$$\beta(\lambda, z) \equiv \beta_0(z).\left(\frac{\lambda_0}{\lambda}\right)^{\alpha(\beta_0(z))}$$

with, $\alpha(\beta_0(z)) \equiv -0.104.\ln(\beta_0(z)) - 0.62$, for λ = 1.06 µm and 0.355 µm,

$\beta_0(z)$ is the aerosol backscatter coefficient at altitude z and wavelength λ_0 = 10.6 µm as shown in the table above.

The aerosol extinction profile α shall be derived from the aerosol backscatter profile β using k = 0.02 sr^{-1} for the near infrared-visible wavelengths and the relation:

$$\beta = k.\alpha$$

Aerosol depolarization:

The backscatter signal from atmospheric aerosols shows a typical depolarisation ratio between 10 % to 25%. 15% depolarisation ratio shall be considered for the instrument sizing.

2.2 Molecules

The contribution from the air molecules can be modeled in the troposphere by an exponentially decreasing function with altitude:

$$\beta_{mol}(z, \lambda) \equiv 1.0 \cdot 10^{-7}.\left(\frac{\lambda_0}{\lambda}\right)^4.\exp\left(-\frac{z}{z_{mol}}\right).m^{-1}.sr^{-1}$$

where λ_0 = 1.06 µm and z_{mol} = 8000 m.

The molecular scattering extinction coefficient is deduced from the molecular backscatter coefficient using the following equation:

$$\alpha_{mol} = \frac{8 \cdot \pi}{3} \cdot \beta_{mol}$$

The backscatter signal I(ν) is frequency broadened due to the Brownian motion of the air molecules. The frequency spread is described by the Gaussian function:

$$I(\nu) = \sqrt{\frac{1}{\pi}}.\frac{I_0}{\delta\nu}.\exp\left[-\left(\frac{\nu - \nu_0}{\delta\nu}\right)^2\right]$$

where I_0 is the total signal

ν = c/λ is the frequency of the signal

$\nu_0 = c/\lambda_0$ is the frequency of the un-broadened signal

δν is the half-width at the 1/e point of the Doppler-broadened return, which is given as:

$$\delta\nu = 2.\sqrt{\frac{2.k.T}{m}}.\frac{\nu_0}{c}$$

where k=1.38 . 10^{-23} J/K is the Boltzmann constant

m = 4.8 .10^{-26} kg is the average mass of the scattering molecules

T is the atmosphere layer temperature. The value shall be taken from the temperature profile listed in Table Annex 1-4.

Molecular depolarisation:

The backscatter signal from molecules shows a depolarisation ratio of 0.78% for circular polarisation (value considering that only the central Cabannes line will be detected).

Molecular backscattering knowledge:

The molecular backscatter scattering is assumed to be known to 3% (from Reagan et al.) in the 30-40km altitude range.

3 Clouds Characteristics

Typical cloud extinction and backscatter coefficients are given in Table Annex 1-2. They shall be considered in the instrument performance assessment. The altitude range column gives typical clouds base and top altitudes.

Cloud type	Backscatter coefficient ($m^{-1}.sr^{-1}$)	Extinction coefficient (m^{-1})	Altitude range (m)
Alto-Stratus	1.0 E-3	0.018	4000 to 4500
Cirrus	1.6 E-4	2.3 E-3	9000 to 10000
Very thin Cirrus	1.4 E-5	2.0 E-4	9000 to 10000
Sub-visible cirrus	8.0 E-7	4.0 E-5	9000 to 10000

Table Annex1-2: Typical cloud type characteristics .

Cirrus optical depth retrieval algorithm:

The following algorithm shall be used for the cirrus optical depth retrieval accuracy assessment.

The Rayleigh signal (range corrected at the entrance of the instrument) is expressed as :

$$z^2 P(z) = C_{lid} \beta_{ray} \exp[-2\tau(0,z)]$$

Which gives : $\log[S(z)] = \log\left(\frac{P(z)z^2}{\beta_{ray}}\right) = \log(C_{lid}) - 2\tau(0,z)$

The optical depth of a layer between altitude z1 and z2 is then given by calculating the ratio between the Rayleigh signal measured at z1 and z2 and correcting for the molecular backscattering (βray):

$$\tau(z1,z2) = 0.5\log\left[\frac{S(z_1)}{S(z_2)}\right]$$

Differentiating the equation gives the absolute optical depth accuracy:

$$\Delta\tau(z1,z2) = 0.5\left[\left(\frac{\Delta S(z_1)}{S(z_1)}\right)^2 + \left(\frac{\Delta S(z_2)}{S(z_2)}\right)^2\right]^{1/2},$$

or the relative optical depth accuracy:

$$\frac{\Delta\tau(z1,z2)}{\tau(z1,z2)} = \frac{0.5}{\tau(z1,z2)}\left[\left(\frac{\Delta S(z_1)}{S(z_1)}\right)^2 + \left(\frac{\Delta S(z_2)}{S(z_2)}\right)^2\right]^{1/2}$$

4 Ground/Cloud Deck Surface Characteristics

Typical albedo values are listed in the table Annex 1-3 to assess ground surface return signals.

Soil	0.03
Ice	0.5
Dry snow	0.8
Water	0.14
Cloud deck	1

Table Annex1-3: ground and cloud deck albedos

5 Extra-terrestrial Solar Irradiance

The reference solar spectral irradiance data are provided in ND-40. The data are for a distance Earth-Sun of 1 astronomical unit (AU).

6 Winds

Doppler shifts induced by horizontal wind velocities up to 30 ms^{-1} (rms) and vertical wind velocities up to 2 ms^{-1} (rms) shall be considered when assessing the radiometric performance of the lidar.

7 Temperature Profile

The temperature of any atmospheric layer shall be assumed to be known to better than 1K (TBC) rms.

8 Pressure Profile

The pressure of any atmospheric layer shall be assumed to be known to better than 2% (TBC) rms.

Table Annex1-4: Standard Temperature Profile

Altitude (km)	Temperature (K)
64.64	231.70
57.42	252.87
51.00	268.42
45.33	265.17
40.61	252.38
36.74	241.72
33.52	232.78
30.79	227.77
28.41	225.09
26.30	223.01
24.41	221.16
22.70	219.45
21.14	217.91
19.70	216.86
18.37	216.70
17.12	216.70
15.97	216.70
14.84	216.70
13.80	216.70
12.81	216.70
11.89	216.73
11.02	218.06
10.19	221.48
9.40	226.66
8.64	231.64
7.90	236.47
7.02	241.11
6.52	245.58
5.86	249.87
5.24	254.00
4.63	257.95
4.05	261.75
3.50	265.38
2.97	268.85
2.47	272.13
1.99	275.24
1.55	278.12
1.14	280.78
0.78	283.13
0.47	285.13
0.23	286.71
0.07	287.78
0	288.20

ANNEX-2 Acronym List

AD	Applicable Document
AIT	Assembly, Integration and Test
AIV	Assembly, Integration and Verification
ALFA	Atmospheric Lidar Filtering and Acquisition chain
AME	Absolute Measurement Error
AOCS	Attitude and Orbit Control System
AP	Automatic (test) Procedure
APE	Absolute Pointing Error
APID	APplication IDentifier
AR	Acceptance Review
ARDL	Applicable & Reference Document List
ARE	Absolute Rate Error
ARMA	Atlid Reference Model of the Atmosphere
ATBD	Algorithms Theoretical Baseline Document
ATLAS	ATlid Laser Source
ATLID	ATmospheric backscatter LIDar
ATOX	ATomic OXygen
AU	Astronomical Unit
BBR	BroadBand Radiometer
BER	Bit Error Rate
BOL	Begin Of Life
BRDF	Bi-directional Reflectance Distribution Function
BTDF	
CAD	Computer Aided Design
CAL	CALibration
CCDB	satellite Characterisation and Calibration DataBase
CCD	
CCN	Contract Change Notice
CCSDS	Consultative Committee for Space Data Systems
CDR	Critical Design Review
CEIS	CPR Electrical Interface Simulator
CFI	Customer Furnished Instrument
CIDL	Configuration Items Data List
CLA	Coupled Load Analysis
CME	Coefficient of Moisture Expansion
CoG	Centre of Gravity
COM	COMmunications subsustem
COP	Commissioning Phase
CPPA	Co-ordinated Parts Procurement Agent
CPI	Contractor Procured Instrument
CPR	Cloud Profiling Radar
CPU	Central Processor Unit
CSG	Centre Spatial Guyanais
CTE	Coefficient of Thermal Expansion
CUC	CCSDS Unsegmented time Code
CVCM	Collected Volatile Condensable Material
DCG	Document Contents Guideline
DDR	Detailed Design Review
DDV	Design, Development and Verification Plan
DHS	Data Handling Subsystem
DL	Design Load
DML	Declared material List
DMPL	Declared Mechanical Parts List
DNEL	Disconnect Non Essential (power) Loads
DPA	Destructive Physical Analysis
DPL	Declared process List
DRL	Document Requirement List
DS	Data Set
DSD	Data Set Descriptor
DSN	Deep Space Network
DSR	Data Set Record
EarthCARE	Earth Clouds, Aerosol and Radiation

	Explorer
ECEESIM	EarthCARE End-to-End mission Simulator
ECGP	EarthCARE Ground Processor
ECSS	European Cooperation for Space Standardization
EDAC	Error Detection And Correction
EGM	
EGSE	Electrical Ground Support Equipment
EIDP	End Item Data Package
EIRP	Effective Isotropic Radiated Power
EMC	Electro Magnetic Compatibility
EOEP	Earth Observation Envelope Programme
EOL	End Of Life
EOP	End of Life Phase
EPS	Electrical Power Sub-system
EQM	Engineering & Qualification Model
ESA	European Space Agency
ESD	Electro-Static Discharge
ESOC	European Space agency Operation Centre
ESSS	EarthCARE Satellite System Simulator
FAT	Factory Acceptance Test
FDIR	Failure detection, Isolation and Recovery
FEM	Finite Element Model
FGSE	Fluid Ground Support Equipment
FM	Flight Model
FMECA	Failure Mode…
FOM	Flight Operation Manual
FOP	Flight Operation Plan
FOS	mechanical Factor Of Safety
FOSU	Factor Of Safety to Ultimate
FOSY	Factor Of Safety to Yield
FOS	Flight Operation Segment
FOV	Field Of View
GMM	Geometrical Mathematical Model
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSDR	Ground Segment Design Review
GS	Ground Segment
GSE	Ground Support Equipment
GSRQR	Ground Segment Requirements Review
GSRR	Ground Segment Readiness Review
GSTR	Global Annotation Data Set
H/W	HardWare
HK	HouseKeeping
HR	High Rate
HSR	High-Spectral Resolution
IC	Integrated Circuit
ICD	Interface Control Document
ICRF	International Celestial Reference Frame
ID	Informative Document
IE	Integrated Energy
IMDD	Instrument measurement Data Definition database
IOCR	In-Orbit Commissioning Review
IOV	In-Orbit Validation
IOVR	In-Orbit Verification Review
IPD	Instrument Pre-Development
IRD	Interface Requirement Document
ITRF	International Terrestrial Reference Frame
ITT	Invitation To Tender
IV&V	Independent software Verification and Validation
JAXA	Japan Aerospace eXploration Agency
JET	Joint Engineering Team
JMAG	Joint Mission Advisory Group

KIP	Key Inspection Point
L1B	Level 1 B
L3CCD	Low Light Level CCD
LCDA	Launch Coupled Dynamic Analysis
LDA	
LEOP	Launch and Early Operations Phase
LL	Limit Load
LLI	Long Lead Item list
LN	Local Normal (reference frame)
LO	Local Orbital (reference frame)
LOS	Line Of Sight
LRR	Launch Readiness Review
LSB	Least Significant Bit
LW	Long-Wave
MAG	Mission Advisory Group
MCR	Mission Commissioning Review
MDF	Modulation Transfer Function
MDP	Maximum Design Pressure
MDS	Measurement Data Set
MEOP	Maximum Expected Operating Pressure
MGSE	Mechanical Ground Support Equipment
MIFC	Manufacturing and Inspection Flow Chart
MIP	Mandatory Inspection Point
MOIS	Mission Operations Information System
MOP	Measurement / Operational Phase
MOS	Margin Of Safety
MPH	Main Product Header
MRT	Management Requirements and Tasks
MSI	MultiSpectral Imager
MTF	Modulation Transfer Function
MTL	Mission TimeLine
NCR	Non-Conformance Report
NCTS	Non Conformance Tracking System
ND	Normative Document
NDIU	Network Data Interface Unit
NEDL	Noise Equivalent Differential Radiance
NEDT	Noise Equivalent Differential Temperature
NICT	National Institute of information and Communications Technology
NIR	Near Infra-Red
OBCP	On-Board Control Procedure
OBT	On-Board Time
OCM	Orbit Control Mode
OGSE	Optical Ground Support Equipment
OOB	Out-Of-Band
OPS	Orbit Position Sequence
ORR	Operations Readiness Review
OTS	Off-The-Shelf
OZA	Observation Zenith Angle
PA	Product Assurance
PAD	Part Approval Document
PCD	Product Confidence Data
PDR	Preliminary Design Review
PDGS	Payload Data Ground Segment
PFD	Power Flux Density
PFM	Proto-Flight Model
PISA	Platform Interface Simulator Assembly
PLL	Phase Locked Loop
PRF	Pulse Repetition Frequency
PROM	Programmable Read Only Memory
PS	Packet Store
PSF	Point Spread Function
PUS	Packet Utilisation Standard
QR	Qualification Review
RAM	Random Access Memory
RF	Radio-Frequency

RMS	Root Mean Square
RSS	Root Square Sum
RTU	Remote Terminal Unit
SADM	Solar Array Driving Mechanism
SCF	SpaceCraft Frame
SDVE	Software Development and Verification Environment
SEU	Single Event Upset
SI	International Unit System
SIOVT	Satellite In-Orbit Verification Tool
SNR	Signal to Noise Ratio
SOW	Statement Of Work
SPH	Specific Product Header
SPR	Software Problem Report
SRD	System Requirements Document
SRDB	Satellite Reference DataBase
SRR	System Requirements Review
SSC	Source Sequence Counter
SSD	Spatial Sampling Distance
STE	Special Test Equipment
SVF	Software Validation Facility
SVT	System Validation Test
SW	SoftWare
SW	Short Wave
SZA	Sun Zenith Angle
TB	Thermal Balance
TBC	To Be Confirmed
TBD	To Be Defined
TBS	To Be Supplied
TC	Thermo-Couples
TCS	Thermal Control Subsystem
TIR	Thermal Infra-Red
TM/TC	Telemetry/Telecommand
TMM	Thermal Mathematical Model
TOA	Top Of the Atmosphere
TRB	Test Review Board
TRP	Temperature Reference Point
TRR	Test Readiness Review
TRRB	Test Readiness Review Board
TTC	Telemetry & TeleCommand
TV	Thermal Vacuum
TW	Total Wave
UTC	Universal Time Coordinated
UUT	Unit Under Test
UV	Ultra-Violet
VAL	VALidation
VC	Virtual Channel
VCD	Verification Control Document
VCDU	Virtual Channel Data Unit
VCID	Virtual Channel IDentifier
VIS	VISible
XML	eXtensible Mark-up Language
XSVE	X-band System Verification Equipment
YS	Yaw Steering (reference frame)

ANNEX-3 BBR Reference Scenes

1. SOURCE REFERENCE: Input from University of Valencia, 7 December 2006.

2. BACKGROUND INFORMATION – SCENE OVERVIEW

Simulations carried out with Streamer, v3.0b8 (24 streams SW & 16 streams LW).

2.1 Scene 1

Scene Name: **maxSWrad**

Scene Description: The **maxSWrad** scene corresponds to the maximum TOA shortwave radiation values. This result has been obtained by running the RTC over a **vegetation surface in cloudy conditions**. A small concentration of O3 (**150DU**) has been included to obtain maximum response in the UV range. Deep convective cloud has been used with **15km** physical thickness, **250 optical depth** and **2.5µm Reff** (to increase multiscattering processes). The **lowest Earth-Sun** distance (maximum solar flux), **solar zenith angle** (according to the BBR orbital restriction) and **viewing zenith angle** (nadir BBR view) in **forward scattering** (maximum reflectance in clouds) has been used.

Surface reflectance:	Generic Vegetation (Average of spectral albedos for grass, dry grass, deciduous forest, and coniferous forest. Grass, dry grass, deciduous forest, and coniferous forest were taken from the ASTER Spectral Library v1)
Surface temperature:	288.15 K
Aerosol model:	Rural (50 km visibility)
Atmosphere model:	Tropical(O3=150DU)
SZA:	22°
VZA:	0° (nadir)
RAA:	0° (forward scattering)
Date:	04/January/00 (perihelion)
Clouds:	Deep convective cloud (bottom altitude=1km; top altitude=16km; optical depth=250; Water drops Reff 2.5 µm)

2.2 Scene 2

Scene Name: **minSWrad**

The **minSWrad** scene spectrum corresponds to the TOA shortwave radiation values close to likely TOA shortwave minumum values. This result has been obtained by using an **ocean scene in clear sky conditions**. The **tropical standard atmosphere** profile has been employed with big concentration of O3 **(400DU**) to help the shortwave gaseous absorption bands. The **highest Earth-Sun distance** (minimum solar flux**), solar zenith angle** (according to the BBR orbital restriction) and **viewing zenith angle** (offnadir BBR view) in **backward scattering** (minimum reflectance in this surface) has been used.

Surface reflectance:	Open sea water (Brieglieb et al., 1985)
Surface temperature:	288.15 K
Aerosol model:	Maritime (50 km visibility)
Atmosphere model:	Tropical(O3=400DU)
SZA:	80°
VZA:	55° (nadir)
RAA:	180° (forward scattering)
Date:	04/July/00 (aphelion)
Clouds:	Clear sky

2.3 Scene 3

Scene Name: **maxLWrad**

The **maxLWrad** scene spectrum corresponds to TOA longwave radiation values close to the maximum that may be achieved for a spectral radiometer in space. This spectrum has been computed by using Streamer RTC over **desert surface** (high surface temperature) **in clear sky.** The standard profiles are not suitable for this type of simulation, so a real atmospheric profile has been employed extended by mid-latitude summer standard profile. Specifically, this desert profile corresponds to **Al-Madinah observations at 12Z 30 Aug 2005**. The **nadir view** has been used since it gives higher TOA radiances.

Surface reflectance:	Dry sand (Tanre et al., 1986)
Surface temperature:	338.15 K
Aerosol model:	Rural (5 km visibility from 0-2 km vertically and 23 km visibility between 2-10 km)
Atmosphere model:	Mid-latitude summer
SZA:	45°
VZA:	0° (nadir)
RAA:	0°
Date:	04/July/00
Clouds:	Clear sky

2.4 Scene 4

Scene Name: **minLWrad**

The **minLWrad** scene corresponds to minimum TOA longwave radiation values. This result has been obtained with an **ocean surface** (low surface temperature) **in cloudy conditions**. Deep convective cloud has been used with **15km** physical thickness, **250 optical depth** and **50µm Reff** (to help absorption processes). The **off nadir view** has been used since it gives lower TOA radiances.

Surface reflectance:	Open sea water (Brieglieb et al., 1985)
Surface temperature:	278.15 K
Aerosol model:	Rural (50 km visibility)
Atmosphere model:	Tropical
SZA:	45°
VZA:	55° (offnadir)
RAA:	0°
Date:	04/July/00
Clouds:	Deep convective cloud (bottom altitude=1k top altitude=16km; optical depth=250; Water drops Reff 50 μm)

3. DATA SETS

The calculation outputs are given below along with atmospheric background information. The applicable spectra are respectively labelled as ‘Radiance (W/m^2-sr) Spectral Interval (1/cm)’.

3.1 Scene 1 – maxSWrad

Streamer, v3.0b8 (beta test)

Input File: ../inputs/maxSWrad.inp

INITIAL OPTIONS (later changes will not be noted):
Number of Streams, Shortwave: 24, Longwave: 16
Number of coefficients: 48
Gaseous absorption included.
Rayleigh scattering included.
Default profile: Tropical
Default aerosol optical model: Rural
Default aerosol vertical profile: Background trop. and strat.
No spectral (band) weighting.
Using internal cloud optical properties.
No surface BRDF used.
++
Liquid Cloud, Vegetation, all wavebands
Year: 2000, Month: 1, Day: 4, Hour: 12.00
Lat: 0.000, Lon: 0.000, Zenith Angle (degrees): 22.00

Unscaled Atmospheric Profiles (25 Levels)

	Height(km)	Press(mb)	T(K)	H2O(g/m^3)	RH(%)	O3(g/m^3)	Aer(km^-1)
1	100.00	0.00	210.80	0.000000	0.00	0.0000000	0.000000
2	70.00	0.06	219.50	0.000000	0.00	0.0000001	0.000000
3	50.00	0.85	270.00	0.000004	0.00	0.0000025	0.000001
4	45.00	1.59	264.90	0.000007	0.00	0.0000077	0.000002
5	40.00	3.05	254.30	0.000014	0.00	0.0000242	0.000005
6	35.00	6.00	243.30	0.000028	0.01	0.0000544	0.000010
7	30.00	12.20	232.30	0.000059	0.04	0.0001419	0.000041
8	25.00	25.70	221.30	0.000131	0.26	0.0002010	0.000081
9	20.00	56.50	207.60	0.000308	3.24	0.0001123	0.000366
10	15.00	132.00	203.60	0.000757	13.56	0.0000278	0.000245
11	14.00	156.00	210.40	0.000986	7.24	0.0000266	0.000275
12	13.00	182.00	217.00	0.001790	5.88	0.0000266	0.000321
13	12.00	213.00	223.80	0.006080	9.23	0.0000254	0.000398
14	11.00	247.00	230.40	0.017900	13.50	0.0000242	0.000496
15	10.00	286.00	237.20	0.049000	18.84	0.0000231	0.000708
16	9.00	329.00	243.80	0.121000	25.22	0.0000231	0.001131
17	8.00	378.00	250.60	0.250000	28.82	0.0000231	0.002094
18	7.00	432.00	257.30	0.471000	31.40	0.0000242	0.003871
19	6.00	492.00	264.00	0.860000	34.23	0.0000254	0.004790
20	5.00	559.00	270.70	1.530000	37.46	0.0000266	0.005784
21	4.00	633.00	277.40	2.660000	41.16	0.0000278	0.006337
22	3.00	715.00	283.60	4.700000	48.64	0.0000302	0.009071
23	2.00	805.00	288.40	9.290000	71.39	0.0000319	0.016154
24	1.00	904.00	294.10	13.000000	71.19	0.0000331	0.025784
25	0.00	1013.00	300.00	19.000000	74.41	0.0000331	0.000000

Total Column Amounts (scaled) -
Water Vapor: 42462.81 g/m^2
Ozone: 3.21 g/m^2
Aerosol Optical Depth: 0.08 (unitless)
Scaling Factors - w.v., O3, haze RH, CO2, O2, w.v. continuum:
1.00 1.00 1.00 1.00 1.00 1.00
Cloud/clear types (models) in scene (101=clear): 1
INDIVIDUAL CLOUD CHARACTERISTICS:

Model Index	Top	Bott	Zthick (km)	Pthick (mb)	Frac	Tau	Ttop (K)	Ptop (mb)	Re (um)	WC (g/m^3)	Phase
1	10	24	15.000	792.6	1.00	250.0	204.4	111.4	2.5	0.025	Liquid

(Note: Above cloud fractions do not include overlapping portion, if any.)

SURFACE CHARACTERISTICS:
Clear Sky Fraction: 0.00
Surface Type Fractions -
Sea Water: 0.00, Freshwater: 0.00, Meltponds: 0.00, Melting snow: 0.00
Fresh snow: 0.00, Bare Ice: 0.00, Dry Sand: 0.00, Vegetation: 1.00

Grass: 0.00, Dry grass: 0.00, Deciduous: 0.00, Coniferous: 0.00
Clear-sky visible, broadband, integrated multi-band albedos (ALBTYPE=1,2,3):
0.142 0.278 0.067
Clear-sky albedo for each band (in order): 0.067

```
Polar Angle(deg)  Azim Angle(deg)
       (cosine)
-------------------------------------
     0.00 ( 1.00)       0.00

TOP LEVEL ALBEDO (ADJUSTED FOR SOLAR ZEN ANG):
Polar Angle(cos)  Azim Angle(deg)  Albedo
-------------------------------------------
    1.00             0.00         0.106
```

Radiance (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end
0.28304	33340.00	35710.00	0.00429	1780.00	1800.00	1.61087	980.00	1000.00
6.18263	30300.00	33340.00	0.00450	1760.00	1780.00	1.74395	960.00	980.00
9.22832	27780.00	30300.00	0.00526	1740.00	1760.00	0.27019	940.00	960.00
14.14589	25000.00	27780.00	0.00635	1720.00	1740.00	0.28213	920.00	940.00
21.81969	22720.00	25000.00	0.00735	1700.00	1720.00	0.30430	900.00	920.00
25.58923	20840.00	22720.00	0.00827	1680.00	1700.00	0.32714	880.00	900.00
24.43792	19240.00	20840.00	0.00909	1660.00	1680.00	0.35062	860.00	880.00
30.29489	17540.00	19240.00	0.01011	1640.00	1660.00	0.37484	840.00	860.00
39.32516	15620.00	17540.00	0.01097	1620.00	1640.00	0.40089	820.00	840.00
24.53012	14500.00	15620.00	0.01195	1600.00	1620.00	0.42777	800.00	820.00
27.24697	13300.00	14500.00	0.01308	1580.00	1600.00	0.45581	780.00	800.00
10.52936	12820.00	13300.00	0.01460	1560.00	1580.00	0.48587	760.00	780.00
30.08807	11540.00	12820.00	0.01598	1540.00	1560.00	0.52982	740.00	760.00
36.82439	10000.00	11540.00	0.01721	1520.00	1540.00	0.58728	720.00	740.00
20.11542	9120.00	10000.00	0.01860	1500.00	1520.00	0.67275	700.00	720.00
15.67828	8400.00	9120.00	0.01941	1480.00	1500.00	0.86104	680.00	700.00
11.70999	7840.00	8400.00	0.02104	1460.00	1480.00	1.04026	660.00	680.00
24.22127	6520.00	7840.00	0.02273	1440.00	1460.00	0.98311	640.00	660.00
7.46378	6080.00	6520.00	0.02485	1420.00	1440.00	0.83932	620.00	640.00
15.86562	4700.00	6080.00	0.02730	1400.00	1420.00	0.80201	600.00	620.00
4.14052	4200.00	4700.00	0.03022	1380.00	1400.00	0.79379	580.00	600.00
0.35983	3440.00	4200.00	0.03351	1360.00	1380.00	0.80769	560.00	580.00
0.21915	2920.00	3440.00	0.03742	1340.00	1360.00	0.83426	540.00	560.00
1.52456	2500.00	2920.00	0.04160	1320.00	1340.00	0.86205	520.00	540.00
0.00022	2400.00	2480.00	0.04604	1300.00	1320.00	0.88812	500.00	520.00
0.00044	2320.00	2400.00	0.05116	1280.00	1300.00	0.91172	480.00	500.00
0.00085	2240.00	2320.00	0.05686	1260.00	1280.00	0.93281	460.00	480.00
0.00192	2160.00	2240.00	0.06305	1240.00	1260.00	0.94973	440.00	460.00
0.00347	2080.00	2160.00	0.06987	1220.00	1240.00	0.96210	420.00	440.00
0.00450	2000.00	2080.00	0.07716	1200.00	1220.00	0.96819	400.00	420.00
0.00142	1980.00	2000.00	0.08506	1180.00	1200.00	0.96964	380.00	400.00
0.00157	1960.00	1980.00	0.09368	1160.00	1180.00	0.96618	360.00	380.00
0.00176	1940.00	1960.00	0.10333	1140.00	1160.00	0.95709	340.00	360.00
0.00196	1920.00	1940.00	0.12318	1120.00	1140.00	1.14122	320.00	340.00
0.00220	1900.00	1920.00	0.13608	1100.00	1120.00	1.29679	300.00	320.00
0.00246	1880.00	1900.00	0.14583	1080.00	1100.00	1.22983	280.00	300.00
0.00276	1860.00	1880.00	0.16082	1060.00	1080.00	1.15368	260.00	280.00
0.00310	1840.00	1860.00	0.20777	1040.00	1060.00	0.99437	240.00	260.00
0.00349	1820.00	1840.00	0.22950	1020.00	1040.00	0.92408	220.00	240.00
0.00401	1800.00	1820.00	0.37167	1000.00	1020.00	0.77231	200.00	220.00

3.2 Scene 2 – minSWrad

Streamer, v3.0b8 (beta test)

Input File: ../inputs/minSWrad.inp

INITIAL OPTIONS (later changes will not be noted):
Number of Streams, Shortwave: 24, Longwave: 16
Number of coefficients: 48
Gaseous absorption included.
Rayleigh scattering included.
Default profile: Tropical
Default aerosol optical model: Maritime
Default aerosol vertical profile: Background trop. and strat.
No spectral (band) weighting.
Using internal cloud optical properties.
No surface BRDF used.
++
Clear sky, Ocean, all wavebands
Year: 2000, Month: 7, Day: 4, Hour: 11.00
Lat: 0.000, Lon: 0.000, Zenith Angle (degrees): 80.00

Unscaled Atmospheric Profiles (25 Levels)

	Height(km)	Press(mb)	T(K)	H2O(g/m^3)	RH(%)	O3(g/m^3)	Aer(km^-1)
1	100.00	0.00	210.80	0.000000	0.00	0.0000000	0.000000
2	70.00	0.06	219.50	0.000000	0.00	0.0000001	0.000000
3	50.00	0.85	270.00	0.000004	0.00	0.0000068	0.000001
4	45.00	1.59	264.90	0.000007	0.00	0.0000205	0.000002
5	40.00	3.05	254.30	0.000014	0.00	0.0000646	0.000005
6	35.00	6.00	243.30	0.000028	0.01	0.0001451	0.000010
7	30.00	12.20	232.30	0.000059	0.04	0.0003784	0.000041
8	25.00	25.70	221.30	0.000131	0.26	0.0005361	0.000081
9	20.00	56.50	207.60	0.000308	3.24	0.0002996	0.000366
10	15.00	132.00	203.60	0.000757	13.56	0.0000741	0.000245
11	14.00	156.00	210.40	0.000986	7.24	0.0000710	0.000275
12	13.00	182.00	217.00	0.001790	5.88	0.0000710	0.000321
13	12.00	213.00	223.80	0.006080	9.23	0.0000678	0.000398
14	11.00	247.00	230.40	0.017900	13.50	0.0000646	0.000496
15	10.00	286.00	237.20	0.049000	18.84	0.0000615	0.000708
16	9.00	329.00	243.80	0.121000	25.22	0.0000615	0.001131
17	8.00	378.00	250.60	0.250000	28.82	0.0000615	0.002094
18	7.00	432.00	257.30	0.471000	31.40	0.0000646	0.003871
19	6.00	492.00	264.00	0.860000	34.23	0.0000678	0.004790
20	5.00	559.00	270.70	1.530000	37.46	0.0000710	0.005784
21	4.00	633.00	277.40	2.660000	41.16	0.0000741	0.006337
22	3.00	715.00	283.60	4.700000	48.64	0.0000804	0.009071
23	2.00	805.00	288.40	9.290000	71.39	0.0000851	0.016154
24	1.00	904.00	294.10	13.000000	71.19	0.0000883	0.025784
25	0.00	1013.00	300.00	19.000000	74.41	0.0000883	0.000000

Total Column Amounts (scaled) -
Water Vapor: 42462.81 g/m^2
Ozone: 8.57 g/m^2
Aerosol Optical Depth: 0.08 (unitless)
Scaling Factors - w.v., O3, haze RH, CO2, O2, w.v. continuum:
1.00 1.00 1.00 1.00 1.00 1.00
Cloud/clear types (models) in scene (101=clear): 101

SURFACE CHARACTERISTICS:
Clear Sky Fraction: 1.00
Surface Type Fractions -
Sea Water: 1.00, Freshwater: 0.00, Meltponds: 0.00, Melting snow: 0.00
Fresh snow: 0.00, Bare Ice: 0.00, Dry Sand: 0.00, Vegetation: 0.00
Grass: 0.00, Dry grass: 0.00, Deciduous: 0.00, Coniferous: 0.00
Clear-sky visible, broadband, integrated multi-band albedos (ALBTYPE=1,2,3):
0.227 0.227 0.227
Clear-sky albedo for each band (in order): 0.227

```
Polar Angle(deg)  Azim Angle(deg)
     (cosine)
-----------------------------------
  55.00 ( 0.57)    180.00
```

```
TOP LEVEL ALBEDO (ADJUSTED FOR SOLAR ZEN ANG):
Polar Angle(cos)  Azim Angle(deg)  Albedo
-----------------------------------------
    0.57          180.00        0.026
```

Radiance (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end
0.01228	33340.00	35710.00	0.04136	1780.00	1800.00	1.45136	980.00	1000.00
0.53138	30300.00	33340.00	0.04093	1760.00	1780.00	1.70383	960.00	980.00
1.22496	27780.00	30300.00	0.03796	1740.00	1760.00	1.82576	940.00	960.00
1.76448	25000.00	27780.00	0.04236	1720.00	1740.00	1.90776	920.00	940.00
2.42263	22720.00	25000.00	0.04087	1700.00	1720.00	1.96671	900.00	920.00
2.50200	20840.00	22720.00	0.04114	1680.00	1700.00	2.03305	880.00	900.00
2.00592	19240.00	20840.00	0.05012	1660.00	1680.00	2.09901	860.00	880.00
2.21683	17540.00	19240.00	0.05078	1640.00	1660.00	2.13764	840.00	860.00
2.32466	15620.00	17540.00	0.06692	1620.00	1640.00	2.21722	820.00	840.00
1.32173	14500.00	15620.00	0.09226	1600.00	1620.00	2.20955	800.00	820.00
1.25772	13300.00	14500.00	0.13703	1580.00	1600.00	2.19255	780.00	800.00
0.41913	12820.00	13300.00	0.07985	1560.00	1580.00	2.19123	760.00	780.00
1.22466	11540.00	12820.00	0.07038	1540.00	1560.00	1.68364	740.00	760.00
0.96056	10000.00	11540.00	0.07296	1520.00	1540.00	1.27054	720.00	740.00
0.82138	9120.00	10000.00	0.07870	1500.00	1520.00	0.95011	700.00	720.00
0.27916	8400.00	9120.00	0.10988	1480.00	1500.00	0.94081	680.00	700.00
0.49406	7840.00	8400.00	0.12635	1460.00	1480.00	1.12009	660.00	680.00
0.24924	6520.00	7840.00	0.15447	1440.00	1460.00	1.06116	640.00	660.00
0.31535	6080.00	6520.00	0.17697	1420.00	1440.00	1.04089	620.00	640.00
0.31193	4700.00	6080.00	0.20349	1400.00	1420.00	1.33200	600.00	620.00
0.17085	4200.00	4700.00	0.21827	1380.00	1400.00	1.74094	580.00	600.00
0.00617	3440.00	4200.00	0.28212	1360.00	1380.00	2.06184	560.00	580.00
0.00407	2920.00	3440.00	0.35746	1340.00	1360.00	2.18353	540.00	560.00
0.16957	2500.00	2920.00	0.42961	1320.00	1340.00	2.15914	520.00	540.00
0.06993	2400.00	2480.00	0.55219	1300.00	1320.00	2.03933	500.00	520.00
0.09447	2320.00	2400.00	0.65684	1280.00	1300.00	2.07295	480.00	500.00
0.12585	2240.00	2320.00	0.66268	1260.00	1280.00	1.94003	460.00	480.00
0.16719	2160.00	2240.00	0.82031	1240.00	1260.00	1.88927	440.00	460.00
0.21558	2080.00	2160.00	0.90978	1220.00	1240.00	1.84485	420.00	440.00
0.24394	2000.00	2080.00	0.96123	1200.00	1220.00	1.83665	400.00	420.00
0.05604	1980.00	2000.00	1.03503	1180.00	1200.00	1.71712	380.00	400.00
0.06617	1960.00	1980.00	1.08395	1160.00	1180.00	1.63612	360.00	380.00
0.05523	1940.00	1960.00	1.14658	1140.00	1160.00	1.45339	340.00	360.00
0.05627	1920.00	1940.00	1.17966	1120.00	1140.00	1.32227	320.00	340.00
0.05332	1900.00	1920.00	1.22720	1100.00	1120.00	1.25341	300.00	320.00
0.06083	1880.00	1900.00	1.30321	1080.00	1100.00	1.18987	280.00	300.00
0.05010	1860.00	1880.00	1.07138	1060.00	1080.00	1.11809	260.00	280.00
0.05023	1840.00	1860.00	0.84939	1040.00	1060.00	0.96679	240.00	260.00
0.04317	1820.00	1840.00	0.92663	1020.00	1040.00	0.89919	220.00	240.00
0.05100	1800.00	1820.00	1.10699	1000.00	1020.00	0.78094	200.00	220.00

Scene 3 – maxLWrad

Streamer, v3.0b8 (beta test)

Input File: ../inputs/maxLWrad.inp

INITIAL OPTIONS (later changes will not be noted):
Number of Streams, Shortwave: 24, Longwave: 16
Number of coefficients: 48
Gaseous absorption included.
Rayleigh scattering included.
Default profile: Mid-latitude Summer
Default aerosol optical model: Rural
Default aerosol vertical profile: High trop., background strat.
No spectral (band) weighting.
Using internal cloud optical properties.
No surface BRDF used.
+++
Clear sky, Desert, all wavebands
Year: 2000, Month: 7, Day: 4, Hour: 12.00
Lat: 0.000, Lon: 0.000, Zenith Angle (degrees): 45.00

Unscaled Atmospheric Profiles (91 Levels)

	Height(km)	Press(mb)	T(K)	H2O(g/m^3)	RH(%)	O3(g/m^3)	Aer(km^-1)
1	100.00	0.00	210.70	0.000000	0.00	0.0000000	0.000000
2	70.00	0.07	219.10	0.000000	0.00	0.0000001	0.000000
3	50.00	0.95	276.20	0.000003	0.00	0.0000043	0.000003
4	45.00	1.76	269.70	0.000005	0.00	0.0000130	0.000006
5	40.00	3.33	257.50	0.000010	0.00	0.0000410	0.000018
6	30.98	10.50	233.85	0.003790	2.02	0.0001788	0.000025
7	30.00	12.10	236.80	0.005046	2.02	0.0002000	0.000101
8	27.50	17.54	226.79	0.001853	2.04	0.0002500	0.000101
9	25.00	25.77	220.54	0.000935	2.04	0.0003000	0.000200
10	22.50	38.12	216.73	0.001052	3.57	0.0003200	0.000400
11	19.00	67.33	201.69	0.000676	15.76	0.0003100	0.000900
12	17.50	86.99	196.40	0.000395	19.66	0.0002650	0.000900
13	16.00	112.87	197.72	0.000474	19.43	0.0002200	0.000801
14	14.50	145.60	206.11	0.001126	14.39	0.0001850	0.000651
15	13.00	185.78	216.88	0.002239	7.46	0.0001500	0.000853
16	11.50	233.14	230.29	0.003964	3.02	0.0001150	0.001140
17	10.00	289.97	241.33	0.007724	2.02	0.0000900	0.001742
18	9.75	300.42	243.54	0.009420	2.01	0.0000890	0.001742
19	9.50	310.93	245.76	0.011492	2.01	0.0000880	0.001742
20	9.25	321.69	247.99	0.013934	2.01	0.0000870	0.001742
21	9.00	332.88	250.18	0.016791	2.01	0.0000860	0.002781
22	8.75	344.50	252.58	0.020587	2.01	0.0000842	0.002781
23	8.50	356.53	254.93	0.024871	2.01	0.0000825	0.002781
24	8.25	368.70	255.11	0.025210	2.00	0.0000807	0.002781
25	8.00	381.20	255.17	0.027513	2.18	0.0000790	0.005149

26	7.75	394.15	255.36	0.039078	3.04	0.0000780	0.005149
27	7.50	407.52	257.03	0.044180	3.01	0.0000770	0.005149
28	7.25	421.23	258.98	0.051169	2.99	0.0000760	0.005149
29	7.00	435.40	260.92	0.060176	3.03	0.0000750	0.009519
30	6.75	449.88	259.71	0.848441	46.84	0.0000735	0.009519
31	6.50	464.89	261.08	1.231648	61.15	0.0000720	0.009519
32	6.25	480.36	262.83	1.355704	58.94	0.0000705	0.009519
33	6.00	496.16	264.86	1.537613	57.43	0.0000690	0.011781
34	5.75	511.81	267.32	1.640566	51.14	0.0000683	0.011781
35	5.50	527.78	269.67	1.676066	44.13	0.0000675	0.011781
36	5.25	544.38	272.05	1.716962	38.25	0.0000668	0.011781
37	5.00	561.46	274.48	1.772867	33.40	0.0000660	0.014226
38	4.75	578.98	276.92	1.828477	29.21	0.0000655	0.014226
39	4.50	596.99	279.34	1.867814	25.42	0.0000650	0.014226
40	4.25	615.65	281.73	1.887410	22.00	0.0000645	0.014226
41	4.00	634.91	284.12	1.912055	19.16	0.0000640	0.028268
42	3.90	642.79	285.07	1.935316	18.26	0.0000638	0.028268
43	3.80	650.82	286.03	1.975210	17.55	0.0000636	0.028268
44	3.70	658.94	286.99	2.024189	16.95	0.0000634	0.028268
45	3.60	667.07	287.96	2.074522	16.38	0.0000632	0.028268
46	3.50	675.14	288.93	2.121188	15.79	0.0000630	0.028268
47	3.40	683.20	289.91	2.178017	15.28	0.0000628	0.028268
48	3.30	691.27	290.89	2.230148	14.75	0.0000626	0.028268
49	3.20	699.35	291.87	2.255189	14.07	0.0000624	0.028268
50	3.10	707.41	292.85	2.247593	13.24	0.0000622	0.028268
51	3.00	715.45	293.83	2.226930	12.39	0.0000620	0.052868
52	2.90	723.59	294.80	2.202035	11.58	0.0000618	0.052868
53	2.80	731.94	295.77	2.181273	10.84	0.0000616	0.052868
54	2.70	740.44	296.75	2.161764	10.16	0.0000614	0.052868
55	2.60	749.02	297.72	2.140694	9.53	0.0000612	0.052868
56	2.50	757.68	298.69	2.118633	8.92	0.0000610	0.052868
57	2.40	766.42	299.67	2.096149	8.36	0.0000608	0.052868
58	2.30	775.24	300.64	2.073810	7.84	0.0000606	0.052868
59	2.20	784.13	301.61	2.052183	7.35	0.0000604	0.052868
60	2.10	793.09	302.58	2.031838	6.90	0.0000602	0.052868
61	2.00	802.13	303.55	2.013342	6.49	0.0000600	0.094888
62	1.90	811.23	304.52	1.997262	6.11	0.0000600	0.094888
63	1.80	820.40	305.49	1.984169	5.76	0.0000600	0.094888
64	1.70	829.63	306.46	1.974629	5.45	0.0000600	0.094888
65	1.60	838.92	307.42	1.969210	5.17	0.0000600	0.094888
66	1.50	848.36	308.39	2.006116	5.00	0.0000600	0.094888
67	1.48	850.77	308.62	2.020908	4.98	0.0000600	0.094888
68	1.45	853.16	308.86	2.023401	4.92	0.0000600	0.094888
69	1.43	855.55	309.09	2.025447	4.87	0.0000600	0.094888
70	1.40	857.94	309.31	2.027096	4.82	0.0000600	0.094888
71	1.38	860.32	309.54	2.028398	4.77	0.0000600	0.094888
72	1.35	862.70	309.76	2.029402	4.71	0.0000600	0.094888
73	1.32	865.08	309.98	2.030160	4.66	0.0000600	0.094888
74	1.30	867.45	310.20	2.030721	4.61	0.0000600	0.094888
75	1.28	869.83	310.42	2.031135	4.56	0.0000600	0.094888
76	1.25	872.21	310.64	2.031453	4.51	0.0000600	0.094888

77	1.23	874.59	310.86	2.031725	4.46	0.0000600	0.094888
78	1.20	876.97	311.08	2.032001	4.41	0.0000600	0.094888
79	1.18	879.35	311.30	2.032330	4.36	0.0000600	0.094888
80	1.15	881.75	311.52	2.032765	4.31	0.0000600	0.094888
81	1.12	884.14	311.74	2.033353	4.27	0.0000600	0.094888
82	1.10	886.55	311.96	2.034147	4.22	0.0000600	0.094888
83	1.07	888.96	312.19	2.035195	4.17	0.0000600	0.094888
84	1.05	891.38	312.42	2.036548	4.13	0.0000600	0.094888
85	1.02	893.81	312.65	2.038256	4.08	0.0000600	0.094888
86	1.00	896.25	312.88	2.040370	4.04	0.0000600	1.176548
87	0.97	898.70	313.12	2.042939	4.00	0.0000600	1.176548
88	0.95	901.19	313.36	2.057651	3.98	0.0000600	1.176548
89	0.93	903.70	313.62	2.089510	3.99	0.0000600	1.176548
90	0.90	906.20	313.87	2.117864	3.99	0.0000600	1.176548
91	0.64	932.00	318.15	3.919498	5.98	0.0000600	0.000000

Total Column Amounts (scaled) -
Water Vapor: 11966.04 g/m^2
Ozone: 6.89 g/m^2
Aerosol Optical Depth: 0.66 (unitless)
Scaling Factors - w.v., O3, haze RH, CO2, O2, w.v. continuum:
1.00 1.00 1.00 1.00 1.00 1.00
Cloud/clear types (models) in scene (101=clear): 101
SURFACE CHARACTERISTICS:
Clear Sky Fraction: 1.00
Surface Type Fractions -
Sea Water: 0.00, Freshwater: 0.00, Meltponds: 0.00, Melting snow: 0.00
Fresh snow: 0.00, Bare Ice: 0.00, Dry Sand: 1.00, Vegetation: 0.00
Grass: 0.00, Dry grass: 0.00, Deciduous: 0.00, Coniferous: 0.00
Clear-sky visible, broadband, integrated multi-band albedos (ALBTYPE=1,2,3):
0.149 0.229 0.091
Clear-sky albedo for each band (in order): 0.091

```
 Polar Angle(deg)  Azim Angle(deg)
      (cosine)
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    0.00 ( 1.00)       0.00
```

TOP LEVEL ALBEDO (ADJUSTED FOR SOLAR ZEN ANG):

```
Polar Angle(cos)  Azim Angle(deg)  Albedo
-----------------------------------------
     1.00             0.00        0.013
```

Radiance (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end
0.02519	33340.00	35710.00	0.06742	1780.00	1800.00	2.78444	980.00	1000.00
1.29073	30300.00	33340.00	0.06824	1760.00	1780.00	3.15120	960.00	980.00
2.06167	27780.00	30300.00	0.06677	1740.00	1760.00	3.30539	940.00	960.00
2.63980	25000.00	27780.00	0.07330	1720.00	1740.00	3.40741	920.00	940.00
3.39872	22720.00	25000.00	0.07365	1700.00	1720.00	3.45732	900.00	920.00
3.48478	20840.00	22720.00	0.07583	1680.00	1700.00	3.52440	880.00	900.00
3.04451	19240.00	20840.00	0.08787	1660.00	1680.00	3.58985	860.00	880.00
3.67237	17540.00	19240.00	0.09084	1640.00	1660.00	3.58787	840.00	860.00
4.76103	15620.00	17540.00	0.11039	1620.00	1640.00	3.69094	820.00	840.00
3.28065	14500.00	15620.00	0.14148	1600.00	1620.00	3.59857	800.00	820.00
4.09830	13300.00	14500.00	0.22356	1580.00	1600.00	3.50359	780.00	800.00
1.54451	12820.00	13300.00	0.13257	1560.00	1580.00	3.47069	760.00	780.00
5.21663	11540.00	12820.00	0.12527	1540.00	1560.00	2.52927	740.00	760.00
5.68104	10000.00	11540.00	0.13075	1520.00	1540.00	1.76454	720.00	740.00
4.06503	9120.00	10000.00	0.14021	1500.00	1520.00	1.11228	700.00	720.00
2.26191	8400.00	9120.00	0.17772	1480.00	1500.00	0.90061	680.00	700.00
2.81041	7840.00	8400.00	0.19846	1460.00	1480.00	1.05962	660.00	680.00
2.57925	6520.00	7840.00	0.23170	1440.00	1460.00	1.00362	640.00	660.00
2.06525	6080.00	6520.00	0.26040	1420.00	1440.00	1.12649	620.00	640.00
2.91014	4700.00	6080.00	0.29557	1400.00	1420.00	1.62981	600.00	620.00
1.36259	4200.00	4700.00	0.31532	1380.00	1400.00	2.20420	580.00	600.00
0.20350	3440.00	4200.00	0.41777	1360.00	1380.00	2.62428	560.00	580.00
0.16811	2920.00	3440.00	0.57807	1340.00	1360.00	2.77701	540.00	560.00
1.08864	2500.00	2920.00	0.74565	1320.00	1340.00	2.67363	520.00	540.00
0.40075	2400.00	2480.00	1.06228	1300.00	1320.00	2.41598	500.00	520.00
0.50605	2320.00	2400.00	1.32802	1280.00	1300.00	2.45868	480.00	500.00
0.61556	2240.00	2320.00	1.29160	1260.00	1280.00	2.22863	460.00	480.00
0.75574	2160.00	2240.00	1.71741	1240.00	1260.00	2.14794	440.00	460.00
0.87744	2080.00	2160.00	1.92476	1220.00	1240.00	2.08157	420.00	440.00
0.84488	2000.00	2080.00	2.00863	1200.00	1220.00	2.06231	400.00	420.00
0.16335	1980.00	2000.00	2.15856	1180.00	1200.00	1.91524	380.00	400.00
0.19953	1960.00	1980.00	2.23104	1160.00	1180.00	1.82020	360.00	380.00
0.14340	1940.00	1960.00	2.36283	1140.00	1160.00	1.64753	340.00	360.00
0.13935	1920.00	1940.00	2.42986	1120.00	1140.00	1.51125	320.00	340.00
0.11926	1900.00	1920.00	2.47162	1100.00	1120.00	1.42732	300.00	320.00
0.14023	1880.00	1900.00	2.60795	1080.00	1100.00	1.34676	280.00	300.00
0.09330	1860.00	1880.00	2.19245	1060.00	1080.00	1.25809	260.00	280.00
0.08839	1840.00	1860.00	1.72900	1040.00	1060.00	1.09063	240.00	260.00
0.06970	1820.00	1840.00	1.86956	1020.00	1040.00	1.00830	220.00	240.00
0.08327	1800.00	1820.00	2.20622	1000.00	1020.00	0.87068	200.00	220.00

Scene 4 – minLWrad

Streamer, v3.0b8 (beta test)

Input File: ../inputs/minLWrad2.inp

INITIAL OPTIONS (later changes will not be noted):
Number of Streams, Shortwave: 24, Longwave: 16
Number of coefficients: 48
Gaseous absorption included.
Rayleigh scattering included.
Default profile: Tropical
Default aerosol optical model: Rural
Default aerosol vertical profile: Background trop. and strat.
No spectral (band) weighting.
Using internal cloud optical properties.
No surface BRDF used.
++
Liquid Cloud, Ocean, all wavebands
Year: 2000, Month: 7, Day: 4, Hour: 12.00
Lat: 0.000, Lon: 0.000, Zenith Angle (degrees): 45.00

Unscaled Atmospheric Profiles (25 Levels)

	Height(km)	Press(mb)	T(K)	H2O(g/m^3)	RH(%)	O3(g/m^3)	Aer(km^-1)
1	100.00	0.00	210.80	0.000000	0.00	0.0000000	0.000000
2	70.00	0.06	219.50	0.000000	0.00	0.0000001	0.000000
3	50.00	0.85	270.00	0.000004	0.00	0.0000025	0.000001
4	45.00	1.59	264.90	0.000007	0.00	0.0000077	0.000002
5	40.00	3.05	254.30	0.000014	0.00	0.0000242	0.000005
6	35.00	6.00	243.30	0.000028	0.01	0.0000544	0.000010
7	30.00	12.20	232.30	0.000059	0.04	0.0001419	0.000041
8	25.00	25.70	221.30	0.000131	0.26	0.0002010	0.000081
9	20.00	56.50	207.60	0.000308	3.24	0.0001123	0.000366
10	15.00	132.00	203.60	0.000757	13.56	0.0000278	0.000245
11	14.00	156.00	210.40	0.000986	7.24	0.0000266	0.000275
12	13.00	182.00	217.00	0.001790	5.88	0.0000266	0.000321
13	12.00	213.00	223.80	0.006080	9.23	0.0000254	0.000398
14	11.00	247.00	230.40	0.017900	13.50	0.0000242	0.000496
15	10.00	286.00	237.20	0.049000	18.84	0.0000231	0.000708
16	9.00	329.00	243.80	0.121000	25.22	0.0000231	0.001131
17	8.00	378.00	250.60	0.250000	28.82	0.0000231	0.002094
18	7.00	432.00	257.30	0.471000	31.40	0.0000242	0.003871
19	6.00	492.00	264.00	0.860000	34.23	0.0000254	0.004790
20	5.00	559.00	270.70	1.530000	37.46	0.0000266	0.005784
21	4.00	633.00	277.40	2.660000	41.16	0.0000278	0.006337
22	3.00	715.00	283.60	4.700000	48.64	0.0000302	0.009071
23	2.00	805.00	288.40	9.290000	71.39	0.0000319	0.016154
24	1.00	904.00	294.10	13.000000	71.19	0.0000331	0.025784
25	0.00	1013.00	300.00	19.000000	74.41	0.0000331	0.000000

```
Total Column Amounts (scaled) -
          Water Vapor: 42462.81 g/m^2
          Ozone:   3.21 g/m^2
          Aerosol Optical Depth: 0.08 (unitless)
Scaling Factors - w.v., O3, haze RH, CO2, O2, w.v. continuum:
          1.00  1.00  1.00  1.00  1.00  1.00
Cloud/clear types (models) in scene (101=clear):    1
INDIVIDUAL CLOUD CHARACTERISTICS:
Model Top Bott Zthick Pthick  Frac  Tau  Ttop   Ptop    Re    WC   Phase
       Index   (km)   (mb)            (K)    (mb)   (um)(g/m^3)
--------------------------------------------------------------------------------
   1  10  24  15.000  792.6   1.00 250.0 204.4  111.4  50.0 0.551  Liquid
  (Note: Above cloud fractions do not include overlapping portion, if any.)
SURFACE CHARACTERISTICS:
          Clear Sky Fraction: 0.00
          Surface Type Fractions -
          Sea Water: 1.00, Freshwater: 0.00, Meltponds: 0.00, Melting snow: 0.00
          Fresh snow: 0.00, Bare Ice: 0.00, Dry Sand: 0.00, Vegetation: 0.00
          Grass: 0.00, Dry grass: 0.00, Deciduous: 0.00, Coniferous: 0.00
          Clear-sky visible, broadband, integrated multi-band albedos (ALBTYPE=1,2,3):
                    0.060 0.060 0.060
          Clear-sky albedo for each band (in order):  0.060
Polar Angle(deg)  Azim Angle(deg)
      (cosine)
 -----------------------------------
   55.00 ( 0.57)      0.00

TOP LEVEL ALBEDO (ADJUSTED FOR SOLAR ZEN ANG):
Polar Angle(cos)  Azim Angle(deg)  Albedo
 -------------------------------------------
   0.57            0.00        0.067
```

Radiance (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end	Radiance (ctned) (W/m^2-sr) TOA	Spectral Interval (1/cm) start	end
0.12851	33340.00	35710.00	0.00477	1780.00	1800.00	0.23593	980.00	1000.00
4.33971	30300.00	33340.00	0.00534	1760.00	1780.00	0.23942	960.00	980.00
6.88218	27780.00	30300.00	0.00603	1740.00	1760.00	0.25626	940.00	960.00
10.71682	25000.00	27780.00	0.00668	1720.00	1740.00	0.27645	920.00	940.00
16.65494	22720.00	25000.00	0.00752	1700.00	1720.00	0.29831	900.00	920.00
19.63314	20840.00	22720.00	0.00845	1680.00	1700.00	0.32130	880.00	900.00
18.77853	19240.00	20840.00	0.00922	1660.00	1680.00	0.34548	860.00	880.00
23.34381	17540.00	19240.00	0.01031	1640.00	1660.00	0.37060	840.00	860.00
30.24703	15620.00	17540.00	0.01117	1620.00	1640.00	0.39730	820.00	840.00
18.85422	14500.00	15620.00	0.01219	1600.00	1620.00	0.42484	800.00	820.00
20.87126	13300.00	14500.00	0.01337	1580.00	1600.00	0.45372	780.00	800.00
8.01722	12820.00	13300.00	0.01527	1560.00	1580.00	0.48488	760.00	780.00
22.57417	11540.00	12820.00	0.01738	1540.00	1560.00	0.53498	740.00	760.00
25.98554	10000.00	11540.00	0.01937	1520.00	1540.00	0.60152	720.00	740.00
12.92506	9120.00	10000.00	0.02142	1500.00	1520.00	0.70322	700.00	720.00
9.20411	8400.00	9120.00	0.02283	1480.00	1500.00	0.92381	680.00	700.00
6.03036	7840.00	8400.00	0.02508	1460.00	1480.00	1.11892	660.00	680.00
10.26003	6520.00	7840.00	0.02746	1440.00	1460.00	1.05389	640.00	660.00
2.76520	6080.00	6520.00	0.03021	1420.00	1440.00	0.87924	620.00	640.00
3.56663	4700.00	6080.00	0.03323	1400.00	1420.00	0.82317	600.00	620.00
0.55557	4200.00	4700.00	0.03663	1380.00	1400.00	0.80317	580.00	600.00
0.00000	3440.00	4200.00	0.04015	1360.00	1380.00	0.81096	560.00	580.00
0.00000	2920.00	3440.00	0.04410	1340.00	1360.00	0.83601	540.00	560.00
0.01559	2500.00	2920.00	0.04847	1320.00	1340.00	0.86303	520.00	540.00
0.00049	2400.00	2480.00	0.05326	1300.00	1320.00	0.88848	500.00	520.00
0.00078	2320.00	2400.00	0.05851	1280.00	1300.00	0.91068	480.00	500.00
0.00124	2240.00	2320.00	0.06427	1260.00	1280.00	0.93002	460.00	480.00
0.00195	2160.00	2240.00	0.07052	1240.00	1260.00	0.94492	440.00	460.00
0.00306	2080.00	2160.00	0.07734	1220.00	1240.00	0.95516	420.00	440.00
0.00478	2000.00	2080.00	0.08477	1200.00	1220.00	0.96006	400.00	420.00
0.00157	1980.00	2000.00	0.09288	1180.00	1200.00	0.96017	380.00	400.00
0.00175	1960.00	1980.00	0.10182	1160.00	1180.00	0.95373	360.00	380.00
0.00195	1940.00	1960.00	0.11195	1140.00	1160.00	0.94329	340.00	360.00
0.00218	1920.00	1940.00	0.12381	1120.00	1140.00	0.92420	320.00	340.00
0.00243	1900.00	1920.00	0.13482	1100.00	1120.00	0.89797	300.00	320.00
0.00271	1880.00	1900.00	0.14670	1080.00	1100.00	0.86104	280.00	300.00
0.00303	1860.00	1880.00	0.18475	1060.00	1080.00	0.81830	260.00	280.00
0.00339	1840.00	1860.00	0.23759	1040.00	1060.00	0.77355	240.00	260.00
0.00380	1820.00	1840.00	0.24946	1020.00	1040.00	0.71262	220.00	240.00
0.00422	1800.00	1820.00	0.24887	1000.00	1020.00	0.65203	200.00	220.00

ANNEX-4 EarthCARE SRD Requirements & Paragraphs Numbering Matrix

This annex intends to help the reader to identify the SRD section into which a SRD requirement reference (listed here below by alphabetic order) is specified:

SRD Req. Reference & Meaning:		SRD Section Number:
AIT-GS	AIT Ground Support	7.4.1
AIT-SD	AIT Software Development	7.4.2
ALT-DF	Altitude definitions	3.5.1
ATL-CA	ATLID Calibration	5.2.9
ATL-DE	ATLID Design requirements	5.2.6
ATL-DP	ATLID Data Product	5.2.10
ATL-FR	ATLID Functional	5.2.2
ATL-GR	ATLID Geometrical	5.2.7
ATL-OP	ATLID Operational	5.2.3
ATL-PO	ATLID Polarisation	5.2.5
ATL-PR	ATLID Performance	5.2.8
ATL-SR	ATLID Spectral	5.2.4
AOS-FU	AOCS Functional	7.3.1.2
AOS-GE	AOCS General	7.3.1.1
AOS-OP	AOCS Operational	7.3.1.4
AOS-PE	AOCS performance	7.3.1.3
BBR-BS	BBR Bright Scenes	5.5.6.5
BBR-CC	BBR Sun illumination	5.5.6.5
BBR-CO	BBR Contamination	5.5.4
BBR-DP	BBR Data Product	5.5.10
BBR-DS	BBR Design	5.5.6
BBR-FO	BBR Functional & Operational	5.5.3
BBR-GD	BBR Geometrical Data Quality	5.5.8.1
BBR-GR	BBR Geometrical Requirements	5.5.6.2
BBR-IC	BBR In-flight Calibration	5.5.9
BBR-IE	BBR Integrated Energy	5.5.6.3
BBR-LW	BBR LW Requirement	5.5.7
BBR-PR	BBR Procurement	5.5.5

BBR-PS	BBR Polarisation Sensitivity	5.5.6.4
BBR-RD	BBR Radiometric	5.5.8.2
BBR-SR	BBR Spectral	5.5.6.1.1
COM-FU	Communications TTC	7.3.6.2
COM-GE	Communications General	7.3.6.1
COM-HR	Communications High Rate	7.3.6.3
CPR-DA	CPR Data	5.3.6
CPR-DP	CPR Data Product	5.3.9
CPR-DR	CPR Design	5.3.10
CPR-FO	CPR Functional & Operational	5.3.2
CPR-FR	CPR Frequency	5.3.3
CPR-GR	CPR Geometrical	5.3.5
CPR-PO	CPR Polarisation	5.3.4
CPR-PM	CPR Performance Modelling	5.3.8
CPR-RA	CPR Radiometric	5.3.7
CPR-SP	CPR Spacecraft	5.3.12
DER-EN	Design Requirements Environment	7.2.2
DER-GE	Design Requirements General	7.2.1
DER-LL	Design Requirements Launcher	7.2.3
DHS-FD	Data Handling FDIR	7.3.5.8
DHS-GE	Data Handling General	7.3.5.1
DHS-IO	Data Handling Interface	7.3.5.3
DHS-MM	Data Handling Data Storage	7.3.5.6
DHS-PC	Data Handling Processing	7.3.5.7
DHS-TC	Data Handling TC Requirements	7.3.5.2
DHS-TI	Data Handling Datation (Time)	7.3.5.4
DHS-TM	Data Handling TM requirements	7.3.5.5
DPR-DP	Data Processing Data Product	8.1
DPR-GP	Data Processing Ground Processor	8.4
DPR-GS	Data Processing Ground Software	8.2
DPR-PF	Data Processing Product Format	8.5
DPR-SI	Data Processing Simulator	8.3
EMC-EC	EMC Electromagnetic Compatibility	7.2.4

PRO-FU	Propulsion Functional	7.3.2.2
PRO-GE	Propulsion General	7.3.2.1
PRO-OP	Propulsion Operational	7.3.2.4
PRO-PE	Propulsion Performance	7.3.2.3
REF-0D	Reference Frame 0-Doppler	3.6.2
REF-IR	Reference Frame Celestial	3.6.3
REF-SF	Reference Frame Spacecraft	3.6.5
REF-TR	Reference Frame Terrestrial	3.6.4
REF-UM	Reference Frame Units	3.7
REF-YS	Reference Frame Yaw steering	3.6.1
TCS-AD	Thermal Additional requirements	7.3.3.5
TCS-AV	Thermal Analysis & Verification	7.3.3.4
TCS-DR	Thermal Design Requirements	7.3.3.3
TCS-GE	Thermal General	7.3.3.1
TCS-MP	Thermal Mission Phases	7.3.3.2

End of document