Post-EPS Mission Requirements Document

(*Initial Version*)

All requirements in this document are DRAFT and to be confirmed

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1 INTRODUCTION

EUMETSAT and ESA have initiated joint preparatory activities for the definition of the Post EUMETSAT Polar System (PEPS) that needs to be available in the 2019 timeframe as a replacement for the EUMETSAT Polar System.

Based on the first outputs of the EUMETSAT post-EPS User Consultation process initiated in 2005, ESA and EUMETSAT have started pre-phase A studies at instrument and system levels with the support of industry and representatives of the user and science communities. Such studies are planned for completion in 2008 and aim at defining and trading off possible mission and system concepts fulfilling the high-level user needs and priorities, established during the user consultation.

This document captures the mission requirements assigned to PEPS as a result of the analysis and interpretation of high-level user needs and the identification and assessment of relevant observing techniques by remote sensing and satellite experts. It is one of the key user inputs to the system level pre-phase A studies planned in 2006. The generation of the mission requirements have been supported substantially be the Post-EPS Mission Experts Team (PMET):

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1.1 Purpose and Scope of this Document

This PEPS Mission Requirements Document defines and characterises the missions that the EUMETSAT Customers and users wish to assign to the Post-EPS (PEPS) polar orbiting satellite system. The requirements it contains are fully traced

- upwards to high level user needs and priorities identified in the user consultation process and documented in the AEG position papers,
- downwards to lower level pre-phase A requirements documents like the Mission Assumptions and Technical Requirements (MATER).

The PEPS Mission Requirements captured in this document are preliminary and do not at this stage reflect any consideration of technical feasibility or affordability. They are intended to provide a *key user input* to notional studies and a reference for trade off of mission concepts and architectures planned in the context of pre-phase A activities.

Therefore, none of the PEPS missions presented in this document should be equated to an instrument design or any explicit implementation option. Likewise, this document does not identify any technical or programmatic constraints for the definition of the PEPS system. The general objectives, programmatic assumptions, associated constraints and derived requirements common to all missions are identified in the Programmatic Assumptions and Requirements Document (PARD). Mission and programmatic requirements have therefore to be taken together when trading the possible mission scenarios and architectures.

Pre-Phase A studies at system level will establish preliminary mission concepts and functional requirements for full or partial implementation of the PEPS Mission Requirements, as well as associated complexity, schedule and cost drivers and needs for critical R&D. This, considering also the priorities assigned by the users to various PEPS missions and requirements, will help in narrowing the uncertainties on the scope of the mission concepts to be further considered and traded-off during feasibility (phase A) studies. The convergence between the user needs and priorities reflected in this and higher level user documents, and foreseeable capabilities in the relevant timeframe will be achieved throughout phase 0 and phase A studies, based on system-mission trade–off involving interactions between users, EUMETSAT Customers, EUMETSAT, ESA and industry.

A draft End User Requirements Document to be produced during phase A will extract and expand those elements from this PEPS Mission Requirements Document that will be retained at the end of pre-phase A studies, following the PEPS Mission Definition Review. The EURD will then become the applicable user reference for the design of the PEPS system. The requirements engineering process shall ensure that the System Requirements Document (SRD) produced during phase-A is in line and traced to the EURD.

1.1.1 Ownership and control

The EUMETSAT Council represents the EUMETSAT Member States and is the Customer of the potential PEPS Programme. In this capacity, and in accordance with the EUMETSAT Convention [AD.1] the EUMETSAT Council is the owner of the high level requirements applicable to the development of the PEPS system. It will approve the End User Requirements Document to be established in the course of phase A studies and baselined as an input to phase B. The preliminary requirements captured in this MRD document are precursors to the EURD.

The requirements captured in this document are subject to change or reformulation as the result of reviews of the user needs and priorities, new scientific findings and assessment of the feasibility of relevant observational capabilities.

The EUMETSAT Secretariat controls and maintains this MRD document.

1.1.2 Content and structure

- Section 1 is a brief introduction, purpose and scope of the document and its relationship to other documents;
- Section 2 provides background information on the PEPS planning and the processes that have produced the requirements captured in this MRD;
- Section 3 addresses mission requirements traceability and priorities;
- Section 4 introduces terms and definitions
- Section 5 defines the observation missions;
- Section 6 defines the support missions.

1.1.3 Documentation

The documentation referenced in this document falls into two categories, namely: applicable and reference.

The documents listed in section 3.3.1 are higher level documents that provide information directly related to the requirements defined in this MRD, and are therefore applicable globally or to the extent specifically stated in this MRD.

Reference documents listed in section 3.3.2 provide complementary or background information that may be helpful to read in conjunction to the MRD for a better understanding of its contents.

1.1.3.1 Applicable documents

AD.1	EUMETSAT Convention
AD.2	EUMETSAT Strategy. EUM/C/59/06/DOC/28
AD.3	AEG position papers (TBD)

AD.4 EUMETSAT Principles on Data Policy
Resolution of EUMETSAT Council (EUM/C/98/RecIV)

AD.5 PEPS Programmatic Assumptions and Requirements Document (PARD) (EUM/PEPS/REQ/05/0073)

1.1.3.2 Reference documents

RD.1 WMO Statement of Guidance (SOG)
Technical Document
WMO/TD No. 1052, and Revision
CBS/OPAG-IOS (ODRRGOS-5)/Doc.5/Add.5

RD.2 Vision for the Future WMO Information System
1 October 2002
www.wmo.ch/web/www/WDM/report/FIWS-vision-2002.html

RD.3 International Data Collection System
Users' Guide
CGMS.02 Issue 9

RD.4 Final Report of the "CAPACITY: Composition of the Atmosphere: Progress to Applications in the user CommunITY" study, ESA Contract No.: 17237/03/NL/GS, October 2005.

RD.5 Final Report of the "Study on Upper Troposphere / Lower Stratosphere Sounding", ESA Contract No.: 12053/97/NL/CN, December 1998.

RD.6 Final Report of the study on "Definition of Mission Objectives and Observational Requirements for an Atmospheric Chemistry Explorer Mission – 1st Extension", ESA Contract No: 13048/98/NL/GD, January 2002.

RD.7 Final Report of the study on "Definition of Mission Objectives and Observational Requirements for an Atmospheric Chemistry Explorer Mission – 2nd Extension", ESA Contract No: 13048/98/NL/GD, December 2004.

2 PEPS PLANNING AND GENERATION OF PEPS MISSION REQUIREMENTS

2.1 Need and planning for a Post-EPS (PEPS) Programme

The first Metop satellite of the EUMETSAT Polar System, was launched on 19th October 2006. EPS has become the EUMETSAT reference operational polar mission on 15 May 2007, after completion of commissioning, and, as a result, is now the primary European source of global polar observations. Data and products will be broadcast in real time over Europe, Africa, the Eurasian and part of the American continent by a EUMETCast multicast service based on commercial KU-band and C-band services.

The main application of EPS and Post-EPS is numerical weather prediction (NWP), and climate monitoring.

The Metop-2 satellite – renamed Metop-A after successful launch – is the first in a series of three satellites expected to deliver operational services at least until 2019 – hopefully longer – at which time a Post-EPS (PEPS) system needs to be available. Considering the typical development cycle of new complex space systems, and the time required for the definition phases and the approval of expensive programmes, it has already become necessary for EUMETSAT and ESA to plan for PEPS, based on the following tentative planning for the definition and development of the system (see [AD.5] for more details):

Phase 0: Mission Analysis 2005 – 2008

Phase A: Feasibility Studies 2009-2010

Phase B: Preliminary Definition 2011 – 2013

Phase C, D: Detailed Definition, production 2014 – 2019

Phase E: Utilisation 2018/2020

2.2 Process for the generation of PEPS mission requirements

The full process implemented to generate PEPS mission requirements captured in this MRD document is summarised hereafter.

2.2.1 High level user needs and priorities for future EUMETSAT missions: the EUMETSAT User Consultation Process

In 2000, EUMETSAT initiated a post-MSG User Consultation Process with the support of ESA. The process aimed at capturing the foreseeable high-level needs and priorities of EUMETSAT customers and users in the 2015-2025 timeframe. Considering the timeframe of interest, this had to be based on the long-term strategic objectives of the main customers of EUMETSAT, namely the National Meteorological Services. Additionally, objectives of other operational environmental organisations from EUMETSAT Member and Cooperating States, the European Centre for Medium-Range Weather Forecasts (ECMWF), EUMETNET and the World Meteorological Organization (WMO) have been acknowledged.

In practice, the process was implemented through the setting up of Applications Expert Groups (AEGs) tasked to propose their vision on operational services and information systems in the 2015-2025 timeframe and to define associated needs and priorities for input information and observations. The AEGs concentrated on two families of applications, defined in sufficiently broad terms to address even non-meteorological applications:

- "Nowcasting & Very Short Range Forecasting (VSRF)" defined in a very broad sense as "user-driven services using appropriate meteorological and related science to provide information on expected conditions up to 12 hours ahead" and hence covering e.g. air pollution, ocean, hydrology at these timescales;

- "Numerical Weather Prediction" including marine forecasting and emerging applications like extended range weather forecasting and seasonal prediction.

The AEGs produced three position papers that were endorsed by the EUMETSAT Council and consolidated following specialised workshops on climate monitoring and atmospheric chemistry requirements.

Remote Sensing and satellite Experts (RSE) were then tasked, based on a continuous dialogue with the Applications Experts, to:

- Determine which observational needs could possibly be met by future space systems operated from Low Earth or geostationary orbits;

- Identify space-based observing techniques (from GEO and LEO orbits) that could possibly meet requirements;

- Conduct a preliminary assessment of their potential capability with respect to "threshold" and "breakthrough" performance levels defined by the AEGs, and qualify their level of technical maturity.

In 2005 EUMETSAT initiated a delta user consultation process. Starting with an initial identification of six potential PEPS missions, and building on the post-MSG user consultation process, four AEGs have been set up to derive user needs for a PEPS. The initial missions identified cover:
- Atmospheric sounding,
- Wind profiling,
- Cloud and precipitation imaging, including large-scale land surface imaging,
- Ocean imaging, including surface winds,
- Ocean topography,
- Atmospheric chemistry.

On top of these six missions, user needs relevant to climate monitoring have to be taken into account. Initial mission scope documents, covering the requirements from the post-MSG position papers were provided to the AEGs to start with. The mission scopes have been udated according to the position papers provided by the AEGs, according to new developments in recent years and corresponding extrapolations into the PEPS era.

2.2.2 Extraction of PEPS Mission Requirements

PEPS-specific requirements were extracted through the identification of all observational needs that could be met from polar orbit and that are complementary to the geostationary orbit, based on two criteria:

a) The required repeat frequency of the targeted observation is less than one cycle per 1.5 hours;

b) The targeted parameter can only be estimated from the polar orbit, i.e. not be extracted from the analysis of observations from geostationary orbit.

A subset of observing techniques compatible with the polar orbit was identified and assessed in more depth.

This last step of the process produced the inputs required to support the PEPS definition studies (pre-phase A) jointly planned by ESA and EUMETSAT for 2007, including this PEPS Mission Requirements Document (MRD). The overall process leading to the production of the MRD is captured in Figure 1.

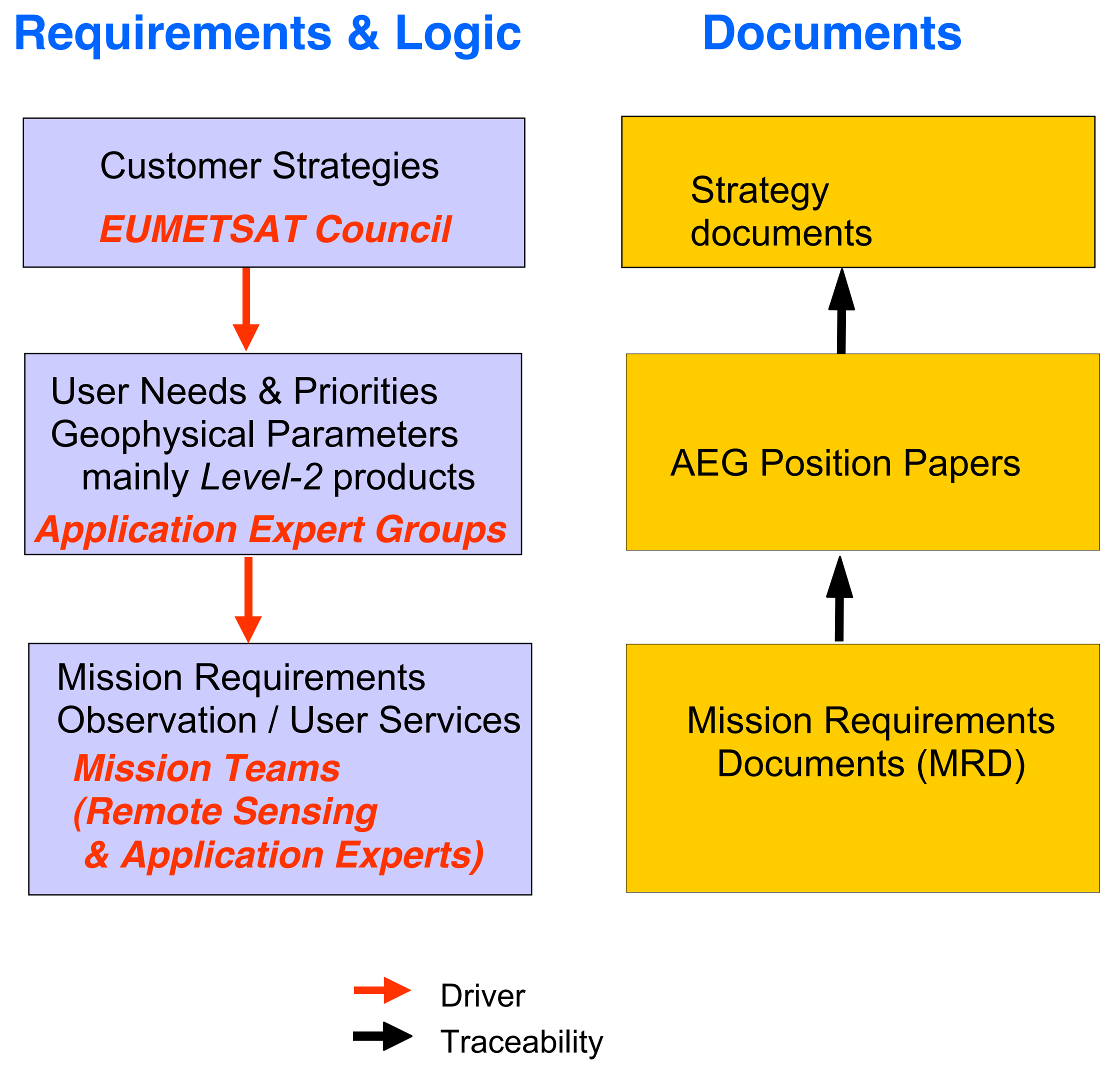

Figure 1: Overview of the process for the definition of the PEPS Mission Requirements Document. The user needs are captured through the user consultation process (left part). Documents are produced as a result of a dialogue between Applications Experts and Remote Sensing and Satellite (RSE) Experts.

3 MISSION REQUIREMENTS TRACEABILITY AND PRIORITIES

Feasibility, cost drivers, value, affordability and possible commitments of other potential customers will ultimately play an important role, in the future, when EUMETSAT Member States will have to decide on the actual scope of the PEPS programme. Meanwhile, the initial definition of user needs and priorities is recognised to be subject to refinement and change.

It is therefore essential to be in a position to re-assess any output in the programme preparation and decision processes, against priorities established by the PEPS Programme Customer and affordability, taking due account of the results of design and feasibility studies, programmatic and financial constraints. In this respect a possible cooperation with NOAA in the frame of a Joint Polar System needs to be taken into account. Possible additional funding sources outside EUMETSAT, e.g. in the context of the European GMES (Global Monitoring for Environment and Security) initiative will have an influence on priorities and possible implementation.

3.1 Affordability and strategic priorities

It is recognised that cost drivers, technology risks, financial constraints and other programmatic constraints (refer to PARD [AD.5]) may lead to a situation where:

- not all PEPS mission requirements can be fulfilled or funded;
- not all requirements for a given mission can be fulfilled;
- quality of service and level of support needs to be re-adjusted.

The EURD, when baselined and approved by the EUMETSAT Council at the end of phase A, will define the user requirements applicable to the PEPS development.

Should affordability become an issue, it is important to recall that the EUMETSAT Strategy [AD.2] approved by the EUMETSAT Council recognises that "….the priority for EUMETSAT will be to maintain and ensure continuation of the existing core meteorological services. This will involve consolidating the services and products based on existing systems and preparing the implementation of services from future systems."

This recognises that the meteorological service and mission requirements captured in this document have the highest level of priority to EUMETSAT, although the objective is clearly to contribute to the fulfilment of the full mandate assigned by the Convention, including climate monitoring and detection of global climatic change [AD.1].

3.2 Traceability to priorities defined in the user consultation process

The possible need for reassessment requires keeping full traceability between
a) observational needs and mission requirements captured in this document,
b) the critical application objectives that drive these needs and their levels of priority,
c) the observational performance that could make the targeted difference at end-user level, for a given application.

This traceability is maintained by the EUMETSAT Secretariat, with priorities and importance of requirements defined at two levels:

- the level of priority of the application that is the main driver of a requirement;
- the “breakthrough” performance level that, if achieved, would make a difference in terms of application output.

The level of priority of applications has been compiled in the AEGs position papers including the table of observables relevant for the corresponding applications. The needs have been expressed according to levels of priority assigned to each product, ranging from 1 (highest priority) to 4 (lowest priority).

These levels of priority are recalled in this document, wherever appropriate, in the presentation of the observation missions.

4 TERMS, CONVENTIONS AND DEFINITIONS

Absolute Accuracy
The absolute accuracy is the root mean square (RMS) difference between the measurement and truth including both random and bias errors. Error distributions are to be understood as Gaussian and the values given refer to one standard deviation, unless otherwise stated.

Absolute pointing accuracy
See LOS absolute error

Actual Site (AS)
This site corresponds to the detector line of sight (response's CoG) at the instant that the sample was taken.

Aliasing
Aliasing is the irreversible corruption of sub-Nyquist scene frequencies by higher order frequency components that are not adequately sampled by the measurement system. Requirements relating to aliasing should either be specified in terms of a maximum power contribution of the alias to the overall measured signal (e.g. for a radar), or by the modulation transfer function (MTF) e.g. in the case of an imager.

Bandwidth
See spectral resolution

Beam Axis (or electrical-bore sight)
The beam axis or electrical-bore sight is defined as the far field axis for which any cut along this axis, splits the beam energy into equal amounts, consistent with the respective beam pointing requirement.

Beam Efficiency
The beam efficiency is defined as the ratio of energy received by an instrument within its main beam to the total energy received from all angles.

Bias Error
The bias error is the systematic difference between a measured (or derived) value and truth in the absence of random errors. Unless otherwise stated, the performance specifications for bias error given in this document relate to the unknown component of the overall systematic error and that corrective measures (such as calibration) would be required to remove any known component.

Calibration Homogeneity
This specification gives the constraints on the absolute accuracy (bias and random component) behaviour between spectral channels and pixel positions. It is split into two parts; a spectral and a geometric part. The spectral part describes the RMS difference between different channels of the same pixel when viewing a spatially homogeneous, stable, reference scene. The geometrical part describes the RMS difference between different pixels of the same channel when viewing a spatially homogeneous, stable, reference scene.

Channel
A channel is defined and delineated by its spectral boundaries.

Co-registration or co-alignment of channels
See inter-channel co-registration.

Coverage
The coverage is defined as the geographical region covered by a set of measurements.

Cross talk
Channel to channel cross talk is defined as the change in any channel output when one channels' illumination is changed from the minimum to the maximum of the dynamic range while all other channels remain illuminated at the minimum of the dynamic range. The contribution to cross talk includes electrical, optical, spatial and spectral parameters.

Data Level
The following definitions of data levels are used:

- Observation Level 0: Raw data after restoration of the chronological data sequence for the instrument(s) operating in observation mode.
- Level 1a: Level 0 data with corresponding radiometric, spectral and geometric (i.e. Earth location) correction and calibration computed and appended, but not applied.
- Level 1b: As level 1a data but radiometrically and spectrally calibrated and annotated with satellite position and pointing.
- Level 1c: Level 1b data re-sampled to a specified rectangular grid
- Level 2: Earth located pixel values converted to geophysical parameters.

Dwell Time
The dwell time is the time period required to acquire data for all spectral channels for a given spatial sample.

Effective Diameter
The effective diameter D is used to describe a footprint area, which is not necessarily circular; the area is $\pi D^2/4$.

Full width at Half Maximum (FWHM)
The full width at half maximum is the full width of a function at half-maximum points.

Geometrical Field of View
The geometrical field of view is defined as the center of the IPSF ± FWHM of the IPSF.

Image
An image is defined as the ensemble of spatial samples acquired in a repeat cycle for a given channel.

Image Line
Image Lines are defined as the sequence of either horizontal or vertical adjacent pixels along an image regular grid line for a given channel.

Image navigation
Image navigation refers to the determination of the location of each sample relative to a fixed reference coordinate system.

Inter-channel co-registration

Channel to channel co-registration refers to the physical distance between detector pixel PSF barycentres when viewing the same target on Earth.

Incidence Plane

The incidence plane is defined by the radiation propagation direction vector and the surface normal of the surface of which the radiation is incident upon.

Instrument Point Spread Function (IPSF)

See System Point Spread Function

Instrument Spectral Response Function (ISRF)

The ISRF relates the radiometrically calibrated, spectrally integrated radiance L'(ν_o) measured by a detector element, i, in a spectral band, j, with the spectral radiance L(ν) emanating from a spatially homogeneous scene. The ISRF Φ_{ij} is normalised such that its spectral integral yields 1. It is defined by:

$$L'_{ij}(\nu_0) = \int_0^{+\infty} \Phi_{ij}(\nu_0, \nu).L(\nu).d\nu$$

Integrated Energy (IE)

Integrated Energy, IE(d), for spatial dimension d is the integral of the system PSF, Ψ, of a detector element i and a spectral channel j over a circular area with a diameter *d or a square area of size d* ×d centred around the system PSF barycentre position (x_o,y_o).

$$IE_{ij}(d) = \int_{y_0-\frac{d}{2}}^{y_0+\frac{d}{2}} \int_{x_0-\frac{d}{2}}^{x_0+\frac{d}{2}} \Psi_{ij}(x, y)dxdy$$

IE is the ratio of the energy measured by an instrument over an area of dimension *d* to the energy measured by the same instrument from the entire large and uniform scene.

Lifetime Repeatability / Stability

Lifetime repeatability is the maximum allowed variation of the random component of the error for all pixels and channels over the lifetime of the instrument.

LOS absolute error

LOS absolute error is defined as the separation between the actual and the commanded payload generalised pointing vectors as defined by the ESA pointing error handbook.

LOS instability

The line of sight (LOS) instability is defined as the deviation of the actual pointing from the nominal pointing

Main beam

The main-beam is defined as 2.5 times the full beam width between the half-power points (i.e. 2.5 times the FWHM).

Modulation Transfer Function (MTF)
The modulation transfer function describes the ratio of the image spatial frequency spectrum to the object spatial frequency spectrum and such defines the limit to which spatial frequencies within the object can be resolved. The MTF includes the optical transfer function as well as the rest of the measurement system's transfer function.

Nadir Angle
Angle between nadir and actual instrument's viewing direction, also referred to as viewing angle.

Noise equivalent Brightness Temperature (NEΔT)
See radiometric resolution

Noise equivalent Spectral Radiance (NESR)
See radiometric resolution

Nyquist frequency
Nyquist frequency is given by 1/(2*SSD).

Orbit Calibration Repeatability
Orbit calibration repeatability is the maximum allowed variability in the random component of the calibration error for all pixels and channels over the time period taken to complete a full orbit.

Out-of-Band Response
The out-of-band response is the contribution to the total measured signal from radiation of wavelength outside the spectral region $\lambda_{centre} \pm \Delta\lambda$, where $\Delta\lambda$ is the bandwidth and λ_{centre} is the channel central wavelength.

Pixel
Image pixels (picture elements) are defined as re-sampled radiances/brightness temperatures of a channel registered to a regular grid.

Point Spread Function (PSF)
See System Point Spread Function

Polarisation sensitivity
Assuming measurement of a stable, spatially uniform, linearly polarized Lambertian scene, the polarization sensitivity is defined as P = (Smax - Smin)/(Smax + Smin), where Smax and Smin are the maximum and minimum sample values obtained when the polarization is gradually rotated over 180°.

Radiometric Resolution (NEΔT, SNR, NEΔR) or Radiometric Noise
The 'radiometric resolution' or noise is the standard deviation of a series of radiance measurements for a specific channel on a stable and spatially uniform reference image. For the thermal channels, the radiometric resolution is specified in terms of noise equivalent temperature difference (NEΔT) associated with a reference temperature (usually 280 K unless

otherwise specified). For the solar channels, the radiometric noise is often expressed by the signal to noise ratio (SNR) or the noise equivalent radiance difference (NEΔR) for a given reference radiance. Error distributions are to be understood as Gaussian and the values given refer to one standard deviation, unless otherwise stated.

Repeat Cycle

The Repeat Cycle is defined as the time elapsed between the start of two consecutive sets of measurements covering the same geographical region, where the corresponding sub-satellite tracks match within a distance of 500 m.

Relative Radiometric Accuracy (repeatability)

The relative radiometric accuracy defines the range of variability of the measured radiances L(t) allowed over a fixed time period, τ, for a stable scene such that:

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

or

$$\left|T_b(t_k)-T_b(t_j)\right| < \mathrm{Re}lative\ Accuracy\ in\ [K]\ for\ the\ thermal\ channels$$

where t_j , t_k are any two fixed times within the specified time period τ.

Sample

A radiometric measurement taken at some location.

Spatial Sample

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

Site

The location of a sample in terms of latitude and longitude or position at SSP.

Spatial Resolution (ΔX)

- For the Sounding Channels: The spatial resolution ΔX_{ij} of a detector *i* in a spectral channel *j* is defined as the dimension ΔX_{ij} of a squared area at SSP centred at the system PSF barycentre position (x_o, y_o) that contains 70% of the integrated energy: $IE_{ij}(\Delta X_{ij})=0.7$.
- For the Imaging Channels: The spatial resolution ΔX is expressed in terms of a MTF template.

Spatial Sampling Angle (SSA)

The angle subtended by the spatial sampling distance, as seen from the satellite

Spatial Sampling Distance (SSD)

The Spatial Sampling Distance (SSD) is defined as the barycentre-to-barycentre distance between adjacent spatial samples on the Earth's surface as measured at the sub-satellite point (SSP). The actual SSD outside the SSP is calculated from the Spatial Sampling Angle (SSA).

Spatial Cluster of Spectral Soundings

A spatial cluster of spectral soundings is defined as a grouping of three spatially contiguous spectral soundings in any direction within a given repeat cycle.

Spectral resolving power
The resolving power is a dimensionless number defined to be the ratio of the wavelength to the spectral resolution ($\Re \equiv \nu/\Delta\nu = \lambda/\Delta\lambda$).

Spectral Resolution
The spectral resolution, in $\Delta\lambda$ or in $\Delta\nu$, is defined as the FWHM of the ISRF.

Spectral Sampling Interval
The Spectral Sampling Interval is the spectral distance between the centroid of the ISRF of two adjacent channels.

Spectral Band
A spectral band is a contiguous sub-region of the whole spectral range covered by a mission.

Spectral Cluster of Channels
A spectral cluster of channels is defined as a group of three adjacent spectral channels.

Spectral Sounding
A spectral sounding is defined as the spectrum derived from all sounder spectral channels for any fixed spatial sample position within a given repeat cycle.

Spectral Binning
The combination of several spectral channels to form a single spectral channel at reduced spectral resolution.

Spectral Oversampling
Spectral oversampling is the number of spectral samples per FWHM of the ISRF.

Stability
Stability is a measure of the repeatability and reproducibility of the instrument meteorological characterisitics with time and is particularly important for climate change detection. With regard to requirement specification, the stability of an observation is the unknown drift in time of the bias error, usually defined over the lifetime of a mission or over a decade.

Stokes Vector
The polarisation state of light is described by the Stokes vector $\underline{\mathbf{L}}$ equal to $[L, Q, U, V]^T$, where the superscript T means transpose (e.g. Chandrasekhar, 1960). The unit of the four components represent real intensities in units of $W/(m^2\ sr)$ and are observables of the polarisation ellipse.
Of particular relevance to remote sensing are the L and Q components of the Stokes vector. If L_l and L_r represent the radiance of light after it has passed through a linear polariser with its orientation parallel and perpendicular to a reference plane, then L (representing the total intensity) is given by $L_l + L_r$ and Q, (representing the amount of linear horizontal or vertical polarised light) by $L_l - L_r$.

Sub-Satellite Point (SSP)
The sub-satellite point (SSP) is the point on the Earth's surface that intersects the line between the satellite and the geocentric centre of the Earth.

Swath Width

The swath width is defined as the length of area on the Earth's surface, perpendicular to the satellite velocity, that is imaged during a given satellite pass.

System Point Spread Function

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

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

where: $\Psi_{ij}(x,y)$ is the system Point Spread Function (PSF) for detector i in a channel j. The system PSF is the integral over dwell time of the instantaneous PSF, including optical effects, detector characteristics, electronic fluctuations and nominal pointing variation during the dwell time, but excluding effects due to unknown LOS instability. The spatial integral of $\Psi_{ij}(x,y)$ is normalised to 1.

Temperature Sensitivity

The temperature sensitivity is defined as the minimum detectable change of brightness temperatures at the collecting aperture, given by

$$\Delta T = \frac{T_{Instrument} + T_{Scene}}{\sqrt{\tau \times \Delta f}} \;,$$

where $T_{Instrumen't}$ is the instrument temperature, T_{Scene} is the scene temperature, τ is the integration time, and Δf is the channel bandwidth.

Viewing Angle

Angle subtended by the instrument line of sight (or viewing direction) and the nadir direction, also referred to as nadir angle.

Zenith Angle

The zenith angle at a point on the Earth surface is defined as the angle subtended by the Earth surface normal and the vector joining the surface point to the instrument viewing that point.

5 OBSERVATION MISSIONS

This chapter introduces the main observation missions considered for the PEPS system.

The observation missions basically reflect the observing capabilities expected from the PEPS system. From a user perspective, their associated mission requirements are generally expressed in terms of the expected level (1b or 1c) output and its characteristics, considering that these levels of data are or would be directly used by real time users applications in the 2019 timeframe.

The observation missions were defined in response to the high level user needs and priorities established by the Applications Expert Groups and documented in the relevant Position Papers [AD.3].

Eighteen observation missions have been identified:

- High-resolution infrared sounding mission (IRS);
- Microwave sounding mission (MWS);
- Radio occultation sounding mission (RO);
- Differential absoprtion lidar mission (DIA);
- Doppler wind lidar mission (DWL);
- Optical medium resolution imaging mission (VII);
- Microwave imaging mission (MWI);
- Cloud and precipitation profiling radar mission (CPR);
- Radiant energy radiometry mission (RER);
- Dual view imaging mission (DVR);
- Ocean colour imaging mission (OCI);
- Scatterometry mission (SCA);
- Altimetry mission (ALT);
- Nadir-viewing UV-SWIR spectrometry mission (UVNS);
- Limb-viewing IR sounding mission (LIR);
- Limb-vieving mm-wave sounding mission (MMW);
- Aerosol lidar mission (APL);

- Multi-viewing multi-channel multi-polarisation imaging mission (3MI, 3MI');
- Total Solar Irradiance Monitoring Mission (TSIM).

The implementation of the individual missions does not necessarily result in respective individual instruments. A resulting instrument concept could combine different missions or it could implement any particular mission in one or more instruments.

5.1 High-Resolution Infrared Sounding Mission (IRS)

5.1.1 Objectives

Considering that most NWP users plan to directly assimilate calibrated and geolocated radiances, the Infrared Sounding mission is specified in terms of its targeted real time level 1b data output. The IRS mission will be important also for climate monitoring, and atmospheric chemistry, and, to a lesser extent also for oceanography and hydrology.

The InfraRed Sounding mission (IRS) has a direct EPS IASI (Infrared Atmospheric Sounding Interferometer) heritage. The main IASI mission rationale is the measurement of temperature and moisture profiles in clear or partly cloudy scenes at high accuracy (1 K and 5%, respectively) at a vertical resolution in the lower troposphere of 1 km. The requirements are established on the basis of user requirements, but also taking into account the heritage from similar missions such as IASI.

As a baseline, the minumum expected performance of the IRS mission is that of the IASI mission.

The **primary objective** of the IRS mission is to support Numerical Weather Prediction at regional and global scales, through the provision of:

- Atmospheric temperature profiles at high vertical resolution in clear and partly cloudy air;
- Atmospheric water-vapour profiles at high vertical resolution in clear and partly cloudy air;
- Surface temperature over sea, ice, and land surfaces;
- Cloud parameters;
- A number of atmospheric trace gases.

Infrared soundings with high vertical, horizontal, vertical/spectral resolution greatly enhance the National Meteorological Services' (NMS) ability to initialise global and regional NWP models with realistic information on temperature and moisture.

The frequent availability of detailed temperature and moisture soundings would also contribute to fulfil other key requirements common to Nowcasting and Very Short-Range Forecast (VSRF) at regional scales:

- Monitoring of instability, for early warning of convective intensity;
- Early warning for CAPE/convective instability;
- DCAPE (down draught intensity), for early warning of risks by downburst and severe outflow gusts;
- Cloud microphysical structure.

The level of fulfilment of these objectives will depend strongly on the space-time resolution of the IRS mission, and is particularly critical at high latitudes where information from geostationary spacecraft is scarce or even unavailable.

The **secondary objectives** of the IRS mission is to support pollution monitoring and air quality forecasting at global and regional scales with further trace gas measurements and the assessment of composition – climate interaction.

The main users of the IRS mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF. Operational nowcasting services of National Meteorological Services may also be users of the IRS mission. The IRS mission is also relevant to non real-time users, such as for climate monitoring and atmospheric chemistry.

5.1.2 Products

The primary products to be derived from the IRS mission include (in descending order of priority):

1. Temperature profile
2. Water vapour profile
3. Sea surface temperature
4. Land surface temperature
5. Cloud cover profile
6. Cloud top height
7. Cloud top temperature
8. Outgoing spectral radiance at the top of the atmosphere
9. Surface emissivity in window channels
10. O_3 profile
11. O_3 total column[1]
12. CO total column and profile
13. CH_4 total column and profile
14. HNO_3 total column
15. N_2O total column
16. CO_2 total column

Further products to which IRS contributes:

17. Depth of the planetary boundary layer
18. Tropopause height

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[1] IRS has low sensitivity to trace gases near the surface, so auxiliary information is needed to derive total columns of O_3, HNO_3, NO_2, SO_2, CO, CH_4 and CO_2 to the required accuracies from its measuremnents. This can be provided by UVNS.

19. Downwelling longwave spectral irradiance at the surface
20. Volcanic SO_2 total column
21. C_2H_6
22. PAN

5.1.3 Priority of Requirements

MRD_IRS.005

1. Spectral and radiometric noise shall have priority over spatial resolution as long as the footprint diameter is less than the specified threshold value.
2. Spectral resolution shall have priority over radiometric noise for the atmospheric chemistry application as long as the threshold values are not exceeded.
3. Radiometric resolution shall have priority over spectral resolution for the NWP application.

5.1.4 Spectral Requirements

5.1.4.1 Spectral Range and Resolution

MRD_IRS.010

The IRS shall cover the spectral range from 645 cm^{-1} to 2760 cm^{-1} (i.e. 3.62 µm to 15.5 µm). Extensions on the short-wave side to 2900 cm^{-1} (3.45 µm) to capture CH_4 and, on the long-wave side, to approach as much as possible 550 cm^{-1} (18 µm) so as to observe upper tropospheric water vapour in the rotational H_2O band, are interesting options to be investigated. The IRS band characteristics and priorities are listed in

Table 1. and Table 2.

Mission Band	**Wavenumber Range (cm-1)**	**Purpose**	**Priority**	**Spectral Resolution T/B/O**	**Radiometric Noise (NEΔT@280 K) T/B/O**
IRS-0	550-645	Water-vapour profile	4	0.5/0.3/0.1	0.5/0.3/0.2
IRS-1	645 – 770	Temperature profile	1	0.5	0.3/0.2/0.1
IRS-2	770 – 1000	Temperature and water-vapour profiles,	1	0.5	0.15/0.1/0.05K

		SST, surfaces and cloud properties			
IRS-3	1000 – 1070	O_3 column	2	0.5/0.3/0.1	0.5/0.3/0.1
IRS-3a	1030 – 1080	O_3 profile	2	0.15/0.1/0.075	0.1/0.075/0.05
IRS-4	1070 – 1150	Surfaces and cloud properties	2	0.5/0.3/0.2	0.1/0.075/0.05
IRS-5	1150 – 1650	Water vapour profile	1	0.5/0.25/0.1	0.15/0.075/0.05
IRS-5b	1280 – 1360	Temperature profile, and N_2O, CH_4 columns	2	0.3/0.15/0.1	0.2/0.1/0.05
IRS-6	1650 – 2100	Water-vapour profile NO_2 Column	1	0.5/0.25/0.1	0.15/0.075/0.05
IRS-8	2160 – 2250	Temperature profile, N_2O and CO_2 columns	2	0.5/0.3/0.1	0.3/0.2/0.1
IRS-9	2250 – 2420	Temperature profile	1	0.5/0.3/0.1	0.3/0.2/0.1
IRS-10	2420 – 2700	SST, surfaces and cloud properties	2	0.5/0.3/0.1	0.3/0.2/0.1

O: Objective, B: Breakthrough, T: Threshold

Table 1: IRS band characteristics and priorities for NWP

Mission Band	**Wavenumber Range (cm-1)**	**Purpose**	**Priority**	**Spectral Resolution T/B/O**	**Radiometric Noise (NEΔT@280 K) T/B/O**
IRS-2a	800 – 850	C_2H_6	3	0.5/0.25/0.1	0.1/0.075/0.05

IRS-2b	860 – 900	HNO$_3$, CFC	2	0.15/0.1/0.075	0.1/0.075/0.05
IRS-3[2]	1000 – 1070	O$_3$ column	1	0.5/0.3/0.1	0.5/0.3/0.1
IRS-3a	1030 – 1080	O$_3$ profile	1	0.15/0.1/0.075	0.1/0.075/0.05
IRS-4a	1120 – 1160	Volcanic SO$_2$	2	0.5/0.25/0.1	0.1/0.075/0.05
IRS-4b	1130 – 1200	PAN	3	0.5/0.25/0.1	0.1/0.075/0.05
IRS-5a	1340 – 1380	Volcanic SO$_2$	4	0.5/0.25/0.1	0.1/0.075/0.05
IRS-5b	1280 – 1360	Temperature profile, and N$_2$O, CH$_4$ columns	2	0.3/0.15/0.1	0.2/0.1/0.05
IRS-6	1650 – 2100	Water-vapour profile NO$_2$ Column	3	0.5/0.25/0.1	0.15/0.075/0.05
IRS-7[3]	2100 – 2150	CO column	1	0.5/0.25/0.1	0.3/0.2/0.1
IRS-7a	2140 – 2180	CO profile	1	0.15/0.1/0.075	0.15/0.1/0.05
IRS-8	2160 – 2250	Temperature profile, N$_2$O and CO$_2$ columns	2	0.5/0.3/0.1	0.3/0.2/0.1
IRS-11	2700 – 2760	CH$_4$ column	3	0.5/0.3/0.1	0.3/0.2/0.1
IRS-12	2760 – 2900	CH$_4$ column	4	0.5/0.3/0.1	0.3/0.2/0.1

O: Objective, B: Breakthrough, T: Threshold

Table 2: IRS band characteristics and priorities for Atmospheric Chemistry

MRD_IRS.020

The unapodised spectral resolution shall be as specified in Table 1 and Table 2.

5.1.4.2 Spectral Response Function

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[2] Note that if band 3a is available for the measurement of O$_3$ profiles with the spectral resolution and radiometric noise as specified band IRS-3 is not required.

[3] Note that if band 7a is available for the measurement of CO profiles with the spectral resolution and radiometric noise as specified band IRS-7 is not required.

MRD_IRS.030

The knowledge of the spectral response function shall be such that for any spectral sample/channel the associated uncertainty shall not cause errors greater than 0.05(O)/0.1(T) K in the measured brightness temperature.

5.1.5 Radiometric Requirements

MRD_IRS.100

The radiometric requirements (noise, absolute accuracy) shall be met over the target temperature range. At temperatures T different from 280 K, the specified noise/accuracy shall be scaled by the factor $\left[\frac{dB(\nu_0, 280K)}{dT}\right] \Big/ \left[\frac{dB(\nu_0, T)}{dT}\right]$, where B is the Planck's function, ν_0 is the wavenumber of the channel and T is the target temperature in K. This implies a constant requirement in terms of accuracy of measured radiance.

5.1.5.1 Dynamic Range

The dynamic range covers the range of radiances to be measured, expressed in brightness temperatures, covering the range from the darkest to the brightest scene radiances to be measured in any spectral channel.

MRD_IRS.110

The system dynamic range of the IRS shall be optimised to cover the spectral radiances derived from a nadir measurement over a clear sky hot desert target with a 335 K surface temperature and a thick cirrus cloud placed at the tropopause of a tropical atmosphere with a cloud top temperature of 180 K, as presented in Figure 2.

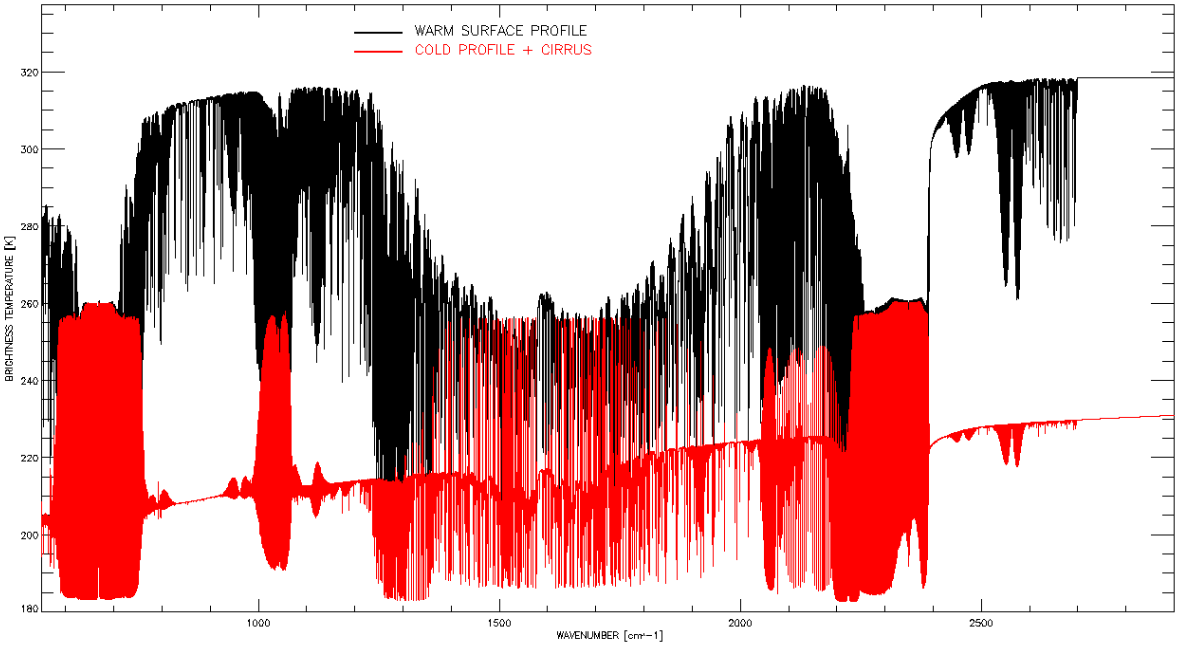

Figure 2: Brightness temperatures for a hot desert and cold thick cirrus scene

5.1.5.2 Radiometric Noise

MRD_IRS.120

The radiometric noise shall be as specified in Table 1. The NEΔT value is to be understood as one standard devation. It is specified at a reference temperature of 280 K and depends on the spectral range.

5.1.5.3 Bias error

MRD_IRS.140

For measurements of a spatially uniform scene at 280 K, the bias error shall be < 0.5 K for all channels.

5.1.5.4 Orbit Stability

MRD_IRS.150

Variations (RMS) of systematic errors in the measured brightness temperature during any single orbit shall be < 0.10 K (Breakthrough), < 0.05 K (Objective) (at 280 K).

5.1.5.5 Lifetime Stability

MRD_IRS.160

Variations (RMS) of the running average over one orbit of systematic errors in the measured brightness temperature shall be < 0.10 K (Breakthrough), < 0.05 K (Objective) (at 280 K).

5.1.5.6 Radiometric Homogeneity

MRD_IRS.170

RMS differences between brightness temperatures of different spectral samples/channels of the same spatial sample shall be < 0.1 K for a scene temperature of 280 K.

MRD_IRS.180

RMS differences between brightness temperatures of different spatial samples of the same spectral sample/channel shall be < 0.1 K for a 280 K target temperature.

5.1.6 Geometric Requirements

These requirements cover the horizontal coverage and resolution.

MRD_IRS.200

The IRS shall be optimised for operation in a sun-synchronous orbit.

MRD_IRS.210

The IRS shall maximise the useful viewing angle and provide 90% global coverage within 12 hours, and 100% within 24 hours, preferably with a single instrument.

MRD_IRS.220

An amount of > 99% of the Integrated Energy (IE) of the respective IPSF shall be contained within an on-ground footprint with an area described by an effective diameter $D < 5$ km (Objective), < 8 km (Breaktrough), < 12 km (Threshold), where D describes an area (circular or non-circular) of size $\pi D^2/4$.

MRD_IRS.240

The absolute pointing accuracy, i.e. the RMS difference between the actual IRS viewing direction and the commanded one, shall be < 4 mrad for all Earth views.

MRD_IRS.245

The geolocation accuracy shall be < 5 km (threshold), < 1 km (breakthrough), < 500 m (objective).

MRD_IRS.250

Within a scan all the Earth measurements shall be equally spaced in nadir angle distance. The on-ground sampling distance at nadir shall be < 10 km (Objective), < 15 km (Breakthrough), and < 50 km (Threshold).

MRD_IRS.260

1. The IRS shall be synchronised with a medium-resolution (~1 km) optical imager for cloud detection within the IRS IPSFs. As a minimum requirement the imager shall have spectral channels at 0.670, 0.865, 1.64, 3.75, 10.8 and 12.02 µm. The band characteristics for these channels shall be those defined for the corresponding VII channels 12, 17, 24, 26, 37 and 39.
2. The temporal synchronisation shall be performed within < 10s.
3. The spatial co-registration shall allow for an assignment of imager pixel centres to any IPSF coordinates with an accuracy < 500 m (Breakthrough), < 1km (Threshold).

5.1.6.1 IPSF Requirements

MRD_IRS.300

Within 0.8 *D*, the IPSF non-uniformity (peak-to-peak ripples) shall be less than 5%.

MRD_IRS.310

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MRD_IRS.320

The IPSF of each spatial sample shall be determined out to an angle 2 *D*.

5.2 Microwave Sounding Mission (MWS)

5.2.1 Objectives

Considering that most NWP users plan to directly assimilate calibrated and geolocated radiances, the MicroWave Sounding mission (MWS) is specified in terms of its targeted real time level 1b data output. It involves all PEPS system functions required to generate this basic output, excluding the functions required to make it available to users.

The MWS mission has a direct heritage from instruments such as the Advanced Microwave Sounding Unit A (AMSU-A), the Microwave Humidity Sounder (MHS), and the Advanced Technology Microwave Sounder (ATMS). The main mission rationale of the MWS is the measurement of temperature and moisture profiles in all weather conditions.

As a baseline, the minimum expected performance of the MWS is that of the combined AMSU-A and MHS missions.

The **primary objective** of the Microwave Sounding mission is to support Numerical Weather Prediction at regional and global scales, through the provision of:

- Atmospheric temperature profiles in clear and cloudy air;
- Atmospheric water-vapour profiles in clear and cloudy air;
- Cloud liquid water columns (droplet size > 100 μm)

Microwave soundings greatly enhance the National Meteorological Services' (NMS) ability to initialise global and regional NWP models with realistic information on temperature and moisture.

The frequent availability of detailed temperature and moisture soundings would also contribute to fulfil other key requirements common to Nowcasting and VSRF at regional scales:

- Monitoring of instability, for early warning of convective intensity;
- Early warning for CAPE/convective instability;
- DCAPE (down draught intensity), for early warning of risks by downburst and severe outflow gusts;
- Cloud microphysical structure.

The level of fulfilment of these objectives will highly depend on the space-time resolution of the MWS mission, and is particularly critical at high latitudes where information from geostationary spacecraft is scarce or even unavailable.

The main users of the MWS mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF. Operational nowcasting services of National Meteorological Services may also be users of the MWS mission. The MWS mission is also relevant to non real-time users.

5.2.2 Products

The primary products to be derived from the MWS mission include in order of descreasing priority:

1. Temperature profile
2. Water-vapour profile
3. Cloud liquid-water total column (droplet size < 100µm)

Further products to which MWS contributes:

4. Freezing-level height in clouds
5. Melting-layer depth in clouds
6. Cloud liquid-water profile (droplet size < 100 µm)
7. Cloud drop effective radius profile
8. Cloud ice total column
9. Cloud ice effective radius profile
10. Precipitation profile (liquid and solid)
11. Precipitation rate at the surface (liquid or solid)
12. Accumulated precipitation
13. Downwelling longwave irradiance at the surface

5.2.3 Priority of Requirements

In case of conflicts radiometric requirements shall have higher priority than geometric requirements.

5.2.4 Spectral Requirements

5.2.4.1 Spectral Range and Resolution

MRD_MWS.010

The MWS shall measure upwelling radiance in spectral channels distributed in the region between 23.8 GHz and 229 GHz, as detailed in Table 3. As an option, additional channels in the O_2 band around 118 GHz should be considered, to better correct for liquid water interference and, conversely, enable precipitation inference over land.

Channel	Frequency (GHz)	Bandwidth per passband[1] (MHz)	Utilisation	Priority
MWS-1	23.8	270	Water-vapour column	1
MWS -2	31.4	180	Window, water-vapour column	1

MWS -3	50.3	180	Quasi-window, surface emissivity	1
MWS -4	52.8	400	Temperature profile	1
MWS -5	53.596±0.115	2x170	Temperature profile	1
MWS -6	54.40	400	Temperature profile	1
MWS -7	54.94	400	Temperature profile	1
MWS -8	55.50	330	Temperature profile	1
MWS -9	57.290344	330	Temperature profile	1
MWS-10	57.290344±0.217	2x78	Temperature profile	1
MWS-11	57.290344 ±0.3222±0.048	2x36	Temperature profile	1
MWS-12	57.290344±0.3222±0.022	4x16	Temperature profile	1
MWS-13	57.290344±0.3222±0.010	4x8	Temperature profile	1
MWS-14	57.290344±0.3222±0.0045	4x3	Temperature profile	1
MWS-15	89.0	4000[2, 3]	Window	1
MWS-16	89.0	4000[2, 3]	Window	1
MWS-17	164-167	3000[2]	Quasi-window, water-vapour profile	1
MWS-18	183.311±7.0	2x2000	Water-vapour profile	1
MWS-19	183.311±4.5	2x2000	Water-vapour profile	1
MWS-20	183.311±3.0	2x1000	Water-vapour profile	1
MWS-21	183.311±1.8	2x1000	Water-vapour profile	1
MWS-22	183.311±1.0	2x500	Water-vapour profile	1
MWS-23	229	2000	Quasi-window, water-vapour profile[4]	1
MWS-24	118.7503 ± 5.0000	2000	Temperature profile (optional)	3
MWS-25	118.7503 ± 3.0000	1000	Temperature profile (optional)	3
MWS-26	118.7503 ± 2.1000	800	Temperature profile (optional)	3
MWS-27	118.7503 ± 1.5000	400	Temperature	3

			profile (optional)	
MWS-28	118.7503 ± 1.1000	400	Temperature profile (optional)	3
MWS-29	118.7503 ± 0.7000	400	Temperature profile (optional)	3
MWS-30	118.7503 ± 0.4000	200	Temperature profile (optional)	3
MWS-31	118.7503 ± 0.2000	100	Temperature profile (optional)	3
MWS-32	118.7503 ± 0.0800	20	Temperature profile (optional)	3

Table 3: MWS Channel Characteristics

Notes to Table 3:
1: Multiple passband bandwidths are also provided.
2: This is a maximum badwidth.
3: MWS-15 and 16 only both need to be included if they are on separate instruments. If they are on the same instrument (e.g. as in ATMS) then MWS-15 may be dropped.
4: Channel MWS-23 could be partially shifted in frequency if trade offs need to be made, especially for the baseline configuration.

MRD_MWS.060

The maximum absolute shift of any channel centre frequency shall be such that the related contribution to the radiometric sensitivity is < 0.01 K (Objective), < 0.05 K (Breakthrough), <0.10 K (Threshold). It shall be understood as short and long-term stability. Long-term means lifetime of the instrument, including any storage period before launch.

MRD_MWS.070

The knowledge of the channel centre frequencies and the ISRF shapes shall be such that the associated contribution to the radiometric sensitivity is < 0.05 K.

MRD_MWS.080

The passband characteristics can be relaxed to single-side bands if performances can be retained.

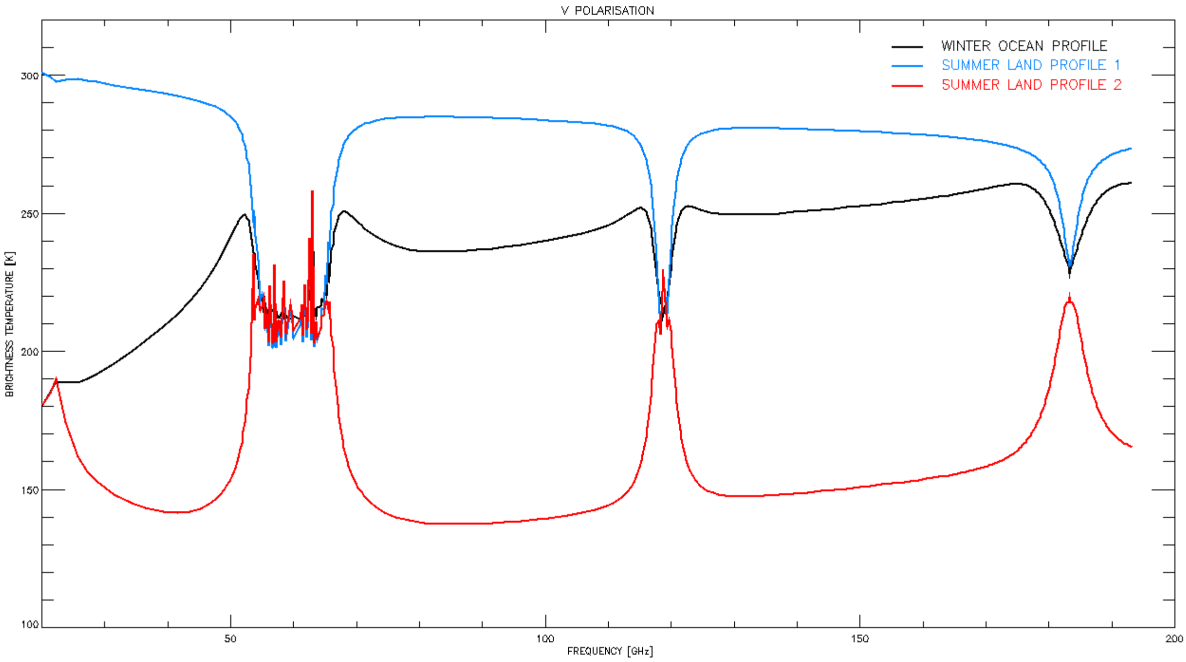
5.2.5 Radiometric Requirements

5.2.5.1 Dynamic Range

The dynamic range covers the range of radiances to be measured, expressed in brightness temperatures, covering the range from the darkest to the brightest scene radiances to be measured in any spectral channel.

MRD_MWS.110

The measurement dynamic range of the MWS shall be optimised to cover the spectral radiances derived from a nadir measurement over a hot desert target with a 335 K surface temperature, a rainforest scene with surface temperature of 295 K and a and winter ocean scene with sea surface temperature < 278 K, as presented in Figure 3.



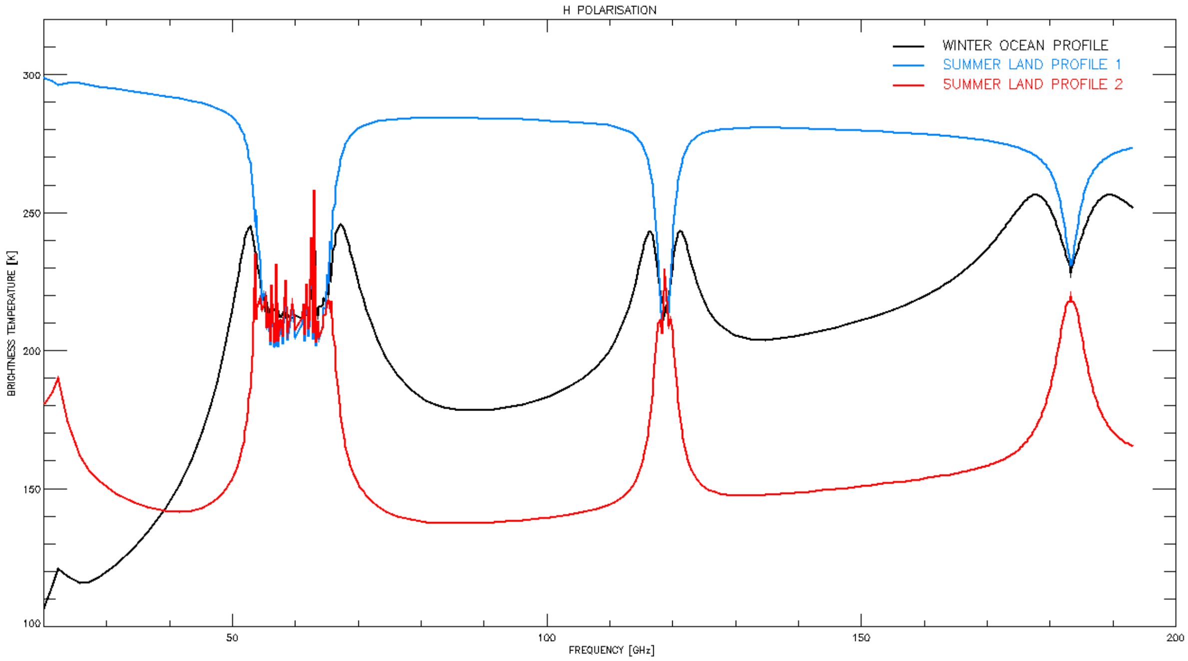


Figure 3: Brightness temperatures (V and H polarisation) for two land scenes (summer) and an ocean scene (winter)

5.2.5.2 Radiometric Noise

The temperature sensitivity includes all noise contributions which are independent of the scene and which have a time constant less than or equal to the radiometric calibration period (receiver and electronic subsystems, processing, fluctuations of the radiometric calibration within this period including in particular errors in the calibration coefficients resulting from noise in the calibration measurements).

MRD_MWS.130

The radiometric noise requirement is given in Table 4. The values listed are to be understood as one standard deviation and depend on the spectral channel.

Channel	Frequency (GHz)	NEΔT (K) O/B/T	Bias (K) O/B/T	Polarisation	IPSF Size at 3dB (km)
MWS-1	23.8	0.15/0.30/0.60	0.2/0.5/1.0	V	40
MWS -2	31.4	0.20/0.30/0.40	0.2/0.5/1.0	V	40
MWS -3	50.3	0.40/0.50/0.60	0.2/0.5/1.0	V	20
MWS -4	52.8	0.25/0.30/0.50	0.2/0.5/1.0	V	20
MWS -5	53.596±0.115	0.30/0.40/0.50	0.2/0.5/1.0	V	20

MWS -6	54.40	0.25/0.40/0.50	0.2/0.5/1.0	V	20
MWS -7	54.94	0.25/0.30/0.40	0.2/0.5/1.0	V	20
MWS -8	55.50	0.30/0.40/0.50	0.2/0.5/1.0	V	20
MWS -9	57.2903	0.30/0.40/0.50	0.2/0.5/1.0	V or H	20
MWS-10	57.2903±0.217	0.45/0.60/0.75	0.2/0.5/1.0	V or H	20
MWS-11	57.29±0.332±0.048	0.45/0.60/0.75	0.2/0.5/1.0	V or H	20
MWS-12	57.29±0.332±0.022	0.70/1.0/ 1.2	0.2/0.5/1.0	V or H	20
MWS-13	57.29±0.322±0.010	1.0/1.2/1.5	0.2/0.5/1.0	V or H	20
MWS-14	57.29±0.322±0.004	1.6/1.8/2.0	0.2/0.5/1.0	V or H	20
MWS-15	89.0	0.25/0.30/0.50	0.2/0.5/1.0	V	20
MWS-16	89.0	0.50/0.60/1.0	0.2/0.5/1.0	V	15
MWS-17	164-167	0.30/0.50/1.0	0.2/0.5/1.0	V	15
MWS-18	183.31±7	0.40/0.50/0.80	0.2/0.5/1.0	V	15
MWS-19	183.31±4.5	0.40/0.50/0.80	0.2/0.5/1.0	V	15
MWS-20	183.31±3.0	0.60/0.75/1.0	0.2/0.5/1.0	V	15
MWS-21	183.31±1.8	0.60/0.75/1.0	0.2/0.5/1.0	V	15
MWS-22	183.31±1.0	0.75/1.0/1.5	0.2/0.5/1.0	V	15
MWS-23	229	0.70/1.0/1.5	0.2/0.5/1.0	V	15
MWS-24	118.7503 ± 5.000	0.25/0.5/0.75	0.2/0.5/1.0	V or H	15
MWS-25	118.7503 ± 3.000	0.30/0.5/0.75	0.2/0.5/1.0	V or H	15
MWS-26	118.7503 ± 2.100	0.40/0.70/1.0	0.2/0.5/1.0	V or H	15
MWS-27	118.7503 ± 1.500	0.55/0.75/1.0	0.2/0.5/1.0	V or H	15
MWS-28	118.7503 ± 1.100	0.55/0.75/1.0	0.2/0.5/1.0	V or H	15
MWS-29	118.7503 ± 0.700	0.55/0.75/1.0	0.2/0.5/1.0	V or H	15
MWS-30	118.7503 ± 0.400	0.75/1.0/1.3	0.2/0.5/1.0	V or H	15
MWS-31	118.7503 ± 0.200	1.1/1.5/2.0	0.2/0.5/1.0	V or H	15
MWS-32	118.7503 ± 0.080	2.45/2.75/3.0	0.2/0.5/1.0	V or H	15

O: Objective, B: Breaktrough, T: Threshold

Table 4: MWS noise, bias, polarisation, and IPSF requirements

5.2.5.3 Bias Error

MRD_MWS.150

The bias shall be as listed in Table 4 for the whole dynamic range, under all circumstances.

5.2.5.4 Orbit Stability

MRD_MWS.160

Variations (RMS) of systematic errors in the measured brightness temperature during any single orbit shall be < 0.10 K, (objective), < 0.15 K (breakthrough), < 0.20 K (threshold), at 280 K scene temperature.

5.2.5.5 Lifetime Stability

MRD_MWS.170

Variations (RMS) of the running average over one orbit of systematic errors in the measured brightness temperature shall be < 0.10 K, (objective), < 0.15 K (breakthrough), < 0.20 K (threshold), at 280 K scene temperature.

5.2.5.6 Radiometric Homogeneity

MRD_MWS.180

Inter-channel RMS differences between brightness temperatures of the same spatial sample shall be < 0.1 K (objective), < 0.2 K (breakthrough), < 0.3 K (threshold) at a target temperature of 280 K.

MRD_MWS.190

RMS differences between brightness temperatures of the same spectral channel at different spatial samples shall be < 0.1 K (objective), < 0.2 K (breakthrough), < 0.3 K (threshold) for a 280 K target temperature.

5.2.6 Polarisation Requirements

The MWS channels shall be linearly polarised.

MRD_MWS.210

Each MWS channel shall be linearly polarised as specified in Table 4.

The terms “vertical” (V) and “horizontal” (H) polarisations in Table 4 refer to a conically scanning radiometer with constant nadir viewing angle. In case of a cross-track scanning instrument these are to be understood as quasi vertical (QV) and quasi horizontal (QH), respectively, to account for the fact that the electric field vector rotates as the antenna scans away from nadir, assuming that the antenna feedhorn remains fixed while the antenna (flat relector) rotates. QV refers to the mode where, approaching nadir view, the electrical field vector of the electromagnetic wave lies entirely in the incidence plane, while QH refers to the an electric field vector which is perpendicular to the plane of incidence when the antenna approaches the nadir position.

5.2.7 Geometric Requirements

These requirements cover the horizontal coverage and resolution.

MRD_MWS.300

The MWS shall be optimised for operation in a sun-synchronous orbit.

MRD_MWS.310

The MWS shall maximise the useful viewing angle and provide a 90% global coverage within 12 hours, and 99% within 24 hours, preferably with a single instrument. In view of the heritage from AMSU-A, MHS, and ATMS, the preferred instrument is a cross-track scanner.

MRD_MWS.320

The scanning mode shall provide 'image-like' data (i.e. contiguous IFOV's both along- and across-track) in the channel MWS-16.

5.2.7.1 Beam and Pointing Requirements

The following requirements include beam efficiency, beam shape, beam axis and pointing accuracy.

MRD_MWS.330

The instrument shall have a beam efficiency of 95% or greater. This shall be met for all channels and all valid beam positions.

MRD_MWS.340

The MWS main-beam beamwidths shall be within 10% of its specified beamwidth values as listed in Table 4. This shall hold for any gain pattern "cut" that contains the main beam axis. The beam shape shall be rotationally symmetric around the main-beam axis and the half-power beamwidth in any plane that contains the axis of the main-beam shall be within 10% of its specified beamwidth.

MRD_MWS.360

The maximum deviation of the beam axes from the specified scan plane shall be less than 0.05° and be known within 0.03°. In the scan plane reference the total pointing accuracy of the position of each beam centre shall be 0.05°, with knowledge of 0.03°. All channel co-registrations shall be done within these accuracies.

5.2.7.2 Synchronisation requirement

MRD_MWS.270

Within a scan all the Earth measurements shall be equally spaced in viewing angle.

5.3 Radio Occultation Sounding Mission (RO)

5.3.1 Objectives

User requirements expressed in the Atmospheric Sounding and Wind profiling EUMETSAT position paper state the importance of measurements related to atmospheric temperature and humidity profiles. Improvements in the vertical resolution of retrieved temperature profiles currently have been shown to be important by many sources. Also, detailed vertical profiles of water vapour are of critical importance, but cannot be retrieved with enough vertical resolution by passive microwave radiometers.
A Radio Occultation (RO) mission can provide useful information on these parameters, although with relatively coarse horizontal resolution based on a single satellite. A constellation of 12 RO instruments on different satellites could offer to meet the stringent horizontal sampling requirements for atmospheric temperature and water-vapour soundings. A first system of such kind has recently been launched in the frame of COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate).

The **main objective** of the GNSS Radio Occultation mission is therefore to provide measurements of refractivity profiles in the troposphere and the lower stratosphere with a good vertical resolution and sufficient accuracy to meet these requirements. From refractivity profiles atmospheric temperature and humidity profiles as well information on surface pressure can be retrieved.

A **secondary objective** is the retrieval of depth of the planetary boundary layer and the height (and structure) of the tropopause. Additionally, ionospheric total electron content (TEC) and electron density profiles can be retrieved.

The main users of the RO mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF. The RO mission is also relevant to non real-time users, in particular for climate monitoring.

5.3.2 Products

The primary products to be derived from the RO mission include:

1. Temperature profile
2. Water-vapour profile
3. Bending angle
4. Refractivity Profile

Further secondary products of the RO mission contributes are:

5. Depth of the planetary boundary layer
6. Height (and structure) of the tropopause
7. Atmospheric layer thicknesses between defined pressure levels
8. Electron density profile (supporting space weather)
9. Total electron content (supporting space weather)

5.3.3 Priority of requirements

Operational data assimilation modules for NWP and climate monitoring rely on accurate high-quality observations. Hence, measurements in the neutral atmosphere providing information on temperature profiles have the highest priority in this context.
With respect to temperature profiles, accuracy and high vertical resolution are of highest priority. Maximisation of coverage can be obtained by using radio-occultations from different GNSSsuch as the current GPS, GLONASS and the future Galileo.

5.3.4 Measurement principle

The RO sensor is a passive instrument measuring the excess path length of GNSS signals as they are occulted by the atmosphere. Excess path length depends on the refractive index of the atmosphere which is a function of pressure, temperature and humidity. It is measured as phase change rate over time in the signal carrier phase (equivalent to a signal Doppler shift). The ray propagation is also affected by the electron density in the ionosphere: this effect can be corrected by observing two or possibly three frequencies. Contextually with this correction, information on ionosphere and plasmasphere may be retrieved. Such an instrument will also support spacecraft operation by providing real time platform navigation information.

5.3.5 Spectral requirements

5.3.5.1 Spectral range

MRD_RO.010

The RO sensor shall be operating in the Radio Navigation Satellite Service (RNSS) region allocation of the spectrum.

MRD_RO.020

The GNSS-RO sensor shall be capable to use signals from GPS, GLONASS and the Galileo systems. Central sub-band frequencies are defined in Table 5.

Mission Frequencies	Sub-Band	Frequencies (MHz)	System	Priority
RO-1	L1	1575.42	GPS	1
RO-2	L2	1227.60	GPS	1
RO-3	L5	1176.45	GPS	3
RO-4	E5a (GPS L5)	1176.45	Galileo	1
RO-5	E5b	1207.14	Galileo	3(TBC)
RO-6	E6	1278.75	Galileo	3(TBC)
RO-7	L1	1575.42	Galileo	1
RO-8	L1 (*)	$F_0 = 1602.0$ $\Delta f = 562.5$ kHz	GLONASS	2
RO-9	L2 (*)	$F_0 = 1246.0$ $\Delta f = 437.5$ kHz	GLONASS	2
RO-10	L3 (L5) TBC	1164-1215 (TBD)	GLONASS-K	3

(*) GLONASS L1 and L2 exact frequencies are depending on the channel number K that is assigned to a satellite:

$$F(K) = F_0 + K \cdot \Delta f$$

With Δf and F_0 defined as above. Beyond 2005 GLONASS satellites will use K = (-7…+6), where channel numbers K = +5 and K = +6 may be used for only technical purposes over the Russian Federation. Use of GLONASS will depend on the future evolution and maintenance of the system.

Table 5: RO Mission Frequencies

MRD_RO.030

The RO sensor shall be capable to operate with at least two frequencies for each system, a third frequency is desirable (see Table 4):

- GPS: L1, L2, L5;
- Galileo: L1, E5a and one of E5b or E6 (to be selected based on which offers better performance in the terms of occultation tracking, noise reduction and ionospheric correction);
- GLONASS: L1, L2, L5 (TBC).

5.3.6 Radiometric Requirements

MRD_RO.040

The RO sensor shall be able to provide code and carrier phase measurements and pseudo-range estimates from the code phases.

MRD_RO.050

The RO sensor shall be able to provide carrier amplitude measurements for all measured frequencies and tracked codes.

MRD_RO.060

The RO sensor shall be able to operate within its performance requirements independent of the presence of Selective Availability (SA) and/or Anti Spoofing (AS) for GPS system, if applicable.

MRD_RO.080

The RO sensor shall be able to estimate carrier phase residual Doppler shifts due to the neutral atmosphere with an accuracy (random noise component) < 1 mm/s (threshold) and < 0.5 mm/s (breakthrough).

5.3.6.1 Dynamic Range

MRD_RO.110

The RO sensor shall be able to acquire and track an occulting GNSS signal and capable to observe a maximum Doppler shift of 55 kHz, equivalent to a relative velocity between the orbiting platform and any GNSS satellite of approximately 10 km/s.

5.3.7 Coverage Requirements

These requirements deal with the positioning of the sensor, horizontal coverage and vertical resolution.

MRD_RO.112

The total number of radio-occultation events available shall be 1000/day (threshold), 2000/day (breakthrough), 8000/day (objective). Uniformity of sampling in space and time shall be sought.

MRD_RO.114

The RO sensor shall be designed such as to maximise the tracked occultation events. Hence, Galileo and GLONASS satellites must also be tracked beside GPS;

The target number of radio-occultation events undertaken by a single satellite shall be > 1000 / day (threshold); > 1500 / day (breakthrough).

MRD_RO.116

The vertical coverage of the measurement of neutral atmosphere shall be between the ground and 80 km altitude, allowing for different sampling rates as in Table 5.

MRD_RO.120

The vertical coverage of the measurement of ionosphere shall be between 80 km altitude and the satellite orbit height, allowing for different sampling rates as in Table 5.

5.3.7.1 Scan Pattern Requirements

MRD_RO.160

The high vertical spatial resolution of an occultation measurement shall be preserved.

MRD_RO.170

The sampling rate in closed-loop tracking mode shall be adjustable within each altitude range as defined in Table 6.

Height Range (km)	**Atmospheric Regions**	**Sampling rates (Hz)**
0-30	troposphere, lower stratosphere	10, 50, 100, 200
30-150	stratosphere, mesosphere, Ionosphere E region	10-50
150-to satellite orbit	Ionosphere	0.5, 1.0, 2.0, 5.0, 10

Table 6: RO Sampling Rates in closed-loop tracking mode

MRD_RO.171

The RO receiver shall be able to perform tracking in the lower troposphere using advanced tracking methods such as open-loop or improved (*) closed loop tracking in order to deal with multi-path propagation.

(*)This just means a TBD tracking technique.

5.3.7.2 Beam and Pointing Requirement

The following requirements include alignment accuracy and stability effects. It takes into account bias and random errors.

MRD_RO.180

The RO receiver antennas' gain pattern shall be arranged in order to extend the measurements into the ionosphere and above 80 km height.

5.4 Differential Absorption Lidar Mission (DIA)

5.4.1 Objectives

Accurate knowledge of water vapour profiles with high vertical resolution and frequent sampling is an important NWP requirement, as stated in the Atmospheric Sounding and Wind Profiling Position Paper.

The **main objective** of the DIfferential Absorption lidar mission (DIA) is to globally provide vertical profiles of water vapour with at least breakthrough accuracy and vertical resolution.

The knowledge of the water-vapour distribution is essential for the forecast of cloud and fog formation and is important for cloud and precipitation forecasting. An accurate description of the humidity field convergence is deemed crucial for the forecast of convective (and potentially damaging) phenomena by regional NWP systems.
The main users of the DIA mission will be the WMO real time users, i.e. NWP centres of National Meteorological services and ECMWF. The DIA mission is also relevant to climate monitoring since lower stratospheric humidity contributes as a Greenhouse gas and passive sounders are rather insensitive to low amounts of humidity.
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5.4.2 Products

The main Level 2 product will be water vapour profiles with high vertical resolution and accuracy, in the troposphere and lower stratosphere. The same principle may be used for other gases sufficiently abundant (e.g. ozone, carbon dioxide), using appropriate absorption bands. This, however, would require a change in source and detector technology, and is not straightforward in a single operational sensor. In this MRD we deal exclusively with water vapour.
The secondary products to be derived from the DIA mission are cloud top height and aerosol backscatter profile.

5.4.3 Priority of requirements

Vertical resolution and accuracy have the highest priority. Horizontal resolution (integration length) is the following relevant requirement.

5.4.4 Measurement principle

The DIAL technique compares the attenuation of two laser pulses emitted at a pair of closely spaced wavelengths in proximity of a water vapour absorption line. The on-line wavelength falls on the centre of a water vapour absorption line, and the off-line wavelength falls on the line wing, where absorption is significantly reduced. The water vapour density as a function of range is directly derived from the on and off-line measurements. Range can then be converted to a height assignment. An underlying assumption of this technique is that backscatter and extinction coefficients are identical on and off-line, thus the difference between the two signals is only due to water vapour absorption. Since the dynamic range of water vapour in the troposphere can be changing over order of magnitudes several wavelength pairs can be used, each characterised by different attenuation cross sections.The DIAL equation is calculated applying the lidar equation twice, taking the logarithm of the ratio of the on-line and off-line backscattered signals P_{on} and P_{off}, and calculating the derivative:

$$n_{H_2O}(R) = \frac{1}{2\Delta R(\sigma_{on} - \sigma_{off})}\left\{\ln\left[\frac{P_{on}(R_1)P_{off}(R_2)}{P_{off}(R_1)P_{on}(R_2)}\right]\right\}$$

where $n_{H_2O}(R)$ is the water vapour number density as a function of range R. σ_{on} and σ_{off} are the on-line and off-line absorption cross sections, while ΔR is the range difference between R_1 and R_2. This equation does not show any calibration constant, indicating that the DIAL technique can potentially provide very accurate measurements of absolute humidity.

5.4.5 Spectral requirements

Spectral requirements define the main spectral characteristics of the lidar. Options for the number and specification of each wavelength pair, including specification of the effective laser linewidth, should be determined by theoretical studies examining the options available for achieving the breakthrough requirements (in accuracy and resolution) for a broad range of meteorological situations.

MRD_DIA.010

The DIA shall emit pulses in the spectral range 925-950 nm, at one wavelength, λ_{on}, centred on a water-vapour absorption line and another wavelength, λ_{off}, in a nearby window and receive the backscattered radiation from the atmosphere to measure the lidar ratio of the received power $P(\lambda_{on})/P(\lambda_{off})$. At least three wavelength couples shall be selected in order to probe from the surface to the lower stratosphere.

MRD_DIA.040

DELETED.

MRD_DIA.050

DELETED.

MRD_DIA.060

DELETED.

5.4.6 Radiometric Requirements

The radiometric requirements are written in terms of Level 2 observationals requirements.

MRD_DIA.070

The observational requirements for the DIA mission are expressed in Table 7.

Threshold				
Dynamic Range [g/kg]	0.01-15			
For this dynamic range:				
Random error [%, 1 sigma]	10			
Bias [%]	<5			
Altitude range [km]	0-5	5-10	10-16	-
Vertical resolution [km]	1	1	2	-
Horizontal integration [km]	50	150	200	-

Breakthrough				
Dynamic Range [g/kg]	0.01-20			
For this dynamic range:				
Random error [%, 1 sigma]	5			
Bias [%]	<3			
Altitude range [km]	0-5	5-10	10-16	-
Vertical resolution [km]	1	1	2	-
Horizontal integration [km]	50	50	50	-

Objective				
Dynamic Range [g/kg]	0.001-25			
For this dynamic range:				
Random error [%, 1 sigma]	2			
Bias [%]	<2			
Altitude range [km]	0-5	5-10	10-15	15-20
Vertical resolution [km]	0.3	0.5	1	2
Horizontal integration [km]	15	15	50	100

Table 7: DIA required vertical resolutions and horizontal integrations

In order to provide water vapour profiles with the accuracy specified within the Atmospheric Sounding and Profiling position paper, the DIA needs an estimated knowledge from auxiliary data of the atmospheric temperature profile within 5K.

5.4.7 Geometric Requirements

MRD_DIA.110

The DIA shall be viewing 5 degrees off nadir to exclude reception of surface-reflected signals and cloud specular reflection.

MRD_DIA.120

The spatial sample shift for measurements targeted for the same atmospheric volume shall be less than one fifth of the FWHM of the spatial sample size.

MRD_DIA.135

The DIA shall measure power ratios $P(\lambda_{on})/P(\lambda_{off})$ to resolve the watervapour profile between surface and 20 km height.

5.4.7.1 Beam and Pointing Requirement

The following requirements include alignment accuracy and stability effects. It takes into account bias and random errors.

MRD_DIA.140

The DIAL pointing accuracy shall be known within 0.2°. (TBC)

MRD_DIA.150

DELETED

MRD_DIA.160

The background light shall be measured within 100 µs after ground echo.

5.5 Doppler Wind Lidar Mission (DWL)

5.5.1 Objectives

Accurate wind profiles would eliminate a major identified deficiency in the Global Observing System, as stated in the Atmospheric Sounding and Wind Profiling Position Paper. A Doppler Wind Lidar mission (DWL) is capable to provide useful vertically-resolved wind information in clear air, above cloud but also below partly cloudy layers. The DWL has heritage from the ADM-Aelolus mission in orbit and instrument characteristics.

The **main objective** of the DWL mission is to provide measurements of wind profiles along the Line-Of-Sight (LOS) direction throughout the troposphere and the lower stratosphere with a good vertical resolution and sufficient accuracy to meet the requirements defined in support of Numerical Weather Prediction (NWP) at global and regional scales.

This kind of information is very important for the modelling of tropical dynamics through the observation of the essential component of the flow, which would lead to a significant increase in the accuracy of tropical forecasts.

Forecasting of intense wind events could be improved through a proper measurement of vertical wind shear.

Through the assimilation of DWL measurements into operational systems the skill of medium-range forecasts for the extra-tropical region is expected to increase by a better definition of planetary-scale waves and stratospheric dynamics. Finally, DWL represent an additional and independent source of information needed to perform quality control of satellite data within data assimilation modules, for example, on the height assignment of Atmospheric Motion Winds, AMV, from GEO satellites and in the polar regions from LEO satellites. This will also lead to improvements in meteorological analyses, particularly in the Southern Hemisphere and tropics, where remote sensing data are the primary source of information.

The **secondary objectives** of the DWL mission are to provide information on cloud top altitudes, vertical distribution of clouds and aerosol layers, aerosol properties, and the altitude of the planetary boundary layer.

The main users of the DWL mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services (NMS) and ECMWF. The DWL mission is also relevant to non real-time users that use NMS or ECMWF analyses or reanalyses, for example to model atmospheric circulation and transport.

5.5.2 Products

The products to be derived from the DWL mission include in decreasing order of priority:

1. Profile of a horizontal wind component, in any viewing direction
2. Cloud top height
3. Cloud backscatter and extinction profile
4. Aerosol optical depth profile
5. Aerosol backscatter profile
6. Total aerosol optical depth

5.5.3 Priority of requirements

Operational data assimilation modules for NWP rely on accurate high-quality observations. This stresses the importance that the accuracy associated with each wind observation has the highest priority in this context.

5.5.4 Measurement principle

The basic measurement consists of the Doppler shift of the frequency of the backscattered light with respect to the emitted laser pulse. Viewing angle is off-nadir, in order to observe Doppler shift signal due to horizontal wind projected on the LOS direction. The scattering objects may be air molecules (Rayleigh scattering) or aerosol and cloud particles (Mie scattering).

In the current context, by Doppler shift measurement is meant a sub-set (in extreme cases could be composed by a single element) of single read-outs from accumulated return pulses for a defined height bin. By wind observation is meant the final altitude-assigned LOS wind component value with the specified performance characteristics obtained after processing of a number of Doppler shift measurements.

The DWL sensor design shall take account of the heritage on the ESA ADM-Aeolus instrument (ALADIN). However, attempts to reduce the instrument size and/or improve operational characteristics should be pursued.

MRD_DWL.005

The DWL shall generate and transmit laser pulses and shall acquire backscattered radiation to measure Doppler shift.

MRD_DWL.010

DELETED.

MRD_DWL.020

Both Rayleigh and Mie scattering signals should in principle be observed. Rayleigh detection has higher priority, allowing for observation of upper troposphere and lower stratosphere, where additional wind information is most required.

Retrieval of wind information from Rayleigh detection requires an estimated knowledge from auxiliary data of the atmospheric temperature profile within 10K.

5.5.5 Wind Dynamic Measurement Range

At altitudes of 10 km, 120 m/s wind velocities occasionally occur. The typical core jet stream wind speed in wintertime over the northern hemisphere is around 50-70 m/s, for altitudes between 6 and 12 km.

The horizontal LOS, HLOS, requirement below is converted to a LOS requirement by multiplication with the sine of the local angle between LOS and vertical directions.

MRD_DWL.030

Full measurement performance shall be achieved for all HLOS wind components in the range ± 100 m/s. HLOS wind speeds up to ± 150 m/s shall be detectable.

5.5.6 Spectral requirements

Spectral requirements define the main spectral characteristics and performance of the DWL. The Mie and Rayleigh channel measurement performance requirement (see 5.5.4) dictates the wavelength choice. For continuity, ADM and Earth-Care will be in the UV, a UV system would be favourable.

5.5.6.1 Spectral range

MRD_DWL.040

The Doppler wind lidar shall favourably be operating in the UV region of the spectrum.

5.5.7 Radiometric requirements

The definition of the wind observation accuracies reflects directly on the radiometric requirements, once the viewing geometry has been defined.

The requirement is for an observation of the mean wind along the linear observation track. This is, the so-called spatial representativeness error contribution (to represent a more useful 2D mean) has been excluded.

MRD_DWL.050

The RMS error of the processed HLOS wind observations, expressed in m/s, shall be the following (height levels defined according to WMO definitions);

Higher stratosphere: 10 (threshold), 5 (breakthrough), 1 (objective);

Lower stratosphere, higher and lower troposphere: 3 (threshold), 1.5 (breakthrough), 0.5 (objective).

Measurements in the lower stratosphere and in the whole troposphere have higher priority than measurements in the higher stratosphere.

MRD_DWL.055

The wind bias of the HLOS observations shall be less than 0.4 m/s over each half orbit.

MRD_DWL.057

The slope error standard deviation (systematic error proportional to windspeed) associated to the wind observations shall be less than 0.7% of the wind observation over the whole measurement range.

5.5.7.1 Signal Strength Dynamic Range

MRD_DWL.060

Ground echos and cloud top returns shall be exploitable for Doppler estimation. Moreover, the specified wind performance shall be met over the specified height range.

5.5.8 Geometric Requirements

These requirements cover the horizontal and vertical coverage and resolution.

MRD_DWL.070

One (threshold) or two (breakthrough) LEO DWLs at polar inclination shall be in measurement mode continuously and make at least one HLOS observation profile every 200 km.

5.5.8.1 Observation geometry requirements

The off-nadir viewing angle is a trade-off between i) LOS-projected horizontal wind component, ii) range distance, and iii) cloud hit probability. Local incidence angles over 40 degrees will substantially increase the cloud hit rate.

MRD_DWL.080

The DWL shall be able to observe off-nadir LOS wind in one direction (threshold), but preferably in two orthogonal horizontal directions (breakthrough).

MRD_DWL.085

The DWL shall observe off-nadir with a local incidence angle less than 40 degrees.

5.5.8.2 Pointing and geolocation requirements

Pointing requirements shall fulfil the following requirements for horizontal and vertical geolocation.

MRD_DWL.090

Geolocation of each wind measurement shall have a localisation error < 2 km and vertical localisation error < 200 m.

5.5.8.3 Wind observation horizontal resolution

Horizontal subsampling is required in heterogeneous atmospheric conditions in order to classify and control the measurements.

MRD_DWL.100

Along flight, the integration distance (horizontal resolution) of the final wind observation shall be < 50 km (breakthrough), <15 km (objective). The sampling distance (minimum distance between two consecutive observations) shall be <200 km.

MRD_DWL.105

Along flight, the integration distance (measurement resolution) of the measurements shall be such that at minimum 10 measurements constitute an observation.

5.5.8.4 Vertical Localisation Requirements

Vertical subsampling is required in heterogeneous (stratified) atmospheric conditions in order to control the measurement signal height.

MRD_DWL.110

The vertical resolution of final wind observations shall be < 0.5 km below 2 km height from the ground, <1 km in the free troposphere, <2 km in the stratosphere.

MRD_DWL.112

It shall be possible to change the altitude resolution at different measurement altitudes in-flight in steps of multiples of 250 m, independently on the molecular and aerosol backscatter channels.

MRD_DWL.115

The vertical resolution (by integration) of the Mie measurements shall be at least twice the vertical resolution of the final wind observations below 15 km.

MRD_DWL.116

None of the vertical range gates of the Mie measurement channel shall fit only partially within a vertical range gate of the Rayleigh measurement channel, and vice versa. This is, only whole multiple Mie range gates are allowed within a Rayleigh range gate, and vice versa.

5.5.8.5 Vertical Range

MRD_DWL.120

The DWL shall be capable of taking valid measurements from the Earth surface to 20 km (threshold), 30 km (breakthrough) and 45 km (objective) altitude.

5.5.8.6 Measurement Range Error

The measurement range error defines the required knowledge of the height for each measurement range gate.

MRD_DWL.130

The uncertainty in the vertical of the measurement position shall be < 50 m (threshold), or < 20 m (breakthrough).

5.5.8.7 Correction of Orbit Height Variations

Systematic orbit height variations need be compensated for every measurement in order to meet the wind RMS and bias performances for the observations. In addition a requirement is needed on the absolute knowledge of height on observation level as stated in 5.5.8.6.

MRD_DWL.140

Orbit attitude and altitude shall be controlled in order to meet all wind performance and geolocation requirements.

5.6 VIS/IR Imaging Mission (VII)

5.6.1 Objectives

The PEPS VIS/IR Imaging Mission (VII) is a cross-purpose medium resolution, multi-spectral optical imaging serving operational meteorology, oceanography and climate applications as derived in terms of user needs by application experts.

Considering that most NWP users plan to directly assimilate calibrated and geolocated radiances, the VII mission is specified in terms of its targeted real time level 1b data output. It involves all PEPS system functions required to generate this basic output, excluding the functions required to make it available to users.

The primary objectives of the Post-EPS VII mission are to provide high quality imagery data for global and regional NWP and NWC through the provision of:

- High horizontal resolution cloud products including microphysical analysis
- Aerosol products
- Atmospheric water-vapour gross profiles at high horizontal resolution
- Polar atmospheric motion vectors

- Vegetation snow coverage and fire monitoring products
- Sea and ice surface temperature, sea ice coverage

Other mission objectives include:

- Land surface temperature
- Atmospheric temperature gross profiles at high horizontal resolution
- Support the PEPS sounders, particularly:
    - Geolocation
    - Cloud characterisation
    - Scene inhomogeneity quantification for correction of the spectral response.
- To provide continuity of other key imager channels in support of long-term climate records.

The main users of the VII mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF in addition to operational nowcasting services of National Meteorological Services. The VII mission is also relevant to non real-time users.

The instrument will be a passive satellite radiometer capable of measuring thermal radiance emitted by the Earth and solar backscattered radiation, in specified spectral bands in the UV, visible and infra-red parts of the electromagnetic spectrum.
The level of fulfilment of these objectives will highly depend on the space-time resolution of the VII mission, and is particularly critical at high latitudes where information from geostationary spacecraft is scarce or even unavailable.

As a baseline, the minumum expected performance of the VII mission consists of covering the priority 1 channels listed below.

5.6.2 Products

The following products requiring observation from a medium resolution VIS/IR imager of this type have been identified by the Post-EPS application experts.

Primary products to be derived from the VII mission are:

- Cloud mask
- Cloud imagery
- Cloud cover profile
- Cloud optical depth
- Cloud top temperature
- Cloud top height
- Cloud type
- Cloud drop (liquid) or particle (solid) effective radius at the cloud top,
- Polar Atmospheric Motion Vectors (AMVs)
- Water-vapour imagery
- Aerosol optical depth (total columnar amount and gross profile)
- Earth surface albedo,
- SW Earth's surface bi-directional reflection
- SW cloud reflectance
- Vegetation:

  - Leaf area index (LAI)
  - Vegetation type
  - Fraction of vegetated land
  - Fraction absorbed photosynthetically active radiation (FAPAR)
  - Photosynthetically active radiation (PAR)
  - Normalised Differential Vegetation Index (NDVI)
- Snow and land ice:
  - Snow detection
  - Snow cover
  - Snow surface temperature
  - Snow albedo
- Fire:
  - Fire detection
  - Fire fractional cover
- Sea surface temperature
- Sea ice:
  - Imagery
  - Sea ice coverage
  - Sea ice drift

Further products to which the VII mission contributes include:

- Land surface temperature
- Aerosol type (total columnar amount and gross profile)
- Aerosol effective radius (total columnar amount and gross profile)
- Total aerosol single scatter albedo,
- Downwelling SW radiation at the Earth's surface
- Glacier cover
- Frozen soil and permafrost
  - Fire Smoke detection
  - Fire temperature
  - Fire radiative power
- Sea ice meltpond fraction

Assumptions regarding external data sources
Retrieval of these data will depend on the availability of:

- High vertical resolution temperature and water vapour sounding data
- Land type databases

5.6.3 Priority of Requirements

The driving requirements for this mission are:

1. Spatial resolution
2. Radiometric noise
3. Implementation of priority 2 channels
4. Implementation of priority 3 channels
5. Implementation of priority 4 channels

5.6.4 Spectral Requirements

5.6.4.1 Spectral Range and Resolution

MRD_VII.010

In order to achieve the mission objectives, the Post-EPS VII shall measure scene radiances in a number of spectral channels. Table 8 lists candidate spectral channels and their bandwidths defined in terms of the full width at half maximum (FWHM). Priorities for the channels are also given, 1 being highest priority, 4, the lowest.

Channel number	Central Wavelength (µm)	FWHM (µm)	Primary Use	Priority
VII-1	0.34	0.01	Aerosol, with inference of height	3
VII-2	0.38	0.01		3
VII-3	0.415	0.015		3
VII-4	**0.443**	**0.02**	**Aerosol, 'true colour imagery' (blue channel), vegetation**	**1**
VII-5	0.47	0.02	Aerosol, surface albedo, cloud reflectance, cloud optical depth, vegetation	2
VII-6	0.49	0.01	Aerosol, surface albedo, cloud reflectance, cloud optical depth	3
VII-7	0.531	0.01		3
VII-8	**0.555**	**0.02**	**Clouds, vegetation, 'true colour imagery' (green channel)**	**1**
VII-9	0.565	0.01	Cloud characterisation	4
VII-10	0.653	0.015	Aerosol, surface albedo, cloud reflectance,sea and land surface features (snow, ice), vegetation	3
VII-11	0.659	0.05		3
VII-12	**0.67**	**0.02**	**Clouds, vegetation, 'true colour imagery' (red channel)**	**1**
VII-13	0.681	0.01	Atmospheric corrections (aerosol) vegetation	4
VII-14	0.708	0.02		2
VII-15	0.763	0.01	Atmospheric corrections (aerosol), optical cloud top height assignment, vegetation	2
VII-16	0.763	0.04		2
VII-17	**0.865**	**0.02**	**Vegetation, aerosol, clouds, surface features**	**1**
VII-18	0.905	0.03	Water vapour imagery Water vapour total column	3
VII-19	0.936	0.01		2
VII-20	**0.94**	**0.05**		**1**
VII-21	1.02	0.02	Aerosol correction, water vapour, snow grain size	3
VII-22	1.24	0.02	Vegetation, aerosol	2
VII-23	**1.375**	**0.03**	**High level aerosol, cirrus clouds, water vapour imagery**	**1**
VII-24	**1.64**	**0.02**	**Cloud phase, snow, vegetation, aerosol, fire**	**1**
VII-25	**2.25**	**0.05**	**Cloud microphysics at cloud top, vegetation, aerosol over land, fire (effects)**	**1**
VII-26	**3.75**	**0.18**	**Cloud parameters, cloud microphysics at cloud top, absorbing aerosol, SST, LST,fire, sea and land ice**	**1**
VII-27	3.8	0.6		4
VII-28	3.959	0.06	SST, LST, fire	2
VII-29	3.959	0.06	Fire temperature and radiative power (high	4

			dynamic range channel)	
VII-30	4.05	0.05	SST, LST fire	2
VII-31	4.465	0.05	Temperature profile (coarse vertical resolution)	3
VII-32	4.515	0.05		3
VII-33	**6.715**	**0.36**	**Water vapour imagery (including wind in polar regions), water vapour profile (coarse vertical resolution)**	**1**
VII-34	**7.325**	**0.3**		**1**
VII-35	**8.55**	**0.3**	**Cirrus clouds, cloud emissivity**	**1**
VII-36	**9.73**	**0.3**	**Total ozone**	**1**
VII-37	**10.8**	**1**	**Cloud parameters including cirrus detection, surface temperatures and other radiative parameters, surface imagery (snow, ice etc)**	**1**
VII-38	11.03	0.3		2
VII-39	**12.02**	**0.5**		**1**
VII-40	**13.335**	**0.3**	**CO_2slicing for accurate cloud top height. Temperature profile (coarse vertical resolution)**	**1**
VII-41	13.635	0.3		3
VII-42	13.935	0.3		3
VII-43	14.235	0.3		3
VII-44	18.2	2.0	Thin cirrus cloud detection over ocean and land	4
VII-45	24.4	2.0		4
VII-46	0.7	0.33	Day/Night Band	4

Table 8: VII channels

Notes:

The 16 channels assigned with priority 1 in the above table provide the baseline VII configuration. Other channels could be added on the basis of cost effectiveness consideration. Once the number of channels and their approximate location are preliminarily fixed, the final channel positions and their bandwidths shall be re-assessed.

Several bands for aerosol and thin cirrus clouds observation present on the VII could also be implemented on the 3MI. If these channels are implemented on the 3MI, they are still of value on the VII due to the higher spatial resolution, however, they would all have priority 4. The channels concerned are.

- VII-1 (340 nm)
- VII-2 (380 nm)
- VII-44 (18.2 µm)
- VII-45 (24.4 µm)

MRD_VII.020

1. The total out-ot-band response of the channels 1 to 25 shall be < 2% of the total integrated response within two times the FWHM bandpass region when viewing a source that simulates the solar spectral energy distribution.
2. The total-out-of-band response of the channels 33 to 45 shall be < 2% of the total integrated response within two times the FWHM bandpass region when viewing a 300 K blackbody source.
3. The total out-of-band response of channels 26 to 32 shall meet both previous requirements.

MRD_VII.030

The out-of-band response shall be sufficiently characterised such that the absolute accuracy requirements given in 5.6.5.2 are met.

5.6.5 Radiometric Requirements

5.6.5.1 Radiometric Noise

MRD_VII.100

The radiometric noise shall meet the requirement as given in

Table 9 (for the baseline16 channels and the priority 2 channels). The quoted figures are understood as one standard deviation. The required dynamic range is also reported. At this stage, the radiometric requirements given for the priority 2 channels serve only to provide a guideline of the eventual values. They are present here as estimates to enable a preliminary feasibility assessment of implementing the priority 2 channels in addition to the priority 1 channels.

Channel number	**Central Wavelength (µm)**	**$R_{typical}$ W/m^2/sr/µm**	**R_{high} W/m^2/sr/µm**	**R_{low} W/m^2/sr/µm**	**NeDR W/m^2/sr/µm**	**SNR at $R_{typical}$**
VII-4	**0.443**	**42**	**687**	**8**	**0.19**	**221**
VII-5	0.47	35	TBC	TBC	0.15	235
VII-8	**0.555**	**22**	**667**	**11.94**	**0.19**	**115**
VII-12	**0.670**	**9.56**	**1010**	**2.7**	**0.15**	**66**
VII-14	0.708	7	452	2	0.02	350
VII-15	0.763	20	377	5	0.06	333
VII-16	0.763	20	377	5	0.04	500
VII-17	**0.865**	**6.04**	**349**	**6.04**	**0.1**	**60**
VII-19	0.936	3.6	TBC	TBC	0.06	60
VII-20	**0.94**	**15**	**238**	**5.01**	**0.08**	**187**
VII-22	1.24	5.4	165	3.5	0.06	90
VII-23	**1.375**	**6**	**109**	**0.58**	**0.02**	**300**
VII-24	**1.640**	**7.3**	**104**	**0.4**	**0.1**	**73**
VII-25	**2.25**	**3.2**	**31.8**	**0.12**	**0.04**	**80**
Channel number	**Central Wavelength (µm)**	**$BT_{typical}$ (K)**	**BT_{high} (K)**	**BT_{low} (K)**	**NeΔT at 280K**	
VII-26	**3.75**	**300**	**450**	**220**	**0.109**	
VII-28	3.959	300	TBC	TBC	0.15	
VII-30	4.05	300	TBC	230	0.15	
VII-33	**6.715**	**250**	**271**	**180**	**0.100**	
VII-34	**7.325**	**250**	**275**	**180**	**0.108**	
VII-35	**8.55**	**300**	**324**	**180**	**0.065**	
VII-36	**9.73**	**250**	**275**	**180**	**0.076**	
VII-37	**10.8**	**300**	**400**	**180**	**0.060**	
VII-38	11.03	270	TBC	180	0.06	
VII-39	**12.02**	**300**	**400**	**180**	**0.058**	
VII-40	**13.335**	**270**	**285**	**180**	**0.185**	

Table 9: VII Noise and dynamic range specification

Note: the high dynamic range for channel VII-26 (3.75 µm) should not be a design driver and impact the radiometric resolution of the sensor over the meteorological range of interest (220-350 K)

MRD_VII.120

DELETED

MRD_VII.140

The radometric requirements shall be met in the target temperature range. At temperatures T different from 280 K, the specified noise shall be scaled by the factor $\left[\frac{dB(\nu_0, 280K)}{dT}\right] \Big/ \left[\frac{dB(\nu_0, T)}{dT}\right]$, where B is the Planck's function, ν_0 is the wavenumber of the channel and T is the target temperature in K. This implies a constant requirement in terms of radiance.

MRD_VII.175

Gaps in the data due to calibration campaigns and/or any on-line calibration shall be minimised and preferably be scheduled while the instrument passes over the South Pole.

5.6.5.2 Bias Accuracy

MRD_VII.180

1. The bias error of the shortwave channels shall be < 5% (threshold), < 4 % (breakthrough), < 3 % (objective) over the dynamic range given in Table 9 (up to 80% albedo for channels VII-20 and VII-23), for a uniform scene.
2. The bias error of the longwave channels shall be < 0.5 K brightness temperature at a reference temperature of 280 K.

5.6.5.3 Orbit Stability

The following specification gives the stability during one orbit (i.e. 102 minutes).

MRD_VII.190

1. Variations (RMS) of systematic errors in the shortwave channels during any single orbit shall be < 1% of the typical scene radiance (see Table 9 for reference scene, $R_{typical}$).
2. Variations (RMS) of systematic errors in the longwave channels during an orbit shall be < 0.15 K (at 280 K) in the typical scene brightness temperature (see Table 9 for reference scene, $R_{typical}$).

5.6.5.4 Lifetime Stability

The following specification gives constraints on the bias part of the measurement error during the instrument lifetime.

MRD_VII.200

1. Variations (RMS) of running averages over one orbit of the systematic errors in the shortwave channels shall be < 1% for a typical scene radiance (Table 9).
2. Variations (RMS) of running averages over one orbit of the systematic errors in the longwave channels shall be < 0.15 K (at 280 K) in brightness temperature.

5.6.5.5 Radiometric Homogeneity

This specification gives the constraints on the error terms of which behaviour varies with spectral channels, and scan mirror positions. It is split into a spectral and a geometric homogeneity.

MRD_VII.210

1. Inter-channel radiance differences between different shortwave channels of the same pixel shall be < 1% in the radiance measured when viewing the same spectrally and spatially homogeneous scene (see Table 9 for reference scene, $R_{typical}$).
2. Inter-channel brightness temperature differences between different longwave channels of the same pixel shall be < 0.1 K, for a spatially homogeneous target of 280 K.

MRD_VII.220

1. Inter-pixel radiance differences between different pixels of the same shortwave channel at different scan angles shall be < 1% in the radiance measured when viewing the same spectrally and spatially homogeneous scene (see Table 9 for reference scene, $R_{typical}$).
2. Inter-pixel brightness temperature differences between different pixels of the same longwave channel shall be < 0.1 K for a 280 K target temperature.

5.6.6 Polarisation Requirements

MRD_VII.240

The VII channels with wavelength < 3 µm shall be insensitive to polarisation. The polarisation sensitivity shall be < 5% (threshold), < 2% (goal).

5.6.7 Geometric Requirements

MRD_VII.250

The VII imager shall be optimised for operation in a sun-synchronous orbit.

MRD_VII.260

The VII shall maximise the useful viewing angle and provide 99% global coverage within 12 hours (independent of day/night constraints), preferably with a single instrument.

MRD_VII.270

The on ground pixel size at nadir shall be < 0.5 km for all channels of the baseline configuration. For the additional channels, 0.5 km is still preferred but relaxation up to 1 km is acceptable. For channels VII-12 (0.670 µm) and VII-17 (0.865 µm), a smaller pixel of < 0.25 km at nadir is requested.

MRD_VII.300

The normalised Modulation Transfer Function (MTF) shall be isotropic within 10 % and shall be greater than 0.3 at the spatial wavelength given by twice the specified footprint (pixel) size.

5.6.7.1 Pointing Requirement

MRD_VII.315

The absolute pointing knowledge shall be < 0.1 mrad.

5.6.7.2 Synchronisation requirement

The following requirements refer to the synchronisation of measurements in different spectral channels.

MRD_VII.320

Measurements at different spectral channels shall be co-registered so that at least 90% of the the covered areas of each pixel are the same.

MRD_VII.330

Measurements at different spectral channels shall be co-registered within < 1 s (objective), < 2 s (breakthrough), 3 s (threshold).

5.7 Microwave Imaging Mission (MWI)

5.7.1 Objectives

The Post-EPS MicroWave Imager (MWI) is a cross-purpose multi-spectral microwave imager serving operational meteorology, oceanography, sea-ice/snow/land surface observation and climate applications as derived by the Post-EPS application experts.

The **primary objective** of the Microwave Imaging mission is to support Numerical Weather Prediction at regional and global scales, through the provision of:

- Cloud and precipitation products including bulk microphysical parameters
- Total column water vapour, temperature and water vapour profiles (complementary to MWS)
- All weather surface imagery including:
    - Sea surface temperature (SST) and ocean salinity
    - Sea ice coverage (and type)
    - Snow coverage, depth and water equivalent
    - Soil moisture products
- Sea surface winds (complementary to the scatterometer))

Other mission objectives include:

- To provide continuity of other key microwave imager channels (e.g. , SSMI, TRMM TMI, SSMIS, AMSR-E and SMOS) in support of long-term climate records.

The instrument will be a passive satellite radiometer capable of measuring thermal radiance emitted by the Earth, at high spatial resolution in specified spectral bands in the microwave region of the electromagnetic spectrum.

Considering that most NWP users plan to directly assimilate calibrated and geolocated radiances, the MWI is specified in terms of its targeted real time level 1b data output. It involves all Post-EPS system functions required to generate this basic output, excluding the functions required to make it available to users.

The Microwave Imaging mission has a direct heritage from instruments such as the the Special Sensor Microwave/Imager (SSM/I) on the Defence Meteorological Satellite Program (DMSP F-8 to F-15), its successor the Special Sensor Microwave Imager Sounder (SSMIS; DMSP F-16 to F20), the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and the Advanced Microwave Scanning Radiometer (AMSR-E) currently flown on the Earth Observing System (EOS) Aqua satellite. Recent studies on microwave imager concepts have also been drawn upon during the mission requirements definition process, such as the European contribution to the Global Precipitation Measurement (EGPM) proposal and Sula Systems studies performed for ESA to derive instrument concepts for passive microwave radiometry.

Microwave imager data greatly enhances the National Meteorological Services' (NMS) ability to initialise global and regional NWP models with realistic estimations of clouds and precipitation which although are fundamental to the prediction of weather conditions, are currently not well assimilated into NWP models as data of this type is still relatively new compared to clear air temperature and humidity soundings. However, integrated atmospheric moisture as well as near-surface windspeed derived from microwave imager data is considered crucial in operational NWP analyses and is not covered by infrared or microwave sounder observations.

The frequent availability of detailed cloud, precipitation and all weather land surface parameters would also contribute to fulfil other key requirements common to Nowcasting and very short-range forecasting (VSRF) at regional scales:

- Monitoring of instability, for early warning of convective intensity;

- early warning for CAPE/convective instability;
- DCAPE (down draught intensity), for early warning of risks by downburst and severe outflow gusts;
- severe weather warnings for flash flood and mud slides prediction
- heavy snow, icing and avalanche warnings
- low cloud and poor visibility warnings
- cloud microphysical products

The level of fulfilment of these objectives will highly depend on the space-time resolution of the MWI mission, and is particularly critical at high latitudes where information from geostationary spacecraft is scarce or even unavailable.

The main users of the MWI mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF. Operational nowcasting services of National Meteorological Services may also be users of the MWI mission. The MWI mission is also relevant to non real-time users.

5.7.2 Products

The following products requiring observation from a microwave imager of this type have been identified by the Post-EPS application experts.

Primary products to be derived from the MWI mission are:

- cloud liquid water/ice water content (total column and gross profile)
- cloud and precipitation detection;
- precipitation content (liquid and frozen; total column and gross profile);
- precipitation rate near the surface;

- total column water vapour;
- atmospheric water vapour and temperature (gross profiles also in presence of clouds);
- sea surface wind (speed and direction);
- soil moisture
- snow parameters including:
  - snow water equivalent,
  - snow depth,
  - snow status (wet/dry),
  - snow detection,
  - snow cove,
  - snow surface temperature;
- sea surface temperature;
- sea ice imagery including:
  - sea ice coverage,
  - sea ice temperature,
  - sea ice type,
  - sea ice motion,
- ocean surface salinity.

Further products to which the MWI mission contributes include:

- long-wave (LW) Earth radiation budget product;
- land surface temperature;
- cloud drop/ice effective radius (total column and gross profile);

- freezing level height in clouds;
- melting layer depth in clouds;

The current specification of the MWI assumes that the Scatterometer is the primary Post-EPS mission for the retrieval of ocean wind vectors. In the event the scatteometer is de-scoped, the priority for retrieval of the full Stoke's components for the polarimetry channels on the MWI becomes 1. It is also assumed that MWS is the primary Post-EPS mission for temperature and moisture sounding. The sounding-type channels included in MWI are primarily supporting cloud/precipitation profiling. Potential trade-offs between MWS and MWI for sounding and imaging applications are to be investigated.

5.7.3 Priority of Requirements

MRD_MWI.005

The order of priority for the requirements shall be

1. **NEΔT,**
2. Bandwidth,
3. Integration time (horizontal sampling).

Note that for sounding type (contrary to window type) channels, bandwidth determines the shape of the weighting function and thus the vertical resolution.

5.7.4 Spectral Requirements

5.7.4.1 Spectral Range and Resolution

MRD_MWI.010

In order to achieve the mission objectives, the Post-EPS MWI shall measure scene radiances in a number of bands and channels covering the spectrum between 1.4 GHz and 700 GHz. Table 10a-c displays candidate channels, not necessarily to be implemented in a single instrument, for each of the following application areas:

- Clouds
- Precipitation
- Land surfaces and oceans
- Atmospheric temperature and moisture

The division of the channels per application does not represent a physical subdivision of the mission, rather it serves as an insight into the effects of mission subdivision on the respective applications.

The nominal spectral bandwidth for each channel is defined in this table in terms of the full width at half maximum (FWHM). Priorities for the channels are also given, 1 being highest priority, 4 being the lowest.

Ocean and Land

Channel name	Frequency (GHz)	Bandwidth (MHz)	Stability (MHz) All TBC	Primary Utilisation (secondary utilisation in brackets)	Priority
MWI-1	**1.4**	**27**	**1**	**Ocean salinity, soil moisture**	**1**
MWI-2	2.7	10	1	Soil moisture	3
MWI-3	**6.9**	**350**	**50**	**SST, (LST, soil moisture)**	**1**
MWI-4	10.65	100	50	Sea surface wind, (surface roughness correction for SST)	2
MWI-5	18.7	200	50	Sea-surface wind, (surface roughness correction for SST), sea-ice	2
MWI-6	23.8	400	50	Total column water vapour over sea	3
MWI-7	36.5	1000	50	Sea-surface wind, sea-ice & snow	2
MWI-12	**89.0**	**4000**	**100**	**Sea ice & snow imagery**	**1**

Table 10a: MWI channels, bandwidths and stability requirements for ocean and land observation

Notes:

- The priority of channels for sea surface wind should be re-considered in the event of the scatterometer being de-scoped (the scatterometer is assumed to be the primary instrument for sea surface winds).

- Ocean salinity and soil moisture at 1.4 and possibly 2.7 GHz require correction for SST (6.9 GHz) and surface roughness (10.65 and 18.7 GHz) which in turn require correction for water vapour (23.8 GHz). Furthermore, ocean salinity should be observed together with intense precipitation and sea ice to derive fresh water flux, and SST to derive sea surface density. Despite the need for these auxiliary data for salinity measurements, it is not mandatory to receive them from an instrument on the same platform. A free-flying salinity mission should not be ruled out on these grounds but considerations for providing the necessary auxiliary SST and surface roughness data to a sufficient accuracy must be made.

- For sea ice, measurements relying on 10 GHz and lower channels are sufficient to distinguish ice from water. However, the classification of first year and multi-year ice requires an additional channel around 30 GHz (currently 10/37 GHz or 18/37 GHz channels are used in AMSR-E retrievals for this purpose). If a large antenna, low frequency (10 GHz and below) implementation of this mission is considered, provisions for timely co-registration with the higher frequency channels on board another platform would have to be made in order to be able to distinguish the first and multi-year sea ice types.

- The frequency for SST retrieval is currently 6.9 GHz in view of the AMSR-E heritage and the higher achievable spatial resolution but other frequencies (down to 4.3 GHz in the protected band) could be considered for SST retrieval.

- From the ocean prespective, spectral stability is not a driving requirement and should not constrain the instrument design.

- The fully protected frequency of 31.4 GHz can be used in place of 36.5 GHz as long as the radiometric noise requirement is still met and the sensitivity to the main observation target at this frequency (sea-surface wind, cloud liquid water, precipitation) is ensured.

<u>Additional note on SST</u>
The measurement of sea surface temperature (SST) using microwave radiometry produces fields that are complementary in nature to those derived using infrared radiometers. Recent results (TMI, AMSR-E and MODIS on NASA Aqua) show the absolute accuracy of the microwave retrievals are close to that of those in infrared. The main advantage offered by microwave radiometers is the ability to measure SST through all but the densest, raining, clouds. Cloud cover is the major cause of missing SSTs in the infrared. The main disadvantage of the microwave measurement is the spatial resolution, 25 to 50 km compared to ~ 1 km in the infrared. Furthermore, the microwave measurement is diffraction limited with significant energy being received through side-lobes. However, over the ocean this is not an over-riding limitation and the availability of microwave SST data under all weather conditions does provide significantly better temporal sampling than available from interpolated infrared SST data. But in coastal regions where there is a strong emissivity contrast between the land (high) and the ocean (low) it results in significant errors in the SST measurement, with the result that reliable retrievals are not feasible within one to two foot-prints of a coastline or island.

Given the advantages and disadvantages of each system to measure SST, in the future, the microwave and infrared-SST fields should be blended routinely, to produce global SSTs that are essentially cloud-free over most of the oceans and of better quality than either alone. These techniques are currently being developed in the GODAE High Resolution SST Pilot-Project (GHRSST-PP) and are expected to be mature and widely used before the Post-EPS timeframe.

Because the microwave emission comes from the upper millimeter or more of the ocean whereas the infrared emission is from the upper fraction of a millimeter, the two have different sensitivities to changes in the thermal skin layer, with the infrared emission being more sensitive. If both infrared and microwave radiometers were significantly well built and calibrated with relative accuracies <0.1K, then, in principle, the differences in their measurements would reveal the thermal skin effect, which is responsive to local wind (also retrieved by the microwave radiometer) and net air-sea heat fluxes: these fluxes are currently inaccessible to measurement from space. While still a scientific issue at this time, it might be mature in the post-EPS time frame to provide new information for meteorological models.

Precipitation

Channel name	Frequency (GHz)	Bandwidth (MHz)	Stability (MHz)	Utilisation	Priority

			All TBC		
MWI-4	10.65	100	50	Heavy precipitation over sea	2
MWI-5	**18.7**	**200**	**50**	**Precipitation over sea**	**1**
MWI-6	23.8	400	50	Total column water vapour over sea	2
MWI-7	**36.5**	**1000**	**50**	**Precipitation over sea and (marginally) land**	**1**
MWI-8	**50.3**	**200**	**10**	**Precipitation over sea and land includingdrizzle, snowfall, height and depth of the melting layer**	**1**
MWI-9	**52.610**	**400**	**10**		**1**
MWI-10	**53.24**	**300**	**10**		**1**
MWI-11	**53.750**	**300**	**10**		**1**
MWI-12	**89.0**	**4000**	**100**	**Precipitation (sea & land) & snowfall**	**1**
MWI-13	**100.49**	**4000 (TBC)**	**100 (TBC)**	**Precipitation over sea and land**	**1**
MWI-14	**118.7503±2.00**	**1000**	**10**	**Precipitation over sea and land including light precipitation and snowfall, height and depth of the melting layer**	**1**
MWI-15	**118.7503±1.6**	**400**	**10**		**1**
MWI-16	**118.7503±1.4**	**400**	**10**		**1**
MWI-17	**118.7503±1.200**	**400**	**10**		**1**
MWI-18	166.9	1425	100	Quasi-window, water-vapour profile, precipitation over land, snowfall	2
MWI-19	**183.31±8.4**	**3000**	**100**	**Water vapour profile and snowfall**	**1**
MWI-20	**183.31±6.1**	**1500**	**100**		**1**
MWI-21	183.31±4.9	1500	100		2
MWI-22	**183.31±3.4**	**1500**	**100**		**1**
MWI-23	183.31±2.0	1500	100		3

Table 10b: MWI channels, bandwidths and stability requirements for precipitation observation

Notes:

- The oxygen sounding channel sets at (50-60 GHz) and (118.75 GHz) should be considered together. However, if descoping is required, the 50-60 GHz channels seem more important.

- The exact placing of the channels at 50-60 GHz, 118 GHz and 183 GHz is still TBC. Approximately 3-4 eventual channels are anticipated for each band.

- The prefered implementation of the 183.31 GHz channels furthest from the absorption peak (MWI-19) is by single-sideband channels at 191 and 175 GHz.

Cloud

Channel	**Frequency**	**Bandwidth**	**Stability**	**Utilisation**	**Priority**

name	(GHz)	(MHz)	(MHz) All TBC		
MWI-7	**36.5**	**1000**	**50**	**Cloud liquid water**	**1**
MWI-8	**50.3**	**200**	**10**	**Cloud liquid water**	**1**
MWI-10	**53.750**	**300**	**10**		**1**
MWI-12	**89.0**	**4000**	**100**	**Cloud liquid water**	**1**
MWI-13	**100.49**	**TBC**	**TBC**	**Cloud liquid water**	**1**
MWI-15	118.7503±1.6	400	10	**Cloud liquid water**	2
MWI-16	**118.7503±1.4**	**400**	**10**		**1**
MWI-17	118.7503±1.2	400	10		2
MWI-19	**183.31±8.4**	**3000**	**100**	**Water vapour profile, cloud ice water path retrieval**	**1**
MWI-22	183.31±3.4	1500	100		2
MWI-23	183.31±2.0	1500	100		2
MWI-24	243.2±2.5	3000	100	Quasi-window, cloud ice retrieval, cirrus clouds	3
MWI-25	325.15±9.5	3000	200	Cloud ice effective radius	2
MWI-26	325.15±3.5	2400	200		2
MWI-27	**325.15±1.5**	**1600**	**200**		**1**
MWI-28	**340**	**8000**	**400**	**Quasi-window, cloud ice and cirrus**	**1**
MWI-29	**448±7.2**	**3000**	**200**	**Cloud ice water path and cirrus**	**1**
MWI-30	448±3.0	2000	200		2
MWI-31	448±1.4	1200	200		2
MWI-32	664±4.2	3000	400	Cirrus clouds, cloud ice water path	2

Table 10c: MWI channels, bandwidths and stability requirements for cloud observation

Notes:

- The oxygen sounding channel sets at 50-60 GHz and 118.75 GHz should be considered together.

- The prefered implementation of the 183.31 GHz channels furthest from the absorption peak (MWI-19) is by single-sideband channels at 191 and 175 GHz (like MHS channel 5).

- For cloud ice retrievals, the 183 GHz channels need to be on the same instrument and cannot be ‘traded off’ with the MWS channels.

- The 664 GHz channel can be dropped without losing significant retrieval performance IF lower noise is assumed for the other cloud ice channels.

Table 10d presents a compromise instrument (MWI baseline) that would allow both the observation of the main parameters currently required by operational applications and the continuation of the microwave imager heritage. The added channels (priority 2) refer to upgrades serving ocean and land surface applications as well as improved cloud/precipitation observation.

Channel name	Frequency (GHz)	Bandwidth (MHz)	Stability (MHz) All TBC	Primary Utilisation (secondary utilisation in brackets)	Priority
MWI-3	6.9	350	50	SST, (LST, soil moisture)	2
MWI-4	10.65	100	50	Sea surface wind, SST, (surface roughness correction for SST)	2
MWI-5	**18.7**	**200**	**50**	**Sea-surface wind, sea-ice, precipitation, surface correction for water vapour**	**1**
MWI-6	**23.8**	**400**	**50**	**Total column water vapour over sea, precipitation**	**1**
MWI-7	**31.4 or 36.5**	**1000**	**50**	**Sea-surface wind, sea-ice & snow, cloud liquid water, precipitation**	**1**
MWI-8	50.3	200	10	Precipitation over sea and land, drizzle, snowfall, temperature in cloudy areas	2
MWI-9	52.61 or 52.80	400	10		2
MWI-12	**89.0**	**4000**	**100**	**Sea-ice & snow imagery, cloud liquid water, precipitation**	**1**
MWI-13	100.49	TBC	TBC	Clouds and precipitation over sea and land	2
MWI-19	183.31±8.4	3000	100	Water vapour profile and snowfall	2
MWI-20	183.31±6.1	1500	100		2
MWI-22	183.31±3.4	1500	100		2

Table 10d: MWI baseline channel specification

Notes:

- The channels with priority 1 constitute an SSM/I-like instrument given that both polarizations are available. The channel centre frequencies are slightly different from the SSM/I selection due to frequency protection issues.
- Channels at 6.9 and 10.65 GHz mainly support surface observation.
- The oxygen sounding channel at 52.61 could be moved to 52.80 GHz to mimic AMSU-A channel 4.
- The sounding channel (MWI-8, 9, 19, 20, 21) bandwidths and stabilities are assumed identical to those from AMSU-A channels 3, 4 and AMSU-B-channels 3-5 to support cross-calibration. They may be slightly relaxed due to technical constraints. MWI-13 may be configured similar to MWI-12.

Temperature and Moisture

Although the driving observations for the MWI mission are precipitation, clouds and ocean/land surface imaging, the benefits of a microwave imager for temperature and humidity observations, also in the presence of cloud and humidity observations, should not be overlooked. Traditionally, cross-track scanning instruments are used for these applications to reduce antenna size, to enhance calibration accuracy and to achieve a larger swath width (although currently data near the swath edges are not assimilated due to effects from beam contamination so the advantage of calibration accuracy and swath are to be investigated).

In the Post-EPS time-frame, assimilated microwave observations will not be initially classified into clear and cloudy profiles with separate treatment for each case (and indeed many assumed clear profiles are in fact cloud contaminated), rather the data will be commonly assimilated within all-encompasing algorithm that includes moist processes on demand by default. The application of such an already complex model is significantly simplified by the use of a constant scan angle from which no angular dependency of sounding altitude and surface emissivity/polarisation is encountered for the retrieval. Furthermore, the fixed H and V polarisations offered by the conical scanning geometry can be of benefit to temperature and humidity profiling in the lower troposphere.

The channels required for all weather (low-moderate cloud water but no precipitation in lower peaking channels) temperature and humidity observations are those given in the MWS specification. Although the current specification of the MWI is optimised for precipitation, clouds and land/ocean imaging, there is nevertheless a clear overlap between the channel selection for both the MWS and MWI. This overlap presents an opportunity of cross-calibration between instruments onboard the same satellite which will enable improved temperature/moisture sounding in the presence of clouds and precipitation.

Aside from the refinement of bandwidths to meet the noise requirements for the different scan geometries, the only additional channels required for temperature and humidity not already included in the MWI would be those centred around the oxygen absorption band at 57 GHz (MWS-8 to MWS-14) and the optional expansion of the channels around 118.75 GHz.

MRD_MWI.030

The maximum absolute shift of any channel centre frequency shall be less than the values listed in the fourth column of Table 10a-c. The maximum shift is defined with respect to the centroid nominal position.

MRD_MWI.040

The knowledge of the channel centre frequencies and the ISRF shapes shall be such that the associated radiometric uncertainty will not exceed 0.05 K in brightness temperature at a reference temperature of 280 K.

MRD_MWI.050

The centre frequency stability values listed in Table 10a-c shall be understood as short and long-term stability. Long-term refers to the lifetime of the instrument.

5.7.5 Radiometric Requirements

5.7.5.1 Dynamic Range

The dynamic range covers the range of radiances to be measured, expressed in brightness temperature, covering the range from the darkest to the brightest scene radiances to be measured in any spectral channel.

MRD_MWI.070

The system dynamic range of the MWI shall be optimised to cover the spectral radiances derived from a nadir measurement over a hot desert target with a 335 K surface temperature, a rainforest scene with surface temperature of 295 K and a and winter ocean scene with sea surface temperature < 278 K, as presented in Figure 3.

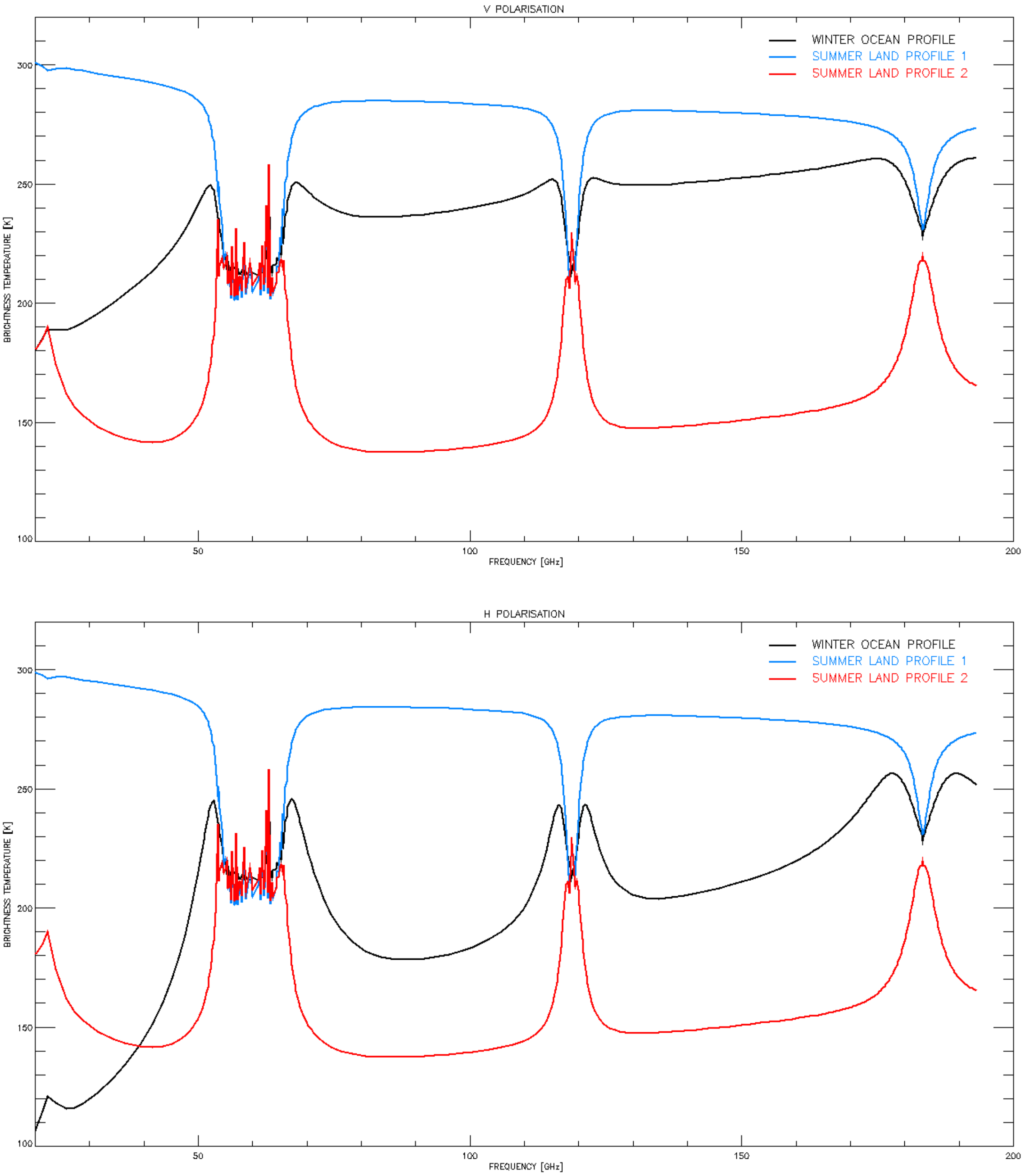

Figure 4: Brightness temperatures (V and H polarisation) for two land scenes (summer) and an ocean scene (winter)

5.7.5.2 Radiometric Noise

MRD_MWI.090

The radiometric temperature sensitivity requirement is given in the third column of Table 11a-c. The values listed are to be understood as one standard deviation. They are specified at a reference temperature of 280 K and depend on the spectral channel. The noise contribution of the calibration process is included.

Ocean and Land

Channel name	Frequency (GHz)	NEΔT (K) (T/B/O)	Bias (K)	Polarisation (*)	IPSF Size at 3dB (km) (T/B/O)
MWI-1	1.4	0.15/0.1/0.08	0.5	V, H	100/50/20
MWI-2	2.7	0.15/0.1/0.08	0.5	V, H	50/20/10
MWI-3	6.9	0.35/0.3/0.25	0.25	V, H	50/40/30
MWI-4	10.65	0.5/0.44/0.4	0.35	V, H	30/20/15
		0.25/0.22/0.2	0.25	(S_3, S_4)	
MWI-5	18.7	0.6/0.5/0.44	0.5	V, H	20/15/10
		0.3/0.25/0.22	0.25	(S_3, S_4)	
MWI-6	23.8	0.3/0.45/0.6	0.5	V, H	20/15/10
MWI-7	36.5	0.6/0.5/0.42	0.5	V, H	20/15/10
		0.3/0.25/0.21	0.25	(S_3, S_4)	
MWI-12	89.0	1.0/0.8/0.5	1.0	V, H	25/10/5

Table 11a: MWI channel noise, absolute calibration, polarisation and footprint requirements for ocean and land observation

Notes:

Determination of the full Stoke's vector components for the 18.7 and 36.5 GHz channels is not required if the MWI flies on the same platform as the scatterometer (H and V would be sufficient). However, it is recommended to retain at least 3 Stoke's vector components at 10.65 GHz for correction of sea surface roughness for the lower frequency channels.

Precipitation

Channel name	Frequency (GHz)	NEΔT (K) (T/B/O)	Bias (K)	Polarisation (*)	IPSF Size at 3dB (km) (T/B/O)
MWI-4	10.65	0.5/0.44/0.4	0.5	V, H	30/20/15
MWI-5	18.7	0.6/0.5/0.44	0.5	V, H	20/15/10
MWI-6	23.8	0.3/0.45/0.6	0.5	V, H	20/15/10
MWI-7	36.5	0.6/0.5/0.42	0.5	V, H	20/15/10
MWI-8	50.3	0.3/0.2/0.1	0.5	V, H	15/10/8
MWI-9	52.61	0.3/0.2/0.1	0.5	V, (H)	15/10/8

MWI-10	53.24	0.3/0.2/0.1	0.5	V, H	15/10/8
MWI-11	53.75	0.3/0.2/0.15	0.5	V, (H)	15/10/8
MWI-12	89.0	1.0/0.8/0.5	1.0	V, H	15/10/8
MWI-13	100.49	TBC	TBC	V, H	15/10/8
MWI-14	118.7503±2.0	0.5/0.4/0.3	1.0	V, (H)	15/10/8
MWI-15	118.7503±1.6	0.5/0.4/0.3	1.0	V, (H)	15/10/8
MWI-16	118.7503±1.4	0.5/0.4/0.3	1.0	V, (H)	15/10/8
MWI-17	118.7503±1.2	0.5/0.4/0.3	1.0	V, (H)	15/10/8
MWI-18	166.9	0.8	1.0	V	15/10/8
MWI-19	183.31±8.4	0.8/0.6/0.5	1.0	V	15/10/8
MWI-20	183.31±6.1	1.0/0.75/0.5	1.0	V	15/10/8
MWI-21	183.31±4.9	1.0/0.75/0.5	1.0	V	15/10/8
MWI-22	183.31±3.4	1.0/0.75/0.5	1.0	V	15/10/8
MWI-23	183.31±2.0	1.2/1.0/0.75	1.0	V	15/10/8

Table 11b: MWI channel noise, absolute calibration, polarisation and footprint requirements for precipitation observation

Clouds

Channel name	**Frequency (GHz)**	**NEΔT (K) (T/B/O)**	**Bias (K)**	**Polarisation (*)**	**IPSF Size at 3dB (km) (T/B/O)**
MWI-7	36.5	0.6/0.5/0.42	0.5	V, H	20/15/10
MWI-8	50.3	0.3/0.2/0.1	0.5	V, H	15/10/8
MWI-11	53.75	0.3/0.2/0.15	0.5	V, (H)	15/10/8
MWI-12	89.0	1.0/0.8/0.5	1.0	V, H	15/10/8
MWI-13	100.49	TBC	TBC	V, H	15/10/8
MWI-15	118.7503±1.6	0.5/0.4/0.3	1.0	V, (H)	15/10/8
MWI-16	118.7503±1.4	0.5/0.4/0.3	1.0	V, (H)	15/10/8
MWI-17	118.7503±1.2	0.5/0.4/0.3	1.0	V, (H)	15/10/8
MWI-18	166.9	0.8	1.0	V	15/10/8
MWI-19	183.31±8.4	0.8/0.6/0.5	1.0	V, H	15/10/8
MWI-22	183.31±3.4	1.0/0.75/0.5	1.0	V, H	15/10/8
MWI-23	183.31±2.0	1.2/1.0/0.75	1.0	V, H	15/10/8
MWI-24	243.2±2.5	1.1/0.6/0.5	1.5	V, H	15/10/8
MWI-25	325.15±9.5	1.2/1.0/0.8	1.5	V, H	15/10/8
MWI-26	325.15±3.5	1.4/1.0/0.8	1.5	V, H	15/10/8
MWI-27	325.15±1.5	1.1/1.0/0.8	1.5	V, H	15/10/8
MWI-28	340	1.2/1.0/0.8	1.5	V	15/10/8
MWI-29	448±7.2	1.2/1.0/0.8	1.5	V	15/10/8
MWI-30	448±3.0	1.4/1.0/0.8	1.5	V	15/10/8
MWI-31	448±1.4	1.7/1.0/0.8	1.5	V	15/10/8
MWI-32	664±4.2	1.3/1.0/0.6	1.5	V, H	15/10/8

Table 11c: MWI channel noise, absolute calibration, polarisation and footprint requirements for cloud observation

Channel name	Frequency (GHz)	NEΔT (K) (T/B/O)	Bias (K)	Polarisation (*)	IPSF Size at 3dB (km) (T/B/O)
MWI-3	6.9	0.35/0.3/0.25	0.25	V, H	50/40/30
MWI-4	10.65	0.5/0.44/0.4	0.5	V, H	30/20/15
MWI-5	18.7	0.6/0.5/0.44	0.5	V, H	20/15/10
MWI-6	23.8	0.3/0.45/0.6	0.5	V, H	20/15/10
MWI-7	36.5 or 31.4	0.6/0.5/0.42	0.5	V, H	20/15/10
MWI-8	50.3	0.3/0.2/0.1	0.5	V, H	15/10/8
MWI-9	52.61 or 52.80	0.3/0.2/0.1	0.5	V, H	15/10/8
MWI-12	89.0	1.0/0.8/0.5	1.0	V, H	15/10/8
MWI-13	100.49	TBC	TBC	V, H	15/10/8
MWI-19	183.31±8.4	0.8/0.6/0.5	1.0	V, H	15/10/8
MWI-20	183.31±6.1	1.0/0.75/0.5	1.0	V, H	15/10/8
MWI-22	183.31±3.4	1.0/0.75/0.5	1.0	V, H	15/10/8

Table 11d: MWI baseline channel noise, absolute calibration, polarisation and footprint requirements

(*) Notation

Modified Stokes vector polarisation components are used as specification of the first and second stokes vector components is not adequate for microwave radiometry where measurements at either horizontal or vertical (or both) are required. These are defined as follows:

$$\begin{pmatrix} V \\ H \\ S_3 \\ S_4 \end{pmatrix} = \begin{pmatrix} \frac{1}{2}(S_1 - S_2) \\ \frac{1}{2}(S_1 + S_2) \\ S_3 \\ S_4 \end{pmatrix} = \begin{matrix} \text{vertical} & \text{intensity} \\ \text{horizontal} & \text{intensity} \\ I_{45} - I_{-45} & \text{intensity} \\ I_L - I_R & \text{intensity} \end{matrix}$$

Where S_1 to S_4 are the four Stokes vector parameters, V denotes vertical polarisation, H is horizontal polarisation, $I_{\pm 45}$ are represent polarisations at ±45° to the primary polarisation directions and I_L, I_R, are left and right polarisations.

5.7.5.3 Bias Accuracy

MRD_MWI.110

The bias accuracies shall be better than those as listed in Table 11a-d.

5.7.5.4 Orbit Stability

MRD_MWI.120

Variations (RMS) of systematic errors of the measured brightness temperature during an orbit shall be < 0.15 K (at 280 K).

5.7.5.5 Lifetime Stability

MRD_MWI.130

Variations (RMS) of the running average of systematic over one orbit of the measured brightness temperature shall be < 0.15 K (at 280 K).

5.7.5.6 Radiometric Homogeneity

MRD_MWI.140

Inter-channel brightness temperature differences between different channels of the same footprint shall be < 0.2 K (at 280 K).

MRD_MWI.150

Inter-pixel brightness temperature differences between the different footprints of the same channels shall be < 0.1 K.

5.7.6 Polarisation Requirements

MRD_MWI.170

The MWI channels shall be available in one or polarisations as specified in the fifth column of Table 11a-d. Optionally, MWI mission shall measure the full Stokes vector parameters in channels MWI-4, MWI-5 and MWI-7 for the purpose of determining wind direction in addition to wind speed (unless the MWI is flown upon the same platform as the scatterometer).

5.7.7 Geometric Requirements

MRD_MWI.180

In order to manage handling the polarisation information homogeneously across the footprint, the incidence angle shall be constant. The reference zenith angle shall be around 53 degrees.

MRD_MWI.190

The MWI shall provide 90% global coverage within 24 hours, and 99% within 46 hours, preferably with a single instrument.

MRD_MWI.200

The scan lines of the various channels shall be contiguous along track (no gaps between lines) for all channels with frequency below and including 89 GHz. An overlap of increasing amount as the frequency decreases (then the footprint size increases for channels supported by the same antenna) is expected. Appropriate along scan oversampling shall be provided in order to minimise aliasing effects as needed for images that require full re-sampling during pre-processing.

MRD_MWI.210

For conical scanning with 53° zenith angle, the ground footprint will be elliptical, with axes ratio approximately 3:5. We refer to the footprint as the quadratic average of the two axes. The sixth column of Table 11a-d reports the requirements for the average footprint, which has constant size across the scene for a frequency, but changes with frequency if the antenna is the same.

MRD_MWI.220

For all images in the various channels, the normalised MTF shall be 0.3 at the spatial wavelength twice the size of the specified footprint, bearing in mind that this is the quadratic average of the axes of an elliptical footprint in the ratio 3:5. The oversampling factors to be applied along and across scan shall be such that the MTF is as isotropic as possible, within 10 % (TBC) as a target. For channel 23 the requirement applies to the image with 53° incidence angle, whereas at smaller incidence angles MTF will be better (or the reference spatial wavelength will be shorter) and the opposite at larger incidence angles.

MRD_MWI.230

For the lowest frequencies, used for observation of ocean salinity and soil moisture in the roots region (MWI-1 and MWI-2), synthetic aperture antennas could be used although the requirements so far stated are tuned to a mechanical real aperture conical scanner.

5.7.7.1 Synchronisation requirement

MRD_MWI.240

MWI channels MWI-3 to MWI-17 (TBC) shall be co-located to allow for an overlap of 90% for the smaller of the footprints. The measurements shall be taken quasi simultaneously, with time differences < 30 s.

5.7.7.2 Beam and Pointing Requirements

MRD_MWI.300

Knowledge of the pointing shall be better than 1 km for all Earth views and all channels.

MRD_MWI.310

The instrument shall have sufficiently high beam efficiency that the noise requirements are met for the intended footprint size. Beam efficiency requirements will be derived for the instrument definition phase, however 95 % is considered a good initial estimate.

5.8 Cloud and Precipitation Profiling Radar Mission (CPR)

5.8.1 Objectives

The Cloud and Precipitation Profiling Radar is the only space-borne instrument that provides three dimensional maps of clouds, precipitation and storms. Measurements of the Cloud and Precipitation Profiling Radar mission (CPR) provide information on the intensity and distribution of rain, on the rain type, on the storm depth and on the height at which the snow melts into rain in addition to three dimensional maps of cloud coverage, cloud ice and cloud water contents. This information is important for climate models which require knowledge of the vertical distribution of clouds to model their radiative forcing and their overall feedback effect on climate. Furthermore, the composition of clouds is important for predicting cloud evolution and understanding important meteorological processes such as cloud particle growth and the onset of precipitation. The estimates of the heat released into the atmosphere at different heights based on these measurements can be used to improve models of the global atmospheric circulation and are therefore important for both global and regional NWP.

The CPR has been defined according to user requirements for NWP, NWC and climate as derived by the application experts group for cloud, precipitation and large scale land surface imaging mission. In addition, experience from the following proposals/missions has been drawn upon:

- European contribution to the Global Precipitation Mission (EGPM), Precipitation Radar proposal
- The JAXA Dual frequency Precipitation Radar
- Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar
- Earth Observation System CloudSat mission
- The ESA EarthCare CPR

Although cloud and precipitation radar missions are implemented as independent missions, they are considered here as a single mission in order to identify requirements common to both types of hydrometeor and provide visibility of the effects of trade-off of mission requirements for both cloud and precipitation observations. Three potential radar frequencies are identified for measurements of this type and mission requirements for each frequency and hydrometeor type are presented.

The **primary objective** of the Cloud and Precipitation Profiling Radar mission is to support climate monitoring and global and regional NWP, through the provision of three dimensional measurements of cloud and precipitation including intensity, particle/drop size distributions (TBC) and type.

Secondary objectives:

- To advance understanding of the radiative effects of clouds
- To advance understanding of the global energy and water cycles through the provision of rainfall and latent heating data

- To improve understanding of rainfall on global circulation to enable better prediction of rainfall variability
- To improve rainfall climatologies in both the Northern latitudes and the tropics
- To allow some cross calibration with the post-EPS passive microwave sensors
- To improve understanding of the conversion of cloud condensate growth and the conversion to rainfall to enable better precipitation predictions
- To improve cloud microphysical analysis and understanding of particle fall velocities.
- To improve cloud climatologies
- To provide cloud profile information to better constrain retrievals.

The main users of the CPR mission will be the NWP centres of National Meteorological Services and ECMWF, Operational nowcasting services of National Meteorological Services may also be users of the PR mission products particularly for severe weather warnings. The CPR mission is also relevant to non real-time users, such as researchers and climate system modellers.

5.8.2 Products

The products to be derived from the CPR mission include:
Precipitation

- Precipitation profile (solid and liquid, including drizzle)
- Freezing level height and melting layer depth in clouds

Cloud

- Cloud cover profile
- Cloud liquid and ice water profile
- Cloud top height and cloud base height
- Cloud liquid and ice water total column

Additional cloud and precipitation products include microphysical observations such as particle and drop size distributions (DSD), however the retrieval of these products requires the implementation of either a dual frequency radar, or the availability of the VII and APL instruments.

Althought the CPR mission provides valuable 3D information for clouds and precipitation as an independent mission, the coverage that can be achieved from such an instrument is limited. In the scope of Post-EPS, co-registration between the MWI and CPR is required to improve the coverage issue with the larger swath of the MWI providing total column cloud and precipitation observations outside the swath of the radar.
A desired synergy with the APL is also requested.

The baseline implementation of the CPR mission is a high sensitivity nadir pointing radar at 94 GHz (threshold), 94/35 GHz dual frequency (objective).

5.8.3 Priority of Requirements

<u>Sensitivity and vertical resolution are the driving requirements for this mission.</u>

The following additional requirements require investigation but should NOT drive mission design:

- A swath of up to 50 km.
- The feasibility of cross polarisation (HV or VH) channels.

5.8.4 Spectral Requirements

5.8.4.1 Operating Frequencies

MRD_CPR.010

The CPR will operate at two neighbouring frequencies (objective – to enable drop size distribution observation) or a single frequency (threshold) as defined in Table 12:

Approx Frequency	Band	Use	Priority
14 GHz	Ku	Heavy precipitation profile	1
		Weak rain and snowfall profile	2
		Cloud liquid water and ice profile	3
35 GHz	Ka	Heavy precipitation profile	2
		Weak rain and snowfall profile	1
		Cloud liquid water and ice profile	2
94 GHz	W	Heavy precipitation profile	3
		Weak rain and snowfall profile	2
		Cloud liquid water and ice profile	1

Table 12: Radar Frequencies and Corresponding Priorities for different Hydrometeors

5.8.5 Geometric Requirements

MRD_CPR.110

The CPR shall have co-registration with the MWI at nadir. As a result, coverage requirements of the CPR shall be pre-determined by those of MWI.

MRD_CPR.115

The CPR shall have swaths as given by the T/B/O values below.

Band	***Swath [km](T/B/O)***		
Ku[+]	Nadir-only	>200	≥300
Ka[+]	Nadir-only	>100	>200
W[*]	Nadir-only	>50(TBC)	>100(TBC)

Swath should not drive the mission design although a swath of 50 km (size of an NWP grid point) would enable observation of sub grid scale storm variability which is otherwise hard to assume with a nadir pointing radar.

MRD_CPR.120

For precipitation, the horizontal resolution shall be ≤ 5 km along and across track for all frequencies.

For clouds, the horizontal resolution shall be ≤ 5 km (threshold), 2 km (breakthrough) and 1 km (objective).

MRD_CPR.130

The sampling interval shall be adequate in order to achieve the product resolution at the specified sensitivity.

MRD_CPR.170

The CPR shall measure clouds and precipitation from as close as possible to the surface up to 15 km altitude with a range resolution better than 200 m (objective), 250 m (breakthrough), 500 m (threshold) for all views.

5.8.6 Radiometric Requirements

MRD_CPR.180

The dynamic ranges and sensitivities for each radar frequency are defined in Table 13. In all cases, meeting the sensitivity requirement takes priority over the maximum measurable value. The conversion of radar reflectivities to rain intensities or cloud water amount depends on the conditions of the measurements, e.g. on instrument design and operation mode. For example, a compromise between sensitivity and swath width is required because nadir-only instruments will have increased sensitivity[‡].

The values given in Table 13 for maximum detectable reflectivity/rainfall at the bottom of the cloud/rain layer assume uniform rain (complete beamfilling) of 5 km thickness (the maximum rain rate is approximately inversely proportional to the thickness.)

Band	Rainfall rate range near the surface (mm/h)	Max radar reflectivity cloud top (dBZ)	Radar sensitivity (dBZ)	Accuracy = [abs error (mm/h), rel error (%)]					
				Threshold		Breakthrough		Objective	
				(mm/h) RR≤1mm/h	(%) RR>1 mm/h	(mm/h) RR≤1mm/h	(%) RR>1 mm/h	(mm/h) RR≤1mm/h	(%) RR>1 mm/h
Ku$^+$	0.5-50	45	16	0.5	50	0.2	20	0.1	10
Ka$^+$	0.2-10	45	12	0.2	50	0.2	20	0.1	10
Band	Dynamic range (g/m^3)	Max radar reflectivity cloud top	Radar sensitivity	Threshold		Breakthrough		Objective	

		(dBZ)	(dBZ)			
W*	0.05-2.0 (or rain rates up to 2.0 mm/h)	30	-30	100%	50%	20%

Table 13: Sensitivity and Dynamic Range for each Radar Frequency

RR = Rain Rate

+ Input gratefully received from T. Iguchi, NICT, JP

* Input gratefully received from S. Crewell and U Löhnert, Inst für Geophysik und Meteorologie, Universität Köln, DE.

‡The maximum detectable reflectivity/rainfall at the top of the cloud/rain layer depends on the rain structure. There is no upper limit if rain suddenly starts at the top of the rain layer, but such a rain structure is unrealistic. The TRMM precipitation radar rarely produces a radar reflectivity value larger than 45 dBZ. This number is without attenuation correction. Very large reflectivities are often associated with hail. Therefore, it is meaningless to convert the numbers into rainfall rate.

The maximum value of radar reflectivity factor measured at the Ka band is a few dB lower than that at the X band, i.e. about 45 dBZ. However, these measurements were obtained from an airplane with a different configuration than from a satellite-borne system. It may be assumed that the maximum value of apparent reflectivity at the Ka band is approximately the same as that at the Ku band.

At 95 GHz, CloudSAT data can be considered a reference. In the presence of thick clouds, the signal is already attenuated well above the rain layer. Radar reflectivity factors larger than 20 dBZ are rarely observed (even in the bright band reflectivity is between 15 and 20 dBZ). Radar sensitivities of around -30 dBZ have shown to be suitable for detecting most radiatively significant ice clouds however, the ice water content accuracy depends on the reflectivity to ice water content conversion process and the particle size distribution assumed, leading to uncertainties of around 50-100%.

MRD_CPR.190

The absolute accuracy shall be ≤ 1 dB.

MRD_CPR.200

The radiometric stability shall be ≤ 0.4 dB over the life time of the mission.

5.8.7 Polarisation requirements

MRD_CPR.210

Polarisation of all radars shall be HH (threshold) or HV (objective).

5.8.8 Pointing requirement

MRD_CPR.300

Knowledge of the the pixel localisation shall be ≤ 1 km along and across track.

5.8.9 Co-registration requirement

MRD_CPR.400

The footprints from all radars shall be aligned on the ground with an overlap of 95% for the smaller pixel.

5.9 Radiant Energy Radiometry Mission (RER)

5.9.1 Objectives

The Radiant Energy Radiometry mission (RER) covers broadband radiometry to measure radiant energy leaving the Earth's atmosphere, for improving the understanding of the radiation budget and monitoring its effects on the Earth's climate. This mission follows up long series of Earth radiation budget measurements obtained from ERBE (Earth Radiation Budget Experient), which started in 1984 and have been continued by CERES (Clouds and the Earth's Radiant Energy system) from 1997 onwards.

5.9.2 Products

The major products to be derived from the Radiant Energy Radiometer are:

- Solar radiation reflected to space from the Earth-atmosphere system
- Terrestrial radiation emitted to space from the Earth-atmosphere system

5.9.3 Priority of Requirements

Radiometric accuracy is the most important requirement.

5.9.4 Spectral Requirements

MRD_RER.010

The RER shall measure the outgoing radiant energy in three broadband channels as listed in Table 14.

Channel	Bandwidth	Purpose
RER-1	0.2 – 4.0 µm	Total solar radiation at TOA
RER-2	0.2 – 200 µm	Total radiant energy at TOA
RER-3	8 – 12 µm	Emitted radiant energy (TOA) in the main IR window region

Table 14: RER Channels

5.9.5 Radiometric Requirements

MRD_RER.015

The radiometric dynamic range shall be as specified in Table 15

MRD_RER.020

The radiometric noise shall be better than that specified in Table 15.

MRD_RER.030

The bias error shall be better than that specified in Table 15.

Channel	Dynamic Range	Radiometric Noise	Bias B/T
RER-1	0 - 350 W m^{-2} sr^{-1}	0.3 W $m^{-2}sr^{-1}$	0.5/0.8 W $m^{-2}sr^{-1}$@R<100 W $m^{-2}sr^{-1}$, else 0.5%/1%
RER-2	0 - 500 W m^{-2} sr^{-1}	0.3 W $m^{-2}sr^{-1}$	0.5/0.6 W $m^{-2}sr^{-1}$ @R<100 W $m^{-2}sr^{-1}$, else 0.3%/0.5%
RER-3	0 - 30 W m^{-2} sr^{-1}	0.3 W $m^{-2}sr^{-1}$	0.3/0.5 W $m^{-2}sr^{-1}$

B: Breakthrough, T: Threshold

Table 15: RER Radiometric Requirements

MRD_RER.035

The radiometric stability over the lifetime of the mission shall be better than:.

- threshold 0.5 W/m^2/sr
- breakthrough 0.3 W/m^2/sr

MRD_RER.037

1. DELETED

5.9.6 Geometric Requirements

The measurement requirement aims at computing ***irradiances***, which imply tools to estimate corrections for anisotropic effects, particularly in the short-wave region (reflected solar radiation). In principle, a combination of angular sampling modes would be required, some cross-track to sample at different incident angles, some conical to re-conciliate measurements at the same incidence angle but under different azimuth angles. The conversion from radiance to irradiance requires in any case heavy support from modelling the anisotropic effects. Ideally, viewing from more satellites would be necessary. In practice, people are able to reconstruct the irradiance even from a single viewing condition. However, the more one measures, the less the result is model-dependent. This is inspired by the CERES flight unit being flown on Terra and Aqua, a suite of two instruments, one cross-track scanning limb-to-limb, the other bi-axial scanning to get several views of the same IFOV under more viewing angles (the unit on TRMM has only the cross-track component). In the CLOUDS project the broad-band conical scanner is complemented by a multiangle VIS channel to extract the BDRF.

MRD_RER.040

The RER mission shall provide an optimal solution for angular sampling of the entire hemispheric radiative pattern. The baseline requirement for angular sampling is for three measurements of the same geographic location under different viewing conditions, preferably one as close a possible to nadir and the others as close as possible to 55 degree zenith angles but under different azimuth angles. The CERES cross-track and bi-axial scan geometries would meet this baseline requirement. If a multi-angle visible imager is collocated with the broad band measurements, then a conical scanning broad band radiometmeter with 55 degree observation zenith is also a solution as the imager channels can provide sufficient information on atmospheric anisotopic effects in place of the third broad band view.

MRD_RER.050

The footprint size shall be < 20 km (Threshold), < 10 km (Breakthrough).

MRD_RER.060

The horizontal sampling shall be equal to the footprint size.

MRD_RER.070

It should be possible to associate the RER broad-band measurements to the main physical effects impacting on earth radiation budget, e.g. clouds and water vapour patterns as observed by high-resolution VIS/IR imagery. To this end, RER shall operate in an imaging mode. The Modulation Transfer Function shall be > 0.6 at the spatial wavelength of 2 x footprint size.

MRD_RER.080

The RER shall provide 99% global coverage within 48 (threshold) / 24 (objective) hours, preferably with a single instrument.

MRD_RER.085

The inter-channel co-registration shall be better than 0.1 of a pixel (footprint size).

5.9.6.1 Pointing Requirement

MRD_RER.090

The RER shall have absolute pointing accuracy of <5 km, knowledge of the pointing shall be <0.5 km.

5.10 Dual View Radiometry Mission (DVR)

5.10.1 Objectives

The PEPS Dual View Radiometry mission (DVR) is a high performance imaging radiometry mission aimed at providing continuation for sea surface temperature (SST) observations for long-term climate records, operational meteorology oceanography applications. In order to meet the high accuracy and stability requirements for long-term climate records, two separate Earth views along different atmospheric path lengths are required for the atmospheric correction, similar to that of the Advanced Along Track Scanning Radiometer (AATSR) on ENVISAT. Furthermore, the DVR mission must overlap sufficiently with other in-orbit SST missions in order to quantitively establish the magnitude of the instrument biases between the two systems as laid out in the GCOS climate monitoring principles.

Considering that most users plan to directly assimilate calibrated and geolocated radiances, the DVR mission is specified in terms of its targeted real time level 1b data output. It involves all PEPS system functions required to generate this basic output, excluding the functions required to make it available to users.

The primary objective of the DVR mission is to provide high quality SST imagery data for climate records, oceanography, global and regional NWP and NWC through the provision of:

- SST (<0.2K accuracy) at high horizontal resolution

Secondary mission objectives include:

- Vegetation imagery
- Cloud imagery

The current specification of the DVR assumes that the primary mission for cloud and vegetation products is the VII, with the 3MI providing cloud observations requiring multiple viewing geometries.

The main users of the DVR mission will be the WMO climate centres and operational climate monitoring centres in addition to NWP centres of National Meteorological Services, ECMWF and operational nowcasting and oceanographic services of National Meteorological Services.

The instrument will be a passive satellite radiometer capable of measuring thermal radiance emitted by the Earth in specified spectral bands in the visible and infra-red parts of the electromagnetic spectrum.

The level of fulfilment of these objectives will highly depend on the space-time resolution of the DVR mission, and is particularly critical at high latitudes where information from geostationary spacecraft is scarce or even unavailable. As a baseline, the minimum expected performance of the DVR mission is that of the AATSR mission.

5.10.2 Products

The following products, suitable for long-term climate records, requiring observation from multi-angle viewing imaging have been identified by the Post-EPS application experts, in decreasing order of priority:

5.10.2.1 Ocean (driving application)

1. Sea surface temperature,
2. Sea ice temperature,
3. Sea ice concentration (0-100%),
4. Sea ice extent (value 0 or 1),

5.10.2.2 Clouds

5. Cloud mask
6. Cloud imagery
7. Cloud optical depth
8. Cloud top temperature
9. Cloud top height

5.10.2.3 Land surface

10. Land surface temperature (suitable for long term climate records)
11. Earth's surface albedo
12. Vegetation
    - Leaf area index (LAI)
    - Vegetation type
    - Fraction of vegetated land
    - Fraction absorbed photosynthetically active radiation (FAPAR)
    - Photosynthetically active radiation (PAR)
    - Normalised Differential Vegetation Index (NDVI)

Assumptions regarding external data sources
The ability to retrieve these data will depend on the availability of:

- Surface topography and land type databases

5.10.3 Priority of Requirements

The priority of requirements for the DVR mission in decreasing order of priotity is:

1. Radiometric requirements,
2. Spectral requirements,
3. Geometric requirements.

This order has to be taken into accont in case of any conflicting requirements or necessary cost/benefit trade-off.

5.10.4 Spectral Requirements

5.10.4.1 Spectral Range and Resolution

MRD_DVR.010

In order to achieve the mission objectives, the DVR shall measure scene radiances in a number of spectral channels, all with two viewing directions (fore and aft/nadir) as defined in following table. The nominal spectral bandwidth for each channel is defined in Table 16 in terms of the full width at half maximum (FWHM). Priorities for the channels area also given, 1 being highest priority, 4 the lowest.

Mission BAND	Central Wavelength (µm)	FWHM (µm)	Primary Use	Priority
DVR-1	**0.555**	0.02	Clouds, snow and sea ice coverage, vegetation	2
DVR-2	**0.659**	0.02	Clouds, snow and sea ice, vegetation	3
DVR-3	**0.865**	0.02	Clouds, vegetation, sea ice coverage	3
DVR-4	**1.61**	0.06	Clouds, sea ice coverage	1
DVR-5	**3.75**	0.38	Clouds, LST, SST, sea ice coverage	1
DVR-6	**10.8**	0.9	Clouds, LST, SST	1
DVR-7	**12.02**	1.0	Cloud height, LST, SST, sea ice temperature	1

Table 16: DVR channels, FWHM and priorities

MRD_DVR.020

The spectral responses of the DVR channels shall be known to 5% of their peak response at any wavelength.

5.10.5 Radiometric Requirements

5.10.5.1 Dynamic Range

MRD_DVR.110

The DVR channel nominal dynamic ranges are given in Table 17. All spectral and radiometric requirements must be met within these nominal working ranges.

Mission BAND	Central Wavelength (µm)	Nominal working range ($W/m^2/sr/\mu m$)	Nominal working range (K)
DVR-1	**0.555**	0 - 500	
DVR-2	**0.659**	0 - 450	
DVR-3	**0.865**	0 - 300	
DVR-4	**1.61**	0 - 70	
DVR-5	**3.75**		0-323
DVR-6	**10.8**		200-323

DVR-7	**12.02**		200-323

Table 17: DVR Dynamic Range Requirements

5.10.5.2 Radiometric Noise

MRD_DVR.120

The radiometric noise requirements for the DVR are given in Table 18. The SNR/NEΔT values listed are to be understood as one standard deviation. They are specified at a reference temperature of 270 K and apply to calibrated spectra, i.e. the noise contribution of the calibration process is included.

Mission BAND	Central Wavelength (µm)	SNR at 0.5% albedo	NEΔT (K) at 270 K
DVR-1	**0.555**	20	
DVR-2	**0.659**	20	
DVR-3	**0.865**	20	
DVR-4	**1.61**	20	
DVR-5	**3.75**		0.05
DVR-6	**10.8**		0.03
DVR-7	**12.02**		0.03

Table 18: DVR Noise Requirements

MRD_DVR.190

The radiometric requirements shall be met in the target temperature range. At temperatures T different from 270 K, the specified noise or accuracy shall be scaled by the factor $\left[\frac{dB(\nu_0, 270K)}{dT}\right] \Big/ \left[\frac{dB(\nu_0, T)}{dT}\right]$, where B is the Planck's function, ν_0 is the wavenumber of the channel and T is the target temperature in K. This implies a constant accuracy in terms radiance.

5.10.5.3 Bias Error

MRD_DVR.240

The bias error of the thermal channels (Bands DVR-5, DVR-6, DVR-7) shall be < 0.1 K (Objective), < 0.2 K (Threshold) in brightness temperature for a reference scene temperature of 270 K for the duration of the mission.

Specific requirements to monitor SST for climate research are set at zero bias and an uncertainty of ±0.3K (1 sigma) for a 5° latitude x longitude area and 1 month time scale. Data should have a temporal stability of 0.1K per decade or better.

5.10.5.4 Orbit Stability

MRD_DVR.250

Variations (RMS) of the systematic errors of the measured brightness temperature of channels 5, 6, 7 during any single orbit shall be < 0.1 K (at 270 K).

5.10.5.5 Lifetime Stability

The following specification gives constraints on the bias part of the measurement error during the instrument lifetime.

MRD_DVR.260

Variations (RMS) of the running average over one orbit of systematic errors of the measured brightness temperature in channels 5, 6, 7 shall be < 0.1 K (at 270 K).

5.10.5.6 Radiometric Homogeneity

This specification gives the constraints on the error terms of which behaviour varies with spectral channels, and scan mirror positions. It is split into a spectral and a geometric homogeneity.

MRD_DVR.280

Inter-channel brightness-temperature differences between different infrared channels of the same footprint shall be < 0.05 K for a 270 K target temperature.

MRD_DVR.290

Inter-pixel brightness-temperature differences between the different pixels of the same infrared channel at different scan angles shall be less than 0.05 K for a 270 K target temperature.

5.10.6 Polarisation Requirements

MRD_DVR.400

The difference in responsivity between any two orthogonal polarisations shall not be more than 1% for the thermal channels and 6% for the reflection channels.

MRD_DVR.410

For all channels, the responsivity variation with plane of polarisations shall be known to better than 5%.

5.10.7 Geometric Requirements

These requirements cover the horizontal coverage and resolution.

MRD_DVR.610

The DVR shall be optimised for operation in a sun-synchronous orbit.

MRD_DVR.615

The DVR shall maximise the useful viewing angles and provide 100% complete global coverage within 48 (threshold) 24 (objective) hours, preferably with a single instrument (disregarding any cloud/clear conditions).

MRD_DVR.620

The DVR shall measure such that each point on the Earth's surface is sampled twice from two different views through two different atmospheric columns within 10 minutes.

MRD_DVR.640

The on ground pixel size at nadir shall not exceed 1 km.

MRD_DVR.650

The DVR shall provide continuous coverage along the swath, the required overlap between pixels will be defined by the modulation transfer function which describes the image contrast with respect to the actual scene contrast.

MDR_DVR.655

The normalised Modulation Transfer Function (MTF) shall be isotropic within 10 % and shall be greater than 0.3 at the spatial wavelength given by twice the ground pixel size. .

5.10.7.1 Pointing Requirement

MRD_DVR.657

The absolute pointing requirement, the difference between the actual DVR viewing direction and the commanded one, shall be < 1/4 pixel diameter for all Earth views.

MRD_DVR.658

The absolute pointing knowledge shall be < 1/10 pixel diameter.

5.10.7.2 Synchronisation requirement

MRD_DVR.660

Measurements at different spectral channels shall be co-registered so that at least 90% of the the covered areas of each pixel are the same.

MRD_DVR.670

Measurements at different spectral channels shall be co-registered within < 1 s (objective), < 2 s (breakthrough), 3 s (threshold).

5.10.7.3 IPFS Requirements

MDR_DVR.680

The IPSF shall be known to 0.1 sample distance accuracy.

5.11 Ocean Colour Imaging Mission (OCI)

5.11.1 Objectives

The Ocean Colour Imaging mission (OCI) is a fine spectral and medium spatial resolution imager optimised for ocean and coastal zone sensing. Through observations of water colour, the OCI will provide continuation of remotely sensed ocean colour data crucial for operational oceanography and for the understanding the role of ocean productivity in the climate system. NWP will also benefit from these data particularly for seasonal–to-interannual forecasts as changes in ocean productivity often occur in direct response to seasonal fluctuations. The OCI will build upon heritage instruments such as the Medium Resolution Imaging Spectrometer (MERIS) on board ENVISAT, offering high spectral resolution in the visible region of the electromagnetic spectrum to allow the distinction of the multitude of chlorophyll classes and other dissolved matter in ocean and coastal zones. As a baseline, the minimum expected performance of the OCI mission is that of the MERIS mission.

The primary objective of the OCI mission is to provide high quality ocean colour imagery. The primary ocean constituents to be imaged by the OCI are:

- Chlorophyll
- Yellow substance
- Water sediment
- Detection of harmful algae

Although optimised for ocean imaging, the OCI can also provide important global data for atmospheric and land domains. The secondary mission objectives include:

- Vegetation imagery
- Cloud imagery
- Aerosol characterisation (over ocean)

- Total column water vapour over land

The main users of the OCI mission will be operational oceanographic and nowcasting services of National Meteorological Services, climate and environmental centres, in addition to the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF.

The mission will provide measurements of the radiance leaving the Ocean/Earth-atmosphere in specified high resolution spectral bands in the visible and near-infrared part of the electromagnetic spectrum.
The level of fulfilment of these objectives will highly depend on the space-time resolution of the OCI mission, and is particularly critical at high latitudes where information from geostationary spacecraft is scarce or even unavailable.

The OCI mission is specified in terms of its targeted real time level 1b data output. It involves all PEPS system functions required to generate this basic output, excluding the functions required to make it available to users.

5.11.2 Products

The following products requiring observation from the OCI have been identified by the Post-EPS application experts, in decreasing order of priority:

Ocean (driving application)

1. Chlorophyll
2. Yellow substance
3. Sediment
4. Water clarity
5. Detection of harmful algae

Other applications (functional to ocean colour corrections or opportunistic)

6. Photosynthetically Active Radiation (PAR),
7. Fraction of Photosynthetically Active Radiation (FPAR)
8. Sea ice coverage and drift
9. Cloud optical depth
10. Cloud top height
11. SW cloud reflectance
12. Cloud type
13. Aerosol optical depth
14. Vegetation indices
15. Total column water vapour over land

The special feature of the OCI is to focus on measurements that require very narrow bandwidths, very high SNR, and operate in low albedo (ocean) conditions. Although many ocean colour requirements (such as channel frequencies) are partially met by the VIS/IR imaging mission (VII), these radiometric requirements are too demanding for the multi-purpose VII and a dedicated ocean colour imaging mission, tailored to meet the stringent radiometric requirements, is forseen.

5.11.3 Priority of Requirements

The priority of requirements for this mission are:

1. Spectral stability
2. Radiometric stability

5.11.4 Spectral Requirements

5.11.4.1 Spectral Range and Resolution

MRD_OCI.010

In order to achieve the mission objectives, the OCI shall measure scene radiances in the spectral channels defined in Table 19. The nominal spectral bandwidth for each channel is defined in this table in terms of the full width at half maximum (FWHM). Priorities for the channels are also given, 1 being highest priority, 4 the lowest.

MRD_OCI.015

Each spectral channel shall be programmable with respect to position (TBD) and width (TBD) in order to optimise detection of temporal ocean colour feature.

Channel name	**Central Wavelength (nm)**	**FWHM (nm)**	**Primary Use**	**Priority**
OCI-1	**412.5**	10	Yellow substance and turbidity	1
OCI-2	**442.5**	10	Chlorophyll absorption, vegetation	1
OCI-3	**490**	10	Chlorophyll	1
OCI-4	**510**	10	Chlorophyll, sediment, turbidity	1
OCI-5	**560**	10	Chlorophyll reference	1
OCI-6	**620**	10	Sediment loading	1
OCI-7	**665**	10	Chlorophyll, sediment, yellow substance, vegetation	1
OCI-8	**681.25**	7.5	Chlorophyll fluorescence peak, red edge	1
OCI-9	**708.75**	10	Chlorophyll fluorescence baseline	1
OCI-10	**753.75**	7.5	Oxygen absorption, ocean colour	1
OCI-11	**760.625**	3.75	Oxygen absorption, aerosol correction	1
OCI-12	**778.75**	15	Atmosphere/aerosol correction	1
OCI-13	**865**	20	Aerosols and clouds	2
OCI-14	**885**	10	Water vapour absorption reference	1
OCI-15	**900**	10	Water vapour absorption, vegetation	2

Table 19: OCI channels

Requirements at instrument level shall be defined so that the calibration algorithm converges. Classically, they are given by two parameters: the ISRF centroid of each spectral sample and the stability of the corresponding frequency.

MRD_OCI.020

The spectral position of any spatial sample in the instrument footprint and in any spectral band shall be known with an accuracy better than: 0.39 nm.

5.11.5 Radiometric Requirements

5.11.5.1 Dynamic Range

MRD_OCI.110

The OCI shall have adequate dynamic range to accommodate both low oceanic signals in the case of clear atmospheres and higher signals in the case of aerosol loading. For ocean applications a typical signal of about 50 mW m^{-2} sr^{-1} nm^{-1} (including the atmosphere) is expected assuming low chlorophyll concentrations. Taking into account targets on Earth a much higher dynamic range is required and realised. Nominal dynamic ranges (excluding cloud signals) are given in Table 20. All spectral and radiometric requirements must be met within these nominal working ranges.

Channel name	**Central Wavelength (nm)**	**Nominal working range ($mW/m^2/sr/nm$)**
OCI-1	**412.5**	0 - 251.5
OCI-2	**442.5**	0 - 268.3
OCI-3	**490**	0 - 260.8
OCI-4	**510**	0 - 240.1
OCI-5	**560**	0 - 232.7
OCI-6	**620**	0 - 214.2
OCI-7	**665**	0 - 240.3
OCI-8	**681.25**	0 - 199.2
OCI-9	**708.75**	0 - 39.0
OCI-10	**753.75**	0 - 383
OCI-11	**760.625**	0 - 377
OCI-12	**778.75**	0 - 30.0
OCI-13	**865**	0 - 186.3
OCI-14	**885**	0 - 26.0
OCI-15	**900**	0 - 124.4

Table 20: OCI Dynamic Range Specification

5.11.5.2 Radiometric Noise

MRD_OCI.130

The OCI shall have radiometric resolution of 0.03 mW m^{-2} sr^{-1} nm^{-1} in order to discriminate a pigment concentration of 1 mg/m^3.

5.11.5.3 Absolute Accuracy

The following specification gives the absolute accuracy of scene radiance measured in OCI channels.

MRD_OCI.200

The bias error shall be < 2%.

5.11.5.4 Orbit Stability

MRD_OCI.210

The variation (RMS) of systematic errors in the measured radiance during any single orbit shall be <5%.

5.11.5.5 Lifetime Stability

The following specification gives constraints on the bias part of the measurement error during the instrument lifetime.

MRD_OCI.220

The variation (RMS) of the running average over an orbit of systematic errors in the measured radiance shall be such that the SNR variation is < 5%.

5.11.5.6 Radiometric Homogeneity

MRD_OCI.230

The inter-pixel radiance difference between different pixels of the same channel shall be < 1%.

5.11.6 Polarisation Requirements

MRD_OCI.400

Polarisation sensitivity shall be < 1%

5.11.7 Geometric Requirements

MRD_OCI.500

The OCI shall be optimised for operation in a sun-synchronous orbit.

MRD_OCI.610

The OCI shall maximise the useful viewing angle and provide 100% complete global coverage within < 24 hours (objective), < 48 hours (threshold), preferably with a single instrument and ensuring all measurements included in the fore-mentioned coverage requirement are free from sunglint (cloud conditions can be disregarded).

MRD_OCI.620

The on ground pixel size at nadir shall be < 0.3 km in coastal zones and < 1 km in the open ocean.

MRD_OCI.630

The OCI shall provide continuous coverage, the required overlap between pixels will be defined by the normalised modulation transfer function (MTF) which describes the image contrast with respect to the actual scene contrast. The normalised MTF shall be > 0.3 at the spatial wavelength given by twice the ground footprint size in both along and cross track directions.

5.11.7.1 Geolocation

MRD_OCI.640

Geolocation shall be better than 0.5 pixels.

5.11.7.2 Pointing Requirement

MRD_OCI.650

The absolute pointing requirement, the difference between the actual VII viewing direction and the commanded one, shall be < 1 mrad for all Earth views.

MRD_OCI.660

The absolute pointing knowledge shall be < 0.1 mrad.

5.11.7.3 Synchronisation requirement

MRD_OCI.670

Measurements at different spectral channels shall be co-registered so that at least 90% of the the covered areas of each pixel are the same.

MRD_OCI.680

Measurements at different spectral channels shall be co-registered within < 1 s (objective), < 2 s (breakthrough), 3 s (threshold).

5.11.7.4 IPFS Requirements

TBD

5.12 Scatterometry Mission (SCA)

5.12.1 Objectives

Scatterometry (SCA) measurements provide ocean surface wind vectors, which are an important input to global and regional NWP and also models of the ocean surface waves. The demand for ocean wind observations is emphasised by the increased need for storm and hurricane forecasting. NWP users also use Scatterometer-derived surface soil moisture over land.

The Scatterometer mission has a direct heritage from instruments such as the Advanced Scatterometer (ASCAT) flown on the MetOp satellites. As a baseline, the minimum expected performance of the SCA mission is that of ASCAT.

The **primary objective** of the SCA mission is to support NWP and ocean state forecasts at regional and global scales, through the provision of surface wind vector measurements.

Secondary objectives are to provide NWP with measurements of surface soil moisture, leaf-area indices snow-water equivalents and sea-ice type measurements.
The level of fulfilment of these objectives will highly depend on a trade-off between coverage and horizontal resolution.

The main users of the SCA mission will be the NWP centres of National Meteorological Services and ECMWF, Operational nowcasting services of National Meteorological Services may also be users of the SCA mission. The SCA mission is also relevant to non real-time users, such as oceanographic researchers and climate system modellers.

5.12.2 Products

The products to be derived from the SCA mission include, in decreasing order of priority:

1. Ocean surface wind vector,
2. Land surface soil moisture,
3. Leaf area index,
4. Snow water equivalent,

5. Snow cover,
6. Sea-ice type,
7. Sea Ice extent.

5.12.3 Priority of Requirements

MRD_SCA.001

If a trade-off is necessary between swath width and horizontal resolution, the swath width shall have higher priority as long as the horizontal resolution is < 25 km (Breakthrough), < 50 km (Threshold).

5.12.4 General Measurement Principle

The essence of a scatterometer lies in its multi-azimuth viewing. For achieving uniform wind vector sensitivity at least three azimuth views are necessary, ideally separated by 45° each.

MRD_SCA.005

The SCA generates and transmits radar pulses and shall acquire data representative of the target scattering coefficient.

MRD_SCA.006

The SCA measures the target scattering coefficient under at least three azimuth angles, ideally separated by 45° each (heritage ERS/ASCAT instruments).

5.12.5 Operating Frequency

Continuity of the C-band data sets is required. Empirical geophysical model functions exist for C-band (ERS heritage) and Ku-band (NSCAT, SeaWinds heritage), where Ku-band is strongly affected by rain.

MRD_SCA.010

The radar carrier frequency shall operate in C-band

5.12.6 Geometric Requirements

MRD_SCA.110

The SCA shall maximise the useful viewing angle range and provide 90% complete global coverage within 45 hours, preferably with a single instrument.

MRD_SCA.120

The horizontal resolution shall be ≤ 25 km.

MRD_SCA.130

The horizontal sampling interval shall be ≤ 12.5 km.

MRD_SCA.140

The geo-localisation accuracy (knowledge) shall be <1 km (Objective), < 2 km (Threshold).

5.12.7 Radiometric Requirements

MRD_SCA.150

The dynamic range of the backscattering coefficient shall be such that the measured wind speed covers the range between 1 and 25 m/s. Measurements with reduced accuracy above 25 m/s up to 40 m/s are desirable. As geophysical model function for the transfer between wind speed and backscattering coefficient the OSI SAF[4] geophysical model shall be taken.

MRD_SCA.160

The radiometric accuracy (bias error) shall be ≤ 0.35 dB peak to peak per beam.

MRD_SCA.170

1. The radiometric resolution shall be < 1% (Objective), < 3% (Breakthrough), < 10% (Threshold) at 4 m/s.
2. The radiometric resolution shall be < 2% (Objective), < 3% (Breakthrough), < 4% (Threshold) at 25 m/s.

MRD_SCA.180

The overall radiometric stability shall be ≤ 0.1 dB over an orbit and over the mission lifetime.

5.12.8 Polarisation requirements

HH polarisation is less sensitive to the wind at low speeds, but recent aircraft campaign data suggest more sensitivity at 40 m/s (while VV is saturated here). HH also helps solving the wind ambiguity problem, but this is considered a smaller benefit in the ERS or ASCAT geometry (with only dual ambiguity). HH is advantageous in soil moisture and sea ice observation as well.

MRD_SCA.190

The SCA shall operate in HH polarisation (Objective), VV polarisation (Threshold).

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[4] Ocean and Sea Ice Satellite Application Facility

5.13 Radar Altimeter Mission (ALT)

5.13.1 Objectives

Sea Surface Height (SSH) is a fundamental observation needed for operational oceanography, NWP and climate monitoring, as stated in the Ocean Monitoring Position Paper.

The **main objective** of the Altimeter mission (ALT) is to globally provide ocean topography information, i.e. the variation of sea level height above the Earth's reference geoid. The **secondary objective** of the Altimeter mission is to provide information on surface currents and on the sea-state, through Significant Wave Height (SWH) and wind speed (from backscattered power / normalised radar cross section). Note that the sea state measurements are also used to correct for sea state bias in the height determination.Another geophysical parameter that can be retrieved from such a mission is the total electron content.

Ocean topography measurements can be used to monitor and predict ocean tides, currents, seasonal to inter-annual events (such as El Niño/Southern Oscillation), sea level changes, sea ice topography and thickness changes, wind speed and wave height. Also sea level changes on inter-annual to centennial time scale are essential for coastal monitoring and protection.

The main users of the Altimeter mission will be the WMO real time users, i.e. Oceanographic centres, NWP centres of National Meteorological services and ECMWF. The Altimeter mission is also relevant to non real-time users.

As a baseline, the minumum expected performance of the ALT mission is that of the Jason-2 altimeter mission.

5.13.2 Products

The main Level 2 geophysical parameters provided are in decreasing order of priority:

1. Sea surface height (SSH),
2. Significant wave height (SWH),
3. Wind speed,

Further parameters to which the ALT mission provides important information include:

4. Sea ice topography,
5. Ice sheet topography,
6. Rain rate,
7. Total electron content.

5.13.3 Priority of requirements

Operational Oceanography, climate monitoring, and coastal preotection and security rely on accurate high-quality SSH and SWH observations. This stresses the importance that the accuracy associated to each of the SSH and SWH, and backscattered power observations, which have the highest priority in this context. Horizontal resolution is the next most important requirement.

5.13.4 Measurement principle

The Altimeter is an active instrument that emits a radiation pulse at selected wavelengths. The return pulse provides a range measurement of the height of the satellite relative to the Earth surface. The determination of the orbit is an important requirement since it influences the final accuracy of the SSH observations. The range measurement is then converted to the actual height of the sea surface by adding a series of corrections (atmospheric refraction corrections, instrument corrections, external geophysical adjustments). Correction due to the presence of water vapour in the troposphere is assumed and will ensure a corresponding height error of < 1 cm. This implies a co-located observation of the amount of water vapour and liquid water in the atmosphere in order to estimate the tropospheric path delay correction. A microwave passive radiometer in Ka- and Q-band can provide such information.

MRD_ALT.005

The ALT shall emit radiation pulses at selected frequencies and receive return pulses providing range measurements of the height of the satellite above the Earth surface.

MRD_ALT.052

Errors due to the accuracy of the orbit information shall lead to height errors < 2 cm (Objective), < 3 cm (Breakthrough), < 4 cm (Threshold).

5.13.5 Spectral requirements

Spectral requirements define the main spectral characteristics of the altimeter.

MRD_ALT.060

The spectral range shall be within Ku (baseline) and C bands (appropriate 2nd frequency - based on Jason or Envisat RA-2 heritage). An alternative 2nd frequency could be chosen in the S-band if use of C-band is not possible.

MRD_ALT.065

Dual frequency operation shall be included to determine the ionospheric correction to ensure a corresponding height error of < 1 cm.

5.13.6 Radiometric Requirements

MRD_ALT.070

Absolute accuracy of the normalised radar cross section (σ°) shall be < 1 dB, with a resolution of < 0.1 dB.

MRD_ALT.080

The drift of σ° shall be characterised with an accuracy < 0.1 dB.

5.13.7 Geometric Requirements

MRD_ALT.090

The coverage requirement for the post-EPS ALT needs to be considered in conjunction with the availability of other operational altimetry missions in the post-EPS time frame. The general coverage requirement for ocean topography requires two altimeters, one in a non-sunsynchronous repeat orbit, with a repeat period in the 10 to 35 day range to maximise coverage over the non-frozen ocean, the other in a sun-synchronous orbit to achieve coverage over the poles. Choice of height of orbit and repeat period will determine the between-track spacing and so the across-track resolution.

MRD_ALT.100

The horizontal resolution shall be < 5 km (Objective), < 10 km (Breakthrough), < 25 km (Threshold).

MRD_ALT.105

The ALT mission shall provide a ground-track repeat cycle with an accuracy < 500 m.

5.13.7.1 Beam and Pointing Requirement

MRD_ALT.110

The pointing accuracy shall be within 0.1° of nadir and the pointing knowledge shall be maintained within 0.01°.

MRD_ALT.120

The footprint size shall be 2 to 7 km for a SWH range of 1 to 15 m for 1 Hz data (geometrically the footprint size increases with increasing SWH).

MRD_ALT.130

The footprint geolocation shall be < 500 m.

MRD_ALT.140

1. The ALT shall be synchronised with a microwave radiometer measuring total water-vapour column using measurement frequencies of 23.8 and 18.7 GHz.
2. The temporal synchronisation shall be performed within < 10s.
3. The spatial co-registration shall be performed within < 500m.

5.14 Nadir viewing UV/VIS/NIR – SWIR Sounding Mission (UVNS)

The requirements outlined in this section are based on the preliminary instrument assessments presented in the final report of the ESA Capacity study (RD.4). It is recognised that there is a need for consolidation of requirements and that there are remaining open issues to be resolved. Those requirements stated below can be considered as an initial assessment of the anticipated requirements for a nadir sounding UV/VIS/NIR - SWIR (UVNS) mission.

5.14.1 Objectives

Nadir sounding measurements in the UV/Visible/Near-InfraRed region have for many years been used for the monitoring of stratospheric ozone, for example by instruments such as TOMS, SBUV, GOME, OMI, SCIAMACHY and most recently GOME-2. Additionally, the "Air Quality" and "Composition Climate" application areas as detailed in the Atmospheric Chemistry position paper (AD.3) require access to the boundary layer which indicates nadir sounding instrumentation. Nadir sounding measurements in the UV/Visible/NIR region have been demonstrated by GOME, SCIAMACHY, OMI and GOME-2 to yield information on a number of trace species relevant to air quality issues e.g. O_3, NO_2, SO_2, HCHO, and CHOCHO. Of particular relevance to these applications areas is the capability to probe the boundary layer, which is largely determined by the number of cloud-free pixels. Cloud contamination can be minimised by selection of the smallest possible ground pixel size. Furthermore it is anticipated that the combination of spectral data from the TIR and the UV/Vis NIR will improve the discrimination of the PBL from nadir measurements. Addition of bands in the SWIR also offers potential to better discriminate CH_4 and CO in the PBL [5], through synergy with measurements in the thermal infrared (TIR), further supporting the Composition-Climate and Air Quality applications.

The capability to sound the lower troposphere (n.b. O_3 and CO_2) would be increased by maximising the occurence of sun-glint geometry. This could be done by pointing the instrument backwards or forwards along-track (whilst retaining the across track swath). The feasibility of this option should be considered.

5.14.2 Products

The target products for a UV/VIS/NIR – SWIR mission are in order of priority grouping:

Priority 1 Products

- Ozone profile and total column (OSU, CCI, AQ),
- Total columns of sulphur dioxide (AQ), nitrogen dioxide (AQ), and water vapour (CCI)
- Aerosol optical depth, potentially height-resolved information (AQ, CCI),
- Total column of CO (AQ),
- Total column of CH_4 (CCI).

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[5] CO_2 and N_2O are climate gases which also have bands in the SWIR that, in principle, could be utilised in a similar way to add information to TIR specifically in the near-surface layer. In the event that this technique is demonstrated by OCO for CO_2, this would become an instrument driver for post-EPS. For N_2O, deviations from uniform mixing in the lower troposphere are expected to be much smaller than for CH_4 or CO_2, so measurements in an N_2O swir band could be used to normalize CH_4, CO_2 and CO, i.e. as an auxiliary measurement.

- In combination with the IRS, CH_4 (CCI), CO (AQ), and potentially CO_2 (CCI), in the PBL.

Priority 2 Products

- Total column of bromine monoxide (OSU),
- Total column of formaldehyde (AQ),
- Total column of glyoxyl (AQ),
- Total column of CO_2, (with column N_2O as an auxiliary product used for normalisation) (CCI).

Additionally important auxiliary information will be obtained on cloud fraction and cloud top height.

5.14.3 Priority of Requirements

Requirements on spatial resolution are expected to receive the highest priority.

5.14.4 Spectral Requirements

5.14.4.1 Spectral Range and Resolution

	Wavelength range [nm] (TBC)	Spectral Resolution [nm] (TBC)	Spectral Oversampling (TBC)	Target Species
UVNS-1	270 – 330	0.5 – 1.0	3 – 6	O_3 profile (Stratosphere), UV-B Tropospheric O_3
UVNS-2	308 – 325	0.2 – 0.5	3 – 6	SO_2 and Tropospheric O_3,
UVNS-3	325 – 337	0.2 – 0.5	3 – 6	O_3 total column
UVNS-4	337 – 356	0.2 – 0.5	3 – 6	HCHO
UVNS-5	345 – 360	0.2 – 0.5	3 – 6	BrO
UVNS-6	356 – 400	0.2 – 0.5	3 – 6	O_4 & rotational Raman scattering (Cloud Top Height in UV), OClO, UV-A NO_2 in UV window and NO_2 as function of altitude.
UVNS-7	405 – 500	0.2 – 0.5	3 - 6	NO_2 and NO_2 as function of T i.e. altitude

UVNS-8	430 – 460	0.2 – 0.5	3 - 6	Glyoxal (CHO.CHO)
UVNS-9	460 – 490	0.2 – 0.5	3 - 6	O_4 (cloud top height visible, cloud fraction visible)
UVNS-10	330 - 640	0.2 – 0.8	3 - 6	O_3 troposphere-B Aerosol-AOT-(1)
UVNS-11	640 - 730	0.2 – 0.5	3 - 6	H_2O (O_2) total column
UVNS-12	755 - 775	0.05 – 0.2	3 - 6	O_2, Aerosol height and Aerosol- AOT-(2)
UVNS-13 (priority 1)	1400 – 1750	0.05 – 0.3	2 - 6	CO_2 (Total Dry Column - need O_2 UVNS-12), CH_4 (Total Dry Column) Cloud Phase Index and Aerosol (AOT-3)
UVNS-14 (priority 2)	1940 – 2040	0.05 – 0.3	2 - 6	CO_2 Profile info to be coupled with 1.6 micron band, Aerosol
UVS-15 (priority 1)	2295 - 2400	0.05 – 0.3	2 - 6	CO, CH_4, N_2O

Table 21: UVNS Spectral Bands

MRD_UVS.010

The UVNS mission shall cover the spectral bands specified in Table 21.

MRD_UVNS.020

The spectral resolution of the UVNS bands shall be as specified in Table 21.

MRD_UVNS.030

The spectral oversampling of the UVNS bands shall be as specified in Table 21.

5.14.4.2 Spectral Registration Requirements

MRD_UVNS.040

The knowledge of the spectral registration shall be < 0.005(O)/0.01(T) of a spectral pixel for all UVNS bands for all applicable wavelengths and viewing directions.

MRD_UVNS.050

The stability of the spectral registration shall be better than < 0.02(O)/0.05(T) of a spectral pixel for all UVNS bands over one orbit for all applicable wavelengths and viewing angles.

MRD_UVNS.060

For all UVNS bands the shape of the instrument spectral response function (ISRF) shall be known for all applicable wavelengths and viewing angles with at least 20 sampling points to an accuracy of 1% (1σ) for the spectral range where the ISRF is at least 1% of the maximum response at the centre wavelength.

5.14.5 Solar Spectral Irradiance

MRD_UVNS.070

The UNVS mission shall provide measurements of the extraterrestrial solar spectral irradiance in the same bands as defined in MRD_UVNS.010, with the same spectral resolution as defined in MRD_UVNS.020 and with the same spectral oversampling as defined in MRD_UVNS.030.

MRD_UVNS.080

The solar spectral irradiance shall be measured once per day for duration of at least two minutes. It shall be possible to increase the frequency of the solar spectral irradiance measurements during special measurement campaigns.

5.14.6 Radiometric Requirements

Four scenarios are considered: a minimum and a maximum radiance case (dark and bright surface or cloud) for a tropical and a high-latitude situation. The bright cases shall be used to check for saturation, the dark for meeting the Signal-to-Noise-Ratio (SNR) requirement.

5.14.6.1 Dynamic Range

	Wave-length Range [nm]	High Latitude Bright Case Photons/ (s.cm^2.nm.sr)	Tropical Bright Case Photons/ (s.cm^2.nm.sr)	High Latitude Dark Case Photons/ (s.cm^2.nm.sr)	Tropical Dark Case Photons/ (s.cm^2.nm.sr)	Solar Irradiance Photons/ (s.cm^2.nm.sr)
UVNS-1	270 – 330	3.0 e9 @ 270 nm 2.0 e11 @ 310 nm 1.0 e13 @ 330 nm	1.0 e10 @ 270 nm 4.5 e12 @ 310 nm 6.5 e13 @ 330 nm	3.0 e9 @270 nm 1.5 e11 @ 310 nm 5.0 e12 @ 330 nm	1.0 e10 @270 nm 1.8 e12 @310 nm) 1.5 e13 @ 330 nm	5 e13 @ 270 nm 1.5 e14 @ 330 nm 2.5 e14 @ 330 nm
UVNS-2	308 – 325	4.5 e12	3.5 e13	1.0 e11	1.5 e12	2.5 e14
UVNS-3	325 – 337	1.0 e13	6.0 e13	2.5 e12	1.0 e13	2.5 e14
UVNS-4	337 – 356	1.5 e13	6.5 e13	3.0 e12	7.5 e12	2.5 e14
UVNS-5	345 – 360	1.5 e13	6.5 e13	3.0 e12	7.5 e12	2.5 e14
UVNS-6	356 – 400	2.0 e13	1.0 e14	2.5 e12	6.0 e12	4.0 e14
UVNS-7	405 – 500	3.5 e13	1.5 e14	4.0 e12	1.0 e13	5.5 e14
UVNS-8	430 – 460	3.5 e13	1.5 e14	4.0 e12	1.0 e13	5.5 e14
UVNS-9	460 – 490	4.0 e13	2.0 e14	4.0 e12	1.0e13	5.5 e14
UVNS -10	330 - 640	3.5 e13 @ 640nm 1.0 e13 @ 330nm	1.5 e14 @ 640nm 6.5 e13 @ 330nm	2.0 e12 @ 640nm 5.0 e12 @ 330nm	6.0 e12 @ 640nm 1.5 e13 @ 330nm	6.0 e12 |@ 640nm 2.5 e14 @ 330nm
UVNS -11	640 - 730	4.0 e13	1.5 e14	1.0 e12	3.0 e12	5.5 e14
UVNS-12	755 - 775	8.5 e12 (for lowest radiance level in absorption band) 3.5 e13 (in continuum)	3.5 e13 (for lowest radiance level in absorption band) 1.5 e14 (in continuum)	3.5 e11 (for lowest radiance level in absorption band) 1.5 e12 (in continuum)	1.0 e12 (for lowest radiance level in absorption band) 4.0 e12 (in continuum)	5.0 e14
UVNS-13	1400 – 1750	8.5 e12	3.5 e13	5.0 e11	1.0 e12	3.0 e14
UVNS-14	1940 – 2040	8.5 e12	3.5 e13	5.0 e11	1.0 e12	1.5 e14
UVNS-15	2295 - 2400	5.8 e12	2.0 e13	5.0 e11	1.0 e12	8.5 e13

Table 22: Reference Spectral Radiance & Irradiance Values

MRD_UVNS.110

The dynamic range of the UVNS mission bands shall be optimised to measure the unpolarised spectral radiances between the dark and bright scene values as specified in Table Table 22.

MRD_UVNS.120

The dynamic range of the UVNS shall allow measurement of the tropical bright radiance and the solar spectral irradiance, throughout the year for all applicable viewing angles, without saturation.

5.14.6.2 Radiometric Noise

Signal to Noise Ratio (SNR) requirements are given for the tropical and the high-latitude dark cases and for the solar spectral irradiance measurements.

	Wavelength range [nm]	Tropical Dark Case	High-Latitude Dark Case	Solar Spectral Irradiance
UVNS-1	270 – 330	100 @ 270 nm 1000 @ 310 nm 1000 @ 330 nm	50 @ 270 nm (TBD) 1000 @ 310 nm 1000 @ 330 nm	1000 @ 270 nm 3000 @ 310 nm 3000 @ 310 nm
UVNS-2	308 – 325	1000	400	3000
UVNS-3	325 – 337	800	400	3000
UVNS-4	337 – 356	1000	400	3000
UVNS-5	345 – 360	1000	400	3000
UVNS-6	356 – 400	1000	400	3000
UVNS-7	405 – 500	1050	450	4500
UVNS-8	430 – 460	1050	450	4500
UVNS-9	460 – 490	1500	650	4500
UVNS-10	330 - 640	90 @ 650nm 540 @ 330nm	90 @ 650nm 540 @ 330nm	3000 (TBD)
UVNS-11	640 - 730	700	700	4000
UVNS-12	755 - 775	200 (for lowest radiance level in absorption band) 500 (in continuum)	200 (for lowest radiance level in absorption band) 500 (in continuum)	1500
UVNS-13 (TBD)	1400 – 1750	1000	100	1500

UVNS-14 (TBD)	1940 – 2040	1000	100	1500
UVNS-15	2295 - 2400	1000	100	1500

Table 23: SNR requirements.

MRD_UVNS.090

The signal to noise ratios for all UVNS bands shall be better than specified in Table 23 Note: Table 23 may be subject to revision.

5.14.6.3 Radiometric Accuracy

MRD_UVNS.140

Intrachannel relative radiometric accuracy requires that pseudo-spectral features, arising from the instrument when observing the atmosphere and including those for electrical noise, digitalisation noise, stray light etc) shall be < 0.005(O)/0.01(T) % within one channel i.e. between any two or more detector pixels within a channel.

MRD_UVNS.141

Interchannel relative radiometric accuracy between detector pixels in different channels from all sources shall be < 0.02(O)/0.05(T) %.

MRD_UVNS.142

The accuracy of the solar spectral irradiance product, including the contribution of straylight, for all UVNS bands shall be ≤ 1.0(O)/2.0(T) % (1σ) for all applicable solar angles.

MRD_UVNS.143

The accuracy of the unpolarised radiance product, including the contribution of straylight, for all UVNS bands shall be ≤ 1.0(O)/2.0(T) % (1σ) for all applicable viewing angles.

5.14.6.4 Polarisation Requirements

MRD_UVNS.170

For all UVNS spectral bands the sensitivity to polarised state of the incoming radiation field shall be < 0.5(O)/1.0(T) % of the signal at the particular wavelength.

5.14.7 Geometric Requirements

5.14.7.1 Scan Pattern Requirements

MRD_UVNS.190

The measurements of the UVNS mission shall be made with a ground pixel size field of view (FOV) of < 5km x 5km (O)/10km x 10km(B)/20km x 20km(T).

MRD_UVNS.200

The UVNS shall maximise the useful viewing angle and provide 99% global coverage within 24 hours, preferably with a single instrument.

MRD_UVNS.220

The UVNS mission shall provide near contiguous coverage of the Earth's surface (TBC).

5.14.7.2 Co-registration Requirements and Viewing Property Requirements

MRD_UVNS.230

The co-registration of the IPSF of the UVNS bands shall be < 1.0(O)/5.0(T) % of the size of the geometrical field of view.

MRD_UVNS.232

The fraction of the integrated energy of the IPSF function from outside the geometrical field of view shall be < 1.0(O)/5.0(T) % of the total integrated energy for a uniformly illuminated scene.

MRD_UVNS.233

The latitude and longitude of the centre of each SPSF shall be known with an accuracy < 5.0%(O)/10.0(T) % of the 2 * FWHM of the SPSF.

5.14.7.3 Synchronisation requirement

MRD_UVNS.250

The UVNS shall be synchronised with a high-resolution (~1 km) optical imaging mission for cloud & aerosol detection within the UVNS IPSF.

5.15 Limb Millimetre-Wave Mission (MMW)

The primary sources of the instrument requirements listed below are preliminary instrument assessments presented in the final report of the ESA Capacity study (RD.4) and the ESA-funded "Study on Upper Troposphere/Lower Stratosphere Sounding" (RD.5) and "Definition of Mission Objectives and Observational Requirements for an Atmospheric Chemistry Explorer Mission – 1st Extension and 2nd Extension" (RD.6 and RD.7), which included extensive retrieval simulations for the MASTER instrument concept. Instrument requirements were specified in RD.5 for an Explorer-class instrument, which could be descoped to focus specifically on post-EPS monitoring requirements. An alternative concept is outlined in the candidate ESA Earth Explorer mission PREMIER. Requirements and justifications listed below are based on those for MASTER in RD.5, RD.6 and RD.7, but may be subject to revision[6].

5.15.1 Objectives

The principal objective of a millimetre-wave limb-sounding mission (MMW) is to profile key trace gases in the upper troposphere / tropopause region in the presence of cirrus[7], as well as cloud-free scenes, and in the stratosphere at the vertical resolution required to monitor *composition – climate interaction*, which would not be possible for nadir-sounders[8]. Profiling over this height range by the MMW would also enable the lower troposphere to be resolved by combining synergistically with IRS and UVNS nadir measurements to meet requirements for *pollution monitoring and air quality forecasting*, which would otherwise not be possible[9]. The MMW observations would be assimilated operationally into global models and into regional air quality models.

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[6] Half-power beamwidths and system noise / NEBT requirements for channels 3 and 4 in Table 20 are therefore less stringent than specified by RD-6.

[7] Particulates of smaller size than cirrus, ie aerosol and polar stratospheric clouds, are transparent in the mm-wave.

[8] Monitoring of the radiatively important trace gases H_2O and O_3 over this height range with adequate vertical resolution is needed for international assessments of *composition-climate interaction.* Monitoring of trace gases CO and HNO_3 in the upper troposphere / tropopause region is also required, because of their influence on chemistry and as indicators of change in stratosphere-troposphere exchange. Several other trace gases would also be monitored in the stratosphere, to detect change in the Brewer-Dobson circulation (N_2O) or to stratospheric chlorine (ClO) or bromine (BrO) loading and impacts on *stratospheric ozone*.

[9] An exception is H_2O, for which synergy with MMW is not likely to significantly benefit vertical resolution of IRS in the lower troposphere.

5.15.2 Products

The primary target species in the upper troposphere are in order of priority grouping:

Priority 1 Products
- H_2O (CCI)
- O_3[10] (OSU, AQ, CCI)
- CO (AQ)

Priority 2 Products
- Stratospheric ClO (OSU)
- Stratospheric BrO[11] (OSU)
- Stratospheric N_2O (CCI)
- HNO_3[12] (OSU)

Priority 4
- HCl[13] (OSU)

The principal aim is to make high sensitivity measurements with good vertical resolution (~2km) and frequent along-orbit track sampling in the upper troposphere and lower stratosphere (UTLS). The wavelength range chosen is much less sensitive to cloud and aerosol than instruments which observe at shorter wavelengths.

5.15.3 Priority of Requirements

The antenna is of critical importance. Knowledge of the antenna pattern is especially vital. Pointing jitter is critical to the precision on profiles retrieved at high vertical resolution in the UTLS region. Pointing accuracy can be sacrificed if necessary to maximize stability, since it should be recoverable *a posteriori* through retrieval of pointing bias and drift to accuracies of <100 m and <500 m, respectively.

5.15.4 Spectral Requirements

MRD_MMW.010

The MMW mission shall cover the spectral bands specified in Table 24 (TBC).

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[10] H_2O and O_3 are assigned Priority 1 in the User Requirements for *Composition-Climate Interaction* (CCI) (Ref AEG position paper). In addition, O_3 is Priority 1 for both *Ozone & Surface UV (OSU)* and *Air Quality (AQ)* and H_2O is Priority 2 for *AQ*.

[11] In the lower and mid-stratosphere, N_2O is Priority 2 for *CCI* and ClO and BrO are Priority 2 for *OSU*.

[12] CO is Priority 1 for *AQ* and HNO_3 is Priority 2 for *OSU*. In addition, CO and HNO_3 are Priority 2 and 3, respectively, for *CCI* and HNO_3 is Priority 3 for *AQ*.

[13] HCl in the lower and mid-stratosphere is assigned Priority 4 for *OSU*.

MRD_MMW.020

The spectral resolution of all bands specified in Table 24 shall be 50MHz.

5.15.5 Spectro-Radiometric Vertical Half-Power Beam Width Requirements

Receiver	Primary Target	Priority (AEG User Req)	Spectral Coverage (GHz)	Spectral Reso-lution (MHz)	System Noise (SSB) / K	NEΔT (K)	Vertical HPBW (km)
MMW-1	O_3	1	298 – 305	50	4300	1.1	3.0
MMW-2	H_2O	1	318 – 325.5	50	4600	1.2	3.0
MMW-3	CO, HNO_3	2	342.25 – 347.25	50	3200	0.8	3.0
MMW-4	N_2O,ClO, BrO	2	497.0 – 503.0	50	3800	1.0	2.0
MMW-5	HCl	4	624.62–626.62	50	5800	1.5	2.0

Table 24: Spectroradiometric and Vertical HPBW Requirements

MRD_MMW.030

The noise equivalent brightness temperature difference (NEΔT) for individual measurements of the MMW mission at an integration time of 0.3s shall be as specified in Table 24.

MRD_MMW.040

The vertical Half-Power Beam Width (HPBW) for all bands of the MMW mission shall be as specified in Table 24.

MRD_MMW.060

In order to achieve the radiometric accuracy requirements above, knowledge of the ACAP shall be < -45dB (TBC).

5.15.6 Geometric Requirements

To achieve its objective, the MMW mission shall be configured to observe the limb troposphere and stratosphere in the orbit plane, sampling at 1 km in tangent-height and ≤ 100 km along-track in five broad frequency bands. Limb observations are required to cover the nominal scan range plus 1 km at either end

The vertical coverage shall be as follows:

MRD_MMW.080

The number of limb measurements in the main portion, from 4 to 34km, of the altitude range shall be selectable from 1 to 100.

MRD_MMW.100

The extension of an elevation scan above the main portion shall be configurable similarly to the main portion, independently of the main portion, excepted that the number of measurements may be zero. The extension shall be executed once per M elevation scans, with M selectable from 1 to 100.

MRD_MMW.110An elevation offset shall be applied to the main portion of the altitude range as a linear function of limb measurement latitude. The nominal altitude range has a main portion from 4 to 34 km, with 1 km sampling, for duration 31 x 0.15 s. The offset is 0 km at the poles and 7 km at 20 degrees, varying linearly in between. Between 20 degrees and the equator the offset remains constant.

5.16 Limb Infra-Red Mission (LIR)

The primary sources of the instrument requirements listed below are preliminary instrument assessments presented in the final report of the ESA Capacity study (RD.4) and the ESA-funded "Definition of Mission Objectives and Observational Requirements for an Atmospheric Chemistry Explorer Mission – 1st Extension and 2nd Extension" (RD.6 & RD.7) in particular the AMIPAS instrument concept. Additionally the IMIPAS concept outlined in the candidate ESA Earth Explorer mission PREMIER is highly relevant. Revisions of these specifications, in particular reduction of the spectral range to optimise the requirements for an operational mission, could be envisaged however detailed study on this point is required. Addiionally, further refinement of the IMIPAS concept can be expected to lead to revision of these specifications. Note that a Fourier transform spectrometer is assumed and the LIR mission will rely on heritage from MIPAS on ENVISAT.

5.16.1 Objectives

The principal objective of an infrared limb-sounding mission is to profile key trace gases in the upper troposphere / tropopause region, in the absence of cloud, and in the stratosphere at the vertical resolution required to monitor *composition – climate interaction*, which would not be possible for nadir-sounders[14]. Profiling over this height range by the LIR would also enable the lower troposphere to be resolved by combining synergistically with IRS and UVS nadir measurements to meet key requirements for *pollution monitoring* and *air quality*

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[14] Monitoring of the radiatively important trace gases H_2O and O_3 over this height range with adequate vertical resolution is needed for international assessments of *composition-climate interaction*. Monitoring of trace gases CO and HNO_3 in the upper troposphere / tropopause region is also required, because of their influence on chemistry and as indicators of change in stratosphere-troposphere exchange. Several other trace gases would also be monitored in the stratosphere, to detect change in the Brewer-Dobson circulation (N_2O) or to stratospheric chlorine (ClO) or bromine (BrO) loading and impacts on *stratospheric ozone*.

forecasting, which would otherwise not be possible[15]. The LIR observations would be assimilated operationally into global models and into regional air quality models.

5.16.2 Products

The key targets for the LIR mission are identified to be, in order of priority grouping:

Priority 1 Products

- Temperature in the stratosphere and (cloud free) upper troposphere (UT).
- H_2O (CCI), O_3 (OSU, AQ, CCI)and CH_4[16] (CCI) in the UT, lower stratosphere (LS) and above
- Aerosol[17] in the LS and (cloud free) UT if possible (AQ).

Priority 2 Products

- HNO_3 [18] in the UT, lower stratosphere (LS) and above (OSU)
- N_2O [19], together with other trace gases (CFCs, HCFCs) in the LS and above (CCI)
- Cirrus in the UT (CCI)

Priority 3 Products

- PSCs[20] in the LS (OSU)
- NO_2 [21] and other nitrogen oxides (eg N_2O_5 and $ClONO_2$) in the mid-stratosphere; measurement capability in the LS would be desirable (OSU)

Priority 4 Products

- C_2H_2, C_2H_6, PAN[22] and acetone in the (cloud free) UT (AQ).

5.16.3 Priority of Requirements

One of the primary drivers is expected to be the requirement for pointing and thermal stability. Prioritisation of other requirements is TBC.

5.16.4 Spectral Requirements

MRD_LIR.010

The LIR shall measure in two contiguous spectral bands: LIR-A covering the spectral range 770 – 1050 cm^{-1} and LIR-B covering the spectral range 1050 – 1750 cm^{-1}.

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[15] An exception is H_2O, for which synergy with MMW is not likely to significantly benefit vertical resolution of IRS in the lower troposphere.

[16] H_2O, O_3 and CH_4 are Priority 1 for *CCI*. In addition, O_3 is Priority 1 for both *OSU* and *AQ* and H_2O is Priority 2 for *AQ*.

[17] Aerosol in the lower stratosphere / upper troposphere is Priority 1 for *AQ* and Priority 2 for *OSU* & *CCI*

[18] HNO_3 is Priority 2 for *OSU*. In addition, CO and HNO_3 are Priority 2 and 3, respectively, for *CCI* and HNO_3 is Priority 3 for *AQ*

[19] N_2O in the stratosphere is Priority 2 for *CCI*

[20] Cirrus is Priority 2 for *CCI* and PSCs are Priority 3 for *OSU*

[21] NO_2 in the stratosphere is Priority 3 for *OSU*

[22] C_2H_2, C_2H_6 and PAN in the UT are Priority 4 for *AQ*

MRD_LIR.020

The spectral resolution of bands LIR-A and LIR-B shall be in the range 0.025 – 0.2 cm^{-1} unapodized with a preference for 0.1cm^{-1} unapodized (TBC).

MRD_LIR.030

The width of the instrument line shape function shall be known to < 2% (TBC).

MRD_LIR.040

The spectral calibration of the LIR shall be known to < 4% (TBC) of the spectral resolution.

5.16.5 Radiometric Requirements

MRD_LIR.060

The NEΔR shall be < 9.0 nW (cm^2 sr cm^{-1}) in band LIR-A and < 5.5 nW (cm^2 sr cm^{-1}) in LIR-B.

MRD_LIR.070

The LIR dynamic range is from a cold space view to a maximum brightness temperature of 260 K (TBC).

MRD_LIR.071

The knowledge of the radiometric gain of the LIR shall be < 1%.

MRD_LIR.072

The radiometric linearity of the LIR shall be < 0.5% of the radiance value.

MRD_LIR.073

The radiometric offset of the LIR shall be < 0.5 x NEΔR/2.

MRD_LIR.074

The absolute radiometric accuracy of the LIR shall be < 1.5% of the radiance value + NEΔR/2 + NEΔR (from combination of MRD_LIR_60, 71, 72 and 73) (RD.5 requirement 2.2.3.3, combining 2.2.3.2 with 2.2.3.3.1, 2.2.3.3.2 and 2.2.3.3.4).

5.16.6 Geometric Requirements

5.16.6.1 Vertical Coverage & Resolution

MRD_LIR.090

The vertical coverage of the LIR shall be 3 to 65 km at the poles and 10 to 65 km at the 20 degrees, interpolated linearly with latitude and remaining constant from 20 degrees to the equator.

MRD_LIR.091

The total accessible vertical range of the LIR, considering all observation sequences and offset calibration shall be ground to120 km.

MRD_LIR.100

The vertical sampling of the LIR shall be < 2 km over the altitude range < 40km. The vertical sampling strategy at higher altitudes is TBD.

MRD_LIR.101

The FWHM of the vertical extension of the FOV at the tangent point shall be < 2 km over the complete altitude range (TBC). Note that ideally the vertical sampling and the FOV width would be the same.

MRD_LIR.102

The vertical FOV shall not deviate from a boxcar shape by more than 10% within 0.8 FWHM of the FOV (nominally +/- 0.4 FWHM from the FOV centre is the FOV is symmetrical).

MRD_LIR.103

The maximum fraction of the signal originating from outside the vertical FOV FWHM [2*FWHM] shall be < 1(O)(TBC)/15(T) % when exposed to a homogeneous radiation source.

MRD_LIR.104

The vertical co-registration of the tangent altitude as observed by the spectral bands shall be < 0.2 km.

5.16.6.2 Horizontal Sampling & Resolution

Note that the requirements on across-track sampling and coverage are open to discussion. The study on “Definition of Mission Objectives and Observational Requirements for an Atmospheric Chemistry Explorer Mission – 1st Extension” (RD.5) considered five measurement tracks across the orbit track but this was not further studied in the 2nd extension (RD.6) due to resulting instrument complexity. The IMPAS concept considers a horizontal sampling of < 80 km with a horizontal coverage of < 320 km for similar applications. Currently both the requirements from the study from “Definition of Mission Objectives and Observational Requirements for an Atmospheric Chemistry Explorer Mission” and those of IMIPAS are indicated but revision can be expected. The case of no across-track scanning can be assumed to be the threshold case.

MRD_LIR.110

The horizontal across-track range shall be +/- 0(T) and 320(O) or 1400(O) km perpendicular to the along-track direction (TBC taking into account comments above).

MRD_LIR.111

The horizontal across-track sampling shall be < 30(T) and 80(O) or 500(O) km (TBC taking into account comments above).

MRD_LIR.120

The horizontal along-track sampling shall be < 100km (TBC).

MRD_LIR.121

The FWHM of the horizontal extension of the FOV at the tangent point shall be < 30km (TBC).

MRD_LIR.122

The horizontal FOV shall not deviate from a boxcar shape by more than 20% within 0.8 FWHM of the FOV (nominally +/- 0.4 FWHM from the FOV centre is the FOV is symmetrical).

MRD_LIR.123

The maximum fraction of the signal originating from outside the horizontal FOV FWHM [2*FWHM] shall be < 1%(O)(TBC)/20%(T) when exposed to a homogeneous radiation source.

MRD_LIR.124

The horizontal co-registration of the tangent point observed by the spectral bands shall be < 0.1 * Horizontal FOV FWHM.

5.16.6.3 Pointing Requirements

MRD_LIR.125

The knowledge of the tangent point across-track position shall < 0.1 * Horizontal FOV FWHM.

MRD_LIR.130

The knowledge of the tangent point vertical position shall be < 100(O)/500(T) m (TBC).

MRD_LIR.140

The tangent point stability over a period of 1s shall be < 50 m (TBC).

5.17 Aerosol Profiling Lidar Mission (APL)

The sole source of the instrument requirements listed below is the ATLID concept outlined in the ESA Earth Explorer mission EarthCARE (RD.7). Other heritage instruments include LITE and ICESAT.

5.17.1 Objectives

Aerosols have a direct radiative impact by reflecting solar radiation back to space, which leads to cooling. Absorbing aerosols, e.g. carbon from anthropogenic sources, can lead to local heating. Aerosols also control the radiative properties of clouds and their ability to produce precipitation. The low concentration of aerosol particles in marine air leads to water clouds with a small number of relatively large droplets. In contrast, the high concentration of aerosols in continental and polluted air results in water clouds with a much higher concentration of smaller droplets. Continental clouds therefore not only have a higher albedo and reflect more sunlight back to space, but also are much more stable and long-lived and less likely to produce precipitation. Aerosols also control the glaciation process, yet their effect on the properties of ice clouds is essentially unknown. There is a need to quantify the degree to which aerosols are responsible for the observed rapid reduction in the albedo of freshly fallen snow. Present observations of global aerosol properties are limited to optical depth and a crude estimate of particle size.

5.17.2 Products

The APL is a lidar mission optimised for the measurement, in decreasing order of priority, of:

1. Aerosol optical thickness profile,
2. Optically thin cloud optical thickness profile,
3. Particle shape,
4. Altitude of cloud boundaries.

In addition it will discriminate the molecular backscatter (“Rayleigh”) from the aerosol and cloud particle returns (“Mie”).

5.17.3 Priority of Requirements

The priority of requirements is TBD.

5.17.4 General Requirements

MRD_APL.001

DELETED.

5.17.5 Spectral Requirements

Conventional lidar designs can only measure the total aerosol and molecular return signals, but because the extinction-to-backscatter ratio of aerosol (S) is quite variable, it is difficult to estimate aerosol extinction. The APL shall separate the narrow band return from the slowly moving aerosol/cloud particles from the thermally Doppler broadened molecular signal. This ‘High-Spectral Resolution’ (HSR) technique uses any reduction in the molecular return to directly determine the extinction of aerosols and thin clouds, which is then used to correct the back-scatter term in the Mie channel for attenuation.

A single 355 nm wavelength lidar with a High Spectral Resolution (HSR) receiver separating Rayleigh and Mie backscatter returns is required.

MRD_APL.010

The APL shall operate at a single wavelength of 355 nm.

MRD_APL.020

Three channels are to be provided: Mie co- and cross-polar, as well as Rayleigh co-polar.

5.17.6 Radiometric Requirements

MRD_APL.040

The minimum detectable backscatter coefficient (i.e. lidar sensitivity) shall be < 8 x 10^{-7} m^{-1} sr^{-1} (equivalent top of atmosphere backscatter) in the co-polar Mie channel for 100m vertical resolution and 10km horizontal resolution with a radiometric accuracy of < 50%.

MRD_APL.041

The minimum detectable backscatter coefficient (i.e. lidar sensitivity) shall be < 2.6 x 10^{-6} m^{-1} sr^{-1} (equivalent top of atmosphere backscatter) in the cross-polar Mie channel for 100m vertical resolution and 10km horizontal resolution with a radiometric accuracy of < 50%.

MRD_APL.042

The minimum detectable backscatter coefficient (i.e. lidar sensitivity) shall be < 8 x 10^{-7} m^{-1} sr^{-1} (equivalent top of atmosphere backscatter) in the co-polar Rayleigh channel for 300m vertical resolution and 10km horizontal resolution with a radiometric accuracy of < 15%.

MRD_APL.050

The knowledge of the lidar calibration constant in each channel shall be >90%.

5.17.7 Geometric Requirements

The line-of-sight shall be offset from nadir by 2° in the along-track direction to minimize the effects of specular reflection, which may be generated by opaque water and cirrus clouds.

MRD_APL.070

The measurement range extends from the ground to an altitude of 30 km with a vertical resolution of 100 m.

MRD_APL.080

The line-of-sight shall be offset from nadir by 2° in the along-track direction.

MRD_APL.090

The APL shall have an along track sampling better than one sample every 200 m.

MRD_APL.100

The APL shall have an instrument footprint receiver diameter of < 30 m.

5.18 Multi-Viewing Multi-Channel Multi-Polarisation Imaging Mission (3MI/3MI')

5.18.1 Objectives

The PEPS Multi-Viewing Multi-Channel Multi-Polarisation Imaging Mission (3MI) is a high performance radiometer aimed at providing aerosol characterization for climate monitoring, atmospheric chemistry and more specifically air quality. The 3MI also contributes to artefact correction on other sensors (e.g. the IRS, the VII and the UVNS) and addresses those measurements that require multi-viewing capability due to the anisotropy of scattering, and multi-polarisation because of aerosol and cirrus cloud's particle shape and orientation variety.

The primary objective of the 3MI mission is to provide high quality imagery of aerosols parameters for climate records, etc. through the provision of:

- Aerosol optical depths for accumulation, coarse and total modes at high horizontal resolution
- Aerosol particle size for accumulation, coarse and total modes.
- Aerosol type through Angström exponent, refractive index, non sphericity index.
- Aerosol height index
- Aerosol absorption (considered in the latter 3MI' option)

When used as constraints to the models these products will be used to provide:

- Improved Air Quality Index
- PM (Aerosol Load mass for particles smaller than 2.5 μm (PM2.5) or 10 μm (PM10).

Secondary mission objectives include:

- Surface albedo
- Improved cloud characterization : Cloud phase, cloud height, cloud optical depth
- Ocean colour

The PEPS multi-purpose VIS/IR imager (VII) provides information on most cloud parameters (see §5.6), but cirrus clouds observation requires multiviewing and multipolarisation capability to characterise:

- extension, optical depth, particle size.
- a-sphericity factor, crystal orientation, phase function (side and backscattering part).

Due to their small optical depth, cirrus clouds are difficult to be quantitatively observed. 'Invisible cirrus' may cover large fractions of the Earth surface. Global amount of cloud ice in the atmosphere is poorly known whereas, unfortunately, their role in the Earth radiation budget is extremely relevant since they produce a strong greenhouse effect.

Currently, aerosol and cirrus parameters are mostly used in General Circulation Models for climate simulation and prediction, however utilisation of these parameters is becoming increasingly important in operational NWP as the representation of radiative processes in the atmosphere is a recognised area of deficiency.

Multiviewing observation is necessary to observe surface BRDF, essential for computing surface radiative parameters in terms of irradiance, and to measure albedo and vegetation indexes.

The main users of the 3MI mission will be the WMO real time users, i.e. NWP centres of National Meteorological Services and ECMWF in addition to operational nowcasting and oceanographic services of National Meteorological Services. The 3MI imaging mission is also relevant to non real-time users.

Two possible configurations for the 3MI are given in this initial specification. The first of these is based on the POLDER instrument, currently flown on PARASOL and addresses primarily aerosol (scattering) observations, in addition to surface albedo and ocean colour observations (secondary mission objectives). This configuration relies on the VII and RER for observations on absorbing aerosol and radiation budget and represents the baseline configuration for this mission. The second configuration (hereafter refered to as the 3MI') considers a more encompassing mission that considers simultaneously all the main components of 'atmospheric radiative effects'. Aside from the baseline 3MI observations, it considers other measurements useful to be co-processed with the scattering aerosol observations namely; absorbing aerosol, cirrus clouds, water vapour and radiation budget at the TOA.

The instrument will be a passive satellite radiometer capable of measuring polarised radiances reflected by the Earth under different viewing geometries in specified spectral bands from the visible to the shortwaveinfra-red parts of the electromagnetic spectrum in the case of the 3MI and the UV to the FIR in the case of the 3MI'.

The level of fulfilment of these objectives will highly depend on the space-time resolution of the 3MI mission, and is particularly critical at high latitudes where information from geostationary spacecraft is scarce or even unavailable.

5.18.1.1 Heritage

The primary source for the first configuration (3MI) instrument requirements are: 1) the POLDER instrument currently flown on PARASOL, 2) the MISR flown on EOS-Terra, 3) and the APS instrument studied for NPOESS.

The 3MI' requirements draw upon the EC funded 'CLOUDS' project (cloud and radiation monitoring mission) performed in 1998-2000.

5.18.1.2 Relevant instrument synergies

The requirements for multiviewing and multipolarisation capability are essentially limited to short-waves, however, both aerosol and cirrus observations require observation to be extended to the TIR channels. Therefore, the baseline 3MI specification assumes the presence of the VII and the TIR channels. Alternatively, if the 3MI' option is adopted, the TIR channels for absorbing aerosol and cirrus clouds are no longer needed on the VII.

The UV channels are important for large size aerosols. The 3MI is the preferred location for these channels but in the event the 3MI is de-scoped, these channels should be considered for the VII.

Multiviewing capability is required for ERB broad-band radiometry for the conversion of observed radiances into irradiance, hence the RER will benefit from measurements provided by the 3MI. Alternatively, if the extended 3MI' option is adopted (with the ERB channels), the RER instrument could be dropped as the 3MI' covers the ERB observations.
Both configurations contribute to artefact correction on many other PEPS sensors (e.g. the IRS, the VII and the UVNS) and addresses those measurements that require multi-viewing capability due to the anisotropy of scattering, and multi-polarisation because of particle shape and orientation variety.
The ocean colour products are considered opportunistic in light of the OCI instrument which is specifically optimised for observations of this type.

5.18.2 Products from 3MI and 3MI'

The following products requiring observation from a multi-angle viewing imager have been identified by the Post-EPS application experts:

Aerosols (driving application)

Over ocean and land
- Total and small particles optical thickness (aerosol load)
- Angström exponent
- Non sphericity index
- Effective radius and refractive index of the small particles mode
- Refractive index of large spherical particles
- Altitude range
- Aerosol absorption (3MI' only))

Clouds

- Cloud mask
- Cloud imagery
- Cloud optical depth
- Cloud top temperature
- Cloud top height
- Cirrus clouds (3MI' only)

Land surface

- Earth's surface albedo
- BRDFs Bidirectional Reflectance Distribution Functions
- Vegetation
    - Leaf area index (LAI)
    - Vegetation type
    - Fraction of vegetated land
    - Fraction absorbed photosynthetically active radiation (FAPAR)
    - Photosynthetically active radiation (PAR)
    - Normalised Differential Vegetation Index (NDVI)

Ocean

- Ocean colour (chlorophyll concentration)

Earth Radiation Budget (3MI' only)

- Solar radiation reflected to space from the Earth-atmosphere system
- Terrestrial radiation emitted to space from the Earth-atmosphere system

5.18.3 Priority of Requirements

Multi-viewing capability
Multi-polarisation capability
Extension of spectral range
Radiometric accuracy
Relatively narrow bandwidths
Geometric resolution.

5.18.4 Operational Requirements - 3MI

The following requirements define the baseline 3MI mission derived from experience with POLDER. Operational requirements for the extended 3MI' mission to include the UV and TIR channels are given at the end of this section.

MRD_3MI.010

3MI should be operated continuously during local daytime. Measurements shall be acquired for solar zenith angles varying between 24° and 80°. The performance specifications, either geometric or radiometric, are expected to be met for solar zenith angles varying between 24° and 60°.

5.18.5 Spectral Requirements – 3MI

MRD_3MI.020

In order to achieve the mission objectives, the Post-EPS 3MI shall measure scene radiances in a number of spectral channels, all with 10 (threshold) to 14 (goal) viewing directions (fore and aft) as defined in following table. The nominal spectral bandwidth for each channel is defined in the following table in terms of the full width at half maximum (FWHM). Priorities for the channels area also given, 1 being highest priority, 4 the lowest.

Mission BAND	Central Wavelength (µm)	FWHM (µm)	Polarization	Primary Use	Priority
3MI-1	**0.342**	0.06 (TBC)	Y	Absorbing aerosol	2
3MI-2	**0.388**	0.06 (TBC)	Y		2
3MI-3	**0.443**	0.02		Aerosol absorption and height indicators (TBC)	1

3MI-4	**0.490**	0.02	Y	Aerosol, surface albedo, cloud reflectance, cloud optical depth	1
3MI-5	**0.555**	0.02	Y	Surface albedo	3
3MI-6	**0.670**	0.02	Y	Aerosol properties	1
3MI -7	**0.763**	0.01		Cloud height	2
3MI -8	**0.765**	0.04		Cloud height	2
3MI -9	**0.865**	0.04	Y	Vegetation, aerosol, clouds, surface features	1
3MI -10	**1.370**	0.04		Cirrus clouds, water vapour imagery,	1
3MI -11	**1.650**	0.04	Y	Ground characterization for aerosol inversion	1
3MI -12	**2.130**	0.04	Y	Cloud microphysics at cloud top, Vegetation, fire (effects) Ground characterization for aerosol inversion	1

Table 25: 3MI channels, FWHM, Polarization, Priority

MRD_3MI.100

The spectral responses of the 3MI channels shall be known, with 0.5nm sampling, to 1% of their peak response at any wavelength.

MRD_3MI.150

The spectral response stability shall be < 0.1 nm.

5.18.6 Radiometric Requirements – 3MI

MRD_3MI.200

The 3MI channel nominal dynamic ranges are given herafter. All spectral and radiometric requirements must be met within these nominal working ranges.

The dynamic range, expressed in reflectance, shall be between 0 and 1 for both polarised and unpolarised channels.

The dynamic range, expressed in reflectance, shall be between 0 and 1 for both polarised and unpolarised channels. In terms of radiance, the dynamic range of the 3MI channels are given in Table 26. For the polarised channels, the dynamic ranges should be further scaled by the polarisation sensitivity.

Channel wavelength (µm)	**Rmin $W/m^2/sr^{-1}/\mu m$**	**Rmax $W/m^2/sr^{-1}/\mu m$**
0.342	3.05 (TBC)	318
0.388	3.18 (TBC)	332
0.443	4.64 (TBC)	533

0.490	5 (TBC)	550 (TBC)
0.555	5.2	542
0.670	8.7	481
0.763	4.83	396
0.765	4.83	396
0.865	3.71	304
1.370	1.42 (TBC)	105
1.650	0.89 (TBC)	66
2.130	0.37 (TBC)	27

Table 26: 3MI scene dynamic ranges

MRD_3MI.210

The noise equivalent values NEΔR are residual RMS noise given in terms of reflectances (R) and polarised reflectances (Rp).

The requirement for radiometric noise at pixel level shall be:

NEΔR = sup [5×10^{-4}; 5×10^{-3} R] for all channels R

.NEΔRp = sup [10^{-3}; 10^{-2} Rp] for all polarised channels Rp

MRD_3MI.300

The bias error shall be < 2% for all channels.

MRD_3MI.310

RMS differences between measurements from different spectral samples/channels of the same footprint shall be < 1 % for a uniform scene (TBD).

MRD_3MI.320

The bias (inter-calibration) error between nadir and fore/aft viewing directions shall be < 2%.

MRD_3MI.330

RMS accuracy of pixels inside a 10 by 10 image area shall be < 0.1 %.

MRD_3MI.350

Two measurements of the same stable target made at one year intervals should be consistent (after calibration) within 1% RMS for all channels.

MRD_3MI.360

For similar spectral bands, measurements from the 3MI and VII instruments shall be radiometrically cross-calibrated to an accuracy within 1% for all spectral targets.

5.18.7 Polarisation Requirements – 3MI

MRD_3MI.400

As the polarisation of the electromagnetic waves reflected by the Earth and atmospheric targets is supposed linear, the measurements of polarisation in given spectral band are achieved by three polarisers oriented at 0°, 60°, -60° with an accuracy of < 1°. The direction of polarisation shall be known with an accuracy of <10’ while imaging.

The polarisation sensitivity shall be > 96 % for the polarised channels and < 2 % for the unpolarised channels. It shall be known to within 10^{-3} for flight conditions.

MRD_3MI.410

The optic sensitivity to polarisation modifies the polarisation state of the observed light and this perturbation must be minimised. The polarisation rate (lp/l) observed at the output of the instrument when the incident light is totally unpolarised shall be < 6% for the polarisaed channels and < 10% for the others. TBC

MRD_3MI.420

The relative transmittance of the 3 polarised components of a given (polarised) channel must not differ by more than 1 %.

5.18.8 Geometric Requirements – 3MI

MRD_3MI.500

The 3MI shall maximise the useful viewing angle and provide 99% complete global coverage within 12 (breakthrough) or 24 (threshold) hours, preferably with a single instrument.

A two-dimensional footprint is required for directional measurements. The angular sampling is the value of the angle between the viewing directions for two successive acquisitions of the same target. For a given orbit and two-dimensional footprint, the accessible viewing geometries for any target on the Earth define a directional space.

MRD_3MI. 630

Acquisition of measurements close to the principal plane shall be maximized. At least 10 (TBC) (objective 14) directional measurements shall be acquired over the accessible directional space corresponding to an angular sampling in the order of 10°. (As an example, for a 800 km altitude sun-synchronous orbit and a ±43° along track footprint, a 20 s time sampling leads to a number of 12 to 14 directions. Reduction to a 30 s sampling should be acceptable.)

MRD_3MI.640

The on ground footprint size at nadir shall be < 1 km (goal), < 2 km (threshold).

MRD_3MI.650

The 3MI shall provide continuous coverage, the required overlap between pixels will be defined by the modulation transfer function which describes the image contrast with respect to the actual scene contrast.

MRD_3MI.660

For all channels the normalised MTF shall be superior to 0.2 at the spatial frequency given by twice the ground footprint size.

Data acquired in the different channels, spectral or polarized, must be co-registered as follows:

MRD_3MI.700 Multipolarisation registration

For a given polarised channel, the 3 polarised components of the same target on the ground, shall be within a disk of < 0.1 pixel diameter.

MRD_3MI.710 Multispectral/interband registration

For a given viewing angle condition, all spectral channels for the same target on the ground, shall be within a disk of < 0.2 pixel

MRD_3MI.720 Multidirectional registration

For a given channel, the RMS distances between all pixels corresponding to different viewing angles of the same target on the ground and the barycentre of these considered pixels shall be < 0.1 pixel.

MRD_3MI.730 Multitemporal registration

For a given channel, the RMS distances between all pixels acquired from different orbits during 30 days (the duration of monthly syntheses) and the barycentre of these considered pixels shall be < 0.125 pixel (diameter).

5.18.9 Pointing Requirement – 3MI

MRD_3MI.740 Absolute localisation

The absolute geolocation of the measurements shall be < 2 km (objective < 1 km)

5.18.10 3MI' configuration

The 3MI requirements so far stated, inspired to POLDER, are driven by the objective of observing scattering aerosol, relying on VII for absorbing aerosol. The alternative option described hereinafter differs because:

- it considers absorbing aerosol as well, that requires several VII channels (specifically, the UV and TIR ones) not included in Table 25;
- it contextually addresses both aerosol and cirrus clouds, that have similar roles in atmospheric radiation issues and need to be distinguished since they have similar signatures in the SW;
- it includes consideration of other measurements useful to be co-processed with aerosol and cirrus, such as cloud properties, water vapour and radiation budget at TOA, concurring to determine the atmospheric radiation field;
- summing-up, it covers a wider range of requirements from the CPL mission as compared to the 3MI configuration so far described.

Table 27 lists the channels that would be required to comply with the requirement of contextually observing aerosols, cirrus clouds and other main components of atmospheric radiation. This set is reproduced from the EC-funded project "CLOUDS - a Cloud and Radiation monitoring mission" performed in years 1998-2000. It is noted that, differently from the POLDER-derived concept:

- a wide multi-viewing capability (at least 8 views) is requested only for one channel (VIS/NIR) whereas all other channels have only two views (fore- and aft-);
- the multi-polarisation capability is requested for only three wavelengths, and includes three 120°-dephased polarisations to measure three components of the Stokes vector.

Channel	Central wavelength	Bandwidth (half-power)	Polarisations	Multi-view	Use	Spectral region		Remarks
3MI'-01	340 nm	6 nm	not required	Fore & aft	Absorbing aerosol, gross height discrimination, also over land	UV	SW	Channels not in the VII 16-channel short list
3MI'-02	388 nm	6 nm	not required	Fore & aft				
3MI'-03	443 nm	20 nm	not required	Fore & aft	Scattering aerosol, cloud parameters, cirrus clouds, surface radiative properties (albedo, PAR, FPAR, vegetation)	VIS		
3MI'-04	555 nm	20 nm	Three	Fore & aft				
3MI'-05	670 nm	20 nm	Three	Fore & aft				
3MI'-06	865 nm	20 nm	not required	Fore & aft		NIR		
3MI'-07	940 nm	50 nm	not required	Fore & aft	High-level aerosol, cirrus clouds			Water vapour channel
3MI'-08	1,240 nm	50 nm	Three	Fore & aft	Aerosol, cirrus, surface properties			
3MI'-09	1,375 nm	30 nm	not required	Fore & aft	High-level aerosol, cirrus clouds	SWIR		Water vapour channel
3MI'-10	1,610 nm	30 nm	Three	Fore & aft	Cloud microphysical properties,			
3MI'-11	2,130 nm	30 nm	Not required	Fore & aft	Cloud microphysical			

					properties, cirrus			
3MI'-12	3.74 µm	0.4 µm	not required	Fore & aft	aerosol, cirrus, surface properties	MWIR	LW	Channels in the VII 16-channel short list, but with different scanning mode
3MI'-13	6.25 µm	1.0 µm	not required	Fore & aft	Full night observation capability,	TIR		
3MI'-14	7.35 µm	0.5 µm	not required	Fore & aft	cloud characterisation			
3MI'-15	8.70 µm	0.5 µm	not required	Fore & aft	including top height,			
3MI'-16	9.66 µm	0.5 µm	not required	Fore & aft	water vapour, ozone,			
3MI'-17	10.8 µm	1.0 µm	not required	Fore & aft	absorbing aerosol,			
3MI'-18	12.0 µm	1.0 µm	not required	Fore & aft	cirrus clouds,			
3MI'-19	13.4 µm	0.5 µm	not required	Fore & aft	surface temperatures.			
3MI'-20	18.2 µm	2.0 µm	not required	Fore & aft	Invisible cirrus	FIR		Channels not in the VII 16-channel short list
3MI'-21	24.4 µm	2.0 µm	not required	Fore & aft	over land			
3MI'-22	Total short-wave	0.2-4.0 µm	not required	Fore & aft	Earth radiation			Channels similar to RER, but different scanning mode
3MI'-23	Total energy	0.2-100 µm	not required	Fore & aft	budget at TOA			
3MI'-24	$\alpha = 21°, \zeta = 23.9°$ $\alpha = 33°, \zeta = 38.1°$ $\alpha = 45°, \zeta = 53.2°$ $\alpha = 57°, \zeta = 71.7°$	0.4-1.0 µm	not required	At least eight (4 angles. fore & aft)	Bidirectional Reflectance Distribution Function (BRDF)			Not in VII

Table 27: List of candidate 3MI' channels.

It is noted that the channels overlapping with VII, if retained, would provide 3MI' with the capability to act as partial backup of VII; and that channels 21 and 22 could replace RER, or dropped if RER is onboard.

5.18.11 Requirements for the SW component of 3MI'

The SW channels listed in Table 25 (3MI) and Table 27 (3MI') differ for the following features:

- the presence of two UV channels in 3MI', that are essential for absorbing aerosol discrimination along the vertical in the troposphere;
- a different selection of the other SW channels, reflecting differences of the background definition studies (POLDER-derivative and CLOUDS-derivative), but probably easy to be brought to convergence;
- a smaller number of wavelengths with multi-polarisation in 3MI': the CLOUDS study advocated for a minimum of two wavelengths, preferably three for redundancy; 3MI advocates for 6;
- multi-viewing over a wide number of viewing angles only for one channel in 3MI', with all other channels with two views only, whereas 3MI has wide multi-viewing capability for all channels.

Mission requirements that encompass both concepts are as follows.

MRD_3MI'.810

The spectral range covered by 3MI/3MI' channels shall extend from no more than 340 nm to at least 1650 nm and preferably to 2150 nm.

MRD_3MI'.820

In the spectral range defined under MRD_3MI.810, there shall be channels in at least 10 wavelengths. Mandatory central wavelengths are: 340, 380, 443, 670, 865, 1375, 1610 and 2130 nm; secondary wavelengths are 555, 763, 765, 940 and 1240 nm.

MRD_3MI'.830

In a number of wavelengths, multi-polarisation shall be provided. The multi-polarisation shall enable measuring three components of the Stokes vector, e.g. by measuring three polarisations de-phased by 120°. As a minimum, multi-polarisation shall be provided at three wavelengths optimally selected.

MRD_3MI'.840

Multi-viewing observing capability shall be provided for all SW channels. As a minimum, fore- and aft- views shall be provided under a constant zenith angle selected for optimal differentiation of polarisation information (around 53°). More zenith angles shall be provided by at least one channel significant of the VIS/NIR range (in Table 27, 0.4-1.0 µm). At least four zenith angles should be provided, extending to over 70°.

5.18.12 Requirements for the LW component of 3MI'

The purpose of the LW component of 3MI' is to provide, in association with the SW component, uninterrupted signatures of aerosol and cirrus clouds from UV to Far IR. Although VII includes most channels required for 3MI',

- the FIR channels, necessary for thin (invisible) cirrus clouds over land and ocean are not part of the 16-channel short list and, anyway, in that context, would have very low priority and difficult compliance with the constraints of a relatively-high-resolution imager;
- closest co-registration and consistency of viewing conditions with the SW package are very advantageous for multi-spectral processing where tiny differences of large numbers need to be measured.

MRD_3MI'.850

The LW component of 3MI' shall cover the spectral range from the lower end of thermal emission (say, 3.7 µm) to the first quasi-window intervals in the Far IR. Table 27 shows that these quasi-windows, suitable to observe thin cirrus clouds, are around 18.2 and 24.4 µm.

MRD_3MI'.860

In the specified interval, 3MI' shall have about 10 channels. The eight MWIR and TIR channels shown in Table 27 are close to those defined for Meteosat Third Generation and listed in the VII short list (see Table 9).

MRD_3MI'.870

Although not a stringent requirement, it is desirable that the LW component of 3MI' is closely following the viewing geometry of the SW component. This implies that, if the SW component performs conical scanning, the LW component also does.

5.18.13 Requirements for broad band channels – 3MI'

Although a Radiant Energy Radiometry mission (RER) is being considered as stand-alone (see Section 5.9), there is a strong advantage in measuring the components of the earth radiation budget at TOA in a fully contextual way with the main effects that control it: clouds (specifically cirrus clouds), aerosol and water vapour. The 3MI' multi-viewing capability is important for the purpose of converting radiances into irradiances.

MRD_3MI'.875

3MI' shall include broad-band channels for earth radiation budget observation at TOA. The total energy reflected and emitted in the 0.2-100 µm range and the short-wave solar reflected energy, 0.2-4.0 µm shall be measured.

MRD_3MI'.880

The geometry of observation shall be exactly the same as for the LW and the SW narrow-band channels. This implies that, if the SW component performs conical scanning, the broad-band channels also do.

5.18.14 Requirements for spectral, radiometric and geometric resolutions – 3MI'

In general, the channel bandwidths of 3MI' are comparable or slightly narrower than those of VII. The radiometric accuracy (or SNR) of the SW component are much more demanding, but quoted at a relatively higher input radiance (or albedo). The geometric resolution could be coarser, since the mission objectives mostly address the global scale.

MRD_3MI'.910

The required channel bandwidths of 3MI' have been estimated in the "CLOUDS" study. They are reported in column 3 of Table 28.

MRD_3MI'.920

The radiometric accuracy requirements of 3MI' channels have been estimated in the "CLOUDS" study. They are reported in column 4 of Table 28.

MRD_3MI'.930

The bias error of 3MI' channels have been made somewhat more stringent than in the "CLOUDS" study. They are reported in column 5 of Table 28.

MRD_3MI’.940

The geometric resolution requirements of 3MI’ channels (footprint, intended as diameter of a circle of area equivalent to that one subtended by the beam, that in the case of conical scanning is elliptical with ratio 3:5 between minor and major axis) are reported in column 8 of Table 28. Note that, in the conical scanning geometry, the footprint is constant across the image. 5 km corresponds to the SEVIRI average pixel in the footprint (3 km s.s.p.), 40 km to the cross-track average pixel of CERES or ScaRaB (20 km s.s.p.). For the FIR channels the 40 km requirement addresses large-extension cirrus fields, and is accepted as broad to take into account technological limitations (slow-response detectors).

Channel	Central wavelength	Bandwidth (half-power)	SNR†	Reference Input radiance (Wm^{-2} $^{-1}$sr^{-1}) and albedo (%)†	Rounded SNR	Bias error	Polarisations	Footprint
3MI’-01	340 nm	6 nm	550	35.73 (25)	300 @ 10 % albedo	3 %	not required	5 km
3MI’-02	388 nm	6 nm	600	41.06 (25)	300 @ 10 % albedo	3 %	not required	5 km
3MI’-03	443 nm	20 nm	200	30.95 (10)	200 @ 10 % albedo	3 %	not required	5 km
3MI’-04	555 nm	20 nm	200	30.31 (10)	200 @ 10 % albedo	3 %	three	5 km
3MI’-05	670 nm	20 nm	180	24.41 (10)	200 @ 10 % albedo	3 %	three	5 km
3MI’-06	865 nm	20 nm	180	15.20 (10)	200 @ 10 % albedo	3 %	not required	5 km
3MI’-07	940 nm	50 nm	170	12.54 (10)	200 @ 10 % albedo	3 %	not required	5 km
3MI’-08	1,240 nm	50 nm	170	7.33 (10)	200 @ 10 % albedo	3 %	three	5 km
3MI’-09	1,375 nm	30 nm	130	5.61 (10)	200 @ 10 % albedo	3 %	not required	5 km
3MI’-10	1,610 nm	30 nm	120	3.91 (10)	200 @ 10 % albedo	3 %	threee	5 km
3MI’-11	2,130 nm	30 nm			200 @ 10 % albedo	3 %	not required	5 km
3MI’-12	3.74 µm	0.4 µm	-	-	0.10 K @ 300 K	0.5 K	not required	5 km
3MI’-13	6.25 µm	1.0 µm	-	-	0.30 K @ 250 K	0.5 K	not required	5 km
3MI’-14	7.35 µm	0.5 µm	-	-	0.30 K @ 250 K	0.5 K	not required	5 km
3MI’-15	8.70 µm	0.5 µm	-	-	0.10 K @ 280 K	0.5 K	not required	5 km
3MI’-16	9.66 µm	0.5 µm	-	-	0.30 K @ 220 K	0.5 K	not required	5 km
3MI’-17	10.8 µm	1.0 µm	-	-	0.10 K @ 300 K	0.5 K	not required	5 km
3MI’-18	12.0 µm	1.0 µm	-	-	0.10 K @ 300 K	0.5 K	not required	5 km
3MI’-19	13.4 µm	0.5 µm	-	-	0.30 K @ 280 K	0.5 K	not required	5 km
3MI’-20	18.2 µm	2.0 µm	-	-	0.50 K @ 220 K	0.5 K	not required	40 km
3MI’-21	24.4 µm	2.0 µm	-	-	0.50 K @ 220 K	0.5 K	not required	40 km
3MI’-22	Total short-wave	0.2-4.0 µm	-	-	0.3 W m^{-2} sr^{-1}	1.0 W m^{-2} sr^{-1}	not required	40 km
3MI’-23	Total energy	0.2-100 µm	-	-	0.3 W m^{-2} sr^{-1}	0.5 W m^{-2} sr^{-1}	not required	40 km
3MI’-24	$\alpha = 21^\circ$, $\zeta = 23.9^\circ$ $\alpha = 33^\circ$, $\zeta = 38.1^\circ$ $\alpha = 45^\circ$, $\zeta = 53.2^\circ$ $\alpha = 57^\circ$, $\zeta = 71.7^\circ$	0.4-1.0 µm	-	-	200 @ 10 % albedo	5 %	not required	5 km at $\zeta = 53.2^\circ$

Table 28: Candidate 3MI’ channels and their main characteristics.

† The first column of SNR figures quoted are derived for specific aerosol applications and are included to provide visibility of the reference scene radiance. However, the degree of detail implied in these SNR values is not representative of all applications and should not be adhered to,

rather the rounded figures for SNR in the next column should be used. For the polarised channels, the reference radiance is net of loss for the polariser.

5.18.15 Scanning requirements and observing cycle – 3MI'

The requirements so far defined for 3MI', if the multi-viewing capability of most channels is limited to two views (fore- and aft-) and the wide-multi-viewing capability is limited to one channel (or few more, if necessary), can be optimally served by conical scanning. From a satellite altitude of 840 km, the useful swath would be about 1400 km, ensuring global coverage in 48 h (SW) or 24 h (LW).

MRD_3MI'.950

3MI' shall provide global coverage within 48 h for channels exploiting solar reflection, and 24 h for thermal channels. Although there is a preference for maximum illumination conditions (local noon), measurements with solar zenith angles in the range of 24 and 80 degrees are acceptable. Measurements must be sunglint free.

MRD_3MI'.960

The narrow-band SW and LW channel complex, and the broad-band channels (i.e. channels 1 to 22 in Table 27 and Table 28) shall provide imagery by conical scanning, with an incidence angle of about 53°. The VIS/NIR multi-angle channel (channel 23 in Table 27 and Table 28) could operate by a bush-broom matrix array. In the case of channel 23, images at several incidence angles (at least four, shown in Table 27 and Table 28) as they were coming from conical scanning will be synthesised on the ground

MRD_3MI'.970

For all images in channels 1 to 18 the MTF shall be greater or equal to 0.3 at twice the spatial wavelength corresponding to the along-scan size of the (elliptical) footprint. For example, since the average 5 km IFOV is actually sized 3.9 km (along scan) x 6.5 km (along-view), the requirement is MTF ≥ 0.3 @ the spatial wavelength of 7.8 km. For channels 19 to 22 it shall be MTF ≥ 0.3 at the spatial wavelength of 62 km. For channel 23 it is required MTF ≥ 0.3 at the spatial wavelength of 7.8 km for the image with 53° incidence angle, whereas at smaller incidence angles MTF will be better (or the reference spatial wavelength will be shorter) and the opposite at larger incidence angles.

5.18.16 3MI' configurations function of mission scenario

As stand-alone, 3MI' would require channels in the 23 wavelengths listed in Table 27 or Table 28, or similar. Depending on the mission scenario on the same platform, several cases can be considered.

Case 1 - VII includes the two channels in the UV and the two channel in the FIR; and there is RER:

- 3MI as defined in Table 25 should be preferred;

Case 2 - VII does not include the two channels in the UV and in the FIR; and there is RER:

- 3MI' with channels 1 to 10, 19 and 20, and 23 should be considered;

- channels 11 to 18 could be added to have consistent scanning and partial backup to VII.

Case 3 **-** VII does not include the two channels in the UV and in the FIR; and there is no RER:

- same as Case 2, but with the addition of channels 21 and 22 to replace RER.

In order to be able to deal with all cases, we have:

MRD_3MI'.990

The full 3MI' configuration shall be defined and designed in a modular way so as to adapt to different post-EPS mission scenarios.

5.19 Total Solar Irradiance Monitoring mission (TSIM)

5.19.1 Objectives

The TSIM shall measure total solar irradiance (TSI), the integrated solar radiation incident at the top of the Earth's atmosphere, to ensure continuation of this climate record which began in 1978 and is used to determine the sensitivity of the Earth's climate to the natural effects of solar forcing. Precise space measurements obtained during the past 3 decades imply that the TSI varies on the order of 0.1% over the 11-year solar cycle, but with greater variations on day-to-month scales due to solar rotation and the passage of sunspots and facular regions across the solar disk. Variations in TSI occur over time scales from minutes to 11-year solar cycles and longer. For example, climate models including a sensitivity to solar forcing estimate a global climate change of up to 0.2° C due to solar variations over the last 150 years. To determine long-term changes in the Sun's output, which may have time scales extending much longer than the 11-year solar cycle, the TSI climate record requires continuous measurements with very good absolute accuracy and stability.

The baseline level of performance is that achieved by the Total Irradiance Monitor (TIM) on the NASA Earth Observation System SOlar Radiation and Climate Experiment (SORCE).

5.19.2 Products

The TSIM is an ambient temperature active cavity radiometer optimised for the measurement of:

- Downwelling solar irradiance at the TOA.

5.19.3 Priority of Requirements

Stability and bias of observations have the highest priority

5.19.4 Spectral Requirements

MRD_TSIM.020

The TSIM shall measure total downwelling solar radiation, over the full spectral range as viewed from the top of the atmosphere.

5.19.5 Radiometric Requirements

MRD_TSIM.040

The TSIM shall provide measurements of TSI to an accuracy (bias) < 1.5 Wm^{-2} (TBC).

MRD_TSIM.041

The stability of the TSI observations shall be better than 0.3 Wm^{-2} (TBC) over 10 years.

6 SYNERGY OF MISSIONS

For some of the missions it is essential to be co-registered with other missions to make full use of the observations and to enable the product generation. In other case a co-registration of measurements from different missions would be of benefit for the generated products. Both categories are listed in Table 29.

Mission	**Essential Co-registration**	**Desired Synergy**
IRS	VII (lean: 0.670, 0.865, 1.61, 3.75, 10.8 and 12.0 μm)	MWS 3MI
MWS	-	IRS
RO	-	-
DIA	-	IRS
DWL	-	-
VII	-	MWI 3MI
MWI	-	VII SCA CPR
CPR	MWI	APL VII
RER	VII	3MI
DVR	-	OCI
ALT	MWI (lean: 23.8 and 18.7 GHz)	-
OCI	-	DVR
SCA	-	MWI
UVNS	VII	IRS APL 3MI
MMW	-	LIR
LIR	-	MMW
APL	-	UVNS IRS VII
3MI	-	VII

Table 29: Essential and desired co-registration of missions

7 SUPPORT MISSIONS

7.1 Data Collection System (ARGOS) TBC/TBD

Ref. PARD [AD.5].

7.2 Search and Rescue TBC/TBD

Ref. PARD [AD.5].

7.3 User Services

7.3.1 Objectives

User services are defined in order to express requirements on how mission data and products mainly generated by the Post-EPS missions, and possibly from other sources as long as acquired by the Post-EPS system, are to be made available to the users, and on the support to be offered to them to maximize their benefit in using such data and products.

7.3.2 Definitions

Mission Products
Any output required to be generated by the Post-EPS missions, identified in the relevant sections of this document as Level 2, Level 1 or Level 0 data.

The identification of mission products will be refined and extended in subsequent phases of the project to include:
- products acquired by the Post-EPS system from other missions or partner organisations;
- format specifications;
- auxiliary data such as calibration, navigation, satellite and instrument housekeeping and diagnostic data;
- operational and administration status information;
- external verification and validation data;
- documentation;
- data acquisition, processing and visualisation software.

These extensions need to be taken into account whenever mission products are involved.

Additional Data Sets
These are derived from the mission products and include:
- lower resolution and/or lower accuracy data;
- reduced size images based on geographical areas or coordinates;
- merged images based on geographical areas or coordinates;
- overlays of images with other images, landmarks, coastlines, borderlines;
- animations from subsequent images.

Users and User Types

Post-EPS users are identified and classified in [AD.5].

It can be anticipated that the personnel of EUMETSAT and possibly other organisations involved in mission operation will receive mission products required for the performance of their tasks. Missions and products in this document however are not defined for this kind of users, who do not impose themselves mission requirements, and therefore are not considered.

7.3.3 General Requirements on User Services

The user services shall be consistent with, implement and enforce the application of the EUMETSAT Principles on Data Policy and any relevant implementing rule that can be established for the Post-EPS Programme; relevant high level requirements are addressed in [AD.5].

MRD_USR.010

The following user services shall be provided:

Direct Data Broadcast,

Near Real-Time Data Distribution,

Archival and Retrieval,

Reprocessing,

User Support.

MRD_USR.020

Registration through the User Support service is required to obtain access to the other services, unless a service feature is explicitly made available on an free and unrestricted basis.

MRD_USR.030

It shall be possible to grant or deny access to, and usage of, mission products which are not available on a free and unrestricted basis according to any combination of the following keys:

1. per user,
2. per product,
3. per on-board instrument,
4. per operating mode of the on-board instrument,
5. per satellite.

MRD_USR.040

Unauthorized access to, and usage of, mission products shall be prevented through appropriate means such as user identification, authentication and data encryption.

MRD_USR.050

The user services shall provide and maintain up-to date adequate protection mechanisms against security threats.

MRD_USR.060

The user services shall preserve the information content and quality of the mission products.

The above requirement implies that data manipulation and in particular compression techniques can be used as long as the information content and quality parameters of the mission products such as accuracy, resolution and coverage are unaffected. For any additional data required at lower resolution, accuracy or coverage, provision is made for their generation in the Archival and Retrieval user service.

MRD_USR.070

The identification, type, format and any attribute of mission products which is relevant for their handling by the user services shall be configurable in such a way that changes can be applied to the relevant parameters maintaining the proper handling.

MRD_USR.080

It shall be possible to make access to mission products and user services conditional to the payment of fees.

7.3.4 Direct Data Broadcast

The Direct Data Broadcast service provides broadcasting over a geographical area in the view of a satellite of mission products generated on board the same satellite, and mainly derived from observations performed over that area.

The actual mission products generated on-board, the size of the observation area and broadcasting area will be defined also depending on the solutions concerning instruments and communications payload.

MRD_USR.090

The Direct Data Broadcast service shall be available within a broadcasting area in the visibility of the relevant satellite.

MRD_USR.100

The Direct Data Broadcast service shall be available to all types of users within the broadcasting area and equipped with the relevant interfaces.

MRD_USR.110

All mission products generated on-board the satellites within an observation area shall be available for direct broadcast over a corresponding broadcasting area.

MRD_USR.120

The set of mission products to be actually broadcast shall be configurable out of the full set available for this service.

Note that availability requirements are given in [AD.5] which also concern product delivery by this service; the actual apportionment of availability between observation missions and user services will be the result of analysis and design trade-offs.

7.3.5 Near Real-Time Data Distribution

The Near Real-Time Data Distribution concerns all mission products and is mainly driven by the relevant latency requirements.

For the Post-EPS missions, such latency requirements are defined at mission product level as the maximum delay between relevant observation and product delivery at the user interface. In case of data from sources other than the Post-EPS missions, the latency requirements can only concern the processes, from ingestion to delivery, under the control of the Near Real-Time Data Distribution.

The Near Real-Time Data Distribution service should be available to as many users as possible, depending on actual geographical coverage, beyond a minimum that shall include the sites of all NMSs, SAFs and ECMWF.

Reference is made to [AD.5] for requirements on generic external interfaces of the Post-EPS system which are applicable to the interfaces of this service.

MRD_USR.140

The Near Real-Time Data Distribution service shall be available to all NMSs, all SAFs, ECMWF and all other user types within the TBD geographical areas and equipped with the relevant interfaces.

MRD_USR.150

All mission products output by the Post-EPS missions shall be available for near real-time distribution.

MRD_USR.160

The Near Real-Time Data Distribution service shall deliver mission products from the Post-EPS missions at the relevant user interfaces within a maximum delay from time of observation of 2:15 (hours:min) as a threshold, and 30 min. as a breakthrough; the same requirement applies to Level 1 and Level 0 mission products.

The timeliness requirement is derived from the relevant requirements established in the AEG Position Papers [AD.3] on a by product basis, and in order to meet the timeliness of the products with the highest user priority and at the same time identified as primary objectives in this document. As a reference, the figures match the timeliness for temperature and humidity profiles in support of Global NWP; however the 6 hours threshold delay of these products is shortened to 2:15, this being already the timeliness of EPS Level 1 and, nearly, Level 2 data, and in order to satisfy additionally the threshold timeliness for Regional NWP of the same products and the timeliness of all Atmospheric Chemistry products. The objective end-to-end timeliness of 6 min. of above reference products is not retained considering that it would imply, among other challenges, a permanent link between satellite(s) and processing centre(s), the cost of which is assumed to be not affordable.

The figures proposed do not match the timeliness of a number of products in the Position Papers for the following reasons:

- Sounding/Winds products for Regional NWP with breakthrough of 0.25 hours; however the threshold figure would be met, and it is assumed that the application will be more served by the Direct Data Broadcast than Near Real Time Data Distribution service.
- Sounding/Winds products for NWC (down to 0.5 hours threshold, 0.25 breakthrough); however support to NWC is not a primary objective in the relevant MRD missions.
- Clouds/Precipitation products for NWC, Synoptic Meteorology and Regional NWP, e.g. Cloud Imagery with 0.5 hours threshold, 1 min. breakthrough and 30 sec. objective. It is noted that the position paper acknowledges (ref. §3.2) that "In the post-EPS context (near-polar orbit) global mission is a priority, as well as high latitude regional missions. Adopting this principle implies that those nowcasting applications which require very high time resolution (less than an hour) have been eliminated or rated low". It is further assumed that the applications of NWC, Synoptic Meteorology and Regional NWP will be more served by the Direct Data Broadcast than Near Real Time Data Distribution service. Moreover the above consideration on affordability applies to the breakthrough and objective values.
- Clouds/Precipitation products for Global NWP, e.g. Cloud Drop Effective Radius, with 2 hours threshold; however the breakthrough would be met.
- Clouds/Precipitation products for Hydrology, e.g. Precipitation Rate at Surface, with 0.25 hours threshold, 1 min. breakthrough and 30 sec. objective; however support to Hydrology is not a primary objective in the MRD.

An apportionment of the above timeliness requirement between the Space and Ground Segment is, indicatively and to be confirmed or updated on the basis of appropriate analysis and trade-offs, set as follows:

Threshold	Breakthrough	Applicable to
105 min.	20 min.	Space Segment (observation to downlink)
30 min.	10 min.	Ground segment (downlink to user interface)

105 min. exceeds the orbital period at the altitude of MetOp; under the assumption of a similar orbit this threshold value allows to accomplish the downlink of global data with one ground station. 20 min. is a similar fraction of the end-to-end timeliness of 30 min., acknowledging that the use of several ground stations and/or a relay satellite is implied to accomplish the downlink, coupled with a powerful Ground Segment for data processing and delivery.

MRD_USR.170

Mission products from non Post-EPS missions may have to be delivered through near real-time distribution.

MRD_USR.180

The Near Real-Time Data Distribution service shall deliver mission products from non Post-EPS missions at the relevant user interfaces within a given maximum delay from time of acquisition.

MRD_USR.190

The set of mission products to be actually distributed in near real-time shall be configurable out of the full set available for this service.

Note that availability requirements are given in [AD.5] which also concern product delivery by this service; the actual apportionment of availability between observation missions and user services will be the result of analysis and design trade-offs.

7.3.6 Archival and Retrieval

The Archival and Retrieval user service provides an archive for all Post-EPS mission products, a corresponding catalogue of products and means for retrieving them. The service may also be extended to mission products from sources other than the Post-EPS missions.

The Archival and Retrieval service is available to all Post-EPS users, however extent and level of service may differ depending on user type. A basic form of access to the catalogue shall be available on a free and unrestricted basis.

Reference is made to [AD.5] for requirements on generic external interfaces of the Post-EPS system which are applicable to the interfaces of this service.

It is assumed that the Internet and the World Wide Web (referred to as "Web" in the relevant requirements) will, in the relevant timeframe, still provide a popular, convenient, powerful and reliable infrastructure on which the user interface of the service can be largely based.

MRD_USR.200

The user interface of the Archival and Retrieval service shall be available on the Web.

MRD_USR.210

The Archival and Retrieval service shall have an interface with TBD communications networks, including the network of the Future WMO Information System (FWIS).

MRD_USR.220

The Archival and Retrieval service shall be available to all Post-EPS users equipped with the relevant interfaces.

MRD_USR.230

Browsing through the catalogue of the Archival and Retrieval service shall be available on the Web on a free and unrestricted basis.

MRD_USR.240

It shall be possible to archive all mission products generated by the Post-EPS missions.

MRD_USR.250

It shall be possible to archive mission products from the Reprocessing user service.

MRD_USR.260

It shall be possible to archive products generated outside Post-EPS missions.

MRD_USR.270

The set of mission products to be actually archived shall be configurable.

MRD_USR.280

The retention time of mission products in the archive shall be configurable; upon its expiry the relevant storage shall be released.

MRD_USR.290

Mission products generated by the Post-EPS missions shall be archived within 2 hours upon expiry of the relevant latency (i.e. latest 2 hours after the time by which they should be available at the user interface).

MRD_USR.300

Mission products generated outside Post-EPS missions shall be archived within 2 hours from the time of acquisition.

MRD_USR.310

A catalogue of all mission products archived shall be maintained, storing all relevant identification information including:

1. product type,
2. product identifier,
3. date and time of generation or acquisition,
4. geographical area covered,
5. source satellite,
6. source instrument and operating mode,
7. relevant product quality parameters.

MRD_USR.320

The catalogue shall be updated concurrently with any update of the archive.

MRD_USR.330

The catalogue shall have the capability of listing products stored outside of the Post-EPS system, storing similar identification data as with archived products and the identification of the location from where the products can be retrieved.

MRD_USR.340

The Archival and Retrieval service shall provide the capability to derive from the mission products additional data sets (as defined above).

MRD_USR.350

The Archival and Retrieval service shall provide the capability to convert the mission products and additional data sets into the following formats:

TBD (this will be specified in more detail in subsequent phases, including the extent to which the requirement on preservation of the information content is still applicable in this case).

MRD_USR.360

It shall be possible to browse through and query the catalogue using as a key any combination of the types of information stored in the catalogue and the options relevant to additional data sets and formats, obtaining the corresponding listing of available mission products, additional data sets and formats, and applicable fees.

MRD_USR.370

It shall be possible to retrieve mission products stored in the archive and additional data sets either interactively or by submission of an order for their periodic transmission to a pre-defined location on the Web or any network that the service has an interface with.

MRD_USR.380

It shall be possible to retrieve interactively mission products stored in the archive and additional data sets either by selection from a catalogue listing or by providing sufficient information to unambiguously identify the products.

MRD_USR.390

Browsing through the catalogue shall have interactive type response times (this will be specified in more detail in subsequent phases, however interactive type response times are meant to be within 1 second).

MRD_USR.400

The interfaces of the Archival and Retrieval service shall support large data throughputs (this will be specified in more detail in subsequent phases, also depending on actual product sizes and available technical solutions, using as a reference the performance of the Near Real-Time Data Distribution for mission products, adjusted accordingly for the cases of additional data sets and format conversion).

MRD_USR.410

The Archival and Retrieval service shall be usable until 10 years after the end of the operational life of the last Post-EPS satellite.

MRD_USR.420

The Archival and Retrieval service should follow the *Reference Model for an Open Archival Information System (OAIS)* of CCSDS [RD-6].

7.3.7 Reprocessing

The Reprocessing service provides the capability to generate or regenerate Post-EPS mission products from data stored within the Archival and Retrieval user service, therefore at any time after acquisition of the data, on availability of new or updated processing parameters, ancillary data or algorithms.

Although an infrastructure to provide the service must be foreseen as part of the Post-EPS system, activations of the service will be requested individually and handled on a case by case basis.

As specified in the Archival and Retrieval service, mission products from reprocessing can themselves be archived and therefore listed in the catalogue, and retrieved through the relevant facilities.

MRD_USR.430

It shall be possible to generate or regenerate Post-EPS mission products from data stored within the Archival and Retrieval service, using updated processing parameters, ancillary data or algorithms, providing distinct outputs and without affecting the generation of any other required mission product.

7.3.8 User Support

MRD_USR.440

The User Support service shall allow the registration of candidate users, subject to verification of the relevant conditions, in order for them to obtain access to the other services.

MRD_USR.450

The User Support service shall allow the editing and publication of user guides, newsletters and bulletin boards providing information on the Post-EPS missions, products, user services, including up-to-date operational status and planning information.

MRD_USR.460

The User Support service shall provide the capability to accept and respond to questions on the Post-EPS missions, system and services.

MRD_USR.470

The User Support service shall maintain and make available records of any fees incurred and paid by the users.

ANNEX I: LIST OF ACRONYMS

ACAP : Azimuthally Collapsed Antenna Pattern
AEG : Application Expert Group
AMDAR : Aircraft Meteorological Data Relay
AOT : Aerosol Optical Thickness
ASAP : Automated Shipboard Aerological Programme
AVHRR : Advanced Very High Resolution Radiometer

CAL : Calibration
CBA : Cost Benefit Analysis
CCSDS : Consultative Committee for Space Data Systems
CEOS : Committee on Earth Observation Satellites
CGMS : Coordination Group for Meteorological Satellites
CLS : Collecte Localisation Satellites
CMV : Cloud Motion Vectors
COSMIC : Constellation Observing System for Meteorology
COSPAS- : Cosmicheskaya Sistyema Poiska Avariynich Sudov-
-SARSAT : -International Satellite System For Search and Rescue
CPR : Cloud and Prewcipitation Profiling Radar

DCAPE : Downdraught Convective Available Potential Energy
DCS : Data Collection System
DCP : Data Collection Platforms
DCPC : *WMO Information System:* Data Collection or Product Centre
DE : Detection Efficiency
DVR : Dual View Radiometer

ECMWF : European Centre for Medium-Range Weather Forecasts
ECSS : European Cooperation for Space Standardization
EMC : Electromagnetic Compatibility
EOS : Earth Observing System
EPS : EUMETSAT Polar System
ESA : European Space Agency
EUMETSAT : European Organisation for the Exploitation of Meteorological Satellites
EURD : End Users Requirements Document
E/W : East/West

FAR : False Alarm Rate
FOR : Field of Regard
FT : Free Troposphere
FWHM : Full-Width at Half-Maximum
FWIS : Future WMO Information System

GCOS : Global Climate Observing System
GEO : Geosynchronous Earth Orbit
GERB : Geostationary Earth Radiation Budget instrument
GISC : *WMO Information System*: Global Information System Centre
GMES : Global Monitoring for Environment and Security

GMS : *Japanese* Geostationary Meteorological Satellite
GNSS : Global Navigation Satellite System
GOOS : Global Ocean Observing System
GOS : Global Observing System
GTOS : Global Terrestrial Observing Systems
GTS : Global Telecommunication System

HIRLAM : High Resolution Local Area Model
HR : Hit Rate

IADC : Inter-Agency Space Debris Coordination Committee
IDCS : International Data Collection System
IE : Integrated Energy
IFOV : Instantaneous Field of View
IGOS : Integrated Global Observing Strategy
IJPS : Initial Joint Polar System
INR: Image Navigation and Registration
IOC : Intergovernmental Oceanographic Commission (UNESCO)
JPS : Joint Polar System
IR : Infrared
IRS : Infrared Sounding mission
ISRF : Instrument Spectral Response Function
JTA : Joint Transition Agreement
ITU : International Telecommunications Union

LAC : Limited Area Coverage
LEO : Low Earth Orbit
LI : Lightning Imagery Mission
LOS : Line Of Sight
LS : Lower Stratosphere
LST : Land Surface Temperature
LT : Lower Troposphere

MAR : Mesoscale Area Region
MATER : Mission Assumption and Technical Requirements
MDR : Mission Definition Review
MDT : Mean Down Time
MFV : Meteosat Field of View
MODIS : Moderate Resolution Imaging Spectro-radiometer
MSG : Meteosat Second Generation
MRD : Mission Requirements Document
MTBDE : Mean Time Between Downing Events
MTG : Metosat Third Generation
MWI : MicroWave Imager
MWS : MicroWave Sounder

NC : *WMO Information System:* National Centre
NEDN : Noise Equivalent Differential Radiance
NEDT : Noise Equivalent Differential Temperature
NIR: Near-InfraRed

NMS : National Meteorological Services
NOAA : National Oceanic and Atmospheric Administration
NPOESS : National Polar-orbiting Operational Satellite System
NPP : NPOESS Preparatory Programme
NWC : Nowcasting
NWP : Numerical Weather Prediction
N/A : Not Applicable
N/S : North/South

OAIS : Open Archival Information System (CCSDS Std)
OCI : Ocean Colour Imager
OPD : Optical Path Difference

PAN : Peroxy Acetyl Nitrate
PARD : Programmatic Assumptions and Requirements Document
PBL : Planetary Boundary Layer
PMET : Post-EPS Mission Experts Team
PSF : Point Spread Function

QOS : Quality of Service

RDCS : Regional Data Collection System
RER : Radiant Energy Radiometer
RMS : Root Mean Square
RMDCN : Regional Meteorological Data Communication Network
ROI : Region of Interest
RSE : Remote Sensing Expert
RTM : Radiative Transfer Model

SAF : Satellite Application Facilities
SCA : Scatterometer
SEVIRI : Spinning Enhanced Visible and Infrared Imager
SOG : Statement of Guidance
SRD : System Requirements Document
SSA : Aerosol Single Scattering Albedo
SSD : Spatial Sampling Distance
SST : Sea Surface Temperature
STD : Standard
SWIR : Short Wave Infrared

TBC : To Be Confirmed
TBD : To Be Defined
TBR : To be Reviewed/Revised
TBS : To Be Specified
TDI : Time Delay Integration
TIR : Thermal InfraRed
TOA : Top of the Atmosphere

UNCOPUOS : United Nations Committee on the Peaceful Use of Outer Space
UTC : Universal Time Coordinated

UV : Ultra-Violet

VII : Visible/Infrared Imager
VIS : Visible
VSRF : Very Short Range Forecast

WMO : World Meteorological Organisation
WWW : World Weather Watch