# Sounding Requirements for the Future EUMETSAT Polar System

**Peter Schlüssel[1], Christophe Accadia[1], Rosemary Munro[1], Pepe Phillips[1], Ad Stoffelen[2]**

*[1]EUMETSAT, Eumetsat-Allee 1, 64295 Darmstadt, Germany*
*[2]KNMI, Postbus 201, 3730 AE de Bilt, The Netherlands*

**ABSTRACT**

The future EUMETSAT Polar System (EPS), to be operational in 2020, will be a mandatory EUMETSAT programme in support of operational meteorology, climate monitoring and environmental services, such as atmospheric chemistry, operational oceanography, and land surface interactions at large scale. User requirements in terms of geophysical parameters to be measured have been gathered in an extended user consultation process. From these, a number of observation missions have been identified and their requirements specified in terms of radiometric, spectral, and geometric requirements. Atmospheric sounding missions required for Post-EPS cover infrared and microwave sounding, radio occultation measurements, sounding of backscattered solar radiation from the ultra-violet to the shortwave infrared as well as Doppler wind profiling.

## 1. RATIONALE

The current EUMETSAT Polar System (EPS) has been set up as part of the Initial Joint Polar System together with the U.S. National Oceanic and Atmospheric Administration (NOAA). A series of three Metop satellites will be launched in the frame of EPS to provide measurements supporting operational meteorology, climate monitoring, atmospheric chemistry, and oceanography with observations from a Sun-synchronous low-Earth polar orbit with a 09:30 local time of its equator crossings. The EPS will nominally provide measurements until 2020. It has to be succeeded by a new, advanced system, integrated into a Joint Polar System (JPS), which responds to user needs spanning the time period up to 2035.

The EPS follow-on programme, currently labelled Post-EPS, is being defined on the basis of an extensive user consultation process with a subsequent derivation of observation requirements for not less than twenty observation missions.

## 2. USER NEEDS

Starting with the outcome of the user consultation for the Meteosat Third Generation (MTG) [1-3] a further assessment was carried out, driven by Application Experts Groups (AEG). Beyond the MTG requirements Post-EPS has to acknowledge user needs for observations in polar regions. Five AEGs have been set up to provide position papers [4-8] expressing user needs for

- Atmospheric sounding and wind profiling,
- Cloud, precipitation and large-scale land surface imaging,
- Atmospheric chemistry,
- Ocean surface topography,
- Ocean imaging including scatterometry,
- Climate monitoring.

The user needs expressed in the position papers cover a range of user applications: global and regional numerical weather prediction, nowcasting, atmospheric chemistry, operational oceanography, hydrology, and climate monitoring. The requirements are given in terms of accuracy, spatial resolution, timeliness for numerous geophysical parameters. All requirements have been prioritised based on the importance of the observables for the intended applications and the number of beneficiary user groups. They are given in ranges spanning threshold, breakthrough and objective requirements. The threshold value indicates the quality below which the measured variable will be no longer useful for the considered application. The breakthrough level is the quality level at which the measured data are expected to make a delta improvement in the targeted service. The objective is the level, above which no further benefits to the user will be achieved.

The position papers have been adopted by EUMETSAT as requirements basis to derive observation mission requirements for Post-EPS.

## 3. OBSERVATION REQUIREMENTS

Based on the user requirements a number of prioritised observation missions have been identified as listed in Table 1 [9]. Their ranking is based on their importance for the various application areas, but also includes the aspects of continuity with EPS and potential data gaps in the Post-EPS time frame. The purpose of the ranking is to aid the concept studies in preparation of a Post-EPS programme. However, an approach is taken to foresee the implementation of as many requirements as possible and not to focus on the implementation of few very sophisticated instruments. Concepts of four missions dedicated to atmospheric sounding are currently studied for possible implementation in Post-EPS: High-resolution Infrared Sounding (IRS), Microwave sounding (MWS), Radio Occultation (RO), and Nadir viewing UV/VIS/NIR – SWIR Sounding (UVNS). Other missions such as the Doppler Wind Lidar (DWL) and the Differential Absorption Lidar (DIA) await experimental demonstration before further consideration in the frame of Post-EPS.

*© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2*
*Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna*

The observation missions are specified in terms of radiometric, spectral, and geometric requirements in the Post-EPS Mission Requirement document (MRD) [9]. Where applicable they are given in ranges bound by threshold and objective values and further qualified by breakthrough steps.

### 3.1 High-Resolution Infrared Sounding

The primary objective of the IRS is to support Numerical Weather Prediction (NWP) at regional and global scales, through the provision of atmospheric temperature and water vapour profiles at high vertical resolution in clear and partly cloudy air, surface temperature over sea, ice and land surfaces, cloud parameters, and a number of atmospheric trace gases such as ozone, carbon monoxide, methane, nitric acid, and nitrous oxide. Secondary objectives include the support of pollution monitoring and air quality assessment at global and regional scales with further trace gas measurements and the assessment of composition-climate interactions. The IRS concept is a nadir-viewing cross-track scanning infrared sounder operating in a step-and-stare mode following the heritage of the IASI (Infrared Atmospheric Sounding Interferometer) which is flown on the Metop satellites. On-ground spatial sample sizes of 5 to 12 km at sampling distances of 10 to 50 km are required for the IRS mission. The spectral coverage foreseen is contiguous between 3.62 and 15.5 μm. The spectral sampling at breakthrough levels varies according to supported applications. While NWP requirements are satisfied with resolutions between 0.25 and 0.3 $cm^{-1}$ the atmospheric chemistry applications demand 0.15 to 0.2 $cm^{-1}$. The radiometric accuracy, expressed in brightness temperature at a reference temperature of 280 K, has to meet a 0.5 K threshold. The sensitivity requirement varies with the targeted product and has to perform as low as 0.3 K for temperature sounding in the 15 μm $CO_2$ band, 0.075 K for water-vapour sounding in the respective absorption band at 6.3 μm and 0.1 – 0.2 K for the trace gas measurements. Radiometric homogeneity between different spatial or spectral samples is to be met within 0.1 K. In support of climate monitoring the orbit and lifetime stability of the measurements need to meet the 0.1 K level.

*Table 1: Ranked Post-EPS observation missions*

| Mission | Rank |
|---|---|
| High-resolution Infrared Sounding (IRS) | Very High |
| Microwave Sounding (MWS) | Very High |
| Visible/Infrared Imaging (VII) | Very High |
| Scatterometry (SCA) | Very High |
| Radio Occultation Sounding (RO) | High |
| Nadir-viewing UVNS Sounding (UVNS) | Medium |
| Doppler Wind Lidar (DWL) | Medium |
| Multi-viewing Multi-channel Multi-polarisation Imaging (3MI) | Medium |
| Limb Infrared Sounding (LIR) | Medium |
| Millimetre Wave Sounding (MMS) | Medium |
| Cloud and Precipitation profiling Radar (CPR) | Medium |
| Microwave Imaging – Cloud (MWI-C) | Medium |
| Microwave Imaging – Precipitation (MWI-P) | Low |
| Microwave Imaging – Ocean and Land (MWI-OL) | Low |
| Radar Altimetry (ALT) | Low |
| Dual View radiometry (DVR) | Low |
| Radiant Energy Radiometry (RER) | Low |
| Ocean Colour Imaging (OCI) | Low |
| Total Solar Irradiance Monitoring (TSI) | Low |
| Aerosol Profiling Lidar (APL) | Low |
| Differential Absorption Lidar (DWL) | Low |

### 3.2 Microwave Sounding

Following the heritage of the cross-track microwave sounders AMSU-A (Advanced Microwave Sounding Unit A) and MHS (Microwave Humidity Sounder), being flown on Metop and NOAA spacecraft, the Microwave Sounding mission has the primary objective to measure temperature and water vapour profiles in all-weather conditions in support of regional and global NWP. Furthermore, MWS will provide cloud liquid water columns (droplet size < 100 μm). The MWS will also contribute to Nowcasting and very short-range weather forecasts through the monitoring of instability and cloud microphysical structure aiding the early warning of convective intensity and risks by downburst and severe outflow gusts. Requiring almost complete global coverage within a day the MWS mission will consist of the nadir-viewing cross-track or conical scanner with a wide swath. The footprint sizes at 3 dB range from 40 km for the low-frequency channels to 15 km at the higher-frequency ones. The frequency domain covered by MWS ranges from 23.8 to 229 GHz in 34 spectral channels, including temperature sounding channels between 52.8 and 57.29 GHz as well as near 118.75 GHz, water-vapour sounding channels near 23.8 and 183.31 GHz, and window channels at 31.4, 50.3, 89, 166, and 229 GHz. The radiometric accuracy has to meet the 0.5 K level for all channels while the required noise performance depends on the respective channel bandwidths, ranging from 0.15 K at lowest frequency to 2.45 K in the narrowest temperature sounding channel near 118 GHz. The radiometric homogeneity among spatial or spectral samples is expected to be within the 0.2 K level. As for the IRS, support to climate monitoring will require meeting the orbit and lifetime stability at stringent levels of 0.2 K.

### 3.3 Radio Occultation Sounding

The RO main mission objective is to provide measurements of bending angles and refractivity profiles in the troposphere and lower stratosphere with high vertical resolution. From the refractivity profiles temperature and water vapour profiles can be derived at coarse horizontal resolution but with high vertical resolution. The heritage mission is the GRAS (GNSS Receiver for Atmospheric Sounding) instrument that is flown on the Metop satellites. Main applications to be supported are NWP and climate monitoring. The RO

mission is required to receive and use signals from the GPS, Galileo and GLONASSsystems in order to provide from a minimum of 1000 (threshold) up to 4000 (breakthrough) radio-occultation measurements per day. At least two frequencies shall be processed; a third frequency is preferred to improve ionospheric corrections. The bending-angle accuracy must achieve the 1 µrad or 0.4% level, whichever is larger.

### 3.4 Nadir-Viewing UVNS Sounding

The nadir-viewing Ultraviolet / Visible / Near-infrared / Shortwave infrared (UVNS) sounding mission is dedicated to the monitoring of stratospheric ozone and supports the application areas of air quality and composition-climate interactions. The UVNS has its heritage in GOME-2 (Global Ozone Monitoring Experiment 2) which is embarked on the Metop satellites. Target products to be measured with highest priority are ozone profile and total column, columnar amounts of sulphur dioxide, nitrogen dioxide, water vapour, carbon monoxide, and methane as well as aerosol optical depth of deep layers. Some of these products, such as CO, $CH_4$, but also $CO_2$ will require synergetic use of UVNS and IRS measurements to be derived with good accuracy. The UVNS needs to be implemented with a wide swath to maximise the coverage. The required ground pixel size is 5 to 20 km with a breakthrough value of 10 km. The mission covers 15 spectral bands, ranging from 0.27 to 2.4 µm, with a spectral resolution of 0.2 to 0.5 nm in the ultraviolet and visible region and enhanced resolution of 0.05 to 0.25 nm in the near and short-wave infrared spectrum. Spectral over-sampling factors of 2 to 6, depending on spectral region are foreseen. The radiometric requirements in terms of signal to noise ratios are 50 to 650 in high-latitude dark cases and reach 100 to 1500 in tropical dark cases, with lower values in the ultraviolet and higher ones in the near- and shortwave infrared. The radiometric accuracy demanded is 1-2%. Mission requirements for the UVNS are closely harmonised with that of the GMES (Global Monitoring for Environment and Security) Sentinel 5 (S-5), so that a joint implementation is foreseen, i.e. the corresponding S-5 component will be embarked on the Post-EPS satellites.

### 3.5 Cloud and Aerosol Imagery

Besides the already mentioned synergetic use or IRS and UVNS for trace gas measurements, both observation missions need to be synchronised with a medium-resolution (~1 km) multi-spectral imager to support cloud and aerosol detection within the sounders' fields of view. Soundings in the optical spectrum are strongly perturbed by clouds, so that a cloud detection and characterisation is mandatory prior to the retrieval of temperature or constituent profiles. Also atmospheric aerosol loadings may perturb the soundings, so that the corresponding impact has to be taken into account for reliable profile retrievals. Spatial and temporal variability of clouds and aerosols make it necessary to combine the imager with both optical sounders on the same satellite platform.

## 4. Data Processing and Delivery

The Post-EPS programme will support operational users, and therefore it is of utmost importance that the measured data are processed and expedited to the users in near real time. In particular the applications within the operational meteorology have very stringent timeliness requirements. These require support by so-called direct broadcast and near-real-time (NRT) services.

Nowcasting, including very short-range weather forecast, requires the regional data to be down-linked to local reception stations immediately after the respective measurements. This direct broadcast does not allow any centralised data processing; instead the users facilitate the geolocation and calibration under their own responsibility so that the processed data can be used within minutes after the respective measurements. As timeliness requirements for NWP become more stringent, this form of data broadcast is increasingly used by NWP applications as well. In particular the regional NWP requests data within 20 to 30 minutes of their measurements.

For global NRT users, the data will be collected onboard the satellite and down-linked once or more to central reception stations. The product processing will take place centrally and processed products will be distributed to global users. Level 1 mission products (calibrated and geolocated measurements) that serve global users need to reach the user within 60 to 70 minutes after the respective measurements.

Other user without NRT requirements will receive the data via an archival and retrieval facility that hosts all raw and processed data throughout the mission lifetime.

## 5. NEXT STEPS

Initial concepts for the Post-EPS sounding missions have been elaborated by ESA-led industrial studies. Consequently, the requirements can be consolidated in a Mission Definition Review by end of 2009. More detailed feasibility studies at Phase A will follow for a selected set of instrument and system concepts in 2010. In parallel, end user requirements will be derived for the different observation missions which will be the basis for a Post-EPS programme proposal to the EUMETSAT member states.

## REFERENCES

[1] Golding, B. W., S. Senesi, K. Browning, B. Bizzarri, W. Benesch, D. Rosenfeld, V. Levizzani, H. Roesli, U. Platt, T. E. Nordeng, J. T. Carmona, P. Ambrosetti, P. Pagano, M. Kurz, 2003: EUMETSAT position paper on observation requirements for nowcasting and very short range forecasting in 2015-2025, http://www.eumetsat.int/groups/pps/documents/document/pdf_mtg_aeg_nwc_positionpaper.pdf.

[2] Gustafsson, N., M. Capaldo, B. Orfila Estrada, J. Quiby, 2001: Position paper - requirements of observations for regional NWP, http://www.eumetsat.int/groups/pps/docments/document/pdf_mtg_aeg_nwp_regional.pdf

[3] Eyre, J. J.-N. Thépaut, J. Joiner, L. P. Riishojgaard, F. Gérard, 2002: position paper: requirements for observations for global NWP, http://www.eumetsat.int/groups/pps/documents/document/pdf_mtg_aeg_global.pdf.

[4] Stoffelen, A., M. Bonavita, J. Eyre, M. Goldberg, H. Järvinen, C. Serio, J.-N. Thépaut, V. Wulfmeyer, 2006: Position paper - Post-EPS developments on atmospheric sounding and wind profiling, http://www.eumetsat.int/groups/pps/documents/document/005464.pdf.

[5] Rizzi, R., P. Bauer, S. Crewell, M. Leroy, C. Mätzler, W. P. Menzel, B. Ritter, J. E. Russell, A. Thoss, 2006: Position paper – cloud, precipitation and large scale land surface imaging (CPL) observational requirements for meteorology, hydrology, and climate, http://www.eumetsat.int/groups/pps/documents/document/005466.pdf.

[6] Kelder, H., B. Kerridge, I. Isaksen, B. Carli, N. Harris, E. Hilsenrath, 2006: Position paper – requirements for operational atmospheric chemistry monitoring in the Post-EPS time frame beyond 2020, http://www.eumetsat.int/groups/pps/documents/document/005463.pdf.

[7] Stammer, D., J. Johannessen, P.-Y. LeTraon, P. Minnett, H. Roquet, M. Srokosz, 2006: Position paper: requirements for ocean observations relevant to post-EPS, http://www.eumetsat.int/groups/pps/documents/document/005467.pdf.

[8] Tett, S., J. Bates, R. Boers, A. Chédin, S. Dewitte, M. McCarthy, W. Thomas, 2006: Position paper – Post-EPS: generic requirements on climate monitoring, http://www.eumetsat.int/groups/pps/documents/document/005465.pdf.

[9] Schlüssel, P., C. Accadia, R. Munro, P. Phillips, S. Banfi, J. Wilson, 2009: Post-EPS Mission Requirements Document, http://www.eumetsat.int/groups/pps/documents/document/pdf_peps_mrd.pdf.