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The EPS/Metop System as a contribution to Operational Meteorology and Earth System Monitoring

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Abstract: **-** The EUMETSAT Polar System (EPS) is the European contribution to the joint European/US operational polar satellite system (Initial Joint Polar System (IJPS)). It covers the mid-morning (AM) orbit, whereas the US part continues to cover the afternoon (PM) orbit. The future EUMETSAT satellites of this new polar system are the METOP (METeorological OPerational Satellite) satellites, jointly developed with ESA. They will deliver high-resolution sounding and also high-resolution imagery in global coverage. Three METOP spacecraft are foreseen for a sun synchronous orbit in the 9:30 AM equator crossing (descending node). They will provide polar data from 2006 onwards. The EPS programme is planned to cover 14 years of operation. This paper will give an overview on the EPS mission and the products and services provided to users.

Key-Words: - Operational Meteorology, Initial Joint Polar System, Climate Monitoring, High Spectral Resolution Vertical Sounding, Temperature Sounding, Humidity Sounding, Trace gases Retrieval, IASI, ATOVS, GOME, ASCAT, GRAS, GPS

1 Introduction

The EUMETSAT Polar System (EPS) is the European contribution to the joint European/US operational polar satellite system (Initial Joint Polar System (IJPS)) [1],[2]]. It covers the mid-morning (AM) orbit, whereas the US part continues to cover the afternoon (PM) orbit. The EPS Programme comprises the space segment of three Metop satellites with associated launch services and a full ground segment. The space segment is developed in co-operation by EUMETSAT and the European Space Agency (ESA) (see e.g. [3], and also the French Centre National d'Etudes Spatiales (CNES). The launch of the first Metop satellite is planned in the second quarter of 2006.

The Metop-1 Programme includes the development of some payload components as the GOME-2 [4] (Global Ozone Monitoring Experiment), ASCAT [5] (Advanced Scatterometer) and the GRAS [6] (GPS Radio Occultation Sounder), which are in the heritage of successful research missions. Further components of the Metop payload are an AVHRR (Advanced Very High Resolution Radiometer), and the Advanced TIROS (Television and Infrared Operational Satellite) Operational Vertical Sounder (ATOVS) package, composed of HIRS-4 (High Resolution Infrared Radiation Sounder), AMSU-A (Advanced Microwave Sounding Unit - A) and MHS (Microwave Humidity Sounder). MHS is an EUMETSAT development. It replaces the AMSU-B instrument in the ATOVS suite, while NOAA provides the ATOVS and AVHRR instruments. These instruments assure the continuity to the ATOVS suite flown on the NOAA-KLM satellites. The IASI instrument is new technology, developed by CNES and provides high spectral resolution sounding capabilities in the infrared [7].

All these components support operational meteorology and climate monitoring, and hence provide a contribution to Global Earth System Monitoring. This is assured through the mission duration of at least 14 years.

2 Mission Objectives

According to the EUMETSAT convention, the major mission objectives that EPS aims to fulfill are Operational Meteorology and Climate Monitoring. Polar orbiting meteorological satellites have many operational capabilities. Other capabilities have already been implemented at pre-operational level and are mature enough for a transition to operational service. Further promising capabilities have yet to be demonstrated or evaluated.

Operational meteorology covers a wide range of activities, related to the analysis and prediction of the changing weather elements in time. Many meteorological satellite missions are in operational status or have large pre-operational experience in Europe.

To help in the understanding of climate, and its change, Earth observations make an important contribution. Only operational satellites can provide the necessary long term monitoring capabilities and thus contribute to the detection and documentation of climate change. Many requirements for climate monitoring coincide with or overlap with the mission requirements for operational meteorology.

The scientific payload embarked on Metop aims to achieve the objectives outlined above. The mission objectives related to the payload are the following:

- **Advanced Very High Resolution Radiometer (AVHRR/3):** global visible, near infrared and infrared imagery of clouds, the ocean and land surface

- **High Resolution Infrared Radiation Sounder (HIRS/4):** measure the temperature and humidity of the global atmosphere in cloud-free or partly cloudy conditions (Metop-1 and -2 only)

- **Advanced Microwave Sounding Unit-A (AMSU-A):** measure the temperature of the global atmosphere in nearly all weather conditions

- **Microwave Humidity Sounder (MHS):** measure the humidity of the global atmosphere

- **Infrared Atmospheric Sounding Interferometer (IASI):** provide enhanced hyper spectral resolution atmospheric soundings of temperature, humidity, ozone and trace gases

- **GPS Receiver for Atmospheric Sounding (GRAS):** measure the temperature of the upper troposphere and in the stratosphere with high vertical resolution in all weather conditions and potentially measure humidity in the troposphere.

- **Advanced Scatterometer (ASCAT):** provide near-surface wind speed and direction over the global oceans

- **Global Ozone Monitoring Experiment-2 :** provide profiles of ozone and other atmospheric constituents

3 EPS Capabilities and Products

EPS capabilities include the operational sounding of temperature and humidity and associated by-products, measurement and monitoring of Ozone, Greenhouse and Trace gases, ocean surface observations, and land surface and ice observations.

3.1 Temperature and Moisture Sounding

Most of the payload on Metop contributes to the operational sounding of temperature and moisture: ATOVS and AVHRR provide continuity and commonality with the NOAA-satellites, IASI provides the required hyper spectral capability and GRAS makes use of radio occultation technology for sounding.

The suite of ATOVS instrument and the IASI instrument are used in a synergistic way. The AVHRR/3 imager supports them.

The ATOVS suite of instruments is composed of three passive sounding instruments comprising in total 40 channels in the infrared and microwave spectral regions:

- The High Resolution Infrared Radiation Sounder (HIRS/4) is a radiometer, which measures radiances at 19 infrared channels, and one additional channel in the visible;

- The Advanced Microwave Sounding Unit – A (AMSU-A) provides microwave atmospheric measurements in 15 channels for temperature sounding;

- The Microwave Humidity Sounder (MHS) provides atmospheric measurements in five microwave channels for humidity measurements. MHS is now flying successfully on NOAA-18 as the first component of the IJPS in space.

The Advanced Very High Resolution Radiometer is identical to the visible, and near infrared and infrared imager flown on the NOAA-KLM type satellites.

The Infrared Atmospheric Sounding Interferometer (IASI) [4] provides hyper spectral sounding resolution and high vertical resolution required by global NWP. It is a multi-purpose sounding instrument aimed at global measurement of temperature, water vapor, trace-gases such as ozone, nitrous oxide, carbon dioxide, and methane, as well as surface temperature, surface emissivity, and cloud characteristics. The underlying measurement principle is a Michelson Interferometer. The IASI instrument is designed to be the infrared sounder element of the next generation operational sounding system. IASI has 8461 spectral channels, aligned in three bands between 3.62 (corresponding to 2760 cm^{-1}), where solar backscatter begins to contribute, and 15.5 μm (645 cm^{-1}), covering the peak of the thermal infrared and particularly the intense CO_2 ν_2 band with Q-branch around 6666 cm-1. The line spacing in the 15 μm and 4.3 μm CO2 absorption bands drives the spectral resolution requirements. This spacing is equal to 1.5 cm^{-1} in most of the bands and to 0.75 cm^{-1} in some parts. The need to resolve CO_2 absorption bands requires a spectral resolution of 0.5 cm^{-1} after apodisation. Consequently the instrument was specified with a maximum optical path difference (OPD) of 2 cm leading to an unapodised resolution of 0.3 to 0.4 cm^{-1} and a spectral sampling interval of 0.25 cm^{-1}.

Included in the sounding instrument is an Integrated Imaging System (IIS). It consists of a broadband radiometer measuring between 10 and 12 μm with high spatial resolution to obtain detailed analysis of cloud properties inside the IASI sounder pixels. The IIS IFOV is defined by a squared area of 59.63 milliradians $\times$ 59.63 milliradians, covering 64$\times$64 pixels. The information of IIS is used during Level 1 processing for co-registration with AVHRR.

GRAS makes use of the GPS (Global Positioning System) constellation. This constellation consists of 24 satellites distributed in six orbital planes around the globe. An occultation occurs for GRAS, whenever a GPS satellite rises or sets and the ray path from its transmitter traverses the Earth's atmospheric limb. With 24 GPS satellites, a single GRAS instrument in near polar orbit at 824 km will observe over 500 occultations per day, distributed quite uniformly over the globe.

3.2 Ozone, Greenhouse and Trace Gases

The GOME-2 and IASI instruments will provide the capability to monitor the Ozone total column and profiles and the components related to the ozone chemistry in the atmosphere.

The GOME-2 instrument on Metop is a result of the experience gained over a number of years of operations and data analysis with the GOME-1 instrument on ERS-2 [8].

GOME-2 is a medium resolution UV-VIS spectrometer, fed by a scan mirror, which enables across track scanning in nadir, and also side view for polar coverage and instrument characterisation using the Moon as a source. In addition the scan mirror can be directed to internal calibration sources and to a diffuser plate for solar calibration measurements.

The instrument provides measurement data in four optical channels, which provide continuous spectral coverage between 240 and 790 nm, with a spectral resolution between 0.25 nm at 240 nm and 0.5 nm at 790 nm. The spectra are focused on linear detector arrays of 1024 pixels each. There are two Polarization Measurement Devices (PMDs), which measure linearly polarized intensity in two perpendicular directions. The PMDs have similar detector arrays.

A number of potential products are expected to be derived from GOME-2. The trace gases involved in the ozone chemistry are among them. It is expected that the vertical column amount BrO, OClO, NO_2, and SO_2 will be retrieved at an accuracy of better than 20 %. Ozone total column amount and Ozone profiles are expected to be retrieved with an accuracy better than 5 % and 15 % above 30 hPa and better than 50 % below 30 hPa respectively. The objective is 3 % for columns and 10 % accuracy for ozone profiles at all levels. Additionally it is expected that aerosol properties, as Absorbing Aerosol Indication (AAI), Aerosol Optical Depth (AOD) and Aerosol Type (desert dust, smoke and volcanic ash) can be derived. Finally clear sky and cloudy UV fields are expected to be derived.

It is expected that the retrieval of the trace gases like N_2O, CO and CH_4 is possible with IASI, using the spectral regions from 1210 – 1650 cm^{-1} (6.06 - 8.26 µm, CH_4, N_2O and SO_2 column amounts), 2100 – 2150 cm^{-1} (4.65 - 4.76 µm, CO column amount), 2150 – 2250 cm^{-1}(4.44 - 4.76 µm, N_2O and CO_2) and 2700 – 2760 cm^{-1} (3.62 – 3.7 µm, CH_4 column amount). With the IMG instrument on ADEOS some the capabilities to retrieve trace gases with high spectral resolution interferometers could be already demonstrated [9],[10]. There are indicators that the change of CO_2 could be monitored from IASI data [11].

3.3 Ocean Surface Observations

The use of AVHRR/3 measurements for the retrieval of Sea Surface Temperature (SST) has already a long heritage [12], [13]. The IASI instrument itself will also be capable to provide information on SST as well as contribute to the atmospheric correction necessary for the retrieval of SST with AVHRR. With the new channel 3a AVHRR will have improved capabilities to distinguish between sea ice and clouds. Furthermore the distinction of clouds at different levels can be performed better [14].

Further AVHRR capabilities include besides the cloud monitoring and analysis capabilities the retrieval of atmospheric aerosol.

The Advanced wind Scatterometer (ASCAT) is a real aperture, vertically polarized C-band radar with high radiometric stability. ASCAT is in heritage of the SCAT instrument on the ERS satellites and provides improved capability to measure near ocean surface winds.

ASCAT transmits long pulses at a carrier frequency of 5.225 GHz. The received echoes are demodulated and Fourier-transformed on board, resulting in a signal where the frequency components map to slant range. Onboard processed averaged raw echoes together with averaged noise measurements are sent to the ground.

Six antennas illuminate the surface sequentially. The backscatter signal is measured to determine the specific surface backscattering. Wind speed and direction are estimated using a model, which relates them to the normalised radar backscattering cross section (σ^0).

The data are collected from three azimuth angles (45, 90 and 145 °) across both of the 550-km wide swaths on both sides of the nadir track.

The ASCAT design aims at providing ocean surface winds at 50 km resolution over a 25 x 25 km^2 grid along and across both swaths. In addition a high-resolution wind product is generated at 25-km horizontal resolution, using a 12.5 x 12.5 km^2 grid. On the ground ASCAT source packets are processed to obtain normalised backscatter measurements at these spatial resolutions, resulting in 21 nodes per swath (42 in total) for the 50-km resolution winds, and 42 nodes per swath (84 in total) for the 25-km resolution winds. The aim is to measure the ocean wind field at the ocean surface in the range of 4 to 24 m/s with an accuracy of 3 m/s vector RMS.

Further potential of ASCAT lies in the measurement of sea ice boundaries and sea ice concentration and type (e.g. [15]). Other emerging applications are related to land surface observations.

3.4 Land Surface and Ice Observations

Land surface applications are supported with AVHRR for a long time. These include Normalized Differential Vegetation Index (e.g. [16]), desertification monitoring, fire detection, snow cover monitoring. The 1.6µm channel added further capabilities, in ice/cloud distinction and also in fire detection. Further applications include evapo-transpiration retrieval and crop monitoring.

Numerous scatterometer applications over land have been shown using of SCAT data from the ERS satellites [17], see also summary in [18]. New methods for the retrieval of soil moisture [19] will be exploited operationally in the EPS Ground Segment to provide information for NWP in near real time. Further applications, which ASCAT may support, are monitoring of snow and ice coverage [20] and vegetation type and coverage [21]. With ASCAT these applications will be further developed towards operational use.

4 Summary and Conclusion

The EPS system assures on one hand the continuity to the current system through the continuation of the proven ATOVS instrument suite and the AVHRR imager. In addition highly innovative features will be implemented with the EPS system. They can be emphasised as follows:

- High level sounding performances will be provided and thus the enhanced data streams will be available which are needed to further improve the capabilities of advanced NPW systems;
- The multi-instrument capabilities assure a service which goes beyond operational meteorology and enables EUMETSAT to fulfil their commitments vis-à-vis climate monitoring and support to climate research;
- Instruments are embarked which build on the heritage of Earth observation missions. The ASCAT and GOME-2 instruments are introduced into an operational environment and represent EUMETSAT's commitment to provide Near Real Time (NRT) and off-line operational products from these instruments for a period of at least 14 years;
- GRAS is an alternative concept for retrieval of temperature, moisture and electron density with strong potential in climate monitoring. The radio occultation principle is introduced for the first time in an operational environment and will demonstrate the capability to provide high quality vertical soundings in near real time;
- The long mission duration of 14 years will assure that users are provided with long-term near real time and off-line data service for meteorological and in particular climate applications.

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