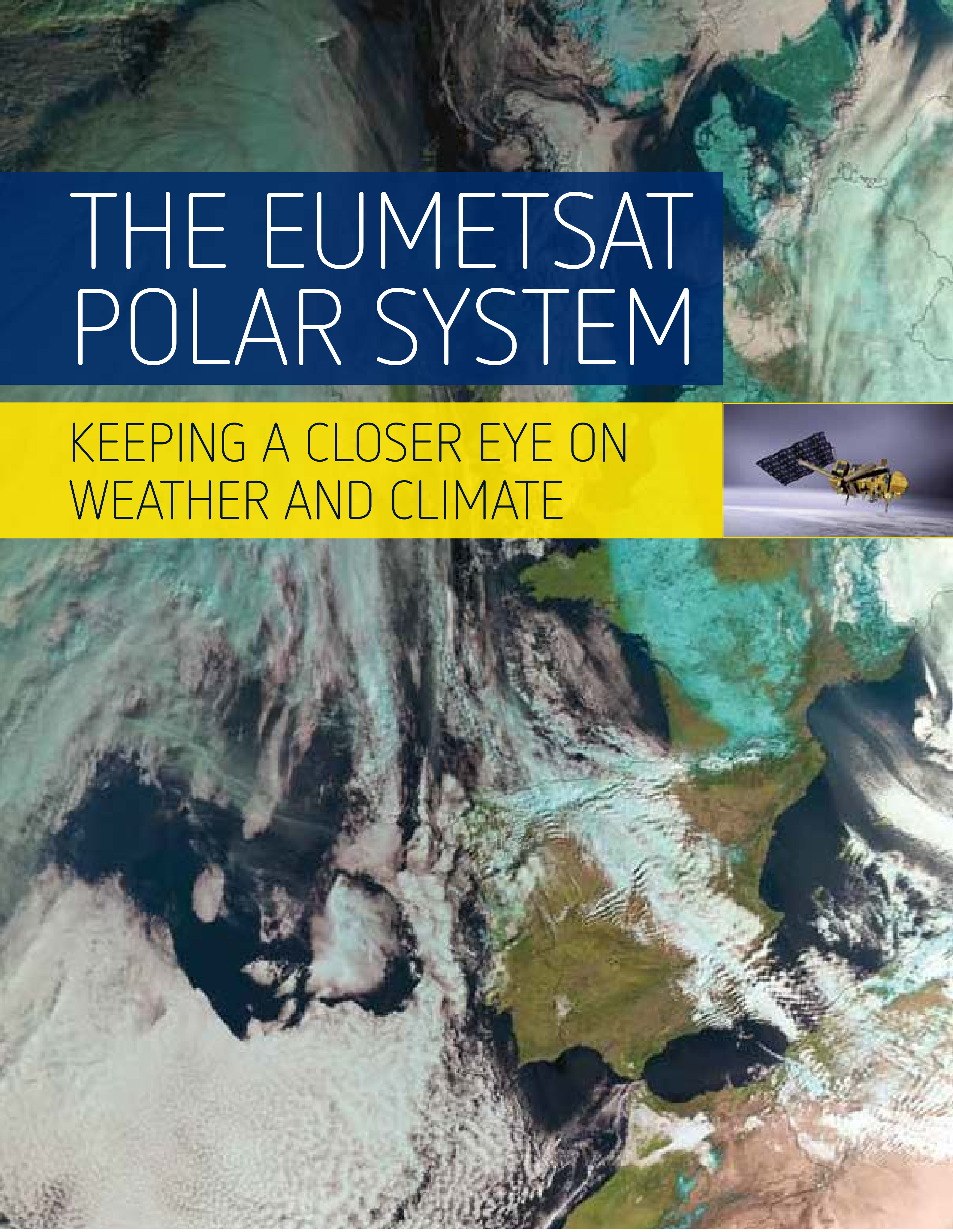


THE EUMETSAT POLAR SYSTEM

KEEPING A CLOSER EYE ON WEATHER AND CLIMATE

MONITORING WEATHER AND CLIMATE FROM SPACE

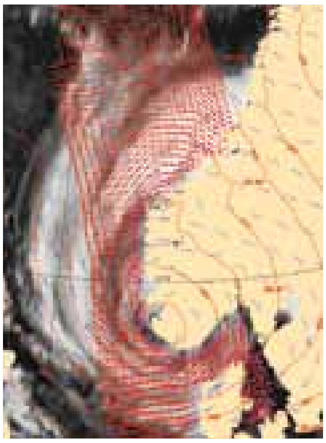
EUMETSAT

THE INCREASING NEED FOR WEATHER AND CLIMATE MONITORING

Extreme weather conditions pose major challenges for our increasingly vulnerable society.

FIG. 1

Wind vectors retrieved from ASCAT (red) superimposed with winds predicted by models (blue), 3 January 2012, 20:30 UTC (Source: KNMI, OSI-SAF)



Weather is a fact of life and accurate forecasts are a commodity that society cannot do without. In fact, there are increasing expectations by citizens and decision makers to receive timely warnings from National Meteorological Services to help save lives and reduce losses to property and infrastructure due to storms heavy precipitation, heat waves (e.g. the 2003 summer), tropical cyclones, as well as other hazards influenced by weather, like floods or dispersion of pollution (e.g. Fukushima in 2011).

The stakes are huge, if one considers that in the 32 Member States of the European Environment Agency (EEA), between 1998 and 2009, weather-related natural hazards caused the loss of close to 80,000 human lives and losses exceeding €120 billion.

Expectations will further grow in our increasingly vulnerable society, also with our changing climate resulting in more frequent severe weather events. 2010 was indeed among the six most costly years for insurance companies due to natural disasters worldwide, with 90% of the more than 950 of these disasters being weather-related , and recent years have seen major storms in Europe, with Erwin in 2005, Kyrill in 2007, Klaus in 2009, and Xynthia in 2010.

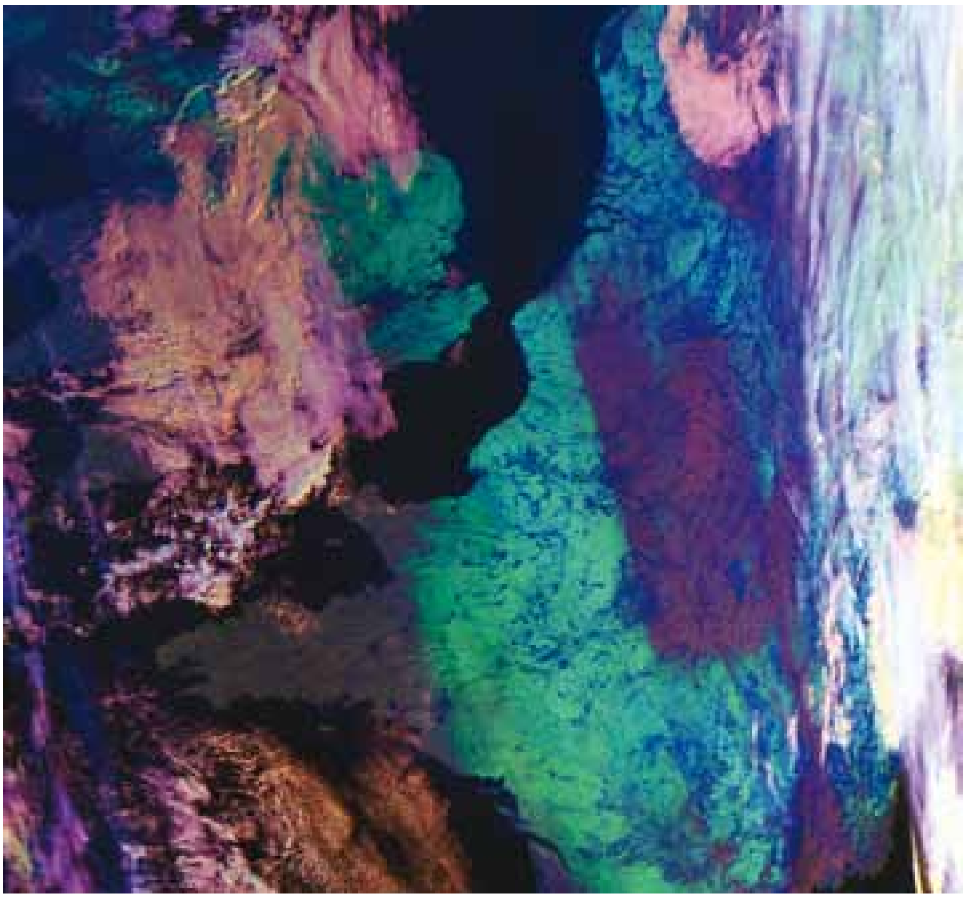


FIG. 2

View of snow cover over Europe (indicated by cyan colour) as seen by the AVHRR instrument on EUMETSAT's Metop-A polar-orbiting satellite, 7 February 2012, 10:31 UTC

The global economy is also becoming increasingly weather sensitive and requiring more accurate and timely forecasts. This is particularly true for energy, transportation, construction, tourism and agriculture. For instance, energy providers rely on weather forecasts to anticipate power demand and adapt production during both hot and cold spells. Likewise, forecasts of fog, snow, high winds, thunderstorms and weather-induced dispersion of ash particles are critical to aviation and air traffic management and hence to the global economy.

As accurate weather predictions need to start from the best possible estimate of the initial state of the atmosphere, it is crucial that meteorologists have up-to-date and global observations on what is happening in the Earth's atmosphere over land and oceans, and for this they rely on weather satellites. Satellite data are today an indispensable input for weather prediction models and forecast systems used to produce safety warnings and other information in support of public and private decision making.

FIG. 3

Ash radiance index image produced using data from the IASI instrument aboard EUMETSAT's Metop-A polar-orbiting satellite, shows the extent of the volcanic ash cloud from the crater beneath the Eyjafjallajökull glacier, 7 May 2010

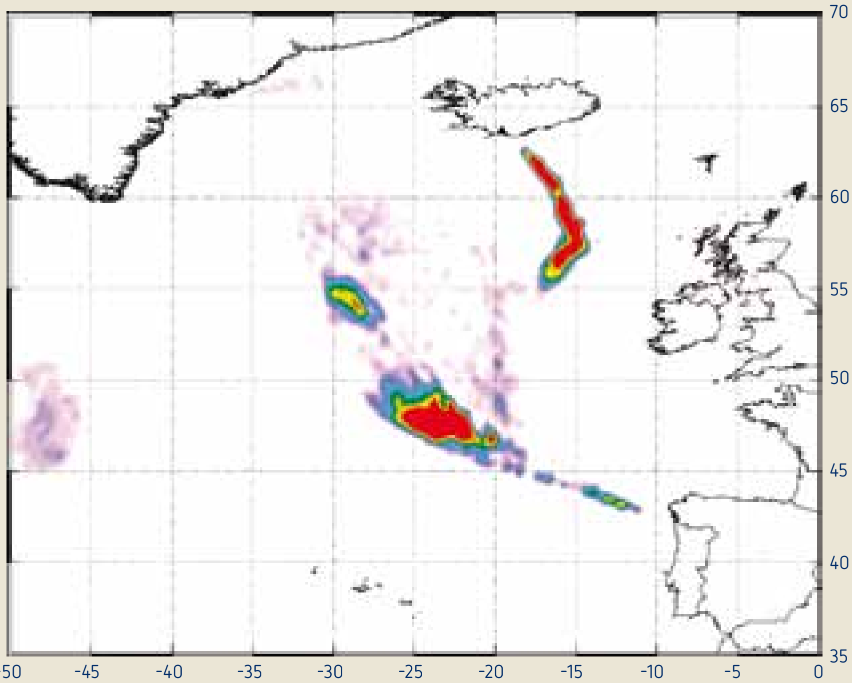


FIG. 4

Cyclone Giovanna approaching Madagascar, as seen by the AVHRR instrument on EUMETSAT's Metop-A satellite, 12 February 2012, 05:40 UTC

EPS: A GLOBAL AND CLOSER VIEW OF EARTH FROM POLAR ORBIT

While geostationary satellites like EUMETSAT's Meteosat provide vital imagery for forecasts of high impact weather ranging from minutes to a few hours, these satellites cannot deliver all the highly detailed and diverse observations required by meteorologists for short and medium range forecasts, owing to their positions high above the Earth.

Additionally, Meteosat only has around 33% of the Earth's surface in its field of view, which is not enough to cover the high latitudes of northern Europe and deliver the global view expected by climatologists for monitoring the changing climate of our planet.

A second system in lower Earth orbit is therefore required to complement the data from geostationary orbit and provide global coverage. This is the purpose of the EUMETSAT Polar System built around the Metop satellites.

The Metop satellites fly in polar orbit at an altitude of approximately 817 km (about 42 times closer to the Earth than a geostationary satellite), providing observations in considerably finer detail and giving access to a unique wealth of ocean, land and atmospheric parameters measured by microwave instruments that cannot be flown in the remote geostationary orbit.

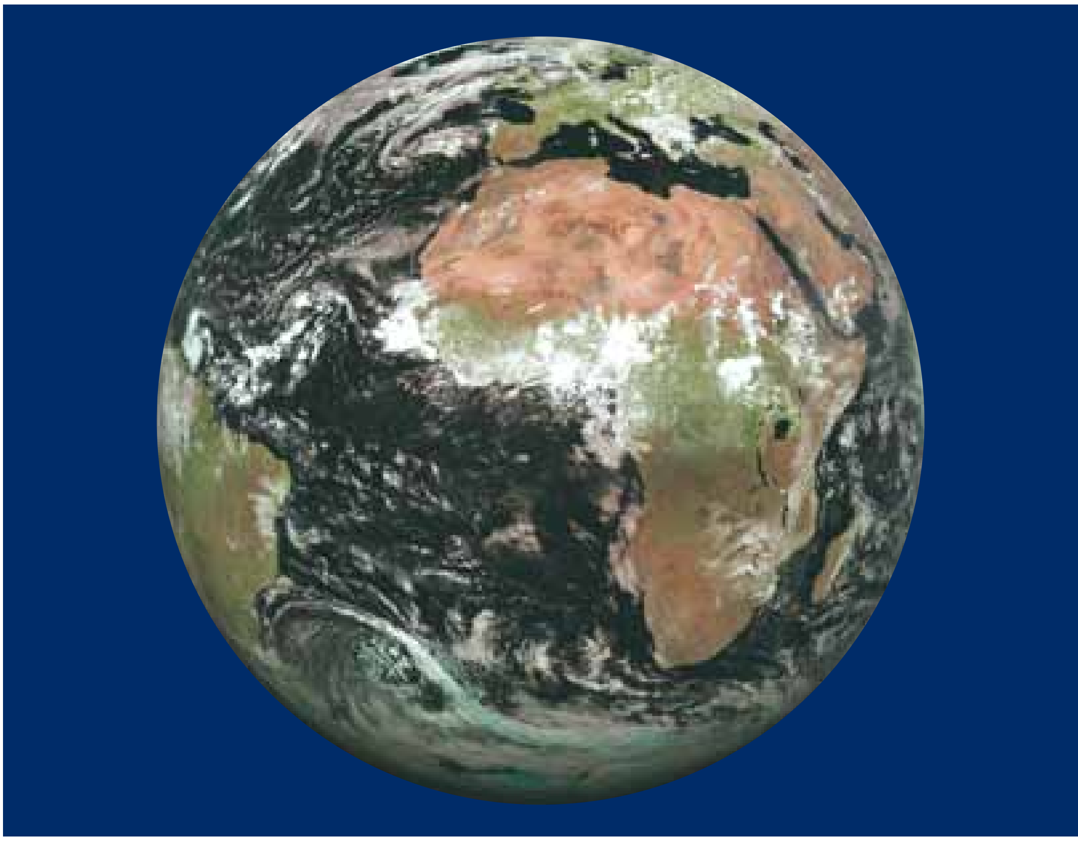
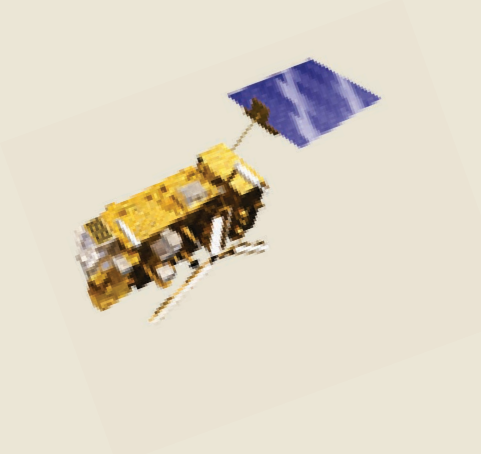


FIG. 5

Meteosat geostationary satellites only have 33% of the Earth's surface in its field of view (right), while Metop polar orbiting satellites provide global coverage (opposite page)



Launch of the Metop-A satellite from the Baikonur Cosmodrome in Kazakhstan, 19 October 2006

Metop satellites thus deliver a great variety of global measurements that are essential for weather forecasting up to 10 days and for climate monitoring. In addition, the availability of Metop data is a key source of real-time observations for Nowcasting severe weather – like the famous "polar lows" - at higher latitudes.

Metop-A, the first satellite of the EUMETSAT Polar System (EPS), was launched on 19 October 2006 from Baikonur, Kazakhstan. It will be followed by Metop-B in 2012, also to be launched from Baikonur, and Metop-C five years later from Kourou, providing coverage of the polar orbit until at least 2020.

THE EPS MISSIONS

The EPS missions serve the operational requirements of the meteorological and climate services of EUMETSAT's Member and Cooperating States and other users around the globe, as well as the World Meteorological Organization (WMO).

Dr. Bryan Conway
Manager
NWP SAF

"Probably the single biggest step to improving numerical weather prediction was the IASI instrument, which offered the unique capability for much finer and accurate operational sounding than ever before."

OPERATIONAL METEOROLOGY

Numerical Weather Prediction (NWP) is the basis of all modern global and regional weather forecasting, the data generated by the instruments carried by Metop satellites are ingested ("assimilated") by NWP models to compute forecasts up to 10 days ahead.

Measurements by infrared and microwave radiometers and sounders on board Metop provide NWP models with global three-dimensional information on the temperature and humidity of the atmosphere with a high vertical resolution. The Infrared Atmospheric Sounding Interferometer (IASI), for example, makes it possible to ascertain temperature and humidity profiles with an unprecedented accuracy of 1°C and 10% respectively, and a vertical resolution of a few kilometres in the lower troposphere, thus significantly increasing the quality and positive impact of the measurements injected into models. The models are further enhanced with the simultaneous measurements provided by the all-weather microwave instruments Advanced Microwave Sounding Unit-A (AMSU-A) and Microwave Humidity Sounder (MHS).

The Global Navigation Satellite System Receiver for Atmospheric Sounding (GRAS) instrument provides a new observation method relevant to weather forecasting and climate monitoring. It uses the radio signals continuously broadcast by the Global Positioning System (GPS) satellites orbiting the Earth to measure the time delay of the refracted GPS radio signals as the ray signal path skirts the Earth's atmosphere on its way from the transmitting GPS satellite to the GRAS receiver on Metop. This delay in the received signals is processed to obtain vertical profiles of atmospheric parameters, such as temperature and water vapour in the stratosphere and troposphere, providing over 500 precise atmospheric profiles per day. These profiles are injected into NWP models to improve the accuracy of weather forecasts.

The data collected by the GRAS instrument is further processed into products, such as near-real-time pressure, temperature and humidity profiles, by the Radio-Occultation Meteorology (ROM) Satellite Application Facility (SAF), hosted by the Danish Meteorological Institute (DMI).

The data from the Advanced SCATterometer (ASCAT) are processed by the Ocean and Sea Ice (OSI) SAF, led by Météo-France, to provide global ocean surface wind vectors that are necessary for the definition of atmospheric circulation over the ocean and in the tropics. The main applications of ASCAT winds have been NWP and marine meteorology. The NWP SAF hosted by the Met Office (UK) provides software packages for exploiting these and other invaluable Metop data to generate supporting data, validation products and a number of other services for use in NWP and atmospheric research. The scatterometer measurements are also used for the monitoring of sea ice, snow cover and land surface parameters such as soil moisture.

The Advanced Very High Resolution Radiometer (AVHRR) measures reflected solar energy and radiated thermal energy from land, sea, clouds and the atmosphere and is useful for a variety of applications, including cloud monitoring, determination of surface properties such as vegetation indices, snow cover, land surface temperature, sea surface temperature and sea ice concentration.

MONITORING CLIMATE AND THE ENVIRONMENT

All instruments on board Metop contribute to global climate monitoring and applications, helping scientists understand the complex interactions between the various factors that influence the Earth's climate. The satellites support the work of the United Nations Framework Convention on Climate Change (UNFCCC), WMO and Global Climate Observing System (GCOS) by monitoring a range of Essential Climate Variables, such as temperature, greenhouse gases, aerosol properties, sea ice and albedo.

In particular, IASI's ability to detect and measure trace and greenhouse gases has provided capabilities beyond expectations. Trace gases include carbon monoxide (CO), sulphur dioxide (SO_2) and ozone, to name a few. Of particular current environmental concern is the depletion of the atmosphere's protective ozone stratospheric layer, which is particularly noticeable over the Arctic and Antarctic regions. The resulting increased levels of ultraviolet radiation are having harmful effects on agriculture, forests and water ecosystems – and people.

The Global Ozone Monitoring Experiment-2 (GOME-2) measures ozone profiles, total columns of ozone and other atmospheric constituents like nitrogen dioxide (NO_2) and SO_2 in full synergy with IASI. The observed trace gases are related not only to the depletion of ozone in the stratosphere, but also to other sources like volcanic eruptions and biomass burning. Additionally, the long-term monitoring of the observed trace gases will provide more insight into the impact of man-made sources of pollution on the environment (including air quality) and the climate on both regional and global scales.

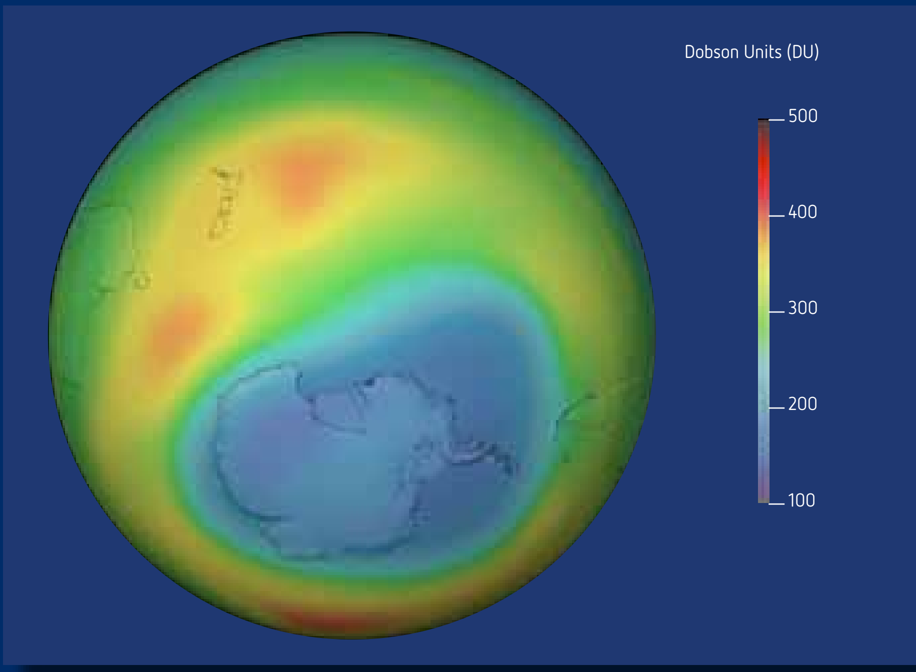


FIG. 6

Atmospheric data from GOME-2 measurements over the Antarctic showing the ozone hole. (Source: DLR, EUMETSAT)

Also very important is GOME-2's capacity to significantly extend the long time series of measurements already gathered by GOME-1, which will help continue the monitoring of ozone depletion.

Last but not least, due to the self-calibration capability of the GRAS instrument, its temperature profile measurements make a significant contribution to climate change monitoring.

All Metop data are processed on an operational basis, and products of climate-relevant parameters extracted at EUMETSAT headquarters and across the network of SAFs are stored by the EUMETSAT Data Centre. Over time, Metop satellites will provide the required long-term data sets from polar orbit that will deliver an even more significant contribution to climate monitoring activities.

A STRATEGIC BALANCED OPERATIONAL COOPERATION WITH THE USA

EUMETSAT and NOAA collaborate in the Initial Joint Polar System, comprising two polar-orbiting systems

By the early 1980s, the US National Oceanic and Atmospheric Administration (NOAA) was looking for a partner to ensure the continuation of the service until then delivered from its civilian weather satellites flying in low Earth orbit both in the morning and afternoon orbits. It was time for Europe to share this responsibility. In 1998, the Councils of EUMETSAT and the European Space Agency (ESA) first approved a plan to design, develop, launch and operate a polar satellite system for Europe for the morning orbit. Following this, EUMETSAT formally approved the EUMETSAT Polar System (EPS) programme in 1999.

In 1998, EUMETSAT and NOAA signed an agreement to collaborate in the Initial Joint Polar System (IJPS), comprising two polar-orbiting satellite systems and their respective ground segments, and forming one key component of the Global Observing System coordinated by the World Meteorological Organisation (WMO).

IJPS cooperation includes the exchange of instruments, such as – on the European side - the European MHS, which measures atmospheric water vapour on NOAA and EUMETSAT satellites, and the American AVHRR, AMSU-A and HIRS/4 instruments also flown on Metop. It involves operational cross-support, including since 2011 the capability to downlink Metop data twice per orbit, once at the US ground station in McMurdo, Antarctica, and once in Svalbard, thus improving timeliness of delivery to users by a factor of two. Through a further agreement, the Joint Transition Activities agreement signed in 2003, EUMETSAT and NOAA have agreed to provide an operational polar-orbiting service until at least 2020.

The Initial Joint Polar System signing ceremony in Washington, DC, United States, 19 November 1998

Erland Källén
Director of Research
ECMWF

"IJPS data play a critical role in maintaining the current rapid rate of improvement of our medium range numerical weather forecasts."

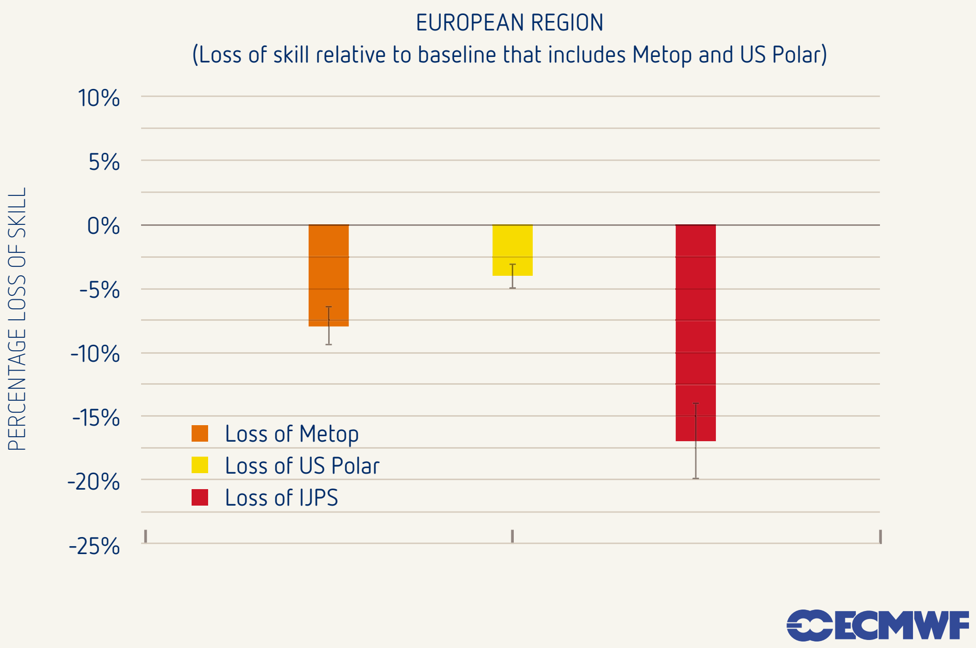


FIG. 7

Simulated loss of observations of polar orbiting satellites clearly shows that the positive impact of the IJPS on NWP forecasts is greater than the sum of the respective impact. (Source: ECMWF)

Studies by the European Centre for Medium range Forecasts (ECMWF) have shown that the positive impact of the full IJPS on the performance of NWP forecasts is more than the sum of the respective impact of EUMETSAT and NOAA satellites. Following the launch of a new generation US satellite in October 2011, the US Suomi National Polar Partnership (NPP) satellite, the IJPS now includes advanced satellites in both morning and afternoon orbits, with the perspective for enhanced impact on forecasts and enhanced benefits to the worldwide user community.

US ground station in McMurdo, Antarctica, where Metop data is downlinked during each orbit, improving the timeliness of delivery to users by a factor of two (Source: John R. Clarke, Ph. D.)

BENEFITS OF TAKING METEOROLOGY TO A NEW LEVEL

Since the launch of the first Metop satellite in October 2006, the benefits obtained from EPS have far surpassed all expectations as a result of its unique and innovative capabilities.

A recent study by the Met Office (UK) has demonstrated that Metop-A observations account for the greatest contribution to the performance of Day 1 NWP forecasts among the various data sources (in situ, airborne and space-based) ingested by advanced NWP models, at an estimated level close to 25%.

Metop data are now indispensable to NWP models providing the basic information used by National Meteorological Services to deliver forecasts, severe weather warnings and other support to public and private decision making.

Based on studies on the socio-economic benefits of weather forecasts, this positive impact is estimated to yield an annual benefit of EPS certainly in excess of €1.2 billion per year in the European Union, and more probably close to €5 billion per year.

More generally, the data gathered by Metop have revolutionised the way the Earth's weather, climate and environment are monitored, with further benefits to be expected from combined operations of Metop-A and Metop-B, starting in 2012, and from the results of ongoing research.

As far as global monitoring of climate is concerned, Metop-A has continued to collect decade-long data series on temperature, humidity, cloud cover and atmospheric composition required in this context. Moreover, EPS instruments deliver a wealth of environmental data that are already highly relevant. Among these are measurements of global ozone levels, air pollution and soil moisture, to name but a few examples.

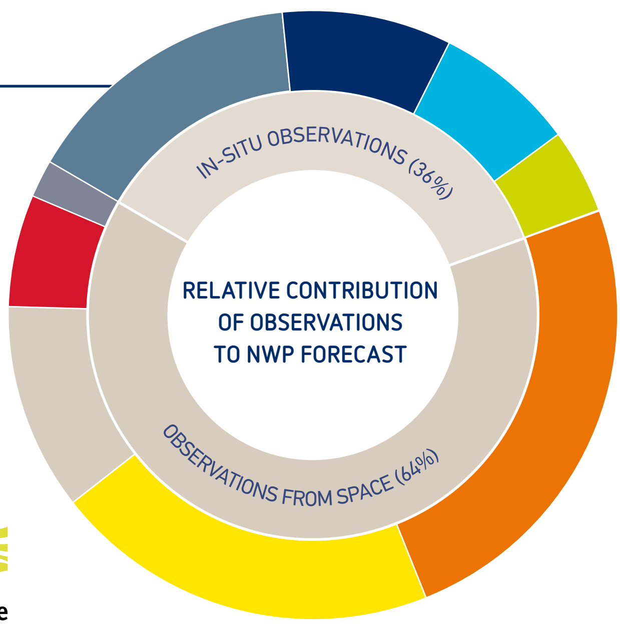
It is absolutely vital that these services continue into the future – and that they are further enhanced to meet future forecasting requirements. Not only is there a need for continuity for NWP purposes, but also for the resulting societal benefits of EPS and the strategically important cooperation with the United States. This continuity will be provided after 2020 by the future EPS-SG, whose new instruments will provide additional capabilities.

FIG. 8

Contribution of Metop data (24%), relative to other data sources, to Numerical Weather Prediction forecasts (Source: Met Office (UK))

OBSERVATIONS FROM SPACE
- **METOP** (24.5%)
- **NOAA** (20.5%)
- **OTHER LEO** (11.0%)
- **GEO** (6.0%)
- **OTHER RO** (2.0%)

IN-SITU OBSERVATIONS
- **"SONDE"** (15%)
- **AIRCRAFT** (9%)
- **SFC LAND** (7.5%)
- **SFC SEA** (4.5%)



Met Office

DEPLOYING AND OPERATING EPS: THE IMPERATIVE FOR CONTINUITY

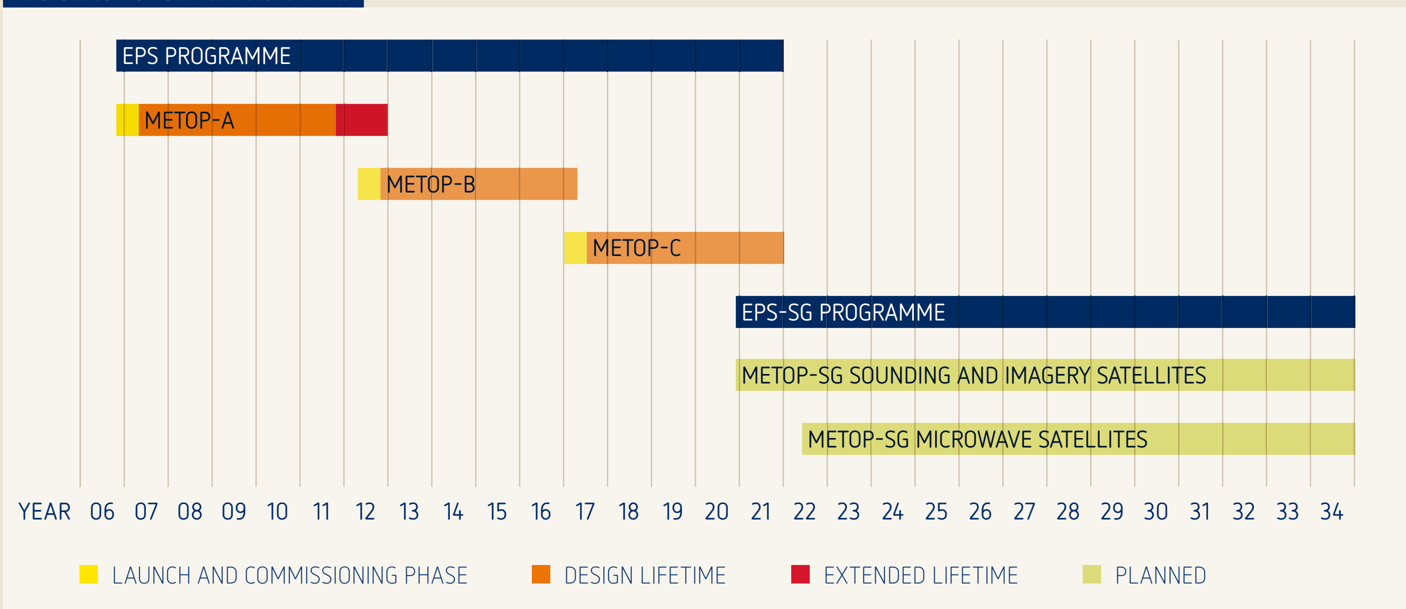
Considering the criticality of low Earth orbit data to forecasts and climate monitoring, and their outstanding socio-economic benefits, continuity is an imperative for EUMETSAT and WMO members.

Starting with its launch in October 2006, Metop-A has been running like clockwork and has extended its nominal five-year lifetime. However, Metop-B needs to be launched in 2012 into its sun-synchronous polar orbit to fulfil the critical need for continuity of measurements from there.

Once it has been launched, the team at ESA's European Space Operations Centre (ESOC) will take over control of the satellite and manoeuvre it close to its final orbit, deploy the various antennas, perform the early orbit phase of operations over the three days following the launch and hand control of the satellite to EUMETSAT for the nominal six-month commissioning phase. EUMETSAT will then conduct in-orbit verification of the satellite as well as the subsequent scientific validation of the products generated by its instruments. The first data are expected to be available to users within a couple of weeks of launch, and the satellite is expected to become operational within six months. Like Metop-A, Metop-B will fly in a mid-morning orbit and cross the equator at 9:30 Local Solar Time when it flies southwards. Metop-C is planned for launch in 2017 and will follow the same commissioning process. Thus, EUMETSAT's service in polar orbit will be provided by EPS and its Metop satellites until at least 2020.

Preparations for the second generation of the EUMETSAT Polar System (EPS-SG) are under way to secure continuity of the steady data service beyond 2020, as well as to deliver significant improvements for weather forecasting, atmospheric chemistry, air quality, hydrology and climate monitoring. Like the EPS, the future EPS-SG programme will be set up in cooperation with the United States and will further respond to the recommendations of WMO.

EPS SPACE SEGMENT ROADMAP



EUMETSAT

THE INFRASTRUCTURE OF EPS

The EUMETSAT Polar System is operated by EUMETSAT and has been developed, procured and implemented in partnership with the European Space Agency (ESA), the Centre National d'Etudes Spatiales (CNES) and the US National Oceanic and Atmospheric Administration (NOAA).

Florence Rabier
CNRM-GAME
Météo France

"It's very impressive how Metop-A observations are now used by meteorologists, atmospheric scientists and climatologists in Europe, and all over the world. The various instruments on board provide a wealth of invaluable data."

THE SPACE SEGMENT

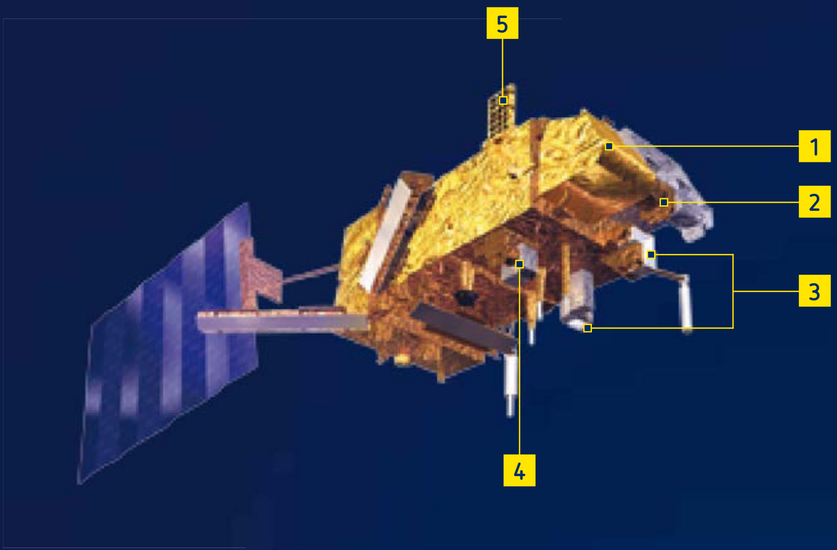
Each Metop satellite has a design lifetime of five years. The satellites will fly consecutively, providing an operational service until at least 2020. There will be an operational overlap of about six months between two successive Metop satellites, when both satellites will provide data in parallel before the latest launched satellite is declared the main operational satellite.

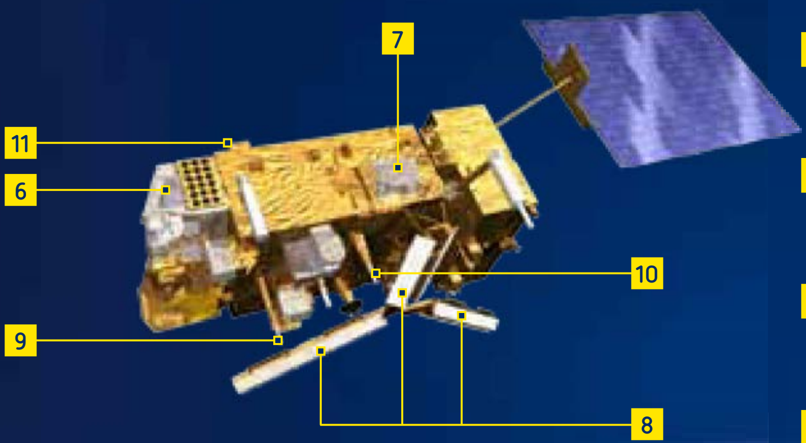
The Metop-A, -B and -C satellites provide continuity of accurate, high resolution observations from a low Earth, sun-synchronous orbit at an altitude of approximately 817 km, circling the planet 14 times a day and covering every point of the Earth twice a day. They fly in a complementary orbit with the NOAA satellites, with EUMETSAT taking operational responsibility for the morning orbit and NOAA for the afternoon orbit.

As the operational Metop satellite circles the Earth, the resulting data are continuously recorded on board using solid-state storage technology. The data stream is downloaded twice per orbit as the satellite passes over the ground station on Spitsbergen, one of the Svalbard islands, as well as the McMurdo station in Antarctica.

CHARACTERISTICS OF THE METOP SATELLITES

Satellite design	Three-axis stabilised, consisting of a service module and a payload module
Dimensions	6.2m x 3.4m x 3.4m (stowed launch configuration) 17.6m x 6.5m x 5.2m (deployed in-orbit configuration)
Launch mass	4093kg
Power	1,812W
Data rate	3.5Mbps
Orbit	817-837 km circular, sun-synchronous, 98.7° inclination, 09:30 local time descending node, 29-day/412-revolution repeat cycle
Design lifetime	Five years





INSTRUMENTS ON BOARD METOP

Metop carries a second generation of European operational meteorological instruments developed by ESA and CNES which offer innovative remote-sensing capabilities. Its payload also contains a set of heritage instruments already flown on the NOAA satellites: the AVHRR instrument and Advanced TIROS Operational Vertical Sounder (ATOVS) suite consisting of the HIRS/4, AMSU-A and MHS instruments, the latter which was procured by EUMETSAT to replace AMSU-B in the ATOVS suite.

Additionally, Metop is equipped with a search and rescue receiver and transmitter for use by emergency services and a data collection and location system (ARGOS) for receiving and retransmitting signals from transmitters installed in buoys and other ground-based systems.

The main instruments and the antenna for transmitting data to ground stations are accommodated on the satellite's Earth-facing side. Instruments requiring low temperature for infrared detectors are mounted on a balcony at the end of the satellite's payload module in the opposite direction of the sun.

INSTRUMENT PAYLOAD OF METOP

1 IASI (CNES)
INFRARED ATMOSPHERIC SOUNDING INTERFEROMETER
Enhanced atmospheric soundings of temperature, humidity and trace gases in cloud-free and partly cloudy conditions, as well as sea surface temperature, cloud characteristics, and surface emissivity

2 HIRS/4 (NOAA)
HIGH-RESOLUTION INFRARED RADIATION SOUNDER
Heritage atmospheric soundings of temperature and humidity in cloud free conditions

3 AMSU-A (NOAA)
ADVANCED MICROWAVE SOUNDING UNIT-A
Temperature soundings in all weather conditions

4 MHS (EUMETSAT procured)
MICROWAVE HUMIDITY SOUNDER
Atmospheric humidity sounding in all weather conditions

5 GRAS (ESA)
GNSS RECEIVER FOR ATMOSPHERIC SOUNDING
Temperature profiling in the troposphere and stratosphere with high vertical resolution

6 AVHRR/3 (NOAA)
ADVANCED VERY HIGH RESOLUTION RADIOMETER
Global visible, near-infrared and infrared imagery of clouds, oceans and land surfaces

7 GOME-2 (ESA)
GLOBAL OZONE MONITORING EXPERIMENT-2
Profiles and columnar amounts of ozone and other atmospheric constituents

8 ASCAT (ESA)
ADVANCED SCATTEROMETER
Near-surface wind speed and direction over the global ocean, and soil moisture

9 A-DCS (CNES)
ADVANCED DATA COLLECTION SYSTEM (ARGOS)
Acquisition and transmission of signals from transmitters on buoys, ships, land sites and mobiles

10 S&R (CNES/NOAA)
SEARCH AND RESCUE TERMINAL
Acquisition and transmission of the location of emergency beacons from ships, aircraft and people in distress to ground stations

11 SEM (NOAA)
SPACE ENVIRONMENT MONITOR
Monitoring of local space plasma and radiation environment

THE INFRASTRUCTURE OF EPS

GROUND SEGMENT

The EPS ground segment comprises the ground station for receiving data transmitted from the Metop satellites and the core ground segment consisting of the satellite and mission control centre, a back-up control centre, and facilities for the reception, processing and exchange of data and generation of products. It also includes a network of Satellite Application Facilities for providing specialised, application-specific products, involving National Meteorological Services all over Europe.

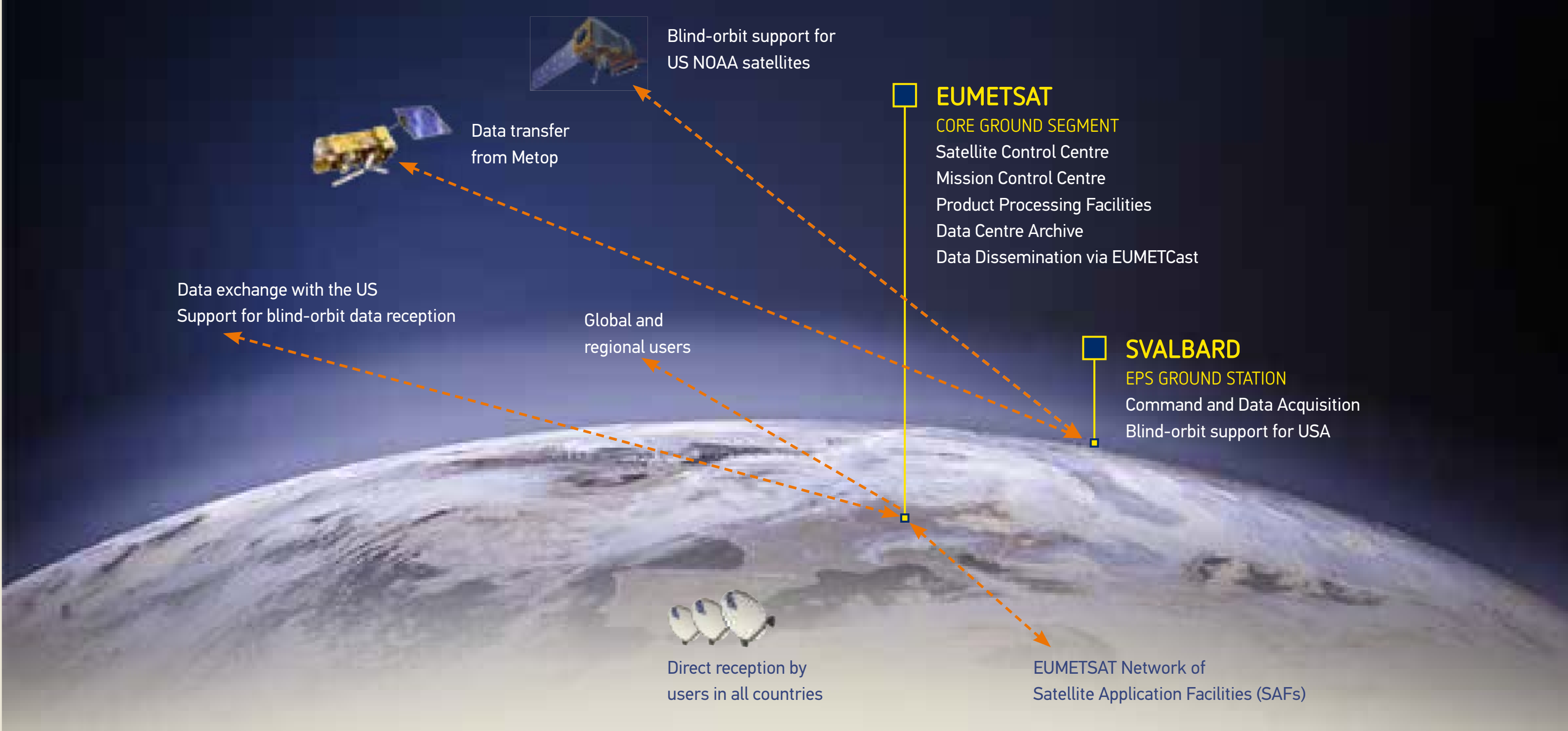
GROUND STATIONS

The purpose-built EPS ground station at Svalbard lies within the Arctic Circle at 78°N, 15°E and comprises two command and data acquisition stations, each providing the capabilities to acquire telemetry and send commands to the Metop satellites. In addition, the station can acquire data from the NOAA satellites, in particular for orbits that are not visible from the NOAA ground stations in Fairbanks and Wallops Island in the USA, known as “blind orbits”. The Metop and NOAA global data acquired at Svalbard are transmitted from the ground station to EUMETSAT headquarters for processing, archiving and further distribution to the user community.

Through cooperation with NOAA under the Antarctic Data Acquisition project, Metop data is also dumped a second time per orbit on a US data acquisition station located at McMurdo, Antarctica. Downlinked data from the first half of the satellite’s (descending) orbit are transferred to EUMETSAT for immediate processing and dissemination to users. These data are subsequently complemented with the second half (ascending) orbit acquired at Svalbard. By downlinking data twice per orbit, once in Antarctica and once in Svalbard, the timeliness of the global level 1 products is improved by a factor of two to approximately 60 minutes. Metop satellites can also broadcast high resolution real-time data from all instruments to local user stations around the world.

EPS ground station, Svalbard

EPS GROUND SYSTEM



CORE GROUND SEGMENT

The core ground segment (CGS), located at EUMETSAT's headquarters in Darmstadt, Germany, operates the Metop satellites and coordinates all ground operations. It includes the functions of commanding and acquisition of data from Metop and NOAA satellites, mission control, data processing and product generation, product quality control, online calibration, as well as dissemination of data and products. In an emergency, its monitoring and control role can be taken over by a back-up control centre located close to Madrid, Spain. The CGS also receives and processes data from the NOAA satellite and forwards data collected by Metop to NOAA.

The data are disseminated to EUMETSAT Member States' National Meteorological Services and other users all over the world via the Global Telecommunication System (GTS) and EUMETCast, the organisation's unique satellite-based data broadcasting service, which covers Europe, Africa and part of America.

The data and products gathered by Metop satellites (over at least 14 years) are being archived in the EUMETSAT Data Centre to ensure availability of long-term data series, which are necessary in particular for climate research and monitoring.

EPS Mission Control Centre, EUMETSAT headquarters, Darmstadt, Germany

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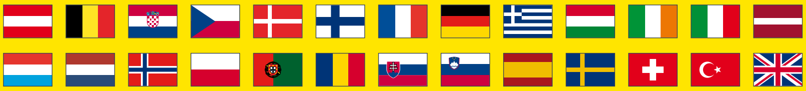
EUMETSAT also has established cooperation agreements with organisations involved in meteorological satellite activities, including the National Meteorological Services of Canada, China, India, Japan, Korea, Russia and USA.

MEMBER STATES



COOPERATING STATES

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