1.3 THE EUMETSAT GEOSTATIONARY AND POLAR SATELLITE SYSTEMS AND PRODUCTS

Kenneth Holmlund and Marianne König
EUMETSAT

1. INTRODUCTION

Satellite data are the main source of information in Numerical Weather Prediction (Szyndel (2003)), with 99% of the available data for global numerical weather prediction (NWP) being satellite based. It should also be noted that satellites are one of the few observing systems that can provide data at sufficiently high temporal and spatial frequency for regional and mesoscale models. The derivation of quantitative meteorological parameters from the Meteosat satellites started already with Meteosat-1 in 1979. Major improvements in the algorithms during the 1980's established the derived products as a major source of information for global NWP, with initially Atmospheric Motion Vectors (AMV) and later also Clear Sky Radiances being the key products for the assimilation. Lately, AMVs are also used both in regional and mesoscale NWP models (e.g. Bonavita and Torrisi (2004)), proving the importance of this data. The Meteosat First Generation satellites were the first to provide observations in the water vapour band from geostationary orbit with a 5 km resolution every 30 minutes. The water vapour data combined with the infrared window measurements have proven to be a powerful combination enabling the derivation of high quality cloud height measurements and other products. However, the addition of new channels on the Meteosat Second Generation (MSG) imager SEVIRI (Spinning Enhanced Visible and InfraRed Imager) will further improve the capabilities to determine cloud heights. Additionally, information on cloud properties, aerosol and total ozone amongst other potential applications can be provided with the new instrument. The first MSG satellite MSG-1 was successfully launched in August 2002. The commissioning ended in December 2003 and the satellite entered operations as Meteosat-8 in January 2004. The new imager is performing well (for details see e.g. Hanson et al. (2004), Müller et al. (2004)) and with improved image and product quality. The following sections will give an overview and status of the EUMETSAT Meteorological Product Extraction Facility (MPEF) and the derived products. The last sections will shortly introduce the current status of the EUMETSAT system of polar orbiting satellites and EUMETSAT's contribution to the JASON-2 programme.

Corresponding author address: Kenneth Holmlund and Marianne König, EUMETSAT, Am Kavalleriesand 31, 64295 Darmstadt, Germany;
e-mail: holmlund@eumetsat.de, koenig@eumetsat.de

2. THE GEOSTATIONARY SATELLITE SYSTEM

The first generation Meteosat satellites, which are currently controlled under the Meteosat Transition Programme (MTP), have as payload a three-channel imager with broadband channels in the visible, infrared and water vapour region of the spectrum. The resolution at the sub satellite point is 2.5 km for the visible and 5 km for the infrared and water vapour channels. The Meteosat satellites are spin stabilised rotating at 100 rpm providing a full field of view imagery every 30 minutes. Currently, three Meteosat satellites are used operationally. Meteosat-7 provides the primary mission at 0°, and Meteosat-5 supports the Indian Ocean Data Coverage (IODC) mission at 63°E. The current hot-standby satellite for the primary mission, Meteosat-6, located at 10°E, is used for the rapid scan service providing 10 minute imagery over Europe. It is currently foreseen that the IODC service will be continued until 2005, whereas the primary mission will be taken over by the new MSG satellites.

The first spacecraft MSG-1 was successfully launched in August 2002 and has become operational in early 2004, when it was renamed to Meteosat-8. The MSG satellites are also spin-stabilised rotating at 100 rpm. The SEVIRI instrument is a 12 channel imager scanning the Earth in each spectral band with three detectors (nine for High Resolution Visible, HRV) instead of one as is done with the imager on Meteosat. This enables a 3 km sampling distance between individual measurements (1 km for HRV) and a full field of view coverage of 15 minutes instead of 30 minutes as provided by the first generation satellites. The absolute pointing accuracy is within 3 km RMS for a single image and 1.2 km for image to image registration. The relative accuracy for image sub-areas is even higher with 1.2 km for 500 pixels and 0.75 km over 16 km. The co-registration of the channels is for the HRV, 0.6, 0.8 and 1.6µm 0.6 km and for the other channels 0.75 km. The image data from all satellites is disseminated in near-real-time.

The successful Meteosat era is now being complemented and continued by MSG. The current operational products derived from MSG imagery data will be enhanced with new products and algorithms. The improved capability of the MSG image data as compared to Meteosat enables more accurate cloud detection and classification. Especially the higher number of channels in the infrared and near-infrared and also the three channels in the visible band provide new data that will improve the detection and classification of clouds and other atmospheric features. The SEVIRI instrument will also have the capability to detect the cloud phase and provides the potential to derive completely new products like Total Ozone and instability information. The higher sampling rate in time and space provides further improvements that will directly increase the quality of several of the existing key products like Clear Sky Radiance and the Atmospheric Motion Vector product. The multitude of channels will also enable the estimation of cloud top heights with higher accuracy than before.

The SEVIRI instrument provides observations in 12 spectral bands, three visible channels (HRV, 0.6, 0.8µm) a near-infrared channel (1.6µm) and 8 infrared channels (3.9, 6.2, 7.3, 8.7, 9.7, 10.8, 12.0, 13.4µm). Figure 1 presents the spectral response functions of the 8 infrared channels together with the atmospheric transmission for a mid-latitude summer standard atmosphere (nadir-view) and the corresponding weighting functions. Table 1 summarises the channel information.

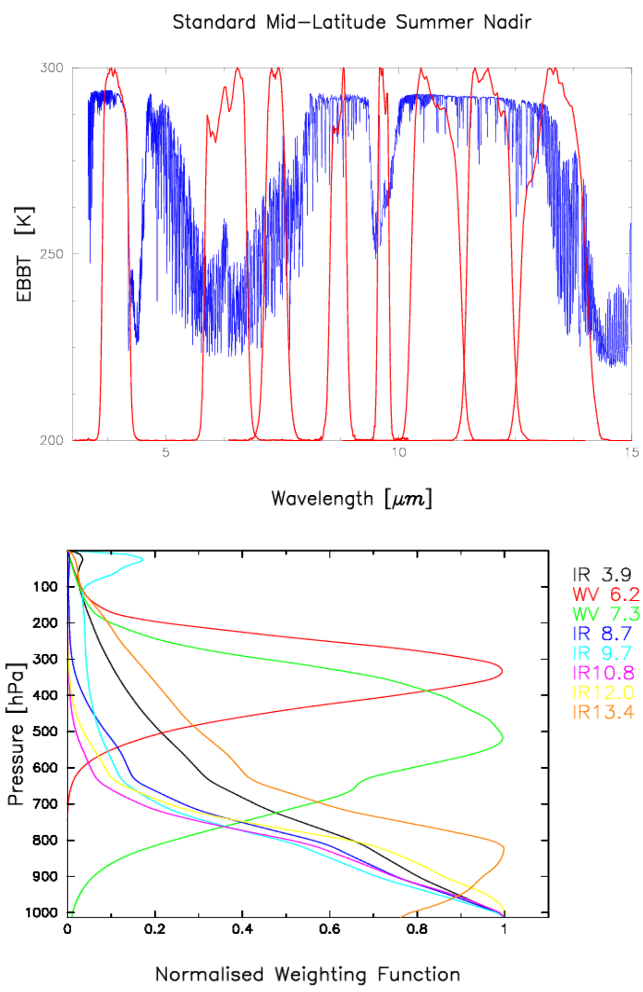


Figure 1: The SEVIRI spectral response functions of the 8 infrared channels together with the atmospheric transmission for a mid-latitude summer standard atmosphere at nadir (top) and the corresponding weighting functions (bottom).

Channel Number and Name	minimum, central, and maximum wavelength (µm)	Identification
01 VIS0.6	0.56 0.635 0.71	solar
02 VIS0.8	0.74 0.81 0.88	solar
03 NIR1.6	1.50 1.64 1.78	solar
04 IR3.9	3.48 3.90 4.36.	window(solar/thermal)
05 WV6.2	5.35 6.25 7.15	water vapour
06 WV7.3	6.85 7.35 7.85	water vapour
07 IR8.7	8.30 8.70 9.10	window
08 IR9.7	9.38 9.60 9.94	ozone
09 IR10.8	9.80 10.8 11.8	window
10 IR12.0	11.0 12.0 13.0	window
11 IR13.4	12.4 13.4 14.4	carbon dioxide
12 HRV	broadband 0.4 –1.1	solar

Table 1: Overview over the spectral bands of the SEVIRI instrument

3. STATUS OF THE MSG MPEF PRODUCTS

3.1 Overview

The EUMETSAT MSG Meteorological Product Extraction Facility (MPEF) is a near-real time system (Holmlund et al. (2003)). The fully automated product generation is controlled by a schedule that starts all the activities from data acceptance, product generation, quality control, product distribution to product verification. Currently, the input data are rectified (i.e. geo-located) and calibrated Level 1.5 image data. In addition to the image data the MPEF uses ECMWF (European Centre for Medium Range Weather Forecasts) model data and meteorological observations like radiosonde data. All activities are configurable with setup parameters, and the processes are continuously monitored. The system also produces automated statistical reports for various purposes like monitoring, validation, verification, and reporting. The generated products are distributed to the users via the Global Telecommunication System (GTS), via satellite (EUMETCast), or are available via the U-MARF (Unified Meteosat Archiving and Retrieval Facility) at EUMETSAT. The new system very quickly reached a high level of reliability. The required availability of 98.5% is generally reached. In April 2004 99.8% and in May 99.8% of all scheduled products were generated and disseminated. A high quality of the products is of course also required. The following sections will give an overview of the status of the various products. It is expected that most products will experience further improvements during the early operations through tuning of the setup parameters and algorithms. Additional implementation of new algorithms will also take place as well as the introduction of new products.

3.2 The MPEF Baseline Products

One of the main objectives of MSG is to provide continuity to the already well established products derived with current first generation Meteosat data. The SEVIRI data enables the derivation of new and improved products. At EUMETSAT the SEVIRI capabilities are used to improve the quality of the derived products like the Atmospheric Motion Vectors, cloud analysis and clear sky radiance products. New products like mid-tropospheric humidity, Global Instability Index, Total Ozone and Clear Sky Reflectance Map are also produced. Table 2 presents the current baseline products and distribution means.

Products	Acronym	UMARF	GTS	EUMETCast
Atmospheric Motion Vectors	AMV	Yes	Yes	Yes
Cloud Analysis	CLA	Yes	Yes	Yes
Cloud Analysis Image	CLAI	Yes		Yes
Cloud Mask	CLM	Yes		Yes
Cloud Top Height	CTH	Yes		Yes
Clear Sky Radiance	CSR	Yes	Yes	
Climate Data Set	CDS	Yes		
High Resolution Precipitation Index	HPI	Yes		
ISCCP Data Set AC, B1 & B2	IDS	Yes		
Tropospheric Humidity	TH	Yes	Yes	Yes
Total Ozone	TOZ	Yes	Yes	Yes
Sea Surface Temperature (1)	SST			
Scenes Analysis (1)	SCE			
Radiative Transfer Model (1)	RTM			
Calibration Support	CAL	Yes		
Global Instability	GII	Yes		Yes
Clear-sky Reflectance Map (2)	CRM	Yes		Yes

Table 2: The status of the meteorological products extracted centrally with Meteosat-8.
1) Internal products only, 2) Not fully operational

3.3 The MPEF Radiative Transfer Model

The MSG MPEF Radiative Transfer Model (RTM) is a coarse resolution line-by-line model that performs monochromatic calculations at about 1 cm^{-1} wave-number resolution (Tjemkes and Schmetz (1997)). It currently uses HITRAN 92 with CDK 2.0 line parameters as static input data as well as static surface emissivity data. The dynamic atmospheric data are provided by ECMWF forecasts at 31 levels and radio-sonde data. The accuracy of the model has been verified already before launch against LBL-RTM and amounts to 1 – 2 %. The model output is used for the subsequent scenes and cloud analysis, height assignment, atmospheric correction tables, tropospheric humidity and calibration monitoring.

3.4 Calibration Monitoring

One of the most important aspects of satellite data is the availability of high quality calibration. On MSG the SEVIRI instrument has an on-board blackbody calibration for the infrared channels. This calibration is monitored by the vicarious calibration in the MPEF (Holmlund et al. (2003)). This vicarious calibration scheme is similar to that used with the Meteosat first generation satellites, further improvements, however, have been introduced for MSG. In addition to monitoring, it also supports the selection and tuning of the blackbody models. The vicarious calibration can be executed both with observational data like radiosonde data or with NWP data. The advantage of the observational data is that it is a truly independent approach. However, shortcomings in observable parameters (e.g. ozone) and quality (e.g. upper tropospheric / lower stratospheric humidity) together with availability (e.g. radiosonde stations are limited, and sondes are generally launched only twice daily) limit the use of the data. The use of model data on the other hand has the scope of good availability for all variables, locations and levels, however, the quality is dependent on the model performance and is also not always fully independent through the use of the satellite data in the models themselves. However, both data types provide currently a consistent view of the MSG blackbody calibration. In general the blackbody and vicarious calibration agree to within 1 K for most IR channels. For visible channels only a vicarious calibration approach is used (Govaerts (2003)). The expected accuracy is of the order of 5%.

3.5 Scenes and Cloud Analysis

The algorithm used for the scenes and cloud analysis in the MSG MPEF is a pixel-based thresholding technique based on the work by Saunders and Kriebel (1988). Their approach has been further refined, enhanced, and adapted to MSG data by Lutz (2003). The scenes and cloud analysis is a pre-requisite for further processing and contributes crucially to the derivation of Clear Sky Radiances and AMVs as well as most other products. The current performance of the scenes and cloud analysis is demonstrated in Figure 2. In the cloud mask the clouds are identified in white, and the clear sky areas are coded in different shades according to information from the static scene type file. For the cloud analysis different cloud types are identified in different shades of grey, the surface information is again derived from the surface scene type.

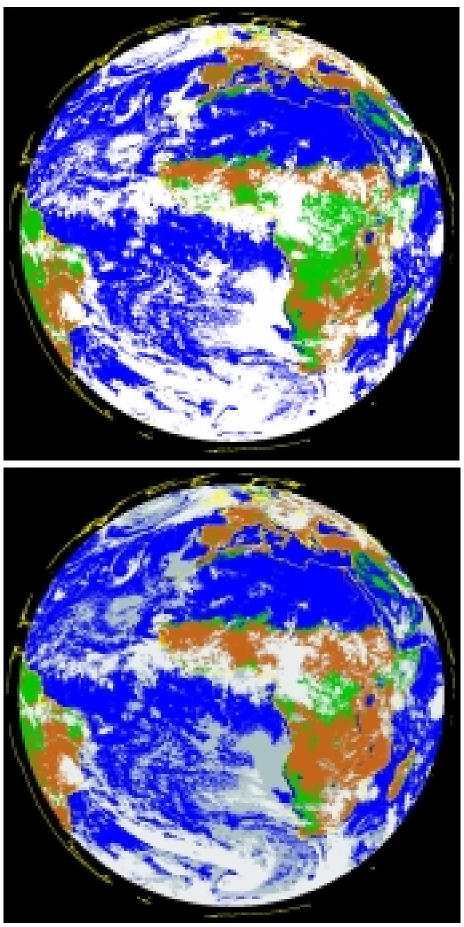


Figure 2: The cloud mask derived by the MSG MPEF (top) and the corresponding cloud analysis (bottom) on 29 June 2004 11:45 UTC. Cloud heights are represented by different grey shades

3.6 The Clear Sky Radiance Product

The derivation of the clear sky radiance (CSR) product is performed in all 8 infrared channels. The basic derivation is on pixel basis, and the final product is the average CSR on a segment size of 16*16 pixels. The main processing factors are the need for a proper cloud clearance and good calibration. As an example, Figure 3 presents the clear sky radiances derived for two MSG IR channels; 3.9 and 6.2µm on 02 July 2004 at 0545 UTC. It should be specifically noted that the use of the radiances of the 3.9µm channel is difficult during daytime. This is well illustrated by the high observed radiances in the eastern part of the 3.9µm CSR, where reflected solar radiance significantly enhances the observed radiance. The water vapour CSR products from geostationary satellites are operationally used in global NWP, while the use of radiances from the ozone channel at 9.7µm and the infrared window channel still pose a challenge in data assimilation.

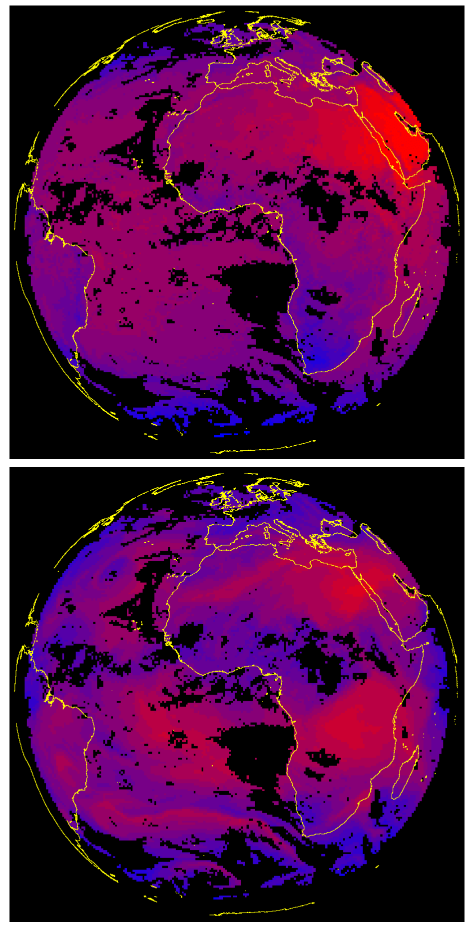


Figure 3: The CSR product for the IR channels at 3.9µm (top) and at 6.2µm (bottom), 02 July 2004, 0545 UTC.

3.7 The Tropospheric Humidity Product

The relationship between observed radiances in the 6.2 and 7.3µm channels and the corresponding mid- and upper-tropospheric humidity is based on the regression approach by Soden and Bretherton (1993). Figure 4 presents an example of the upper tropospheric humidity product.

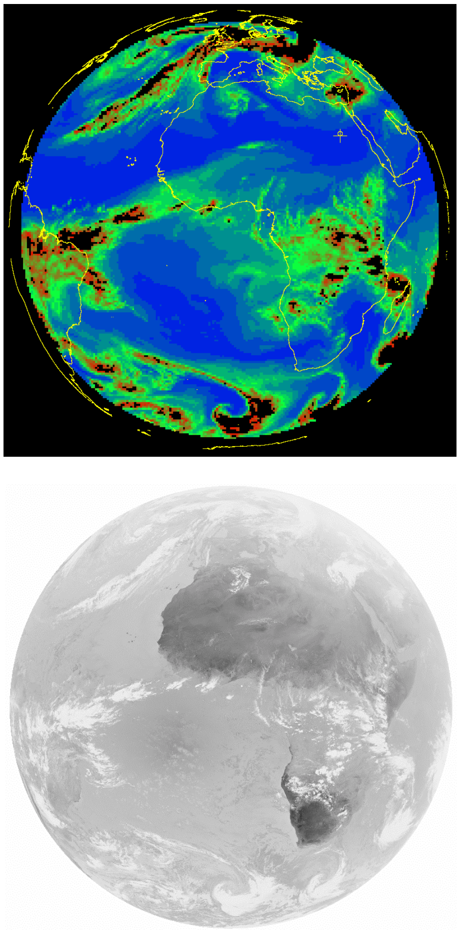


Figure 4: The Upper Tropospheric Humidity (UTH) field as derived within the MSG MPEF (top) and the corresponding IR window channel image showing the cloud distribution.

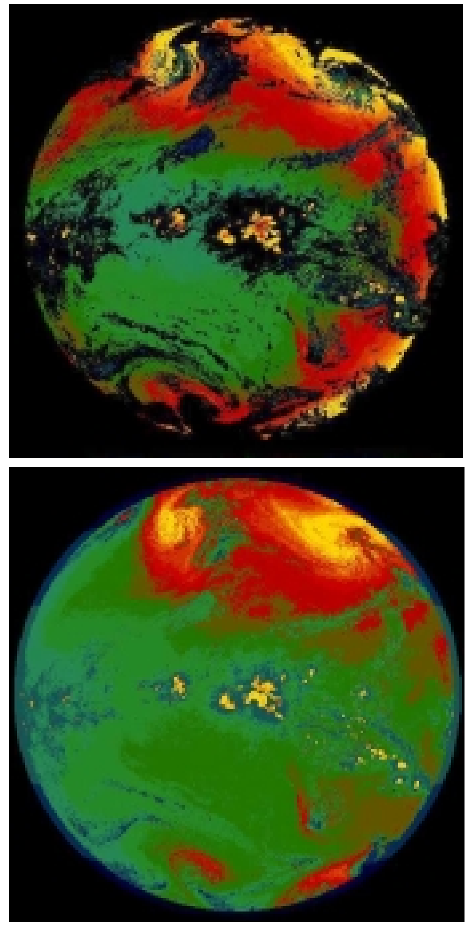


Figure 5: The operational Total Ozone product based on a linear regression model (top), compared to the corresponding result based on an optimal estimation technique (bottom)

3.8 The Total Ozone Product

The total ozone product is currently derived with a statistical/physical regression model. However, the current operational product shows some deficiencies (noisy retrieval, no retrieval over high level clouds). Hence a new method based on an optimal estimation technique has been developed and is expected to become operational during 2004. Figure 5 presents an example of the derived ozone fields derived with the two methods.

3.9 The Atmospheric Motion Vectors Product

The derivation of Atmospheric Motion Vectors (AMV) is based on the approach already used with the current geostationary satellites. One of the main differences to the current operational approach is the dynamic target selection scheme, which enables not only a better selection of features for tracking, but also the flexilbility to change the resolutino of the product according to user requirements (Holmlund (2000)).

An important feature of the new AMV scheme is the multitude of height assignment methods that can be used in parallel. Figure 6 shows an overview of the performance of the various height assignment methods together with a detailed comparison for the so-called CO_2 height assignment with colocated radiosondes. In these examples the performance of the height assignment is rather satisfactory, which is not always the case, and the operational height assignment needs further tuning. Currently, one of the biggest concerns with the AMVs is the horizontally correlated error as observed by Bormann et. al. (2003). These errors may be related to the correlated errors in the NWP temperature fields, and hence a forecast independent approach for height assignment would be highly desirable. The existence of two water vapour channels enables a derivation of cloud heights that is completely independent of forecast data and is a potential future improvement.

The new capability of Meteosat-8 provides already now 5 times more wind vectors than the first generation satellites. Monitoring of the data has shown that already at this early stage of operations the quality of the

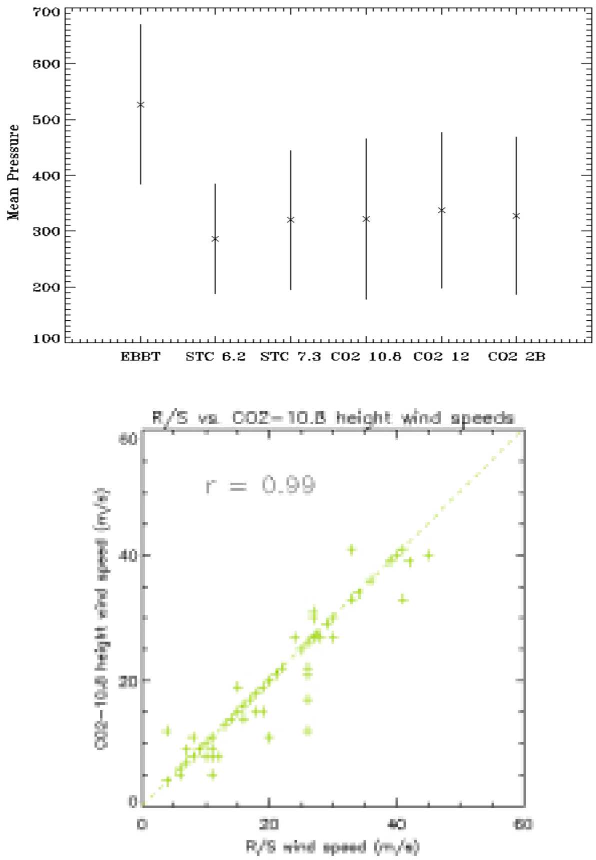


Figure 6: Comparison of various height assignment methods (top) and colocated wind speeds (Meteosat-8 / radiosondes, bottom)

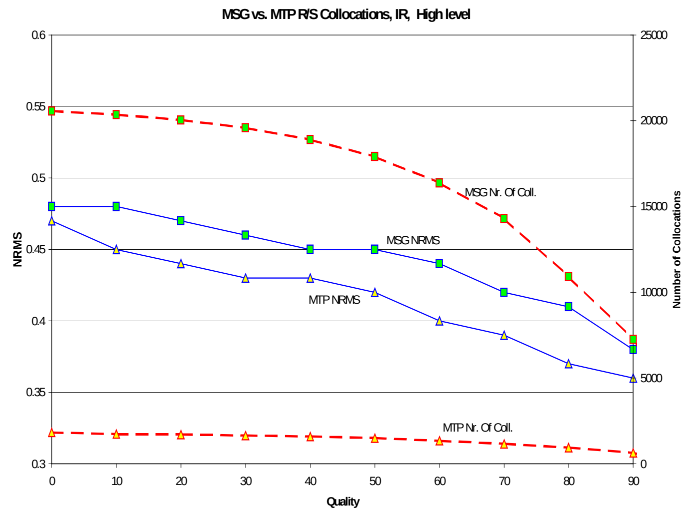


Figure 7: Meteosat-8 (MSG) and Meteosat-7 (MTP) IR high level AMV quality as determined by the NRMS difference (solid line) derived against colocated radiondes. Additionally the number of winds (dshed line) for all categories is shown. (squares = Meteosat-8, triangles = Meteosat-7).

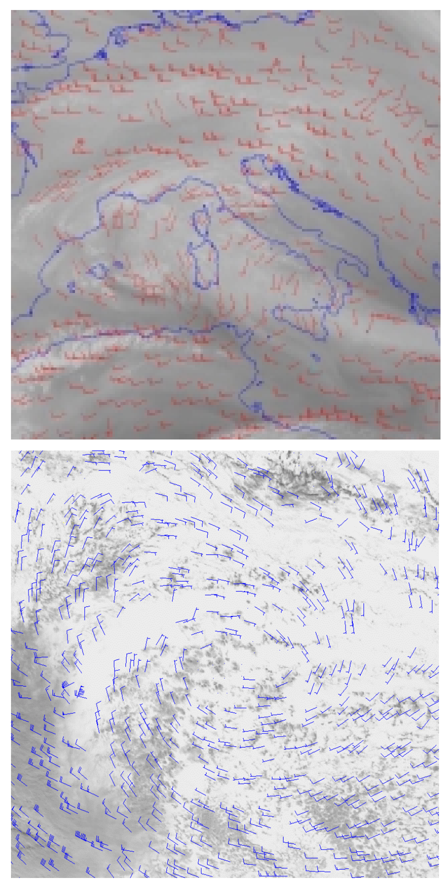


Figure 8: High level Atmospheric Motion Vectors (AMV) derived from cloudy targets with the WV channel over central Europe (top) and low level AMVs derived with the VIS channel over the South Atlantic (bottom).

Meteosat-8 winds are comparable to Meteosat-7, and that with appropriate filtering or data selection the quality is even higher. This is illustrated in Figure 7 where the quality of the derived vectors from the two systems is defined by the normalised RMS (NRMS) difference to colocated radiosonde wind measurements for different quality categories as determined by the Automatic Quality Control. The normalisation is performed by the mean wind speed of the colocated observations. The figure also presents the number of winds for the different quality classes. It can be seen that for a specific quality class the NRMS is higher for Meteosat-8, but if a higher quality class is selected, the NRMS is equal or better and that at the same time the number of vectors is still higher. The selection of different quality classes for different satellites is a typical behaviour of the used Automatic Quality Control (AQC) scheme. the increased positive impact of Meteosat-8 AMV data for regional NWP has been demonstrated by Bonavita and Torrisi (2004).

The high density of the Meteosat-8 AMV field is illustrated in Figure 8 for two examples, which both show areas of high curvature and high spatial variation. Figure 9 presents an example of high level winds derived in a jet stream area using infrared window, water vapour, and visible image data.

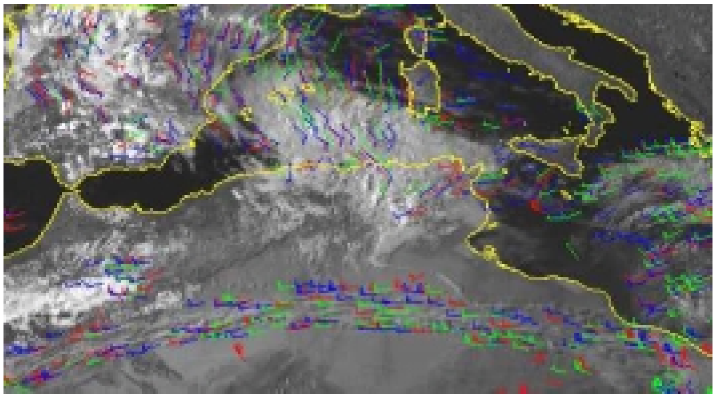


Figure 9: A high level jet-stream area depicted by Atmospheric Motion derived from cloudy targets with the IR channel (red), the water vapour channel (blue), and the visible channel (green)

3.10 The Global Instability Index Product

The Global Instability Index (GII) product is operationally derived with a statistical regression model for which the parameters have been derived with a neural network approach. The current algorithm works well for the Total Precipitable Water (TPW) index as verified with comparisons to a physical retrieval method and to radiosonde observations. However, the reliability of the other parameters (K index, KO index, Lifted Index, Maximum Buoyancy) with the current algorithm is significantly lower. Therefore, during 2004/2005, the current statistical method will be replaced by a physical retrieval, based on an optimal estimation method, (König (2002)). Figure 10 gives an example of the Total Precipitable Water as one of the derived airmass parameters.

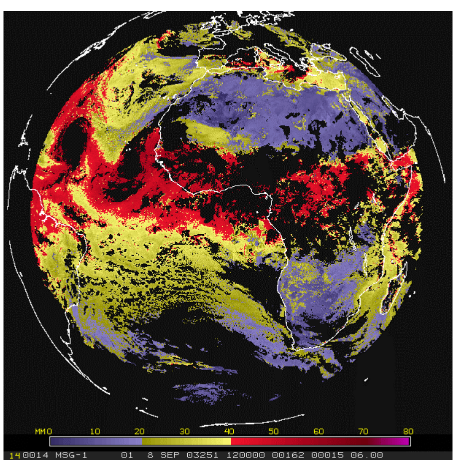


Figure 10: The Total Precipitable Water derived on a global scale as one of the GII products (8 September 2003, 1200 UTC)

3.11 The Clear Sky Reflectance Map

The Clear-Sky Reflectance Map (CRM) is based on the average clear sky reflectance derived in cloud-free areas using three images around a central time slot. The observed daily clear sky reflectances are averaged over a 10-day period. Figure 11 gives an example of a CRM product derived with data from the 0.6 and 1.6µm channels.

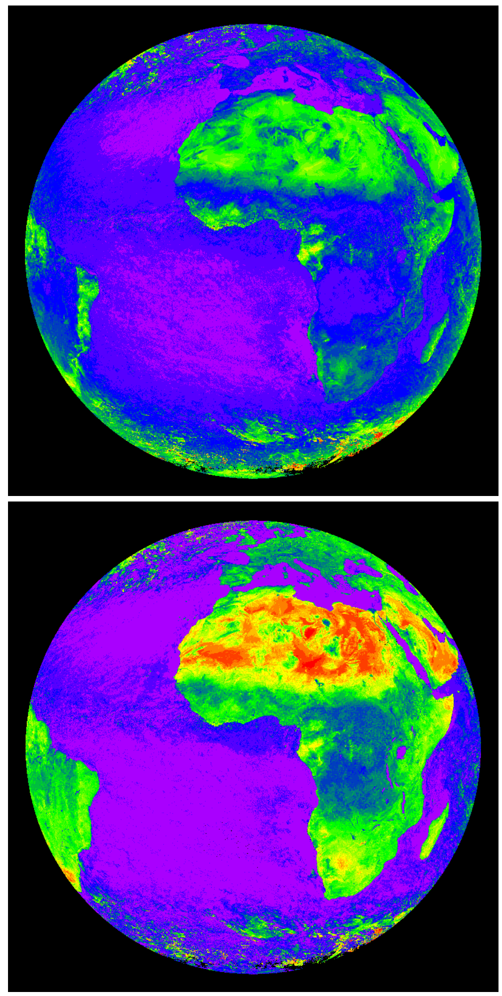
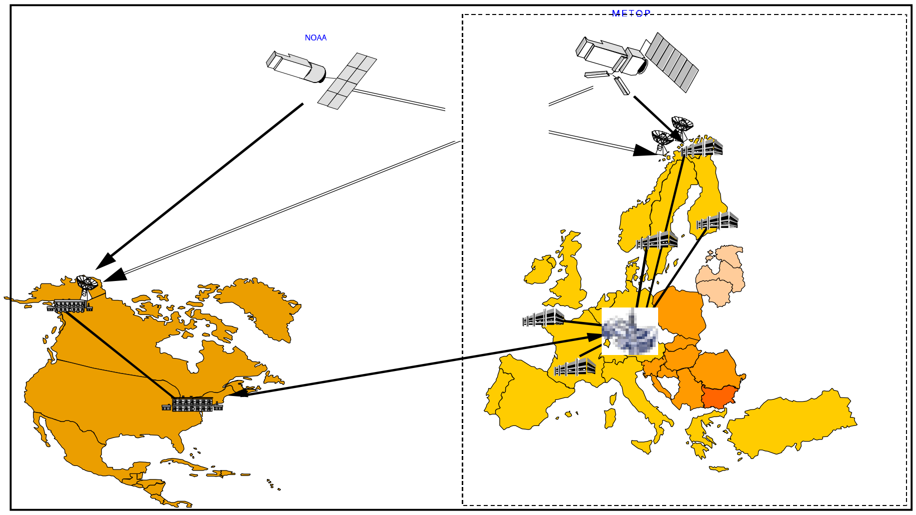


Figure 11: The Clear-Sky Reflectance Map derived with the 0.6µm (top) and 1.6µm (bottom) channel from cloudfree data averaged over a 10-day period in June 2004.



4. THE EUMETSAT POLAR SYSTEM (EPS)

The EUMETSAT Polar System will complement the US provided system and together with the latter continue the present NOAA polar orbiting satellite system in the frame of the Initial Joint Polar System (IJPS) (Figure 12).

The future EUMETSAT satellites of this new polar system are the METOP (METeorological OPerational Satellite) satellites, jointly developed with ESA. They will provide high-resolution sounding and also high-resolution imagery in global coverage. The first two of the METOP satellites will be operated in the framework of the Initial Joint Polar System (IJPS) together with the present NOAA system of the United States. These METOP-1 and METOP-2 spacecraft are foreseen for a sun synchronous orbit for the 9:30 AM equator crossing (descending node). The first METOP satellite is currently scheduled for launch towards the end of 2005. With the third spacecraft the converged military and civilian US-Systems NPOESS will form together with METOP-3 the Joint Polar System (JPS). METOP-3 is planned to be a recurrent copy of METOP-1 and 2, however no HIRS/4 will be flown on METOP-3. Payload options for the imager and the microwave sounding instruments are VIRI-M and ATMS in case AVHRR and AMSU are not available and are currently being investigated. The EPS programme is planned to cover 14 years of operation.

4.1 The EPS Products

The main mission objectives for the system are Operational Meteorology and Climate Monitoring. In addition the Search and Rescue Instruments and also the Space Environment Monitor are on-board the spacecraft. To achieve the mission objectives the METOP satellites contain a wide variety of instruments, including a number of sounding instruments. The HIRS/4 (High Resolution Infrared Radiation Sounder) instrument, the AMSU-A (Advanced Microwave Sounding Unit -A) and the MHS (Microwave Humidity Sounder) instrument asuccessor instrument of AMSU-B, will provide the continuity to the current sounding capabilities onboard the NOAA-15, -16 and -17 spacecraft. Highly improved sounding capability will be provided by the IASI (Infrared Atmospheric Sounding Interferometer) instrument, both in accuracy and also in vertical and horizontal resolution. The sounding payload is complemented by the AVHRR/3 (Advanced Very High-Resolution Radiometer) high-resolution imager. The EPS products comprise centrally processed Level 1 products from all instruments, Level 2 sounding products from ATOVS and IASI, and a large number of Level 2 and higher products from the distributed European Satellite Application Facility (SAF) network.

Figures 13 and 14 present examples of ozone derived with ERS-2 and scatterometer wind data derived with QuickScat. Similar data will also be obtained by EPS. Ozone data will be provided by GOME-2, which, in addition to ozone profiling, can be used for other trace gas retrievals. The wind vector field near the surface over the oceans will be provided with an Advanced Scatterometer (ASCAT).

Other EPS instruments are the GRAS (GPS Radio-Occultation Atmospheric Sounder) sounding system. GRAS uses the information on the atmosphere and ionosphere contained in the radio-occultation of the GPS navigation satellite signals. For further information and examples on the capabilities of the EPS instrumentation see the EUMETSAT web pages www.eumetsat.de.

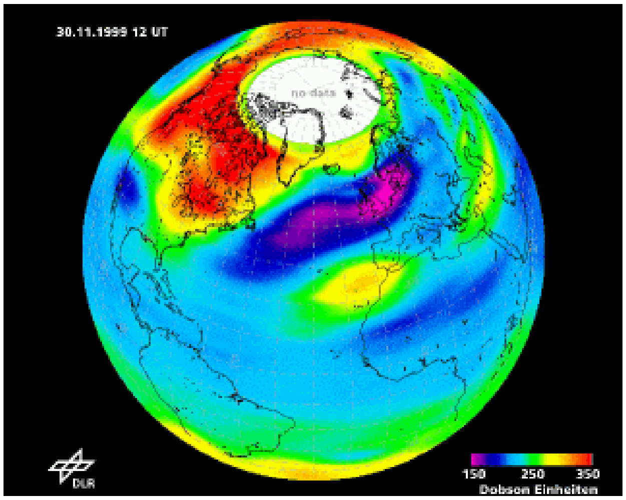


Figure 13: : GOME/ERS-2 30 November 1999. Global ozone total column concentration (courtesy of DLR)

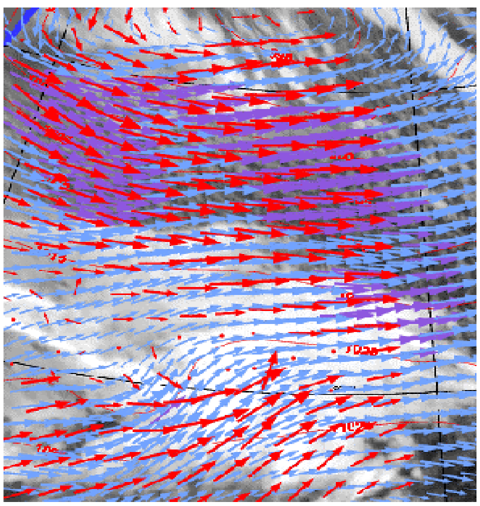


Figure 14: Surface wind field derived with QuickScat data (courtesy KNMI)

5. OPTIONAL PROGRAMMES

The Optional Jason-2 programme on altimetry entered into force on 27 June 2003, after a sufficient number of EUMETSAT Member States have subscribed to the programme. The Jason-2 altimetry programme is the first EUMETSAT optional programme to implement EUMETSAT's amended Convention from November 2000. This Convention expands the mandate given to EUMETSAT by its Member States in operational climate monitoring and the detection of global climatic changes. EUMETSAT will contribute to the operations of the overall system and to the generation of the data stream, using a European Earth Terminal and a real time processing chain. The programme is EUMETSAT's contribution to a joint undertaking with the French Centre National d'Etudes Spatiales (CNES), the US National Oceanic and Atmospheric Administration (NOAA) and the US National Aeronautics and Space Administration (NASA), known as the Ocean Surface Topography Mission (OSTM). It is an important element in the overall altimetry data system and will bring high precision altimetry to a full operational status, as a result of a balanced co-operation between Europe and the USA.

6. CONCLUSIONS

During commissioning of MSG-1 the main objective of the product validation has been to verify the implementation of the scientific algorithms and to validate the baseline products. Many of the capabilities of the SEVIRI instrument are not yet fully exploited. Further improvements in cloud height assignment as well as in the resolution of products is expected. Also the use of new and better algorithms, e.g. a physical retrieval of the Global Instability Index and the use of optimal estimation for the derivation of Total Ozone are currently being explored. The current scenes and cloud analysis scheme does also not fully utilise the multi-spectral information and could be further enhanced to derive cloud properties like optical depth. This information may turn out to be crucial for several products e.g. for the AMVs in order to properly establish the level at which the clouds travel. Many improved algorithms and products are developed and distributed by the EUMETSAT Satellite Application Facilities (SAFs). For some further details on the products and algorithms planned within the SAF context consult the EUMETSAT WEB pages www.eumetsat.de.

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