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METEOSAT SECOND GENERATION (MSG): CAPABILITIES AND APPLICATIONS

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1. INTRODUCTION

Meteosat Second Generation (MSG) is the new generation of European geostationary meteorological satellites MSG (Meteosat Second Generation). It has capabilities greatly enhanced over the current Meteosat series. The twelve channel imager, called SEVIRI (Spinning Enhanced Visible and Infrared Imager), observes the full disk of the Earth with an unprecedented repeat cycle of 15 minutes. Pixels are sampled with a distance of 3 km and the high resolution visible (HRV) channel even has 1 km sampling distance. The spectral channels, at 3.9, 6.2, 7.3, 8.7, 9.7, 10.8 ,12.0 and 13.4 µm and at 0.6, 0.8 and 1.6 µm, draw on experience from existing satellites, thus providing continuity of services and facilitating the development of novel operational applications. Thermal IR channels have an onboard calibration and for the solar channels an operational vicarious procedure is developed aiming at an accuracy of 5%. The core operational meteorological products are derived by the Meteorological Product Extraction Facility (MPEF) at EUMETSAT in Darmstadt. Other products will be derived in Satellite Application Facilities (SAF), a decentralised part of the Applications Ground Segment. As additional scientific payload MSG carries a Geostationary Earth Radiation Budget (GERB) instrument. The MSG system is established under a cooperation between ESA and EUMETSAT. The MSG Programme consists of a series of three identical satellites, which will provide observations and services over at least 12 years. The first launch of MSG is scheduled for 2002.

A novelty of MSG is the full disk imaging at time intervals of 15 minutes. Studies have shown that this has great potential to improve wind products mainly used for global Numerical Weather Prediction (NWP). The repeat cycle also provides unprecedented multi-spectral observations of rapidly changing phenomena (e.g. deep convection) and provides novel insight into rapid changes in cloud microphysics. Ongoing studies reveal the potential for monitoring atmospheric instability.

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2. THE SEVIRI INSTRUMENT

The primary mission of MSG is the continuous observation of the Earth's full disk. This is achieved with the Spinning Enhanced Visible and Infrared Imager (SEVIRI) imaging radiometer, a twelve channel imager observing the Earth-atmosphere system with a spatial sampling distance of 3 km in eleven channels. A high-resolution visible (HRV) channel covers half of the full disk with a 1 km spatial sampling. The actual field of view of the channels is about 4.8 km and 1.67 km.

A repeat cycle of 15 minutes for full-disk imaging provides unprecedented multi-spectral observations of rapidly changing phenomena (e.g. deep convection) and provides better and more numerous wind observations from the tracking of cloud features. Rapid scans of limited latitude belts are possible with shorter time intervals.

The imaging is performed by combining the satellite spin with the rotation (stepping) of the scan mirror. The images are taken from South to North and East to West. The nominal spin rate is 100 revolutions per minute. The spin axis is nominally parallel to the North-South axis of the Earth. The scan from South to North is achieved with 1250 E-W scans; this provides 3750 image lines for channels 1 through 11 (see Table 1) since 3 detectors for each channel are used for the imaging. For the HRV (channel 12) 9 detectors sweep the Earth for one line scan. The number of line scans is programmable such that shorter repeat cycles can be performed. A full disk image is obtained within about 12 minutes (see Figure 1). This is followed by the calibration of thermal IR channels (see section 2.2).

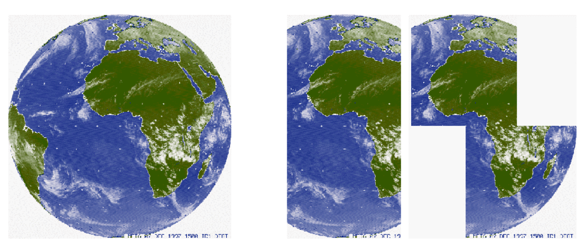

Figure 1: Coverage of MSG for the repeat cycle of 15 minutes for channels 1 through 11 (ref. Table 1). The High resolution Visible (HRV), i.e. channel 12, covers only half the Earth in E-W, however the area of imaging can be selected.

Channel No.		Channel Spectral Band in µm		
		λ_{cen}	λ_{min}	λ_{max}
12	HRV	Broadband (silicon response)		
1	VIS0.6	0.635	0.56	0.71
2	VIS0.8	0.81	0.74	0.88
3	NIR1.6	1.64	1.50	1.78
4	IR3.9	3.90	3.48	4.36
5	WV6.2	6.25	5.35	7.15
6	WV7.3	7.35	6.85	7.85
7	IR8.7	8.70	8.30	9.1
8	IR9.7	9.66	9.38	9.94
9	IR10.8	10.80	9.80	11.80
10	IR12.0	12.00	11.00	13.00
11	IR13.4	13.40	12.40	14.40

Table 1: Spectral channel characteristics of SEVIRI providing central, minimum and maximum wavelength of the channels.

Most SEVIRI spectral channels build upon the heritage from other satellites which has the great advantage that the operational user community can readily use existing know-how to utilise SEVIRI radiance observations. The heritage of channels can be summarised as follows:

VIS0.6 and VIS0.8: Known from the Advanced Very High Resolution Radiometer (AVHRR) of the polar orbiting NOAA satellites. Essential for cloud detection, cloud tracking, scene identification, aerosol and land surface and vegetation monitoring.

NIR1.6: Discriminates between snow and cloud, ice and water clouds, and provides aerosol information.

IR3.9: Known from AVHRR. Primarily for low cloud and fog detection (Eyre et.al., 1984). Also supports measurement of land and sea surface temperature at night. For MSG, the spectral band has been broadened to higher wavelengths to improve signal-to-noise ratio.

IR6.2 and IR7.3: Continues mission of Meteosat broadband water vapour channel for observing water vapour and winds. Enhanced to two channels peaking at different levels in the troposphere. Also support height allocation of semitransparent clouds.

IR8.7: Known from the High resolution Infra Red Sounder (HIRS) instrument on the polar orbiting NOAA satellites. The channel provides quantitative information on thin cirrus clouds and supports the discrimination between ice and water clouds.

IR9.7: Known from HIRS and current GOES satellites. Ozone radiances could be used as an input to Numerical Weather Prediction (NWP). As an experimental channel, it will be used for tracking of ozone patterns that should be representative for wind motion in the lower stratosphere. The evolution of the total ozone field with time can also be monitored.

IR10.8 and IR12.0: Well-known split window channels (e.g. AVHRR). Essential to measure sea- and land-surface and cloud top temperatures.

IR13.4: CO_2 absorption channel known from former GOES VAS instrument. It improves height allocation of tenuous cirrus clouds (Menzel et al., 1983). In cloud free areas, it will provide temperature information from the lower troposphere that can be used to infer static instability.

2.1 Radiometric Performance

The radiometric requirements for SEVIRI specify: i) short term error or noise, ii) mid-term drift error, and iii) bias or long-term drift error.

The short term error or noise requirement includes all factors affecting the radiometry during one nominal repeat cycle (15 minutes duration) and applies to in-orbit conditions at End Of Life (EOL). These are essentially: random noise, stability of temperature of detectors, crosstalk and straylight, stability of gain. Table 2 provides the measured performance of SEVIRI on MSG-1 and the specified requirements. Measured performance is based on tests complemented by a prediction of in-flight performances. Except for channel NIR1.6, the predicted in-orbit radiometric performances at EOL are better than the requirements. Thus excellent radiometric image quality can be expected.

The mid-term drift requirement limits the variation of the mean radiometric error in a sequence of nominal images. The requirement for the warm channels is a maximum drift over 1 day (i.e. 96 nominal repeat cycles) of less than 0.1% of the maximum of the dynamic range. The requirement for the cold (i.e. the thermal IR with cooled detectors) channels is a maximum drift between two on-board calibrations of less than 0.05K (or 0.1K for WV6.2 and WV7.3) at the maximum temperature of the dynamic range. The ground tests have shown that the worst case applies to channel IR12.0 requiring an on- board calibration every 10 images. It should, however, be noted that the baseline design of SEVIRI enables to perform one calibration per image cycle.

Channel	Short term radiometr error performances	Short term radiometric error requirements
HRV	0.93 at 1.3 W/(m² sr µm)	1.07 at 1.3 W/(m² sr µm)
VIS0.6	0.37 at 5.3 W/(m² sr µm)	0.53 at 5.3 W/ (m² sr µm)
VIS0.8	0.37 at 3.6 W/(m² sr µm)	0.49 at 3.6 W/(m² sr µm)
NIR1.6	0.25 at 0.75W/(m² sr µm)	0.25 at 0.75 W/(m² sr µm)
IR3.9	0.24K at 300K	0.35K at 300K
WV6.2	0.40K at 250K	0.75K at 250K
WV7.3	0.48K at 250K	0.75K at 250K
IR8.7	0.17K at 300K	0.28K at 300K
IR9.7	0.24K at 255K	1.5K at 255K
IR10.8	0.15K at 300K	0.25K at 300K
IR12.0	0.22K at 300K	0.37K at 300K
IR13.4	0.30K at 270K	1.80K at 270K

Table 2: Noise equivalent radiances and temperatures for the channels of the SEVIRI instrument on MSG-1 compared with the requirements. Values for the thermal IR channels refer to a focal plane temperature of 95K.

The bias and long-term drift requirement specifies the absolute radiometric error (i.e. the difference between the measured radiance and the actual radiance at the input of the instrument). Tests confirmed that the performance for all thermal IR channels is about 0.5 K for typical warm scene temperatures of 300 to 335 K (see also following section on calibration).

2.2 SEVIRI Calibration

The thermal IR channels of SEVIRI are calibrated with an on-board blackbody (Pili, 2000). The relationship between digital counts and the observed radiance is assumed to be linear:

$$C(L) = g\, L(\lambda, T) + C_0$$

Where C(L) is the digital count output from SEVIRI, L(λ, T) the measured radiance, λ the wavelength (in practice a spectral interval), T the effective blackbody temperature of an observed scene, g the gain (or calibration coefficient) and C_0 the offset. The assumption of a linear relationship between counts and radiance is valid since small non-linearity are corrected for on ground before applying the linear calibration procedure.
SEVIRI uses the deep space as cold source and an internal blackbody as warm source for the calibration. While the deep space view is obtained by viewing through the complete optical path of the instrument the blackbody is moved into the optical path avoiding the front optics. This design necessitates a correction to be applied to the blackbody calibration considering the optical properties of the front optics, whose characteristics have been measured before launch and whose temperature is monitored continuously. The blackbody can also be heated to allow for the determination of the correction factor. Overall a calibration performance better of about 0.5 K is expected for all thermal IR channels (Pili, 2000).

The solar channels (channels 1 –3 and 12) do not have an on-board calibration but have to rely on a vicarious method based on radiance observations over well-characterised targets (clear-sky desert, clear-sky ocean and optically thick high level clouds) and radiative transfer simulations (Govaerts et al., 2000). This new method of solar channel calibration will achieve an accuracy of the about 5% after the first year of operations as the characterisation of targets improves and quality control parameters will become better tuned.

3. MSG PRODUCTS

The derivation of level 2.0 meteorological products, is performed within the Applications Ground Segment (AGS) which consists of:
1) a central Meteorological Products Extraction Facility (MPEF)
2) a network of satellite Application Facilities (SAF) located at National Weather Services and other institutions of EUMETSAT member states.

3.1 Products from the Central MPEF

The Scenes Analysis (SCE) is the first step and an intermediate product of the MSG MPEF which is further used in the derivation of other products requiring either cloudy or clear pixels. The results of Scenes Analysis algorithm will provide per pixel and repeat cycle:
i) Identification of cloudy and clear pixels and a cloud mask, ii) Identification of scene type for each pixel, iii) Radiances at the top of the atmosphere.
The Scenes Analysis algorithm is based on threshold techniques (e.g. Saunders and Kriebel, 1988). Advantage is taken of the 15 minute repeat cycle by using results of the previous image as first guess in the current image. SCE and Cloud Analysis are described in more detail by Lutz (1999).

Cloud Analysis (CLA) is based on the Scenes Analysis results and provides on a scale of 100 km x 100 km (or better) information about cloud cover, cloud top temperature, cloud top pressure/height and cloud type and phase. An important objective of the Cloud analysis product is to support the generation of the Atmospheric Motion Vectors (AMV). Therefore an intermediate product for each pixel and repeat cycle, which provides the necessary internal input to the Atmospheric Motion Vectors, is derived, but not disseminated. This intermediate (pixel scale) Cloud Analysis is also used for the Cloud Top Height product. It also provides input to the statistical information contained in the off-line Climate Data Sets product.
Cloud Top Height (CTH) is a derived product image, which provides the height of the highest cloud at a super-pixel resolution of 3x3 pixels. This product is for use in aviation meteorology. It provides the heights with a vertical resolution of 300 meter.
Clear Sky Radiance (CSR) gives mean radiances (in $Wm^{-2}\ sr^{-1}\ (cm^{-1})^{-1}$) for cloud-free pixels. Operational NWP centres will use CSR products from the MSG infrared channels in their analyses. The benefit will emerge with the advent of 4-d variational data assimilation systems that have the capability to utilise the frequent time observations from geostationary orbit (e.g. Munro et al., 1998).
Tropospheric Humidity (TH) provides estimates of layer-mean relative humidity for two tropospheric layers. One layer humidity (between about 600 and 200 hPa) is based on 6.3 µm clear sky radiances; this product is also known as UTH (upper tropospheric humidity) from the current Meteosat MPEF. The mean relative humidity of a second layer (between 850 and 350 hPa) uses clear sky 7.3 µm and is named MTH (mid-tropospheric humidity). The algorithm follows the improved UTH retrieval presented in Schmetz et al. (1995).

Atmospheric Motion Vectors (AMV) are the most important product for numerical weather prediction. The tropospheric AMVs will be derived from cloud and water vapour motion using primarily the 0.6 or 0.8 µm channel, the 10.8 µm channel and the 6.2 and 7.3 µm channels, respectively. The capabilities to extract lower stratospheric displacements vectors from ozone will also be exploited.

The product is based on conceptually validated ideas and methods (e.g. Schmetz at al., 1993 and Holmlund, 2001). An important feature, already implemented in the current Meteosat products, is the improved automatic quality control using quality indicators (Holmlund, 1998). The MSG algorithm also features novel concepts, such as i) a wind vector assignment to the exact target position, ii) improved target selection and enhancement, iii) improved quality control which benefits from the fact that wind fields from a single repeat cycle are used to derive a spatially dense final AMV product, iv) improved height assignment for semitransparent cloud tracers.

ISCCP Data Set (IDS) continues the support to the International Satellite Cloud Climatology Programme (ISCCP) providing three different data formats.

High Resolution Precipitation Index (HPI) continues the support to the Global Precipitation Climatology Project (GPCP) and provides the frequency of pixels for classes of brightness temperatures. Since it is indicative of convective (tropical) rainfall the product is confined to the latitudes between 40°S and 40°N.

Climate Data Set (CDS) provides statistical information about the scene classes in a processed segment (nominally 32x32 pixels). It is a concise summary of the radiances observed in a segment and potentially very useful for climatological studies of cloud and radiation fields.

Global Instability Index (GII) is an air mass parameter indicating the stability of the atmosphere at a scale of about 30 km. It is closely related to products from the SAF for Nowcasting and Very Short Range Forecasting, except that the GII is derived globally and disseminated. Based on successful applications and experience by NOAA/NESDIS with GOES lifted index products (Menzel et al., 1998) the idea for the GII emerged. Two algorithms are currently foreseen for the GII product i) a physical retrieval (Ma et al., 1999) and ii) an artificial neural network. Details on GII product are provided in this issue (König et al., 2001).

Total Ozone Product (TOZ) uses the 9.7 µm channel, other SEVIRI channels and correlative data and is derived with a regression algorithm (Orsolini and Karcher, 2000). The ozone observations are useful input for monitoring and forecasting UV radiation at the ground level. Preliminary studies show that ozone observations at high temporal and spatial resolution may provide useful information about the winds in the upper troposphere and lower stratosphere, although the derivation of dense vector fields seems difficult. Alternatively, the ozone observations can be assimilated into a numerical model with a suitable multivariate data assimilation system in which the forecast includes a prognostic equation for ozone (e.g. Riishojgaard, 1996).

3.2 Products from Sattellite Application Facilities (SAF)

Satellite Application Facilities (SAF) are specialised development and processing centres within the EUMETSAT Applications Ground Segment. Utilising specialised expertise in Member States, they will complement the production of meteorological products derived from satellite data at EUMETSATs Central Facilities (the MPEF) and will also distribute user software packages. There are currently seven SAFs. Links to relevant web pages are provided via the EUMETSAT web page www.eumetsat.de/SAF/. A generic list of products, relevant ot the use of MSG, from the Ocean and Sea Ice SAF, the SAF for Land Surface Analysis and the Climate SAF reads as follows:

- Examples of products from the Ocean and Sea Ice SAF include i) Atlantic Sea Surface Temperature, ii) Surface radiative fluxes over the Atlantic, iii) Sea Ice (Polar Atlantic): ice edge/cover, thickness/age.
- Examples of products from the Climate SAF are i) Sea Surface Temperature and sea ice cover, ii) Cloud parameters, iii) Surface radiation budget components, iv) Radiation budget components at TOA, v) humidity products.
- Examples of targeted products from the Land Analysis SAF are i) Vegetation parameters and biophysical indicators, ii) Snow cover, iii) Land Surface Temperature, emissivity and moisture, iv) Short wave and long wave radiation parameters.

Some SAF products are composites and based on multi-mission data including MSG data as one source. It is also noted that the SAF on Nowcasting and Very Short Range Forecasting develops software for a suite of products that can be derived from MSG. The software will be made available for local implementation.

3.3 Development Toward New Applications

The improvement of products will be a continuous task. Several improvements are already planned. For instance, Tjemkes and Watts (2000) report on a research study which investigates new ways to perform a scenes analysis. The new method uses 'optimum estimation' Rodgers (1976) as novel way to infer simultaneously a set of cloud parameters and possibly surface features. This Enhanced Cloud Product (ECP) derives the following cloud micro-physical properties from SEVIRI observations: Optical Thickness, Mean Particle Radius, Cloud Top Temperature, Cloud Top Pressure, and Cloud Phase.

An area for improvement are the Atmospheric Motion Vectors (Holmlund, 2001) where two products will complement the current Day-1 baseline products:

i) Ozone Motion Vectors describe the displacement of total ozone features and include a height assignment of the derived vectors. In the baseline of the MSG-MPEF the use of total ozone product derived from observations in the IR 9.6 channel for the derivation of displacement vectors in the stratosphere was not foreseen. ii) Low Level Winds over Land and Ocean will be an enhancement of the current low-level wind products. It gives the displacement of low level clouds derived from HRVIS, 0.6, 0.8 and 3.9 µm observations. In order to improve the quality of the low level wind field over land a new target selection, image enhancement, and cloud height and tracking procedures are developed that utilise the full capabilities of the SEVIRI instrument. Initial study results are encouraging (Szantai et al., 2000).

MSG will also provide new potential for observing components of the hydrological cycle which undergo rapid changes. Convective cloud processes related to thunderstorms or frontal systems require an appropriate monitoring with a high temporal repeat cycle. Cloud glaciation and precipitation formation occur rapidly and imagery from current geostationary satellites at the 30 minute time scale seem to be inadequate for capturing the transient processes that influence precipitation formation. The change in time of cloud microphysical state as observable from multispectral imagery may provide useful information on the formation of precipitation. Recent work by Rosenfeld and Lensky (2000) shows that microphysical processes, relevant to precipitation, can be observed with multispectral satellite imagery.

MSG also provides novel perspectives for applications over land (see EUMETSAT-SAI Report, 1999) because of its multispectral imagery in the visible, near-infrared and thermal infrared bands. The quantitative application of the visible and near-infrared bands will be facilitated through the development of an accurate operational vicarious calibration (Govaerts, 2000a). An interesting application is the monitoring of the land surface reflectance. The utility of such a product has been demonstrated by Pinty et al. (2000a and b) who derive a Meteosat surface albedo (i.e. confined to the spectral band of the VIS channel of the current generation of Meteosat satellite) with an algorithm accounting for water vapour and ozone absorption, aerosol scattering and surface anisotropy.

4. GERB

The Geostationary Earth Radiation Budget Experiment (GERB) is a visible-infrared radiometer for Earth radiation budget studies (Harries, 2000). It makes accurate measurements of the shortwave (SW) and longwave (LW) components of the radiation budget at the top of the atmosphere. It is the first ERB experiment from geostationary orbit. It measures the solar waveband from 0.32 – 4 µm and the total from 0.32 – 30 µm. The LW from 4 – 30 µm is obtained through subtraction. With a nominal pixel size of about 45 by 40 km (NS x EW) at nadir view it obtains an absolute accuracy better than 2.4 $Wm^{-2}ster^{-1}$ (< 1%) in the SW and better 0.4 $Wm^{-2}ster^{-1}$ for the SW. The channel co-registration with respect to SEVIRI is 3 km at the subsatellite point. The cycle time for full disk is 5 minutes for both channels (15 minutes for full radiometric performance). The derivation of products from GERB is described by Dewitte et al. (2000).

5. CONCLUDING REMARKS

The Meteosat Second Generation (MSG) system will significantly enhance the observation capabilities for rapidly changing phenomena such as cloud and water vapour structures. These will help nowcasting, short range forecasting and numerical weather prediction through improved and more frequent products. The capabilities of MSG are also expected to be of great value to research in various disciplines. Notably investigations of convective phenomena will benefit from the operational 15 minute repeat cycle. It will be a major challenge to enhance the utilisation of the multispectral image data in weather forecasting (e.g. NWP and Nowcasting). Images do contain a wealth of information on cloud and humidity structures which can be used to improve the corresponding analyses of humidity and cloud; however this has only an impact on the very short range forecast unless the wind and mass fields get also adjusted in consistent way. Sequences of images do contain information on dynamical development, which currently is hardly used in a quantitative manner. Future developments of models resolution, the ability of models to represent humidity and cloud features together with the development of 4-d assimilation systems may provide the basis for improved utilisation of the satellites image data (Eyre, 2001).

The current network of Satellite Application Facilities provides the basis for a wide use of the capabilities of MSG in various disciplines in meteorology. More information on MSG is available on the EUMETSAT webpage under www.eumetsat.de (go to Meteosat Second Generation) and www.eumetsat.de/saf/.

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