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Short Note

FMet—an integrated framework for Meteosat data processing for operational scientific applications☆

Jan Cermak*, Jörg Bendix, Maik Dobbermann

Laboratory for Climatology and Remote Sensing, Philipps-Universität Marburg, Germany

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Abstract

This paper introduces the FMet software package for the scientific processing of Meteosat SEVIRI data. A number of individual modules handle the processing steps from image format conversion to calibration and product generation and presentation. The package is designed for operational applications. It can be freely extended and configured using a dynamic graphical user interface.

Keywords: Meteosat second generation; SEVIRI; Software package; Operational processing

1. Introduction

1.1. The MSG SEVIRI system

With increasing user demands and improving technical possibilities, the Meteosat second generation (MSG) series of meteorological satellites was designed in the last decade of the 20th century. After a commissioning phase of about one year, the first of a planned four MSG systems, MSG 1, became operational in early 2004. It has since been known as 'Meteosat 8'. In April 2007 the identical MSG 2 satellite became the primary system operating at 0° longitude as Meteosat 9. MSG 4, the last in the series, is planned to commence operation about 2013,[1] so that continuity is provided for Munro et al. (2002), Schmetz et al. (2002), and Schumann et al. (2002).

The MSG satellites carry two sensors: the geostationary earth radiation budget (GERB) instrument and the spinning-enhanced visible and infrared imager (SEVIRI). GERB, as its name indicates, is intended for the study of the earth's radiation budget; it is equipped with one shortwave and one longwave band (Harries et al., 2005; Mueller et al., 1999; Sandford et al., 2003; Harries and Crommelynck, 1999). SEVIRI on the other hand is designed for the continuous monitoring of the earth–atmosphere system. At a repeat rate of 15 min data are collected in 12 spectral bands (see Table 1). The Meteosat 9 satellite is centred at 0° longitude; one scan cycle covers the hemisphere seen from this point (see Fig. 1).

☆Code available from server at http://sourceforge.net/projects/fmet.

*Corresponding author.
E-mail address: cermak@lcrs.de (J. Cermak).

[1]www.eumetsat.int.

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Table 1
SEVIRI channels (Schmetz et al., 2002, modified)

Band no.	λ_c	λ_{min}	λ_{max}	Main absorber/window	Main use (LCRS)
1	0.64	0.56	0.71	Window	CMP
2	0.81	0.74	0.88	Window	SOFOS
3	1.64	1.50	1.78	Window	CC
4	3.90	3.48	4.36	Window	SOFOS, CMP
5	6.25	5.35	7.15	Water vapour	RADS
6	7.35	6.85	7.85	Water vapour	RADS
7	8.70	8.30	9.10	Window	CC
8	9.66	9.38	9.94	Ozone	
9	10.80	9.80	11.80	Window	SOFOS
10	12.00	11.00	13.00	Window	SOFOS
11	13.40	12.40	14.40	CO_2	SOFOS
12	(Broadband)	~ 0.4	~ 1.1	Window, water vapour	

λ_c: central wavelength, λ_{min} and λ_{max}: lower and upper wavelength limits (all in μm). Last column gives information on main use of channels in LCRS products (see Section 3).

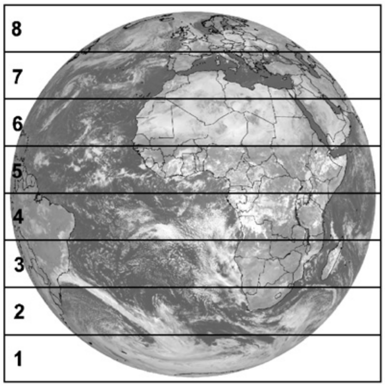

Fig. 1. SEVIRI spatial coverage (30 September 2004, 1100 UTC) with country borders and HRIT image segments for 3 km channels. HRV channel data are split into 24 segments (not shown).

Channel 12, the high resolution visible (HRV) channel, has a nominal spatial resolution of 1 km at sub-satellite point. The other channels feature spatial resolutions of 3 km. SEVIRI level 1.5 data are rectified on a constant grid with its centre on 0° longitude (Schmetz et al., 2002).

1.2. The need for a data processing system

MSG data are readily available to a large user community via the EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) Broadcast system, EUMETCast. This wide availability can be seen as an important strength of the system; as a consequence, a number of commercial and free software packages are available for MSG data handling. However, the main focus of these programs is on the visualisation of the data in colour composites and animations. For scientific and operational automated applications though, full access to all dimensions of the data is essential. EUMETSAT provides a 'SEVIRI Pre-processing Toolbox (SPT)' package (available at www.eumetsat.int). SPT is a collection of tools for reading in SEVIRI data. However, as the manual clearly states, its main purpose is to illustrate how the data can be accessed and it does not provide capabilities for automated and operational data processing (Govaerts et al., 2007).

Therefore the framework for Meteosat data processing (FMet) package was developed at the Laboratory for Climatology and Remote Sensing (LCRS). It provides both, a framework for the processing of SEVIRI data and a logistic wrapper for operational higher-level product generation. FMet is used for processing Meteosat SEVIRI data at the LCRS. It is also available for use by other groups.

2. The FMet system

FMet is a modular collection of FORTRAN 90 programs coordinated by a central application. Each component fills a position in the processing chain. FMet is designed to run on a Linux system, with the possibility of linking a number of computers to increase processing power (e.g. for re-processing operations). If more than one computer is available, individual instances of FMet running on multiple computers 'collect' scenes from a central file server according to capacity. While designed to run on a Linux platform, the generic nature of the code provides for portability to other systems.

MSG SEVIRI data have been received at the Marburg Satellite Station (MSS) since 2003, when MSG 1 was still in the commissioning phase. FMet development began immediately and has been continuing since then. A detailed description of the scheme is provided in the following; an overview of the scheme with its modules is given in Fig. 2.

The raw count data provided in the EUMETCast data stream are referred to as level 1.5 data (EUMETSAT, 2005b). Since the raw image counts do not have a geophysical meaning they cannot be used directly in product generation. Within FMet, level 1.5 data are transformed into elementary geophysical and higher-level products.

FMet is fully configurable. Options include: the satellite channels to be processed; the calibration level desired for each channel; products required; free configuration of all relevant parameters and settings for each routine. The program can be run in online (i.e. operational processing) and offline (i.e. re-processing of archived data) modes. The FMet modules shown in Fig. 2, MetGet, MetGeo, MetCal, MetProd and MetOut, are described in detail in the following. Some of these modules combine several small program utilities, each of which adds to the task of the module. These utilities are given in italics and also shown in the overview figure.

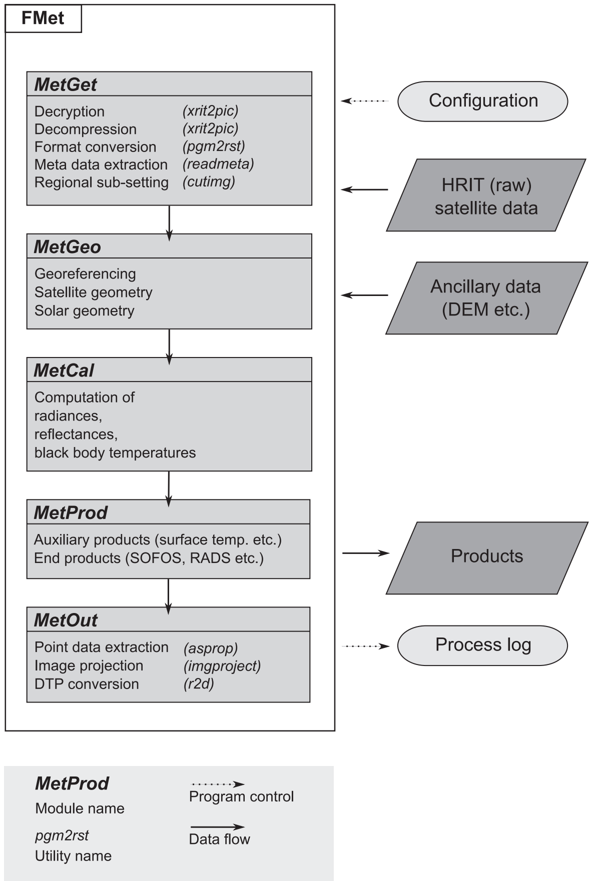

Fig. 2. Overview of FMet scheme. Explanations see text.

2.1. MetGet: HRIT data handling and import

In a first module, MetGet, data conversion, import and regional sub-setting are performed. Level 1.5 data are thus made accessible for higher-level product generation. The high rate information transmission (HRIT) data stream received contains wavelet encrypted, compressed and segmented imagery. In a first step, the individual channels of a scene therefore need to be decrypted, decompressed and concatenated (EUMETSAT, 2001, 2003).

Decryption is performed using the EUMETCast Client Software (EUMETSAT, 2004), with a hardware device, the EUMETCast Key Unit (EKU). Wavelet decompression requires a software package available under license from EUMETSAT. This software is incorporated in the *xrit2pic* package,[2] which also handles image concatenation. MetGet controls the operation of *xrit2pic* and captures its output for further use. The image concatenated by *xrit2pic* is then converted from pgm (pixel grey map) to a flat binary format with geometry information in separate text files by the *pgm2rst* utility. The EUMETCast software and *xrit2pic* are the only external components used in the FMet scheme. All other utilities were newly developed.

After the image data have been made available in this way, the *readmeta* utility extracts ancillary information from the original HRIT file headers (cf. EUMETSAT, 2003, 2005a, b). These meta data include information on channel radiometric calibration, geolocation and nominal line timing, among others. These parameters are saved for later use.

[2]Alblas, R., Xrit2pic software manual, available from http://www.alblas.demon.nl/wsat/software/man_xrit2pic.html.

Finally, based on user-defined settings, a region of interest is cut by *cutimg* from all channels and also from any ancillary data files provided (e.g. a digital elevation model). This region is set in the main FMet configuration file.

2.2. MetGeo: geolocation and geometry

SEVIRI images are available in a normalised geostationary projection according to Coordination Group for Meteorological Satellites (CGMS, 1999). This projection is defined in relation to the sub-satellite (nadir) longitude ϕ_n (0°W in the case of MSG). The view point (satellite) is assumed to be located perfectly above the equator and exactly at ϕ_n. The geolocation accuracy for SEVIRI is better than 3 km at nadir and better than 0.75 km within a 16 by 16 pixel environment. The relative image-to-image collocation accuracy yields a root mean square error (RMSE) of 1.2 km (Schmetz et al., 2002).

The conversion of image coordinates into geographical coordinates is described in CGMS (1999). For each image coordinate, latitude and longitude are computed accordingly and saved in corresponding data sets for use by succeeding programs. Likewise, satellite and solar geometry, i.e. zenith and azimuth angles are calculated and saved.

These actions are performed for the 3 km channels as well as the 1 km HRV channel. Thus, operations combining both resolutions become possible in later processing.

2.3. MetCal: image calibration

Image calibration converts level 1.5 raw image counts to geophysically meaningful parameters. These are spectral radiance, black body temperature (thermal channels) and reflectance (solar channels).

For each channel i the conversion of raw image counts C_i to spectral radiance I_i is performed using

$$I_i = C_i s_i + o_i \ (\mathrm{W\,m^{-2}\,sr^{-1}\,cm}) \tag{1}$$

with scaling (s_i) and offset (o_i) factors derived from on-board blackbody calibration for the thermal channels and using bright desert target sites for channels in the visible range (Govaerts et al., 2001; Govaerts and Clerici, 2004).

For the thermal channels, equivalent blackbody temperatures (T_i) are computed using an analytic relationship with observed radiances based on the inverted Planck function:

$$T_i = \left[C_2 \nu_{ci} \Big/ \ln\left(\frac{C_1 \nu_{ci}^3}{I_i} + 1\right) - B_i \right] \Big/ A_i \ (\mathrm{K}) \tag{2}$$

with the radiation constants $C_1 = 2\pi hc^2$ and $C_2 = (hc)/k$, where c (m s^{-1}): speed of light, h (J s): Planck constant, and k (J K^{-1}): Boltzmann constant. ν_{ci} (cm^{-1}) is the central wavenumber for channel i, A_i and B_i (K) are constants derived in non-linear regression for each channel.

For the shortwave channels, reflectance r_i is computed as follows:

$$r_i = \frac{\pi I_i D^2}{E_i \cos(\theta_0)} \tag{3}$$

with D the earth–sun distance, θ_0 the solar zenith angle and E_i (W m^{-2} cm) the spectrally integrated extraterrestrial irradiance for channel i. The latter was derived by polynomial interpolation of extra-terrestrial solar spectral radiance data (presented in Wehrli, 1985).

2.4. MetProd: operational product generation

Using the georeferenced and calibrated data produced by MetGeo and MetCal, higher-level product generation can be performed in the FMet framework. The MetProd module allows for the dynamical inclusion and configuration of external algorithms. Some products computed at LCRS are listed in the next section; additional products can be added at any time.

2.5. MetOut: output formatting

In the MetOut module products of any processing stage can be reformatted for post-processing, e.g. for presentation or use in other applications. Options are:

- The *asprop* utility extracts product information for selected individual pixels, e.g. for inter-comparison with point data or for localised time series analysis.
- For conversion of output images to common desktop publishing formats *r2d* was developed. This program supports a range of colour palettes, annotations and legend formats. Selected products are routinely converted for presentation on the internet.
- With *imgproject*, the images can be transformed from the geostationary view to other projections.

This step is performed only after processing, because of the information loss (pixel redundancy and gaps) incurred in re-sampling. Currently, a nearest-neighbour algorithm is implemented to arrange image values on a simple latitude/longitude grid.

2.6. *Configuring FMet*

The configuration of FMet and all component programs is implemented in an ASCII file holding a number of FORTRAN namelists. There is one namelist for each program component. For instance, the borders of the region to be cut out can be set here. Also, it is possible to define what products are to be computed for each scene and what thresholds are to be applied in various tests. Directory paths can be modified, backup and disk cleanup options defined. In addition, email addresses for log and error report dispatch can be specified.

To ease editing of program options, a graphical user interface (GUI) has been developed in Java (see Fig. 3). This GUI automatically reads the configuration file, allows for easy editing of the same and saves user settings to make them available to FMet.

3. Selected operational applications

A number of higher-level meteorological products are generated by algorithms linked into the MetProd module (see above). At the moment these include various cloud area and cloud property retrievals:

- Cloud mask: This is computed using dynamic histogram thresholding in the thermal and middle infrared (Cermak and Bendix, 2008).
- Cloud classification (CC): A multi-step procedure using spectral and spatial characteristics to discriminate between various cloud types.
- Cloud microphysical properties (CMP) based on schemes by Kawamoto et al. (2001) and Kokhanovsky et al. (2003).
- SOFOS—Satellite-based Operational Fog Observation Scheme: A technique for daytime and nighttime detection of ground fog and elevated fog areas (Cermak and Bendix, 2007, 2008); cloud microphysical and spatial properties are assessed jointly.
- RADS—Rain Area Delineation Scheme: A set of algorithms for the delineation of raining areas (Nauss et al., 2005); this technique heavily draws on cloud microphysical properties.

These algorithms are listed here to highlight the modular design of FMet that allows for the inclusion of any scientific algorithms into the operational processing chain. The details of the specific methods are described in the publications referenced above.

One example product implemented within FMet at LCRS is cloud liquid water path (LWP). Fig. 4 shows an example from a validation study performed for this product. LWP has been compared with values retrieved using data from the ASMUWARA microwave radiometer (Martin et al., 2006) during a campaign in Payerne, Switzerland. Disagreements in this particular sample could be traced to vertical cloud inhomogeneities. A detailed analysis of similar cases and a treatment of potential synergies of such joint measurements can be found in Cermak et al. (2006).

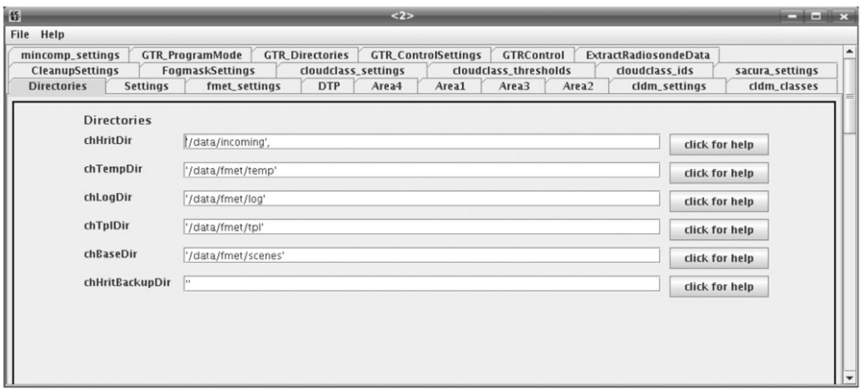

Fig. 3. Graphical user interface used to configure FMet and component programs.

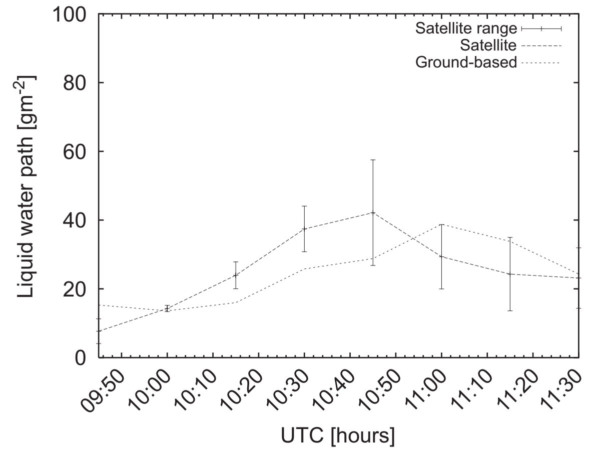

Fig. 4. An intercomparison between ground-based LWP measurements (radar) and satellite product for Payerne, Switzerland, 30 December 2003. 'Satellite range' refers to values in a 3 by 3 pixel environment.

4. Conclusions and outlook

The FMet framework combines a range of tools that can be used to automate the processing of SEVIRI data, including the computation of user-defined products, freely configurable by the user. The major strengths of FMet are its modularity and suitability for operational processing. Examples of products currently computed at LCRS are given in the paper. However, a user can individually define what algorithms he/she wants to run in this framework.

The software framework is applicable to all SEVIRI data, including Meteosat 8, Meteosat 9 and Rapid Scans. Recently, routines for the processing of GOES (Geostationary Operational Environmental Satellite) data, also contained in the EUMETCast stream, have been added. Thus, operational processing of GOES can now also be performed in this framework.

The FMet software package is available free of charge under an open source license (http://sourceforge.net/project/fmet). The software may be freely downloaded, used and tailored to individual requirements.

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