MTG-FCI: ATBD for Outgoing Longwave Radiation Product

Doc.No.	:	EUM/MTG/DOC/10/0527
Issue	:	v2
Date	:	14 July 2011
WBS	:	MTG-834200

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Document Change Record

Issue / Revision	*Remarks*
v1 Draft	For internal review
v1D of 17 January 2011	First published version
V2 of 14 July 2011	Second published version, following the recommendations of the System PDR Science Panel

Table of Contents

1 INTRODUCTION

1.1 Purpose of this Document

This document describes the algorithm theoretical basis for the derivation of the Outgoing Longwave Radiation (OLR) product, as it shall be derived from the Meteosat Third Generation Flexible Combined Imager (MTG-FCI).

1.2 Structure of this Document

Section 2 of this document provides a short overview over the MTG imaging instrument characteristics and the derived meteorological products, which will be referenced later in the text. This is followed by a detailed description of the underlying algorithm of the OLR product – its physical basis, the required input data, and a more detailed description of the product retrieval method.

A full list of acronyms is provided in section 1.4, a glossary of the equation symbols used in this document can be found in section 4.

1.3 Applicable and Reference Documents

The following documents have been used to establish this document:

Doc ID	***Title***	***Reference***
[AD-1]	MTG End Users Requirements Document	EUM/MTG/SPE/07/0036
[AD-2]	MTG Products in the Level-2 Processing Facility	EUM/C/70/10/DOC/08
[AD-3]	MTG-FCI ATBD for Cloud Mask and Cloud Analysis Product	EUM/MTG/DOC/10/0482
[RD-1]	An Improved Model for the Calculation of Longwave Flux at 11 µm	P. Abel and A. Gruber, 1979: NOAA Tech Report NESS **106**, 24 pp, Natl. Oceanic and Atmos. Admin., Washington, DC
[RD-2]	Outgoing Longwave Radiation and Its Diurnal Variation at Regional Scales Derived from Meteosat	Schmetz, J. and !. Liu, 1988. J. Geophys. Res., **93**, D9, 11,192 – 11,204

1.4 Acronyms and Definitions

The following table lists definitions for all acronyms used in this document.

Acronym	*Full Name*
AER	Aerosol Product
AMV	Atmospheric Motion Vectors
ASR	All Sky Radiance
ATBD	Algorithm Theoretical Basis Document
CLA	Cloud Analysis
CRM	Clear Sky Reflectance Map
CT	Cloud Type Product
ECMWF	European Centre for Medium Range Weather Forecast
FCI	Flexible Combined Imager
FCI-FDSS	FCI Full Disk Scanning Service
FCI-RSS	FCI Rapid Scanning Service
FDHSI	Full Disk High Spectral Resolution Imagery
GERB	Geostationary Earth Radiation Budget (instrument onboard MSG)
GII	Global Instability Indices
HRFI	High Spatial Resolution Fast Imagery
HRV	High Resolution Visible Channel of SEVIRI
IR	Infrared (channel)
LPW	Layer Precipitable Water
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
NIR	Near Infrared (channel)
NWP	Numerical Weather Prediction
OCA	Cloud Product (Optimal Cloud Analysis)
OLR	Outgong Longwave Radiation
RTM	Radiative Transfer Model
RTTOV	Radiative Transfer for TOVS
SCE	Scene Identification
SAF	Satellite Application Facility
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SSD	Spatial Sampling Distance
TIROS	Television and Infrared Observation Satellite
TOA	Top of Atmosphere
TOVS	TIROS Operational Vertical Sounder
TOZ	Total Column Ozone
VIS	Visible (channel)

2 OVERVIEW

2.1 Relevant Instrument Characteristics

The mission of the Meteosat Third Generation (MTG) System is to provide continuous high spatial, spectral and temporal resolution observations and geophysical parameters of the Earth / Atmosphere System derived from direct measurements of its emitted and reflected radiation using satellite based sensors from the geo-stationary orbit to continue and enhance the services offered by the Second Generation of the Meteosat System (MSG) and its main instrument SEVIRI.

The meteorological products described in this document will be extracted from the data of the Flexible Combined Imager (FCI) mission. The FCI is able to scan either the full disk in 16 channels every 10 minutes with a spatial sampling distance in the range 1 – 2 km (Full Disk High Spectral Resolution Imagery (FDHSI) in support of the Full Disk Scanning Service (FCI-FDSS)) or a quarter of the earth in 4 channels every 2.5 minutes with doubled resolution (High spatial Resolution Fast Imagery (HRFI) in support of the Rapid Scanning Service (FCI-RSS)).

FDHSI and HRFI scanning can be interleaved on a single satellite (e.g. when only one imaging satellite is operational in orbit) or conducted in parallel when 2 satellites are available in orbit. Table 1 provides an overview over the FCI spectral channels and their respective spatial resolution.

The FCI acquires the spectral channels simultaneously by scanning a detector array per spectral channel in an east/west direction to form a swath. The swaths are collected moving from south to north to form an image per spectral channel covering either the full disk coverage or the local area coverage within the respective repeat cycle duration. Radiance samples are created from the detector elements at specific spatial sample locations and are then rectified to a reference grid, before dissemination to the End Users as Level 1 datasets. Spectral channels may be sampled at more than one spatial sampling distance or radiometric resolution, where the spectral channel has to fulfil FDHSI and HRFI missions or present data over an extended radiometric measurement range for fire detection applications.

Table 1: Channel specification for the Flexible Combined Imager (FCI)

Spectral Channel	*Central Wavelength, $\lambda 0$*	*Spectral Width, $\Delta\lambda 0$*	*Spatial Sampling Distance (SSD)*
VIS 0.4	0.444 µm	0.060 µm	1.0 km
VIS 0.5	0.510 µm	0.040 µm	1.0 km
VIS 0.6	0.640 µm	0.050 µm	1.0 km 0.5 km [#1]
VIS 0.8	0.865 µm	0.050 µm	1.0 km
VIS 0.9	0.914 µm	0.020 µm	1.0 km

Spectral Channel	***Central Wavelength***, $\lambda 0$	***Spectral Width***, $\Delta\lambda 0$	***Spatial Sampling Distance (SSD)***
NIR 1.3	1.380 µm	0.030 µm	1.0 km
NIR 1.6	1.610 µm	0.050 µm	1.0 km
NIR 2.2	2.250 µm	0.050 µm	1.0 km 0.5 km #1
IR 3.8 (TIR)	3.800 µm	0.400 µm	2.0 km 1.0 km #1
WV 6.3	6.300 µm	1.000 µm	2.0 km
WV 7.3	7.350 µm	0.500 µm	2.0 km
IR 8.7 (TIR)	8.700 µm	0.400 µm	2.0 km
IR 9.7 (O_3)	9.660 µm	0.300 µm	2.0 km
IR 10.5 (TIR)	10.500 µm	0.700 µm	2.0 km 1.0 km #1
IR 12.3 (TIR)	12.300 µm	0.500 µm	2.0 km
IR 13.3 (CO_2)	13.300 µm	0.600 µm	2.0 km

#1: The spectral channels VIS 0.6, NIR 2.2, IR 3.8 and IR 10.5 are delivered in both FDHSI sampling and a HRFI sampling configurations.

2.2 Generated Products

The agreed list of MTG-FCI Level 2 products is detailed in [AD-2] and is repeated here for easy reference:

1. **SCE-CLA**:
   Scene Identification (cloudy, cloud free, dust, volcanic ash, fire) and a number of cloud products (cloud top height, phase)
2. **OCA**:
   Cloud Product (cloud top pressure and temperature, cloud top phase, cloud top effective particle size, cloud optical depth, cloud sub-pixel fraction)
3. **ASR**:
   All Sky Radiance (mean IR radiance on an n x n pixel grid, together with other statistical information, for different scenes)
4. **CRM**:
   Clear Sky Reflectance Map (VIS reflectance for all non-absorbing channels, accumulated over time)
5. **GII**:
   Global Instability Indices (a number of atmospheric instability indices and layer precipitable water contents)
6. **TOZ**:
   Total Column Ozone (technically retrieved within the GII product)
7. **AER**:
   Aerosol Product (asymmetry parameter, total column aerosol optical depth, refractive index, single scattering albedo, size distribution)
8. **AMV**:
   Atmospheric Motion Vectors (vector describing the displacement of clouds or water vapour features over three consecutive images, together with a vector height)
9. **OLR**:
   Outgoing Longwave Radiation (thermal radiation flux at the top of the atmosphere leaving the earth-atmosphere system)

The products will be derived from the spectral channel information provided by the FDHSI mission, on the resolution detailed in [AD-2].

This ATBD describes the algorithm of the OLR product. The retrieval process makes use of the results of the SCE-CLA product. The product will be derived over a certain processing area, defined as all pixels lying within a great circle arc of pre-defined size around the subsatellite point (typically 70°).

3 ALGORITHM DESCRIPTION

3.1 Physical Basis Overview

The Earth Radiation Budget is made up of the incoming solar flux and the outgoing Top-of-the-Atmosphere (TOA) radiative fluxes. The TOA outgoing fluxes consist of the reflected or back-scattered part of the incoming solar flux, as well as the thermal flux emitted by the earth-atmosphere system. The thermal flux in the wavelength range 2.5 µm – 100 µm is referred to as Outgoing Longwave Radiation (OLR).

The OLR is a very important parameter for earth's radiation budget studies as well as for weather and climate model validation purposes. Variations in the OLR reflect the response of the earth-atmosphere system to solar diurnal forcing. Those variations can be found in particular in surface temperature, cloud cover, cloud top height, and related quantities like precipitation. The OLR is therefore well suited for validation of global circulation models (GCMs) simulating the diurnal cycle (which is well depicted by a geostationary imager), as this cycle constitutes the combination of different model aspects.

The OLR can be directly estimated from broadband radiance measurements, as e.g. the GERB instrument onboard MSG. Alternatively, the OLR can be indirectly inferred from a number of narrowband observations, as are available on MTG-FCI. The OLR can be obtained from the MTG-FCI infrared observations via a regression scheme, taking the local satellite zenith angle into account. A similar scheme has been developed (and compared to GERB) for MSG; fundamental differences, when applied to MTG-FCI, are not expected, as similar infrared channels are available on both instruments.

3.2 Assumptions and Limitations

The OLR regression algorithm makes use of simulated radiance and flux calculations performed over a number of atmospheric profiles and cloud conditions. For a single instance, however, the OLR regression result can deviate from the true OLR because of a specific atmospheric or cloud state. Also, the OLR scheme uses different regression schemes depending on cloud conditions (as derived by the SCE-CLA product) – errors in this product will then translate into biases in the OLR product, which could locally amount to several Wm^{-2}. Comparisons done with a similar scheme applied to MSG-SEVIRI with the GERB OLR measurements showed overall (i.e. averaged over the full disk) small differences of ~3 Wm^{-2}.

The presented OLR regression scheme is valid for satellite zenith angles up to 70 deg and should not be applied to higher viewing angles.

3.3 Algorithm Basis Overview

Following the work of [RD-2], the derivation of OLR from spectral radiances is performed in two steps:

(1) Conversion of each spectral radiance into a spectral flux (i.e. correction for limb darkening)
(2) Conversion of all spectral fluxes to a total flux OLR (i.e. correction for spectral sampling)

For MTG-FCI, seven of the eight infrared channels will be used in this regression scheme – the IR3.8 channel is not taken into account due to its strong solar component during daytime. The underlying principle here is that radiative transfer calculations are performed for a number of atmospheric profiles, with and without clouds of different properties: These model calculations result in a wide range of possible spectral radiances, at various satellite zenith angles, and corresponding OLR, so that simple regression techniques can be used on such a dataset.

It should be noted that the computations of the regression coefficients is an offline task, which has to be performed only once for each MTG-FCI instrument, and which is not part of this ATBD. It is assumed that such model simulations exist together with the appropriate regression coefficients.

[RD-2] proposes the following regression relationship between the spectral radiances L_ν and the spectral fluxes F_ν:

$$F_\nu = a_\nu(\zeta_{sat}) + b_\nu(\zeta_{sat})\, L_\nu(\zeta_{sat}) \qquad \textbf{(1)}$$

with

$$a_\nu(\zeta_{sat}) = k_{\nu 0} + k_{\nu 1}(\sec\zeta_{sat} - 1) + k_{\nu 2}(\sec\zeta_{sat} - 1)^2 \qquad \textbf{(2a)}$$

$$b_\nu(\zeta_{sat}) = k_{\nu 3} + k_{\nu 4}(\sec\zeta_{sat} - 1) + k_{\nu 5}(\sec\zeta_{sat} - 1)^2 \qquad \textbf{(2b)}$$

where

F_ν : spectral radiation flux for channel centred at wavenumber ν (in Wm^{-2})
L_ν : spectral radiance for channel centred at wavenumber ν (in W/m^2 ster cm^{-1})
ζ_{sat} : satellite zenith angle; $\sec(\zeta_{sat}) = 1/\cos(\zeta_{sat})$
a_ν, b_ν : regression coefficients, depend on ζ_{sat}
$k_{\nu j}$: regression coefficients needed to derive a_ν and b_ν

Equations (2a) and (2b) describe a limb-darkening function after [RD-1] "Limb-darkening" refers to the observed decrease in radiance with increasing viewing angle, i.e. toward the limb of the earth's disk. This phenomenon is simply due to the longer path length through the atmosphere, i.e. increased absorption, at larger viewing angles.

Again following [RD-2], the conversion from spectral fluxes to OLR is realised via

$$OLR = n_0 + \sum_{i=1}^{i=m} n_{vi} F_v^i \qquad (3)$$

where

OLR : final OLR value (in Wm^{-2})
F_v : spectral fluxes as defined in equation (1)
n_0 : constant offset (from regression)
n_{vi} : spectral regression coefficients for polynomial of order m

It is thus the task of the regression analysis to find a best fit for the spectral coefficients k_{vj} and n_{vi} and for the general offset n_0.

As for the radiance to flux conversion, it is assumed here that a set of such coefficients exist, pre-computed in some offline (science) environment.

Experience has shown that best results are achieved if the regression coefficients are made scene dependent, i.e. a special coefficient set for clear sky, opaque clouds and semi-transparent clouds must exist. This implies that a full scenes and cloud analysis (e.g. the SCE-CLA algorithm) has to be performed on the MTG-FCI image prior to the OLR calculations.

3.4 Algorithm Input

Table 2 lists the data that needs to be available before the start of the OLR processing.

Table 2: Necessary input data for the OLR processing

Parameter Description	Variable Name
Radiances for seven MTG-FCI channels WV 6.3, WV 7.3, IR 8.7, IR 9.7, IR 10.5, IR 12.3, IR 13.3, for each pixel within the processing area	L_v
Satellite viewing angle for each pixel within the processing area	ζ_{sat}
Results of the Cloud Type (CT) product, for each pixel within the processing area (specifically information whether the cloud is opaque or semitransparent)	CT_result

3.4.1 Primary Sensor Data

For each pixel, the radiances in seven MTG-FCI channels, as listed in Table 2, must be available, in units $W/(m^2 \text{ ster } cm^{-1})$.

3.4.2 Ancillary Dynamic Data

The availability of the image data goes together with the Cloud Type Product CT, which is also a pixel based product, defined on the same IR grid as the IR channels. Of special interest here is the information whether a pixel is cloud free or cloudy, and in the cloudy case, whether the cloud is opaque or semi-transparent. Details of the CT product can be found in [AD-3].

3.4.3 Ancillary Static Data

Three sets of regression coefficients need to be available: one for the cloud free case, one for the opaque cloud case, and one for the semi-transparent cloud case. Each set comprises the coefficients k_{v0}, k_{v1}, k_{v2}, k_{v3}, k_{v4}, k_{v5} as described by equations (2a) and (2b), the general offset n_0 and the polynomial fit coefficients n_{vj} for j=1,m. Coefficients have to be available for all seven infrared channels, i.e. a total of 126 values for k (7 channels, 6 values, 3 scene conditions, 3 values for n_0 (3 scene conditions) and m*21 values for n (7 channels, 3 scene conditions) must be present.

3.5 Detailed Description

For a given pixel within the processing area, with known seven infrared radiances R_v and satellite viewing angle ζ_{sat}, the algorithm first needs to decide which set of regression coefficients have to be selected:

(1) If the CT product flags the pixel as cloud free, the set of cloud free coefficients are chosen
(2) If the CT product flags the pixel as cloudy with an opaque cloud, the set of opaque cloud coefficients are chosen
(3) If the CT product flags the pixel as cloudy with a semi-transparent cloud, the set of semi-transparent cloud coefficients are chosen
(4) If the CT product flags the pixel as “unknown”, the processing is skipped, and the pixel is assigned a final OLR value indicating “unknown”, e.g. -999

For cases (1)-(3) the processing continues by first applying equations (2a) and (2b), using the chosen set of k-coefficients, to derive a_v and b_v for all seven infrared channels. Then equation (1) is applied to derive the corresponding seven spectral fluxes. Finally, equation (3) is solved, again using the appropriate set of n-coefficients. The polynomial order m is prescribed with the regression data (for MSG-SEVIRI, m=2 provided a good fit).

3.6 Output Description

The output of the OLR processing is the pixel-based OLR value, expressed in Wm^{-2}. Associated quality information can be provided through the quality information of the underlying CT product (as described in the output parameters of the CT product).

4 GLOSSARY OF SYMBOLS

Variable Name	Meaning	Unit
a_ν, b_ν	Regression coefficients used for the spectral flux calculations, for each channel centred at wavenumber ν	a_ν: Wm^{-2} b_ν: ster cm^{-1}
CT_result	Result of the Cloud Type processing, especially information whether cloud is opaque or semi-transparent	
F_ν	Spectral flux for channel centred at wavenumber ν	Wm^{-2}
$k_{\nu j}$	Regression coefficients to perform limb darkening correction, for channel centred at wavenumber ν; j=0,5	Wm^{-2} for j=0,1,2 ster cm^{-1} for j=3,4,5
L_ν	Spectral radiance for MTG-FCI channel centred at wavenumber ν	W/m^2 ster cm^{-1}
n_0, $n_{\nu i}$	Regression coefficients to perform total flux calculations, using a general offset n_0 and coefficients for the spectral fluxes F_ν	n/a
OLR	Final Outgoing Longwave Flux	Wm^{-2}
ζ_{sat}	Satellite zenith angle	deg
ν	Central Wavenumber of MTG-FCI channel	cm^{-1}