MTG-FCI: ATBD for Clear Sky Reflectance Map Product

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1 INTRODUCTION

1.1 Purpose of this Document

This document describes the algorithm theoretical basis for the Clear Sky Reflectance Map (CRM) 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 CRM product – its physical basis, the required input data, and a more detailed description of the product retrieval method. Section 4 describes possible future developments of the CRM algorithm.

A full list of acronyms is provided in section 1.4, literature references are listed in the following section.

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 Radiative Transfer Model	EUM/MTG/DOC/10/0382
[AD-4]	MTG-FCI: ATBD for Cloud Mask and Cloud Analysis Product	EUM/MTG/DOC/10/0542

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
CMa	Cloud Mask
CRM	Clear Sky Reflectance Map
CT	Cloud Type
CTTH	Cloud Top Temperature and Height
FCI	Flexible Combined Imager
FCI-FDSS	FCI Full Disc Scanning Service
FCI-RSS	FCI Rapid Scanning Service
FDHSI	Full Disc High Spectral Resolution Imagery
GII	Global Instability Indices
HRFI	High Spatial Resolution Fast Imagery
HRV	High Resolution Visible Channel of SEVIRI
IR	Infrared
LUT	Lookup Table
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
NWP	Numerical Weather Prediction
OCA	Cloud Product (Optimal Cloud Analysis)
OLR	Outgoing 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
TOVS	TIROS Operational Vertical Sounder
TOZ	Total Column Ozone
VIS	Visible (solar)
VOL	Volcanic Ash Product

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 / Atmopshere 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 disc in 16 channels every 10 minutes with a spatial sampling distance in the range 1 – 2 km (Full Disc High Spectral Resolution Imagery (FDHSI) in support of the Full Disc 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 disc 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
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 height 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 a 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
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].

An important tool for product extraction is a radiative transfer model (RTM), as described in [AD-3]. The IR model choice for the Level 2 product extraction is RTTOV, which is developed and maintained by the Satellite Application Facility on Numerical Weather Prediction (NWP-SAF). An RTM for solar channels is likely to be product specific and is yet to be fully determined.

This ATBD describes the algorithm of the Clear-sky Reflectance Map (CRM) product generation. The product will be derived over a certain processing area, defined as 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 Clear-sky Reflectance Map (CRM) describes the reflection that would be registered by the solar MTG channels in cloud free conditions, using the actual satellite position and including (possible) atmospheric effects. This implies that neither atmospheric nor viewing angle corrections are applied. The CRM thus corresponds to the clear-sky top-of-atmosphere (TOA) reflectance and is derived for every pixel within the processing area.

The main principle of the CRM generation is to accumulate clear sky reflectance values over a period of time (e.g. over a few days), during which most areas will have encountered a cloud free condition. This time period has to be defined in a way that the chances to find clear pixels are maximized, but reflectance changes due to changes in solar illumination and vegetation conditions are minimized.

The pixel based cloud information is taken from the Scenes Analysis Product (SCE).

3.2 Assumptions and Limitations

A valid CRM value cannot be obtained for pixels which are continuously cloud covered during the data accumulation period or which are always under very low light conditions (e.g. in the very north or south during the respective winter months), which make cloud detection more difficult.

The quality of the CRM product obviously depends on the quality of the preceding cloud detection within the SCE algorithm.

Pixels with sun glint conditions are not excluded from the processing, or filtered out from the product. The original reflection values are kept for these pixels.

3.3 Algorithm Basis Overview

For each cloud free pixel, for which the sun is positioned high enough in the sky, the reflectance value is extracted for defined time slots T_{CSRM} (typically 7 time slots per day), from a set of repeat cycles (typically 2) around each time slot. First, the values from the repeat cycles for each time slot are averaged. Then, a sliding average is computed from the values of the corresponding time slots over a pre-defined time period (typically 7 days), using the averaged values from the current day and the ones from the preceding (typically 6) days. This is done for each of the visible and near-infrared channels, i.e. VIS 0.4, VIS 0.5, VIS 0.6, VIS 0.8, VIS 0.9, NIR 1.3, NIR 1.6, NIR 2.2.

In addition the mean solar zenith angle and the mean relative azimuth angle (sun/satellite) for each specific daily extraction time for that period are determined, together with the number of clear sky scenes that have contributed to the average.

If a pixel has no clear scene in the sliding average time window, the reflectance value (together with the associated angular geometry) from the CSRM product of the preceding (typically 7 days) period is used. This period is covered by the CSRM product from only the last day just before the time window. In order to avoid abrupt transitions, the reflectance value from this period is used together with the Climatology value, applying an appropriate weighting factor for both (typically 90% to historical CSRM and 10% Climatology). In this manner, these padded reflectance values converge gradually to Climatology over time, which would typically happen for regions at higher latitude during seasonal dimming. The number of observations for these padded pixels is set to 0. If (for whatever reason) after this gap filling still no clear sky reflectance value is available for the given pixel, its reflectance value is set to a default 'valid undefined value' (VUV), e.g. -999 or a NaN.

The resulting product will contain derived reflectance values over a certain processing area, defined as pixels lying within a great circle arc of pre-defined size (typically 70°) around the sub-satellite point.

3.4 Algorithm Input

Table 2 lists the data that needs to be available at the start of the CRM processing.

Table 2: Necessary input data for the CRM processing

Parameter Description	Variable Name
Reflectances for all MTG-FCI visible and near-infrared channels for each pixel within the processing area, channels are VIS 0.4, VIS 0.5, VIS 0.6, VIS 0.8, VIS 0.9, NIR 1.3, NIR 1.6, NIR 2.2	ρ(ch)
Solar zenith angle, satellite viewing angle and relative azimuth angle sun/satellite for each pixel within the processing area	ζ_{sun}, ζ_{sat}, ϕ_{sun_sat}
Scenes type information (cloudy, clear, sun glint condition) from SCE for each pixel within the processing area	Stype

3.4.1 Primary Sensor Data

For each pixel the reflectances of MTG-FCI, as listed in Table 2, must be available. The pixel resolution is 1 km for all channels. For a given extraction time t_{CRM}, the images just before and after t_{CRM} (t_{CRM} (-1,0)) are used as input (e.g. for t_{CRM} = 1200 UTC, the images with scan start 1150 and 1200 UTC shall be used).

3.4.2 Ancillary Dynamic Data

The Scenes Analysis Product (SCE) needs to be available for the CRM processing. The scenes type (Stype) is used to determine the cloud free pixels which are needed to generate the CRM product. Pixels with an "unknown" scenes type are excluded from the CRM processing. In addition the viewing geometry, i.e. solar zenith angle, satellite viewing angle and relative azimuth angle sun/satellite, need to be known for each pixel. In addition the CRM product of the previous processing period needs to be available.

3.4.3 Ancillary Static Data

The CRM processing needs to have climatological clear sky reflectance values and the corresponding bi-directional reflectance distribution look-up tables. In addition the CRM processing needs static configuration parameters, i.e.:

- extraction times (t_{CRM}),
- maximum solar zenith angle for processing ($\zeta_{sun,\ max}$)
- minimum number of valid pixels to allow averaging (N_{ave})
- weighting factor (F_{pad}) for a smooth transition between periods with current CRM, historical CRM and climatology

3.5 Detailed Description

The CRM product is derived for a set of pre-defined times t_{CRM} over the processing area (e.g. 2-hourly, 0600, 0800, ... UTC). Low sun conditions (solar zenith angle ζ_{sun} > 70°) pixels. Pixels under sun glint conditions are not excluded from the processing.

The reflectance values ρ(ch), and the angles ζ_{sun} and ϕ_{sun_sat} for clear pixels are collected:

- for every pixel within the processing area
- for every solar channel
- for every daily extraction time t_{CRM}
- for a given $t_{CRM}(0)$, the images just before and after t_{CRM} (t_{CRM} (-1,0)) are used as input (e.g. for t_{CRM} = 1200 UTC, the images with scan start 1150 and 1200 UTC shall be used)

The processing of the CRM product is done in three steps:

1. Filtering using the cloud mask and the solar zenith angle
2. Averaging
3. Padding

3.5.1.1 Filtering

The reflectance values for all 8 solar channels, for the incoming repeat cycles (t_{CRM} (-1, 0)) corresponding to the given time slot T_{CSRM}, are filtered over the full processing area using the CM input data, such that only cloud free pixels are included, whereas pixels under low sun conditions (solar zenith angle $\zeta_{sun,\ max}$ > 70°) are excluded from the processing. For those pixels that do not pass the filter conditions, a default value (e.g. -999 or a NaN) is inserted. The resulting filtered subsets of reflectance values ρ(ch), as well as the associated geometrical values (ζ_{sun}, ζ_{sat}, ϕ_{sun_sat}), are passed on to the next processing function (averaging) as separate data streams for each repeat cycle (t_{CRM} (-1, 0)).

3.5.1.2 : Averaging

For the given extraction time t_{CRM}, first the reflectance values of the repeat cycles in the filtered subset are averaged, for each pixel. For the case where N_{ave} = 2 (operational default):

$$\bar{\rho}_{chan} = \frac{1}{2}(\rho_{chan,\,tcrm\,-1} + \rho_{chan,\,tcrm\,0})$$

For the computation of the 7 days sliding average value of the clear sky reflectance, for each pixel and for each solar channel, the individual values from the current day (as from the equation above) plus the ones from the preceding 6 days must be taken into account, separately for each repeat cycle, which are averaged to $\rho_{chan}(i)$ using the above equation. The (7 days) sliding average is obtained by averaging all $\rho_{chan}(i)$ over the accumulated number of valid values per pixel:

$$\rho_{mean,chan} = \frac{1}{n_{chan}} \sum_{i=1}^{n_{chan}} \bar{\rho}_{chan}(i)$$

where $\rho_{chan}(i)$ is the individual average reflectance value for each day i of each pixel with a clear sky scene (averaged over the two contributing repeat cycles as described above) for t_{CRM} in the complete time period, and n_{chan} is the accumulated number of valid observations for these pixels (that thus contribute to the average value).

Note that, for the computation of the sliding average over a configurable period of N days, the reflectance values of the preceding N-1 days are used, together with the averaged values from the current day. The operational default is 7 days. The mean reflectance from above equation (valid for time slot t_{CRM}) is denoted in the Functional Breakdown as 'ρ_{mean} (day 0 to -6) [8 chans]'.

Moreover, for pixels where the reflectance value $\rho_{chan}(i)$ is not valid, the observation is considered invalid (missing value) and is not included in the associated value of n_{chan} for that pixel. This will have to be taken into account as a natural part of the above averaging procedures.

The subset of mean reflectance values $\rho_{mean,\ chan}$, together with the associated averaged geometrical values ($\zeta_{sun,\ mean}$, $\zeta_{sat,\ mean}$, $\phi_{sun\_sat,\ mean}$) and the computed value of n_{chan} are passed on to the next processing function (padding).

3.5.1.3 A23: Padding

Finally, the pixels in the sliding average subset that form gaps, i.e. where a not valid value (e.g. -999 or a NaN) is present, will be padded with reflectance values ρ_{ave} (day -7) from the time period preceding the time window used for the sliding averaging. Again, the length (scope) of this padding time period is configurable with a default duration of 7 days. Hence, the reflectance values from the 'historical' CRM product of the last day just before the time window (typically from day -7, which typically covers day -7 to -13), are used as gap fillers.

In order to smoothen the transitions, the clear-sky reflectance value from this period is used together with the climatological reflectance value ρ_{ave} (Clim), applying an appropriate (configurable) weighting factor F_{pad} for both (typically 90% to historical CRM and 10% Climatology). If no historical CRM product value is available, the value is fully taken from Climatology. ρ_{ave} (Clim) is computed from the climatological bi-hemispherical albedo, using a Bi-directional Reflectance Distribution Function (BRDF). Values for that are supplied in a LUT.

The number of observations for the padded pixels is set to 0. If after this gap filling still no clear sky reflectance value is available for the given pixel, its reflectance value being set to not valid remains.

The thus obtained subset of reflectance values $\rho_{mean,\ chan}$, together with the associated averaged geometrical values ($\zeta_{sun,\ mean}$, $\zeta_{sat,\ mean}$, $\phi_{sun\_sat,\ mean}$) and the updated values of n_{chan} is the final output.

After a pre-defined CRM product period (typically a number of days), the values ρ(ch), ζ_{sun} and ϕ_{sun_sat} are averaged. The number n of individual reflectance values which contribute to the pixel average is also determined. In case of n=0, the corresponding values of the previous period are used. If that value is not available, the value is set to a default invalid value.

3.6 Output Description

For every extraction time t_{CRM} the following information is stored in the output dataset per pixel:

- Average clear-sky reflectance ρ_{ave}(ch)for each solar channel
- Mean solar zenith $\zeta_{sun,ave}$ and mean relative azimuth angle $\phi_{sun\_sat,ave}$
- Number of accumulations n used to derive the clear-sky reflectances

4 FUTURE DEVELOPMENTS

The currently used CRM setting for MSG can be enhanced, .e.g.

- extraction period (current MSG settings 6 UTC to 20 UTC)
- extraction interval (current MSG setting 2 hours)
- time period of accumulation (current MSG setting 7 days)
- images used per extraction time (initial setting the image before and after the extraction time)