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MTG-FCI: ATBD for All Sky Radiance Product

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1 INTRODUCTION

1.1 Purpose of this Document

This document describes the algorithm theoretical basis for the All Sky Radiance (ASR) 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 ASR algorithm. Section 4 describes possible future developments of the ASR product.

A full list of acronyms is provided in section 1.4, literature references are listed in the following section. A glossary of the symbols used in this document can be found in section 5.

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
[AD-5]	MTG-FCI: ATBD for Optimal Cloud Analysis Product	EUM/MTG/DOC/11/0654
[RD-1]	Loveland T.R. and Belward A.S., 1997: The IGBP-DIS global 1km land cover data set, DISCover: first results.	Int. Journal of Remote Sensing, Vol. 18, No. 15, pp. 3289

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 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, λ0*	*Spectral Width, Δλ0*	*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 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
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 yet to be fully determined.

This ATBD describes the algorithm of the All Sky Radiance (ASR) product. The product will be derived over a certain processing area, defines 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 All Sky Radiances product (ASR) provides averages, together with a number of other statistical parameters, of radiances in each MTG-FCI channel over a certain image section defined as a box of m by m image pixels. This basic processing box will hereafter be referred to as Field-of-Regard (FoR).

In addition, the radiances are also expressed as brightness temperatures for the infrared channels and as reflectances for the solar channels.

Different ASR values are derived for different cloud categories:

- **ASR-all:** statistics for all pixels within a FoR
- **ASR-clear:** statistics for all clear pixels within a FoR
- **ASR-cloudy:** statistics for all cloudy pixels within a FoR
- **ASR-low:** statistics for all low-level cloud pixels within a FoR
- **ASR-mid:** statistics for all mid-level cloud pixels within a FoR
- **ASR-high:** statistics for all high-level cloud pixels within a FoR

The ASR product is derived for predefined extraction times, which may be every repeat cycle.

The ASR product is thus a direct result of the Scenes Analysis (SCE) and Cloud Analysis (CLA) products: The SCE processing decides whether a pixel is cloudy or cloud free, and the CLA product contains the cloud top heights (expressed as pressure) for the cloudy pixels. Alternatively, the output of the Optimal Cloud Analysis (OCA) product could be used for the cloud heights (pressures).

Figure 1 provides an illustration of the concept.

3.2 Assumptions and Limitations

The quality of ASR product depends heavily on the quality of the results of the cloud detection and cloud analysis.

3.3 Algorithm Basis Overview

For each given image extraction time the algorithm extracts a number of statistical parameters for each FoR within the processing area. Relevant parameters are averages (radiances, brightness temperatures or reflectances), minima, maxima, standard deviations, percentage of pixels in each category, together with some geographical information like

latitude, longitude, solar zenith angle, MTG-FCI image line and pixel of the FoR centre (see also Figure 1 for illustration).

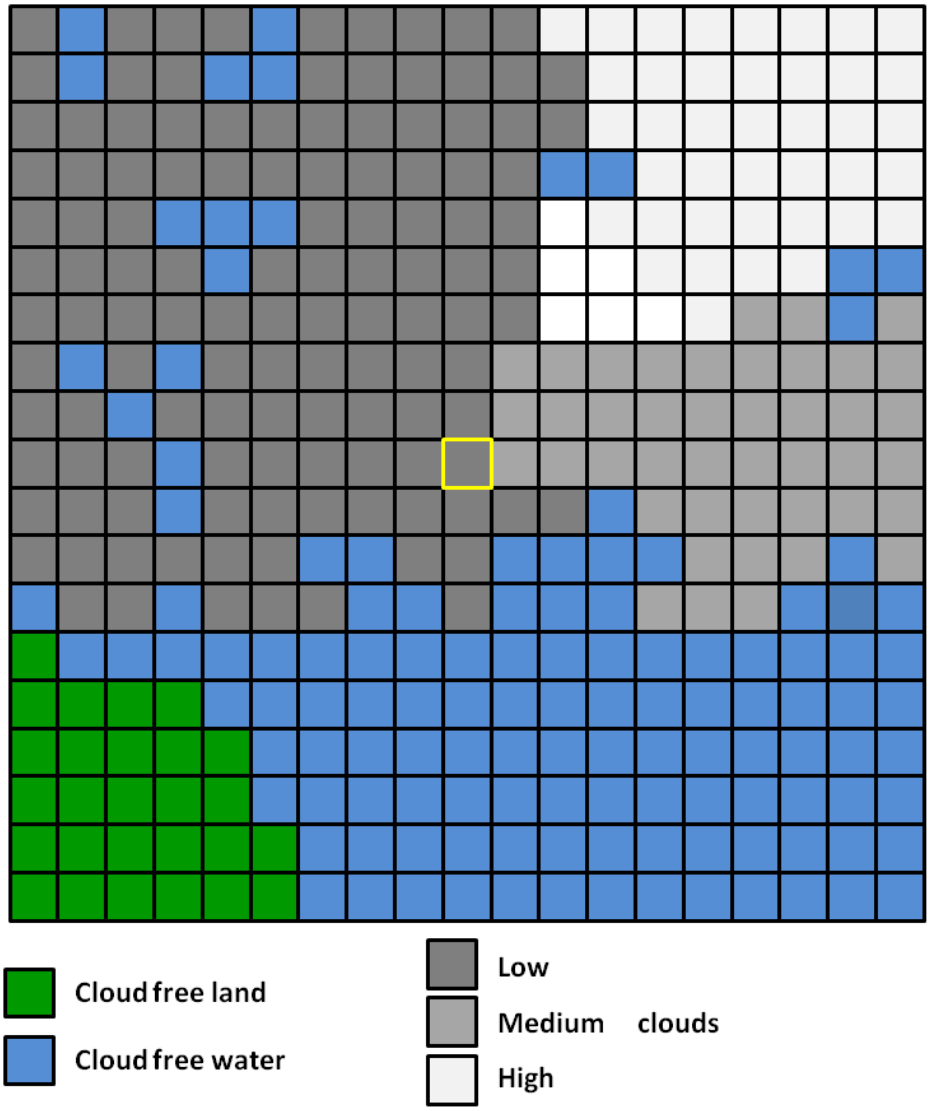

Figure 1: Illustration of the concept of the ASR product, here for an 19 x 19 pixel FoR: The figure shows the 19 x 19 individual pixels and their respective scene identification (land/water/cloud), where 3 different cloud height classes are identified according to the CLA or OCA output. The ASR product provides the mean radiances and brightness temperatures resp. reflectances for these five identified classes, together with their standard deviations, minima and maxima, with the category pixel number (as a percentage of 19 x 19) and the geographical information of the FoR centre (yellow square).

3.4 Algorithm Input

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

Table 2: Necessary input data for the ASR processing

Parameter Description	Variable Name
Reflectances and radiances for all MTG-FCI solar channels for each pixel within the processing area (for channels VIS 0.4, VIS 0.5, VIS 0.6, VIS 0.8, VIS 0.9, NIR 1.3, NIR 1.6 and NIR 2.2)	$\rho(c)$, $r(c)$
Brightness Temperatures and radiances for all MTG-FCI infrared channels for each pixel within the processing area (for channels (IR 3.8, WV 6.3, WV 7.3, IR 8.7, IR 9.7, IR 10.5, IR 12.3, IR 13.3)	$T_B(c)$, $r(c)$
Solar zenith angles for each pixel within the processing area	ζ_{sun}
Cloud top height (expressed as pressure) information from SCE/CLA (or OCA) for each pixel within the processing area	P_{cloud}
Surface type information for each MTG-FCI pixel (land type or sea)	$SType_{MTG}$
Geographic information: latitude and longitude for each pixel within the processing area	φ, λ
Geometric information: MTG-FCI image line and column number for each pixel	lin, col

3.4.1 Primary Sensor Data

For each pixel the brightness temperatures (for the IR channels), reflectances (for the visible channels), and radiances (for all channels) of MTG-FCI, as listed in Table 2, must be available.

The pixel resolution of the channel with the lowest resolution (i.e. 2 km resolution) determines the resolution of the product. This means that the channels with a higher pixel resolution (1 km or 0.5 km resolution) need to be averaged to the coarser resolution.

3.4.2 Ancillary Dynamic Data

Pixel based cloud top height (pressure) information has to be available for the ASR processing, for every pixel within the processing area. This height information could be provided by either the Cloud Analysis (CLA, see [L2SCE]) product or the Optimal Cloud Analysis (OCA, see [L2OCA]) product. As ASR only needs height categories (low, mid-level, high), a cloud height categorisation into low/mid/high is of course possible prior to the ASR processing.

In addition, the ASR processing needs the local solar zenith angle ζ_{sun} for every pixel within the processing area.

3.4.3 Ancillary Static Data

ASR uses the following ancillary static datasets:

- Pixel-based land-sea mask/surface-type-map, $SType_{MTG}$
- Line and column number for each pixel, lin, col
- Latitude and longitude for each pixel, φ, λ

The pixel-based land-sea-mask/surface-type-map consists of 17 different land surface types and one ocean/open water surface type. This map has been derived from the International Geosphere-Biosphere Programme (IGBP) surface type map [RD-1]. In the context of ASR, only the information whether a pixel is "land" or "sea" needs is used.

In addition, the geographical coordinates φ and λ for each pixel need to be available.

3.5 Detailed Description

For each given image extraction time the algorithm performs four main processing steps:

Step 1: FoR Definition
The level 1c image data (all channels) and related ancillary data are divided into FoRs, each FoR is defined as a block of m by m pixels. "Pixels" here refer to the 2 km resolution pixels; channels of higher resolution need to be averaged to this resolution.

Each pixel within each FoR contains the information as listed in Table 2.

Step 2: Solar Zenith Angle Check
The solar zenith angle ζ_{sun} for every pixel is used to determine whether the pixel has "day" or "night" conditions. A pixel is regarded as “under day conditions” if the solar zenith angle is smaller than a predefined threshold:

$$\zeta_{sun} < \zeta_{sun,thresh}$$

If not all pixels in the FoR are under day conditions, the following steps are skipped for the solar channels and the solar ASR values are set to a default number (e.g. -999).

Step 3: Extraction of pixels for the different ASR categories within a FoR:

According to the information provided by the SCE and CLA (or OCA) product, the pixels in each FoR are sorted into the different ASR categories, resulting in

n_{cat}:	number of pixels for every category
$r_{cat}(i, i=1,\ldots,n_{cat})$:	radiance values in all 16 channels for every category
$T_{B.cat}(i, i=1,\ldots,n_{cat})$:	brightness temperatures in all 8 infrared channels for every category

$\rho_{cat}(i, i=1,\ldots,n_{cat})$: reflectances in all 8 solar channels for every category

where the categories are

all pixels
all clear pixels
all cloudy pixels
all pixels with low clouds (P_{cloud} > 700 hPa)
all pixels with medium-high clouds (P_{cloud} between 400 hPa and 700 hPa)
all pixels with high cloud (P_{cloud} < 400 hPa)

For each of the categories the number of pixels is calculated as a percentage (%) of the total number of pixels. In case the total number n_{cat} of a given category is less than a certain threshold ($n_{thresh,\ with\ nthresh} \geq 2$) in a given FoR, the following step is skipped for this specific category, and the ASR values for this category and this FoR are all set to some default (e.g. -999).

Step 4: Determination of the Final ASR

The ASR is generated for each FoR, for each category and for each channel. The following statistical parameters are computed:

(a) Mean radiances, mean brightness temperatures (infrared) or mean reflectances (solar), indicated by subscript "mean" in the following equations:

$$r_{mean,cat} = \frac{1}{n_{cat}} \sum_{i=1}^{n_{cat}} r_{cat}(i) \quad \textbf{(1)}$$

$$T_{B,mean,cat} = \frac{1}{n_{cat}} \sum_{i=1}^{n_{cat}} T_{B,cat}(i) \quad \textbf{(2)}$$

$$\rho_{mean,cat} = \frac{1}{n_{cat}} \sum_{i=1}^{n_{cat}} \rho_{cat}(i) \quad \textbf{(3)}$$

(b) Standard deviations of the radiances, the brightness temperatures (infrared) or reflectances (solar), indicated by subscript "σ" in the following equations:

$$r_{\sigma,cat} = \sqrt{\frac{\left(r_{cat}(i) - r_{mean,cat}\right)^2}{n_{cat} - 1}} \quad \textbf{(4)}$$

$$T_{B,.\sigma,cat} = \sqrt{\frac{\left(T_{B,cat}(i) - T_{B,mean,cat}\right)^2}{n_{cat} - 1}} \quad \textbf{(5)}$$

$$\rho_{\sigma,cat} = \sqrt{\frac{\left(\rho_{cat}(i) - \rho_{mean,cat}\right)^2}{n_{cat} - 1}} \quad \textbf{(6)}$$

(c) Maximum radiances, maximum brightness temperatures (infrared) or maximum reflectances (solar): $r_{max,cat}$, $T_{B,max,cat}$ and $\rho_{max,cat}$

(d) Minimum radiances, minimum brightness temperatures (infrared) or minimum reflectances (solar): $r_{min,cat}$, $T_{B,min,cat}$ and $\rho_{min,cat}$

If a certain scene type or cloud category is not present in the FoR, the respective values (mean, standard deviation, minimum and maximum) are set to a default number (e.g. -999).

In addition, the following (channel independent) information is provided for each FoR:

(e) Percentage of the pixels contributing to each of the ASR categories:

$$p_{cat} = \frac{n_{cat}}{n_{total}} \cdot 100 \quad \textbf{(7)}$$

(f) percentage of sea and land pixels within the FoR

$$p_{sea} = \frac{n_{total}(\text{where } SType_{MTG} \text{ is "sea"})}{n_{total}} \cdot 100 \quad \textbf{(8)}$$

$$p_{land} = \frac{n_{total}(\text{where } SType_{MTG} \text{ is "land"})}{n_{total}} \cdot 100 \quad \textbf{(9)}$$

(g) latitude and longitude of the FoR centre: φ_{centre}, λ_{centre}

(h) Line and column number (in MTG 2km resolution coordinates) of the FoR centre, lin_{centre}, col_{centre}

3.6 Output Description

The ASR product is the output of Step 4 as described in the previous section. Table 3 provides a summary of the output. For each FoR, the ASR output shall thus contain 69 numbers.

Table 3: ASR Output, per FoR

Description	Symbol	Units
FoR centre latitude and longitude	φ_{centre}, λ_{centre}	Deg
FoR centre line and column in MTG-FCI coordinates	lin_{centre}, col_{centre}	n/a
Percentage of land type pixels in FoR	p_{land}	%
Percentage of water type pixels in FoR	p_{sea}	%

Description	Symbol	Units
Percentage of pixels: for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	p_{cat}	%
Mean radiances for all 16 channels: for ASR-all, ASR-clear, ASR-cloudy, ASR-low, ASR-mid, ASR-high	$r_{mean,cat}$	$mW/m^2/ster/cm^{-1}$
Mean brightness temperatures for all 8 infrared channels: for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	$T_{B,mean,cat}$	K
Mean reflectances for all 8 solar channels: for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	$\rho_{mean,cat}$	%
Standard deviations of the radiances for all 16 channels for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	$r_{\sigma,cat}$	$mW/m^2/ster/cm^{-1}$
Standard deviations of the brightness temperatures for all 8 infrared channels: for ASR-all, ASR-clear, ASR-cloudy, ASR-low, ASR-mid, ASR-high	$T_{B,\sigma,cat}$	K
Standard deviations of the reflectances for all 8 solar channels: for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	$\rho_{\sigma,cat}$	%
Radiance maxima and minima for all 16 channels for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	$r_{max,cat}$, $r_{min,cat}$	$mW/m^2/ster/cm^{-1}$
Brightness temperature maxima and minima for all 8 infrared channels for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	$T_{B,max,cat}$, $T_{B,min,cat}$	K
Reflectance maxima and minima for all 8 solar channels for ASR-all, ASR-clear, ASR-cloudy, ASR-low/mid/high	$\rho_{max,cat}$, $\rho_{min,cat}$	%

4 FUTURE DEVELOPMENTS

With the higher resolution of some MTG-FCI channel, there might be the need to generate the ASR on different FoR sizes (with 0.5, 1, 2 km pixel resolution)

5 GLOSSARY OF SYMBOLS

Variable Name	Meaning	Unit
c	Index for MTG-FCI channel	n/a
col	Pixel column number (MTG-FCI coordinates)	n/a
col_{centre}	FoR centre pixel column number (MTG-FCI coordinates)	n/a
i	pixel counter within an FoR	n/a
lin	Pixel line number (MTG-FCI coordinates)	n/a
lin_{centre}	FoR centre pixel line number (MTG-FCI coordinates)	n/a
m	Describes size of ASR FoR: each FoR is made up of m by m pixels	n/a
n_{cat}	Number of pixels in a given FoR of a given category	n/a
n_{thresh}	Minimum number of pixels in any category, per FoR	n/a
n_{total}	Total number of pixels in an FoR (= m · m)	n/a
P_{cloud}	Pixel cloud top pressure	hPa
p_{cat}	Percentage of pixels in an FoR of a given category	%
p_{land}	Percentage of land type pixels in an FoR	%
p_{sea}	Percentage of sea type pixels in an FoR	%
r	Pixel radiance for a given channel	mW/m^2 ster cm^{-1}
r_{cat}	Pixel radiance if pixel falls into a given category (for a given channel)	mW/m^2 ster cm^{-1}
$r_{mean,cat}$	FoR mean radiance for a given category and channel	mW/m^2 ster cm^{-1}
$r_{\sigma,cat}$	FoR radiance standard deviation for a given category and channel	mW/m^2 ster cm^{-1}
$r_{max,cat}$	FoR maximum radiance for a given category and channel	mW/m^2 ster cm^{-1}
$r_{min,cat}$	FoR minimum radiance for a given category and channel	mW/m^2 ster cm^{-1}
$SType_{MTG}$	Pixel surface type (land or sea)	n/a
T_B	Pixel brightness temperature for a given channel	K
$T_{B,cat}$	Pixel brightness temperature if pixel falls into a given category (for a given channel)	K
$T_{B,mean,cat}$	FoR mean brightness temperature for a given category and channel	K
$T_{B,\sigma,cat}$	FoR brightness temperature standard deviation for a given category and channel	K
$T_{B,max,cat}$	FoR maximum brightness temperature for a given category and channel	K
$T_{B,min,cat}$	FoR minimum brightness temperature for a given category and channel	K
λ	Pixel geographic longitude	Deg
λ_{centre}	FoR centre pixel geographic longitude	Deg
φ	Pixel geographic latitude	Deg
φ_{centre}	FoR centre pixel geographic latitude	Deg
ρ	Pixel reflectance for a given channel	%
ρ_{cat}	Pixel reflectance if pixel fall into a given category (for a given channel)	%
$\rho_{mean,cat}$	FoR mean reflectance for a given category and channel	%

Variable Name	Meaning	Unit
$\rho_{\sigma,cat}$	FoR reflectance standard deviation for a given category and channel	%
$\rho_{max,cat}$	FoR maximum reflectance for a given category and channel	%
$\rho_{min,cat}$	FoR minimum reflectance for a given category and channel	%
ζ_{sun}	Pixel solar zenith angle	Deg
$\zeta_{sun,thresh}$	Threshold solar zenith angle to define "night" conditions	Deg