EUMETSAT

MTG-FCI: ATBD for Radiative Transfer Model

Doc.No. : EUM/MTG/DOC/10/0382
Issue : v2
Date : 14 July 2011
WBS : MTG-834200

EUMETSAT
Eumetsat-Allee 1, D-64295 Darmstadt, Germany
Tel: +49 6151 807-7
Fax: +49 6151 807 555
http://www.eumetsat.int

Document Change Record

Issue / Revision	***Remarks***
v1 Draft	For internal review
v1C of 17 January 2011	First published version
v2 of 14 July 2011	Updated following the recommendations of the System PDR Science Panel

Table of Contents

1 INTRODUCTION

1.1 Purpose of this Document

This document describes the long wave radiation model to be used within the MTG-FCI Level 2 processing.

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. This is followed by a high-level description of the radiative transfer model RTTOV.

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 Global Instability Indices Product	EUM/MTG/DOC/10/0381
[RD-1]	A Fast Radiative Transfer Model for Satellite Sounding Systems	Eyre, J.R., 1991, ECMWF Research Dept. Tech. Memo 176, available from ECMWF
[RD-2]	An Improved Fast Radiative Transfer Model for Assimilation of Satellite Radiance Observations	Saunders, R., M. Matricardi, and P. Brunel, 1999, Q. J. R. Meteorol. Soc., 125, 1407-1425
[RD-3]	RTTOV v10 Users Guide	Hocking, J., P. Rayer, R. Saunders, M. Matricardi, A. Geer, and P. Brunel, 2011, NWP-SAF document NWPSAF-MO-UD-023, available from www.nwpsaf.org

Doc ID	Title	Reference
[RD-4]	RTTOV-9 Science and Validation Report	Saunders, R., M. Matricardi, A. Geer, P. Rayer, O. Embury, and C. Merchant, 2008, NWP-SAF Document NWPSAF-MO-TV-020, available from www.nwpsaf.org

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
CRM	Clear Sky Reflectance Map
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
FoR	Field of Regard
GII	Global Instability Indices
GOES	Geostationary Operational Environmental Satellite
HRFI	High Spatial Resolution Fast Imagery
HRV	High Resolution Visible Channel of SEVIRI
IR	Infrared (channel)
MSG	Meteosat Second Generation
MTG	Meteosat Third Generation
NIR	Near-infrared (channel)
NWP	Numerical Weather Prediction
OLR	Outgoing Longwave Radiation
OCA	Cloud Product (Optimal Cloud Analysis)
RMS	Root mean square difference
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

Acronym	Full Name
TOVS	TIROS Operational Vertical Sounder
TOZ	Total Column Ozone
VIS	Visible (solar channel)
WV	Water vapour (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 / 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)*
VIS0.4	0.444 µm	0.060 µm	1.0 km
VIS0.5	0.510 µm	0.040 µm	1.0 km
VIS0.6	0.640 µm	0.050 µm	1.0 km 0.5 km [#1]
VIS0.8	0.865 µm	0.050 µm	1.0 km
VIS0.9	0.914 µm	0.020 µm	1.0 km
NIR1.3	1.380 µm	0.030 µm	1.0 km
NIR1.6	1.610 µm	0.050 µm	1.0 km
NIR2.2	2.250 µm	0.050 µm	1.0 km 0.5 km [#1]
IR3.8 (TIR)	3.800 µm	0.400 µm	2.0 km 1.0 km [#1]
WV6.3	6.300 µm	1.000 µm	2.0 km
WV7.3	7.350 µm	0.500 µm	2.0 km
IR8.7 (TIR)	8.700 µm	0.400 µm	2.0 km
IR9.7 (O_3)	9.660 µm	0.300 µm	2.0 km
IR10.5 (TIR)	10.500 µm	0.700 µm	2.0 km 1.0 km [#1]
IR12.3 (TIR)	12.300 µm	0.500 µm	2.0 km
IR13.3 (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].

An important tool for product extraction is a radiative transfer model (RTM), as described in this document. 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 document describes the functionality of RTTOV, where applicable and relevant for the MTG-FCI Level 2 processing. A full description of RTTOV can be found in [RD-1], [RD-2], and in the relevant documents of the NWP-SAF [RD-3], [RD-4].

All descriptions of RTTOV in this document refer to RTTOV Version 10. Future versions with further improvements can be expected.

3 RADIATIVE TRANSFER MODEL RTTOV

3.1 Requirement

The extraction of Level 2 meteorological products from the MTG-FCI Level 1 data crucially depends on the results of a radiative transfer model (RTM) in the IR spectral range:

The RTM computes the expected radiances (or brightness temperatures) at the top of the atmosphere and at discrete levels in the atmosphere for cloud free and cloudy conditions, for a given atmospheric state described by vertical profiles of temperature, humidity, other trace gases and various surface parameters.

Many Level 2 algorithms use the RTM results for a comparison with the actual satellite measurements. The SCE algorithm e.g. compares the clear sky brightness temperatures in a number of IR channels (notably the window channels IR10.5, IR12.0, IR8.7, IR3.8) to the RTM simulations: if the satellite measurements are significantly colder (i.e. lower brightness temperatures) than the clear sky RTM results, the scene probably contains a cloud. Other brightness temperature comparisons help in the detection of dust, volcanic ash or fire within a pixel. A number of cloud height assignment techniques also crucially depend on the RTM results to correctly perform a semi-transparency correction. This in turn impacts the AMV product, as the height assignment for an extracted AMV refers back to the cloud top height, or in case of the WV winds, to the RTM results for the WV channels. Also the GII processing uses RTM results within the retrieval.

Information about the atmospheric conditions in a specific location is provided by ECMWF forecasts, which are available on a specific latitude/longitude grid and at specific vertical levels. The GII processing is somewhat exceptional, as in its iterative retrieval the original profiles are perturbed and then again fed into RTTOV. This special usage is described in detail in [AD-3], while this document is confined to RTTOV usage in support of the other products.

3.2 RTTOV Brief Explanation

RTTOV-10 has its roots in the fast radiative transfer model for TOVS, RTTOV, originally developed at ECMWF in the early 1990s [RD-1]. Since then, the original code has gone through several developments, especially within the framework of the EUMETSAT NWP-SAF. The model allows rapid simulations of radiances for satellite infrared or microwave instruments, given an atmospheric profile of temperature, variable gas concentrations (notably water vapour), cloud and surface properties. The only mandatory user-supplied gas for RTTOV-10 is water vapour, while ozone, carbon dioxide, nitrous oxide, methane and carbon dioxide profile data can be optionally included. All these parameters are included in the state vector x, as listed in Table 2 in section 3.4. Not all parameters have to be supplied as RTTOV can assume default values.

An important feature of RTTOV is that it not only computes the forward (or direct) radiative transfer calculation but also the gradient of the radiances with respect to the state vector variables.

Given a state vector x, a radiance vector y is computed by the forward model:

$$y = H(x) \quad \textbf{(1)}$$

where H is the radiative transfer model (or also called "observation operator"). This is realised in the RTTOV subroutine *rttov_direct*.

The Jacobian matrix **K** gives the change in radiance δy for a change in any element of the state vector δx assuming a linear relationship about a given atmospheric state x_0:

$$\delta y = \mathbf{K}(x_0)\, \delta x \quad \textbf{(2)}$$

The elements of **K** contain the partial derivatives $\partial y_i/\partial x_j$, where the subscript i refers to a specific instrument channel and j to a position in the state vector. The Jacobian matrix thus gives the top of atmosphere radiance change for each channel given a unit perturbation at each respective level of the profile vectors and in each of the surface or cloud parameters. The **K** calculations are done in the RTTOV subroutine *rttov_k*.

A very specific feature of RTTOV is that the atmospheric transmittances τ, which play an important role in the equation of radiative transfer, are computed by means of a linear regression in optical depth based on variables from the input profile vector, where the regression coefficients are pre-computed predictors. This approach implies that the predictors are channel, i.e. instrument dependent.

RTTOV comes with a set of coefficient files specific for a given instrument and its set of infrared or microwave channels. RTTOV-10 supports 26 satellite platforms with a total of 50 different sensors. Although MTG-FCI is currently not in the list of supported sensors, it can be safely assumed that a coefficient file for MTG-FCI will be available in the future.

The coefficient files also contain coefficients needed in the conversion of radiances to brightness temperatures, using a modified Planck function:

$$L_B(i,T_B) = \frac{c_{1i}}{\mathrm{EXP}\left(\dfrac{c_{2i}}{a_i + b_i T_B}\right) - 1} \quad \textbf{(3)}$$

where $L_B(i,T_B)$ is the Planck radiance integral over the spectral width of channel i at temperature T_B. c_{1i}., c_{2i}, a_i and b_i are pre-computed coefficients for each channel. $c_{1i} = c_1 \nu_i^3$ and $c_{2i} = c_2 \nu_i$, where c_1 and c_2 are the normal Planck function coefficients[1] and ν_i is the central wavenumber of the channel. a_i and b_i are the so-called band correction coefficients.

For the MTG-FCI Level 2 processing it is important to note that the conversion between brightness temperatures and radiances must be consistent with the respective conversion within RTTOV, i.e. the same central frequencies and band correction factors must be used.

[1] $c_1 = 2hc^2$, $c_2 = hc/k_B$, where h is Planck's constant, c the speed of light, k_B the Boltzmann constant

3.3 RTTOV Usage

The RTTOV-10 Users Guide [RD-3] provides a detailed description of how to run RTTOV within a user application. RTTOV-10 is written in highly modular Fortran-90 code. There are only two subroutines that must be called to run RTTOV-10: *rttov_setup* and a call to the forward model (*rttov_direct*) or the K (Jacobian) model (*rttov_k*). Three further subroutines are useful as they do the allocation and deallocation of various arrays: *rttov_alloc_prof*, *rttov_alloc_rad* and *rttov_dealloc_coef*. Any user application also must provide some functionality to populate the state vector x. The core RTM calculations (*rttov_direct* or *rttov_k*) can be done for many state vectors, i.e. rttov_direct or rttov_k can be called within a loop over the number of state vectors (provided the satellite or instrument does not change).

Concerning vertical levels, RTTOV has the limitation that the atmospheric profile had to be provided on 51 fixed pressure levels, where pressure ranges between 1050.00 and 0.05 hPa (earlier RTTOV versions even had the limitation to only 43 levels between 0.1 and 1013.25 hPa). RTTOV-10 allows a user defined number of levels, and the radiances and transmittances output are on user defined levels. Internally, however, RTTOV, RTTOV-10 still uses optical depth calculations defined by the number of levels in the respective coefficient file (51 for MSG SEVIRI).

For the MTG-FCI Level 2 processing, the RTTOV usage will be:

- Simulation of IR channels
- Input atmospheric profiles will be ECMWF forecast profiles, available for two forecast times adjacent to the actual image time, available at a fixed number of vertical levels and at a fixed latitude/longitude grid (typically 1 deg or better)
- ECMWF forecast profiles for the two forecast times adjacent to the nominal image time will be used as input
- Simulations will be done only at the specific forecast model grid points
- Surface emissivity will be assumed to be 1.0 at each grid point; corrections for actual pixel resolution surface emissivity will be done at a later processing stage (as described in the individual product ATBDs)

The RTTOV Fortran code makes use of "structures"; a full description of these structures (or derived types) is given in the Users Guide [RD-3].

As already mentioned in section 2.2, an exception to this strategy is the internal usage of RTTOV within GII processing (see [AD-3]), which is not repeated in this document.

3.4 RTTOV Input

Table 2 (extracted from the RTTOV-10 Users Guide) lists all atmospheric and surface parameters that RTTOV accepts as input for the state vector x.

Table 2: Definition of the state vector x in RTTOV-10

	Variable	Description
Surface Information (Type *skin_type*)	Surface Type	0=land, 1=sea, 2=sea ice
	Water Type	0=fresh water, 1=ocean water
	T_{skin}	Surface skin temperature (K)
Near Surface Values (2m / 10m height) (Type *s2m_type*)	T(2m)	2m Temperature (K)
	q(2m)	2m water vapour (ppmv)
	O_3(2m)	2m ozone (ppmv)
	u(10m)	10 m wind component u (m/s)
	v(10m)	10 m wind component v (m/s)
	Wfetch	Wind fetch (m)
Atmospheric Profile: Switches for some specific calculation/inclusion (Type *profile_type*)	Solar	Include solar radiation for NIR channels
	Refrac	Include variable path length calculation
	Aerosol	Include aerosol calculation
	O_3 Data	Ozone profiles available
	CO_2 Data	Carbon dioxide profiles available
	CLW Data	Cloud liquid water profiles available (for microwave)
	N_2O Data	Nitrous oxide profiles available
	CO Data	Carbon monoxide profiles available
	CH_4 Data	Methane profiles available
	CLD Data	Cloud liquid water profiles available (IR)
	Aerosol Data	Aerosol profiles available
	Nlevels	Number of atmospheric levels
	idg	Flag of which effective diameter scheme shall be used
	ish	Shape of ice crystals: 1=hexagonal, 2=aggregated
Atmospheric parameters defined on nlevels (Type *profile_type*)	p(1:nlevels)	Pressure (hPa)
	T(1:nlevels)	Air Temperature (K)
	q(1:nlevels)	Water Vapour (ppmv)
	O3(1:nlevels)	Ozone (ppmv)
	CO2(:nlevels)	Carbon dioxide (ppmv)
	CLW(1:nlevels)	Cloud liquid water (kg,kg, microwave only)
	N2O(1:nlevels)	Nitrous oxide (ppmb)
	CH4(1:nlevels)	Methane (ppmv)
	AEROSOLS(1:nlevels)	Aerosols (cm^{-3})
	CLOUD(1:nlevels,6 types)	Cloud water/ice (g m^{-3}, IR only
	CFRAC(1:nlevels, 6 types)	Cloud fractional cover (IR only)
Blackbody Cloud (Type *profile_type*)	CTP	Cloud top pressure (hPa)
	Cfraction	Cloud fraction (0-1)

In addition, RTTOV needs information concerning the viewing geometry (local satellite zenith angle, also of type *profile_type*).

For the specific MTG-FCI Level 2 processing usage, however, only the following parameters are used to populate the state vector x:

- Surface skin temperature (K)
- Surface air pressure (hPa)
- Air temperature at 2m height
- Air temperature profile between surface and 0.1hPa (K)
- Humidity at 2m height (ppmv, if necessary derived from the available dew point temperature)
- Humidity profile between surface and 0.1hPa (ppmv)
- Ozone profile between surface and 0.1hPa (ppmv)
- Surface emissivity is always set to 1.0
- Local satellite zenith angle for the specific latitude/longitude grid point

All the other parameters for x have to fall back to their default value, as provided by RTTOV.

3.4.1 Instrument Data

RTTOV shall provide RTM results for the MTG-FCI channels:

- IR3.8
- WV6.3
- WV7.3
- IR8.7
- IR9.7
- IR10.5
- IR12.3
- IR13.3

3.4.2 Forecast Profiles

3.4.2.1 Interpolation to RTTOV Vertical Levels

As already mentioned in section 3.3, RTTOV internally uses a fixed number of vertical levels (nlevels), where the associated pressure values are specified in the RTTOV coefficient file. The input forecast profiles shall be interpolated to these fixed pressure levels, and the RTTOV output is also obtained for these levels. The detailed specification of how the vertical interpolation shall be done is still TBD, but it can be noted that RTTOV-10 provides the required functionality.

3.4.2.2 Unit Conversions

Conversions of units may be necessary for some input variables:

Pressure p has to be provided to RTTOV in hPa, so the conversion from Pa is

$$p(hPa) = p(Pa)/100. \qquad \textbf{(5)}$$

Humidity and ozone have to be provided to RTTOV in ppmv; the conversion from mixing ratio, expressed in kg/kg, is:

$$q(ppmv) = q(kg/kg) * 1.60771704E+06 \qquad \textbf{(6a)}$$
$$o_3(ppmv) = o_3(kg/kg) * 6.03504E+05 \qquad \textbf{(6b)}$$

where q and o_3 refer to water vapour and ozone, resp..

In case humidity is provided in the ECMWF data as dew point temperature TD, mixing ratio q in kg/kg is obtained by:

$$q = \frac{0.622\ e}{p - 0.378\ e} \qquad \textbf{(7)}$$

p is the pressure of the respective level (in hPa), and e is the local vapour pressure, also expressed in hPa. By definition, e is the saturation vapour pressure E for TD, obtained through

$$E(TD) = 6.11 \cdot 10^{7.5 \cdot (TD - 273.15)/(TD - 273.15 + 237.3)} \qquad \textbf{(8)}$$

where TD is expressed in K.

3.4.2.3 Local Satellite Zenith Angle

For each RTTOV simulation, the local satellite zenith angle for the given (model grid point) latitude and longitude must be used. This angle shall be computed for the actual local position of the satellite (which may differ from the nominal one). Only those ECMWF grid points shall be used which fall within a certain great circle arc around the satellite position, i.e. if the local satellite zenith angle exceeds this threshold, the grid point can be discarded.

3.5 RTTOV Output

RTTOV provides as output a set of radiances (*radiance_type*) and transmittances (*transmission_type*). Table 3 summarises the RTTOV output that is needed for the MTG-FCI Level 2 processing. The output will also be available on the prescribed forecast model grid.

Table 3: RTTOV Output needed for MTG-FCI (reference is RTTOV 9)

	Variable	Description
Radiances (Type *radiance_type*)	*clear(:)*	Clear sky top of atmosphere radiance output, for all 8 IR channels
	dnclear(:)	Clear sky downwelling radiance at surface, for all 8 IR channels
	up(:,:)	Above cloud (level) upwelling atmospheric radiance for each pressure level down to surface, for all 8 IR channels
	overcast(:,:)	Level to space overcast radiance given black cloud on each level, for all 8 IR channels
Transmittances (Type *transmission_type*)	*tau_total(:)*	Transmittance from surface for all 8 IR channels
	tau_layers(:,:)	Transmittance from each of the standard pressure levels to top of atmosphere, for all 8 IR channels

The computed radiances are of unit $mW/m^2/ster/cm^{-1}$, the transmittances are dimensionless.

A number of the Level 2 algorithms need brightness temperatures rather than radiances: RTTOV offers as direct output the clear sky brightness temperatures (equivalent to the *radiance % clear* variable in Table 3), as *radiance % bt* for all 8 IR channels (in units K). However, the radiance to temperature conversion can always be performed through Equation (3).

Some Level 2 products (e.g. AMV and OCA) need the Normalised Total Contribution function (NTC) and/or the Normalised Total Cumulative Contribution (NTCC), which are defined as follows:

$$\mathrm{NTCC}(j) = \frac{L\uparrow(j)\,\tau(j)}{L_{clear}} \qquad \textbf{(9)}$$

$$\mathrm{NTC}(j) = \frac{\mathrm{NTCC}(j-1) - \mathrm{NTCC}(j)}{\Delta p(j)} \qquad \textbf{(10)}$$

with

$$\Delta p(j) = \mathrm{LN}\left(\frac{p(j)}{p(j-1)}\right) \qquad \textbf{(11)}$$

j : index for RTTOV pressure level (j=1 is top of atmosphere)
$L\uparrow(j)$: upwelling radiance at level j (from surface and atmosphere below)
L_{clear} : clear sky top of atmosphere radiance
$\tau(j)$: atmospheric transmission from level j to top of atmosphere

$L\uparrow(j)$ is derived from

$$L\uparrow(j) = \frac{L_{clear} - L_{up}(j)}{\tau(j)} \quad \textbf{(12)}$$

With reference to Table 3, L_{clear} is the RTTOV output "*clear*", $L_{up}(j)$ is the RTTOV output "*up*" of the specific level, and $\tau(j)$ is the RTTOV output "*tau_layers*" of the specific level.

For level j=1, NTC(1) = 0.0 and NTCC(1) = 1.0 are prescribed.

As RTM results are computed on the given ECMWF grid and for a given set of forecast times, the results need to be interpolated in space and time to be applied to pixel based products of an MTG-FCI image time. The specifications for these interpolations are still TBD.

4 FUTURE ENHANCEMENTS

Improved use of visible wavelength channels, e.g. OCA cloud product, aerosol products, demands more accurate radiative transfer modelling. The radiative transfer results required are analogous to the IR quantities but restricted to atmospheric transmissions (there is no emission to consider, and the scattering components required by product retrieval algorithms are likely to continue in the form of product specific treatments for the foreseeable future.)

For OCA the requirement is clear: two path transmissions from sun-cloud-satellite at each level. These quantities almost certainly can be calculated within the RTTOV formulism, a study due to close end 2010 (Eumetsat RFQ 10/202521 07/840) should confirm this and provide RTTOV-9 coefficients with the required capability. It is likely that such a functional upgrade will appear at some point in SAF RTTOV releases. An issue here that does not arise with the analogous IR RTM products is the dependency on solar angle. This has two implications; first that solar geometry must be available to, or calculated specifically at the RTM call given the location and time. Secondly, the solar angle (incidence with the surface) changes rapidly and non-linearly near the terminators making linear interpolation of results at these local times unsafe unless a high temporal resolution is used. The problem is that a suitably high temporal resolution would imply much wasteful computation outside the terminator regions. A solution to this problem is TBD.

In the case of aerosol products the requirements are less clear and will depend on the particular algorithm formulation used. Unlike the cloud case where gaseous absorption and cloud scattering can reasonably be assumed de-coupled, the diffuse nature of aerosol and it's shared (lower troposphere) location with humidity (the main absorbing gas) means that accurate radiative transfer depends on correct representation of the interaction between the two. This cannot be achieved with the treatment, described generally in this document for the IR and here for OCA visible radiative transfer, where quantities are pre-calculated independently of the retrieval (aerosol) variable.

It is most likely then, that aerosol radiative transfer will be an integral part of any aerosol algorithm and therefore not an issue for the RTM product.

5 GLOSSARY OF TERMS USED IN EQUATIONS

Variable Name	Meaning	Unit
a	Planck band correction coefficient, see Equ. (3)	K
b	Planck band correction coefficient, see Equ. (3)	n/a
c_1	Planck function coefficient	Jm^2/s
c_2	Planck function coefficient	K m
c_{1i}	Band corrected Planck function coefficient	W/m^2 ster cm^{-1}
c_{2i}	Band corrected Planck function coefficient	K
E(T)	Saturation vapour pressure at temperature T	hPa
e	Vapour pressure	hPa
H	RTM operator (proxy for RTM)	n/a
i	Channel index	n/a
J	Index for atmospheric level	n/a
K	Matrix of Jacobians for T and T_{skin}: for q and o_3:	K/K K/[ppmv]
L_B	Blackbody radiance for a channel of a certain spectral width	W/m^2 ster cm^{-1}
L_{clear}	Top of atmosphere clear sky radiance	W/m^2 ster cm^{-1}
L_{up}	Above level upwelling atmospheric radiance at a given pressure level	W/m^2 ster cm^{-1}
L↑	Below level upwelling radiance (including atmosphere and surface)	W/m^2 ster cm^{-1}
NTC	Normalised Total Contribution	W/m^2 ster cm^{-1}
NTCC	Normalised Total Cumulative Contribution	W/m^2 ster cm^{-1}
o_3	Ozone mixing ratio	kg/kg or ppmv
p	Pressure	hPa or Pa
T_B	Brightness temperature	K
T_D	Dew point temperature	K
t	Time	s
x, x_0	Atmospheric state vector	{various}
y	Radiance vector (proxy for RTM output)	{various}
x_0	Observation vector background value	{various}
ν	Wavenumber	1/cm
τ	Transmission	n/a