MAIA VERSION 4 FOR NPP-VIIRS AND NOAA/METOP-AVHRR CLOUD MASK AND CLASSIFICATION

SCIENTIFIC USER MANUAL

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1.0	Dec 12	L.Lavanant	Initial release, with AAPP v7.5
1.1	Feb 14	P.Roquet	Update atlas descriptions in section 3.3
1.2	Nov 16	L.Lavanant/P.Roquet	Update version maia 4.3 for AAPPv7.14
1.3	Dec 17	P. Roquet	Update SST formulas

1. INTRODUCTION

The first in a new series of NOAA/NASA Earth-observing satellites, the Suomi National Polar-orbiting Partnership (NPP), was successfully launched on 28 October 2011. The Visible Infrared Imager Radiometer Suite (VIIRS) onboard NPP acquired its first measurements on 21 November 2011 and data have been available at Météo-France (MF) since February 2012.

The VIIRS imager represents a significant step ahead compared with the AVHRR radiometer, available on the NOAA and Metop platforms, with its increased spatial resolution (750m for the medium resolution channels and 350m for the imager resolution channels) compared to the 1km for the AVHRR channels. But the major improvement is its enhanced spectral characteristics (16 spectral bands at medium spatial resolution and 5 spectral bands at high spatial resolution against only six bands for AVHRR) which allow an accurate cloud cover analysis even at night-time, the detection of new products such as the aerosol, dust, fire and the computation of numerous products in cloud free areas, such as sea and land surface temperatures, normalized difference vegetation index (NDVI) and snow cover.

A key processing step to obtain all these products is the detection and characterization of the clouds, which are the main tasks of the MAIA software package developed at MF for polar orbiting platforms. The cloud mask allows the identification of cloud free areas for remote sensing applications over continental or oceanic surfaces. The cloud type aims to support weather forecasting activities as an image for its display at the forecaster’s desk to help in identifying significant meteorological features. The cloud top pressure and cover are an important information for the documentation of the co-registered sounding instrument.

The development of the MAIA cloud mask started in 1998 for the processing of the imagers onboard polar platforms. The Ocean and Sea Ice Satellite Application Facility (OSISAF) of EUMETSAT has developed an operational processing chain aiming to produce METOP and now NPP derived SST fields globally in near real time. The cloud masking step which is a crucial part of the SST production is assured by the MAIA cloud mask. The third release of the MAIA software package, processing the NOAA and METOP AVHRR data, was developed in the course of the OSISAF and is distributed by EUMETSAT since 2007 as part of the Numerical Weather Prediction Satellite Application Facility (NWPSAF) AAPP software package (Atkinson, 2011). The fourth operational release, also developed in the course of the OSISAF, allows now to process in more VIRRS observations and this new version was first distributed in 2013 within the NWPSAF AAPPv7 package.

The use of radiative transfer models to fit the algorithm to the exact spectral characteristics of each radiometer allows an easy tuning with real data. The version 4 package was applied to the VIIRS data as soon as the observations were made available at MF, after applying the Community Satellite Processing Package (CSPP) pre-processing package (Gumley, 2012). Since then, the algorithm and software have been checked and tuned using a training dataset manually gathered by experienced forecasters before being implemented in the NWPSAF AAPPv7 package. Validation activity has been performed and validation results of the cloud mask are available, based on the analysis of the algorithm’s performance.

The main purpose of this paper is to document the algorithms that have been implemented in the version4 operational release.

2. CLOUD PACKAGE GENERAL CHARACTERISTICS

The MAIA cloud detection and classification is performed based on a multispectral thresholding technique applied to individual pixels (Saunders and Kriebel 1988, Derrien et al. 1993, Stowe et al. 1999, Lavanant 2002, Derrien et al 2012). The method was chosen, mainly because this robust method can easily optimize the use of the rich spectral content of VIIRS (see table 1), and can also be easily applied in case only a limited number of channels is available like AVHRR (see table 2) during the night for example.

The software follows the scientific method described in Derrien et al, (2012) for MSG/SEVIRI, with the computation of most of test thresholds dynamically derived during the run. Details concerning the scientific explanation of the MSG/SEVIRI tests and results of simulations can be found at the web site http://www.nwcsaf.org. The current MAIA version 4, with the processing of additional channels for the VIIRS instrument compared to AVHRR, obliged us to update the in-depth code. In the MAIA version 3, a situation was said to be cloudy if one test was not satisfied. In the current version 4, all tests of the series (for VIIRS or AVHRR) are passed and a confidence value is appended to each test depending on the proximity to the threshold. Then the individual confidence values are combined to determine a final cloud confidence for each pixel. This follows the approach described in Ackerman et al (2010) and in the VIIRS cloud mask VCM ATBD, see Baker (2011).

To allow the processing of several imagers with different channel numbers (e.g. AVHRR and VIIRS), generic channel bands have been defined with an appended quality flag which depends on the quality of the observation itself or the lack of the channel. For example M5 and A1 are considered to be the same 0.6µm (even if the filters are slightly different) and band 1.3µm (M9) is always put to a bad quality flag for AVHRR and, as a consequence, this test will never be considered in the AVHRR processing.

	M1	M4	M5	M7	M9	M10	M11	M12	M13	M14	M15	M16
µm	0.41	0.55	0.67	0.86	1.38	1.61	2.25	3.74	4.05	8.55	10.76	12.01
			I1	I2				I4			I5	
µm			0.64	0.86				3.74			11.45	

Table 1. List of VIIRS spectral bands used in the MAIA package and corresponding central wavelength in µm. M stands for Medium spatial resolution (750m at nadir) and I stands for Imaging spatial resolution (375m at nadir).

	A1	A2	A3a	A3b	A4	A5
µm	0.63	0.86	1.61	3.72	10.78	11.94

Table 2. List of AVHRR spectral bands and corresponding central wavelength in µm for METOP-B. Channel A3a is activated during the day and A3b during the night.

The general strategy of the algorithm is first to detect clouds with the cloud detection module and then to classify them using the cloud type module and give a cloud top pressure when possible. Most thresholds used are computed in-line from lookup tables, using ancillary data such as atlas, climatology maps and numerical weather prediction (NWP) model forecast fields. The lookup tables are established offline from calculations with radiative transfer models (RTM): 6S (Tanre et al. 1990) for solar bands and RTTOV (Eyre 1991, Saunders 2010) for thermal bands. This allows to apply the software in any geographical area.

A fine tuning of the thresholds is performed after the launch of the instrument using a training database which gathers several thousands of targets manually selected in the acquisition area and labeled by experienced forecasters as cloud free or covered by one specific cloud type (such as stratus, stratocumulus, cumulonimbus). The full satellite information and required ancillary data are kept in each of these square targets thus allowing tuning activities.

The cloud detection, classification and pressure algorithms are detailed respectively in chapters 5, , and 8. The test sequences and the technique to compute the dynamic thresholds are presented. The required inputs are listed in chapter 2.1 and the product content is presented in chapter 2.2.

2.1 List of required inputs

The input data to the algorithms are summarized in table 3 with the mandatory inputs flagged.

The VIIRS channels are input by the user in the HDF5 output format of the pre-processing CSPP package (Gumley, 2012). A preliminary interface routine converts the AVHRR data from the EUMETSAT native PFS format or from the AAPP level1b format (depending on the source) to HDF5 to allow a similar processing between VIIRS and AVHRR. The data are treated on a pixel basis which allows indifferently to process granules (global acquisition) or of longer passes from direct readout acquisitions for example. The software check the availability and quality of the channels for each pixel. Only the 10.8µm channel is mandatory to call the MAIA routine. If missing for one pixel, the cloud products are not provided for this pixel. If non-mandatory channels are missing for one pixel, the tests using these channels are not applied and the confidence in the product is lower.

NWP forecast fields are input in Gridded Binary (GRIB) format by the user and interpolated in time and space at the pixel location by the MAIA package. Some NWP fields are mandatory: the land surface temperature and the total water vapor content of the atmosphere for the cloud detection routine and for the cloud characterisation, the air temperature at 850 hPa, 700 hPa, 500 hPa .

SST and surface reflectance climatologies are available in the MAIA software package at a 0.05 degree spatial resolution in HDF5 format. The land/sea and elevation atlases are available at a 0.02 degree resolution also in HDF5 formats. Climatology and atlas are extracted on the users' defined area by the software itself.

The surface type, altitude and solar zenith angle are input arguments of the maia library and are defined in the calling program. Surface and altitude are optional and if not available, the MAIA scheme makes their determination from the situation position using provided datasets.

Satellite data (reflectance corrected from solar elevation in %, brightness temperature in K)	0.6 (AVHRR / VIIRS) 0.8 (AVHRR / VIIRS) 1.3 (VIIRS) 1.6 (AVHRR / VIIRS) 3.7 (AVHRR / VIIRS) 4.0 (VIIRS) 8.7 (VIIRS) 10.8 (AVHRR / VIIRS). Mandatory. 12.0 (AVHRR / VIIRS)
NWP parameters (mandatory)	▪ Land surface temperature ▪ total water vapor content of the atmosphere ▪ altitude of the NWP model grid ▪ air temperature at 850 hPa, 700 hPa, 500 hPa
Atlas and climatology (mandatory)	▪ Land/sea atlas ▪ Elevation atlas ▪ Monthly minimum SST climatology (over sea) ▪ Monthly mean SST climatology ▪ Monthly maximum 0.6 µm surface reflectance climatology (over land)

Table 3. List of input data to the MAIA algorithm

2.2 List of outputs

The MAIA output file is in HDF5 format. For details, please see the AAPP *Data Formats* document provided on the AAPP web pages (see link in the REFERENCES). The name of the file is constructed using the data acquisition type (DB=direct broadcast or GL=global), the date, the starting and ending time information of the granule, the ascending or descending orbit condition (ASC=ascending, DES=descending), the Day/Night illumination condition(D=day, N=night), the latitude and longitude in degree of the centered pixel of the granule, the orbit number. For example:

viiCT_npp_DB_20121214_S013613_E013737_DES_N_La068_Lo0018_00001.h5

The content of the header dataset is given in table 4.

dataname	Name of the MAIA output file.
site1c	Dataset creation site ID ('CMS')
dataname_gmodo	dataname of the input geo file
N_Granule_ID	granule identifier
site1b	creation site of the input dataset ('CMS', 'NOA')
sat_id	satellite id (11=METOP-1, 12=METOP-2, 14=NPP)
inst_id	instrument identification (AVHRR=1, VIIRS=2)
datatyp	data acquisition type code (1 =Direct Readout, 2 = global)
start_year	start of dataset: year
start_day	start of dataset: day of year
start_time	start of dataset: UTC time of day in ms
start_orbit	start of orbit
end_year	end of dataset: year
end_day	end of dataset: day of year
end_time	end of dataset: UTC time of day in ms
end_orbit	end of orbit
Nb_Granules	number of granules in the dataset
Nb_Lines	count of scan lines in the data set
Nb_pixels	number of pixels in line
CMa_Version	version number of the cloud mask
ModScan	Scan operational mode (0: processed)

Table 4. Description of the Header of the MAIA output product.

The output file is at full resolution and in satellite projection. The data datasets provide the information for each pixel and the content is summarized in table 5.

The cloud detection process starts with the detection of pixels contaminated by surface snow or sea-ice for daytime situations only. If found, the cloud detection process is not done and the pixel is considered cloud-free with the surface contaminated by snow or sea-ice. If no snow/sea-ice is found, the cloud detection process is activated.

A confidence level is appended to the cloud detection process. Based on the proximity of each passed test to its confident clear or confident cloudy threshold value, it summarizes the strength in conviction in the cloud/no cloud decision. A cloud detection quality flag is also determined. It depends on the illumination conditions and the surface topography (e.g. coast), the availability of AVHRR/VIIRS input observations and the quality of the processing itself.

Four possible categories summarizes the cloud detection process: clear (confident clear level), cloud contaminated (probably clear, probably cloudy and confident cloudy levels), clear over snow surfaces (for daytime only), clear over sea-ice surfaces (for daytime only).

If the situation is flagged confident clear over sea, a Sea Surface Temperature is computed using the OSISAF split-window model from LeBorgne (). Otherwise, the surface temperature from climatology (over sea) or from the NWP background is provided.

A set of flags for heavy aerosols, dust and volcanic ash, and active fire can be also activated but are not available in the current version.

When a situation is flagged confident cloudy or probably cloudy, the cloud opacity is tested using the 10.8µm-12.0µm brightness temperature difference (flag in the product) and a further process is done to determine its cloud type.

Fourteen possible cloud types are available in the cloud classification product. The numbering is defined to be similar to the one defined in the NWCSAF product and because the separation between stratiform and cumuliform clouds is not performed, the numbers 5, 7, 9, 11 and 13 which allow to the separation cumuliform/stratiform in the NWCSAF product do not exist in the MAIA outcome.

For cloudy pixels classified as Very low cloud (n°6), Low cloud (n°8), Medium cloud (n°10), High opaque cloud (n°12), Very high opaque cloud (n°14), a cloud top temperature and a cloud top pressure is determined.

In the current version, the cloud phase flag is still not available.

Ancillary information which were used in the treatments (Day/Night/Twilight/Sunglint flag, Land/Sea/Coast flag, surface temperature and total water vapor content source).

Positioning (latitude, longitude), satellite zenith viewing angle, surface altitude and time of the pixel from the input data are also available in the output product.

Pixel time	▪ scan line year ▪ scan line day ▪ scan line time
Scan line quality	
Pixel positioning	▪ Latitude in degree*10000 (-9999=missing) ▪ longitude in degree*10000 (-9999=missing)
Satellite zenith angle	in degree *100 (-9999=missing)
Surface altitude	in meter*100 (-9999=missing)
Pixel quality flags	Pixel quality flags for each medium and imaging channels: Bit 0-1: input info quality for cloud mask 0= ok mask done with highest information quality 1= poor some channels are discarded 2= bad cloud mask not done Bit 2: summarized geo-location quality 0= ok 1= bad Bit 3: IBAND SDR summarized quality flag of used channels (0= ok 1= bad) Bit 4: MBAND SDR summarized quality flag of used channels (0= ok 1= bad) Bit 5 Qual_M(1) 0= ok 1= bad Bit 6 Qual_M(2) 0= ok 1= bad Bit 7 Qual_M(3) 0= ok 1= bad Bit 8 Qual_M(4) 0= ok 1= bad Bit 9 Qual_M(5) 0= ok 1= bad Bit 10 Qual_M(6) 0= ok 1= bad Bit 11 Qual_M(7) 0= ok 1= bad Bit 12 Qual_M(8) 0= ok 1= bad Bit 13 Qual_M(9) 0= ok 1= bad Bit 14 Qual_M(10) 0= ok 1= bad Bit 15 Qual_M(11) 0= ok 1= bad Bit 16 Qual_M(12) 0= ok 1= bad Bit 17 Qual_M(13) 0= ok 1= bad Bit 18 Qual_M(14) 0= ok 1= bad Bit 19 Qual_M(15) 0= ok 1= bad Bit 20 Qual_M(16) 0= ok 1= bad Bit 21 Qual_I(1) 0= ok 1= bad Bit 22 Qual_I(2) 0= ok 1= bad Bit 23 Qual_I(3) 0= ok 1= bad Bit 24 Qual_I(4) 0= ok 1= bad Bit 25 Qual_I(5) 0= ok 1= bad
Day/Night/Twilight/Sunglint	0=Night, 1=Twilight, 2=Day, 3=Sunglint
Land/Water Background	0=Sea Water, 1=Land , 2=Inland Water , 3=Coast
Mask processing indicator	bit 0 snow/ice from external data 0 Not Done bit 1 Cloud mask on pixel 0 Not Done bit 2 Thin Cirrus detection 0 Not Done bit 3 cloud type 0 Not done bit 4 cloud phase 0 Not Done

	bit 5 Cloud Height 0 Not Done bit 6 Active fire detection for clear/land 0 Not Done bit 7 Aerosols 0 Not Done bit 8 Cloud Shadow from Neighbors 0 Not Done bit 9 CMa update from Neighbors 0 Not Done bit 10 Fire detection texture 0 Not Done bit 11 Aerosols texture 0 Not Done
Cloud detection categories	-99=Non-processed (no data or corrupted data) 1=Cloud-free 2=Cloud contaminated 3=cloud-free with surface contaminated by snow 4=cloud-free with surface contaminated by sea-ice
Confidence level	0=confident clear 1=probably clear 2=probably cloudy 3=confident cloudy
test series quality	0=high 1=medium 2=poor 3=bad
Surface temperature	-9999=not available in C*100 cloud free over sea: from split-window cloud contaminated: over sea: from climatology over land/coast: from NWP
Aerosol flag Dust / Volcanic ash flag Fire flag	-9999=not processed in the current version -9999=not processed in the current version -9999=not processed in the current version
Cloud type categories	-99=Non-processed (no data or corrupted data) 1=Cloud free land 2=Cloud free sea 3=Land contaminated by snow 4=Sea contaminated by snow/ice 6=Very low cloud 8=Low cloud 10=Medium cloud 12=High opaque cloud 14=Very high opaque cloud 15=High semi-transparent thin cloud 16=High semi-transparent fairly thick cloud 17=High semi-transparent thick cloud 18=Semitransparent above low or medium cloud 19=Fractional cloud (sub-pixel water cloud)
Cloud phase flag water or ice	0=not processed in the current version

Cloud top temperature	-9999=not available in C*100
Cloud top pressure	-9999=not available in hPa*10

Table 5. Description of the MAIA software output.

3. EXTERNAL GEOGRAPHICAL INFORMATION

A set of global and monthly climatological datasets and atlas are available with the MAIA package. The NWP forecast is also mandatory to run the MAIA software. A unix script first links the adequate datasets using the date and time of the observation. The script searches for the two forecast files surrounding the observation that are nearest in time.

3.1 Minimum Sea Surface Temperature atlas

Global and twice-monthly climatological datasets of minimum SST at a resolution of 0.05 * 0.05 degrees are provided with the scheme. Each of the 24 HDF5 files have been established using climatologies based on NOAA-AVHRR imagery and elaborated by Faugère et al, 2001. Unit of SST is Celsius*100. The size is of 50MB each. The files are organized by latitude bands of 10 degrees. They are of the form sstmin_month_nn.h5, with nn=1 or 2 for the first or the second part of the month. The data are used for the in-line computation of the thresholds for the cloud detection test on SST.

3.2 Surface Visible Reflectivity atlas

Global and about twice-monthly climatological data-sets of visible reflectivity (0.659µm band) at a resolution of 0.05 * 0.05 degrees are provided with the scheme. Each of the 23 HDF5 files contains the maximum of the monthly visible reflectivity on the grid over land only and are based on MODIS black-sky albedo maps of one minute resolution. Unit of visible reflectivity is %*100. The size of the files is of 50MB each. The files are organized by latitude bands of 10 degrees. They are of the form albmax_mm.dat, dd is the day of the year. The data are used for the in-line computation of the thresholds for the visible cloud detection test.

3.3 Surface type and elevation atlas

Two global datasets landsea.h5 for the surface type (flag sea/land) and elevation.h5 for the surface elevation (in meter) are provided with the MAIA scheme. The elevation.h5 atlas is at a 0.02*0.02 degrees resolution and is based on the Global 30 Arc-Second Elevation (GTOPO30) product.
The landsea.h5 atlas is at a 0.01*0.01 degrees resolution and is based on the MODIS Collection 5 Land Cover Type (MCD12Q1 C5) using the 2012 data.

3.4 Forecast

The two forecast files surrounding the observation are read by the scheme in GRIB format. The necessary fields in the forecast files are the geometric altitude, the surface pressure, the surface and air surface temperatures and the forecast profile (T, H, P) on atmospheric levels. The air surface temperature and total water vapor are used for example to interpolate in lookup threshold tables.

3.5 Mean Sea Surface Temperature atlas

Global and twice-monthly climatological datasets of mean SST at a resolution of 0.05 * 0.05 degrees are provided with the scheme. Each of the 24 HDF5 files have been established using climatologies based on NOAA-AVHRR imagery and elaborated by Faugère et al, 2001. Unit of SST is Celsius*100. There size is of 50MB each. The files are organized by latitude bands of 10 degrees. They are of the form sstmoy_month_nn.h5, with nn=1 or 2 for the first or the second part of the month. The data are used for the in-line computation of the SST when the situation is declared confident clear over sea.

4. DETERMINATION OF ENVIRONMENTAL CONDITIONS

4.1 Calling program

Two different main programs are available for VIIRS and AVHRR respectively. However, both read the complete input satellite observation and analyze the input field to get the four corners (minimum and maximum latitude/longitude) and determine the working boxes in which the environmental conditions remains identical.

4.2 First call of the MAIA library

At the first call of the MAIA routine, the software reads the

- the three climatological global atlases of minimum SST, maximum SST, and maximum visible reflectivity. The field area corresponding to the observation are extracted using the four corners and put in memory.
- The two topographic atlases and only the data corresponding to the observation area are put in memory.
- the forecast fields of surface altitude, T2m, TWVC, surface pressure and the temperature and humidity profiles on the NWP levels are put in memory. The field of total water vapor content is computed from the forecast profile and the surface pressure if not already available in the file.
- the coefficients to compute the sea surface temperature for the processed satellite
- The lookup IR and Visible tables for computing the test thresholds

4.3 Environmental conditions

In order to save computation time, the environment conditions are updated at a different spatial resolution than the input observation. For example, the NWP data are often at a coarser resolution (e.g. 0.5*0.5 degrees) than the full VIIRS or AVHRR resolution and the interpolation in the forecast for each pixel will not improve significantly the result but takes a lot of computer time. For that reason, the observations are processed box by box (in this version boxes of 0.1 degree latitude by 0.1 degree longitude have been chosen) and all the environmental conditions remain unchanged during the run in the box. The environmental conditions are determined at the first call of a new box and saved for all MAIA routine calls for the considered box. They are:

- climatological minimum SST, mean SST and visible reflectivity data
- the land/sea/coast flag from the landsea data and the surface elevation Illumination condition (day/night/glint/twilight)
- forecast data, T2m, TWVC, T500hPa, T700hPa, T850hPa, surface pressure and elevation, the T,q profile interpolated on the 51 levels of RTTOV
- secant of the solar zenith angle
- IR and Visible threshold values depending on the previous information and the lookup tables. Over sea, the visible thresholds are computed using the Cox and Munk model and no input external data is used.

To assure the accuracy of the product, some information are also determined at the pixel resolution. They are: the land/sea/coast flag from the landsea data and the surface and Illumination condition (day/night/glint/twilight) and secant of the solar zenith angle.

5. CLOUD DETECTION DESCRIPTION

The algorithm is based on a multispectral threshold technique applied to each pixel of the input file (granule or direct readout acquisition).

A first test allows the identification of snow or sea-ice. If the test is successful, the pixel is considered as clear and the process is stopped. Otherwise, a sequence of tests is applied for the identification of pixels contaminated by clouds. The main characteristics of this set of tests are summed up below:

- The test sequence applied to sea, land or coast pixels, depending on the illumination conditions (daytime, night-time, twilight, sunglint, as defined in table 6), are shown on tables 7 and 8. Individual tests are detailed in following sections.

- Most thresholds are dynamically determined from satellite-dependent look-up tables using as input the viewing geometry (sun and satellite viewing angles), NWP model forecast parameters (surface temperature and total atmospheric water vapor content) and ancillary data (elevation and climatological data). More details are given in section 7. Confident clear and confident cloudy threshold values surrounding each threshold are also defined.

Night-time	Twilight	Daytime	Sunglint
$\theta>90$	$83<\theta<90$	$\theta<83$	$Ref_{Cox}>10\%$ & $\theta<83$

Table 6. Definition of illumination conditions. Ref_{Cox} stands for the top of atmosphere 0.6µm reflectance simulated over the ocean using the Cox and Munck theory (Cox and Munck 1954). The solar zenith angle θ is expressed in degrees.

The tests are done on single channels (10.8µm brightness temperature, visible reflectance), on combination of channels, in brightness temperature, for 10.8µm-12.0µm, 10.8µm-3.7µm, 3.7µm-12.0µm, on spatial local variances of channels 0.6µm, 0.8µm, 10.8µm, 3.7µm-10.8µm computed inside the VIRRS pixel or on a local box centered on each AVHRR pixel.

Each test of a series is passed provided the quality flags of the channels involved in the test are good. A confidence value for each test between 0 and 1 is computed based on the proximity of each passed test to its confident clear or confident cloudy threshold value. Then, at the end of the test series, a summarized confidence level is computed following the method developed for the the MODIS mask, see Ackerman (2010).

A cloud detection quality flag is also determined. It depends on the illumination conditions and the surface topography (e.g. coast), the availability of AVHRR/VIIRS input observations and the quality of the processing itself.

An additional process, but still not available in the current version, will allow the identification of heavy aerosols, dust clouds and volcanic ash clouds, the result being stored in separate flags.

group	Cloud tests	Sea-Ice ($\theta<86$)	Snow ($\theta<86$)	Sea/lake	sunglint	Land	Desert	Coast	
	ndvi	x	x					x water	x land
I	10.8	x	x	x (if not lake)	x (if not lake)	x	x	x (if not lake)	x
V	10.8-12.0	x	x	x	x	x	x	x	x

II	3.7-4.0			x		x	x		
II	10.8-3.7			x		x	x	x	x
	3.7-10.8	x (if no 1.6)	x (if no 1.6)						
II	8.7-10.8			x	x	x	x	x	x
IV	1.6	x	x	x					
	1.6/0.6	x							
III	0.6 & 3.7-10.8				x			x (if sunglint)	
III	0.6	x	x			x	x		x
III	0.8	x	x	x	x			x	
III	0.8/0.6			x	x	x			
IV	1.3					x	x		
	texture			x	x	x			

Table 7. Description of the test sequences used in the cloud detection for daytime situations. The tests and the dynamic thresholds are detailed in the text.

		night				twilight			
group	Cloud tests	Sea/lake	Land	Desert	Coast	Sea/lake	land	desert	coast
I	10.8	x (if not lake)	x	x	x	x (if not lake)	x	x	x
V	10.8-12.0	x	x	x	x	x	x	x	x
II	12.0-3.7	x				x			
II	3.7-4.0						x	x	
II	10.8-3.7	x	x	x	x	x	x	x	x
II	3.7-10.8	x	x	x	x	x	x	x	x
II	8.7-10.8	x	x	x	x	x	x	x	x
II	8.7-3.7			x					
III	0.4							x	
III	0.6						x		
III	0.8					x (if not lake)			
IV	1.6					x			
	texture	x	x	x		x	x	x	

Table 8. Description of the test sequences used in the cloud detection for night time and twilight situations. The tests and the dynamic thresholds are detailed in the text.

5.1 Snow or ice detection test

Ice and snow appear rather cold and bright, and may therefore be confused with clouds (especially with low clouds) during the cloud detection process. Ice and snow must therefore be identified first, prior to the application of any cloud detection test. The test series, summarized in table 7, aims to detects pixels contaminated by snow or ice: if it is satisfied, the pixel is classified as snow or ice and no further cloud detection is attempted.

The snow and ice tests are applied for daytime period only if the solar elevation is greater than 20 degrees (10 degrees for 1.6µm), since it relies on the analysis of the solar reflection in the visible (0.6µm) and the medium-infrared (3.7µm, 1.6µm) wavelengths. The bases of this test are the following:

- Snow and ice are separated from water clouds by their low reflectance at 1.6µm (or at 3.7µm if the1.6µm channel is not available), whereas water clouds have relatively high reflectance in both channels.
- The 3.7µm channel is used when the 1.6µm observations are unavailable. During the day, it includes solar reflection and thermal emission and the solar reflection part is roughly approximated by the 3.7µm -10.8µm brightness temperature difference.
- Snow and ice are separated from cloud free oceanic or continental surfaces by their higher 0.6µm visible reflectance and slightly colder 10.8µm brightness temperature.
- 10.8µm –12.0µm brightness temperature difference helps to discern cirrus from snow and ice.
- 0.8µm is useful to separate shadows from snow and ice.
- The reflectance ratio between 1.6µm and 0.6µm is used in the separation of water clouds from snow cover (over land and sea-ice) and sunglint.

5.2 Cloud detection tests description

The tests are detailed in this section, while the computation of the thresholds is described in next section.

5.2.1 Test on sea surface temperatures for all cold clouds

This test allows to detect most of the clouds (medium, high-level clouds) over the ocean for any illumination conditions. Sea surface temperatures (SST) are estimated from 10.8µm and 12.0µm brightness temperatures using a nonlinear split window algorithm and a background minimum climatological SST (Le Borgne et al. 2003). A pixel is classified as cloudy if its estimated SST value is lower than a monthly climatological minimum SST value by 4K, put to account for water vapor absorption and imperfection or climatology.

The test is not applied where the climatological SST is lower than 270.15 K, which indicates that the ocean could be frozen. In that case, the following test is applied.

5.2.2 Test on 10.8µm for all cold clouds

This test is applied over land and sea (only if the SST test could not be applied). It allows the detection of medium and high-level clouds with a 10.8µm brightness temperature lower than the clear sky surface brightness temperature. The threshold is computed from NWP surface temperature forecast, by accounting for atmospheric absorption and small-scale height effects (over land) as described below:

- The surface temperature is a time and spatial interpolation at the pixel location from the two nearest NWP fields
- The atmospheric absorption is accounted for through an offset.
- A dry adiabatic law is used to account for the height difference between the elevation of the NWP grid and of the pixel (obtained from the GTOPO30 atlas at 30 arc-second horizontal resolution) to roughly simulate small-scale height effects in mountainous regions.

5.2.3 Test on 10.8µm –12.0µm for thin cirrus and cloud edges detection

This test is applied over all surfaces and for any solar illumination. It allows the detection of thin cirrus clouds and cloud edges characterized by higher 10.8µm –12.0µm values than cloud-free surfaces. Over land, this test is applied only if 10.8µm is lower than 303.15K to avoid the confusion of very moist, warm, cloud free areas with clouds.

5.2.4 Test on 8.7µm –10.8µm for thin cirrus detection

This test aims to detect thin cirrus clouds over all surfaces for any solar illumination. It is based on the fact that high semi-transparent clouds are characterized by relatively high 8.7µm–10.8µm difference compared with surface values.

5.2.5 Test on 3.7µm –10.8µm in night-time conditions for cirrus clouds detection

This test is only used at night-time conditions. It allows the detection of high semi-transparent clouds or sub-pixel cold clouds. It is based on the fact that the contribution of the relatively warm grounds to the brightness temperature is higher at 3.7µm than at 10.8µm, due to a lower ice cloud transmittance, and to the high nonlinearity of the Planck function at 3.7µm. The test is usable only at night-time, when solar irradiance does not contribute to the 3.7µm channel radiance. The nonlinearity effect makes the test much more efficient than the 10.8µm–12.0µm or the 8.7µm–10.8µm tests to detect high semi-transparent clouds over rather warm grounds at night-time. The brightness temperature difference 3.7µm -10.8µm is a function of the cloud height, thickness (for cirrus) and cloudiness (for subpixel clouds).

5.2.6 Tests on 10.8µm –3.7µm and 12.0µm –3.7µm for low water cloud detection

These tests allow the detection of low water clouds over all surfaces at night-time, but also low clouds shadowed by higher clouds during the day. A basic assumption is that the 3.7µm channel is not affected by the solar irradiance, which is the case only at night-time and in shadows. The tests are based on the fact that the water cloud emissivity is lower at 3.7µm than at 10.8µm or at 12.0µm, which is not the case for cloud free surfaces (except sandy desert areas). Over water and night-time, the contrast between low clouds and the surface with 3.7µm seems slightly larger if 12.0µm is used instead of 10.8µm. A safety check is applied to 8.7µm –10.8µm to minimize the confusion of sandy arid areas with low clouds.

5.2.7 Test on 8.7µm –3.7µm over desert for low water cloud detection

This test allows the detection over the desert of low water clouds at night-time. Low clouds are usually detected at night-time by their 10.8µm–3.7µm brightness temperatures differences. This is practically never the case over desert because there is no contrast in this feature between low clouds and desert. The 8.7µm–3.7µm test is based on the fact that desert areas usually have low emissivities at 3.7µm and 8.7µm, whereas low water clouds have low emissivities at 3.7µm, but not at 8.7µm. A consequence is that low clouds are characterized by higher 8.7µm –3.7µm differences compared with values over desert.

5.2.8 Tests on 0.4µm, 0.6µm, 0.8µm or 1.6µm

The tests, applied to the visible (0.4µm and 0.6µm) or near-infrared (0.8µm and 1.6µm) reflectances, are very useful at daytime in detecting low clouds having a reflectance higher than the underlying surfaces.

Over sea, the visible or near-infrared reflectance measured over the cloud-free oceans mainly corresponds to Rayleigh and aerosol scattering (weaker in the near-infrared band), and to the solar reflection over the ocean which is very low, apart from sunglint conditions and in turbid areas (for the

0.6µm visible channel only). Therefore near-infrared bands (0.8µm and 1.6µm) are used over the ocean, the visible band (0.6µm) being used only in case 0.8µm is not available.

As the cloud-free land reflectance is usually much higher in the near-infrared than in the visible wavelengths (due to the vegetation spectral radiative behavior at these wavelengths), the test over land is therefore only applied to the 0.6µm visible reflectance (to the 0.4mm is applied over non-polar desert area). This increases the contrast between land and cloud.

5.2.9 Test on the 0.8µm /0.6µm ratio

This test is performed over daytime water and land pixels. It makes use of the fact that the spectral reflectance at these two wavelengths is similar over clouds (ratio is near 1) and different over water and vegetation (less than 0.9) due to the increase affect of Rayleigh scattering on the 0.6µm. As the ratio is between 0.9 and 1.0 over desert, the test is not used over desert area. For more details, see

5.2.10 Test on 1.3µm for high-level cirrus detection

This test is efficient to detect the presence of thin cirrus cloud in the upper troposphere under daytime conditions, due to the strong water vapor absorption in the 1.38µm region. With sufficient atmospheric water vapor present (estimated to be about 0.4cm precipitable water) in the beam path, no upwelling reflected radiance from the Earth's surface reaches the satellite. Since 0.4cm is a small atmospheric water content, most of the earth's surface will indeed be obscured in this channel. With relatively little of the atmosphere's moisture located high in the troposphere, high clouds appear bright and reflectance from low and mid level clouds is partially attenuated by water vapor absorption. However, Ben-Dor (1994) demonstrated that thin cirrus detection using 1.38µm observations may be more difficult for elevated surfaces, dry atmospheric conditions, and high albedo surfaces. Also volcanic aerosols into the stratosphere may impact this test.

5.2.11 Test on 3.7µm – 4.0µm

This test is not performed in areas with bright surfaces such as polar regions, land and coastal areas where NDVI is less than a specified value, and under conditions of sunglint. Due to the small wavelength differences between these two bands the thermal contribution due to temperatures within a pixel are relatively close. The largest difference between these two bands is the solar component in the 3.7µm channel. The difference removes the thermal emission, resulting in the solar component of 3.7µm alone. It allows to detect clouds due to both the low reflectance of most surface types and the relative high reflectance of clouds in the 3.7µm channel.

5.2.12 Tests on 0.6µm and 3.7µm -10.8µm for low cloud detection in sunglint

Low clouds can easily be detected at daytime over the ocean by their high visible or near-infrared reflectances. This is not possible in the case of sunglint, as the sea reflectance at these wavelengths may then be higher than that of clouds. The use of both 0.6µm and 3.7µm channels allows to detect low clouds in areas affected by sunglint. Indeed, oceanic areas in sunglint conditions with high 0.6µm reflectances also have very high 3.7µm reflectances, which is usually not the case for low clouds. The test consists in flagging pixels as cloudy if the ratio between their 3.7µm –10.8µm brightness temperature difference normalized by the solar illumination (approximation of the solar contribution in the 3.7µm channel) and their 0.6µm visible reflectance is smaller than a constant value (0.15), and provided that their 0.6µm visible reflectance and 3.7µm –10.8µm brightness temperature difference are larger than 60% and 0K, respectively. The rapid saturation of the 3.7µm radiance limits the use of this test in cases of strong sunglint.

5.2.13 Test on 3.7µm –10.8µm in daytime or twilight conditions

This test allows the detection of low clouds at daytime (except in sunglint areas over the ocean) and twilight conditions. It is based on the fact that solar reflection at 3.7µm (approximated by the 3.7µm–

10.8µm brightness temperature difference) may be rather high for clouds (especially low clouds), which is not the case for cloud free areas (except ocean sunglint). Over arid areas, a safety test is applied to 8.7µm –10.8µm to limit the confusion of bright areas with clouds.

5.2.14 Local spatial texture tests

These tests have been designed to detect small broken clouds, thin cirrus or cloud edges by their high horizontal variations in the visible, near infrared or infrared channels. The difficulty of applying these tests comes from the natural heterogeneity of the surface background: oceanic areas are rather homogeneous, with the exception of strong thermal fronts (large 10.8µm variation), turbid coastal areas (large 0.6µm variation), and sunglint areas (large 0.6µm and 0.8µm variation). Land surfaces are generally much more inhomogeneous, especially in mountainous or arid regions.

For AVHRR, the method relies on the computation of local standard deviations in the 10.8µm, 10.8µm–3.7µm, 0.6µm and 0.8µm features using the eight surrounding pixels. For VIIRS, the local standard deviations are computed using the four pixels of the imaging channels (350m resolution) co-registered in the medium channels for the 0.6µm (I1), 0.8µm (I2), 3.7µm (I4) and 11.4µm (I5).

Over the ocean, the simultaneous thresholding of 10.8µm (11.4µm for VIIRS) and 10.8µm –3.7µm (11.4µm –3.7µm for VIIRS) local standard deviations with constant values (respectively 0.4K and 0.1K (0.4K at daytime)) is efficient for all illumination conditions in detecting clouds while minimizing the misclassification of thermal fronts. The test on the 0.8µm local standard deviation with a threshold increasing with the sunglint intensity (the minimum value being 0.8%) allows to overcome most problems linked to turbidity and sunglint.

Over land, the use of the same channels with different thresholds values (1.0K (2.0K at daytime) for both features) allows us to reduce misclassifications to the minimum, except in very mountainous (elevation larger than 1500 m) or in arid areas (climatological 0.6µm surface reflectance higher than 20%). The 0.6µm and 10.8µm local horizontal heterogeneities are analyzed simultaneously using a method detailed in Derrien et al. (2010). It relies on the fact that a surface (outside arid areas) with a higher 0.6µm reflectance than the neighborhood is less vegetated and therefore warmer; consequently a pixel brighter than its surroundings is cloudy if it is also colder.

6. CLOUD CLASSIFICATION DESCRIPTION

When a situation is flagged confident cloudy or probably cloudy, a further process is done to determine its cloud type. A multispectral thresholding algorithm is applied at the pixel scale to a set of spectral and textural features depending on the illumination conditions. The threshold values are dependent on the illumination and viewing geometry, the geographical location and the NWP data describing the water vapor content and a coarse vertical structure of the atmosphere.

Ten cloud categories are defined :

- five opaque cloud classes according to their altitude: very low, low, medium, high and very high
- three semi-transparent classes according to their thickness: thick, mean and thin
- one class of semi-transparent clouds above lower clouds
- one fractional clouds class

The cloud classification algorithm is based on the following approach:

- Main cloud types are separable within two sets: the fractional and high semi-transparent clouds, from the low/medium/high opaque clouds. These two systems are distinguished using the following spectral features: 10.8µm–12.0µm, 3.7µm–10.8µm (in night-time conditions only), 0.6µm and local spatial texture computed from 10.8µm and 0.6µm (in daytime conditions only).

- Within the first set, the fractional and high semi-transparent are separated mainly using their 8.7µm–10.8µm brightness temperature differences.
- The remaining categories are distinguished through the comparison of their 10.8µm to NWP forecast air temperatures at several pressure levels (850, 700 and 500 hPa).
- No separation between cumuliform and stratiform clouds is performed in the current version.
- No cloud phase flag is available in the current version.

The test sequences of the cloud classification algorithm are summarized in tables 9 and 10. The thresholds applied to the infrared brightness temperature differences are obtained by a procedure similar to that described in previous section, whereas the thresholds applied to the visible channels are empirically derived using the training dataset (see § 2.1). The 10.8µm infrared thresholds allowing the separation between low, medium or high clouds are linear functions of NWP forecast air temperatures at 850, 700, 500 hPa tuned using the training dataset.

6.1 classification tests applied in night-time conditions

Very High Opaque	10.8<max108vh & 10.8-12.0 <s108_120_thick
High Opaque	max108vh <10.8<max108hi & 10.8-12.0 <s108_120_thick
Medium	max108hi<10.8<max108me & [10.8-12.0 <s108_120_thick or 3.7-10.8 <s37_108_thin]
Low	max108me<10.8<max108lo & [10.8-12.0 <s108_120 or 3.7-10.8 <s37_108_thin]
Very Low	max108lo<10.8<max108thin & 10.8-12.0 <s108_120_thick & 3.7-10.8 >s37_108_thin
	max108lo<10.8<max108thin & 3.7-10.8 <s37_108_thin & [10.8-12.0 <s108_120_thick or 3.7-10.8 <s37_108_low]
	max108thin<10.8 & [10.8-12.0 <s108_120 or 3.7-10.8 <s37_108_low]
Fractional	max108lo<10.8<max108thin & 10.8-12.0 >s108_120_thick & 3.7-10.8 <s37_108_thin & 3.7-10.8 >s37_108_low
	max108lo<10.8<max108thin & 10.8-12.0 >s108_120_thick & 3.7-10.8 >s37_108_thin
	max108thin<10.8 & 10.8-12.0 >s108_120 & 3.7-10.8 >s37_108_low
Semi-transparent thick	10.8<max108vh & 10.8-12.0 >s108_120_thick
	max108vh <10.8<max108hi & 10.8-12.0 >s108_120_thick
Semi-transparent mean	max108hi<10.8<max108me & [10.8-12.0 >s108_120_thick or 3.7-10.8 >s37_108_thin]
Semi-transparent thin	max108me<10.8<max108lo & [10.8-12.0 >s108_120 or 3.7-10.8 > s37_108_thin]

Table 9. Description of the test sequences used in the cloud classification for night time situations.

The thresholds are

s108_120_thick= s_108_120opaq if less than cst_45_opaq_max. Otherwise, it is put to cst_45_opaq_max

37_108_thin = s_34opaq if less than cst_34_semi_max. Otherwise, it is put to cst_34_semi_max*100

37_108_low = s_34opaq - cst_34_low_delta*100

max108_thin = max108lo +2*s_4

6.2 classification tests applied in day-time conditions

Very High Opaque	10.8<max108vh & 10.8-12.0 <s108_120_thick
High Opaque	max108vh <10.8<max108hi & 10.8-12.0 <s108_120_thick
Medium	max108hi<10.8<max108me & 10.8-12.0 <s108_120_thick & 0.6>max06
	max108hi<10.8<max108me & 10.8-12.0 <s108_120_above & 0.6<max06
Low	max108me<10.8<max108lo & [10.8-12.0<s108_120_above or Sdlog108 <Sdlog06] & 0.6>max06
Very Low	max108lo<10.8<max108thin & 10.8-12.0 <s108_120_edge & 0.6>max06
	max108thin<10.8 & 10.8-12.0 <s108_120_edge & 0.6>min06
Fractional	max108me<10.8<max108lo & 10.8-12.0 <s108_120_above & 0.6<max06
	max108lo<10.8<max108thin & 10.8-12.0 >s108_120_edge & 0.6>max06
	max108lo<10.8<max108thin & 10.8-12.0 <s108_120_edge & 0.6<max06
	max108thin<10.8 & [10.8-12.0 >s108_120_edge or 0.6< min06]
Semi-transparent thick	10.8<max108vh & 10.8-12.0 >s108_120_thick
	max108vh <10.8<max108hi & 10.8-12.0 >s108_120_thick
Semi-transparent mean	max108hi<10.8<max108me & 10.8-12.0 >s108_120_above & 0.6<max06
Semi-transparent thin	max108me<10.8<max108lo & 10.8-12.0 >s108_120_above & Sdlog108 >Sdlog06 & 0.6>max06
	max108me<10.8<max108lo & 10.8-12.0 >s108_120_above & 0.6<max06
	max108lo<10.8<max108thin & 10.8-12.0 >s108_120_edge & 0.6<max06
Semi-transparent above	max108hi<10.8<max108me & 10.8-12.0 >s108_120_above & 0.6>max06

With

s108_120_thick= s108_120opaq if less than cst_45_opaq_max. Otherwise, it is put to cst_45_opaq_max

s108_120_edge = s108_120

s108_120_above = s108_120_thick

max108_thin = max108lo +2*s108_120

Sdlog108 = 100.*(15.*(log(1+sd33_t4)))

Sdlog06 = 30.*(log(1+sd33_a1))

6.3 classification tests applied during dawn

Very High Opaque	10.8<max108vh & 10.8-12.0 <s108_120_thick
High Opaque	max108vh <10.8<max108hi & 10.8-12.0 <s108_120_thick
Medium	max108hi<10.8<max108me & 10.8-12.0 <s108_120_thick
Low	max108me<10.8<max108lo & 10.8-12.0 <s108_120
Very Low	max108lo<10.8<max108thin & 10.8-12.0 <s108_120_thick
	max108thin<10.8 & 10.8-12.0 <s108_120
Fractional	max108lo<10.8<max108thin & 10.8-12.0> s108_120_thick
	max108thin<10.8 & 10.8-12.0 >s108_120
Semi-transparent thick	10.8<max108vh & 10.8-12.0 >s108_120_thick
	max108vh <10.8<max108hi & 10.8-12.0 >s108_120_thick

Very High Opaque	10.8<max108vh	& 10.8-12.0 <s108_120_thick
Semi-transparent mean	max108hi<10.8<max108me	& 10.8-12.0 >s108_120_thick
Semi-transparent thin	max108me<10.8<max108lo	& 10.8-12.0 >s108_120

With

s108_120_thick= s_108_120opaq if less than cst_45_opaq_max. Otherwise, it is put to cst_45_opaq_max*100

max108thin = max108lo + s_108_120

7. THRESHOLDS DETERMINATION

7.1 IR lookup tables creation

Threshold lookup tables were created off line to give the variation of the different thresholds (e. g. 10.8µm-12.0µm, 10.8µm -3.7µm, 3.7µm -10.8µm, 10.8µm, ..) with the secant of the zenith angle and the total water vapor content in the atmosphere, for different surface temperature, emissivity and solar elevation.

First, we used a sub-set (2995 profiles) of the ECMWF dataset (Chevallier,) which represents the global atmosphere. Each profile is documented with a profile code (sea, coast, land), its position and date, its total water vapor content.

The RTTOVv9 fast forward model (Saunders, 2010) was used to compute synthetic brightness temperatures for channels 3.7 µm, 4.0 µm, 8.7 µm, 10.8 µm and 12.0 µm, for 5 different secant angles (from 1 to 2 with a step of 0.25), 7 surface-air skin temperatures (-10,-5,-3,0,+3,+5,+10) and 60 emissivities from 0.8 to 1. (with 2 different steps of 0.005 and 0.0025). The brightness temperatures depend on the channel characteristics and consequently on the satellite number. The output file is of about 500MB. Sub-files of smaller size were extracted for the 4 conditions: sea/coast, vegetation, desert and cloud. Only profiles with the correct code are kept, and a selection in the range of emissivity is done. For vegetation, 3 sets of emissivities are considered and 2 over desert. Over sea, the emissivity depends on the secant.

The four preceding files are used to create the lookup tables of the channel differences for all the possible air-sol differences. The means and standard deviations for the secant angles, and 7 twvc (from 0.25 to 7.75) are computed and curves of maximum values of the channels differences are estimated. The resulting curves are then interpolated and extrapolated on 7 secant angles (from 1. to 2.5) and 16 twvc (from 0.25 to 7.75). The results correspond to more than 100 tables per satellite for the different channel differences, the different surface conditions (sea, vegetation, desert) , several air-skin surface temperature departures and three for cloud conditions. In practice, only a subset of them are used and concatenated within 3 files separately over sea, land and opaque clouds.

For more details, see Derrien et al, 2005

7.2 Dynamic threshold computation for thermal bands

At night-time, the dynamic thresholds applied to thermal bands differences tests (10.8µm-12.0µm, 8.7µm-10.8µm, 10.8µm-3.7µm, 8.7µm-3.7µm, 12.0µm-3.7µm, 3.7µm-10.8µm, 3.7µm-4.0µm) or for the 10.8µm test are obtained by interpolation into look-up tables using the satellite zenith angles and the NWP forecast integrated water vapor content. The choice of the tables depends on the climatological SST and of the solar zenith angle over sea. It depends on the type of surface (vegetation, desert), the local climatological visible reflectance and on the solar zenith angle over land. Over coast, the threshold used is the maximum value between computed values over sea and land.

The threshold used in the test on the 3.7µm-10.8µm test in daytime or twilight conditions is derived from that used in night-time conditions by adding an empirical solar contribution computed over the ocean from the maximum reflectance simulated by the Cox and Munck model (Cox and Munck 1954) and over land from the monthly mean 0.6 µm surface reflectance climatology.

The quality of the thresholds mainly depends on the forecast quality and the real vertical structure of the atmosphere (a dry adiabatic law is used to account for the height effect), but also on the land type (emissivity effect, presence of snow), the solar conditions (radiative cooling during night-time or maximum warming at around 14 h solar local time depending on the land type), and the delay between the time of observations and the time of the forecast field. That is why some additional constant thresholds are added (e.g. on the 10.8µm test over land) to take into account possible incertitude.

7.3 Dynamic threshold computation for the solar bands

The dynamic thresholds applied to the solar bands (0.4µm, 0.6µm, 0.8µm, 1.6µm, Snow 1.6µm), are computed from the simulation of the surface (ocean, land or snow) top of atmosphere (TOA) reflectance by adding an offset and a corrective factor. More details are given in Derrien et al, 2005. The TOA reflectance is simulated as:

$Ref_{toa} = \cos(\theta) * (a0 + a1*Rsurf/(1-a2*Rsurf)) + offset$ θ= zenith viewing angle.

where:

a0, a1 and a2 are coefficients computed from the input satellite and solar angles, the NWP water vapor and ozone (put to a default value) contents using look-up tables to take into account the atmosphere absorption. The look-up tables have been pre-computed for a wide range of angles and water vapor and ozone content using a very fast model based on 6S (Tanré et al. 1990), using a maritime and continental aerosol of 70km horizontal visibility for sea and land, respectively.

- Rsurf is the land, ocean or snow surface reflectance: The ocean surface reflectance is given by the maximum reflectance for wind speed lower than 20 ms^{-1} computed by the Cox and Munck model (Cox and Munck 1954). The land surface reflectance is computed from a monthly maximum 0.6µm surface reflectance climatology. The bi-directional effects are simulated using a model developed by Roujean (Roujean et al. 1992). The snow surface reflectances at 1.6µm have been tabulated for various viewing geometries by applying the radiative transfer model developed by C. Le Roux (see Le Roux et al. 1996) to 250 µm and 70 µm hexagonal particles.

Offsets (4% over sea, 8% over land, 6% over snow) are added; an additional offset (3%) is added over sea in coastal areas to account for possible mis-registration.

A corrective factor is added over land to allow a strong reflectance increase in the forward scattering direction: corrective factor (in %) = $1.5 + 25*(\cos(\varphi)-0.8)^2$ where φ is the scattering angle ([0., π] from the backward to the forward direction.

If the value is negative, the threshold is put to cos(θ)*15%.

7.4 Constant thresholds and offset values

As said in the previous sections, the thresholds are dynamically computed in-line. However, some thresholds are still constant. It concerns the 3.7µm -4.0µm , 0.8µm /0.6µm and 1.3µm tests and some values in glint condition. Also, a set of constant values are used for interpolation in lookup tables. Default values and offsets are also provided to secure the software. Table 9 gives a list of the main constant values used in the software, their values and comments.

Visible constant thresholds are normalized by the solar zenith angle before their use.

Name	values	comment
sst_frozen	271.35	ocean could be frozen

lst_min	263.15	min land surface temp if climatology used
37_saturation	320.0	to prevent 3.7 saturation
lst_desert	20. 0	threshold on 10.8 test and desert
LD_37_40_Ccl, LD_37_40, LD_37_40_Ccld	9.5, 10., 10.5	Clear/mean/cloudy thres 3.7-4.0 LandDay
LD_06_08_Ccl, LD_06_08, LD_06_08_Ccld	1.87,1.82,1.78	Clear/mean/cloudy thres 0.8/0.6 LandDay
LD_13_Ccl, LD_13, LD_13_Ccld	3., 3.5, 4.	Clear/mean/cloudy thres 1.3 LandDay
06_HiNDVI	0.65	High NDVI threshold
DD_13_cwv_cutoff	0.25	min cwv to apply the test 1.3 DesertDay
SD_37_40_Ccl, SD_37_40, SD_37_40_Ccld	5.5, 6., 6.5	Clear/mean/cloudy thres 3.7-4.0 SeaDay
SD_06_08_Ccl,SD_06_08, SD_06_08_Ccld	.94, .99, 1.05	Clear/mean/cloudy thres 0.8/0.6 SeaDay
glint_08_Ccl,glint_08, glint_08_Ccld	17, 19, 21	Clear/mean/cloudy thres 0.8 SeaGlint
glintRatio_Ccl, glintRatio, glintRatio_Ccld	.95, 1.0, 1.05	Clear/mean/cloudy thres 0.8/0.6 SeaGlint
Glint_06	60.	Thres used for low cloud detection in sunglint
glint_37_108, glint06coef	5.0, 0.15	Thres used for low cloud detection in sunglint
SID_13, DD_13 , CD_13	3.5, 3.5, 3.5	Thres used in the thin cirrus detection
Desert_albmin	25.	Minimum 0.6 climatology to declare desert
rlivthr, rsivthr	-0.1, -0.04	Ndvi thresh to separate sea/land over coast
ice108, ice108120, 08shadow, ice37108, irs	5., 2.,20., 15.,3.	Thres for the surface ice/snow detection
cst_HiElev, cst_sst	2000, 4.	Thres to declare mountain and for sst test
I_sd08, I_sd108s,I_sd10837sd	.5, .25,.5	To compute texture values for VIIRS img
I_sd10837sn	.5	To compute texture values for VIIRS img
I_sd108l, I_sd10837l, I_valdt	1., 1.,-3., 0., .5	To compute texture values for VIIRS img
I_10806, cstl_slope10806	2., 5., 15., 1., 20.	To compute texture values for AVHRR
A_sd08, A_sd108s, A_sd10837sd	.5, .25,.5	To compute texture values for AVHRR
A_sd10837sn	.5	To compute texture values for AVHRR
A_sd108l, A_sd10837l, A_valdt,	1., 1. ,-3., 0.,.5	To compute texture values for AVHRR
A_10806, A_slope10806	2., 5., 15., 1., 20.	To compute texture values for AVHRR
temp_cold, temp_warm ,sst_cold, sst_warm	278,288,278,288	Thres for interpolation in lookup tables
des_min_alb, veg_max_alb	30.1, 20.1	Thres for interpolation in lookup tables
sol_high, sol_night,	60.,90., 0.006	Thres for interpolation in lookup tables
adiarate	0.006	adiabatic constant to account for height
BG_snow_37_108_LoElev, …	9.0, …	flag surface contaminated with snow (day)

Table 9. List of constant values used in the software and included in a module. Units are in K and %.

7.5 Thresholds for cloud type determination

A set of specific dynamic thresholds adapted is also computed for the classification tests.

Infra-red thresholds are used to separate opaque clouds from semi-transparent clouds from interpolation in two IR lookup tables. Visible thresholds (max06, min06), also used to discriminate between opaque and semi-transparent clouds, are computed using the measurement conditions and the surface temperature.

8. SEA SURFACE TEMPERATURE

For each pixel declared confident clear by the test series and over sea, a sea surface temperature is computed with formulas used by the EUMETSAT OSI SAF from Le Borgne (2007) and OSI SAF documents (see references).

9. CLOUD TOP TEMPERATURE AND PRESSURE

For cloudy pixels classified as Very low cloud, Low cloud, Medium cloud, High opaque cloud and Very high opaque cloud, a cloud top temperature and a cloud top pressure is determined.

The cloud top temperature is computed using the 10.8mm brightness temperature corrected from atmospheric absorption. The atmospheric absorption is estimated by interpolation in a lookup table function of the local zenith angle and the 10.8mm brightness temperature.

If temperature inversion is detected in the boundary layer and if the cloud is classified Very low, Low or Medium, the cloud top is set below the inversion. Otherwise, the cloud top pressure is estimated using the NWP temperature vertical profile.

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