SAF for Land Surface Analysis (LSA SAF)

Product User Manual

Meteosat Second Generation Evapotranspiration (MET)

Reference Number:	SAF/LAND/IM/PUM_MET/2.0
Issue/Revision Index:	Issue 2.1
Last Change:	10/07/2008

DOCUMENT SIGNATURE TABLE

	Name	Date	Signature
Prepared by :	RMI Team	10/07/2008	
Approved by :	Land SAF Project Manager (IM)	10/07/2008	

DOCUMENTATION CHANGE RECORD

Issue / Revision	Date	Description:
Version 1.0	26/07/2007	Version presented at Checkpoint Meeting (04/09 2007)
Version 2.0	11/04/2008	Version presented for the ORR3 review (14 /05/2008)
Version 2.1	10/07/2008	Improved version after ORR3 review

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1 Introduction

The Satellite Application Facility (SAF) on Land Surface Analysis (LSA) is part of the SAF Network, a set of specialised development and processing centres, serving as EUMETSAT (European organization for the Exploitation of Meteorological Satellites) distributed Applications Ground Segment. The SAF network complements the product-oriented activities at the EUMETSAT Central Facility in Darmstadt. The main purpose of the LSA SAF is to take full advantage of remotely sensed data, particularly those available from **EUMETSAT** sensors, to measure **land surface** variables, which will find primarily applications in meteorology (http://landsaf.meteo.pt/).

The spin-stabilised Meteosat Second Generation (MSG) has an imaging-repeat cycle of 15 minutes. The Spinning Enhanced Visible and Infrared Imager (SEVIRI) radiometer embarked on the MSG platform encompasses unique spectral characteristics and accuracy, with a 3 km resolution (sampling distance) at nadir (1km for the high-resolution visible channel), and 12 spectral channels (Schmetz et al., 2002).

The EUMETSAT Polar System (EPS) is Europe's first polar orbiting operational meteorological satellite and the European contribution to a joint polar system with the U.S. EUMETSAT will have the operational responsibility for the "morning orbit" with Meteorological-Operational (MetOp) satellites, the first of which was successfully launched on October 19, 2006. Despite the wide range of sensors on-board MetOp (http://www.eumetsat.int/), most LSA SAF parameters make use of the Advanced Very High Resolution Radiometer (AVHRR) and, to a lesser extent, of the Advanced Scatterometer (ASCAT).

Several studies have stressed the role of land surface processes on weather forecasting and climate modelling (e.g., Dickinson et al., 1983; Mitchell et al., 2004; Ferranti and Viterbo, 2006). The LSA SAF has been especially designed to serve the needs of the meteorological community, particularly Numerical Weather Prediction (NWP). However, there is no doubt that the LSA SAF addresses a much broader community, which includes users from:

- Weather forecasting and climate modelling, requiring detailed information on the nature and properties of land.
- Environmental management and land use, needing information on land cover type and land cover changes (e.g. provided by biophysical parameters or thermal characteristics).
- Agricultural and Forestry applications, requiring information on incoming/outgoing radiation and vegetation properties.
- Renewable energy resources assessment, particularly biomass, depending on biophysical parameters, and solar energy.
- Natural hazards management, requiring frequent observations of terrestrial surfaces in both the solar and thermal bands.
- Climatological applications and climate change detection, requiring long and homogeneous time-series.

Table 1 LSA SAF products operational or under-development at the beginning of the 3rd phase of the project – Continuous Development and Operations Phase (CDOP). Expected horizontal resolution and spatial coverage, generation frequency, and target accuracy are also indicated. Temporal resolution specifies the time interval to which the product applies. In the near future, the LSA SAF team plans to use AVHRR/Metop data (and ASCAT/Metop in the case of SC and SMET) for the retrieval of all the products described below.

	Product	Horizontal Resolution & Coverage	Temporal Resolution	Generation Frequency	Target Accuracy
Surface Radiation Budget	**AL** – Albedo	MSG disk	5-day & 30-day	Daily & 10-day	10 %
	LST – Land Surface Temperature	MSG disk / Global*	Instantaneous	15min & 12-hourly*	2 K
	EM – Emissivity	MSG disk / Global*	5-day & 30-day	Daily & 10-day	5 %
	DSSF – Down-welling Surface Short-wave Flux	MSG disk / Global*	Instantaneous & Daily	30 min & Daily	5-10 %
	DSLF – Down-welling Surface Long-wave Flux	MSG disk / Global*	Instantaneous & Daily	30 min & Daily	5-10 %
Biogeophysical Parameters I	**SC** – Snow Cover	MSG disk / Global	Daily	Daily	<3% false alarms >75% hit rate forest > 90% for other areas
	MET /MSG based Evapotranspiration	MSG disk	Daily / 30 min	Daily / 30 min	25% if ET >0.4 mm/h, 0.1 mm/h otherwise
Biogeophysical Parameters II	**FVC** – Fraction of Vegetation Cover	MSG disk / Global*	5-day & 30-day	Daily & 10-day	10-15% (SEVIRI+AVHRR) 20% (SEVIRI)
	LAI – Leaf Area Index	MSG disk / Global*	5-day & 30-day	Daily & 10-day	25-30% (SEVIRI+AVHRR) 40% (SEVIRI)
	FAPAR – Fraction of Absorbed Photosynthetic Active Radiation	MSG disk / Global*	5-day & 30-day	Daily & 10-day	10-15% (SEVIRI+AVHRR) 20% (SEVIRI)
	RFM – Risk of Fire Mapping	Europe	Daily	Daily	---
	FD&M – Fire Detection & Monitoring	MSG disk	15-min & Daily	15-min & Daily	---
	FRP/E – Fire Radiative Power/Energy	MSG disk	15-min & hourly	15-min & hourly	---

*Global and 12-hourly products refer to retrievals from AVHRR/EPS.

The LSA SAF products (Table 1) are based on level 1.5 SEVIRI/Meteosat and/or level 1b MetOp data. Forecasts provided by the European Centre for Medium-range Weather Forecasts (ECMWF) are also used as ancillary data for atmospheric correction.

The SEVIRI/Meteosat derived products are generated for 4 different geographical areas within Meteosat disk (Figure 1):

- Euro – Europe, covering all EUMETSAT member states;
- NAfr – Northern Africa encompassing the Sahara and Sahel regions, and part of equatorial Africa.
- SAfr – Southern Africa covering the African continent south of the Equator.
- SAme – South American continent within the Meteosat disk

MetOp derived parameters are currently available at level 1b full spatial resolution and for the processed Product Distribution Units (PDUs), each corresponding to about 3 minutes of instrument-specific observation data. Composite and re-projected products are foreseen for a later stage of the LSA SAF.

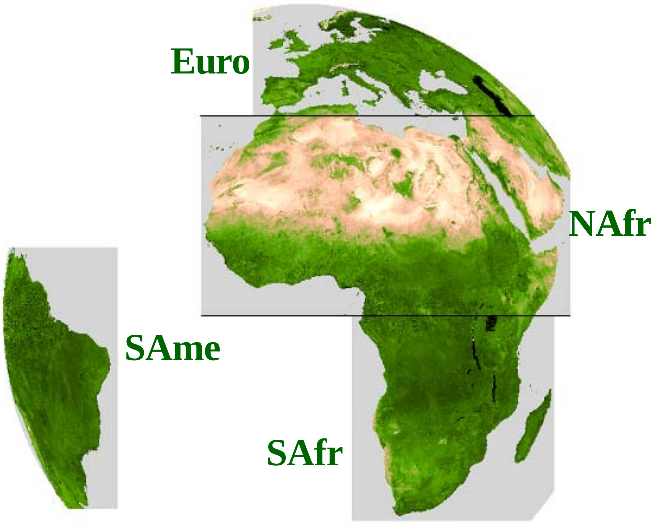

Figure 1 - The LSA SAF geographical areas.

The LSA SAF system is fully centralized at IM and will be able to operationally generate, archive, and disseminate the products. The monitoring and quality control, also centralized at IM, are performed automatically by the LSA SAF software, which provides quality information to be distributed with the products. The LSA SAF products are currently available from LSA SAF website (http://landsaf.meteo.pt) that contains real time examples as well as updated information.

This document is one of the product manuals dedicated to LSA SAF users. The algorithm and the main characteristics of the Evapotranspiration (ET) generated by the LSA SAF system are described in the following sections.

2 LSA-SAF ET algorithm

The information consigned in this document, concerns the version 04 of the LSA-SAF MSG derived EvapoTranspiration ('MET') algorithm, which will replace the version 03 running at the LSA-system since November 2006 over the European window. Main differences with the previous version are related with the equation solving procedures and minor modifications in vegetation parameter values, taken from the ECOCLIMAP database. The current version estimates ET values images over the full MSG disk (four defined windows), at MSG spatial resolution with a time step of 30 minutes.

2.1 Overview

The EvapoTranspiration (ET) algorithm developed in the framework of LSA-SAF, targets the quantification of the flux of water vapour from the ground surface (soil and canopy) into the atmosphere using input data derived from MSG satellites. The method follows a physical approach and can be described as a simplified Soil-Vegetation-Atmosphere Transfer (SVAT) module modified to accept as forcing Satellite Remote Sensing (SRS) derived data combined with data from other sources mainly NWP. The physics of this model is based on the physics of the Tiled ECMWF Surface Scheme for Exchange Processes over Land - TESSEL- SVAT scheme (Viterbo and Beljaars, 1995; van den Hurk et al., 2000).

2.2 Physics of the problem

Evapotranspiration is one of the main components of the water cycle and it is directly associated with the latent heat flux (LE), which establishes a key link between the energy and water cycles. Evaluating energy fluxes at the Earth surface is of great importance in many disciplines like weather forecasting, global climate monitoring, water management, agriculture, ecology, etc. When dealing with ET at specific locations or at small watershed scales, most of the proposed methods are based on classical measurements of eddy correlation, Bowen ratio, and soil-water balance, supported by a network of ground stations.

At regional and global scales, the satellite remote sensing (SRS) stays as the only method capable to provide wide area coverage at economically affordable costs. Most of proposed methods use SRS derived data combined into models with different degrees of complexity. These models rang from empirical direct methods to complex deterministic models based on SVAT modules that compute the different components of the energy budget. A major difficulty to the use of SRS for monitoring ET is that the phase change of water molecules produces neither emission nor absorption of an electromagnetic signal. Therefore the ET process is not directly quantifiable from satellite observations. It has to be assessed, taking advantage of information gained through the satellite about surface variables influencing evapotranspiration (Choudhury, 1991).

2.3 Proposed method

In the proposed method, the area for which ET has to be assessed is divided into independent pixels, in a one-to-one correspondence with the pixels of a satellite image. Each pixel is in turn considered as being a mix of homogeneous *tiles*, each tile representing a particular soil surface: bare soil, grassland, forests, *etc*. In Figure 2, a schematic representation of the image pixel composition is presented. In the model, some variables are defined at the pixel level and are thus shared by all the tiles composing the pixel, while others are defined at the tile level. Intermediate variables (aerodynamic resistance, Obukhov length, friction velocity) are computed at the tile level (see next section). The global pixel value is obtained through the weighted contribution of each tile. Theoretically, ET can be derived in near real time at the time resolution of MSG satellite images, in practice, the generation of ET will be limited by the availability of input data (DSLF is generated every 30 minutes). In the current version, snow sublimation is not modelled. Permanently snow covered pixels are labelled as not processed. For snow events only evapotranspiration from the vegetation is considered.

Figure 2 Schematic representation of pixel composition

2.3.1 Mathematical description of the algorithm

The main set of equations used for deriving ET are common to most SVAT schemes with specific parameterizations adopted from the ECMWF TESSEL SVAT scheme (van den Hurk et al., 2000) in which some adaptations have been done in order to use SRS derived data. For a detailed mathematical description of the algorithm, please refer to the Algorithm Theoretical Basis Document (ATBD).

2.3.1.1 At tile level

Neglecting the energy storage into the vegetation layer, each tile satisfies an energy balance given by

$$Rn_i + H_i + LE_i + G_i = 0 \quad (1a)$$

with

$$Rn_i = (1-\alpha)S_\downarrow + \varepsilon(L_\downarrow - \sigma T_{sk,i}^4) \quad (1b)$$

In these equations, the index *i* refers to a given tile, α and ε are respectively albedo (AL) and emissivity, $S_\downarrow$ and $L_\downarrow$ the Downward Surface Short-wave Flux (DSSF) and the Downward Surface Long-wave Flux (DSLF), H_i and LE_i are the sensible and latent heat fluxes respectively, G_i is the heat flux into the soil, $T_{sk,i}$ the skin temperature and σ is the Stephan-Boltzmann constant. R_{ni}, $S_\downarrow$,and $L_\downarrow$ are positive downward whereas H_i, LE_i ,and G_i are positive upward.

The latent and sensible heat fluxes are obtained via a resistance analogy:

$$LE_i = \frac{L_v \rho_a}{(r_a + r_c)}\left[q_{sat}(T_{skin,i}) - q_a(T_a)\right] \quad (2)$$

$$H_i = \frac{\rho_a}{r_a}\left[c_p(T_{sk,i} - T_a) - g z_a\right] \quad (3)$$

where ρ_a is the air density, r_a the aerodynamic resistance, T_a is the air temperature, z_a the measurement height of the air parameters, r_c the canopy resistance, L_v the latent heat of vaporisation (function of the air temperature), q_a the specific humidity and q_{sat} is the specific humidity at saturation. The canopy resistance r_c is a function of DSSF, leaf area index (LAI), average unfrozen soil water content (θ), atmospheric water pressure deficit and a minimum stomatal resistance ($r_{s,min}$).

The heat flux into the ground is estimated according to

$$G_i = \beta_i * Rn_i \quad (4)$$

In this equation coefficient β_i is estimated as a function of Leaf Area Index (LAI), through the Modified Soil Adjusted Vegetation Index -MSAVI- (Chehbouni et al., 1996) as following

$$\beta_i = 0.5 * EXP(-2.13 * MSAVI_i) \quad (5)$$

$$MSAVI_i = 0.88-0.78*EXP(-0.6 * LAI_i) \quad (6)$$

2.3.1.2 At pixel level

$$LE = \sum \zeta_i LE_i \qquad \text{and} \qquad H = \sum \zeta_i H_i \qquad (7)$$

where ζ_i is the relative coverage of the tile in the pixel.

The LE obtained, expressed in W/m², is converted in evapotranspiration (in mm/h) by means of

ET = 3600 LE/Lv. (8)

Snow sublimation is not considered in this version.

2.3.2 Input data

2.3.2.1 Radiative data

The main radiative variables driving the model are taken from corresponding LSA-SAF products. These variables are at first the Downward Surface Short-wave Flux (DSSF) based on the three short-wave channels (VIS 0.6µm, NIR 0.8µm, SWIR 1.6µm); for more details see the DSSF (PUM) document. Secondly, the Downward Surface Long-wave Flux (DSLF) is obtained by an hybrid method based on two different bulk parameterisation schemes for clear and cloudy sky conditions using as input ECMWF forecasts of 2m temperature, 2m dew point temperature and total column water; for details see the DSLF (PUM) document. Finally, the albedo (AL) product is used as input. It is based on the three short-wave channels (VIS 0.6µm, NIR 0.8µm, SWIR 1.6µm). For more details see the albedo (PUM) document.

2.3.2.2 Meteorological data

Meteorological auxiliary data needed by the MET algorithm is automatically retrieved from ECMWF forecasts by the processing modules of the LSA-SAF system. This data originally gathered at ECMWF spatial resolution is transposed into the MSG grid and spatially interpolated. Currently, the meteorological variables used by the MET algorithm are:

- 2-m temperature [K]
- 2-m dew point temperature [K]
- 10-m wind speed [m/s]
- Atmospheric pressure at sea level [Pa]
- Soil moisture for 4 soil layers [m^3/ m^3]
- Soil temperature for 4 soil layers [K]

2.3.2.3 Land cover

The version 04 of the MET algorithm uses the ECOCLIMAP land cover classification (Masson et al., 2003). In this database, the parameters associated to a given tile vary temporally (on monthly basis) and spatially (parameters associated to tiles depend on the considered climatic region). In Figure 3, the first and second predominant vegetation types (tiles) used by the LSA-MET algorithm are presented.

In the present method, up to three different tiles are allowed on each single grid point (see Figure 3), this to provide a more realistic surface description compared to the restriction to dominant land cover type. This approach is particularly relevant in very patchy landscapes. In the current version, the following ECOCLIMAP fields have been exploited: land cover types, fraction of vegetation cover, LAI and roughness length.

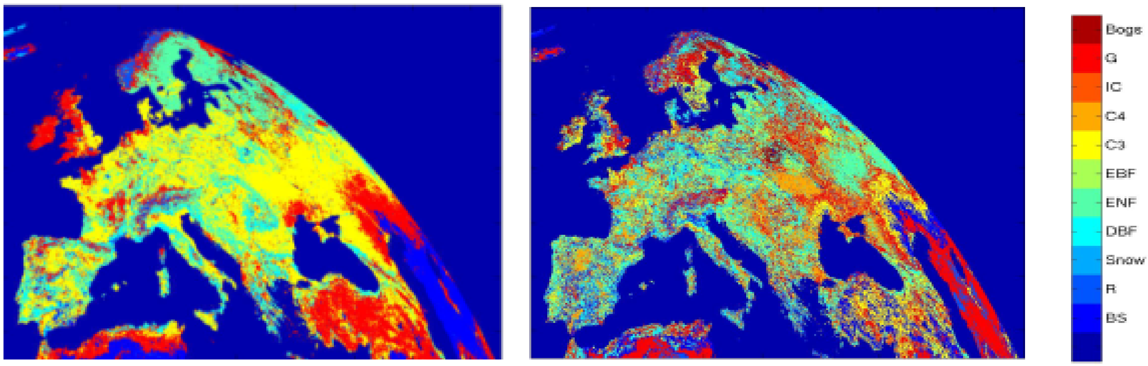

Figure 3 First (left) and second (right) vegetation types used by the LSA SAF ET algorithm. 'Bogs' stands for bogs/swamp vegetation/gardens, 'G' for grass land, 'IC' for irrigated crops, 'C4' for C4 crops, 'C3' for C3 crops, 'EBF' for evergreen broadleaf forest, 'ENF' for evergreen needle leaf forest, 'DBF' for deciduous broadleaf forest, 'Snow' for permanent snow, 'R' for rocks and 'BS' bare soil.

2.3.3 Processing scheme

The algorithm execution may be decomposed in three steps represented at Figure 4 by a schematic flowchart. The first step corresponds to the pre-processing. At this stage, the algorithm verifies that all necessary input data is available, executes the gap filling procedure over missing DSLF pixels values over land, initialises internal structures and loads input data into internal arrays. The second step is the equations solving process. Here the algorithm starts with the first pixel on the image. If all necessary input data is available, the algorithm solves the set equations for each tile and, if convergence is reached, computes ET for the whole pixel. Based on the quality of input data and the performances of the algorithm itself, a quality flag value is calculated for the pixel. The third step is output formatting. Here the algorithm sets the scaling factor for the whole image, performs data type casting, set the data and attributes and writes the output in HDF5 formats, following. Then, the algorithm frees used memory, returns control to the wrapper and stands idle till next call.

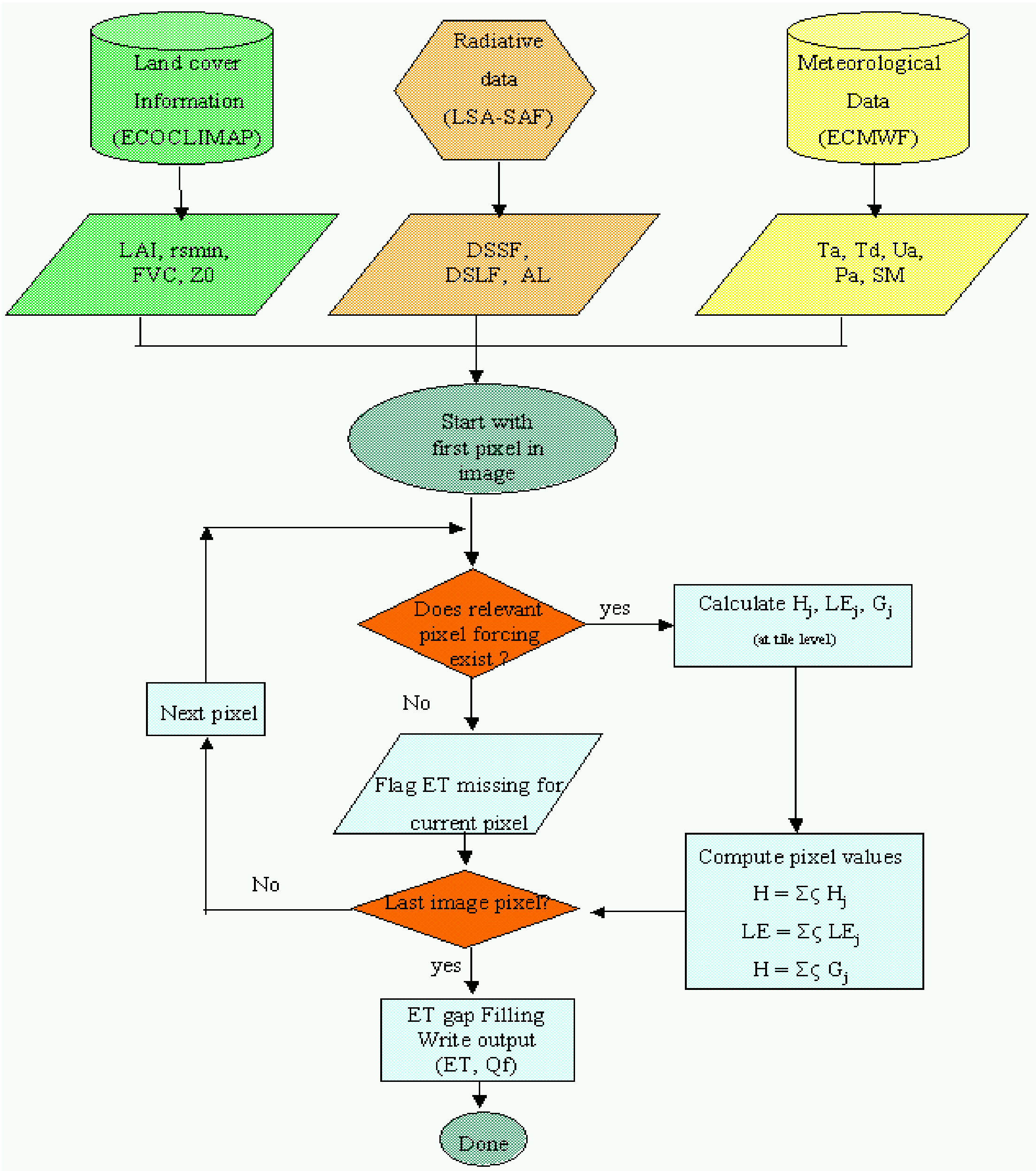

Figure 4 - Diagram of ET processing chain.

2.3.4 Error budget estimates

A first source of uncertainties is introduced by the physical formalism of the algorithm itself. Another important source of uncertainties results from the errors associated to the error in the estimation of input variables and particularly DSSF, DSLF, albedo, air temperature, specific humidity, wind speed, etc. From a global point of view, the main sources of uncertainties cumulated on the ET product deal with sensors performance, accuracy of cloudy pixels identification, accuracy of atmospheric corrections, surface heterogeneity and land cover classification.

In order to evaluate the impact of input variables uncertainties on the estimation of the ET algorithm performances, an extensive sensitivity analysis is performed over the main input variables. In this test, the ET algorithm is run 5000 times with a time step of 30 minutes over a selected dataset at the Cabauw site. The test consists in running the ET model allowing the input variables to vary randomly over its range of possible values, with a dispersion determined by the maximum possible error specified for a given variable: DSSF -15 W/m² by clear sky conditions, DSLF and Albedo - 10% of the actual value as specified by products developers.

A global sensitivity study of all input variables varying simultaneously concludes that the total error induced on ET is lower than the sum of individual contributions. A soil moisture analysis revealed that ET algorithm is very sensitive to this variable, especially for dry regions for which soil water availability is the main limiting factor. Among variables coming from LSA-SAF, DSSF is the most important driver for the ET. Figure *5* shows the relation between the range of DSSF values and the relative error induced on ET by uncertainty on input variables. We see that for high DSSF values (greater than 350 W/m2) introduced error is less than 10%. A detailed discussion about error and uncertainties due to input variables (DSLF, AL, air temperature, air humidity, wind speed) is included in the Algorithm Theoretical Basis Document (ATBD).

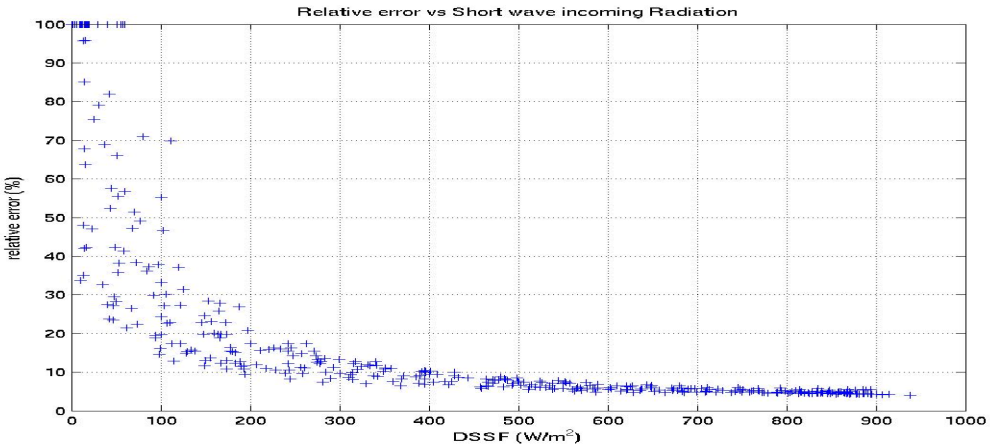

Figure 5 Relation between DSSF range of values and relative error induced on ET by uncertainty on input variables.

3 Product description

3.1 Product content

The ET algorithm produces evapotranspiration estimates in mm/h over the four LSA-SAF defined windows at MSG/SEVIRI spatial resolution and a time step of 30 minutes. Together with the ET map, a quality flag image is also generated. This image has the same size as the ET image and provides information on pixel-by-pixel basis about the confidence of estimated values. It informs about the quality of input variables and if pre/post-processing (gap filling) was performed on input or output data. After each algorithm execution, four output files are generated. Each of them is labelled: "HDF5_LSASAF_MSG_ET_Area_yyyymmddhhhh", with 'Area' being one of 'Euro', 'NAfr', 'SAfr' or 'Same')

Figure 6 shows ET estimates over Europe and the corresponding quality flag images for the day 2007/08/01 at 12:00 UTC. Images corresponding to North Africa, South Africa and South America are represented at Figures 7, 8 and 9 respectively.

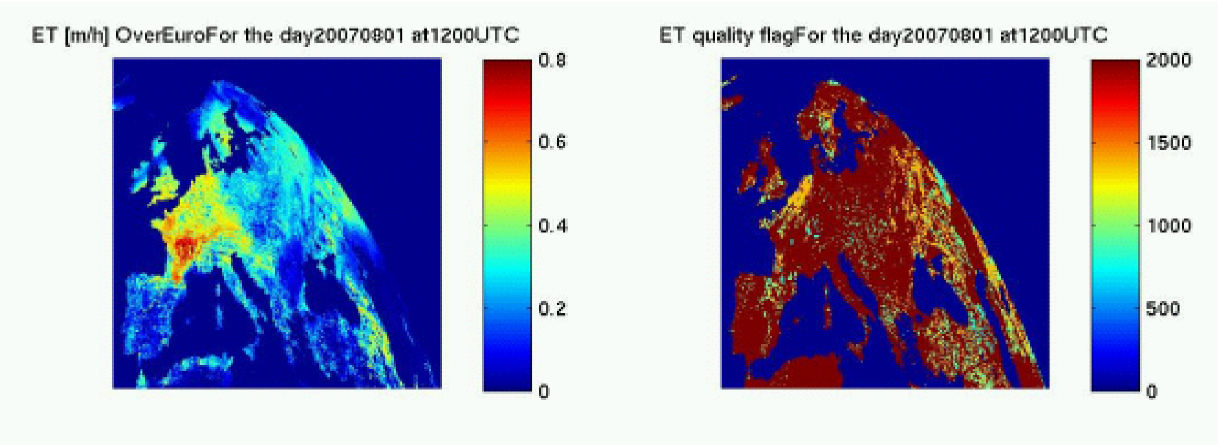

Figure 6 ET image over Europe (left) and corresponding quality flag image (right) for the 1st August 2007 at 12 h UTC.

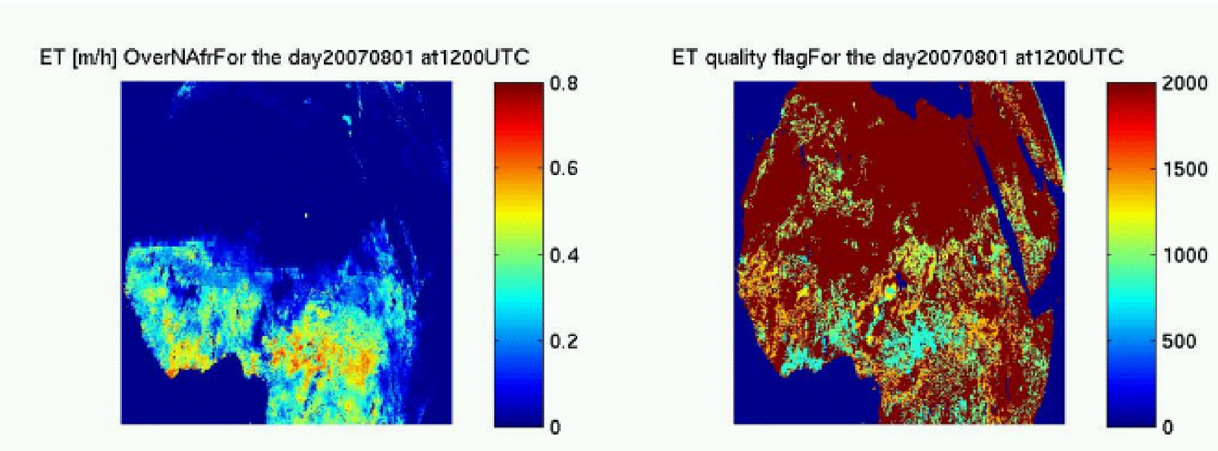

Figure 7 ET image over Northern Africa (left) and corresponding quality flag image (right) for the 1st August 2007 at 12 h UTC.

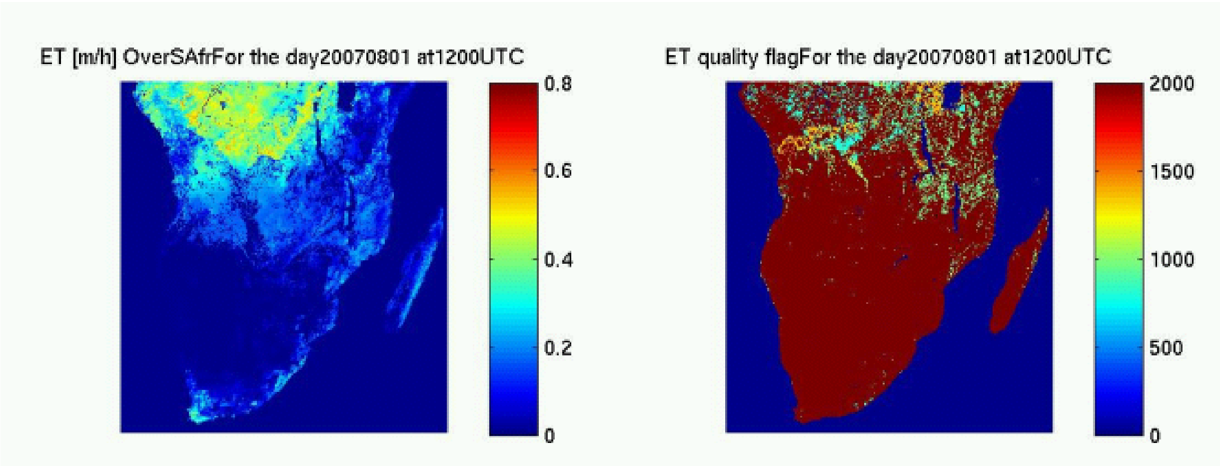

Figure 8 ET image over Southern Africa (left) and corresponding quality flag image (right) for the (right) for the 1st August 2007 at 12 h UTC.

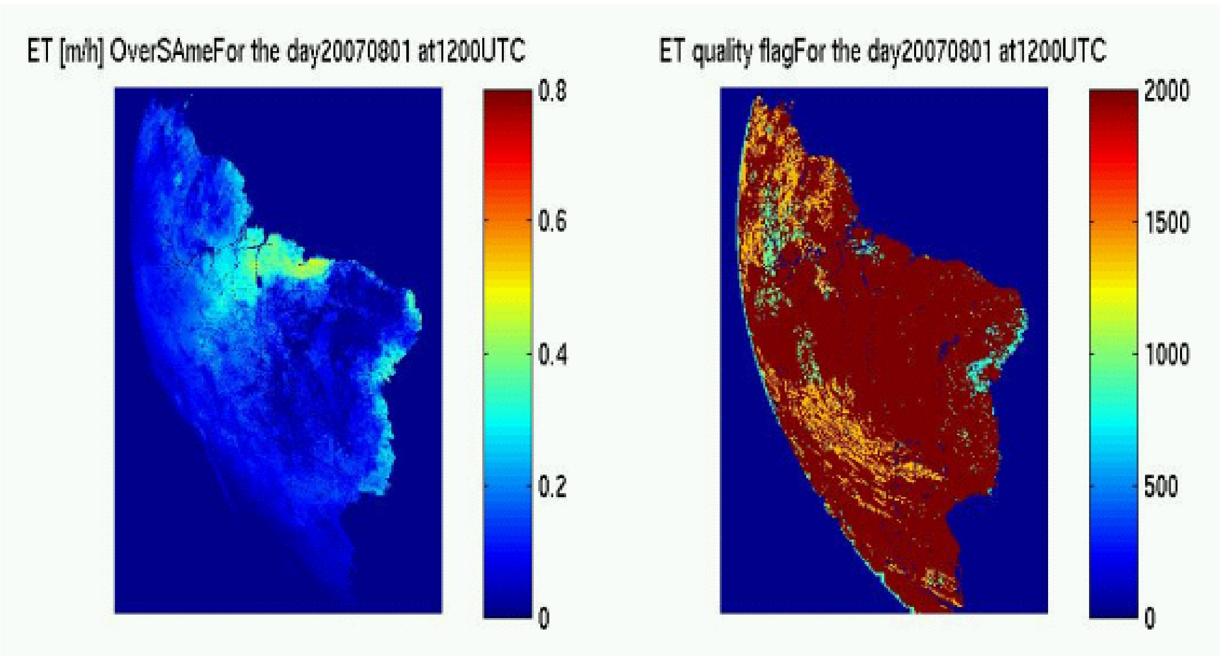

Figure 9 ET image over Southern America (left) and corresponding quality flag image (right) for the 1st August 2007 at 12 h UTC

3.2 Files format

The data format used by the LSA-SAF consortium is the Hierarchical Data Format, version 5 (HDF5), developed by the National Center for Supercomputing Applications (NCSA). This is a public, general-purpose and machine independent standard for storing and sharing scientific data. In this format, each file contains also the necessary information for manipulating the data. General attributes common to all LSA SAF products are described in Annex A. The latest version of HDF5 libraries for several platforms can be found in ftp://ftp.ncsa.uiuc.edu/HDF/HDF5/hdf5-1.6.2/. A free software to open and view HDF5 files is available in http://hdf.ncsa.uiuc.edu/hdf-java-html/hdfview/.

3.3 Summary of product characteristics

Product Name: Evapotranspiration

Product Code: ET

Product Level: Level III

Description of Product: Evapotranspiration from surface into the atmosphere

Product Parameters:

Coverage:	Full disk (land pixels)		
Units:	mm/h		
Range:	0 - 1		
Sampling:	pixel by pixel basis		
Spatial Resolution:	MSG full resolution (3km×3km at nadir)		
Accuracy:	25% if ET >0.4 mm/h; 0.1 mm/h else.		
Geo-location Requirements:			
Format:	16 bits signed integer		
Appended Data:	Quality control information (16 bits integer)		
Frequency of generation:	30 min		
Size of Product:	Europe:	(Non-compressed)	4.23 MB
		Compressed	0.50 MB
	North Africa	(Non-compressed)	9.72 MB
		Compressed	0.90 MB
	South Africa:	(Non-compressed)	5.52 MB
		Compressed	0.70 MB
	South America:	(Non-compressed)	4.05 MB
		Compressed	0.60 MB

Additional Information:

Identification of bands used in algorithm: Not applicable

Assumptions on SEVIRI input data: Not applicable

Identification of MSG derived data:

- Downward Surface Short-wave Flux (DSSF)
- Surface Albedo (AL)
- Downward Surface Long-wave Flux (DSLF)

Identification of ancillary and auxiliary data:

- Land-sea mask
- 2-m temperature (from ECMWF)
- 2-m dew point temperature (from ECMWF)
- Wind speed (from ECMWF)
- Atmospheric pressure al sea level (from ECMWF)
- Soil moisture for 4 soil layers (from ECMWF)
- Soil temperature for 4 soil layers (from ECMWF)
- ECOCLIMAP land cover database

3.4 Quality indices

Each ET field is associated with a quality flag index, coded in 16-bit word. The expected values for quality control flag as well as their meaning are described in Annex B. Only fields related to land/sea mask (bit 0), land cover (bit 1), AL (bit 7), DSLF (bit 10-11), DSSF (bit 12-13), and ET (bit 14-15) are used. Non-used bits are set to 0. The quality of the ET output is defined as: nominal, below nominal, poor or non-processed:

1) Nominal:
- The quality flag of all LSA-SAF (DSSF, DLSF, ALBEDO) variables is at least nominal and
- ET algorithm processed correctly

Possible values: 1989

2) Below nominal:
- DLSF gaps filled in pre-processing (quality flag set to = 965)
- The quality of at maximum one of LSA-SAF variable is below nominal

Possible values: 965, 1349, 1413, 1093, 1221, 1157, 1029, and 1285

3) Poor quality:
- The quality of more than one LSA-SAF variable is below nominal and/or
- LSA-SAF AL non-processed (Albedo taken from ECOCLIMAP database)
- Gaps filled in post-processing (quality flag set to = 800)

Possible values: 581, 645, 709, 800

4) Non-processed:

-Pixel on the sea
-Missing input variables and
-Not gap filled in pre/post-processing
-Algorithm failure (no convergence)

Possible values: values below 100

3.5 Gap filling procedure

In order to provide ET with a limited amount of missing values, a gap filling procedure is implemented in pre-processing (for land pixels where DLSF is not available) and post processing (for land pixels for which it is not possible to calculate ET, because of missing input variables or no convergence of the algorithm). The gap filling procedure estimates the value for a given pixel based on the neighbouring pixels values weighted by distance (closest pixels have more weight). The quality flag for those pixels is set to a default value of 965 (below nominal) if DSLF was initially missing or to 800 (poor) if pixel ET value is obtained by interpolation from post-processing.

4 Validation

In this chapter we present shortly the different validation tests done in order to assess the performances and limitation of the proposed method. For a detailed description of the validation procedure and recent results please refer to the Validation Report on the LSA-SAF web site (http://landsaf.meteo.pt/). Three validation strategies have been adopted in order to assess the accuracy of the produced evapotranspiration values:

- Off-line validation
- Continuous validation
- Comparison with output from reference models

4.1 Off-line validation.

The output of the algorithm run in **off-line** mode is compared to observations of reference sites from known measurements networks like CarboEurope, CEOP, the Belgian Automatic Weather Stations (AWS) network, etc. Local observations are used as input as well as local available parameters.

4.2 Continuous validation.

The output of the **on-line** version of the algorithm is compared for tiles to measurements on selected locations. In order to closely follow the performances of the algorithm, a set of 120 sites were predefined over Europe (75 for other MSG disk regions) with results saved on separated validation files.

4.3 Comparison with output from reference models.

LSA-SAF ET estimates cumulated over 3 hours (6 images by estimate) are compared to 3-hourly ECMWF and GLDAS output. 3 types of statistical tests have been performed: One-to-one comparison of images, global analysis of images over a long period and finally a regionalized statistical test to determine the differences between models predictions over different biomes.

In Figure10, the scatter plots of 30 minutes observations vs simulation are presented for four different sites (Cabauw, Wetzstein, Kaamanen an Vielsalm) from the CarboEuroIP network over Europe. Uncertainty bounds are also included. as well as statistical indices. They are given by the "target accuracy" (Table 1), also included in the Product Requirements Document (PRD).

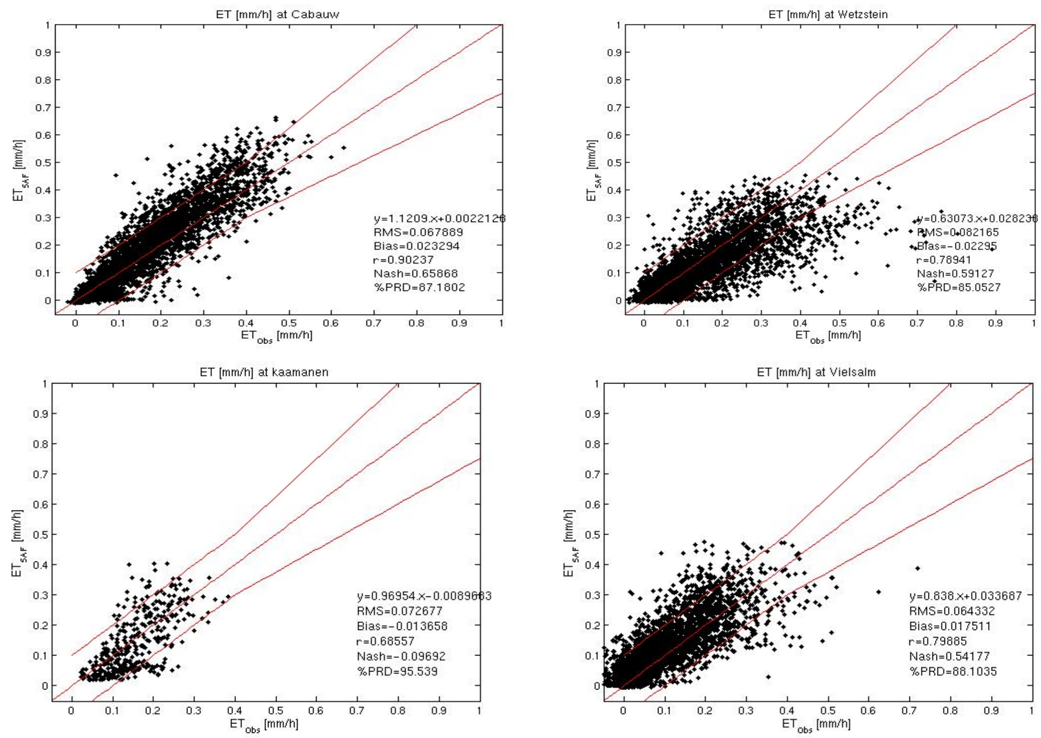

Figure10 Comparison of LSA-SAF MET tiled estimates with in-situ measurements.

From Figure 10, we observed that LSA-SAF MET v04 estimates are globally in agreement with ET estimates provided by ECMWF and GLDAS, with a high spatial correlation, ranging between 85% and 95% for mid-day images through the whole period, i.e. 01/03/2007 to 30/11/2007. While similarity with GLDAS is observed in case of low solar co-zenithal angle, i.e. early spring/late autumn and morning/evening, summer estimates correlates better with ECMWF. A slight bias found in comparisons with ECMWF can be correlated with a bias in global radiation at surface. We clustered the different geographical regions where differences in time series are noticeable. Most of the differences observed are not systematic: large disparities exist between ECMWF and GLDAS. Most of the ET differences can be explained in terms of differences of input variables/parameters, i.e. incoming global radiation at surface, land cover and resistance to transpiration of the canopy, function of LAI. While global radiation at the surface is the main source of difference on short-term basis, vegetation characteristics and soil moisture act on long-term basis and cause major ET differences observed. LSA-SAF MET estimates over Europe behave in a reasonable range compared to ECMWF and GLDAS. Most of the differences between models output have been attributed to differences in input variables/parameters, indicating that models performance are similar. Figure 11 encompasses the mean distribution of the 3 hourly average ET (09UTC to 12UTC) for MET, ECMWF and GLDAS for the months of April and July 2007. The mean value of the distribution is represented by the red lines.

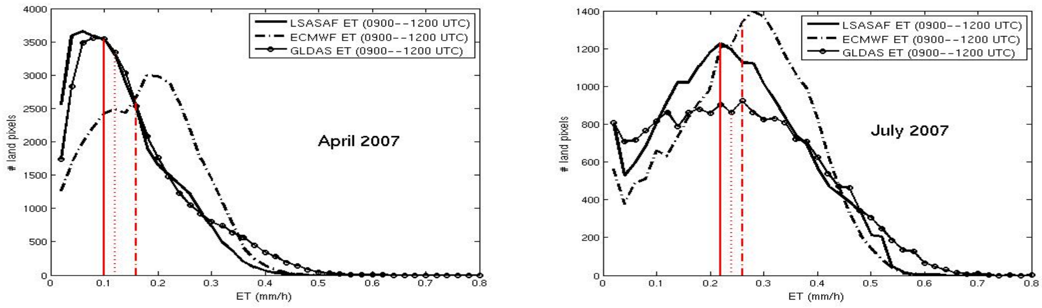

Figure 11 Distributions of ET estimates from LSA-SAF ET (solid line), ECMWF (dash-dotted line) and GLDAS (solid line and circles).

4.4 Conclusions from the validation tests

Based on validation tests it is concluded that the ET algorithm is able to reproduce the temporal evolution of evapotranspiration with values comparable with observations. Good agreement was found for stations over grassland and mixed forest and globally for stations where the cover type at station corresponds closely to the cover type defined in the land cover database used in the model.

From the inter-comparison with ECMWF and GLDAS models, no evidence of systematic bias was observed. A compliance with PRD quality criterion is satisfied to a rate generally higher than 70%, for estimates flagged nominal and below nominal. The mismatches were attributed to differences in solar radiation, vegetation characteristics, considered soil water availability and spatial scales of the compared models output.

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6 Developers

The development and implementation of the method is carried out by the Royal Meteorological Institute of Belgium (RMI)

Coordinator: Françoise Gellens-Meulenberghs

Developers: Alirio Arboleda
Nicolas Ghilain

Glossary

DSLF:	Downwelling Surface Longwave Radiation
ECMWF:	European Centre for Medium-Range Weather Forecasts
EPS:	EUMETSAT Polar System
EUMETSAT:	European Meteorological Satellite Organisation
GOES:	Geostationary Operational Environmental Satellite
HDF	Hierarchical Data Format
IM:	Instituto de Meteorologia (Portugal)
IR:	Infrared Radiation
METEOSAT:	Geostationary Meteorological Satellite
MODIS:	Moderate-Resolution Imaging Spectro-Radiometer
MODTRAN:	Moderate Resolution Transmittance Code
MSG:	Meteosat Second Generation
NWC SAF:	NoWCasting SAF
NWP:	Numerical Weather Prediction
O&SI SAF:	Ocean & Sea Ice SAF
PRD:	Product Requirements Document
QC:	Quality Control
Qf:	Quality flag
RTM:	Radiative Transfer Model
rms:	root mean square
SAF:	Satellite Application Facility
SEVIRI:	Spinning Enhanced Visible and InfraRed Imager
SD:	Standard Deviation
SURFRAD:	Surface Radiation Budget Network
TIGR:	TOVS Initial Guess Retrieval
TOVS:	TIROS-N Operational Vertical Sounder
TPW:	Total Precipitable Water
U-MARF	Unified Meteorological Archiving and Retrieval Facility
URD:	User Requirements Document

ANNEX A –Product Output Format for LSA-SAF MET v04

Description of the following attributes is given in the Product Output Format Document

General attributes

Attribute	Allowed Values
SAF	“LSA”
CENTRE	“IM-PT”
ARCHIVE_FACILITY	“IM-PT”
PRODUCT	“ET”
PARENT_PRODUCT_NAME	“DSSF”,”DSLF”,”ALB/LAI”,”SM/EM”
SPECTRAL_CHANNEL_ID	0
PRODUCT_ALGORITHM_VERSION	“4.0”
CLOUD_COVERAGE	“NWC-CMa”
OVERALL_QUALITY_FLAG	“OK”
ASSOCIATED_QUALITY_INFORMATION	“-“
REGION_NAME	One of: “Euro”, “Nafr”, “SAfr”, “SAme”
COMPRESSION	0
FIELD_TYPE	“Product”
FORECAST_STEP	0
NC	One of: 1701,2211,1211,701
NL	One of: 651,1151,1191,1511
NB_PARAMETERS	2
NOMINAL PRODUCT_TIME	YYMMDDhhmmss
SATELLITE	“MSG2”
SATELLITE_ID	“SEVI”
INSTRUMENT_MODE	“STATIC_VIEW”
IMAGE_ACQUISITION_TIME	YYMMDDhhmmss
ORBIT_TYPE	”GEO”
PROJECTION_NAME	« Geos<000.0> »
NOMINAL_LONG	-10.0
NOMINAL_LAT	0.0
CFAC	781651432

Attribute	Allowed Values
LFAC	-781651432
COFF	1856
LOFF	1856
PIXEL_SIZE	“3.1Km”
GRANULE_TYPE	“DP”
PROCESSING_LEVEL	“04”
PRODUCT_TYPE	“LSAET”
PROCESSING_MODE	“N”
MEAN_SSLAT	1234.
MEAN_SSLON	4321.
DISPOSITION_FLAG	“O”
TIME_RANGE	“30-min”
STATISTIC_TYPE	“N/A”

Dataset attributes

Attribute	Value (Product)	Value (Quality Flag)
CLASS	“Data”	“ET_Q_Flag”
PRODUCT	“ET”	“Data”
PRODUCT_ID	232	232
N_ COLS	One of: 1701,2211,1211,701	One of: 1701,2211,1211,701
N_ LINES	One of: 651,1151,1191,1511	One of: 651,1151,1191,1511
NB_BYTES	2	2
SCALING_FACTOR	10000.	1.
OFFSET	0.	0.
MISS_VALUE	-1	-1
UNITS	“SI”	“SI”
CAL_SLOPE	999.	999.
CAL_OFFSET	999.	999.

YY - Year; MM-Month; DD – Day; hh – Hour; mm – Minute; ss – Second

ANNEX B – Quality Control Information

Bit	Field	Category	Binary code	Description
00-00	**Land/Sea**	Sea	0	
		Land	1	
01-01	**Land cover**			
			0	IGBP
			1	ECOCLIMAP
02-02	**Cloud cover**			
			0	Covered
			1	Clear / partially covered
03-04	**Snow cover**			
			00	Not processed
			01	Snow covered
			10	Partially covered
			11	Snow-free
05-06	**SM**			
			00	Corrupted / not processed
			01	SM from LSAF-SAF
			10	SM from other source (ECMWF)
07-07	**AL**			
			0	Albedo from data base
			1	Albedo from AL product
08-09	**LST**			
			00	Not used by now
			00	
			00	
10-11	**DLSF**			
			00	Corrupted / not processed
			01	Below nominal
			10	Nominal
			11	Above nominal
12-13	**DSSF**			
			00	Corrupted / not processed
			01	Below specified angle of view
			10	Cloudy sky method
			11	Clear sky method
14-15	**ET confidence**			
			00	Corrupted / not processed
			01	Poor quality
			10	Below nominal
			11	Nominal