Product User Manual

Land Surface Temperature (LST)

PRODUCTS: LSA-001 (MLST), LSA-002 (ELST)

The EUMETSAT Network of Satellite Application Facilities

LSA SAF
Land Surface Analysis

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	Name	Date	Signature
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Approved by :	Land SAF Project Manager		

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TABLE OF CONTENTS

List of Figures

List of Tables

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 The LSA SAF Set of Products and respective sensors and platforms. The table covers both existing and future EUMETSAT satellites, and therefore refers operational products and development activities.

Product Family	Product Group	Sensors/Platforms
Radiation	Land Surface Temperature (LST)	SEVIRI/MSG, AVHRR/Metop, FCI/MTG, VII/EPS-SG
	Land Surface Emissivity (EM)	SEVIRI/MSG, FCI/MTG (internal product for other sensors)
	Land Surface Albedo (AL)	SEVIRI/MSG, AVHRR/Metop, FCI/MTG, VII/EPS-SG, 3MI/EPS-SG
	Down-welling Short-wave Fluxes (DSSF)	SEVIRI/MSG, FCI/MTG
	Down-welling Long-wave Fluxes (DSLF)	SEVIRI/MSG, FCI/MTG
Vegetation	Normalized Difference Vegetation Index (NDVI)	AVHRR/Metop, VII/EPS-SG
	Fraction of Vegetation Cover (FVC)	SEVIRI/MSG, AVHRR/Metop, FCI/MTG, VII/EPS-SG, 3MI/EPS-SG
	Leaf Area Index (LAI)	SEVIRI/MSG, AVHRR/Metop, FCI/MTG, VII/EPS-SG, 3MI/EPS-SG
	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)	SEVIRI/MSG, AVHRR/Metop, FCI/MTG, VII/EPS-SG, 3MI/EPS-SG
	Gross Primary Production (GPP)	SEVIRI/MSG, FCI/MTG
	Canopy Water Content (CWC)	AVHRR/Metop, VII/EPS-SG
Energy Fluxes	Evapotranspiration (ET)	SEVIRI/MSG, FCI/MTG
	Reference Evapotranspiration (ET0)	SEVIRI/MSG, FCI/MTG
	Surface Energy Fluxes: Latent and Sensible (LE&H)	SEVIRI/MSG, FCI/MTG
Wild Fires	Fire Detection and Monitoring (FD&M)	SEVIRI/MSG
	Fire Radiative Power	SEVIRI/MSG, FCI/MTG, VII/EPS-SG
	Fire Radiative Energy and Emissions (FRE)	SEVIRI/MSG, FCI/MTG, VII/EPS-SG
	Fire Risk Map (FRM)	SEVIRI/MSG, FCI/MTG
	Burnt Area (BA)	AVHRR/Metop, VII/EPS-SG

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 the full Meteosat disk. However the NRT dissemination via EUMETCast is made by splitting the full disk into 4 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.

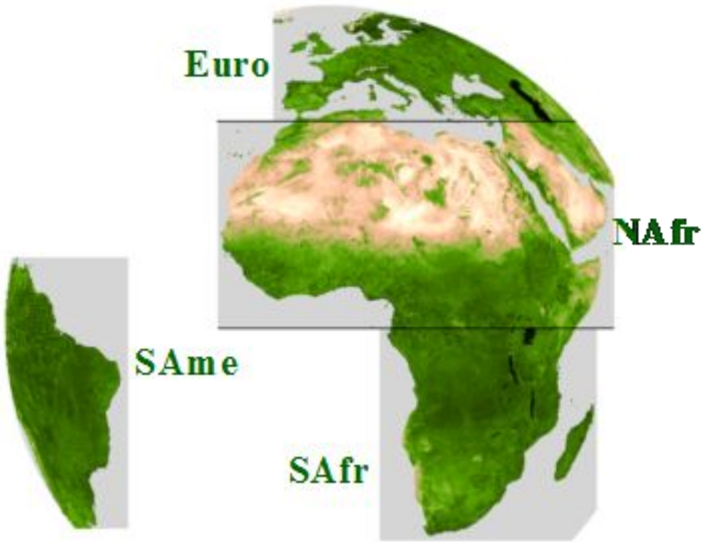

Figure 1 - The LSA SAF geographical areas.

The LSA SAF system is fully centralized at IPMA and will be able to operationally generate, archive, and disseminate the operational products. The monitoring and quality control of the operational products, also centralized at IPMA, is 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 of the products 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 Land Surface Temperature (LST) generated by the LSA SAF from SEVIRI and AVHRR data system are described in the following sections. The characteristics of AVHRR and SEVIRI based LST products provided by the LSA SAF are described in Table 2. Further details on the LSA SAF product requirements may be found in the Product Requirements Document/Table (SAF_LAND_IPMA_PRD_2.8.DOC) available at the LSA SAF website http://landsaf.meteo.pt).

Table 2 Product Requirements for LST, in terms of area coverage, resolution and accuracy.

LST Product	Coverage	Resolution		Accuracy		
		Temporal	Spatial	Threshold	Target	Optimal
MLST: LST_SEVIRI	MSG disk	15 min	MSG pixel resolution	4K	2 K	1K
ELST: LST_AVHRR	Europe & High Latitudes	1/2 day	0.01° x 0.01°	4K	2 K	1K

2 Algorithm

2.1 Overview

Land Surface Temperature (LST) is defined as the radiative skin temperature of land surface, as measured in the direction of the remote sensor. Such a directional radiometric temperature may be derived from a radiative energy balance of a surface and provides the best approximation to the thermodynamic temperature based on a measure of radiance (Norman and Becker, 1995).
LST plays an important role in the physics of land surface as it is involved in the processes of energy and water exchange between the surface and the atmosphere. LST is a useful product for the scientific community namely for those dealing with meteorological and climate models. Accurate values of LST are also of special interest in a wide range of areas related to land surface processes, namely hydrology, meteorology, agrometeorology, climatology and environmental studies. A correct estimation of **Land Surface Emissivity** (**EM**) is crucial for LST retrieval from space as well as for the implementation of atmospheric correction methods.

Instruments on-board satellites provide the only means of LST estimation for large areas in an operational way. The spectral radiance fields measured at the top of the atmosphere are influenced by surface parameters (such as EM and LST) as well as by the composition and thermal structure of the atmosphere. Therefore, in order to obtain LST from space it is necessary to correct the atmospheric influence and take into consideration land surface emissivity, which must be adequately known. On the other hand, the accuracy of the atmospheric corrections depends on the quality of radiative transfer models, uncertainties in atmospheric molecular absorption coefficients, aerosol absorption/scattering coefficients and errors in the atmospheric profiles.

Several algorithms have been developed during the last years to estimate LST and EM from space. Most are based on methods to determine Sea Surface Temperature (SST) that were then adapted to land surfaces. Examples of such techniques include:

- Single channel methods (Price, 1983) applicable to an arbitrary single IR-channel, that rely on radiative transfer calculations based on vertical soundings from NOAA-TOVS (or EPS-HIRS-3 in the future) as well as on radiosonde data (or NWP analyses as an alternative) to estimate the atmospheric effects. It is worth noting that this methodology requires a precise description of the atmospheric structure.
- Multi-channel (split-window) approaches have been used by several authors (*e.g.* Prabhakara *et al.*, 1974, McMillin, 1975, Deschamps and Phulpin, 1980, Price, 1984, Ho *et al.*, 1986). The technique performs an atmospheric correction based on the differential absorption in IR bands. In the IR windows (around 3.7μm and from 8-13 μm), atmospheric attenuation due to water vapour may be approximated by a linear combination of the temperatures measured in two (or more) neighbouring channels.

- Multi-angular methods that are based upon different absorption when the same scene is observed from two different viewing angles (*e.g.* Chedin *et al.*, 1982).
- Physically based methods such as the Temperature Independent Spectral Index (TISI) (Becker and Li, 1990a, Li and Becker, 1993) and the Two-Temperature methods (TTM) (Watson, 1992b; Faysash and Smith, 1999, 2000) that allow a simultaneous retrieval of EM and LST.

An accurate determination of LST is a difficult task. The spectral emissivity varies for different land cover types, the emitted radiance is not homogeneous in space, assumptions of the atmospheric state are uncertain, and LST presents a high variability in time and space. Differences in soil moisture content, vegetation cover, surface cover type, texture and roughness, as well as in vegetation cover structure may significantly affect thermal emissivity (EM) and the directional distribution of the outgoing radiance. EM may also vary with the viewing angle, an effect that is more important over land than over water since the combination of surface slope and satellite scanning angle results in larger local viewing angles (Wan and Dozier, 1989; McAtee et al., 2003). Variability in atmospheric profiles over land is also increased by topography. Finally it is worth mentioning that difficulties may arise because of the variability of both LST and EM within a pixel.

Since the number of unknowns (LST and EM for each channel) is always larger than the number of independent measurements (*i.e.* number of used channels) it is not possible to retrieve both LST and spectral emissivity from passive radiometry (even performing the atmospheric corrections) without introducing closure assumptions. Examples include assuming a blackbody emissivity (Prabakhara et al., 1974), deriving empirical relationships between emissivity and a vegetation index (Van de Griend and Owe, 1993), performing emissivity normalisation (Gillespie, 1985), using a reference channel (Kahle et al., 1980), spectral ratio (Watson, 1992a), alpha coefficients (Kealy and Hook, 1993), a Temperature Independent Spectral Index (TISI) (Becker and Li, 1990a, Li and Becker, 1993), the Vegetation Cover Method (VCM) (Valor and Caselles, 1996, Caselles et al., 1997), a Look Up Table (Wan and Dozier, 1996) or the TTM (Watson, 1992b; Faysash and Smith, 1999, 2000).

2.2 Physics of the Problem

The retrieval of LST is based on measurements from MSG and EPS systems in the thermal infrared window (MSG/SEVIRI–channels IR10.8 and IR12.0 and MetOp/AVHRR-3–channels 4 and 5). Theoretically, LST values can be determined 96 times per day from MSG, and twice per day from MetOp. However, fewer observations are generally available due to cloud cover contamination.

LSA SAF LST retrievals are based on the Generalised Split-Window (GSW) algorithm (Wan and Dozier, 1996). The GSW performs corrections for atmospheric effects based on the differential absorption in adjacent IR bands and requires EM as input data; a look-up table of optimal coefficients is previously determined at individual angles covering different ranges of water vapour and air temperature near the surface. The retrieval of EM is based on the Vegetation Cover Method (VCM; Caselles *et al*., 1997; Trigo et al, 2008) that relies on the use of a geometrical model to compute an effective emissivity based on the knowledge of the Fractional Vegetation Cover (FVC), also provided by the LSA SAF.

IR radiance is strongly absorbed and scattered even by thin clouds and aerosol layers. Retrieval of LST requires identification of cloudy and partly cloudy pixels in order to separate them from cloud-free pixels. Clouds may prevent the retrieval when they totally block the signal from the surface and they may also affect the accuracy of the product when there are thin clouds and aerosols, which attenuate the signal from the surface but do not completely block it (see Table 3). LST will be derived for all clear pixels, *i.e.* all situations in which scattering in the IR can be ignored. Clear sky pixels are identified through the application of the cloud mask available from the software delivered by the Nowcasting and Very Short Range Forecasting Satellite Application Facility (NWC SAF; http://nwcsaf.inm.es/). The NWC SAF developed two software packages prepared to use SEVIRI/MSG and AVHRR (onboard MetOp or NOAA) data, respectively. Accuracy of LST may also be affected by some potential problems (already identified by the NWC SAF), namely:

- Non-detected low clouds (at night) or shadowed cloud layers (daytime); cloud edges; sub-pixel clouds; thin clouds over dark surfaces.
- Cloud free areas that are cloud masked due to very cold winter situations.

Table 3 - Retrieval of LST product according to cloud mask information.

Cloud mask information	**LST product**
Non-processed	Impossible to retrieve
Cloud free	Retrieved
Cloud contaminated (partly cloudy or semitransparent)	Impossible to retrieve
Clouds filled (opaque clouds completely filling the FOV))	Not retrieved (highly affects accuracy)
Snow/Ice contaminated*	Retrieved
Undefined (not classified due to known separability problems)	Not retrieved (may affect the accuracy)

*The information on the presence of snow/ice is obtained from the NWC SAF cloud-mask, which provides a pixel classification every 15-min. The Land-SAF provides a snow cover product, obtained through an independent procedure, which is available to users as a daily composite.

2.3 Mathematical Description of the Algorithm

2.3.1 VCM

Estimation of EM for IR SEVIRI bands relies on the VCM approach (Caselles and Sobrino, 1989, Valor and Caselles, 1996, Caselles *et al.*, 1997). Considering flat surfaces and neglecting the term related to the radiation that indirectly reaches the sensor by means of internal reflections, the pixel effective emissivity may be obtained by combining the vegetated area and exposed soil as follows:

$$\varepsilon_{i,pixel} = \varepsilon_{i,v} FVC + \varepsilon_{i,g}(1 - FVC) \quad (1)$$

where $\varepsilon_{i,v}$ and $\varepsilon_{i,g}$ are respectively the vegetation and ground band-EM on channel i and FVC is the fractional vegetation cover.

Estimation of emissivity involves both static and dynamical information. The International Geosphere Biosphere Programme (IGBP) conventional land cover classification was adopted and consists of a global classification with 17 classes. However the MODIS land cover product may be used as an alternative. The MODIS product identifies the same 17 IGBP classes and is available four times per year, allowing taking into account the annual changes in land cover.

Changes on emissivity pixel values may be taken into account using the FVC product provided by the LSA SAF. Dynamic information on snow cover, provided by cloud mask (NWC SAF), is crucial to insure a correct estimation of emissivity in pixels covered by snow.

Information on emissivity data was obtained from John Hopkins University (JHU) spectral reflectance library and from the Moderate Resolution Imaging Spectrometer – University of California, Santa Barbara (MODIS-UCBS) spectral reflectance library. Both libraries provide reflectance measurements for a wide range of natural and manmade materials. As described in Peres and DaCamara (2005), the assignment of laboratory measurements to IGBP surface types was performed using about 50 surface materials that were individually used or combined in order to characterise the 17 IGBP land cover classes. Combination of vegetation and ground types for the 17 IGBP classes is based on a land cover class description that was adapted from Belward and Loveland (1996). It is worth noting that Permanent Wetlands, Snow and Ice and Water are the only classes that remain unchanged with respect to changes in surface vegetation. Pixels identified as covered by snow and ice will have its original class changed to snow and ice classes. A thoroughly assessment of EM uncertainties associated to the VCM under use at the LSA SAF, and impacts on the LST product are described in Trigo et al. (2008) and in Freitas et al. (2009).

2.3.2 Generalised Split-Windows

Split-window methods for deriving SST in clear sky conditions have proven to be very efficient and are operational at NOAA. However, the application of split-window methods over land implies the a priori knowledge of surface spectral emissivity. In addition the vertical structure of boundary layer is more complex over land than over water and in particular the near surface air temperature over land may be very different from LST. Becker and Li (1990b) have shown that it is theoretically possible to extend split-window methods to retrieve LST when the surface temperature is expressed as a linear combination of the brightness temperatures measured in two adjacent channels using coefficients that depend on spectral emissivities but not on atmospheric conditions. Based on Becker and Li's (1990b) local split-window algorithm, Wan and Dozier (1996) proposed a viewing angle dependent split-window algorithm to derive LST from AVHRR and MODIS data that has been adapted to SEVIRI data (Madeira, 2002). LST (T_s), is obtained from the following equation:

$$T_s = (A_1 + A_2 \frac{1-\varepsilon}{\varepsilon} + A_3 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_{10.8} + T_{12.0}}{2} + (B_1 + B_2 \frac{1-\varepsilon}{\varepsilon} + B_3 \frac{\Delta\varepsilon}{\varepsilon^2}) \frac{T_{10.8} - T_{12.0}}{2} + C \qquad (1)$$

where $T_{10.8}$ ($\varepsilon_{10.8}$) and $T_{12.0}$ ($\varepsilon_{12.0}$) are the brightness temperatures (emissivities) of 10.8 and 12.0 µm MSG/SEVIRI infrared channels respectively; $\varepsilon = 0.5(\varepsilon_{10.8} + \varepsilon_{12.0})$ and $\Delta\varepsilon = \varepsilon_{10.8} - \varepsilon_{12.0}$.

The first step of the GSW algorithm (Figure 2) is the definition of ranges to be considered in the GSW development. These ranges must be wide enough to cover the observed range of atmospheric properties, surface temperature, surface emissivity and SEVIRI viewing angles. Accordingly accurate atmospheric radiative simulations using MODTRAN4 (Berk et *al*., 2000) were performed as described below.

The simulations are performed for the database of global profiles of temperature, moisture, and ozone compiled by Borbas et al. (2005) for clear sky conditions, and referred to as SeeBor. The database contains over 15,700 profiles taken from other datasets, such as NOAA88 (Seemann et al, 2003), TIGR-like (Chevallier et al., 2000), and TIGR (Chedin et al., 1985), that are representative of a wide range of atmospheric (clear sky) conditions over the whole globe. In addition, surface parameters such as skin temperatures (Tskin) and a landcover classification within the International Geosphere-Biosphere Programme ecosystem categories (IGBP; Belward, 1996) are assigned to each profile. Skin temperature over land surfaces corresponds to LST in SeeBor and is estimated as a function of 2m temperature (T2m), and solar zenith and azimuth angles (Borbas et al., 2005). We assume that each profile corresponds to one given pixel within the Meteosat disk. Thus, for radiative simulation purposes, a satellite view zenith angle (v.-a.) chosen randomly within the 0o - 80o range is assigned to each profile, except for cases with (i) Tskin below 270 K, which are constrained to angles above 30o; and (ii) Tskin < 240 K, which are allowed to be observed by a geostationary satellite with a zenith angle within 60 o and 80o. This procedure ensures a realistic cover of simulated radiances for all possible viewing geometries.

The SeeBor database described above was split into two subsets – one used for the calibration of the LST GSW, and an independent one used for verification of the fitted algorithm. The former consists of 77 atmospheres selected to cover a broad variety of water vapour content (from very dry to moist conditions), leaving more than 15,600 profiles for GSW verification. The parameters in the GSW algorithm are estimated for 8 different classes of total column water vapour (W), up to 6 cm, and for 16 classes of v.-a, up to 75o, ensuring that all ranges of atmospheric attenuation within the thermal infrared are covered.. In order to ensure that all W and v.-a class have enough representative cases to provide robust parameter estimations, the radiative transfer simulations are performed over the 77 atmospheric profiles with the following settings: (i) surface temperature ranging between Tskin–15 and Tskin+15 K in steps of 5K; (ii) channel emissivities of IR108 and IR120 (ε108 and ε120, respectively) covering the range 0.96<ε120<0.995 in steps of 0.0175 and ε120-0.030<ε108<ε120+0.018 in steps of 0.006 (excluding cases with the average of ε108 and ε120 below 0.94); and (iii) v.-a. ranging from nadir to 75o in steps of 5o. It is worth noting that the whole simulations cover a range of Tskin between 230 K and 341 K, and a range of [Tskin minus T2m] from -20 to +33 K. The number of different atmospheric and surface profiles obtained by exhausting all the combinations of surface temperature, channel emissivities, and v.-a. are 189728, yielding an equal number of radiative transfer simulations.

The second step (Figure 2) consists of computing the optimal GSW coefficients by separating the ranges of atmospheric water vapour column, tropospheric temperature and the surface temperature (daytime and night time) into tractable sub-ranges. The coefficients were determined by means of separate regression analysis performed on the simulated data in each range for individual viewing angles.

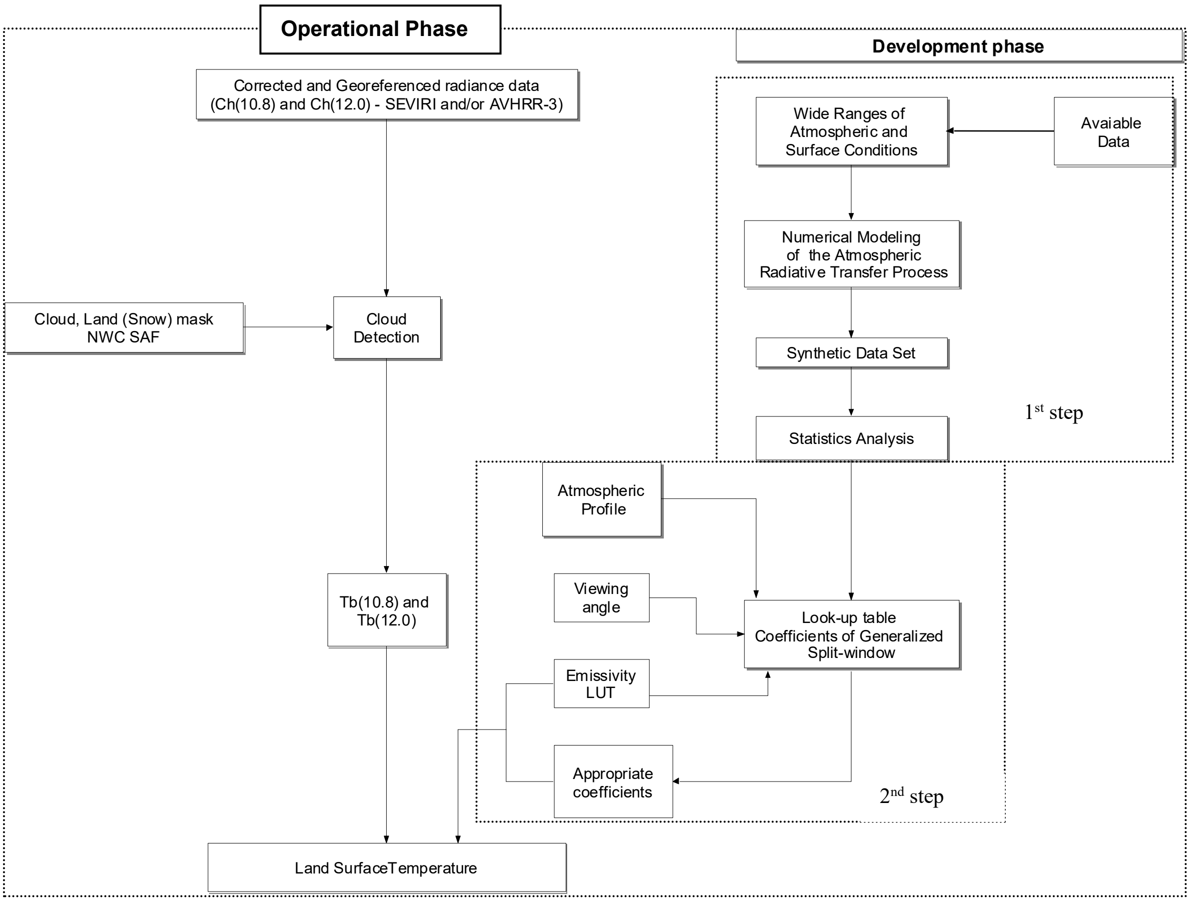

Figure 2 - Flow diagram of the GSW.

The MODTRAN4 simulations of top-of-atmosphere (TOA) brightness temperatures were performed for split-windows channels available from SEVIRI/MSG and AVHRR-3/MetOp, using the respective response functions. These simulations allowed the estimation of two different LUT for the GSW algorithm – LUT_SEVIRI and LUT_AVHRR – that are then used in the SEVIRI/MSG and AVHRR/MetOp processing chains, respectively.

2.4 Error Budget Estimates

The Land-SAF LST products (both derived from SEVIRI/Meteosat and AVHRR/MetOp) are distributed to users along with a quality flag and an uncertainty (or error bar) estimated on a pixel-by-pixel basis. The computation of LST uncertainty takes into account the uncertainties of the generalized split-window algorithm, which heavily depend on the total optical path between the sensor and the surface, essentially determined by the viewing geometry and the total water vapour content in the atmosphere. On top of that, LST uncertainty estimates consider the propagation of input errors, namely: (i) sensor noise; (ii) uncertainties in surface emissivity; and (iii) expected forecast errors in total column water vapour.

A detailed analysis of error statistics may be found in the ATBD_LST (http:/landsaf.meteo.pt) or in Freitas et al. (2009). Figure 3 summarizes the distribution of LST uncertainties within four classes of atmospheric water vapour.

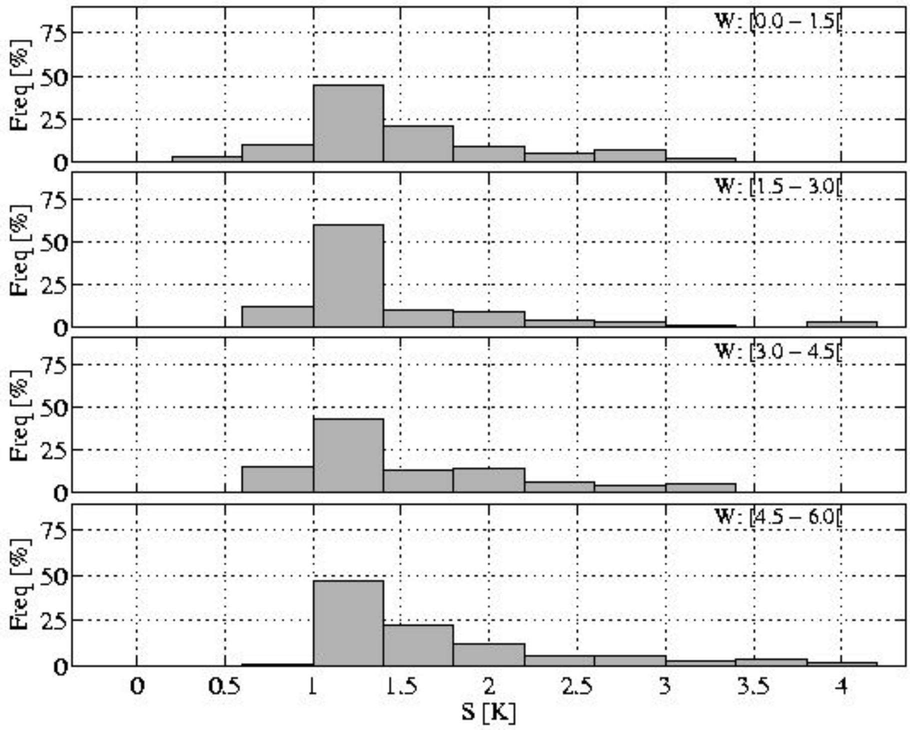

Figure 3 Histograms of LST uncertainties [K] taking into account algorithm uncertainties and propagation of input errors. The results are displayed by four classes of total column water vapour, from top to bottom: < 1.5cm; 1.5 – 3.0 cm; 3.0 – 4.5 cm; and ≥ 4.5 cm.

3 Processing Scheme

3.1 SEVIRI/Meteosat LST Product: LSA-001 (MLST)

EM ALG is based on VCM that is a computationally efficient algorithm since estimation of IR radiances does not require any radiative transfer simulations and atmospheric corrections. EM is estimated daily, using daily values of FVC. The LST ALG then uses the most recent EM available. The main steps of EM ALG execution may be described as follows:

1 outer loop for MSG line
2 Inner loop for MSG column
    2.1.selects FVC input file (static or dynamical file)
    2.2 search for land pixels, skip and flag sea pixels
    2.3 search for FVC pixel value, skip and flag missing values
    2.4 search for Land Cover pixel value, skip and flag missing values
    2.5.search for snow pixels from FVC error flag and land cover file
    2.6 compute EM for IR10.8 and IR12.0, IR 3.9, IR 8.7 SEVIRI channels and IR broad band (3 -14 μm) using FVC
    2.7. compute EM error bars
    2.8 compute EM confidence level and perform QC

LST ALG is based on GSW that is computationally very efficient due to its linear form. The major steps of LST ALG execution may be described as follows:

1 outer loop for MSG line
2 Inner loop for MSG column
    2.1 search for land pixels, skip and flag sea pixels
    2.2 search for valid Tb, skip and flag corrupted Tb pixels
    2.3 search for clear sky pixels, skip and flag cloudy pixels
    2.4 search for emissivity pixel value, skip and flag missing values
    2.5 compute LST with GSW
    2.6. compute LST error bars
    2.7 compute LST confidence level and perform QC

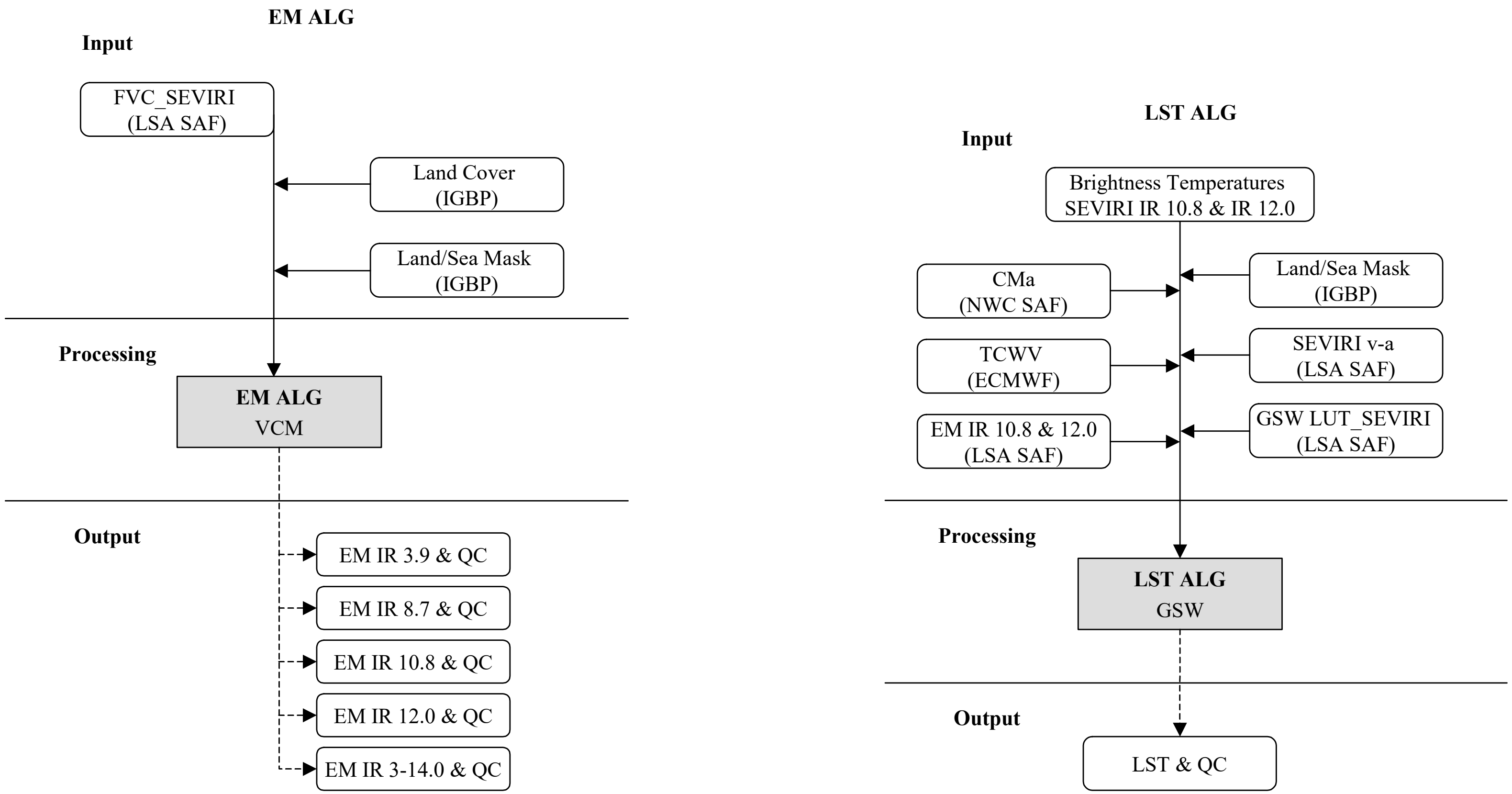

Figure 4 - Diagram of processing chain, for SEVIRI/MSG retrieved EM (left) and LST (right).<

3.2 AVHRR/MetOp LST Product: LSA-002 (ELST)

The main flow of AVHRR/MetOp processing chain follows very closely that described in the previous section for SEVIRI/MSG product. The algorithms are essentially the same, despite using input data with distinct characteristics. EM ALG is based on VCM that is a computationally efficient algorithm since estimation of IR radiances does not require any radiative transfer simulations and atmospheric corrections. EM is estimated daily, using daily values of FVC. The LST ALG then uses the most recent EM available. The main steps of EM ALG execution may be described as follows:

Outer loop for EPS-AVHRR line
2 Inner loop for EPS-AVHRR column
- 2.1.selects FVC input file (static or dynamical file)
- 2.2 search for land pixels, skip and flag sea pixels
- 2.3 search for FVC pixel value, skip and flag missing values
- 2.4 search for Land Cover pixel value, skip and flag missing values
- 2.5.search for snow pixels from FVC error flag and land cover file
- 2.6 compute EM for channel 4(10.3- 11.3 μm) and 5 (10.5- 11.5 μm) using FVC
- 2.7. compute EM error bars
- 2.8 compute EM confidence level and perform QC

LST ALG is based on GSW that is computationally very efficient due to its linear form. The major steps of LST ALG execution may be described as follows:
1 outer loop for EPS-AVHRR line
2 Inner loop for EPS-AVHRR column
- 2.1 search for land pixels, skip and flag sea pixels
- 2.2 search for valid Tb, skip and flag corrupted Tb pixels
- 2.3 search for clear sky pixels, skip and flag cloudy pixels
- 2.4 search for emissivity pixel value, skip and flag missing values
- 2.5 compute LST with GSW
- 2.6. compute LST error bars
- 2.7 compute LST confidence level and perform QC

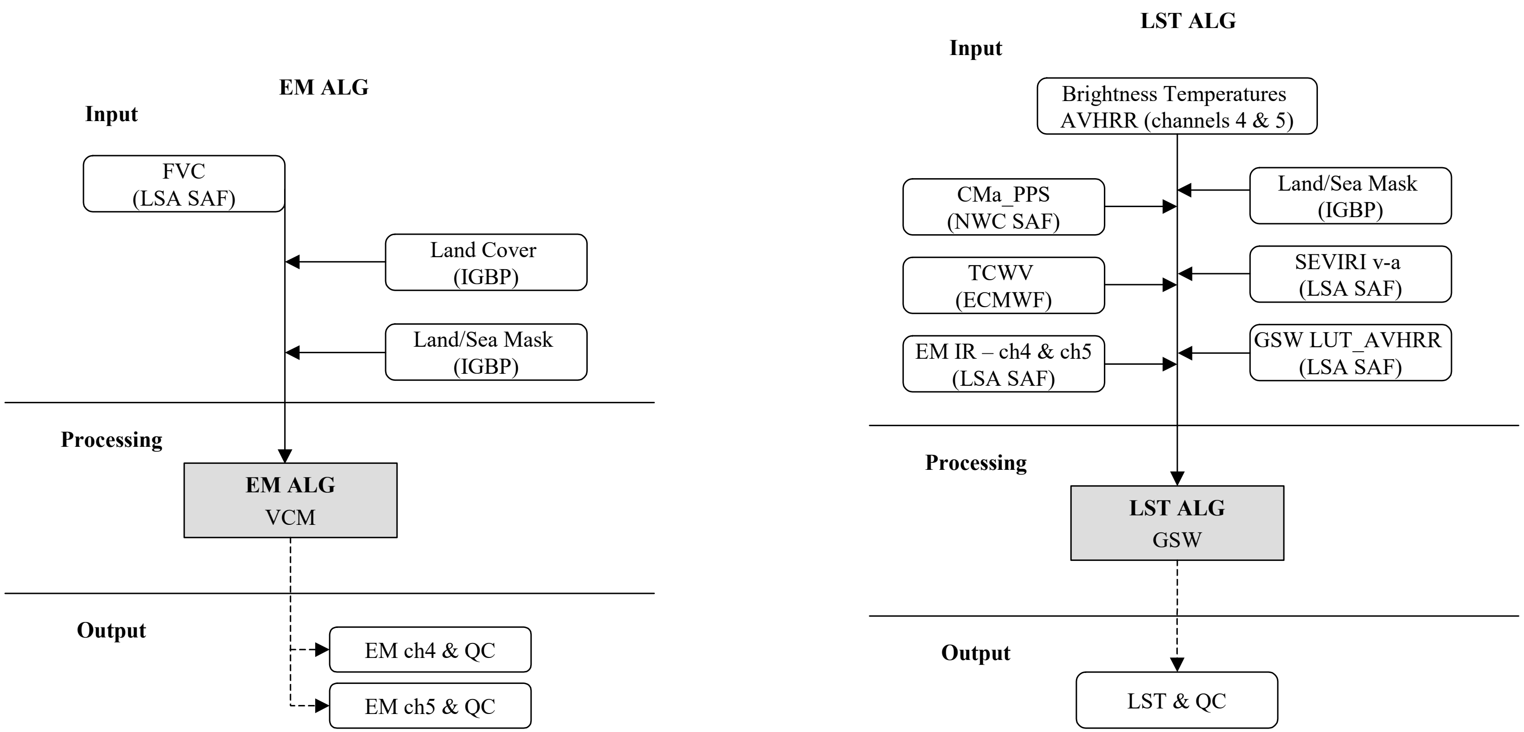

Figure 5 As in Figure 4, but for AVHRR/MetOp processing chain.

4 Data Description - SEVIRI/Meteosat LST Product : LSA-001 (MLST)

4.1 Overview – SEVIRI LST

The LSA SAF SEVIRI/MSG chain processes and distributes products for the full MSG disk. However, the EUMETCast users receive subsets of the full disk for the four geographical areas, described in Table 5 (and in Figure 1). The projection and spatial resolution correspond to the characteristics of Level 1.5 MSG/SEVIRI instrument data. Information on geo-location and data distribution is available at the LSA SAF website:
http://landsaf.meteo.pt.
Data users have access to the following data:

- a LST field;
- a quality control information field.
- a LST error estimate

The data is coded in HDF5 format. The HDF5 files in LSA SAF system have the following structure:

- A common set of attributes for all kind of data, containing general information about the data (including metadata compliant with U-MARF requirements);
- A dataset for the parameter values;
- A dataset for error values
- Additional datasets for metadata (e.g., quality flags).

Table 4 - Characteristics of the LSA SAF geographical areas: Each region is defined by the corners position relative to the full MSG image of 3712 columns per 3712 lines, starting from North to South and from West to East.

Region Name	Description	Initial Column	Final Column	Initial Line	Final Line	Size in Columns	Size in Lines	Total Number of Pixels
Euro	Europe	1550	3250	50	700	1701	651	1.107.351
NAfr	Northern Africa	1240	3450	700	1850	2211	1151	2.544.861
SAfr	Southern Africa	2140	3350	1850	3040	1211	1191	1.442.301
SAme	Southern America	40	740	1460	2970	701	1511	1.059.211
MSG-Disk	Full earth disk observed by MSG	1	3712	1	3712	3712	3712	13.788.944

4.2 Geolocation / Rectification

The **LST** SEVIRI-based fields are generated pixel-by-pixel, maintaining the original resolution of SEVIRI level 1.5 data. These correspond to rectified images to 0º longitude, which present a typical geo-reference uncertainty of about 1/3 of a pixel. Data are kept in the native geostationary projection.

Files containing the latitude and longitude of the centre of each pixel may be downloaded from the Land-SAF website (http://landsaf.meteo.pt; under "Static Data and Tools"):

Longitude

HDF5_LSASAF_MSG_LON_MSG-Disk_.bz2
HDF5_LSASAF_MSG_LON_Euro_.bz2
HDF5_LSASAF_MSG_LON_NAfr_.bz2
HDF5_LSASAF_MSG_LON_SAfr_.bz2
HDF5_LSASAF_MSG_LON_SAme_.bz2

Latitude

HDF5_LSASAF_MSG_LAT_MSG-Disk_.bz2
HDF5_LSASAF_MSG_LAT_Euro_.bz2
HDF5_LSASAF_MSG_LAT_NAfr_.bz2
HDF5_LSASAF_MSG_LAT_SAfr_.bz2
HDF5_LSASAF_MSG_LAT_SAme_.bz2

Alternatively, since the data are in the native geostationary projection, centred at 0º longitude and with a sampling distance of 3 km at the sub-satellite point, the latitude and longitude of any pixel may be easily estimated. Given the pixel column number, *ncol* (where *ncol*=1 correspond to the westernmost column of the file), and line number, *nlin* (where *nlin*=1 correspond to the northernmost line), the coordinates of the pixel may be estimated as follows:

$$lon = arctg\left(\frac{s_2}{s_1}\right) + sub\_lon$$ longitude (deg) of pixel centre

$$lat = arctg\left(p_2 \cdot \frac{s_3}{s_{xy}}\right);$$ latitude (deg) of pixel centre

where

sub_lon is the sub-satellite point ($sub\_lon = 0$)

and

$$s_1 = p_1 - s_n \cdot \cos x \cdot \cos y$$

$$s_2 = s_n \cdot \sin x \cdot \cos y$$

$$s_3 = -s_n \cdot \sin y$$

$$s_{xy} = \sqrt{s_1^2 + s_2^2}$$

$$s_d = \sqrt{(p_1 \cdot \cos x \cdot \cos y)^2 - (\cos^2 y + p_2 \cdot \sin^2 y) \cdot p_3}$$

$$s_n = \frac{p_1 \cdot \cos x \cdot \cos y - s_d}{\cos^2 y + p_2 \cdot \sin^2 y}$$

where

$$x = \frac{ncol - COFF}{2^{-16} \cdot CFAC} \quad \text{(in Degrees)}$$

$$y = \frac{nlin - LOFF}{2^{-16} \cdot LFAC} \quad \text{(in Degrees)}$$

$$p_1 = 42164$$

$$p_2 = 1.006803$$

$$p_3 = 1737121856$$

$$CFAC = 13642337$$

LFAC=13642337

The CFAC and LFAC coefficients are column and line scaling factors which depend on the specific segmentation approach of the input SEVIRI data. Finally, COFF and LOFF are coefficients depending on the location of the each Land-SAF geographical area within the Meteosat disk. These are included in the file metadata (HDF5 attributes; Annex B), and correspond to one set of the values detailed below per SEVIRI/MSG area:

Table 5 Maximum values for number of columns (ncol) and lines (nlin), for each Land-SAF geographical area, and the respective COFF and LOFF coefficients needed to geo-locate the data.

Region Name	**Description**	**Maximum *ncol***	**Maximum *nlin***	**COFF**	**LOFF**
MSG-Disk	Full MSG Disk	3712	3712	1857	1857
Euro	Europe	1701	651	308	1808
NAfr	Northern Africa	2211	1151	618	1158
SAfr	Southern Africa	1211	1191	-282	8
SAme	Southern America	701	1511	1818	398

4.3 File Formats – SEVIRI LST

At each time step the LST algorithm generates an external output file according to the following name convention:

HDF5_LSASAF_MSG_LST_<Area>_YYYYMMDDHHMM

where <**Area**>, **YYYY**, **MM**, **DD**, **HH** and **MM** respectively, denote the geographical region (see Table 4), the year, the month, the day, the hour and the minute of data acquisition.

The LSA SAF products are provided in HDF5 format developed by the National Center for Supercomputing Applications (NCSA) at the University of Illinois. A comprehensive description is available at http://hdf.ncsa.uiuc.edu/.

Libraries for handling HDF5-files in Fortran and C are available at ftp://ftp.ncsa.uiuc.edu/HDF/HDF5/hdf5-1.6.2/. A user friendly graphical interface to open and view HDF5-files may be downloaded from http://hdf.ncsa.uiuc.edu/hdf-java-html/hdfview/.

The HDF5-format allows defining a set of attributes that provide the relevant information. As described in the Appendix A the LST product information includes the general attributes (Table A 1), the dataset attributes (Table A 2) and the quality flag attributes (Table A 3). Within the HDF5-files the information is organised in the form of separate datasets.

4.4 Product Contents – SEVIRI LST

The LST product file contains two datasets containing the values and the respective quality flags. Table 6 and Table 7 show the contents of the LST product file and QC information, respectively. Detailed information is given in Annexes A and C.

Table 6 - Contents of the LST/SEVIRI product file.

Parameter	**Dataset Name**	**Unit**	**Range**	**Variable Type**	**Scale Factor**
Land Surface Temperature	LST	ºC	[-80, +70]	2 Byte Signed Integer	100
Quality Flag	Q_FLAGS	1	[0,14238]	2 Byte unsigned Integer	1
Land Surface Temperature Error	errorbar_LST	ºC	≥ 0	2 Byte Signed Integer	100

Table 7 - Description of LST/SEVIRI QC information.

Binary Value	Decimal Value	Description
000	0	Sea Pixel
0100	4	Corrupted Pixel
0001100	12	CMa - pixel non processed
0101100	44	CMa - pixel contaminated by clouds
0111100	60	CMa - Cloud filled
1001100	76	CMa - contaminated by snow/ice
1011100	92	CMa – Undefined
000011100	28	Emissivity Information Missing
0010011100	156	Viewing Angle Out of Range (EM Poor)
0100011100	284	Viewing Angle Out of Range (EM Nominal)
0110011100	412	Viewing Angle Out of Range (EM Excellent)
01010011100	668	cwv information missing
01100011100	796	cwv information missing
01110011100	924	cwv information missing
01011010011110	5790	Below Nominal (+ EM below nominal)
01011100011110	5918	Below Nominal (+ EM nominal)
01011110011110	6046	Below Nominal (+ EM above nominal)
10011100011110	10014	Nominal (EM nominal)
10011110011110	10142	Nominal (EM above nominal)
11011110011110	14238	Above Nominal (EM above nominal)
10111110011110	12190	pixel with GSW-RMSE > 4 k

4.5 Summary of Product Characteristics – SEVIRI LST

Product Name: Land Surface Temperature

Product Code: LST

Product Level: Level 2

Description of Product**:** Land Surface Temperature

Product Parameters:

Coverage: MSG full disk (Land pixels)

Packaging: MSG-Disk; Euro; NAfr; SAfr; SAme

Units: ºC

Range: -80ºC - +70ºC

Sampling: pixel by pixel basis

Resolution:	Temperature: hundreds of ºC
	Spatial: MSG full resolution (3km×3km at nadir)
Accuracy:	<2ºC
Geo-location Requirements:	
Format:	16 bits signed integer
Appended Data:	Quality control information (16 bits integer)
Frequency of generation:	every 15 min
Size of Product:	

Additional Information:

Identification of bands used in algorithm:

MSG IR10.8 (Channel 9)

MSG IR12.0 (Channel 10)

Assumptions on SEVIRI input data:

Calibration

Identification of ancillary and auxiliary data:

SEVIRI viewing angle (from EUMETSAT)
Pixel latitude and longitude (from EUMETSAT)
Cloud Mask (from NWC SAF)
Land-sea mask

5 Data Description – AVHRR/MetOp LST Product: LSA-002 (ELST)

5.1 Overview – AVHRR LST

The LSA SAF AVHRR/MetOp chain processes all Product Distribution Units (PDUs) at the LSA SAF processing centre, which correspond to about 3 minutes of instrument-specific observation data. The LST product is available at level 1b full spatial resolution. Information on geo-location of each PDU is also disseminated in two separate files, along with the respective LST product. Details on data (and ancillary data) distribution are available at the LSA SAF web-site: http://landsaf.meteo.pt.

Data users have access to the following data:

- LST field;
- quality control information field;

and to the following ancillary data:

- longitude of the pixel centre;
- latitude of the pixel centre;
- sensor viewing angle;
- solar angles.

The data are coded in HDF5 format. The HDF5 files in LSA SAF system have the following structure:

- A common set of attributes for all kind of data, containing general information about the data (including metadata compliant with U-MARF requirements);
- A dataset for the parameter values;
- Additional datasets for metadata (e.g., quality flags).

5.2 File Formats – AVHRR LST

For each PDU, the LST algorithm generates an external output file according to the following name convention:

HDF5_LSASAF_EPS-AVHRR_LST_PDU_YYYYMMDDhhmmss

where **YYYY**, **MM**, **DD**, **hh**, **mm** and **ss** respectively, denote the year, the month, the day, the hour and the minute of data acquisition.

The LSA SAF products are provided in HDF5 format developed by the National Center for Supercomputing Applications (NCSA) at the University of Illinois. A comprehensive description is available at http://hdf.ncsa.uiuc.edu/.

Libraries for handling HDF5-files in Fortran and C are available at http://hdf.ncsa.uiuc.edu/products/hdf5/. A user friendly graphical interface to open and view HDF5-files may also be downloaded from http://hdf.ncsa.uiuc.edu/products/hdf5/.

HDF5-format allows defining a set of attributes that provide the relevant information. As described in the Appendix A the LST product information includes the general attributes (Table B 1), the dataset attributes (Table B 2) and the quality flag attributes (Table B 3). Within the HDF5-files the information is organised in the form of separate datasets.

5.3 Product Contents – AVHRR LST

The LST product file contains two datasets containing the values and the respective quality flags. Table 8 and Table 9 show the contents of the LST product file and QC information, respectively. Detailed information is given in Annexes B and C.

Table 8 - Contents of the LST/AVHRR product file.

Parameter	Dataset Name	Unit	Range	Variable Type	Scale Factor
Land Surface Temperature	LST	°C	[-80, +70]	2-Byte Signed Integer	100
Quality Flag	Q_Flag	1	[0, 14238]	2-Byte Unsigned Int.	1

Table 9 - Description of LST/AVHRR QC information.

Binary Value	Decimal Value	Description
000	0	Sea Pixel
0100	4	Corrupted Pixel
0001100	12	CMa - pixel non processed
0101100	44	CMa - pixel contaminated by clouds
0111100	60	CMa - Cloud filled
1001100	76	CMa - contaminated by snow/ice
1011100	92	CMa - Undefined
000011100	28	Emissivity Information Missing
0010011100	156	Viewing Angle Out of Range (EM Poor)
0100011100	284	Viewing Angle Out of Range (EM Nominal)
0110011100	412	Viewing Angle Out of Range (EM Excellent)
01010011100	668	cwv information missing
01100011100	796	cwv information missing
01110011100	924	cwv information missing
01011010011110	5790	Below Nominal (+ EM below nominal)
01011100011110	5918	Below Nominal (+ EM nominal)
01011110011110	6046	Below Nominal (+ EM above nominal)
10011100011110	10014	Nominal (EM nominal)
10011110011110	10142	Nominal (EM above nominal)
11011110011110	14238	Above Nominal (EM above nominal)

5.4 Summary of Product Characteristics – AVHRR LST

Product Name: Land Surface Temperature

Product Code: LST

Product Level: Level 2

Description of Product**:** Land Surface Temperature

Product Parameters:

Coverage: MetOp PDU - Europe

Packaging: PDU

Units: ºC

Range: -80ºC - +70ºC

Sampling: pixel by pixel basis

Resolution: Temperature: hundreds of ºC

Spatial: AVHRR/MetOp full resolution (1km×1km at nadir)

Accuracy: <2ºC

Geo-location Requirements:

Format: 16 bits signed integer

Appended Data: Quality control information (16 bits integer)

Frequency of generation: ½ day

Size of Product:

Additional Information:

Identification of bands used in algorithm:

AVHRR/3 Channel 4

AVHRR/3 Channel 5

Assumptions on AVHRR input data:

Calibration

Identification of ancillary and auxiliary data:

MetOp/AVHRR viewing angle (from EUMETSAT)
Pixel latitude and longitude (from EUMETSAT)
Land-sea mask

6 Validation and Quality Control

The spectral capability of MSG-SEVIRI has the potential to provide LST with accuracy comparable to that from polar-orbiters like ENVISAT-AATSR, Terra-MODIS, or NOAA-AVHRR. The adopted strategy for validation of LST product consists on three main steps: 1) inter-comparison with other satellite derived LST products; 2) comparison with in situ measurements; 3) evaluation of errors in the main variables used as input for LST algorithm (e.g. ECMWF forecasts fields for 2m-temperature and total column water vapour). See the Work Plan Document for detailed information (SAF_Land_SVWP_v1.0.doc).

The Validation Reports (SAF_Land_IM_VR_LST) include the analysis inter-comparison of LST products derived from different sensor, namely the two LSA SAF products, LST/SEVIRI and LST/AVHRR, MODIS LST and AATSR LST. The validation of LSA SAF LST also includes the comparison with in-situ measurements, although these are relatively scarce within the Meteosat disk.

Automatic Quality Control (QC) is performed on LST data and the quality information is provided on a pixel basis. As shown in Annex C LST QC contains general information about input data quality, specific information related with the limits of application and information about LST confidence level. The LST confidence level was defined based on the following parameters: viewing angle; atmospheric characteristics (i.e. surface temperature and column water vapour); EM confidence level. The three considered levels of confidence (i.e. above nominal, nominal and below nominal) correspond to estimated uncertainties on LST values (respectively less than 1K, between 1 and 2K and above 2K). Sensitivity studies have shown that the algorithm errors are larger for large viewing angles and for wet conditions; on the other hand the algorithm shows to be very sensitive to EM uncertainties for dry atmospheric conditions.

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8 Developers

Responsible: Isabel Trigo (IPMA)

Contributors:

Instituto de Meteorologia (IPMA) **Portugal**
Isabel Trigo
Isabel Monteiro
Sandra Coelho
Carla Barroso
Cristina Madeira

Institute for Meteorology and Climate Research (FZK-IMK) **Germany**
Folke S. Olesen
Frank Göttsche

Institute for Applied Science and Technology (ICAT) **Portugal**
Leonardo Peres

9 Glossary

AATSR:	Advanced Along Track Scanning Radiometer
ARM:	NASA Atmospheric Radiation Measurements Program
ASTER:	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR:	Advanced Very High Resolution Radiometer
cwv:	column water vapour
ECMWF:	European Centre for Medium-Range Weather Forecasts
EM:	Land Surface Emissivity
EMAC:	European Multi-sensor Airborne Campaign
ENVISAT	Environmental Satellite
EOS:	Earth Observing System
EPS:	EUMETSAT Polar System
ESA:	European Space Agency
EUMETSAT:	European Meteorological Satellite Organisation
FIFE:	First ISLSCP Field Experiment
FOV	Field of View
FZK-IMK:	Forschungszentrum Karlsruhe – Insitut für Meteorologie und Klimaforschung (Germany)
GOES:	Geostationary Operational Environmental Satellite
GSW:	Generalized Split-Window
HAPEX:	Hydrological and Atmospheric Pilot Experiment in the Sahel
HDF	Hierarchical Data Format

HIRLAM:	High Resolution Limited Area Model
HIRS:	High Resolution Infrared Radiation Sounder
ICAT:	Instituto de Ciência Aplicada e Tecnologia (Portugal)
IM:	Instituto de Meteorologia (Portugal)
IPMA:	Instituto Português do Mar e da Atmosfera
IR:	Infrared Radiation
ISLSCP:	International Satellite Land Surface Climatology Project
LST:	Land Surface Temperature
LUT:	Look-Up Table
MAS:	Modis Airborne Simulator
METEOSAT:	Geostationary Meteorological Satellite
MODIS:	Moderate-Resolution Imaging Spectro-Radiometer
MODTRAN:	Moderate Resolution Transmittance Code
MSG:	Meteosat Second Generation
NASA:	National Air and Space Administration
NDVI:	Normalised Difference Vegetation Index
NEΔT:	Noise Equivalent Temperature
NIR	Near Infrared Radiation
NOAA:	National Oceanic and Atmospheric Administration (USA)
NWC:	NoWCasting SAF
NWP:	Numerical Weather Prediction
PRISM:	Process Research by Imaging Space Mission
QC:	Quality Control
rms:	root mean square
RSS:	Root Sum Square
SAF:	Satellite Application Facility
SEVIRI:	Spinning Enhanced Visible and InfraRed Imager
SPOT	Système Probatoire d'Observation de la Terre
SST:	Sea Surface Temperature
SURFRAD:	Surface Radiation Budget Network
TCWV:	Total Column Water Vapour
TIGR:	TOVS Initial Guess Retrieval
TIR:	Thermal Infrared
TIROS:	Television and Infrared Observation Satellite
TISI:	Temperature Independent Spectral Index
TOVS:	TIROS-N Operational Vertical Sounder
TSP:	Thermal Surface Parameter
TTM:	Two-Temperature Method
U-MARF	Unified Meteorological Archiving and Retrieval Facility
URD:	User Requirements Document
v-a:	viewing angle
VCM:	Vegetation Cover Method
VIS	Visible Radiation

Annex A. Product Metadata – SEVIRI LST

The following Tables describe the metadata distributed with each SEVIRI-based product, in the form of attributes included in the HDF5 format product files.
As for all LSA SAF products, both image acquisition time and slot time, indicated in the attributes of LST files, correspond to the time of observation of the first segment sensed by SEVIRI (or Metop) sensor. Information about the actual sensing time is given by the sensing start and sensing end times, which correspond to the sensing start / end for a given region. Such regions can be one of the LSA SAF geographical areas (section 4.1), or a PDU in the case of Metop derived parameters.

Table A 1 - General attributes of the files for the SEVIRI LST product.

Attribute	Allowed Values	Data Type
SAF	LSA	String<3>
CENTRE	IM-PT	String<5>
ARCHIVE_FACILITY	IM-PT	String<5>
PRODUCT	LST	String<79>
PARENT_PRODUCT_NAME	Cma, TCWV, Brightness Temperature	Array(4) of string<79>
SPECTRAL_CHANNEL_ID	768	Int
PRODUCT_ALGORITHM_VERSION	X.Y	String<4>
CLOUD_COVERAGE	NWC-CMa,	String<20>
OVERALL_QUALITY_FLAG	OK or NOK	String<3>
ASSOCIATED_QUALITY_INFORMATION	-	String<511>
REGION_NAME	One of: Euro, NAfr, SAfr, SAme	String<4>
COMPRESSION	0	Int
FIELD_TYPE	Product	String<255>
FORECAST_STEP	0	Int
NC	Depend on REGION_NAME (Table 4)	Int
NL	Depend on REGION_NAME (Table 4)	Int
NB_PARAMETERS	2	Int
NOMINAL PRODUCT_TIME	YYYYMMDDhhmmss	String<14>
SATELLITE	MSG*X*	Array[10] of String<9>
INSTRUMENT_ID	SEVI	Array [10] of String<6>
INSTRUMENT_MODE	STATIC_VIEW	String<511>
IMAGE_ACQUISITION_TIME	YYYYMMDDhhmmss	String<14>
ORBIT_TYPE	GEO	String<3>
PROJECTION_NAME	Geos<sub_lon>	String<15>
NOMINAL_LONG	Actual Satellite Nominal Longitude	Real
NOMINAL_LAT	Actual Satellite Nominal Latitude	Real

Attribute	Allowed Values	Data Type
CFAC	13642337	Int
LFAC	13642337	Int
COFF	Depend on REGION_NAME (Table 4)	Int
LOFF	Depend on REGION_NAME (Table 4)	Int
START_ORBIT_NUMBER	0	Int
END_ORBIT_NUMBER	0	Int
SUB_SATELLITE_POINT_START_LAT	0.0	Real
SUB_SATELLITE_POINT_START_LON	0.0	Real
SUB_SATELLITE_POINT_END_LAT	0.0	Real
SUB_SATELLITE_POINT_END_LON	0.0	Real
SENSING_START_TIME	YYYYMMDDhhmmss	String<14>
SENSING_END_TIME	YYYYMMDDhhmmss	String<14>
PIXEL_SIZE	3.1km	String<10>
GRANULE_TYPE	DP	String<2>
PROCESSING_LEVEL	02	String<2>
PRODUCT_TYPE	LSALST	String<8>
PRODUCT_ACTUAL_SIZE	Depends on the region	Integer > 0, encoded as String<11>
PROCESSING_MODE	N	String<1>
DISPOSITION_FLAG	O	String<1>
TIME_RANGE	15-min	String<20>
STATISTIC_TYPE	-	String<20>
MEAN_SSLAT	Depend on REGION_NAME (Table 4)	Real
MEAN_SSLON	Depend on REGION_NAME (Table 4)	Real
PLANNED_CHAN_PROCESSING	0	Integer
FIRST_LAT	0	Real
FIRST_LON	0	Real

Table A 2 - Attributes of the LST/SEVIRI dataset.

Attribute	Description	Data Type
CLASS	Data	String, length=4
PRODUCT	LST	String, length=3
PRODUCT_ID	235	32-bit integer
N_ COLS	Depend on REGION_NAME (Table 4)	32-bit integer
N_ LINES	Depend on REGION_NAME (Table 4)	32-bit integer
NB_BYTES	2	32-bit integer
SCALING_FACTOR	100.0	64-bit floating-point
OFFSET	0.0	64-bit floating-point
MISS_VALUE	-8000	32-bit integer
UNITS	Degrees Celsium	String, length=15
CAL_SLOPE	999.0	64-bit floating-point
CAL_OFFSET	999.0	64-bit floating-point

Table A 3 - Attributes of the LST/SEVIRI Quality Flag information dataset.

Attribute	Description	Data Type
CLASS	Data	String, length=4
PRODUCT	Q_FLAGS	String, length=7
PRODUCT_ID	999	32-bit integer
N_ COLS	Depend on REGION_NAME (Table 4)	32-bit integer
N_ LINES	Depend on REGION_NAME (Table 4)	32-bit integer
NB_BYTES	2	32-bit integer
SCALING_FACTOR	1.0	64-bit floating-point
OFFSET	0.0	64-bit floating-point
MISS_VALUE	-9999	32-bit integer
UNITS	Dimensionless	String, length=13
CAL_SLOPE	999.0	64-bit floating-point
CAL_OFFSET	999.0	64-bit floating-point

Annex B. Product Metadata – AVHRR LST

Table B 4 - General attributes of the files for the AVHRR LST product.

Attribute	Values	Data Type
SAF	LSA	String<3>
CENTRE	IM-PT	String<5>
ARCHIVE_FACILITY	IM-PT	String<5>
PRODUCT	LST	String<79>
PARENT_PRODUCT_NAME	Cma, TCWV, Brightness Temperature	Array(4) of string<79>
SPECTRAL_CHANNEL_ID	24	Int
PRODUCT_ALGORITHM_VERSION	X.Y	String<4>
CLOUD_COVERAGE	NWC-CMa, …	String<20>
OVERALL_QUALITY_FLAG	OK or NOK	String<3>
ASSOCIATED_QUALITY_INFORMATION	-	String<511>
REGION_NAME	PDU	String<4>
COMPRESSION	0	Int
FIELD_TYPE	Product	String<255>
FORECAST_STEP	0	Int
NC	2048	Int
NL	1080	Int
NB_PARAMETERS	2	Int
NOMINAL PRODUCT_TIME	YYYYMMDDhhmmss	String<14>
SATELLITE	METOP*X*	Array[10] of String<9>
INSTRUMENT_ID	AVHR	Array [10] of String<6>
INSTRUMENT_MODE	NORMAL_VIEW	String<511>
IMAGE_ACQUISITION_TIME	YYYYMMDDhhmmss	String<14>
ORBIT_TYPE	LEO	String<3>
PROJECTION_NAME	-	String<15>
NOMINAL_LONG	0	Real
NOMINAL_LAT	0	Real
CFAC	0	Int

Attribute	Values	Data Type
LFAC	0	Int
COFF	0	Int
LOFF	0	Int
START_ORBIT_NUMBER	Depend on the orbit	Int
END_ORBIT_NUMBER	Depend on the orbit	Int
SUB_SATELLITE_POINT_START_LAT	Depend on the orbit and on the PDU	Real
SUB_SATELLITE_POINT_START_LON	Depend on the orbit and on the PDU	Real
SUB_SATELLITE_POINT_END_LAT	Depend on the orbit and on the PDU	Real
SUB_SATELLITE_POINT_END_LON	Depend on the orbit and on the PDU	Real
SENSING_START_TIME	YYYYMMDDhhmmss	String<14>
SENSING_END_TIME	YYYYMMDDhhmmss	String<14>
PIXEL_SIZE	1.1km	String<10>
GRANULE_TYPE	DP	String<2>
PROCESSING_LEVEL	02	String<2>
PRODUCT_TYPE	LSALST	String<8>
PRODUCT_ACTUAL_SIZE	8847360	Integer > 0, encoded as String<11>
PROCESSING_MODE	N	String<1>
DISPOSITION_FLAG	O	String<1>
TIME_RANGE	3-min	String<20>
STATISTIC_TYPE	-	String<20>
MEAN_SSLAT	0	Real
MEAN_SSLON	0	Real
PLANNED_CHAN_PROCESSING	0	Integer
FIRST_LAT	0	Real
FIRST_LON	0	Real

Table B 5 - Attributes of the LST/AVHRR dataset.

Attribute	Description	Data Type
CLASS	Data	String, length=4
PRODUCT	LST	String, length=3
PRODUCT_ID	235	32-bit integer
N_ COLS	2048	32-bit integer
N_ LINES	1080	32-bit integer
NB_BYTES	2	32-bit integer
SCALING_FACTOR	100.0	64-bit floating-point
OFFSET	0.0	64-bit floating-point
MISS_VALUE	-8000	32-bit integer
UNITS	Degrees Celsium	String, length=15
CAL_SLOPE	999.0	64-bit floating-point
CAL_OFFSET	999.0	64-bit floating-point

Table B 6 - Attributes of the LST/AVHRR Quality Flag information dataset.

Attribute	Description	Data Type
CLASS	Data	String, length=4
PRODUCT	Q_FLAGS	String, length=7
PRODUCT_ID	999	32-bit integer
N_ COLS	2048	32-bit integer
N_ LINES	1080	32-bit integer
NB_BYTES	2	32-bit integer
SCALING_FACTOR	1.0	64-bit floating-point
OFFSET	0.0	64-bit floating-point
MISS_VALUE	-9999	32-bit integer
UNITS	Dimensionless	String, length=13
CAL_SLOPE	999.0	64-bit floating-point
CAL_OFFSET	999.0	64-bit floating-point

Annex C. LST Quality Control Information

Table C 7 – LST QC information.

Bit	Field	Category	Binary code	Description
00-01	Data quality	Unprocessed	00	Sea pixel Satellite Data Corrupted Cloud mask (unprocessed; cloud contaminated; cloud filled; snow/ice contaminated; undefined) Emissivity unprocessed Viewing-Angle out of GSW admissible limit TCWV out of GSW admissible limit
		Suspect	01	Pixel in neighbourhood of clouds
		Good	10	The pixel has no known effects
02-02	Land/Sea	Sea	0	
		Land	1	
03-03	Satellite Image [IR10.8 & IR12.0] or [ch 4 & ch 5]	Corrupted	0	
		Ok	1	
04-06	Cloud /Mask	Unprocessed	000	Pixel non processed
		Clear	001	Cloud free pixel
		Contaminated	010	Pixel contaminated by clouds
		Cloud filled	011	Pixel filled by clouds (covered by thick cloud)
		Snow/Ice	100	Pixel Contaminated by snow or ice
		Undefined	101	Not classified due to known separability problems
07-08	Emissivity	Unprocessed	00	
		>1.2%	01	Below nominal Quality
		0.6-1.2%	10	Nominal Quality
		<0.6%	11	Above nominal Quality
10-10	Total Column Water Vapour (TCWV)	Out of GSW Range	0	TCWV ≥ 6 cm
		Inside	1	0≤ TCWV < 6 cm
11-11	Reserved		0	
			0	
12-13	LST confidence Level	>2.0 C	01	Below Nominal performance
		1.0-2.0 C	10	Nominal Performance
		<1.0 C	11	Above Nominal Performance