SAF for Land Surface Analysis (LSA SAF)

VALIDATION REPORT LST

Reference Number:	SAF/LAND/IM/VR_LST/I_09
Issue/Revision Index:	Issue I/2009
Last Change:	17/03/2009

DOCUMENT SIGNATURE TABLE

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DOCUMENTATION CHANGE RECORD

Issue / Revision	Date	Description:
Version I/2009	17/03/2008	Version to be presented to OR-3

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Executive Summary

Land Surface Temperature retrieved from SEVIRI/Meteosat, LST_SEVIRI, is generated on an operational basis since February 2005 for the European region and since July 2005 for the whole Meteosat disk. The regular generation of LST from AVHRR/MetOp, LST_AVHRR, began in September 2007. The main algorithm for LST estimation from both sensors is based on a Generalized Split Window (GSW) that uses the difference between two adjacent window channels to correct the atmospheric absorption.

This document presents the most recent validation results obtained for the Land-SAF LST products. In the case of LST_SEVIRI is compared with that retrieved from MODIS and with ground observations taken at the first Land-SAF in situ station in Evora (Southern Portugal). The relatively short time-series available for LST_AVHRR – regular generation began in September 2007 – limits the validation of this product with ground data.

The comparison of SEVIRI and MODIS LST retrievals with in situ observations is consistent with the analysis performed for the three selected areas. The differences between ground and satellite-derived values show high variability for daytime for both sensors, with LST_SEVIRI overestimating in situ values. It is, however, difficult to draw definite conclusions, taking into consideration the strong contrasts between measurements taken at the site for different elements such as tree crown and grass, particularly during the dryer months. Again, the differences between satellite and in situ LST's are lower for nighttime observations. In this case, both sensors tend to underestimate local measurements, with colder values obtained with MODIS.

The results obtained for the comparison between LST_AVHRR and LST_SEVIRI suggest that the SEVIRI/Meteosat product tends to be on average warmer by about 1 – 1.5ºC for daytime, with discrepancies with half a degree for night-time cases. The analysis of LST obtained from both sensors reveals that differences are strongly dependent on viewing geometry and surface characteristics such as orography or surface type.

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1 Introduction

Land Surface Temperature (LST) in the Land-SAF is calculated via Planck's function from the directional surface leaving IR radiance measurements of cloud free SEVIRI/Meteosat or AVHRR/MetOp pixels. "Surface leaving radiance" means that the atmospheric attenuation along the path is corrected and the reflected downwelling radiance is removed. The "surface" is formed by all elements that emit IR radiance. Thus, LST is the radiative skin temperature of land surface, as measured in the direction of the remote sensor. Such directional radiometric temperature provides the best approximation to the thermodynamic temperature based on a measure of radiance (Norman and Becker, 1995). The main algorithm for LST estimation, from both SEVIR/Meteosat and from AVHRR/MetOp, is based on the formulation first developed for MODIS and AVHRR by Wan and Dozier (1996). Thus Land-SAF LST is estimated as a linear function of clear-sky top of the atmosphere (TOA) brightness temperatures measured by the split-window channels available on SEVIRI (10.8 and 12.0 μm) and on AVHRR (channels 4 and 5), assuming surface emissivity is know for both bands. The estimation of the GSW parameters relied on linear regressions of synthetic brightness temperatures, obtained from radiative transfer simulations (using MODTRAN) over a wide range of surface and atmospheric condition

This document presents the most recent validation results obtained for the Land-SAF LST retrieved from SEVIRI/Meteosat and AVHRR/Metop (hereafter referred as LST_SEVIRI and LST_AVHRR, respectively). The main methodology followed for the validation of LST_SEVIRI is described in Trigo et al. (2008b). The validation of LST_AVHRR is somehow at a less mature stage, and most results are based on the comparison with SEVIRI/MSG LST product (hereafter referred as LST_SEVIRI) for 2008 and with ground observations taken at the first Land-SAF in situ station in Evora (Southern Portugal).

2 LST_SEVIRI versus In Situ Observations (Evora)

2.1 In Situ Data

The SEVIRI and MODIS LST products are compared against in situ observations obtained at the first Land SAF ground-truth station. The site is located near Evora (38.54ºN, 8.00ºW; Southern Portugal), in Quercus woodland plains. Evora was chosen among several other potential European sites within Meteosat's field of view, for setting up an LST ground-truth site taking into account that (Dash et al., 2004): (i) large Meteosat zenith angles correspond to suboptimal conditions for LST retrievals (only SZA up to 60^{o} are admitted in the Land SAF LST algorithm), and thus should be avoided; (ii) the area around the station must be homogeneous in terms of land cover, ensuring equal temperature dispersion; (iii) mountainous regions should be avoided since heterogeneous orography causes additional geometrical distortions in the satellite images; (iv) observations should be carried out continuously, preferably upon years, and thus areas with a relatively stable land cover should be preferred; (v) it is also important the area experiences long clear-sky periods, and low aerosol loads.

The Evora site which follows all of the above-mentioned criteria (Dash et al., 2004), is part of the global network of micrometeorological flux measurements, Fluxnet (Baldocchi et al., 2001). A suite of instruments was added to the existing tower of 28 m, including a rotating radiometer "RotRad", specially designed for LST-validation. The radiometer head is able to rotate about an axis perpendicular to the viewing direction (Figure 1a), allowing the scene to be viewed at varying zenith angles. The instrument calibrates itself automatically at every circle of measurements, making use of two blackbodies; one of them is heated (42ºC), while the other is close to the environment temperature. The sensor takes measurements within the 8-12 µm spectral range, with an expected accuracy of at least 0.2 K. The RotRad measures the brightness temperature for 3 positions on the ground (Figure 1b) with an instantaneous field of view (IFOV) of the order of 6 m, and with 2-minute periodicity. The 3 scenes on the ground correspond to (i) tree crown; (ii) grass (always sunlit during summer); and (iii) a mixture of shadow grass and tree crown. SEVIRI (and MODIS) pixels are essentially composed of these three end-members. For comparison with the satellite-derived LST, we consider the in situ surface brightness temperature, T_{RR_sfc}, to be a weighted average of the brightness temperatures of these 3 scenes, taken within each circle of measurements. The estimation of the weights – 0.37 for "tree spot" and 0.315 for each "grass spot" – used in the average is based on the percent of tree crowns observed in an IKONOS image (1m-resolution), for an area surrounding the station equivalent to that of SEVIRI/Meteosat pixel. These tree crown/grass fractions are in agreement with an independent analysis performed using Landsat Thematic Mapper (TM) data from 1995, which suggests a tree cover of the order of 40% for the same region (Carreiras et al., 2006).

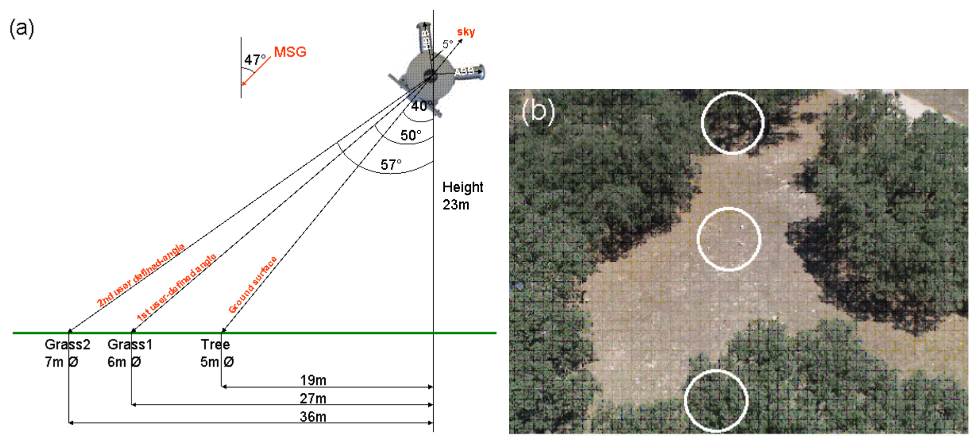

Figure 1 (a) Schematic diagram of the measurements taken by the rotating radiometer installed in the tower at Evora ground station; (b) view of the three spots on the ground corresponding to tree crown, sunlit grass and a mixture of sunlit/shadow grass.

The radiance measured by the radiometer (in the 8-12 µm band) is given by:

$$L_{RR} = L_{RR}\left(T_{RR\_sfc}\right) = \varepsilon_{RR\_sfc}\, L_{RR}\left(T_{sfc}\right) + \left(1 - \varepsilon_{RR\_sfc}\right) L^{\downarrow}_{RR\_atm} \qquad (1)$$

where T_{RR_sfc} and ε_{RR_sfc} are the effective brightness temperature and emissivity of a surface consisting of an ensemble of the scenes described above (Figure 1b), in the radiometer band and; T_{sfc} is the respective surface temperature; and $L^{\downarrow}_{RR\_atm}$ is the downward atmospheric radiance in the RotRad band. The latter is estimated from a fourth measurement of the radiometer during each circle, taken with the sensor facing the sky at a 40° zenith angle (close to the average atmospheric thermal path).

The in situ land surface observations at Evora ground station are obtained by resolving equation (1). The values used for surface emissivity, ε_{RR_sfc}, are approximated from the Land SAF estimations for the region (for the SEVIRI channel centred at 10.8 µm), taking into consideration the vegetation types and respective fraction (Peres and DaCamara, 2005; Trigo et al., 2008). The impact of emissivity uncertainties on LST observation errors is discussed in section 4, where the comparison between clear sky LST retrievals (from SEVIRI and MODIS) and Evora in situ observations is analysed. The comparison is carried out for five 7-day periods between September 2005 and May 2006, when both data types (satellite and gorund-based) are available.

2.2 LST_SEVIRI and LST_MODIS versus In Situ Observations

The variability of LST and emissivity within the pixel is one of the major obstacles to the validation of LST satellite retrievals with ground-based instruments (Wan et al., 2002). To partially overcome this problem, the in situ data at Evora are collected from three spots on the ground, corresponding to the most relevant elements at the pixel subscale (Figure 1b). We then use a single emissivity that represents the “soil/grass and canopy” combined scene to correct the radiometer measurements, taken as the average of sensed temperatures of “tree crown”, “sunlit grass/soil” and “shadow grass/crown” (Figure 1). Emissivity values, corresponding to Land-SAF estimations for the SEVIRI channel centred at 10.8 µm over an area surrounding Evora station, range from 0.9628 for the driest period in September, to 0.9684 for the greenest phase in May. The emissivity computations take into account the type and fraction of vegetation cover within each pixel, following the vegetation cover method described in (Peres and DaCamara, 2005). Emissivity error bars are estimated considering the uncertainty in the fraction of vegetation (maximum absolute errors of 0.1), emissivity variability among the different types of vegetation/bare soil within the pixels surrounding the station and the inherent uncertainty of the vegetation cover method for emissivity (discussed in Trigo et al., 2008a). The resulting uncertainties in the emissivity values are of the order of 1.1% to 1.3%.
A sensitivity analysis of the final LST_{InSitu} values to each uncertainty source is performed for each measurement, allowing us to characterise the observation errors associated to (i) emissivity, δLST_{ε}, (ii) the radiometer noise, $\delta RotRad$, (iii) the variability of the radiometer measurements within the 10-minute intervals, which were then averaged to get each single observation, $\delta LST_{InSituVarT}$, and (iv) the spatial variability of the RotRad measurements, $\delta LST_{InSituVarSp}$, assuming an error in the fraction of tree crowns up to 0.1. The total uncertainty of each LST in situ observation is then given by:

$$\delta(LST_{InSitu}) = \left[(\delta LST_{\varepsilon})^2 + (\delta LST_{InSituVarT})^2 + (\delta LST_{InSituVarSp})^2 + (\delta RotRad)^2\right]^{1/2} \quad (2)$$

Table 1 and Table 2 show the average values of LST_{InSitu} and LST retrievals obtained from SEVIRI and MODIS for the studied periods, corresponding to a total sample of 8 (16) cases around the MODIS daytime (night-time) passage over Evora; the time elapse between in situ observations and satellite retrievals is within +/– 7 minutes for SEVIRI and +/– 2 minutes for MODIS. The availability of data for the comparison of satellite versus “in situ” data is subject to the existence of the four ground measurements – “tree crown”, “sunlit grass/soil”, “shadow grass/crown” and sky brightness temperature – and (clear sky) LST retrievals from both sensors collocated with the station. Despite the existence of systematic differences, the satellite retrievals follow quite well the in situ measurements (Figure 2). Night-time estimations tend to be colder than ground observations, while daytime SEVIRI LST tend to be warmer.

Table 1 Daytime statistics per study period, including: mean LST observation (oC) and respective mean uncertainty (ΔLST; oC); SEVIRI and MODIS average LST (oC) and root mean square difference against the observations (RMSD; oC). The 1st column shows the 7-day periods under study and the respective number of cases available.

Period	OBS		SEVIRI		MODIS	
(no. obs)	LST	ΔLST	LST	RMSD	LST	RMSD
14-20 Sep 05 (2)	40.8	1.85	44.7	4.9	38.2	3.7
11-17 Nov 05 (1)	13.7	0.44	15.1	1.4	14.5	0.9
23-31 Jan 06 (1)	12.1	0.62	14.7	2.7	12.1	0.0
23-29 May 06 (4)	35.4	1.82	36.3	1.0	32.9	3.2

Table 2 As in Table 1, but for night-time.

Period	OBS		SEVIRI		MODIS	
(no. obs)	LST	ΔLST	LST	RMSD	LST	RMSD
14-20 Sep 05 (7)	18.2	0.52	15.7	2.9	15.2	3.1
11-17 Nov 05 (1)	7.8	0.50	5.9	1.9	5.8	2.0
23-31 Jan 06 (5)	4.0	0.59	3.6	0.9	2.4	2.0
23-29 May 06 (3)	21.0	0.51	19.0	2.4	17.7	3.5

As suggested by the analysis of the comparison between MODIS and SEVIRI LSTs (Trigo et al., 2008b), the sun-satellite viewing geometry does influence the retrievals, particularly during daytime. Although not shown, when MODIS and ground values are compared taking into account the MODIS zenith angle, we obtain averaged differences "satellite minus in situ" of –2.8ºC (–0.2ºC) for positive (negative) angles, i.e. for scenes viewed from West (East). Accordingly, SEVIRI LST generally presents a warm bias. The variability of satellite – in situ discrepancies within the whole studied period is also higher for daytime values. The root mean square differences (RMSD) between MODIS and in situ LST are within the 0.0 to 3.7ºC range. The RMSD for SEVIRI estimations are higher, with values varying from 1.6 ºC in November, to 4.9 ºC in September (Table 1). It is worth mentioning that 1 (out of 2) SEVIRI LST value within the latter period overestimate the ground observations by about 7ºC (Figure 1a); in this particular case, the TOA brightness temperature of SEVIRI channel centred at 10.8 μm also exceeds the ground observations by nearly 3ºC. We cannot fully understand the largest discrepancies between SEVIRI and in situ observations obtained for September. However, it should be kept in mind that this is the driest period under study, when the temperature (and emissivity) contrasts between the canopy and the ground are more pronounced, when the morning heat rate is higher, and thus when the uncertainty of the observations is largest.

Night-time LST retrievals from SEVIRI and MODIS are consistently below in situ observations throughout the whole studied period (Table 2 and Figure 2). Such cold bias ranges from 0.4 to 2.5ºC and 1.6 to.3.3ºC for SEVIRI and MODIS, respectively. In contrast with Evora ground observations obtained for daytime MODIS passages, night-time values have relatively low uncertainties associated (of the order of 0.5ºC). These are essentially associated with emissivity uncertainties, particularly in November and January when the temporal and spatial variability of in situ observations are lowest.

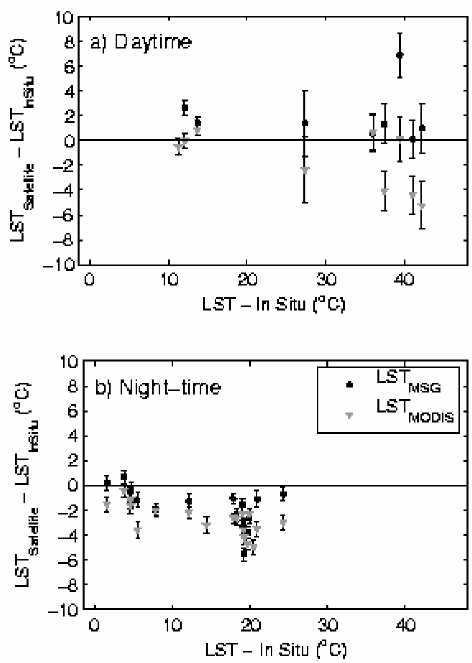

Figure 2 Differences between LST satellite retrievals and ground measurements (°C) as a function of in situ observations taken in Evora, Southern Portugal. Black dots and grey triangles correspond to SEVIRI and MODIS LST, respectively. The error bars represent the estimated uncertainty of each in situ observation.

2.3 LST diurnal cycle: SEVIRI versus In Situ Observations

The Land-SAF project team is currently investigating the behaviour of the full LST diurnal cycle, and how it compares to in situ observations. The next Validation Report will include results for four main LST ground stations (co-)maintained by the Land SAF: Evora (Portugal), Gobabeb (Namibia), Kalahari (Namibia), and Dahra (Senegal).

Below we present the results of the comparison of full (15-minute) LST_SEVIRI with Evora in situ data. The exercise is performed for September, October and November 2008. It is worth mentioning that these results are taken after the changes in level 1.5 SEVIRI radiance definition, which took place in May 2005. The change in the radiance definition on the SEVIRI LST (Barroso et al., 2008) has a rather low impact on LST (generally lower that 0.5 K), however, there is a tendency for extreme hot LST (> 30ºC) to become cooler and colder LST values to become warmer, leading to lower LST amplitudes during the warm season. The results obtained for the 3 months in 2008 suggest overall that LST_SEVIRI tends to underestimate more in situ data, than the comparison performed in 2005. In the meantime, there was a change in the processing of level 1.5 radiances and the tower set up in Evora also had to be changed to a nearby location. Such changes might explain the differences between results obtained for 2005 and for 2008.

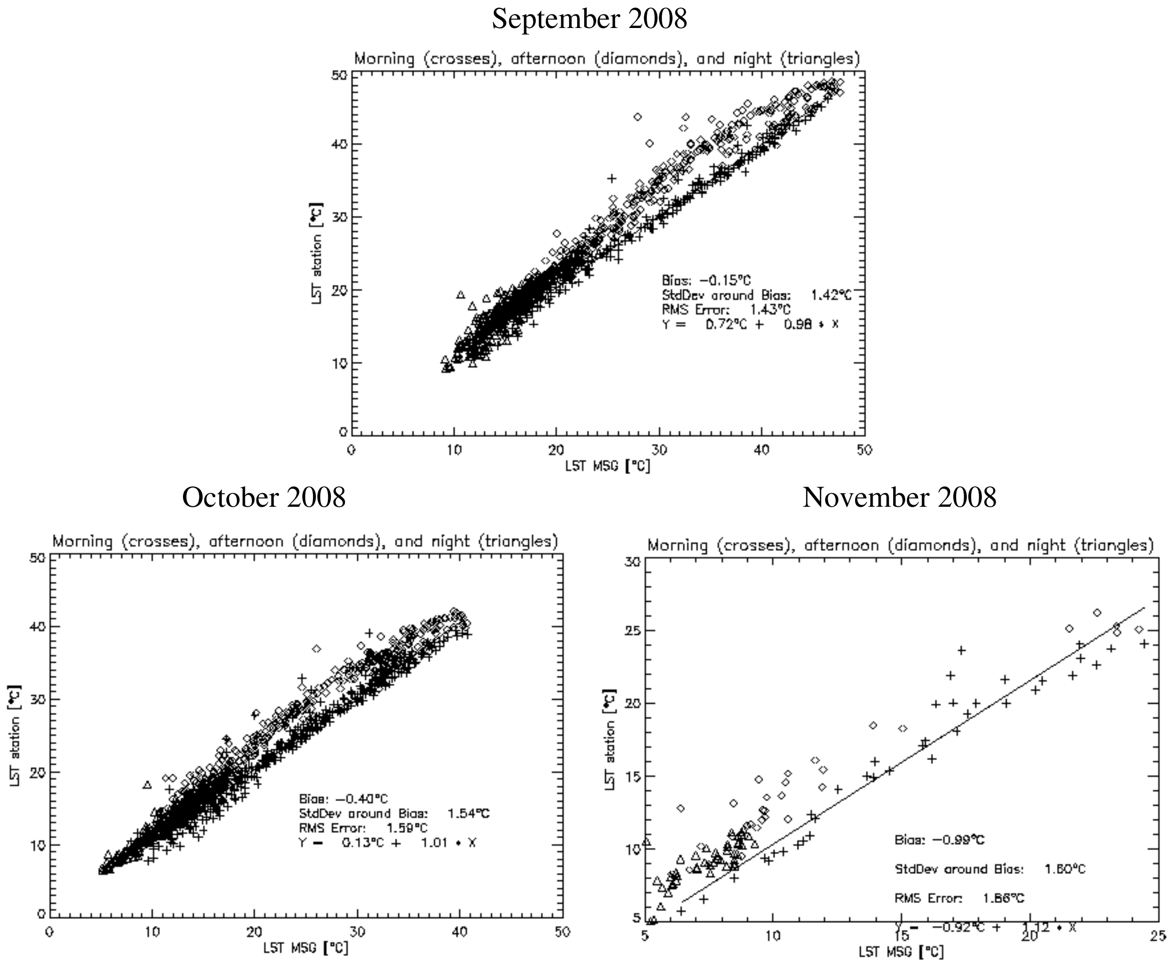

Figure 3 Scatterplots of in situ LST measurements taken at Evora (y-axis) versus SEVIRI/Meteosat retrievals (x-xaxis), for September, October and November 2008, respectively. Crosses, diamonds and triangles represent observations taken during the morning (7:12 UTC – 12:00 UTC), afternoon (12:00 UTC – 19:12 UTC), and night-time (19:12 UTC – 7:12 UTC).

Figure 3 shows the comparison of in situ and satellite measurements for the studied months in 2008. The overall results are fairly good, with LST_SEVIRI following closely ground observations. A closer analysis shows that the discrepancies between satellite and in situ observations depend on the time of the day, with a greater underestimation of observations during the afternoon and during night-time. As discussed in the previous section, we are particularly interested in understanding the systematic differences obtained for night-time. A preliminary analysis suggests that errors in surface emissivity cannot account for more than 0.5ºC. Other sources of error, such as an under-classification of low level or semi-transparent clouds during night-time also need to be looked into.

Table 3 Statistics of the comparison between LST_SEVIRI and in situ measurements, obtained for September, October, and November 2008.

	September 2008		October 2008		November 2008	
	Bias (ºC)	RMSD (ºC)	Bias (ºC)	RMSD (ºC)	Bias(ºC)	RMSD(ºC)
Morning (7:12 – 12:00 UTC)	-0.15	1.43	-0.40	1.59	-0.99	1.66
Afternoon (12:00 – 19:12 UTC)	-3.6	4.12	-3.27	3.63	-3.00	3.27
Night-time (19:12 – 7:12 UTC)	-2.29	2.48	-1.54	1.88	-1.66	1.69

3 Comparison LST_AVHRR- LST_SEVIRI

LST_AVHRR and LST_SEVIRI data are compared for the full year of 2008. The data are collocated in space and time: (i) both fields are projected onto a common regular grid of 0.05º longitude by 0.05º latitude using the nearest neighbour method;(ii) the difference between the observing time of each AVHRR/MetOp and SEVIRI/Meteosat pixel is always below 6 minutes.

The comparison is performed for 3 distinct areas in Europe (i) Iberian Peninsula (35ºN – 45ºN;10ºW – 0º); (ii) Balkan Peninsula (35ºN – 48ºN;15ºE – 30ºE) and (iii) Central Europe(45ºN – 50ºN;10ºE – 25ºE); these are represented in Figure 4 to Figure 7).

Overall, AVHRR LST presents colder values than the corresponding SEVIRI LST (see Figure 4 to Figure 7, as an example). To characterize this bias the differences between the two products were analysed in terms of satellite viewing angle differences; time of the day and surface type. The diurnal and seasonal differences are also addressed.

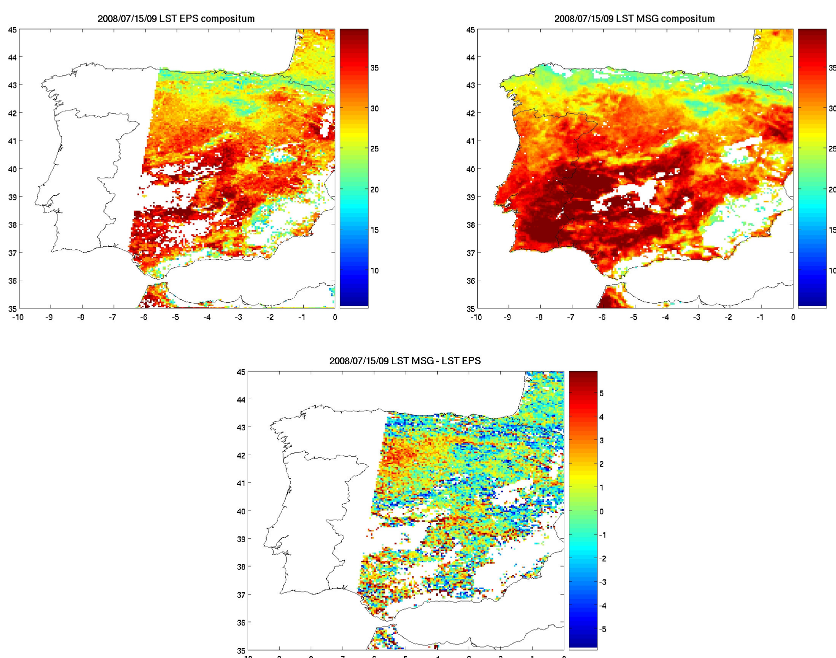

Figure 4 LST (ºC) provided by (a) AVHRR/MetOp, (b) SEVIRI/MSG, and the respective difference (SEVIRI minus AVHRR), for one daytime MetOp passage over the Iberian Peninsula (on the 15th July at 9 UTC).

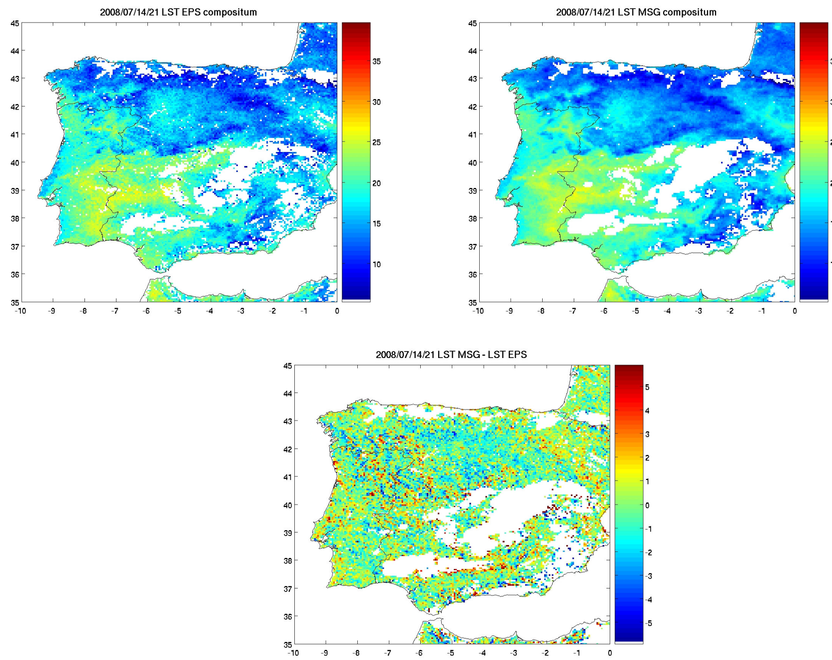

Figure 5 As in Figure 4, but for one night-time passage (on the 14th July at 21 UTC).

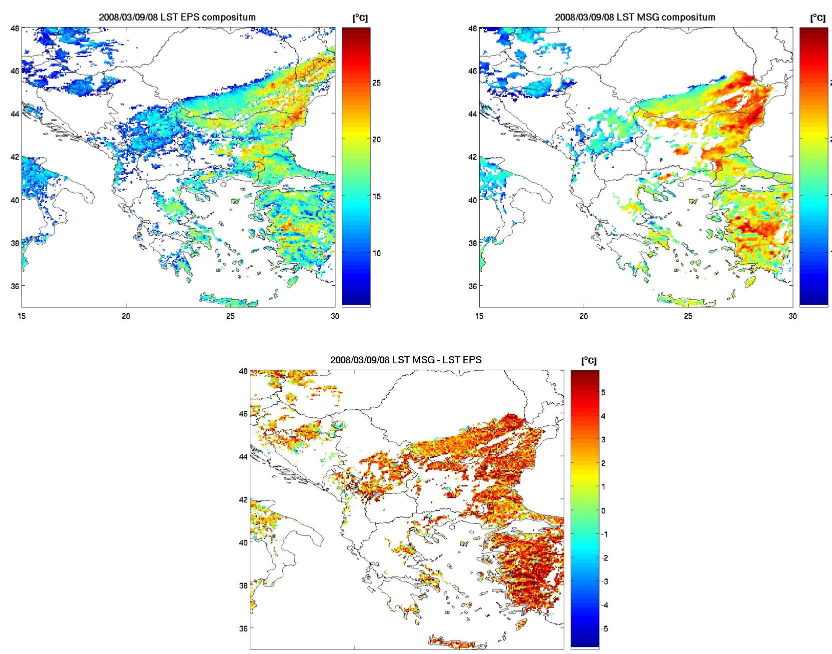

Figure 6. LST (°C) provided by (a) AVHRR/MetOp, (b) SEVIRI/MSG, and the respective difference (SEVIRI minus AVHRR), for one daytime over the Balkan Peninsula (9th March 2008 at 8 UTC).

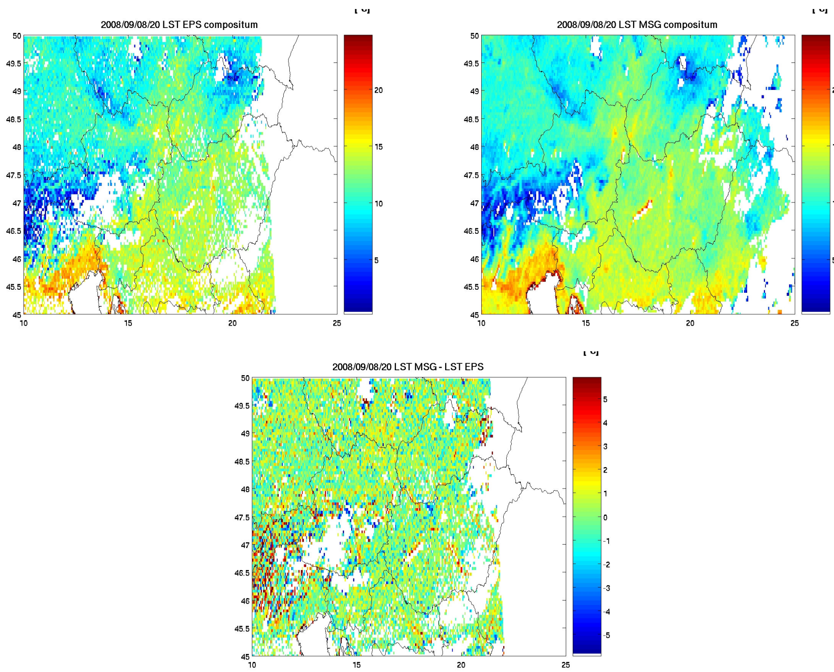

Figure 7. LST (ºC) provided by (a) AVHRR/MetOp, (b) SEVIRI/MSG, and the respective difference (SEVIRI minus AVHRR), for one daytime over central Europe.

In contrast with SEVIRI/MSG LST, AVHRR/MetOp LST values are obtained from a wide range of viewing angle perspectives. The daytime LST corresponds to local morning in all studied areas (~08UTC Balkan, ~08 – 09 UTC central Europe and ~10 – 11 UTC Iberia), the higher discrepancies are observed when AVHRR/MetOp is most likely to observe a higher fraction of shadow surfaces, that is, when the sensor observes the surface from the west (Figure 8). Accordingly, when AVHRR/MetOp observes the surface from the east, in the morning, the lower differences between the two LST are observed corresponding to negative VA (Figure 8).

The dependency on viewing angle geometry is significantly smaller during night-time. Night-time biases are always below ±1.0 ºC, while systematic differences between the two LST products may reach over 4ºC for the morning AVHRR/MetOp passage. LST_AVHRR and LST_SEVIRI have essentially the same algorithms, the night-time differences are likely to result from calibration uncertainties of each sensor and from the differences in the cloud mask of each product. The night-time discrepancies are always bellow ±0.5 ºC.

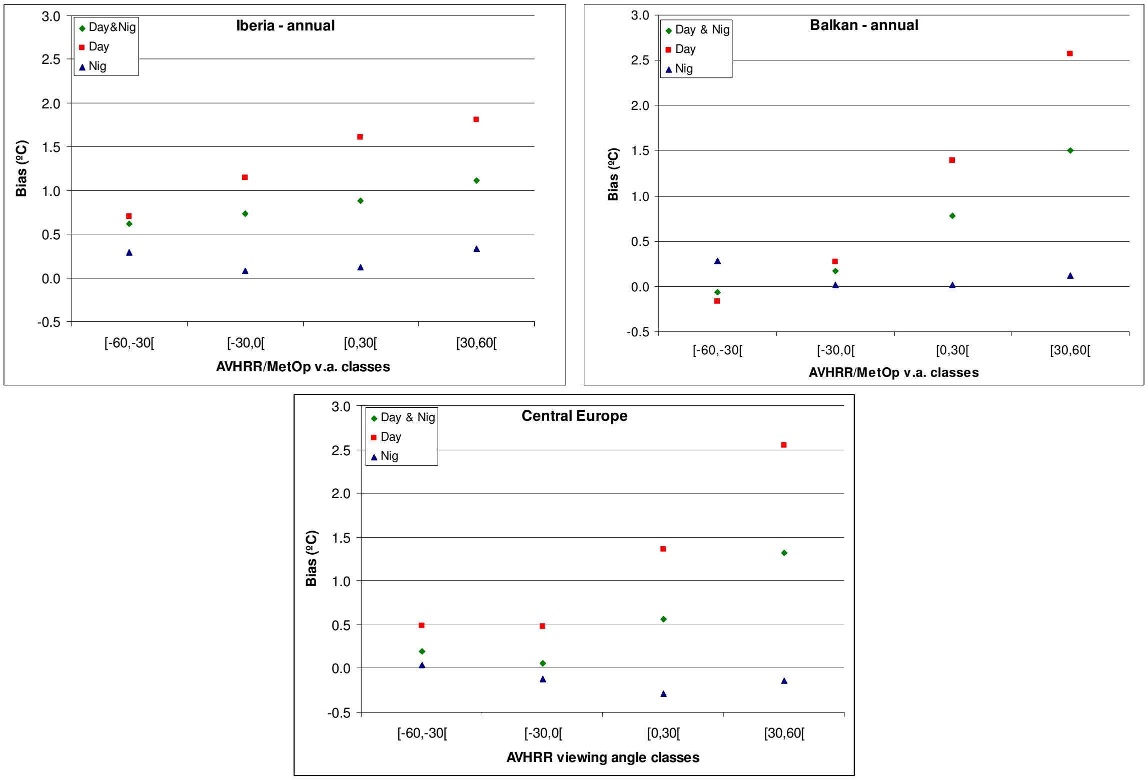

Figure 8 Mean differences of LST_SEVIRI minus LST_AVHRR, as a function of AVHRR view zenith angle, estimated for the 3 areas of study over Continental Europe. Red and Blue dots correspond to daytime and night-time values, respectively.

To analyse the impact of the land cover on daytime retrieved LSTs, we now show biases estimated for two surface types present in the studied areas, “Deciduous Forest” and “Shrubs”, for Iberia and Balkan and Evergreen Forest and Crops for central Europe. The seasonal cycle of vegetation is well represented with growth maxima in March/April, corresponding to maximum shadows seen by AVHRR/MetOp for all areas. In the southern areas, the biases and the discrepancies among classes tend to be lower in Iberia and in the Balkans during November to February and during December-to-February, respectively (Figure 9). This is likely to be associated to the lower differential thermal inertia between canopies and the surface, covered with green grass at that time of the year. In the most northern area analysed here, Central Europe, it is interesting to notice the dramatic decline of biases for crops in April / May and the slow grow of crops from May onwards.

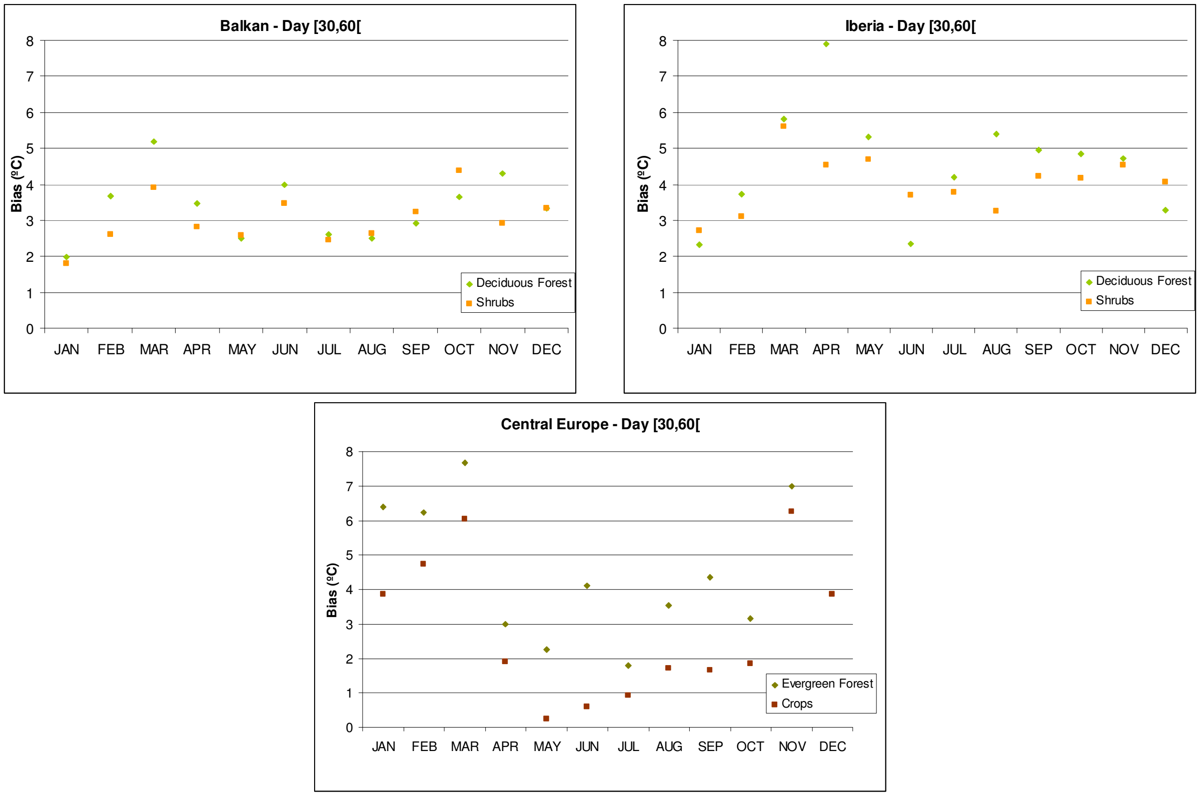

Figure 9 Systematic differences between LST_SEVIRI and LST_AVHRR estimated for each month of 2008. The dots are coloured according to the dominant vegetation type with each pixel.

4 Concluding Remarks

Satellite LST retrievals from SEVIRI and MODIS are compared with in situ observations taken at Evora ground station (Portugal). The comparison is consistent with the inter-comparison of LST_SEVIRI and LST_MODIS performed for the three areas (Trigo et al., 2008b). The differences between ground and satellite-derived values show high variability for daytime for both sensors, with LST_SEVIRI overestimating in situ values. It is, however, difficult to draw definite conclusions, taking into consideration the strong contrasts between measurements taken at the site, for tree crown and grass temperatures, particularly during the dryer months. Again, the differences between satellite and in situ LST's are lower for nighttime observations. In this case, both sensors tend to underestimate local measurements, with colder values obtained with MODIS. These results agree with other studies that compare MODIS LST and ground observation over land, which also suggest an overall underestimation (Noyes et al., 2006; Bosilovich, 2006). Such cold bias may be associated to an overestimation of MODIS surface emissivity based on land cover classification, a problem that has been identified particularly for semi-arid regions (Wan et al., 2002, 2004).

LST_SEVIRI's underestimate night-time observations by 0.5ºC and by ~3ºC for measurements taken within January and September periods, respectively. Further analysis will be carried out to identify the cause for such discrepancies. However, the comparison between SEVIRI and LST in situ measurements presented here also suggests an overestimation of the amplitude of LST daily cycle, with night-time/daytime values colder/warmer than the ground observations. This is likely to be associated to several factors, such as (i) uncertainties in surface emissivity; (ii) sensor calibration; (iii) SEVIRI perspective favouring the view of sunlit surfaces during daytime. The main advantage of LST fields retrieved from sensors onboard geostationary satellites, when compared with those obtained from polar-orbiters, is the ability to describe the diurnal cycle along with an increased probability of obtaining a significant number of (clear sky) retrievals per day.

The comparison of LST_SEVIRI with Evora observations for 2008, and for the full daily LST cycle reveals again fairly good, with LST_SEVIRI following closely ground observations. However, the differences between satellite and ground data depend on the time of the day, with a greater underestimation of observations during the afternoon and during night-time. Different sources of error, such as in the estimation of surface emissivity, an under-classification of low level or semi-transparent clouds during night-time, amongst others are currently being investigated.

The assessment of both Land-SAF LST products, retrieved from SEVIRI and AVHRR, respectively, reveals overall discrepancies bellow 2ºC. As in the case of SEVIRI – MODIS evaluation (Trigo et al., 2008b), the differences depend strongly on solar-view geometries, land cover type and surface orography. Again the comparison between LST retrievals obtained from a polar-orbiter and a geostationary platform put into evidence the directional character of remotely sensed LST, a characteristic common to all currently available LST products, and which needs to taken into consideration by producers and users.

5 References

Baldocchi, D. and 28 co-authors (2001), FLUXNET: A New Tool to Study the Temporal and Spatial Variability of Ecosystem-Scale Carbon Dioxide, Water Vapor, and Energy Flux Densities, *Bull. Amer. Meteor. Soc.*, *82*, 2415-2432.

Barroso, C, I. F. Trigo, S. C. Freitas, P. Viterbo (2008), Impact of changes to SEVIIRI level 1.5 effective radiances on the Land-SAF Land Surface Temperature. Proceedings of the 2008 EUMETSAT Meteorological Satellite Conference, Darmstadt, 8 - 12 September 2008 (http://www.eumetsat.int).

Carreiras, J. M. B., Pereira, J. M. C. and Pereira, J. S. (2006), Estimation of tree canopy cover in evergreen oak woodlands using remote sensing. *Forest Ecology and Management*, *223*, 45 – 53.

Dash, P., F.-S. Olesen and A. J. Prata (2004), Optimal land surface temperature validation site in Europe for MSG, Proceedings of the 2004 EUMETSAT Meteorological Satellite Conference, Prague, 31 May - 04 June 2004 (http://www.eumetsat.int).

Peres L. F., and C. C. DaCamara (2005), Emissivity maps to retrieve land-surface temperature from MSG/SEVIRI, *IEEE Trans. Geosci. Remote Sens.*, *43*, doi: 10.1109/TGRS.2005.851172.

Trigo, I. F., L. F. Peres, C. C. DaCamara, and S. C. Freitas (2008a), Thermal Land Surface Emissivity retrieved from SEVIRI/Meteosat, *IEEE Trans. Geosci. Remote Sens.*, *46*, doi: 10.1109/TGRS.2007.905197.

Trigo, I. F., I. T. Monteiro, F. Olesen, and E. Kabsch (2008b), An assessment of remotely sensed Land Surface Temperature. *J. Geophys Res.*, **113**, **D17108**, doi:10.1029/2008JD010035.

Wan, Z., (1999), *MODIS Land-Surface Temperature*, Algorithm Theoretical Basis Document (LST ATBD), Version 3.3, Contract Number: NAS5-31370, 75 pp.

Wan, Z., and J. Dozier (1996), A generalized split-window algorithm for retrieving land surface temperature from space, *IEEE Trans. Geosci. Remote Sens.*, *34*, 892–905.

Wan, Z., Y. Zhang, Q. Zhang, and Z.-L. Li (2002), Validation of the land-surface temperature products retrieved from Terra Moderate Resolution Imaging Spectroradiometer data. *Remote Sens. Environ.*, *83*, 163-180.