INTERCOMPARISON OF METEOSAT-8 DERIVED LST WITH MODIS AND AATSR SIMILAR PRODUCTS

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ABSTRACT

The Land Surface Analysis (LSA) Satellite Application Facility (SAF) system, currently operational at Instituto de Meteorologia (IM), Portugal, generates Land Surface Temperature (LST), with a 15-minute frequency, over the Meteosat-8 disk. The LST product is available for the European Continent, up to about 60ºN, since February 2005, when the initial operational phase of the LSA SAF has begun.

The LST retrieval is based on a generalised split-window algorithm, using radiances of Meteosat-8/SEVIRI channels 10.8 µm and 12.0 µm, ECMWF forecasts of 2m temperature (T2) and total column water vapour (TCWV), the satellite viewing angle, and fraction of vegetation cover as input. The latter, also one of the LSA SAF products, is used for the estimation of surface emissivity. The LST algorithm is applied to Meteosat-8 cloud free pixels, according to the cloud mask product of the Nowcasting (NWC) SAF algorithm.

LST is an elusive quantity, difficult to define, and thus also difficult to validate. The LST in the LSA-SAF is calculated via Planck’s function from the directional surface leaving IR radiance measurements of cloud free METEOSAT-8 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. The strategy for the validation of LST within the LSA SAF project involves three main tasks, namely: (i) the inter-comparison with other satellite derived LST products; (ii) the comparison of Meteosat-8 LST with measurements in ground-truth sites; and (iii) the evaluation of errors in the main variables used as input for the LSA SAF algorithm (T2 and TCWV).

Here we present the first results obtained from the comparison of Meteosat-8 derived LST with MODIS and AATSR LST, after co-locating data from each polar-orbiter with that of Meteosat-8 in space and time. The high sampling rate of Meteosat-8 provides high quality information on the diurnal cycle, while the higher spatial resolution of the polar-orbiters reveals further surface heterogeneities. Thus, the differences between Meteosat-8 LST and MODIS and AATSR products are analysed in terms of satellite angle differences, time of the day and surface properties, including surface type and topographic heterogeneities.

1 INTRODUCTION

The Satellite Application Facility for Land Surface Analysis (Land SAF) has been processing and archiving Land Surface Temperature (LST), on a routinely basis, since the kick-off of its Initial Operational Phase (IOP) in January 2005. Currently, the Land SAF LST is derived from SEVIRI/Meteosat data, with a 15 min frequency. The regular archiving of LST, for a window within Meteosat-8 disk covering most of Europe, has started on the 1st of February 2005, while the processing of the remaining land pixels within the Meteosat disk began in July 2005.

The first assessment of the accuracy of Land SAF LST relied heavily on sensitivity experiments using: (i) synthetically generated SEVIRI data, taking into account the expected sensor noise; (ii) realistic error estimations of algorithm inputs, particularly when obtained from NWP models (Coellho and Trigo, 2002; Madeira, 2002). Here we present the first validation results, corresponding to an intercomparison between Land SAF LST, estimated using real SEVIRI/Meteosat-8 data, and other LST products retrieved from different platforms. It is clear that a complete validation of LST requires more than the comparison with similar, but also estimated parameters. Ground-truth measurements play an important role in product validation, and since in-situ measurements of surface radiometric temperature within the Meteosat disk are rare, the Land SAF Team has set up a permanent station in Évora site (Southern Portugal). The choice of the site took into account the homogeneity of the surrounding area – in terms of surface type versus the scale of remote sensing measurements – in order to allow comparable ground-based and satellite-based observations (Dash et al., 2004).

A brief description of the Land SAF LST algorithm, as well as of the LST data used for intercomparison purposes, are presented in the next section. The analysis of the different LST estimations, carried out for an area covering the Iberian Peninsula is discussed in sections 3 and 5.

2 DATA

2.1 LAND SAF LAND SURFACE TEMPERATURE

The Land SAF LST is estimated using a Generalized Split Window (GSW) algorithm. The formulation used by the Land SAF system was first proposed by Wan and Dozier (1996) to derive LST from AVHRR and MODIS, being later adapted to SEVIRI data (Madeira, 2002). Surface temperature is estimated as a linear function of clear-sky, top of the atmosphere (TOA) brightness temperatures for the split-window channels 10.8µm and 12.0µm ($Tb_{10.8}$ and $Tb_{12.0}$, respectively):

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

where the regression coefficients depend explicitly on the mean surface emissivity for the two channels (ε) and on their difference ($\Delta\varepsilon = \varepsilon_{10.8} - \varepsilon_{12.0}$). The parameters A1, A2, A3, B1, B2, B3, and C, have been empirically estimated for classes of near surface air temperature (2m-temperature), total column water vapour, and satellite viewing angles. Emissivity depends on land cover types and fraction of vegetation

(Peres and Dacamara, 2005). Further details on the Land SAF LST algorithm may be found in the respective Product User Manual (SAF_LAND_IM_PUM_LST_1.2.pdf, available at the Land SAF web site http://landsaf.meteo.pt/).

The Land SAF LST product is currently being retrieved and archived operationally, for all land pixels within Meteosat-8 disk, corresponding to viewing angles (VA) lower than 57.5°, since retrieval errors increase significantly for long optical paths. LST estimations use a cloud mask obtained from the NWC SAF software, 2m-temperature and total column water vapour forecasts provided by the European Centre for Medium-range Weather Forecasts (ECMWF). The product, available via EUMETCast in near real time, or off-line via the Land SAF website, is then generated pixel-by-pixel, with a 15-min frequency, for the four geographical areas covering Europe, Northern and Southern Africa, and South America, respectively.

2.2 MODIS AND AATSR LAND SURFACE TEMPERATURE DATA

The MODIS data correspond to the so-called MOD11A1 Daily LST (http://www.icess.ucsb.edu/modis/LstUsrGuide/usrguide_1dtil.html), which includes a pair of observations (daytime and nighttime), per day. The algorithm used to estimate MODIS LST is very similar to that described above for the Land SAF LST; the generalised split-window formulation of Wan and Dozier (1996) is also used, with explicit dependency on surface emissivity for MODIS window channels, and implicit dependency on atmospheric conditions and satellite viewing angle.

The inter-comparison between MODIS and Meteosat-8 LST is performed over the Iberian Peninsula (Figure 1), for two different weeks (14-19 Feb and 1-7 Jul 2005) representative of winter and summer periods, respectively. For the Iberian study region analysed here, the MODIS daytime (night-time) passage corresponds to observation times between 10 and 12 UTC (21 and 23 UTC). The original MODIS LST data, at 0.928km by 0.928kmkm spatial resolution, are re-projected to a regular 0.05°×0.05°, by averaging all 1km pixels within each grid box. Land SAF (Meteosat-8) LST data have been co-located to the 0.05° grid, using the nearest LST observation in space and time.

The AATSR LST product used here, available on 1x1km spatial resolution, is retrieved using the nadir split-window (11 and 12 μm) AATSR channels (Prata, 2002). In the AATSR split-window algorithm (Prata 1993, 1994), LST is also estimated as a linear regression of the two window channels TOA brightness temperatures, with regression coefficients depending on land cover type, vegetation fraction, time of the day, precipitable water, and satellite viewing angle. The intercomparison with Land SAF (Meteosat-8) LST is performed for three daytime passages (at about 11 UTC) over the Iberian Peninsula – 21 Mar 2004, 6 Apr 2004, and 25 Apr 2004. The original 1km AATSR LST have been re-projected to a regular 0.06° grid, by averaging all pixels within each grid-box; Land SAF LST data have been co-located in space and time, by using the closest observation to each 0.06° pixel.

3 COMPARISON OF LAND SAF LST PRODUCT WITH SIMILAR SATELLITE RETRIEVALS

3.1 MODIS

Figure 1 presents the daytime MODIS LST product, the corresponding Land SAF LST field, and the difference between the two. Overall, MODIS LST presents colder values than the corresponding Land SAF LST. The highest discrepancies, of the order of –3K to –5K, are generally observed during daytime, while nightime discrepancies are generally around –2K to –3K (not shown).

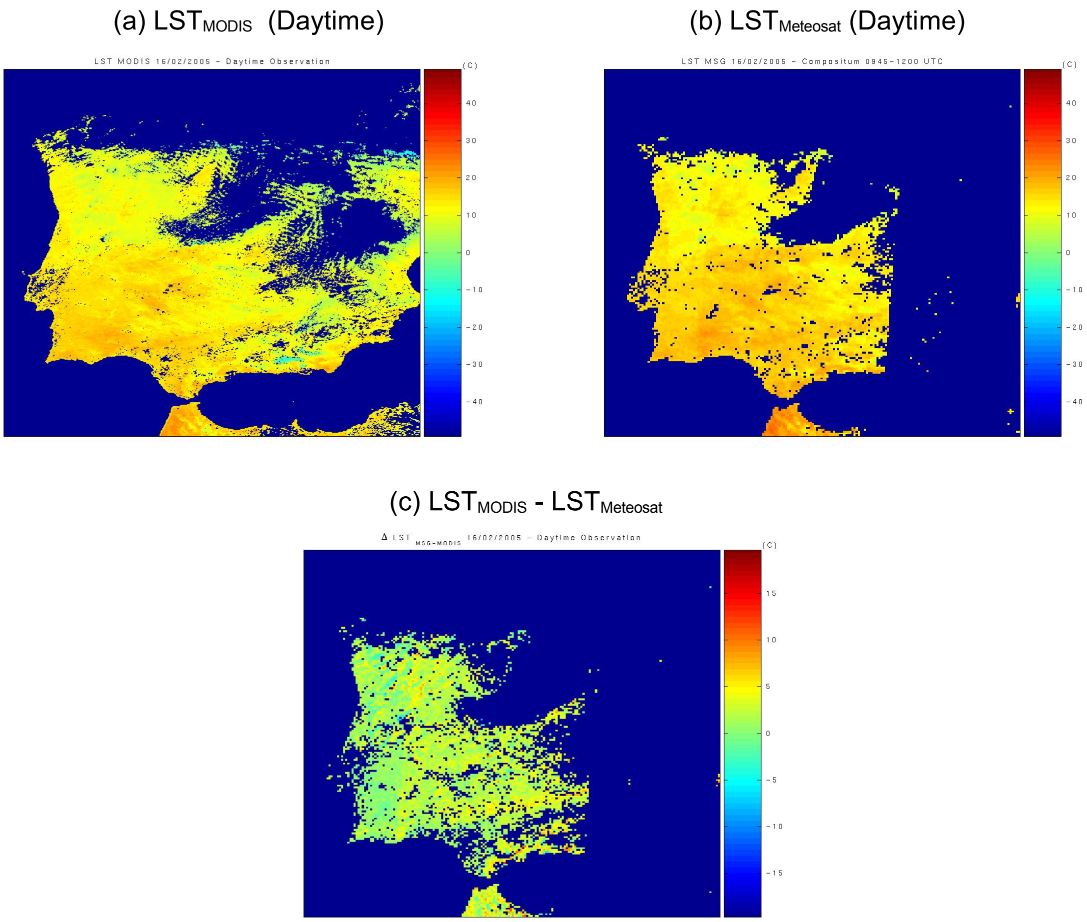

Figure 1 LST (°C) provided for the 16th February 2005 by (a) MODIS, (b) Land SAF system (Meteosat-8), and (c) the respective difference (MODIS minus Meteosat-8), for the daytime MODIS passage (~11UTC).

MODIS LST values are obtained from a wide range of viewing perspectives, in contrast with the fixed view of geostationary satellites. Positive (negative) MODIS VA indicate the sensor observes the surface from the west (east). The mean differences obtained for daytime LST (red dots in Figure 2) show a very clear dependency on MODIS VA. The discrepancies tend to be higher (Meteosat 6-to-7K warmer than MODIS) for positive VA, while smaller differences (Meteosat ~3 K warmer than MODIS) for VA within the –50° to –35° range. Taking into consideration that the daytime LST (11 UTC) corresponds to local morning over Iberia, the higher (lower) differences occur when MODIS is most likely to observe a higher fraction of shadow (sun-lit) surfaces. Moreover, the VA dependency of daytime LST tends to more pronounced for the July period, when the temperature contrasts between shadows and illuminated surfaces are higher. Accordingly, the impact of different MODIS VA on night-time LST (green dots in Figure 2) is small; the slightly higher mean differences for the higher VA classes (above +/- 50°) are most likely associated with the larger uncertainties of the LST algorithm for high optical paths.

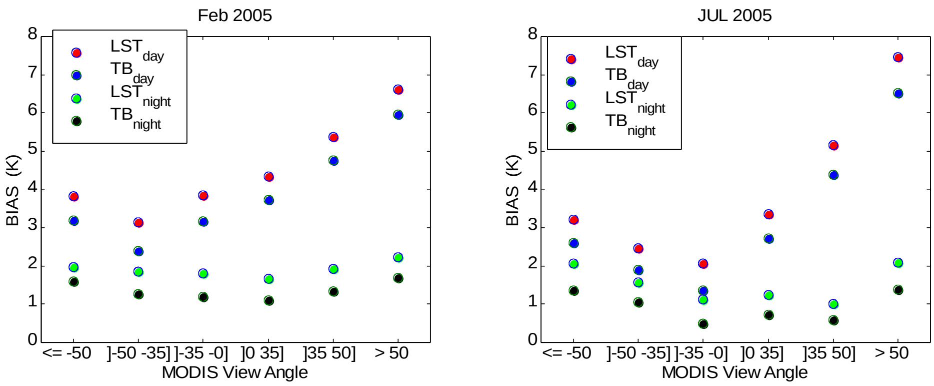

Figure 2 Mean differences ("Meteosat-8" minus "MODIS") estimated for the Iberian Peninsula, for daytime LST (red dots) and surface brightness temperatures (blue dots), and for night-time LST (green dots) and surface brightness temperature (black dots), for the 14-19 Feb (left panel) and 1-7 Jul 2005 (right panel) periods. The values are estimated for the viewing angle (VA) classes shown in the x-axis.

In order to analyse the influence of the different surface emissivity maps used by the two algorithms, Figure 2 presents the mean discrepancies between surface brightness temperatures (Tb_{sfc}), estimated considering the central wavelength of MODIS and SEVIRI/Meteosat window channels are both about 11.5 μm. Although the bias of Tb_{sfc}, for daytime and night-time cases, are 0.5-to-1K lower than the respective LST bias, the systematic warmer surface Meteosat temperatures still persist. In the scatterplot of Figure 3, for night-time MODIS versus Meteosat LST corresponding to absolute MODIS VA lower than 50°, the points are coloured according to classes of emissivity differences ($\Delta\varepsilon=\varepsilon_{Meteosat} - \varepsilon_{MODIS}$, with $\varepsilon_{Meteosat}$ and ε_{MODIS} corresponding to the mean emissivities of Meteosat and MODIS split-window channels, respectively). Although higher dispersion tends to occur for cases with the highest $\Delta\varepsilon$, statistics of mean LST differences (and of root mean square differences) exhibit sensitivities of less than 0.5K for $\Delta\varepsilon$ ranging between –0.02 and +0.01 (Figure 3; right panel).

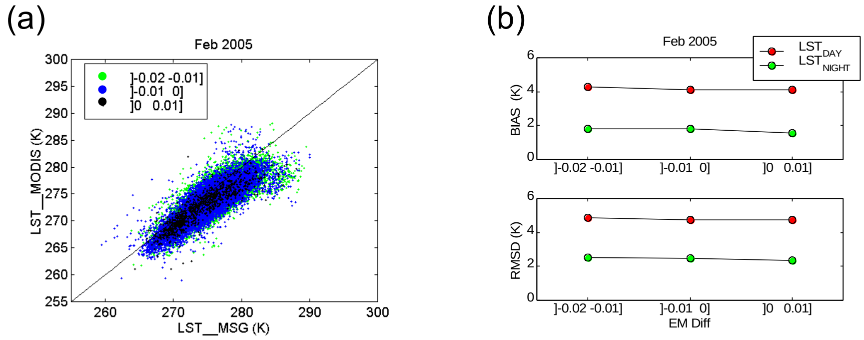

Figure 3 (a) Night-time MODIS versus Meteosat LST, for MODIS VA within the –50° to 50° range, with points coloured according to Δε classes. Both diagrams correspond to values retrieved for the Iberian Peninsula during the 14-19 Feb 2005 period.

3.2 AATSR

The intercomparison between Land SAF and AATSR LST products presented here is also performed over the Iberian Peninsula (Figure 4), for three days in spring 2004. In contrast with the results presented for MODIS, the Land SAF LST values tend to be 2 – to – 3 K cooler, on average, than AATSR (Table 1), while the dispersion observed in AATSR versus Meteosat scatterplots (e.g., Figure 4b), tends to be higher.

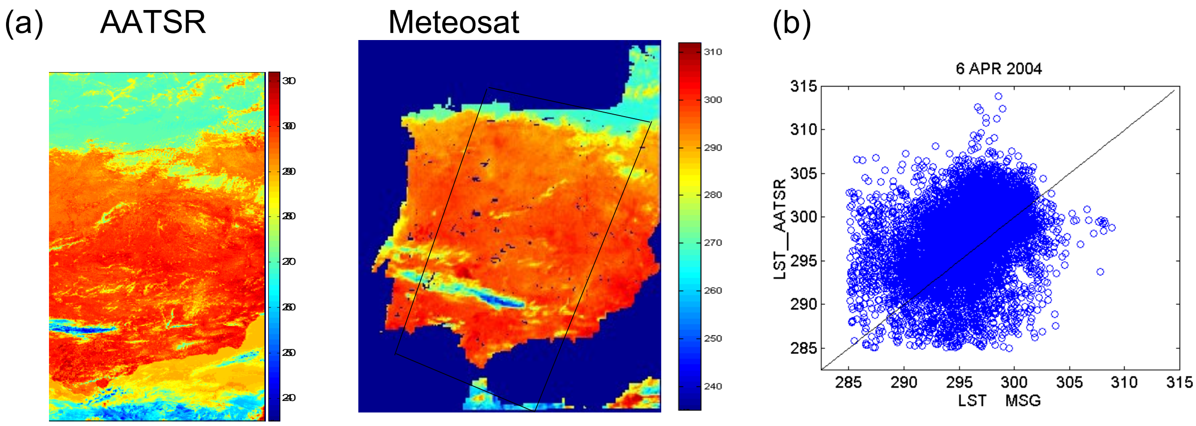

Figure 4 (a) AATSR and Meteosat-8 LST (K) products, over the Iberian Peninsula; and (b) the respective scatterplot AATSR versus Meteosat-8 LST, for clear-sky cases. The data correspond to values retrieved for the 6th April 2004 (~ 11UTC).

The factors contributing to the mismatches between AATSR and Meteosat retrieved values remain to be investigated. The AATSR capability for providing measurements from 2-viewing angles (55° along the track, and nadir), presents a high potential for angular characterisation of surface temperature over land.

Table 1 Mean differences (bias) and root mean square differences (RMSD) of Land SAF LST minus AATSR LST, for three days in spring 2004, for an area covering the Iberian Peninsula.

	Bias (K)	RMSD (K)
21 Mar 2004	-2.4	4.5
6 Apr 2004	-1.7	4.7
25 Apr 2004	-2.7	4.9

4 CONCLUDING REMARKS

The Land SAF has been generating and archiving a Land Surface Temperature (LST) product, using SEVIRI/Meteosat split-window data, since February 2005 (http://landsaf.meteo.pt). The work presented here corresponds to a first comparison between the Land SAF LST product with similar parameters retrieved from MODIS and AATSR. In contrast with the latter, the Meteosat-derived LST, which has a 3-km resolution at nadir and a 15-minute frequency, is capable of characterising the daily cycle of surface temperature, except over permanent cloud-covered regions. Polar-orbiters, in turn, are capable of providing global coverage, and different angle views of the same scene. This characteristic has been used here to put into evidence the large surface heterogeneity of land surface temperature.

There are a number of factors that may significantly contribute to the differences between LST products, namely the different emissivity maps used by the MODIS, and (implicit) in AATSR schemes; undetected clouds, or cloud shadows affecting only one of the products, the different viewing angles, and thus different perspectives of similar scenes by the Meteosat/MODIS/AATSR sensors. To avoid comparing data with ambiguous cloud classifications, only MODIS pixels with the highest quality flags, as well as Meteosat and AATSR pixels clearly classified as clear sky, have been taken into account for the comparison statistics.

Before carrying out the intercomparsion of Meteosat and the respective polar-orbiter LST, the products have been collocated in space and time to common projections (in all cases regular lat/long projections). MODIS LST, compared for two weeks in February and July 2005, are generally 2 – to – 5 K cooler than Meteosat LST, with the highest differences being observed during daytime. In sharp contrast, the AATSR LST, compared for three days in spring 2004, tend to be warmer than Meteosat LST. The impact of emissivity differences, generally lower than 2%, on MODIS-Meteosat discrepancies seems to be fairly small. The factors contributing to AATSR-Meteosat LST differences, such as land cover maps used by the two algorithms, terrain irregularity and orography, will be addressed in future work.

It has been shown that daytime discrepancies are highly influenced by MODIS viewing angle (VA); the most pronounced differences (> 4 K) occur for positive MODIS VA, typically higher than 35°. In this case, MODIS sensor observes the Iberian Peninsula from the West, and since the observation time around 11 UTC corresponds to local morning, the probability of MODIS viewing a higher fraction of shadow surfaces, when compared with the South-east Meteosat observations, is also higher. As expected the influence of MODIS VA on night-time discrepancies is negligible. These results strongly suggest that LST fields retrieved from remote sensing platforms are highly dependent on the viewing angle for daytime time-slots, unless a correction for the angular effects is provided.

5 ACKNOWLEDMENTS

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