VALIDATION OF LAND SURFACE TEMPERATURES OBTAINED FROM METEOSAT-MVIRI AND SEVIRI WITH IN-SITU MEASUREMENTS

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Abstract

Land surface temperature (LST) is one of the main quantities governing the energy exchange between surface and atmosphere. LST based on MSG-SEVIRI measurements is an operational product of the Land Surface Analysis – Satellite Application Facility (LSA-SAF). For the years 1999-2005, Karlsruhe Institute of Technology (KIT) determined LST from Meteosat-MVIRI data within the GMES project “Geoland”. The high temporal resolution of Meteosat and its long time series stretching from the past (1977) to the future (Meteosat Third Generation) make these data very valuable for climate studies. In order to increase confidence in the derived LST, they are validated with radiometric in-situ measurements at four validation sites located within Meteosat’s field of view. LST validation started in 2005 in Evora (Portugal) as a contribution to LSA-SAF and was expanded in 2007 with two stations in Africa, a desert station (Gobabeb, Namibia) and a station in semiarid bush (Dahra, Senegal). A fourth station was set up in 2009 at a farm (“RMZ”, 1500 m asl) in the Kalahari semi-desert (Namibia). All stations are equipped with IR radiometers (Heitronics KT 15.85 IIP) for ground and sky brightness temperature measurements. Additionally, long- and short-wave components of the energy balance are measured at Evora, Gobabeb, and RMZ. Wind speed & direction and air temperature & moisture are measured at 2-3m height and near the tops of the respective masts (12m…30m). Currently the four stations operated by KIT are the only long term LST validation stations in the field of view of the METEOSAT satellites. The work is carried out within the scope of LSA-SAF and is co-funded by EUMETSAT.

INTRODUCTION

Land Surface Analysis – Satellite Applications Facility (LSA-SAF) derives LST operationally from SEVIRI’s 10.8 and 12.0 μm channels using a generalized split-window (GSW) algorithm. Dynamic GSW inputs are atmospheric temperature & moisture profiles and emissivity (Peres and DaCamara, 2005; Trigo et al., 2009a), which is obtained with a fraction of vegetation cover (FVC) method. The rms error of SAF-LST is estimated at ±2°C (Trigo et al., 2008b; Freitas et al., 2009). In principle, Land Surface Temperature (LST) derived from satellite measurements can readily be validated with ground-truth radiometric measurements. However, to actually perform such measurements is a complex task, since satellite pixels are usually many times the size of the ground-truth sensor’s footprint and natural land covers and the corresponding land surface temperatures are quite variable. For validation measurements to be representative for satellite derived LST, they have to be performed in areas which are homogenous on the satellite pixel scale. The size of the area which needs to be viewed by the validation instrument depends on the within-pixel variability of the surface - or on how well measurements of several “end members” can be mixed in order to obtain a representative value for the satellite pixel. When mixing measurements of end members, also their possibly changing fractions (view angle effects, shadow fraction) have to be taken into account (Kabsch, 2009). Karlsruhe Institute of Technology (KIT) operates four permanent validation stations for LST retrieved from TIR satellite measurements (figure 1). The stations are part of LSA-SAF validation effort and supported by EUMETSAT; their main objective is to validate LST derived from the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard MSG. These four stations are in temperate Mediterranean climate (CSh), semi-arid climate (BSh), and warm desert climate (BWh) climate zones (according to Köppen-Geiger). The following station locations within the field of view of the METEOSAT satellites were
chosen: “temperate” Evora (Portugal, since 2005; cork-oak trees and grass), “semi-arid” Dahra (Senegal, since 2008; tiger bush), “desert” Gobabeb (Namibia, since 2007; gravel plain), and “semi-arid” RMZ-Farm (Namibia, since 2009; Kalahari bush). The core instruments of the stations are self-calibrating, chopped radiometers Heitronics KT15.85 IIP (9.6-11.5 μm; SD ±0.3K) which measure the radiation from the relevant components, e.g. grass, soil, tree, shadow, and sky once per minute. All stations record air temperature & humidity and wind speed & direction at two levels. Additionally, Evora, Gobabeb, and RMZ feature shortwave & longwave radiation budget sensors. The validation results presented here are for Gobabeb station and demonstrate the excellent quality of the operationally derived LSA-SAF Land Surface Temperature product.

![Figure 1: Locations of KIT’s validation stations on MSG/SEVIRI earth disk.](image)

**GOBABEB LST VALIDATION STATION, NAMIBIA**

Gobabeb LST validation station is located on large (several thousand km$^2$) and highly homogeneous gravel plains (figures 2 & 3). The station is about 2 km north-east of the Kuiseb river and “Gobabeb Training & Research Centre” ([www.gobabebtrc.org](http://www.gobabebtrc.org)), which is located directly next to the Kuiseb River. The sharp transition from sand to gravel is caused by the Kuiseb (dry, but lined by trees): it forms a natural boundary between the gravel plains and the vast sand dunes of the Namib Desert (south-western corner of figure 2). The river (black-blue = cold in figure 3) usually flows a few days every other year and then washes the advancing sand dunes into the South Atlantic Ocean, thereby stopping the sand from reaching the gravel plain. The effect of the morning sun (about 10 h solar time) on the sand dunes is well visible in the Landsat ETM+ brightness temperatures (BT) in figure 3: the hot (yellow & red) areas are the north-eastern slopes of the dunes. The gravel plain consists mainly of flat gravel and sand, but also contains patches of desiccated grass (rain every few years), some wadis, and rock outcrops. The validation area is indicated by black ovals (figure 2 & 3) in the north east of the station marked with a small yellow square. The 5 km grid spacing corresponds to the approximate size of a METEOSAT pixel. The station’s instruments are mounted at several heights of Gobabeb’s 30m high wind profiling tower, (23°33′S, 15°03′E, 408 m asl).

**Instrumentation at Gobabeb**

Figure 4 gives an overview of the instrumentation of Gobabeb LST validation station. The fields of view (FOV) of the two down-looking “Heitronics KT-15 IIP” radiometers on the gravel plain cover about 13 m$^2$ each. Broad-band shortwave (SW) and longwave (LW) radiative fluxes are measured by an energy balance sensor (Kipp & Zonen CNR1) at the 2 m level; a validation of respective satellite products, e.g. downwelling SW & LW fluxes and albedo, is currently investigated.
Validation at Gobabeb

LSA-SAF LST data were validated with measurements at Gobabeb. The pointing of the radiometers to assumed surface end-members was not changed since the setup in December 2007. Downwelling radiance is also measured, i.e. no atmospheric data used in the SAF-processor enters the ground truth LST. Surface emissivity was set to the value derived by LSA-SAF. Thus, emissivity is not part of the validation. The view direction of the ground measurements close to North was chosen to observe an undisturbed surface; the radiometers are not aligned with MSG’s line of sight to the validation site. Brightness temperatures from the surface pointing radiometers are converted to radiances; these are corrected for reflected downwelling radiance using SAF emissivity and measured downwelling radianc. LST is obtained from these corrected surface leaving radiances.
Figure 5 shows the regression between satellite-retrieved LST and ground truth LST for September 2008. It is clearly visible that the two data sets are in excellent agreement with each other. This means that the GSW algorithm performs very well in desert regions and indicates that the chosen site and instrumentation fulfil the requirements for validating LST on MSG-SEVIRI pixel scale. In particular the high level of agreement gives confidence in the station concept and in measurements performed at other, more complex sites, where atmospheric profiles make a performance assessment of the GSW harder. Figure 6 compares SAF LST and ground truth LST for September 2008: the differences (red triangles) do not show any diurnal cycle, which supports the conclusions already drawn from the regression shown in figure 5.

Figure 5: LST validation results for September 2008 for the Gobabeb site. The low bias of 0.17°C and the closeness to the 1:1 line demonstrate the excellent quality of the SAF LST product. The data are separated into “morning”, “afternoon” and “night”. No additional cloud-clearing was performed; outliers above the 1:1 line are associated with undetected clouds in the MSG data, which result in too low LST MSG (from Freitas et al., 2009).

Figure 6: Comparisons of diurnal temperature cycles for September 2008. The difference MSG - Station LST highlights the episodes with undetected clouds in the MSG data (red triangles). Otherwise there is excellent agreement between LSA-SAF LST and station LST.
DAHRA LST VALIDATION STATION, SENEGAL

Dahra validation site is located in a semiarid climate. Bush and trees are oriented along ancient dunes, causing stripes of high vegetation – hence the name “tiger bush”. The region exhibits a natural seasonality and grass is usually desiccated from October to April (fig. 9). Normally the trees stay green all year: the brown leaves on the lower branches in figure 9 are due to a bush-fire that passed the station. In the rainy season the grass grows dense and the entire site is covered by vegetation. Landsat ETM+ data highlight the situation in the validation area (fig. 7 and 8). The location of the validation site is marked with a small yellow (fig. 7) or black (fig.8) square. The grid indicates the area of a SEVIRI pixel. The well defined red (hot) area is a tree plantation. Some isolated cold areas (dark blue) are due to clouds and their shadows (compare with true colour image).

Figure 7: True colour composite of Landsat ETM+ of channels 1-3 for Dahra validation site, Senegal.

Figure 8: Brightness temperatures from Landsat ETM+ channel 6 for Dahra validation site, Senegal.

Figure 9: Dahra LST validation station, Senegal. Radiometers on the mast measure brightness temperatures of tree crown, grass (sun), grass (shadow) and sky BT. Standard meteorology are available from a nearby station of the University of Copenhagen.
In terms of atmospheric correction the situation at Dahra is more challenging than at Gobabeb. The low elevation of 90 m asl results in a longer atmospheric path and the atmospheric water vapour load varies strongly over the year. Furthermore, occasional outbreaks of Sahara dust complicate cloud detection.

**EVORA LST VALIDATION STATION, PORTUGAL**

The main end-members at Evora LST validation site are evergreen trees (mainly cork oak trees) and grass. Most of the area is used for cattle grazing, but some irrigated fields are also present. The local climate is temperate Mediterranean and the region exhibits a natural seasonality with hot, dry summers, i.e. grass is usually desiccated in July & August. Figure 10 shows a true colour image (Landsat ETM+) of the validation site with the station marked (yellow square). South of the station the area is mainly agricultural, but in the north there is a larger area covered by cork-trees and grass (grid size is 5 km). The blue (cold) areas in the centre of the brightness temperature data (figure 11) are due to a dense acacia tree forests; this area is excluded from validation.

Figure 10 shows the set up of the station. The stability of the station’s core instrument, the Heitronics KT-15.85 IIP radiometer, was tested in a long-term parallel run with the self-calibrating radiometer "RotRad" (courtesy of CSIRO), which is continuously stabilized with 2 blackbodies (Kabsch, 2009). The parallel run at the Evora site started in April 2005; a year later the agreement between the instruments was still excellent (correlation 0.99). The Evora validation dataset was compared in detail with LSA-SAF LST data (Kabsch et. al. 2008 and Kabsch 2009). After a careful reassessment of the ancillary data used for up-scaling and improvements of the SAF-algorithm, the RMS difference between in-situ and satellite derived LST was less than 1.5°C for the second half of 2007.
Figure 12: Evora LST validation station, Portugal. Radiometers on the two masts (Evora North and Evora South) measure brightness temperatures of tree crown, grass (2x), and sky. Standard meteorology and radiation balance (Kipp & Zonen CNR1) are also available.

“RMZ” LST validation station, Namibia

“RMZ” LST validation station was set up in spring 2009 at a farm located on a plateau in the Kalahari semi-desert (about 1500 m asl). The cattle farm alone covers about 50 km² of bush, but the land cover and land use in a wide area (thousands of km²) around the station are identical. Cattle are carefully managed and moved systematically between fenced off “camps” to avoid overgrazing. The region exhibits a natural seasonality: there is a small rainy season with very little rain (September to November) and a big rainy season (January and March) with possible flooding. Main end-members are camel-thorn trees and, depending on the level of dryness, a mixture of grass or sand. Outside the big rainy season the Kalahari bush is dry and grass is quickly desiccated (see figure 13). The atmospheric situation at the high elevation is different from the other stations and frequent cold temperatures below freezing point make this location unique among the stations.

Figure 13: “RMZ” LST validation station, Namibia (set up on 27.04.2009). Radiometers on the mast measure brightness temperatures of tree crown, grass (2x), and sky BT. Standard meteorology, a rain gauge (tipping bucket), and a radiation balance are also available.
CONCLUSIONS

The four stations operated by KIT are the only long term LST validation stations in the field of view of the METEOSAT satellites. The stations represent different surface covers and are located in flat, homogeneous terrains at the scale of several MSG-SEVIRI pixels. The stability of the stations core instrument, the Heitronics KT-15.85 IIP radiometer, was tested in a long-term parallel run with the self-calibrating radiometer "RotRad" from CSIRO, which is continuously stabilized with 2 blackbodies (Kabsch, 2009). The parallel run at the Evora site started in April 2005; a year later the agreement between the instruments was still excellent (correlation 0.99). The Evora validation dataset was compared in detail with LSA-SAF LST data. After a careful reassessment of the ancillary data used for up-scaling and improvements of the SAF-algorithm, the RMS difference between in-situ and satellite derived LST was less than 1.5°C for the second half of 2007. Furthermore, during a CEOS inter-calibration campaign in 2009 (on precision blackbodies and the sea surface), the KT15.85 IIP was shown to have an absolute accuracy of ±0.3K over a temperature range of 5°C to 60°C. Currently there are two existing co-operations at the validation sites: at Dahra with the University of Copenhagen, who – among others - investigate METEOSAT derived vegetation parameters with an independent instrument tower, and at Gobabeb with the University of Basel, who initially perform a one year study of the surface energy balance. The masts of the stations are between 12m and 30m high and data loggers and solar power supplies have spare capacities; additionally, Gobabeb and Evora have remote access. An integration of further instruments into the existing infrastructure is well feasible and offers the research community opportunities for a broad bandwidth of applications.

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REFERENCES


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