VALIDATION OF OPERATIONAL LAND SURFACE TEMPERATURE PRODUCTS WITH THREE YEARS OF CONTINUOUS IN-SITU MEASUREMENTS

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Abstract

Land surface temperature (LST) is an operational product of the Land Surface Analysis – Satellite Application Facility (LSA-SAF). As a contribution to LSA-SAF, Karlsruhe Institute of Technology (KIT) operates four dedicated LST validation stations - the only long term LST validation stations within the field of view of the METEOSAT satellites. In order to match SEVIRI's spatial resolution (about 5x5 km$^2$) and to avoid spatial scaling issues, the stations were set up in carefully selected, large homogeneous areas. Here, results from up to three years of continuous measurements at Evora (Portugal), Dahra (Senegal), Gobabeb (Namibia) and RMZ-Farm (Namibia) are presented. With few exceptions the station data are available at a sampling rate of one minute. The influence of undetected clouds on the validation results was reduced by performing additional filtering with the robust “3-σ Hampel identifier” (outlier detection). During the seasons most affected by clouds, the filtering reduced the data scatter significantly; during the rest of the year, the RMSE between satellite LST and in-situ LST, which was generally below 1.5K, was only slightly improved. At high temperatures SAF LST tended to be warmer than in-situ LST; during dry seasons the absolute monthly bias was generally less than 1.0K.

INTRODUCTION

Land Surface Temperature (LST) is an important quantity for the energy and water exchange between the earth’s surface and the atmosphere and, therefore, an important parameter of many environmental models. LST derived from MSG/SEVIRI is an operational product of the Land Surface Analysis – Satellite Application Facility (LSA-SAF) and has a target accuracy of better than ±2°C. Karlsruhe Institute of Technology (KIT) operates four permanent validation stations for LST retrieved from TIR satellite measurements. The stations are part of the Land Surface Analysis – Satellite Application Facility (LSA-SAF) supported by EUMETSAT and their main objective is to validate LST derived from the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard MSG. As discussed in (Trigo, 2008b) and (Yu, 2008), ground measurements have their own issues, including the following: 1) the low number and discontinuity of high-quality data sets, 2) the lack of global representativeness, and 3) the up-scaling of LST “point” measurements to satellite pixel size. In order to be able to reliably validate LST derived from MSG/SEVIRI, the small spots observed by in-situ radiometers (order of 10m$^2$) need to be representative for satellite pixels with a size of about 5x5 km$^2$. Therefore, KIT’s permanent LST validation stations were set up in carefully selected, large homogeneous areas (see Figure 1): Evora (Portugal), Dahra (Senegal), Gobabeb (Namibia) and RMZ-Farm (Namibia). The stations core instrument is the self-calibrating, chopped “KT-15.85 IIP” IR-radiometer from Heitronics with an absolute accuracy of 0.3°C over the temperature range of interest here (Theocharous, 2010). The long term stability of this type of radiometer was proven at Evora station in a one year parallel run with a self-calibrating unit based on two black bodies (Kabsch et al., 2008). At each station a set of radiometers measures the surface leaving radiance as well as the down-welling “sky”-radiance between 9.6 µm and 11.5 µm. In-situ LST is then determined from one or more ground observing radiometers, one sky view radiometer, and the operationally available LSA-SAF emissivity (Freitas et al., 2010), which at Gobabeb is in very good agreement with emissivity retrieved from ASTER (personal communication Glynn Hulley, JPL). Emissivity is nearly constant at Gobabeb (a hyper-arid
site), but due to vegetation dynamics and changing soil moisture the emissivity varies significantly at the other sites.

**Figure 1:** Locations of KIT’s validation stations on MSG/SEVIRI earth disk.

### IN-SITU DATA AND DATA PROCESSING

The four stations were set up at different dates and the lengths of the available data records vary accordingly: Gobabeb - Jul 2008 to present, Evora-2/3 - Mar 2008 to present (Evora-1: Apr 2005 to Aug 2007), RMZ farm - Apr 2009 to Feb 2011, and Dahra since Sep 2009. Except for Dahra there are only minor data gaps. During "good" months, i.e. with few clouds and a clear atmosphere, there are about two thousand match-ups between SAF LST and in-situ LST per station. However, during wet seasons there may be only several hundred match-ups with increased data scatter (undetected clouds). Station LST is determined with Heitronics KT15.85 IIP radiometers (9.6-11.5µm, accuracy ±0.3K): at each station at least one radiometer observes the ground and one the sky. Operational LSA-SAF emissivity is then used to derive LST from the up and down-welling radiance measurements (Göttche et al., 2011; Göttche et al., 2010). Figure 2 and Figure 3 show an original and a "3-σ Hampel"-filtered scatter plot of LSA-SAF LST vs. in-situ LST, respectively. The colours highlight data in the morning (green), afternoon (red), and at night (blue). The in-situ data from Gobabeb validation station were matched up with SEVIRI acquisition times to within one minute: the small bias & RMSE demonstrate the excellent quality of the original SAF LST (Figure 2). However, there are clearly some cold outliers (undetected atmospheric scattering): most of these are filtered out with the "3-σ Hampel identifier", an algorithm based on robust statistics (see Figure 3). All data used in the further analyses were processed in this way before linear regression between in-situ LST and LSA-SAF LST was performed.
EVORA, PORTUGAL

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. The main end-members at Evora LST validation site are evergreen trees (mainly cork oak trees) and grass. A tree crown cover (TCC) of 33\% was determined by identifying the best correlation between satellite LST and in-situ LST for August 2009. This agrees well with the mean TCC of 29\% determined by Carreiras et al. (2006) from aerial photographs of the area around the validation station. LST is derived from measurements of two separate ground radiometers observing a patch of grass and a tree crown. South of the station the area is mainly agricultural, but to the North there is a larger area covered by a mixture of cork oak trees and grass similar to the one at the station. However, the size of the homogenous area is considerably smaller than for the African sites: in order for the in-situ LST to be representative, they are best compared to the satellite-derived LST for the "station pixel", i.e. the SEVIRI pixel which covers the station, or its direct neighbour to the North. Figure 4 shows the time series of the monthly bias, standard deviation and slope of the fitted line for scatter plots of LSA-SAF LST vs. in-situ LST (see Figure 3) for the "station pixel".

The mean bias is 0.8 K (i.e. SAF LST is warmer) while the mean standard deviation is 1.6 K. The
relatively small mean slope of 0.9 is mainly due to higher night-time SAF LST; the cause of these deviations is currently investigated. In Winter and Spring clouds can considerably reduce the number of valid data, e.g. in February 2010 there were only four valid match-ups between in-situ LST and LSA-SAF LST.

DAHRA, SENEGAL

Dahra LST validation station is located in a hot, semiarid climate (Sahel). 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 November to April. Normally the trees stay green all year and in the wet season the grass grows dense and the entire site is covered by vegetation. In terms of atmospheric correction the situation at Dahra is highly challenging: the low elevation of 90 m asl results in long atmospheric paths and the atmospheric water vapour load varies strongly over the year. Furthermore, occasional outbreaks of Sahara dust complicate cloud detection. The land cover at Dahra is tiger bush with a tree crown cover of 5% (Rasmussen et al., 2011). LST is derived from measurements of two separate radiometers observing a patch of grass and a tree crown. Figure 5 shows the time series of the monthly bias, standard deviation and slope of the fitted line for scatter plots of LSA-SAF LST vs. in-situ LST (see Figure 3) for the “station pixel”.

For all data (only dry season data) the mean bias is -1.5 K (0.1 K), mean standard deviation is 1.6 K (1.0 K) and mean slope is 0.94 (0.98). During the dry season LSA-SAF LST agrees well with in-situ LST.

GOBABEB, NAMIBIA

Gobabeb LST validation station is located on the large and highly homogeneous gravel-plains of the Namib desert at 405 m asl. The gravel plains are a vast and flat area of several 100 km² consisting mainly of coarse gravel and sand, which is very sparsely covered by desiccated grass. On the time scale of years the surface cover is almost constant. Thus the gravel plains are a highly homogeneous area in space and time, which makes them an ideal LST validation site. Using measurements along a 40 km track, Göttsche et al. (2011) showed that the station LST is representative for an area of several 100 km². Towards the south of Gobabeb station the Kuiseb River separates the gravel plains from large sand dunes and, thus, forms a natural boundary. The station’s instruments are mounted at several heights of Gobabeb’s 30m high wind profiling tower, (23°33’S, 15°03’E) and the KT-15 radiometer is at 25 m height, facing downwards under a view angle of 30° in northern direction. This set-up combined with a full view angle of 8.5°of the radiometer results in a field of view (FOV) of about 13 m². Figure 6 shows the time series of the monthly bias, standard deviation and slope of the fitted line for scatter plots of LSA-SAF LST vs. in-situ LST (see Figure 3) for a pixel located on the gravel
plains to the North-east of the station.

The mean bias is 0.3 K and mean standard deviation is 1.3 K. The bias varies by about ±1K and appears to be partly seasonal. The mean slope is generally close to 1.0 but increases together with standard deviation at the end of 2010, which is probably caused by the small (October/November) and the big rainy season (January/February), which were exceptionally wet and cloudy.

RMZ-FARM, NAMIBIA

“RMZ” LST validation station was set up in spring 2009 at a farm located on a plateau in the Kalahari semi-desert (1360 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. 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. In February 2011 RMZ station was re-located to the farm “Heimat”, which has similar land cover (bush) as RMZ and is at 1450 m asl.

*Figure 7* shows the time series of the monthly bias, standard deviation and slope of the fitted line for scatter plots of LSA-SAF LST vs. in-situ LST (see *Figure 3*). The mean bias is -0.4 K, i.e. SAF LST is on average slightly colder. The mean standard deviation is 1.2 K and mean slope 1.06: the high slope and the negative bias may be explained by the fact that the LSA SAF algorithm does not account for the reduced atmospheric path due to the station’s high elevation, i.e. it either overcorrects or under corrects the contribution of the atmosphere. From December to February clouds considerably reduce the number of valid data (wet season in Namibia).
Figure 7: Monthly bias (blue), standard deviation (red) and slope of fitted line (yellow; right y-axis) for LSA-SAF LST vs. in-situ LST at RMZ-farm, Namibia. RMZ farm is located in the Kalahari semi-desert at 1360 m asl.

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 climates and 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 was continuously stabilized with 2 blackbodies (Kabsch, 2008). 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). 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.

Analyses of time series of several years of in-situ LST and LSA-SAF LST showed that the absolute value of the mean and monthly bias between the two data sets is generally less than 1 K for all stations. Mean standard deviation was less than 1.3 K for the three African stations (only for dry the season for Dahra) and below 1.6 K for Evora station in Portugal. The slopes of linear regressions between LSA-SAF LST and in-situ LST are generally close to 1.0 for Gobabeb and Dahra (only dry season). However, the analyses also identify specific points for further improvements: systematically too high regression slopes are observed for RMZ farm, which is probably related to the stations high elevation (1360 m asl), a parameter not accounted for in the SAF algorithm. At Evora station, systematically higher night-time SAF LST result in a mean slope of 0.9: this issue is currently investigated. Furthermore, there are frequently undetected clouds during Winter & Spring. During dry seasons, in-situ LST and LSA-SAF LST generally agree well with each other and the validation results demonstrate an excellent quality of this operational LST product.

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REFERENCES


