ANISOTROPIC EFFECTS IN SATELLITE-RETRIEVED LAND SURFACE TEMPERATURE PRODUCTS – EXPERIMENTAL STUDY

Verena Verestek, Folke Olesen

Karlsruhe Institute of Technology (KIT), Postfach 3640, 76021 Karlsruhe, Germany

Abstract

Accurate long-term in-situ measurements are crucial for the validation of satellite-retrieved land surface temperatures (LST). Karlsruhe Institute of Technology operates four permanent validation stations, which continuously provide accurate in-situ LST for validation purposes. It is essential to know the anisotropy of the thermal radiation at LST validation stations, because the radiometer cannot always be aligned with satellite viewing direction. The knowledge of the anisotropy is also a relevant parameter in the determination of LST from various satellite systems with different observing geometries. The challenge is to characterize the anisotropy of large areas, i.e. at the scale of square kilometres. Here, we present results from a field campaign performed in February/March 2013 at Gobabeb (Namib Desert) and Farm Heimat (Kalahari) validation sites in Namibia. During the campaign, the directionality of LST and its dependency on sensor viewing geometry was investigated. For both sites, the anisotropy is low for typical view angles of operational satellites: the study shows that it can be neglected for angles up to 45°.

INTRODUCTION

Land Surface Temperature (LST) is an important quantity for the energy and water exchange between the earth's surface and the atmosphere. LST derived from MSG/SEVIRI – IR measurements is an operational product of the Land Surface Analysis – Satellite Application Facility (LSA-SAF) of EUMETSAT and has a target accuracy of better than ±2°C. Karlsruhe Institute of Technology (KIT) operates for permanent validation stations within the view of MSG/SEVIRI, which are situated in highly homogeneous and flat areas and continuously provide accurate LST for validation purposes (Göttsche et al. 2013). Apart from the representativeness of the areas observed by station's radiometer it is essential for the validation to know the anisotropy of the surface leaving thermal radiation. Natural surfaces are usually non-Lambertian, i.e. they emit and reflect radiation anisotropically. Thus, remotely sensed thermal radiation depends on the viewing angle of the instrument, during daytime also on the sensor-target-sun-geometry. Anisotropy can be caused by surface material properties as well as macroscopic effects such as scene members (sun-lit and shaded soil and vegetation components within the field of view) with a varying heat balance. Chehbouni et al. (2001) reported differences of up to 5K between nadir and non-nadir brightness temperatures over grassland. Guillevic et al. (2012) compared LST retrieved from geostationary and polar-orbiting satellites and showed differences of up to 12K because of different sensor-target-sun geometries over a forest site in Portugal. In February/March 2013, field measurements were performed at the validation sites Gobabeb (Namib Desert) and Farm Heimat (Kalahari) in Namibia to investigate the anisotropy of the thermal radiation.

MOBILE MEASUREMENTS

The challenge is to characterize the anisotropy of thermal radiation over large areas i.e. at the scale of square kilometres. Goniometric measurements allow the observation of a small area from all observation directions distributed over the hemisphere, i.e. field-goniometer for natural surfaces (Sandmeier et al., 1999). In order to analyse the anisotropy over larger areas it is assumed that numerous stationary measurements of thermal radiation under various viewing directions distributed over the site are sufficiently representative to investigate the anisotropy of the surface leaving thermal radiation.

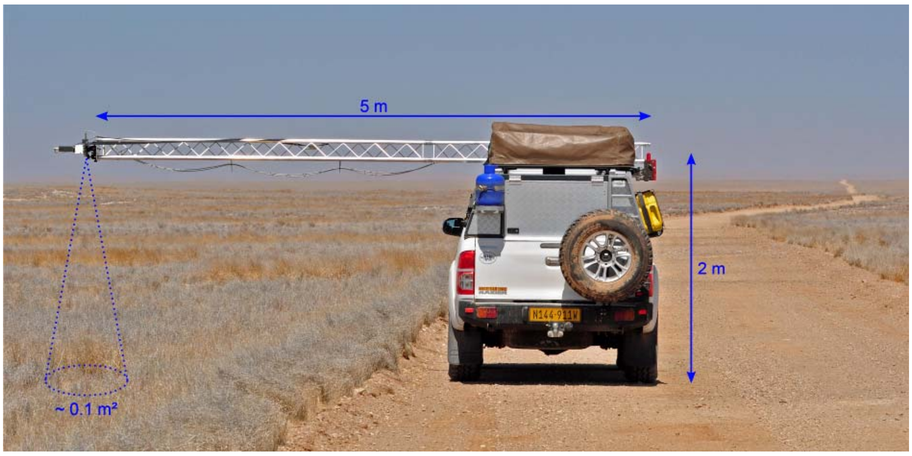

Figure 1: **Setup for investigation drives to investigate the anisotropy of thermal radiation.**

The dependency of LST on the viewing angle was measured with a combination of a line scanning radiometer and a nadir viewing radiometer, i.e. we compare off-nadir to nadir brightness temperatures. The system is mounted on a car and allows the collection of directional data along tracks of typically 30 km length. The system was employed during the field campaign in Namibia in February/March 2013.

The nadir viewing radiometer and the line scanning radiometer were installed at the end of a 5m long horizontal beam. The beam was mounted to the roof of an off-road vehicle (see Figure 1). All used radiometers were radiation pyrometer 'KT15.85 IIP' from Heitronics measuring in the spectral range from 9.6µm to 11.5µm. Compared to other IR radiometer, the chopped KT15 radiometers have a stable absolute accuracy of 0.3K over years, which was confirmed by various studies (Kabsch et al., 2008). The directional measurements were performed with the line scanner SC12 from Heitronics. It scans the surface along a line with view angles from -45° to +45°. In a tilted position, the scan cycle is performed from 0° to 90°. A rotatable mirror inside the instrument redirects the incident radiation of the observed surface to a connected radiometer. The motion of the mirror is programmable: for the measurements, the instrument scanned the full range of view angles in steps of 5°. A radiometer with an aperture angle of 8.5° mounted at a height of 2m has an instantaneous field of view of $0.1m^2$. At a driving speed of 40mk/h and with a sampling rate of 1Hz the integrated area contributing to the measurement was $1m^2$ per second. For each view angle ten measurements were performed. By comparing the measured nadir brightness temperatures with the off-nadir brightness temperatures, the influence of sensor-target-sun geometries can be assessed.

RESULTS

Several radiometric investigation drives were performed at the validation sites Gobabeb and Farm Heimat at different times of the day, i.e. at different sun angles. At Gobabeb, the track is along a 30km, straight gravel road with east-north-east orientation that runs across a vast gravel plain. At Farm Heimat, the data were taken driving along farm tracks. A combined analysis of all measurements from Gobabeb did not show a significant dependency of the brightness temperature difference on the position of the sun. The average difference is 1.2°C, while standard deviation is 2.1°C. The larger differences for small solar zenith angles in Fig. 2 are related to inhomogeneous heating of the gravel plains during the morning. The azimuth angle of the measurements only changes with driving direction. Therefore, the dependency of the brightness temperature differences on the solar azimuth results in the two point clouds shown in Fig. 3.

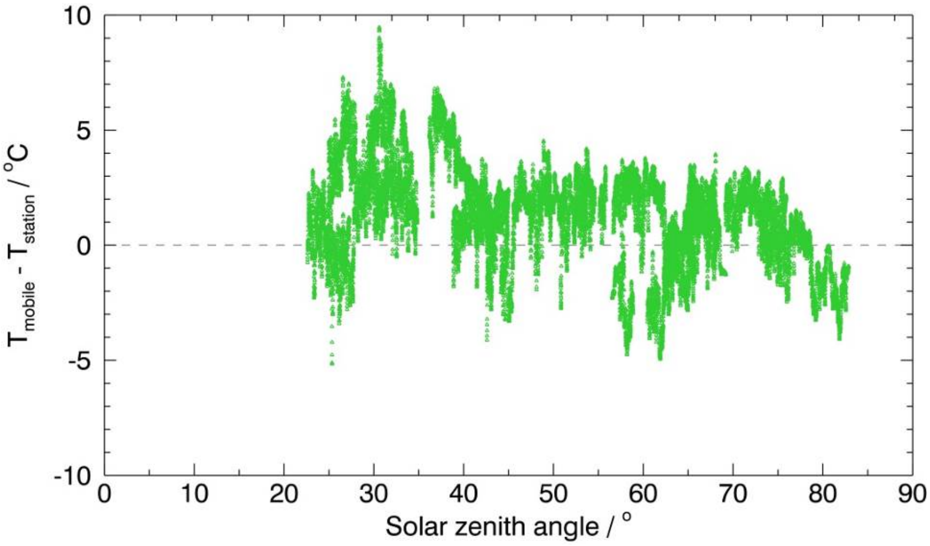

Figure 2: **Differences between nadir and ground truth brightness temperatures versus solar zenith angle at Gobabeb.**

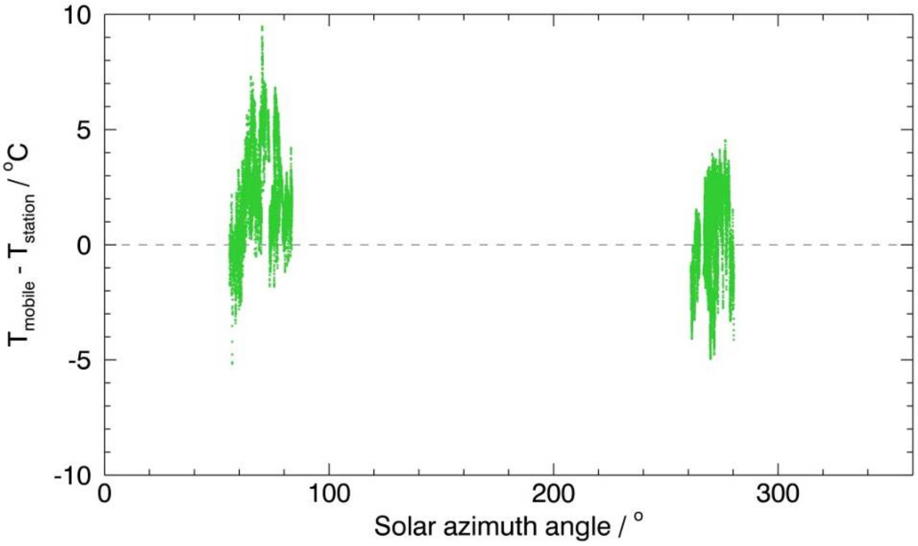

Figure 3: **Differences between nadir and ground truth brightness temperatures versus solar azimuth angle at Gobabeb.**

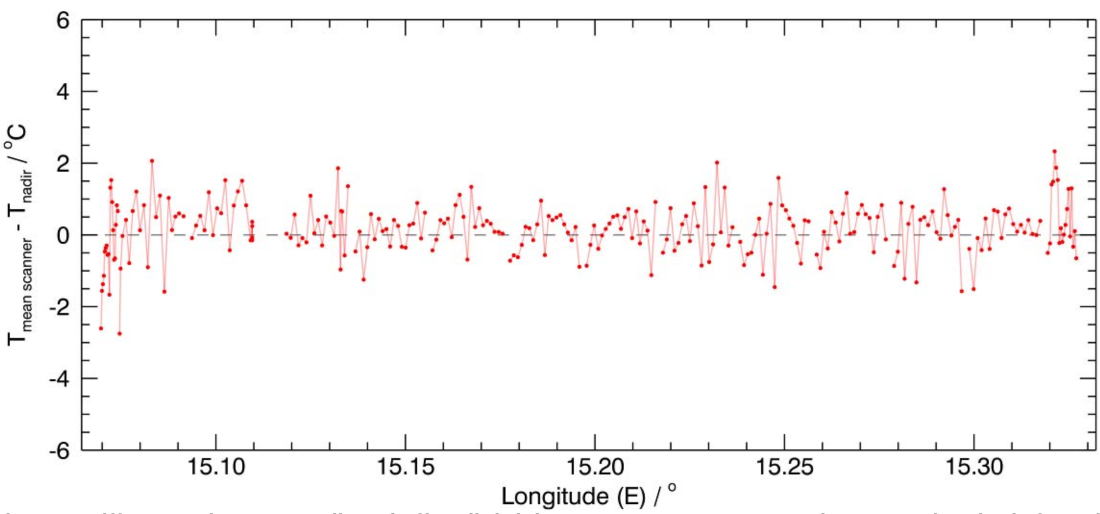

Figure 4: **Differences between nadir and off-nadir brightness temperature versus the eastern longitude from the measurement at Gobabeb on the 20. February 2013.**

The mobile measurements are more sensitive to spatial inhomogeneities than to angular effects. The differences between the mobile nadir and off-nadir brightness temperatures are smaller than the respective differences with station brightness temperatures. Fig. 4 shows the brightness temperature difference between nadir and off-nadir (angles between -45° and +45°) radiometer versus the eastern longitude of a measurements on the 20. February 2013. The mean difference is 0.15°C; the standard deviation is 0.7°C. Thus, angular dependency is negligible for these viewing angles. However, some periodic behavior can be observed at intervals of 0.02° longitude in Fig. 4, where each period corresponds to a complete scan cycle from -45° to +45°.

The difference between nadir and off-nadir brightness temperature increases with view angle: in Fig. 5, these differences are plotted against sensor zenith angle. The differences are averaged over all mobile data from Gobabeb for each sensor zenith angle; error bars depict the standard deviation. From Fig. 5 follows that radiometric measurements for sensor zenith angles of up to 45° result in deviations of up to 1°C compared to nadir measurements, while for view angles up to 60° deviations of up to 2°C can be observed. Fig. 6 shows the differences between nadir and off-nadir brightness temperature for Farm Heimat; like for Gobabeb, the differences increase with view angle. However, the deviation from nadir brightness temperature already exceeds 2°C for sensor zenith angles of 45°.

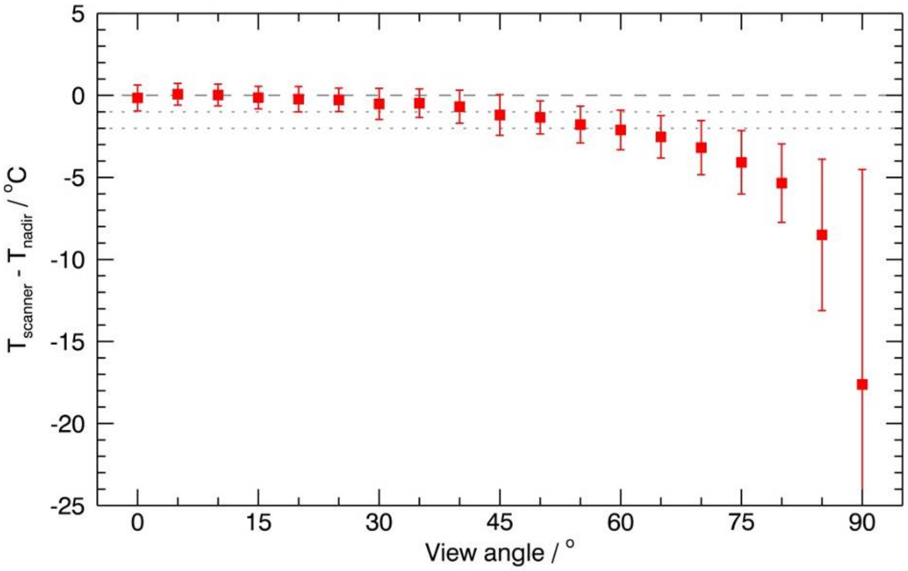

Figure 5: **Differences between nadir and off-nadir brightness temperatures versus view (zenith) angle at Gobabeb.**

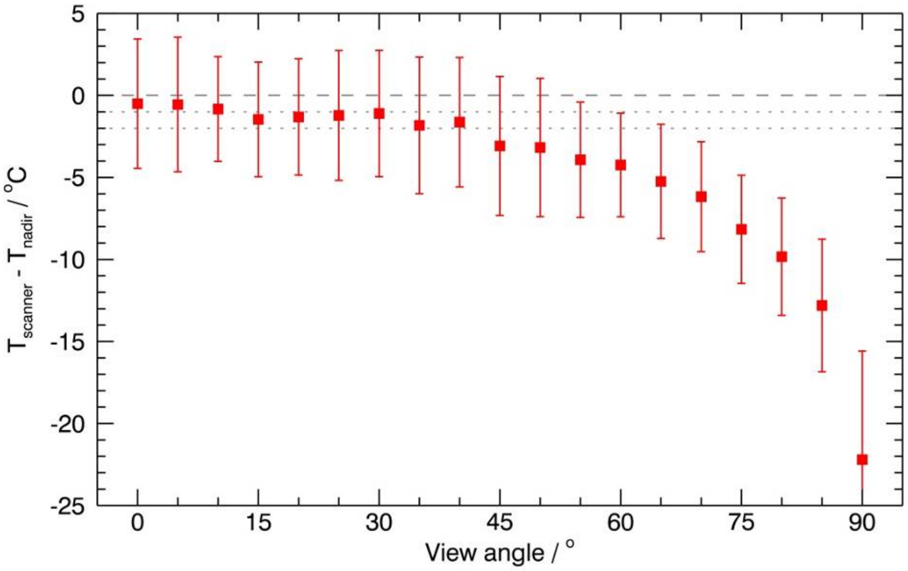

Figure 6: **Differences between nadir and off-nadir brightness temperatures view (zenith) angle at Farm Heimat.**

CONCLUSIONS

For sensor zenith angles up to 45° over areas with homogeneous land surface covers, e.g. at Gobabeb, LST can be retrieved from in-situ measurements without accounting for anisotropy of thermal radiation. In contrast, land surface covers similar to that at Farm Heimat may already exhibit non-negligible directional behavior at sensor zenith angles of 45°. Here directional measurements with view angles of 45° and higher can result in errors of 2°C and higher. MSG/SEVIRI observes Namibia at view angles of around 30°. For these viewing conditions, the anisotropy of the surface leaving thermal radiation at the sites Gobabeb and Farm Heimat is well below the LSA-SAF target accuracy of ±2°C. As long as the radiometer zenith angle is smaller than 40° directional effects due to the orientation of the radiometer for retrieving in-situ LST at Gobabeb and Farm Heimat are negligible. Therefore, the radiometer can be oriented in such a way that the observed surface within its FOV is representative for the satellite viewing conditions.

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