VIS and IR characterization of a permanent LST validation site

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Abstract

The Land Surface Analysis – Satellite Application Facility (LSA-SAF) operationally derives LST from MSG/SEVIRI data with a high temporal resolution of 15 minutes and a target accuracy of ± 2°C. In order to validate this product with long term in-situ measurements, KIT operates four permanent LST validation stations in different climatic regions within the field of view (FOV) of MSG/SEVIRI. All four stations were set up in highly homogeneous and flat areas. However, for reliably validating MSG/SEVIRI derived LST, it has to be ensured that a small radiometer spot (~ 13 m^2) is representative for satellite pixels of about 5x5 km^2. Here, we present new results from 3 field campaigns performed in 2010 and 2011 at Gobabeb validation site in Namibia. The spatial variability of LST was repeatedly investigated at various times of the day along a 20 km track. It was shown that the area within the FOV of Gobabeb station's “KT15-East” radiometer is representative for the gravel plains north-east of the validation station.

INTRODUTION

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. In order to validate satellite derived LST products, KIT operates four permanent ground validation stations: Evora (Portugal), Dahra (Senegal), Gobabeb (Namibia) and RMZ-Farm (Namibia). All four stations are equipped with long-term stable high precision IR radiometers for measuring the surface leaving radiance as well as the downwelling radiance from 9.6 µm to 11.5 µm. In order to be able to validate LST derived from MSG/SEVIRI, the small spots of the in-situ measurements need to be representative for satellite pixels with a size of about 5x5 km^2. Therefore, the validation stations were set up in carefully selected homogeneous areas. Nevertheless, the representativeness of the in-situ LST for the validation area needs to be proven.

GOBABEB VALIDATION STATION

Gobabeb validation station is located about 2 km north-east of “Gobabeb Training and Research Centre” on the gravel plains of the Namib Desert, Namibia. The gravel plains are a vast and flat area of several 100 km^2 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. Towards the south of Gobabeb station the Kuiseb River separates the gravel plains from large sand dunes and, thus, forms a natural boundary.

Instrumentation

The station is powered by solar panels and a battery and has a radio-link to Gobabeb that allows near real-time data download. The instruments are mounted to a 30 m high tower. The main instruments for LST validation are Heitronics KT-15.85 IIP IR radiometers measuring the IR radiance in the range of 9.6 µm to 11.5 µm in terms of brightness temperature with an absolute accuracy of 0.3°C over the entire temperature range that is of interest here [Theocharous, 2010]. The long-term stability of these radiometers was proven by Kabsch et al. [Kabsch, 2008] at KIT's validation station 'Evora', Portugal. In order to measure the surface emitted IR radiance, two KT-15 radiometers are mounted at 25 m height, facing downwards under a view angle of 30° in northern direction. The radiometers observe two neighbouring but slightly different spots on the surface (see fig. 1a). This set-up of the radiometers combined with their full view angle of 8.5° results in a field of view (FOV) of about 13 m^2 for each radiometer.

VIS AND IR CHARACTERIZATION OF THE RADIOMETER SPOTS

In order to validate LST derived from several MSG/SEVIRI pixels, one needs to know the relationship between these data and the in-situ measurements made at Gobabeb validation station. Hence, a characterization of the validation site needs to be performed in order to justify the representation of an area up to 50 km^2 with a comparatively small radiometer FOV on the order of 13 m^2.

As a first step, photos ("vis-data") - in co-operation with the University of Basel (Switzerland) - of the area around the FOV of the two KT-15 radiometers were taken from the top of Gobabeb tower. As outlined by Bork-Unkelbach et. al. [Bork-Unkelbach, 2010], the two radiometer spots are covered by different amounts of desiccated grass and pure gravel. Furthermore, the authors showed that the differences in land cover cause small scale brightness temperature (BT) variations. Therefore, the amount of desiccated grass and pure gravel for each radiometer spot has to be known. The fraction of grass and gravel was obtained from VIS image (photo in fig. 1)which was taken from the top of the tower and analyzed using an object-based image analysis tool, called eCognition. In two processing steps, the pictures were first segmented into small, spectrally homogeneous image objects and then classified as one of the two classes ("grass" and "gravel") using a nearest neighbour classifier (see fig. 2). This way one finds that the spot observed by the KT-15$_{East}$ radiometer is composed of 24.8 % gravel and 73.3% desiccated grass on gravel. A small portion of 1.9% of this area was not classified: This was mainly due to large, bright stones which are spectrally different from the gravel. In contrast, the area observed by the KT-15$_{West}$ radiometer is composed of 77.4 % gravel and just 21.8% desiccated grass. In this case only a very small portion of 0.8% of the analyzed area was not classified, which again is due to large, bright stones.

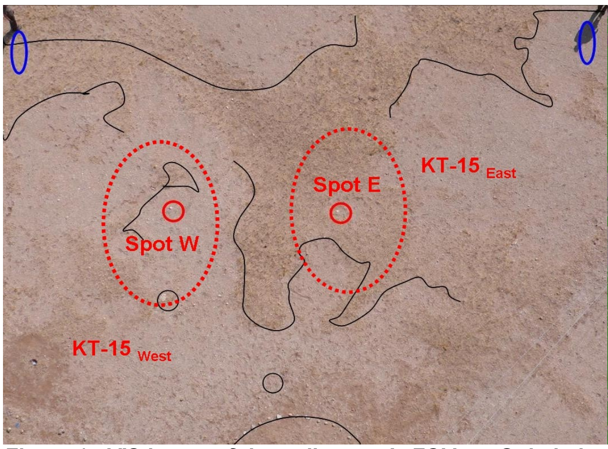

Figure 1: VIS image of the radiometer's FOVs at Gobabeb (red broken lines). Hand drawn lines outline areas with desiccated grass [Vogt, 2009:] .

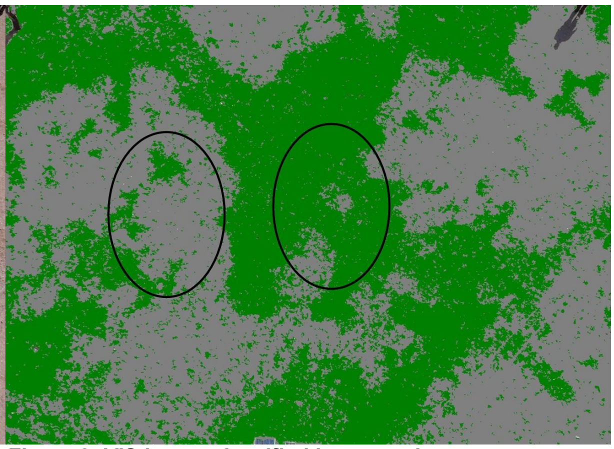

Figure 2: VIS image classified into two classes: green: desiccated grass, grey: pure gravel. The black lines mark the two radiometer spots.

In order to investigate the impact of the difference in land cover, the brightness temperature difference between the KT-15$_{East}$ and KT-15$_{West}$ was plotted over a one year period of time (see fig. 3). In May, June and July the BT difference between the two radiometers is small compared to the BT difference in November, December and January. This behaviour can be explained by the change of the sun elevation angle during the course of the year: In November, December and January the sun elevation is close to 90°, since Gobabeb is very close to the Tropic of Capricorn. At this time of the year the BT difference between the two radiometer spots is about 3 °C. In May, June and July the sun has a much lower elevation angle and shines from a northerly direction. The two radiometers are face to the North and shadow effects from the tower are avoided. However, grass shadows are present in the FOV of the radiometers and thus, the effective BT temperature observed by the KT-15$_{East}$ radiometer is lowered, which in turn leads to the smaller BT difference compared to the KT-15$_{West}$ radiometer.

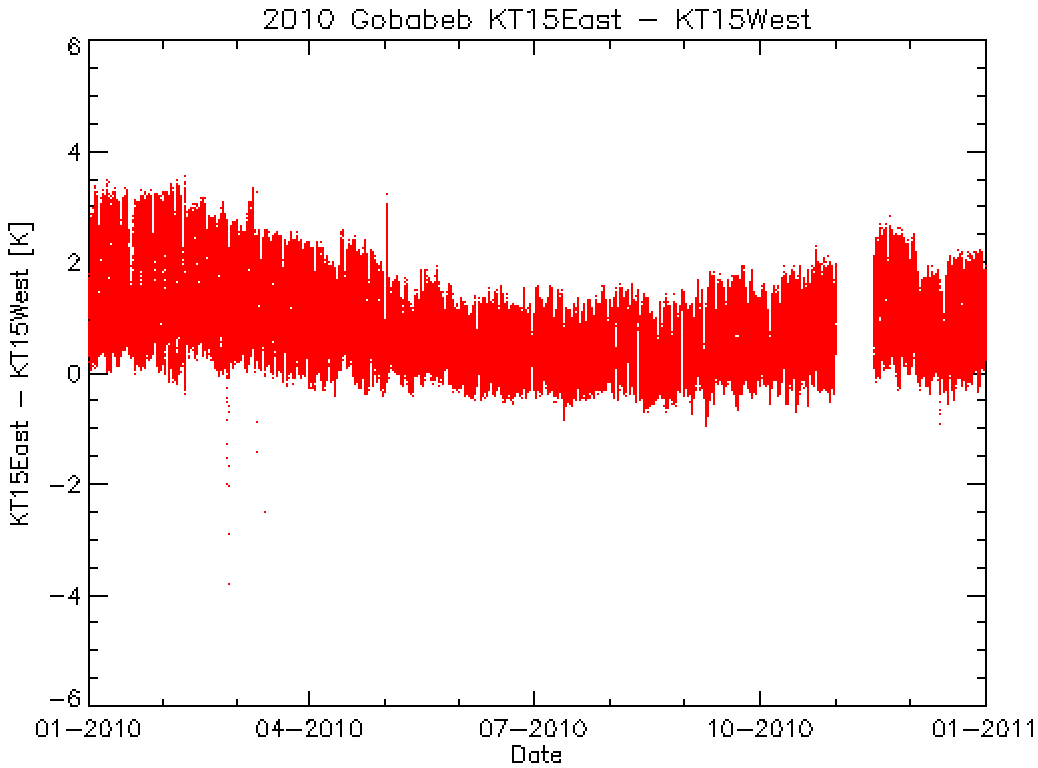

Figure 3: BT difference of station radiometers over the course of the year 2010

IR CHARACTERIZATION OF THE VALIDATION AREA

In order to assess which KT-15 FOV's is more representative for the validation area, further in-situ measurements were carried out during three field campaigns in March 2010 [Göttsche, 2010 and Göttsche, 2011] as well as in February and April 2011. The variability of LST over the site was studied with an additional Heitronics KT-15.85 IIP radiometer mounted to a 3 m boom reaching out horizontally from a 4WD car (see fig. 4). Data were recorded along a 20 km track across gravel plains located within the validation area. In order to be able to compare the resulting LST to the data obtained simultaneously at Gobabeb validation station, the KT-15 radiometer had the same optics (full view angle of 8.5°) and was also mounted under a view angle of 30°. The resulting field of view of the radiometer was approximately 0.1 m^2 (diameter about 0.34 m). At a constant driving speed of 22 km/h (6 m/s) this resulted in an observed surface area of about 120 m^2 per minute - the averaging interval in the data recording.

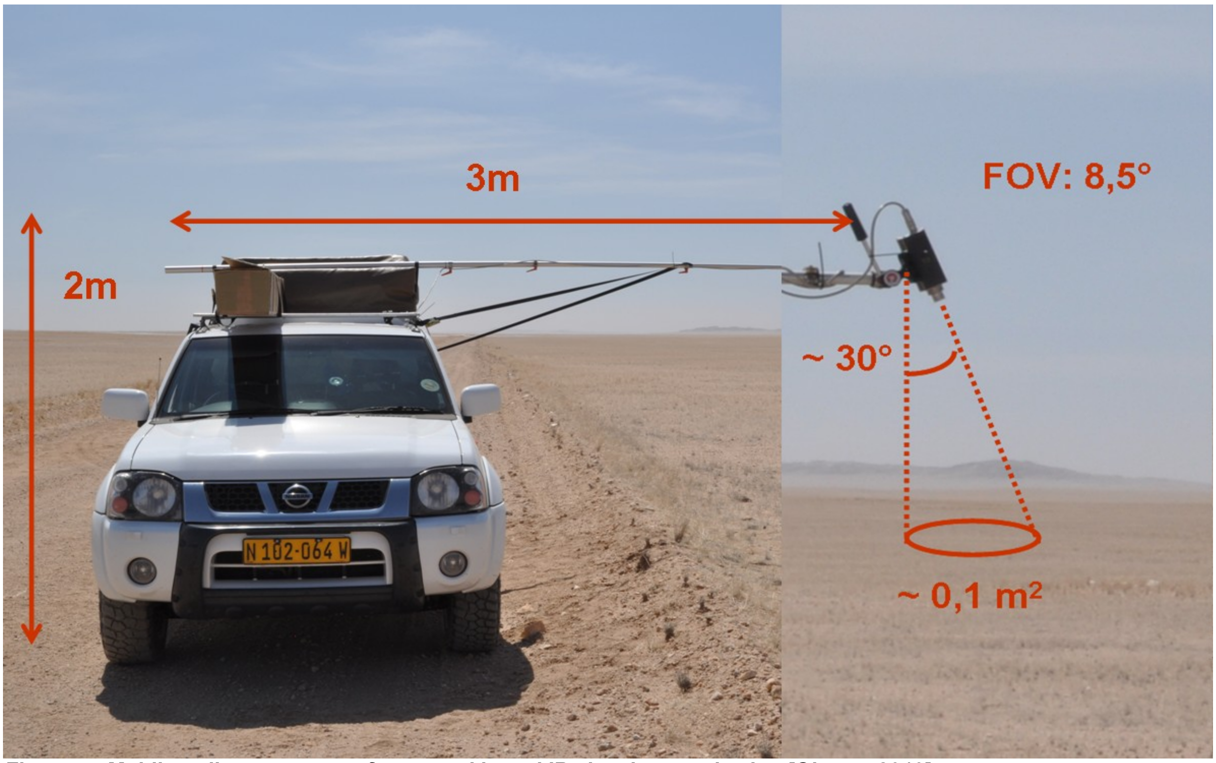

Figure 4: Mobile radiometer set-up for ground based IR site characterization [Olesen, 2010]

The authors showed that the differences between the two measurements have a standard deviation of 1.2°C, which is small when considering that the mobile measurment represents the variability along a track length of 40 km. Furthermore, the small bias of 0.4°C also indicates that the FOV of the KT-15_{East} radiometer is representative for the validation area. In order to validate these results, the mobile measurements were repeated two more times at different times of the year and hours of the day, thus covering a variety of sun elevation angles. The differences between these two mobile measurements (obtained on 02/12/2011 and 04/28/2011 respectively) and the corresponding measurements of the station's KT-15_{East} radiometer have a bias between -0.2 and +0.8 K and a standard deviation which is always less than 1.4 K. This further supports the assumption that the FOV observed by the station's KT-15_{East} radiometer is representative for the validation area and that the validation area is very homogeneous in space and time.

In order to investigate the reason for the observed small scale BT variations, the altitude dependence of the BT differences between the mobile and the station measurements were investigated. Figure 5 shows the altitude dependence of the BT differences between the mobile measurements taken on 04/28/2011 and the corresponding measurements of the station's KT-15_{East} radiometer. Each point along the 20 km track was observed twice: During the eastbound (outward) journey and westbound (return) journey. The mobile measurements in figure 5 show no altitude dependence. Since the altitude varies by about 200 m along the 20 km track (see fig. 6), the observed BT differences must reflect differences in surface cover or orientation.

When comparing the spatial distribution of the BT differences of the first mobile measurement (03/14/2010) with the spatial distribution of the BT differences of the following two mobile measurements (02/12/2011 and 04/28/2011, see fig. 7), one can clearly identify thermal structures, i. e. a similar shape, in all three measurements, which therefore appear to be reproducible. In order to investigate the impact of different surface cover on small scale BT differences and their spatial distribution, these BT differences were compared to high resolution VIS and IR satellite data. Figure 8 and 9 show the BT differences between the mobile measurement obtained on 03/14/2010 and the corresponding measurements at the station's KT-15_{East} radiometer plotted over an image of the ASTER emissivity for SEVIRI channel 10.8 and an Landsat RGB image respectively. One can clearly see, that the thermal structures 1, 2 and 3 from fig. 7 correspond to IR objects (see fig. 8) and VIS objects (see fig 9). A more detailed analysis and quantification of the relationship between small scale BT differences and differences in surface coverage is currently in preparation.

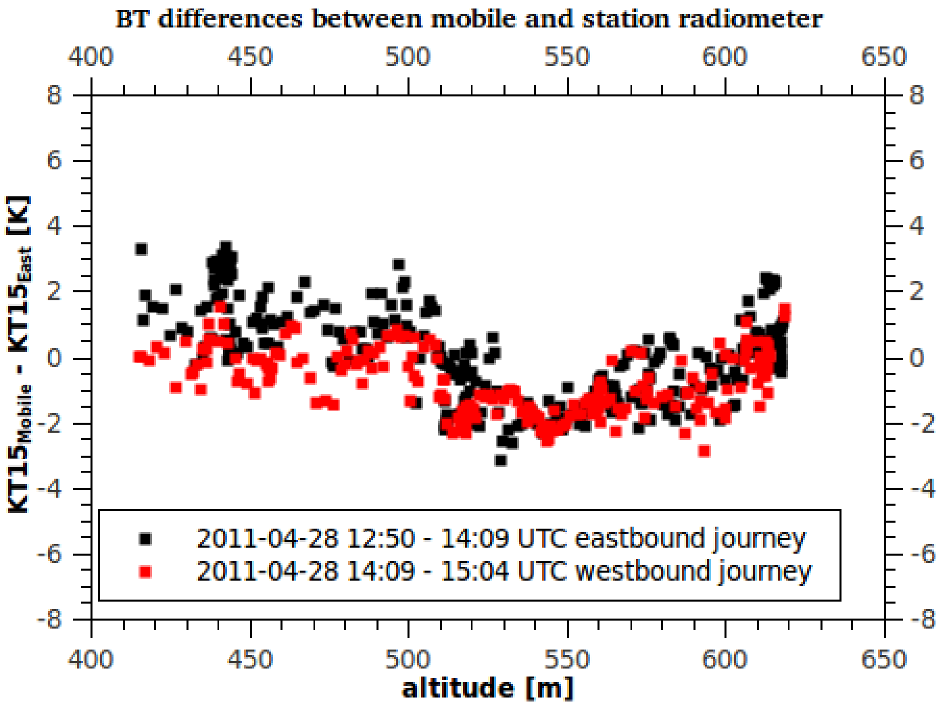

Figure 5: The BT differences between mobile and station measurements are independent of altitude

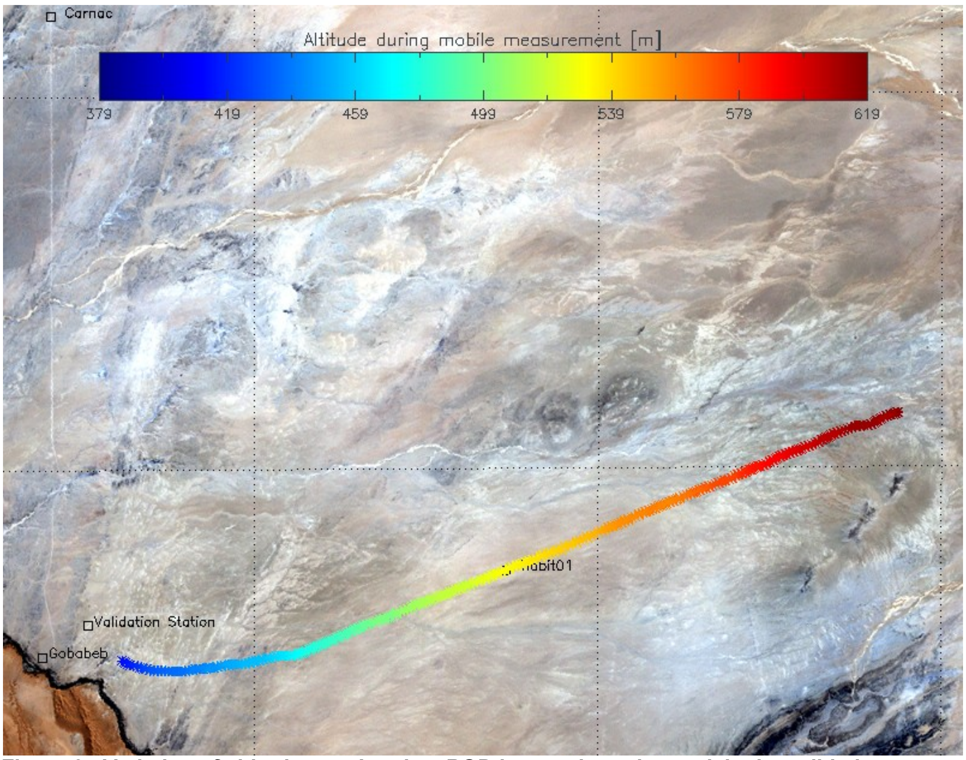

Figure 6: Variation of altitude over Landsat RGB image along the track in the validation area

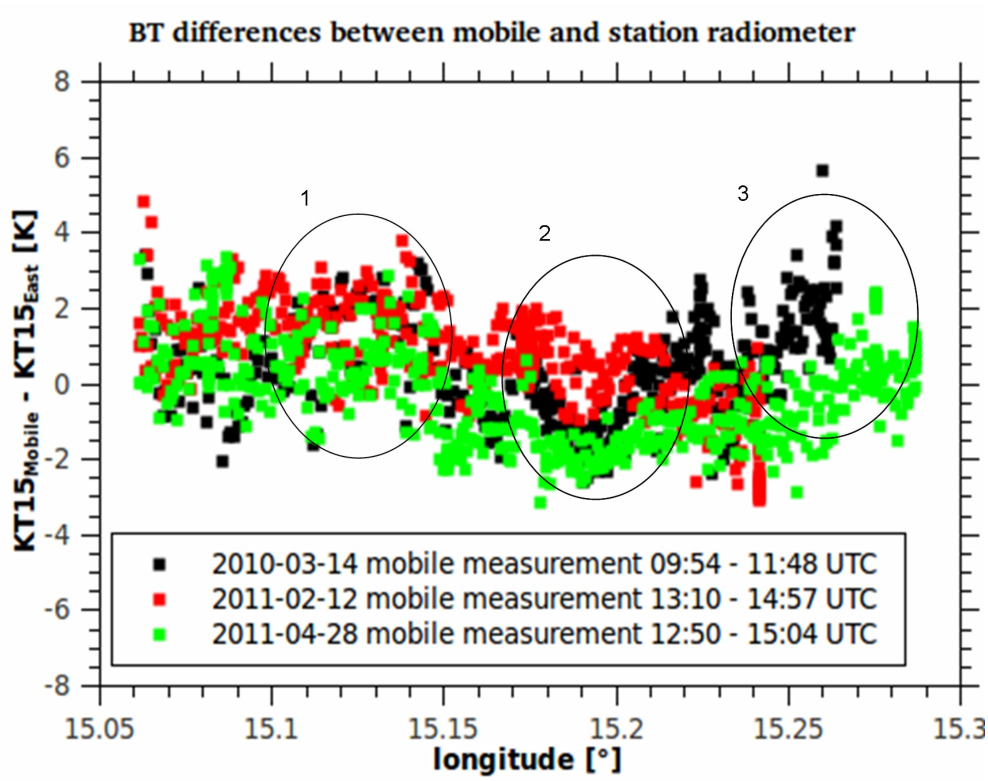

***Figure 7:** Good agreement between the different mobile measurements. Bias of -0.2 to +0.8 K indicates that the station radiometer $KT15_{East}$ is representative for the validation area. Stddev. of less than 1.4 K proves that validation area is highly homogeneous in space and time*

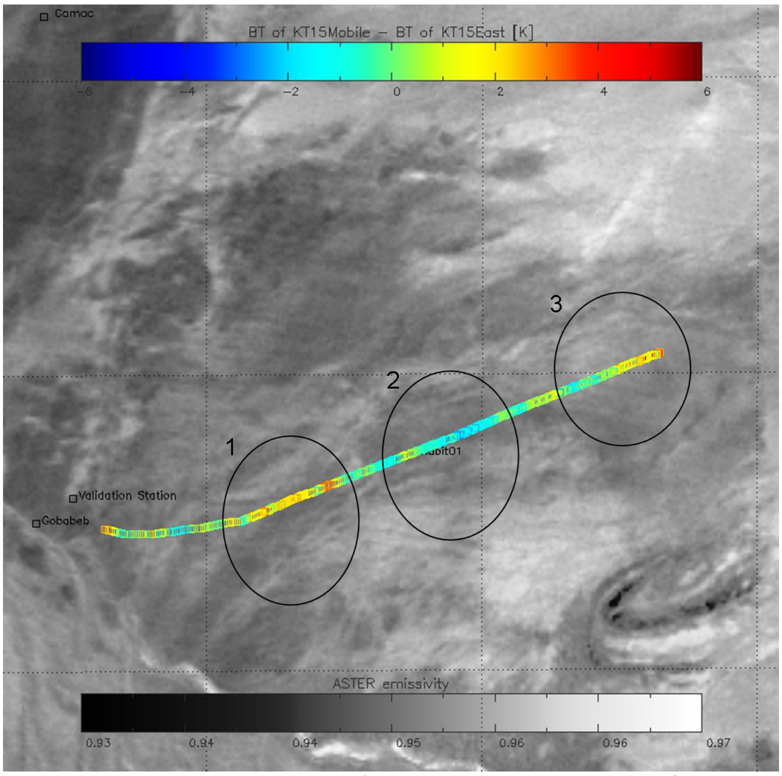

***Figure 8:** Mobile BT measurement from 03/14/2010 plotted over ASTER emissivity for SEVIRI channel 10.8 [Hulley, 2011]*

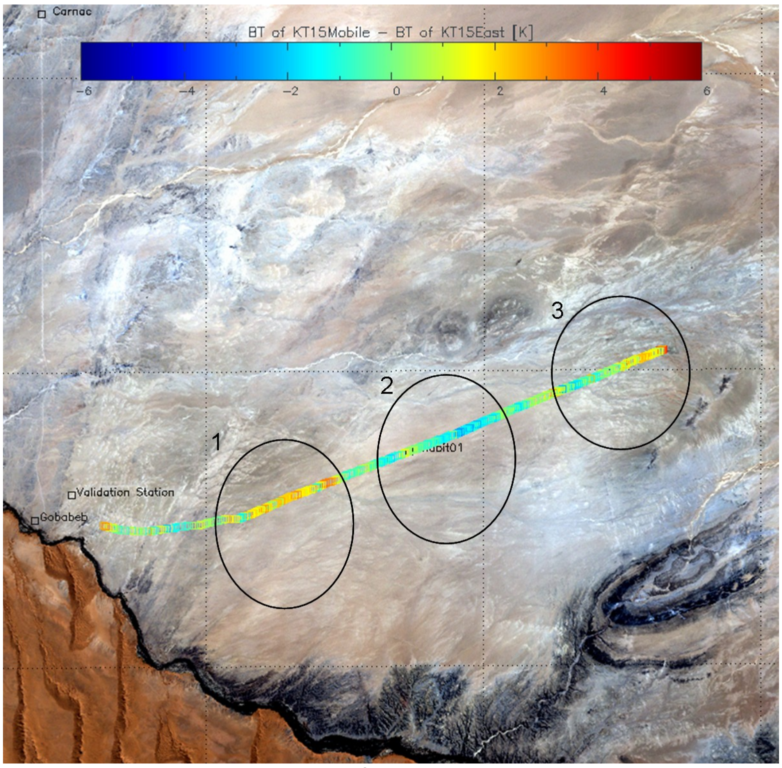

Figure 9: Mobile BT measurement from 03/14/2010 plotted over Landsat RGB

CONCLUSIONS AND OUTLOOK

VIS and IR images of the area around the station's radiometers FOVs showed that local differences in surface cover can lead to differences in brightness temperature of several °C. This clearly demonstrates the need for a more detailed characterization of the validation area. Three field campaigns were carried out with a mobile radiometer system to obtain brightness temperatures at a high spatial resolution. The bias between the mobile measurements and the station's KT-15_{East} radiometer was always comparatively low (between -0.4°C and 0.8°C), thus proving that the KT-15_{East} radiometer observes a spot which is representative for the validation area. Even though the three campaigns were carried out over a longer period and at different times of the day, the results are in good agreement and show that the gravel plains are homogeneous in time. The spatial variation of BT is currently investigated and quantified. Furthermore, more detailed surveys of land cover and spatial variability of LST will be performed at Gobabeb in fall 2011 and spring 2012. During these field campaigns an UAV will be used to systematically survey several MSG/SEVIRI pixels with an KT-15 radiometer and a VIS camera. These results will be used to further quantify the spatial BT differences in the validation area and to investigate how small scale thermal variations contribute to large scale LST. Furthermore, by applying object-based image analysis, the fraction of surface cover types can be estimated and used in combination with in-situ emissivity measurements.

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