An experimental study of angular variations of brightness surface temperature for some natural surfaces

Juan Cuenca, José A. Sobrino, and Guillem Soria

University of Valencia, c./ Dr. Moliner 50, 46100 Burjassot, Spain

Abstract

The design of a precise multiangle algorithm for determining sea and land surface temperature (SST and LST) to be fed with AATSR TIR data requires an accurate knowledge of the angular emissivity behaviour. Today there are very few measurements of this variation. In this work it is presented an experimental investigation of the angular variation of brightness surface temperature on several representative natural samples (bare soil and crops of grass, alfalfa, sugar beet and wheat) for different spectral intervals and field of view of the sensors. This dependence becomes of critical importance when trying to calculate emissivity because of the heterogeneity of the samples. Measurements have been made using three different radiometers with 5º, 10º and 20º of IFOVs with different thermal infrared bands located at 8-13, 8.2–9.2, 10.3–11.3, and 11.5–12.5 µm. The results show the importance of the sample heterogeneity with variations in ∆LSBT (Land Surface Brightness Temperature Differences function) higher than 3 K from an observation angle ranging from -60º to +60º.

1.- Introduction

For most flat and homogeneous surfaces, brightness temperature decreases clearly with increasing viewing angle. This allows obtaining the angular variation of emissivity. Figure 1 shows the angular variation of relative emissivity for some surfaces in several wavelength intervals (Cuenca & Sobrino, 2004), evaluated from angular measurements taken with a 4 channel Cimel radiometer (see §2.1: Experimental setup).

![Figure 1.- Angular variation of relative emissivity of some homogeneous samples in the 4 channels considered.](image-url)
Brightness temperature can be measured and used to estimate angular variation of surface emissivity. A complete method of the procedure is described by Sobrino and Cuenca, 1999, and Cuenca and Sobrino, 2004. These works were carried out studying homogeneous covers (water, sand, clay, slime, gravel and grass). A next step in the investigation is given with natural heterogeneous samples. Before arriving to the emissivity calculation, angular variation of brightness temperature has to be evaluated. With this aim, we start from the LSBT (Land Surface Brightness Temperature function), defined by:

\[
\text{LSBT}(\theta) = B_{\lambda}^{-1} \left[ \frac{\lambda}{\pi} \right] \sin(\theta) \frac{I_{\lambda}(\theta)}{B_{\lambda}(\theta)}
\]

where \(\theta\) is the zenithal observation angle, \(I_{\lambda}(\theta)\) represents the radiance measured by the sensor coming from the surface on the wavelength \(\lambda\), and \(B_{\lambda}^{-1}\) represents the inverse of Planck’s function. From LSBT(\(\theta\)) is it possible to define the \(\Delta\)LSBT (Land Surface Brightness Temperature Differences function) (McAtee et al., 2003). \(\Delta\)LSBT is used because it minimizes the effect of temporal changes in temperature during an angular scan cycle. The values set obtained by this way is then appropriate to the study the impact of the change in the spectral surface emissivity with the viewing angle. The mathematical form of \(\Delta\)LSBT is:

\[
\Delta\text{LSBT}(\theta_i) = \frac{1}{n} \sum_{i=1}^{n} \text{LSBT}(\theta_i)
\]

where \(n\) is the number of angular measurements done.

2.- Experiments

The field campaigns were carried out in Spain, near a little town called Barrax. The Barrax test site is situated in the western part of the province of Albacete, 28 km from the capital town of Albacete (39° 3’ N, 2° 6’ W). The University of Castilla-La Mancha, through the “Escuela Técnica Superior de Ingenieros Agrónomos”, operates three agro-meteorological stations in the study area (Moreno et al., 2001). The dominant cultivation in the 10,000 ha area is approximately 65% dry land (two-thirds in winter cereals, one-third fallow) and 35% irrigate crops (75% corn, 15% barley and 10% others, including alfalfa). We selected plots of wheat, alfalfa grass and bare soil for our analysis. The vegetated plots were all closed-canopy, or nearly so. Spectrally, the test area consists of closed-canopy green vegetation, dry vegetation, partially covered soil, and bare soil. The soil is classified as an Inceptisol, and is developed on shallowly buried flint clasts and bedrock.

These field campaigns were developed during the summers of years 2003 to 2005. Several moments of the measurements can be seen in Figure 2.

![Figure 2. (a) day and (b) night measurements at Barrax.](image)

The way of measuring was in angular series: Starting in nadir and increasing the observation angle, it was took a measurement each 5° or 10°, depending of the experience. From 2003 we start measuring at -60° and we ended at +60°. Before and after a serie we evaluated the downwelling hemispherical radiance by measuring the sky temperature pointing to the zenith. The operation time of such a measuring serie is between 2 and 6 minutes. A deeper description of the measurements can be found at Sobrino & Cuenca (1999).
2.1.- Experimental setup

The experimental material used can be classified in two groups, the own developed material, consisting in the
goniometers, and the instrumentation, being it the radiometers, the thermal camera and the calibration sources. The
goniometers were three, an arc goniometer, an arm goniometer and an automatic goniometer (Figure 3). The measuring
distance from the radiometer to the sample is about 150 cm.

![Figure 3. (a) arc, (b) arm and (c) automatic goniometers.](image)

The sensors used were infrared radiometers (see Figure 4). An Omega OS86, a Raytek Thermalert Mid and an
Everest 3000.4ZLC radiometers, operating all in 8-14 µm, and two band radiometers (Cimel 312-1 and 2) with 4 and 6
bands. The first one operates in broad band and has got two bands coincident with AATSR channels, centred in 11 and
12 µm. The second one has got the same broad band and the other five coincident with ASTER thermal channels. A
thermal camera (Irisys IRI 1001) operating in broad band was used to control the thermal homogeneity conditions of the
samples. Two blackbodies, an Everest single-temperature source and a Galai one, with adjustable temperature
capability, were used to calibrate the TIR instruments.

![Figure 4.- TIR measuring instruments: (a) Omega, (b) Raytek, (c) Everest and (d) Cimel
radiometers and (e) thermal camera.](image)
2.2.- Samples

The studied samples in the WATERMED-SPARC campaign (2003) were alfalfa, wheat, sugar beet, bare soil and forage with the Everest 3000.4ZLC, the Cimel 312-1 and the Raytek Thermalert Mid. So, it was possible to carry out a double study: with the Cimel channels, a spectral study, and with the broad band and the other two radiometers, a study depending of the IFOV: 4° of Everest, 10° of Cimel and 20° of Raytek.

Alfalfa’s canopy (Figure 5a) was 50-70 cm high, with homogenous appearance, fully covering and well irrigated. Bare soil (Fig. 5b) was plain and flat, but with some clods, with an average size of 2-3 cm. Forage (Fig. 5c) was recently mown and, although it was well irrigated, the leaves presented different phenological states. Wheat (Fig. 5d) was about 60 cm high, fully covering, dry and ready for harvesting. Sugar beet (Fig. 5e) was well irrigated, and it had many big leaves so that the ground was not visible from above.

For 2004, a new field campaign was designed introducing the novelty of the night measures besides the day ones. With the night measures we wanted to assure the thermal stability and homogeneity of the samples, a bare soil and a kind of grass. With the aim of controlling the thermal distribution on the samples, we introduced a thermal camera. Finally, we carried out a field campaign during 2005. It took place again in Barrax but this time with an automatic goniometer. The instruments used were both Cimel radiometers and the thermal camera. The selected samples were a more irregular bare soil, a green grass and wheat.

Figure 5.- (a) alfalfa, (b) bare soil, (c) forage, (d) wheat and (e) sugar beet from Barrax.

3.- Results and discussion

Figure 6 shows the case of alfalfa in terms of ΔLSBT. For the Cimel channels (Figure 6a), ΔLSBT reaches an amplitude of ±1.5 K (which means that there is a great thermal heterogeneity of the sample under the actual measuring conditions), and increases significantly at the Everest’s graphic of Figure 6b. It is to be observed that increasing the IFOV of the sensor, ΔLSBT diminishes. On the other hand, the graphics of the four Cimel channels are close together, this means that there is not a spectral dependence at the measurements.
Figure 6: ΔLSBT for alfalfa, depending (a) on the wavelength and (b) on the IFOV.

Table 2.- Thermal amplitudes depending on wavelength and IFOV for the studied samples in the field campaign made in 2003. Second column shows the thermal amplitude of the measurements taken at the 4 Cimel bands, and third column offers the thermal amplitude depending of the IFOV’s instrument (4° of Everest, 10° of Cimel and 20° of Raytek)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$Δ\text{LSBT}_{\text{max}(\lambda)}$ (K)</th>
<th>$Δ\text{LSBT}_{\text{max}(\text{IFOV})}$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Forage</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>Wheat</td>
<td>3</td>
<td>1.5</td>
</tr>
</tbody>
</table>

The results show that the use of a radiometer with a narrow IFOV near the ground (1 or 2 m) produces measurements strongly dependent of the pointing place, and so, the results are not representative when the observed surface is heterogeneous. To use a sensor with a higher IFOV does not solve the problem because the concept of directionality of the measure can be lost due to the difficulty to define the observation angle. A possibility to solve both problems could be to choose a radiometer with narrow IFOV placed at a “large” distance of the sample, although this can add some practical difficulties to the experimental procedure on the field.

Besides, the in situ temperature measurements carried out over the different samples show standard deviation of 1-2 K due to the thermal heterogeneity of the surfaces, even for closed canopy vegetated plots, generally assumed to be more homogeneous than soils at the scale of in situ measurements. This heterogeneity can be attributed to turbulence-induced temperature changes of the surface or canopy (Balick, 2003). These fluctuations would be averaged away in 90-m ASTER pixels but not the 35 to 70 cm ground measurements. At the level of the turbulence-induced temperature fluctuations, there is good agreement between the in situ measurements and the ASTER values for the alfalfa, green grass and corn samples.

To study deeply the heterogeneity problem we designed a different field campaign that included day and night measurements over the same samples and we made use of a thermal camera for thermal control of the samples. Figure 7 shows the obtained results for bare soil, on the left side for day measurements and right one for night measurements. In each case, the first graphic is constructed with the 4 channel Cimel data, the second one with the 6 channel radiometer and the third one with the broad bands of both instruments and the thermal camera.
Figure 7. (left) day and (right) night measurements on bare soil. Data acquired with Cimel 312-1, Cimel 312-2 and broad bands and thermal camera. Field campaign 2004.

From the comparison between day and night measurements it is to be observed that bare soil presents higher variability for day measurements (±2K) than for night ones (±0.5K). For grass (Figure 8), we find a higher thermal variability, for day, up to 2.5K, and for night measurements there is a clear tendency, with a maximum value at nadir decreasing more or less symmetrically with increasing angles.
The thermal camera confirms the results obtained with the radiometers. Figure 9 shows the day thermal images of bare soil (a1) and grass (b1), and the night images of both samples (a2-bare soil) and (b2-grass). For day, the thermal amplitude 12 K (case of bare soil), and during night it is only 4K. The pattern observed at the night measurements of grass (Figure 8) shows that the hottest image at Figure 9 (b) corresponds to nadir.
Figure 9.- Temperature images at (a₁) day and (b₁) night for bare soil and for grass (a₂, b₂ respectively) acquired with the thermal camera in Barrax (2004).
Conclusions

Measuring angular variation of brightness temperature in heterogeneous samples constitutes a difficult task because several perturbing factors have to be taken into account, such as surface geometry, atmospheric contributions and emissivity variations. In order to quantify the influence of viewing conditions on the measured signal, a set of measurements taken over a variety of samples has been presented. The results show that directional effects can be quite significant in a range of variations in the measured brightness temperature relative to the nadir observation. Using a narrow IFOV radiometer, the temperature variation range can be significantly higher for many pixels.

Finally, we have shown the power of an image sensor (thermal camera) for having a precise control on the observed spot by the radiometer, with the aim of assuring the thermal homogeneity of the sample. We have developed a field campaign with day and night measurements and we have found a great thermal variation interval for day measurements (up to 12 K) in bare soil, decreasing to 4 K in the night measurements.

References


