

PROXIMAL REMOTE SENSING: POTENTIAL AND LIMITATIONS OF FT-IR SPECTROMETER FOR VALIDATION OF SATELLITE MEASUREMENTS

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ABSTRACT

There are several methodologies to retrieve land surface temperature (LST) from thermal infrared (TIR) remote sensing data. All of them require validation with field measurements. However, it is difficult to perform ground measurements with the satellite overpass. We investigated the potential and limitations of FT-IR spectrometer for the validation of orbital remote sensing data in the thermal infrared region (TIR). Results indicated that laboratory measurements can be successfully replaced for field validation in the estimation of land surface emissivity (LSE) of quartz sand, avoiding the need of field campaign. In this case, it is essential to pay attention to some factors in the laboratory, such as the time required for the instrument to acquire stability and the calibration process.

Keywords—Emissivity, Sand lands, LST, Field measurements, Laboratory measurements.

1. INTRODUCTION

Land surface temperature (LST) is an essential parameter in investigating environmental, ecological processes and climate change at various scales. Moreover, it is important in the studies of evapotranspiration, soil moisture conditions, surface energy balance, and urban heat islands [1-2]. In this context, many methodologies have been developed to retrieve this variable from satellite imagery measurements and correct the atmospheric effects for thermal infrared (TIR) [3], which are very significant when working in this spectral region.

The methods used to obtain LST from orbital remote sensing require as prior knowledge the land surface emissivity (LSE) and the data need to be validated with field measurements [4]. Nevertheless, this is not an easy task, once ground measurements must be performed concurrently with the satellite overpass in order to be comparable [5]. Furthermore, the measurements might be limited by different sensor data specifications and field data, which makes these measurements a challenge.

Proximal remote sensing is the employment of sensors on a ground level, in contrast to the remote deployment of sensors using aerial or satellite platforms [6].

To identify best approach to collect data on the ground level with a good accuracy, it is crucial to investigate the particularities of each instrument.

MODEL 102F is a *Fourier Transform Infrared Spectrometer* (FT-IR) that has been widely used to collect emissivity of different targets in the spectral range of middle and thermal infrared wavelength (2~25 μ m) with a spectral resolution of 4, 8 or 16cm⁻¹ [7]. The instrument can be suitable to validate remote orbital sensing data, since it allows to calculate LSE and LST in the field from radiance measurements.

Field measurements are a challenge, in addition, they are restricted to a limited number of pixels [8], an alternative to the ground validation is to use measurements performed at the laboratory. There are several spectral libraries available to obtain emissivity from different targets of the surface and retrieve LST [9], but sometimes they are not representatives from the area evaluated.

The paper evaluates the potential and limitations of FT-IR spectrometer for the validation of orbital remote sensing data in the TIR. We focus on investigating the differences between field and laboratory measurements, in order to evaluate the particularities of the instrument in the field and the possibility of replacing field validation by laboratory measurements.

2. MATERIAL AND METHODS

2.1. Laboratory measurements

When retrieving LST, the emissivity is needed, and the values of the targets can be taken from the bibliography based on available spectral libraries. In the most investigations, the emissivity is obtained through the ASTER JPL spectral library (<http://speclib.jpl.nasa.gov>), which provides more than 2300 spectra in wavelengths covering from the visible to TIR region. However, if the values are not representatives from the area evaluated, errors may be introduced [9]. In addition, the available spectral libraries do not have temperature information, and different temperatures might have different emissivities for the same land-surface types [3].

We performed emissivity measurements in controlled environment, based on temperatures by using the Fourier-transform infrared spectroscopy (FT-IR) Model 102F. The atmospheric downward radiance L^{\downarrow}_{λ}

obtained by measuring a golden reference panel with an emissivity of 0.04. The sample spectral emissivity ε is calculated from the following equation:

$$\varepsilon_{\lambda} = \frac{L\lambda - B\lambda(T_s)}{B\lambda(T_s) - L^{\dagger}\lambda} \quad (1)$$

where $L\lambda$ is the spectral radiance and $B\lambda(T_s)$ refers to Planck's equation, given as:

$$B\lambda(T_s) = \frac{C1\lambda^{-5}}{\exp(C2/\lambda T) - 1} \quad (2)$$

where $C1$ and $C2$ are constants ($C1 = 1.191 \times 108 \text{ W } \mu\text{m}^4 \text{ sr}^{-1} \text{ m}^{-2}$, $C2 = 1.439 \times 104 \text{ } \mu\text{m K}$). Assuming that $\varepsilon = 1$ between 7.5 and 8 μm , the sample temperature can be obtained. The downwelling radiance measurement is carried out before and after the sample measurement. If the amount of downwelling radiation changes between measurements, the properties determined for the material will have an associated error. Therefore, the accuracy in the downwelling radiance measurement determines the accuracy of the emissivity and temperature spectra obtained.

We organized two sets of measurements, the first was performed in the first 30-40 minutes of instrument operation and after the first calibration against the blackbodies. The second set was done after 45 minutes and the second calibration of the instrument. In the calibration process, two temperatures were chosen, a temperature for the cold blackbody (below the ambient temperature), and another for the warm blackbody, (above the sample temperature). This leads to a more accurate calibration, since the instrument response between two known radiances and for each longitude is linear [10]. Thus, the calibration interval assumed was 10-40 °C (283-313 K).

The temperature of the laboratory was about 25°C (295 K) and the relative humid 58%. A sample from the sand dune was heated up to +/- 60°C (333 K) and the measurements were taken. They were ceased when the sample temperature reached 26°C, totaling about 61 measurements for the first set, and 63 measurements for the second (1-2 measurement per minute). The calibration of the instrument was carried out twice in the whole process.

2.2 Field measurements

We selected one of the remaining transgressive dunes of Cidreira beach (30 km²) as study area, located in the North Coast of Rio Grande do Sul state, Brazil. The area has a large stock of fine quartz sand (125 to 250 μm), with grains varying among sub-rounded (68%), rounded (18%), sub-angular (14%) and composed of quartz (99.53%) and heavy minerals (0.47%). The dune was chosen mostly because it is considered a pseudo-invariant target therefore appropriate

for the terrestrial validation of LST by remote sensing data [11].

For field measurements, clear sky conditions are preferable, because downwelling radiance is easier to determine and varies more smoothly. Besides, the LST retrieval of passive orbital remote sensors also requires clear sky [12]. We selected a very homogeneous and bare site within the dune area to settle the instrument. As it had not rained in the previous days, we did not have much influence of humidity in the sand, which makes the site highly homogeneous in terms of both surface temperature and emissivity, thus easing the measurements [13].

The ground emissivity and temperature spectra were obtained from radiance measurements with the FT-IR spectrometer as well. At the field, the instrument calibration was carried out same as at the laboratory. However, the downwelling radiance measurements were taken more often, since the radiance in the field may have more variations than in a controlled environment. The FT-IR was placed looking at the surface at angles close to nadir. The standard input optic is 1 inch in diameter with a 4.8 degree expanding field of view. The measurements were taken at a rate of 1-2 per minute, and the emissivity and temperature were calculated by (1) and (2).

3. RESULTS

3.1 Laboratory emissivity measurements

Emissivity curves from laboratory measured at different temperatures are shown (Fig. 1a and 1b). We chose five spectra from each set to represent the variations of the temperature measured (303-318 K). Fig. 1a displays the first set of measurements, in which it can be seen the relation between emissivity and temperature, obtained at the first half hour that the instrument was turned on. As the temperature decreases, the noise is bigger and there are more oscillations in the emissivity curves. Besides, the emissivity increases with the temperature and the difference among curves became greater above 10 μm .

Reststrahlen feature that occurs at 8.5 μm for quartz and feldspar (framework silicates) [14] had an emissivity value bigger than 0.7 for the highest temperatures of the set (318.45 K), and about 0.6 for the lower temperature evaluated (303.95 K). Fig. 1b shows the second set of, taken after the first half hour and the second calibration of the instrument. The emissivity measurements are clearly more accurate and do not vary so much with the temperature.

Although the variation is minimal in the most part of the spectrum, the highest temperature presents also the highest emissivity. Furthermore, noticeable variations among curves after 9.5 μm are observed, which becomes more evident after 11 μm . Another difference is that the reststrahlen feature presents a lower emissivity value (<0.6), and for all temperatures here considered, there are very similar emissivity values at this wavelength.

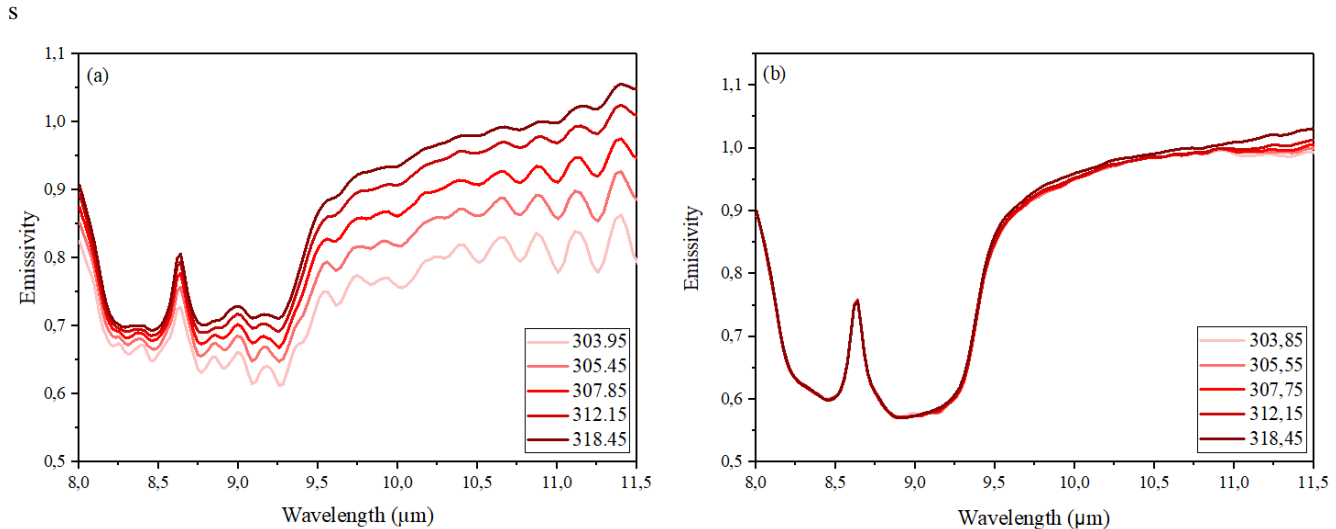


Fig. 1. Emissivity curves of quartz sand sample for five different temperatures (K). (a) refers to the set of measurements performed at the first half hour of the instrument turned on, (b) refers to measurements performed at the time after the second calibration.

When compared the two database sets, it is noted that the lack of calibration and instability of the instrument may induce greater differences in the emissivity measurements. If the first set is used to assign an emissivity value in the methods that estimate LSE as prior knowledge to retrieve LST, bigger errors are observed.

3.2 Laboratory and field measurements comparison

Ground campaign showed that the major portion of the dune were bare, with a few pockets of undergrowth so that we could chose a spot especially bare to measure the quartz sand. Relative humid, near surface air temperature (T_o), and wind speed were about 67%, 299.25 K (26.1 $^{\circ}\text{C}$) and 2 m/s, respectively, at the time of the measurements.

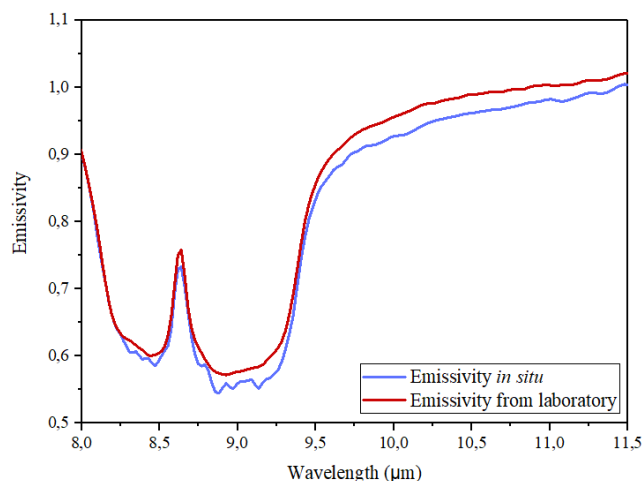


Fig. 2. Comparison between emissivities in the field and laboratory. Both curves chosen to perform the comparison were at exactly 313 K of temperature.

We chose a curve from the database (second set) to compare with another one at the same temperature (313 K) acquired in the field (Fig. 2). In the wavelength that comprises the restrahlen feature more noise is observed in the field measurements than in the laboratory. Moreover, it can be seen a reduction of the emissivity at some points of the feature. After 9.5 μm , the reduction is more evident. Considering that both curves are at the same temperature, when analyzing the wavelength range of 9.5-11.5 μm , an emissivity difference up to 3.25% is verified. However, the most variations are about 2%.

4. DISCUSSION

The first set of measurements performed at the first half hour is not that accurate and can induce systematic errors, which are more significant if the sample is at lower temperatures. This result is probably associated with the sample spectral contrast that is dependent on the environment where the measurements were taken. A lower environment temperature will result in a low thermal contrast between the environment and the sample, if the sample is at a low temperature as well. It is mandatory to turn on the instrument for at least 30 minutes before starting to take measurements in laboratory to reach thermal and mechanical equilibrium. Otherwise, the measurements taken will not be accurate enough.

The emissivity values above 1.0 presented apparent noise effects, since emissivity cannot be greater than 1.0. The temperature of the instrument influenced, since the calibration is carried out in the range from 10 to 40 $^{\circ}\text{C}$. It is worth mentioning that at very high temperatures the instrument has a tendency for reducing its accuracy, even if bigger temperature intervals are considered, which is a limitation of the FT-IR spectrometer.

Field measurements indicated the presence of noise in the emissivity curve, especially in restrahlen feature (Fig. 2). According to [10], the calibration for field measurements deteriorates more quickly because the variable heat load from changing solar insolation typically causes instrument temperature drift. Therefore, for maximum accuracy, calibration measurements in the field must be repeated with each sample measurement. [11] evaluated MODIS product V5 found that the emissivity over a desert region is always overestimated compared to laboratory results. The same was observed here, in which we had a difference up to 3.25% in the emissivity comparing a laboratory and field measurement. Furthermore, meteorological conditions have a great influence on the FT-IR spectrometer measurements.

According to [9] 1% uncertainty in LSE may cause an error of 0.5 K in the LST for a moderate atmospheric condition. [17] found in a standard atmosphere with 302.55 K that an error on emissivity of 1% may lead a LST error of 0.6 K. Solar energy influences the material temperature and therefore its self-emitted energy. Wind speed is also an important factor, as it can cool the surface layer of the material very quickly. Since the surface layer is the one that plays the major role in the TIR emission, if the wind causes quick and long changes in the field of radiance, it will affect the determination of the emissivity, mainly because the LST will change while reading the spectrum.

5. CONCLUSIONS

When using an FT-IR spectrometer in the laboratory, it is essential to pay attention to some factors, such as the time required for the instrument to acquire stability and the calibration process, in order not to introduce errors in the measurements. A difference about 2.2% in the emissivity in relation to the temperature was observed for almost the whole spectrum when analyzing almost pure quartz (99.53%). Considering the limitations of the instrument, laboratory measurements can be successfully replaced for field validation in the estimation of LSE, avoiding the need of field campaign concurrently with the satellite overpass. In this case, the factors mentioned should be considered. New tests are being performed using the emissivities obtained in the field and laboratory as *input* in LST algorithms from orbital remote sensing data.

6. REFERENCES

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