Simultaneous measurement of land surface temperature and emissivity using ground multiband radiometers

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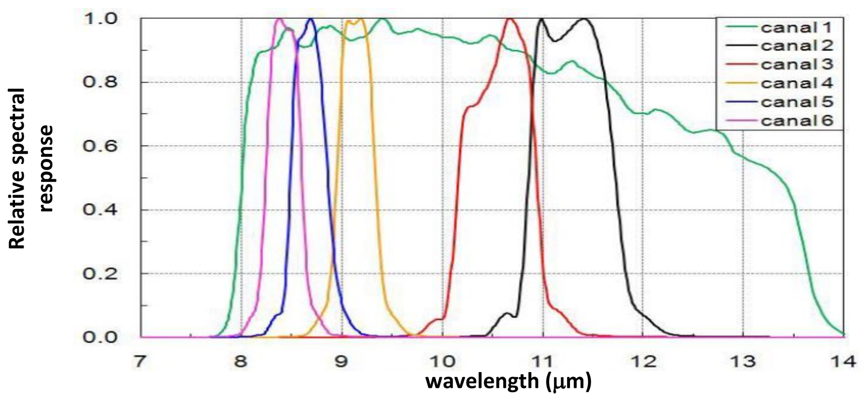
Abstract

The Thermal Remote Sensing Group of the University of Valencia (TRSG-UV) participated in the FRM4STS field radiometer comparison at NPL in 2016, including the laboratory radiometer and black body comparison, the water surface temperature and the land surface temperature (LST) measurements. The aim of this poster is to show the methodology followed by the TRSG-UV team for field measurements of LST and emissivity. As opposed to water, land surface emissivity is not usually known for many ground covers, so an emissivity value has to be either assumed, or assigned from spectral emissivity libraries or measured for each land cover in order to retrieve LSTs from thermal infrared radiometric measurements. We used multiband CE-312 radiometers (five narrow bands in 8-13 μm) to simultaneously retrieve LST and band emissivities by means of the temperature-emissivity separation (TES) method for the different ground covers considered in the experiment (soil, sand, gravel, clover and tarmac). The TES method requires near-simultaneous measurements of ground-leaving radiances and sky-downwelling radiances; the latter measured using a gold reflectance panel. For each surface cover, TES provided the band emissivity in the five CE-312 bands and the LST from continuous radiance measurements performed over time. As a result of the experiment, we present the LST series and band emissivity values for the ground covers considered, together with a detailed LST uncertainty analysis including the uncertainties associated to the calibration of ground radiometers, the emissivity estimation by means of the TES method, and the sky radiance measurements, among others. According to these results, the total LST uncertainty was estimated at 0.4 – 0.5 K for the ground covers measured during the comparison.

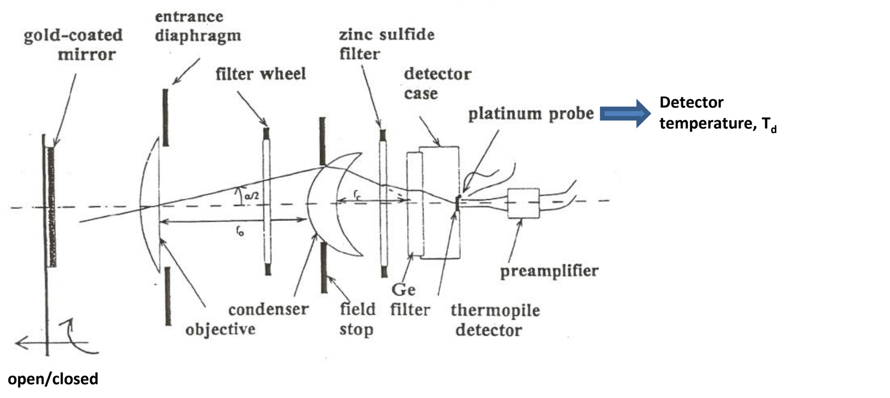
Multiband radiometer CE-312-2. Calibration

Type of detector: thermopile at ambient temperature
Field of view: 10º
Spectral bands:
1 Wideband: B1 (8.0-13.3 μm)
5 Narrowbands (similar to ASTER):
B2 (10.9-11.7 μm) B3 (10.2-11.0 μm) B4 (9.0-9.3 μm)
B5 (8.5-8.9 μm) B6 (8.3-8.6 μm)



Sicard et al. (1999); Legrand et al. (2000)

A gold-coated mirror enables comparison between the target radiance and the radiation from the detector cavity. The temperature of the detector is measured with a calibrated PRT, thus allowing **compensation for the cavity radiation**.



Radiance measured in band i: $L_i = B_i(T_d) + \Delta L_i$

B_i: Planck's radiance function integrated for band i
ΔL_i: Differential target minus cavity radiance (mirror open/closed).

The **Planck's radiance function** for band i can be expressed as

$$B_i(T) = \frac{a_i}{\exp\left(\frac{b_i}{T^{n_i}}\right) - d_i}$$

Coefficients (a_i, b_i, n_i and d_i) provided by the manufacturer.

ΔL_i is obtained from the **differential (mirror open/closed) digital number ΔDN_i** measured by the radiometer

$$\Delta L_i = \Delta DN_i / S_i$$

S_i: Sensitivity coefficients provided by the manufacturer (**standard calibration**).

L_i is obtained from the radiometer outputs (T_d, ΔDN_i).

The **equivalent radiometric** temperature (T_i) is calculated from L_i by **inversion of Planck's radiance function** ($B_i(T_i)=L_i$)

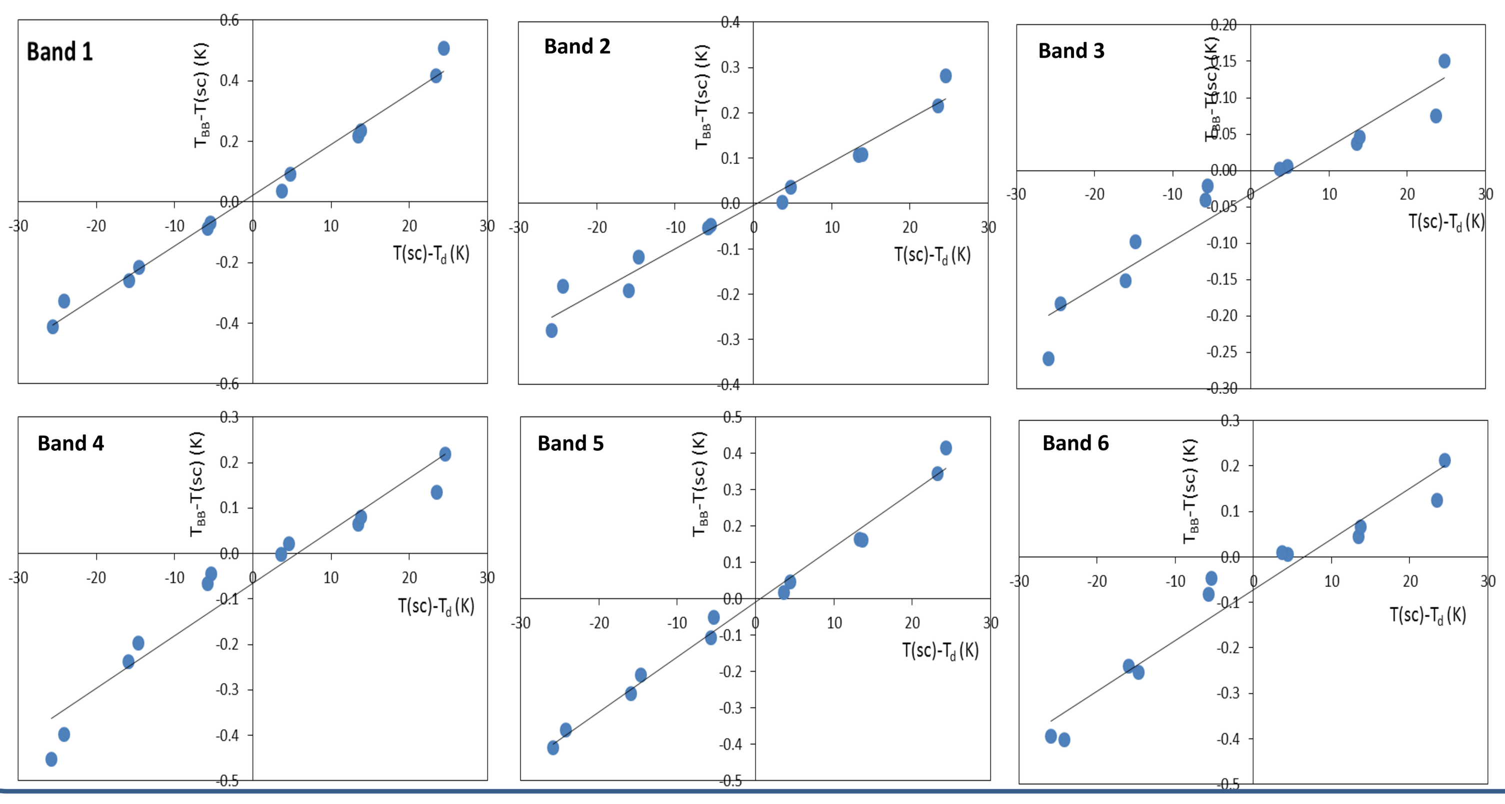
Due to the decrease of the radiometer detector's sensitivity with time, the **standard calibration** must be **corrected for the calibration drift**.

This was done through **laboratory calibration experiments** in Valencia in May 2106, before the FRM4STS comparison at NPL. Two CE-312-2 radiometer units (CE1 and CE2) were used.

Laboratory calibration (Valencia, May 2016).
Blackbody source Landcal P80P, Temperature range: 0 – 50 °C

Linear calibration equations $T_i(cal) = T_i(sc) + A_i(T_i(sc) - T_d) + B_i$

$T_i(cal)$: Calibrated (blackbody) temperature
T_d: Detector's temperature
$T_i(sc)$: Radiometric temperature with standard calibration
A_i, B_i: Calibration coefficients (linear regression)

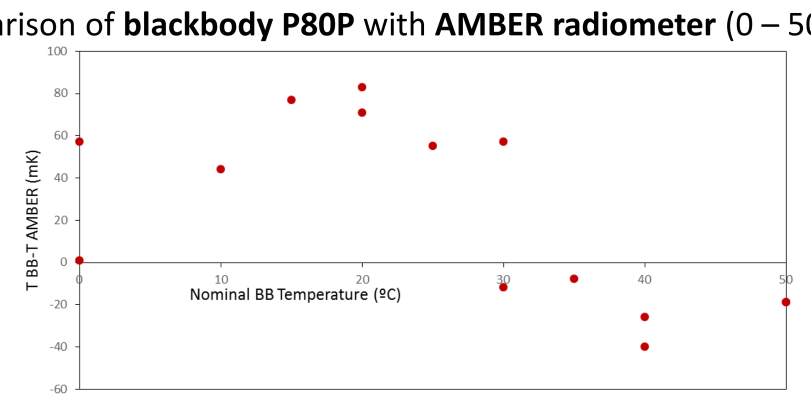


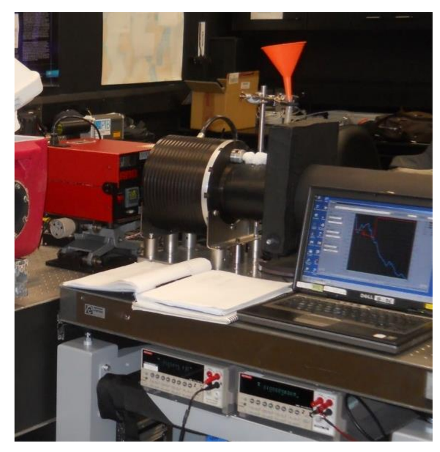
FRM4STS laboratory comparison (NPL, June 2016). NPL reference blackbody. Temperature range: 0 – 45 °C

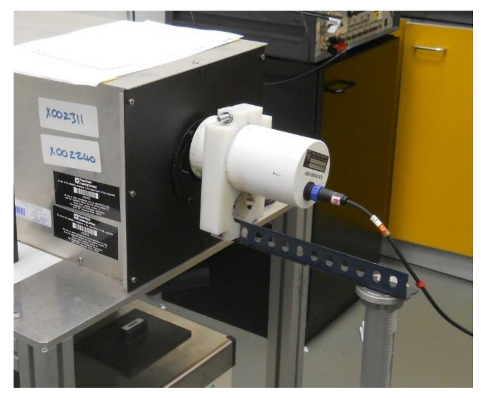
Radiometer CE1	B1	B2	B3	B4	B5	B6
bias (K)	-0.02	-0.05	-0.03	-0.03	-0.02	-0.05
std. dev. (K)	0.08	0.03	0.09	0.17	0.13	0.23
rmsd (K)	0.08	0.06	0.10	0.17	0.13	0.23

Radiomter CE2	B1	B2	B3	B4	B5	B6
bias (K)	-0.02	-0.03	-0.01	-0.01	-0.01	0.01
std. dev. (K)	0.09	0.05	0.10	0.17	0.16	0.22
rmsd (K)	0.09	0.06	0.10	0.17	0.16	0.22

Comparison of **blackbody P80P** with **AMBER radiometer** (0 – 50 °C).







Blackbody P80P

bias (K)	0.02
std. dev. (K)	0.04
rmsd (K)	0.05

Uncertainty budget Radiometer CE1

Uncertainty Contribution	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature, K
Repeatability of measurement	0.015		0.05
Reproducibility of measurement	0.026		0.08
Primary calibration		0.05 K	0.05
Linearity of radiometer			0.06
Drift since calibration			0.07
Ambient temperature fluctuations			0.04
Atmospheric absorption/emission			
RMS total	0.09 K/0.031		0.15

Radiometer CE2

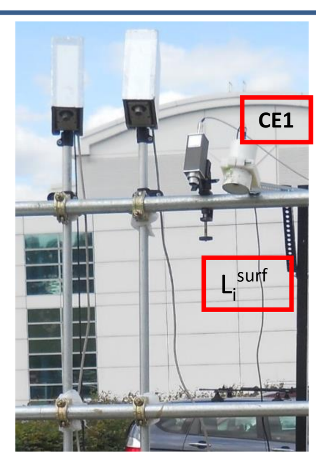
Uncertainty Contribution	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature, K
Repeatability of measurement	0.012		0.03
Reproducibility of measurement	0.018		0.06
Primary calibration		0.05 K	0.05
Linearity of radiometer			0.06
Drift since calibration			0.05
Ambient temperature fluctuations			0.04
Atmospheric absorption/emission			
RMS total	0.07 K/0.022		**0.12**

Temperature-emissivity separation (TES)

Radiance at surface level: $L_i^{surf} = \varepsilon_i B_i(T) + (1-\varepsilon_i) L_i^{sky}$

T: **Land Surface temperature** (LST)
ε_i: **Surface emissivity**. Not usually known for land surfaces and needs to be measured for each land cover
L_i^{sky}: **Sky downwelling radiance**. Measured in the field (gold plate) simultaneously to the target radiance

TES method (Gillespie et al., 1998): **simultaneous retrieval of T and ε_i from multiband measurements**

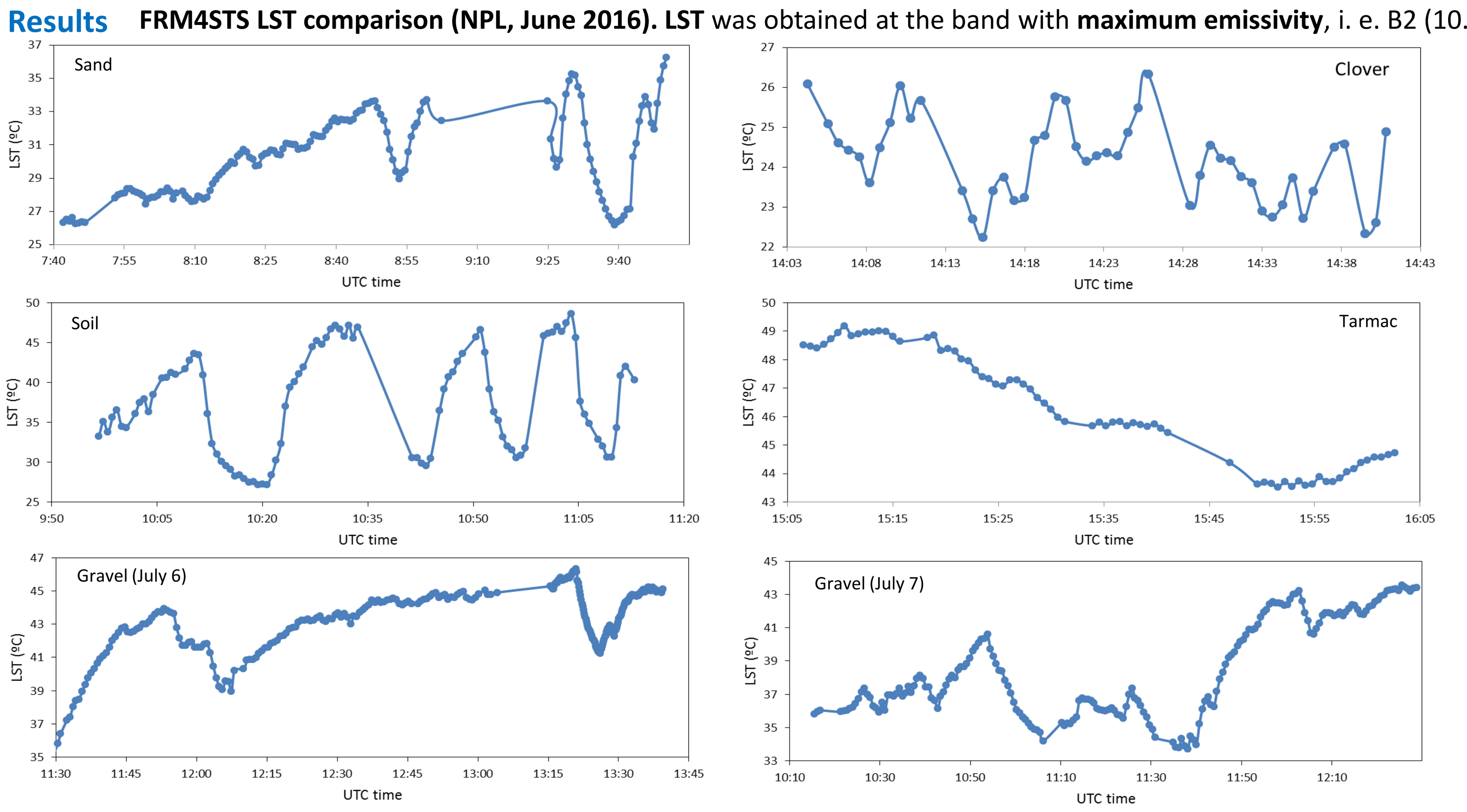


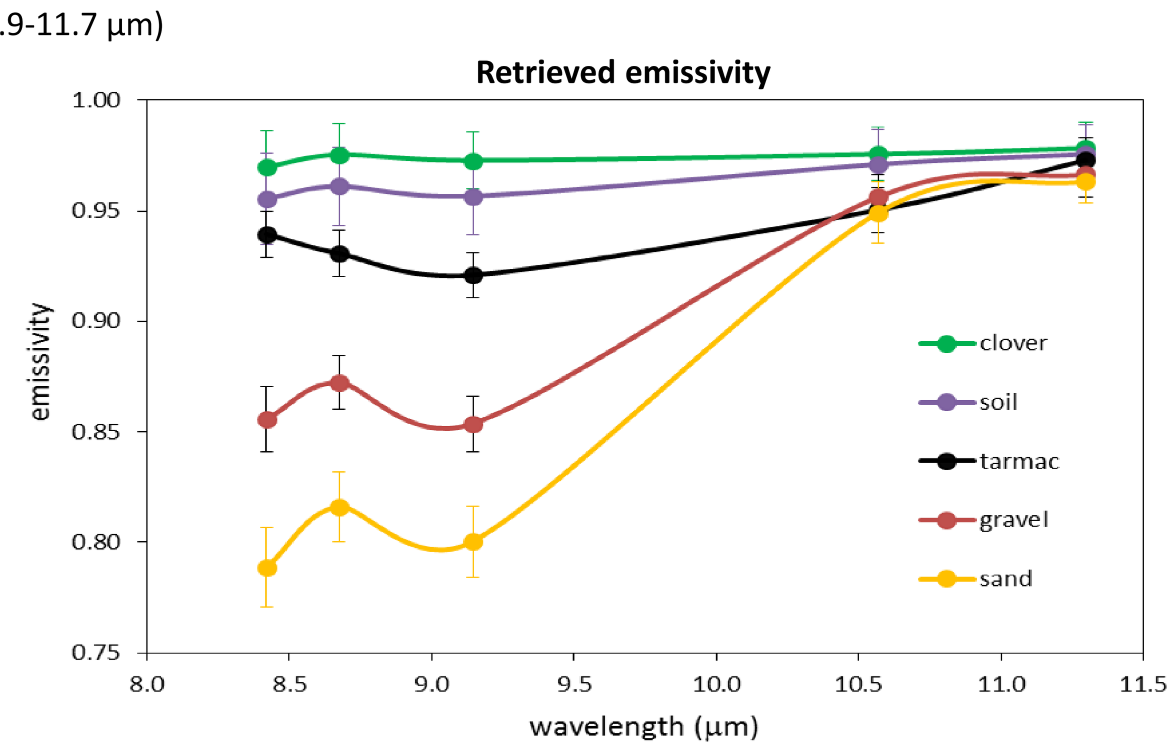
1. **Normalized emissivity method** (NEM): Assume an emissivity value ε_{NEM}=0.98 for all bands and calculate T_{NEMi} for each band ⟹ $$B_i(T_{NEMi}) = \frac{L_i^{surf} - (1-\varepsilon_{NEM}) L_i^{sky}}{\varepsilon_{NEM}}$$
2. Select the maximum value of T_{NEMi}: $T_{max} = \max(T_{NEMi})$, i=1,.., N
3. Use T_{max} to obtain a estimate of the N **NEM emissivities** ⟹ $$\varepsilon_{NEMi} = \frac{L_i^{surf} - L_i^{sky}}{B_i(T_{max}) - L_i^{sky}}$$
4. Calculate the **maximum-minimum difference** (MMD) between the band emissivities. The **minimum band emissivity** (ε_{min}) is obtained using an **empirical relationship** with the **MMD** ⟹ $$\varepsilon_{min} = 0.994 - 0.687 \times MMD^{0.737}$$
5. The NEM **emissivities are scaled** with ε_{min} and used to re-calculate T for each band. the **LST** is taken as the **maximum band temperature**

The TES method was applied to the measurements of the **5 narrow bands** of the CE-312-2 radiometers (CE1 for L_i^{surf}, CE2 for L_i^{sky}).

Results

FRM4STS LST comparison (NPL, June 2016). LST was obtained at the band with **maximum emissivity**, i. e. B2 (10.9-11.7 μm)





Emissivity in band B2 (10.9-11.7 μm)

Target	Emissivity	Uncertainty
Clover	0.978	0.011
Soil	0.976	0.013
Tarmac	0.973	0.010
Gravel	0.966	0.010
Sand	0.963	0.010

Uncertainty Budget (SOIL)

Uncertainty Contribution (SOIL)	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature (K)
Repeatability of measurement	0.012		0.03
Reproducibility of measurement	0.018		0.06
Primary calibration			0.12
Land target emissivity		0.013 in emissivity, 15% in downwelling irradiance	0.55
Angle of view to nadir		2º in vieving angle	0.02
Linearity of radiometer			0.06
Drift since calibration			0.05
Ambient temperature fluctuations			0.04
Atmospheric absorption/emission			0.02
RMS total	0.07K/0.022		**0.57**

Conclusions

- The CE-312-2 radiometers showed good accuracy and precision in the FRM4STS laboratory comparison, with **total uncertainty of 0.15 K (CE1)** and **0.12 K (CE2)** for the temperature range relevant for LST.
- The **TES method** can be applied to multiband ground radiometers to simultaneously retrieve LST and band emissivities.
- The uncertainty in the retrieved LSTs ranges between **0.4 K (clover)** and **0.6 K (soil)**, the largest source of error being the land target emissivity.

References

Gillespie, A. R., T. Matsunaga, S. Rokugawa, and S. J. Hook (1998). Temperature and emissivity separation from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) images, IEEE Transactions on Geoscience and Remote Sensing, 36, 1113-1125.
Legrand, M., C. Pietras, G. Brogniez, M. Haeffelin, N. K. Abuhassan and M. Sicard (2000). A high-accuracy multiwavelength radiometer for in situ measurements in the thermal infrared. Part I: characterization of the instrument, J. Atmos. Ocean Techn., 17, 1203-1214.
Sicard, M., Spyak, P. R., Brogniez, G., Legrand, M., Abuhassan, N. K., Pietras, C., and Buis, J. P. (1999). Thermal infrared field radiometer for vicarious cross-calibration: characterization and comparisons with other field instruments. Optical Engineering, 38 (2), 345-356.

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