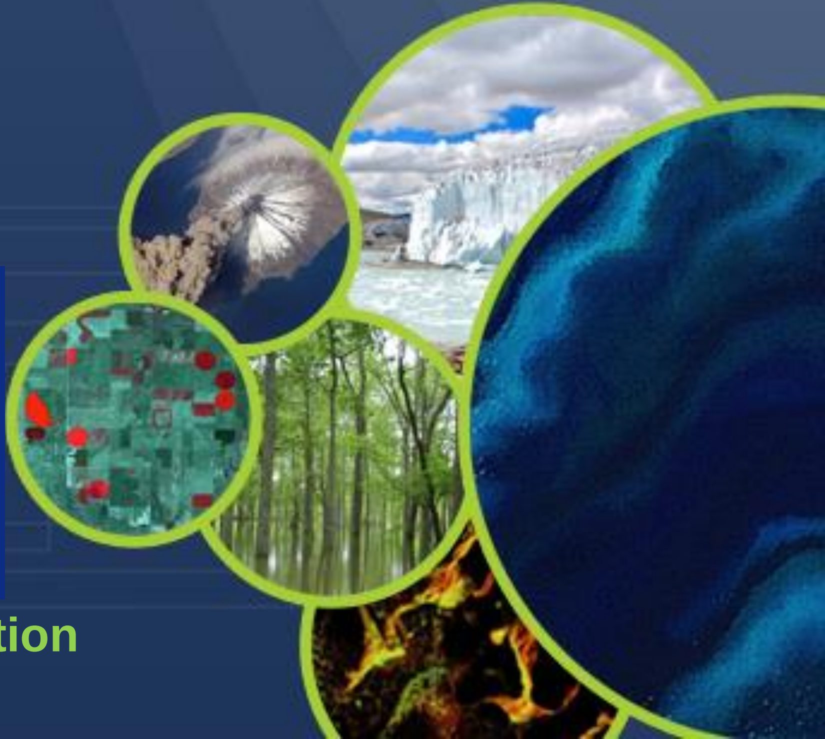
FRM4STS: Fiducial Reference measurements for validation of Surface Temperature from Satellites: Results of Lab and near lab comparisons



Working Group on Calibration and Validation

Overview of project

Aim: to establish and maintain SI traceability of global Fiducial Reference Measurements (FRM) for satellite derived surface temperature product validation and help develop a case for their long term sustainability

NOTE: Validation requires that both satellite derived measurements and 'in-situ' both have independent Uc budgets and consistency within those Uc and any additional due to comparison process is demonstrated

Requires:

- Comparisons to ensure consistency between measurement teams
- Common descriptions and evaluation of uncertainties
- Robust links to SI
- Experiments to evaluate sources of bias/uncertainty under differing operational conditions
- Encouragement of community to strive for – through provision of guidance and best practises and access to standards and comparisons
- Evidence and Publicity of benefits to ensure resources needed to maintain collection of global FRM is forthcoming

Technical objectives to achieve aims

NPL National Physical Laboratory

- Design and implement a laboratory-based comparison of the results of participants calibration processes for FRM TIR radiometers (SST, LST, IST and others)
- Design and implement a laboratory-based comparison to verify TIR blackbody sources used to maintain calibration of FRM TIR radiometers.
- Design and implement field inter-comparisons of SST using pairs of FRM TIR radiometers on board ships to build a database of knowledge over a several years.
- Conduct field-campaigns for FRM TIR of LST.
- Develop a set of best practise protocols for the calibration, operation and performance of FRM of Surface temperatures.
- Conduct a full data analysis, derivation and specification of uncertainties, following agreed NMI protocols on all data collected as part of FRM4-CEOS i.e. establish full SI traceability.
- Publish all outcomes and results in an open and transparent manner using peer reviewed and other grey literature to promote benefits of Cal/Val.
- Perform a study of means to establish traceability and potential benefits to satellites validation and CDRs of high accuracy Ocean temperature measurements using buoys and similar floating systems.

Fiducial?

What are Fiducial Reference Measurements?

*"The suite of independent ground measurements that provide the maximum return on investment for a satellite mission by delivering, to users, the required confidence in data products, in the form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission" (*Sentinel-3 Validation Team)

An FRM must:

- Have documented evidence of its degree of consistency for its traceability to SI through the results of round robin inter-comparisons and calibrations using formal metrology standards
- Be independent from the satellite geophysical retrieval process
- Have a detailed uncertainty budget for the instrumentation and measurement process for the range of conditions it is used over.
- Adhere to community agreed measurement protocols, and management practises.

The key element: Comparisons

Necessary Confidence that measurements can be considered as 'FRM' must come from evidence derived from comparisons, which must include the means to link to SI at the highest level possible (depending on application).

We will include standards from two NMIs (NPL and PTB)

Undertake comparisons in:

- Well-controlled laboratory conditions   (radiometers and associated travelling calibration sources)
- Quasi-controlled external conditions – to evaluate effects of environment (particularly sky brightness)
- Field-based operational conditions – Land & Ocean (proposed extension to Ice)

Context

- **Launch of Sentinel 3 and its Post Launch Validation**

- **Copernicus program and validation of satellite series**
  - **Facilitating resources for a long term program**

- **Climate Change Initiative and CDRs**

- **International coordinated infrastructure for CEOS (WGCV & VC-SST) (note: for WGCV IVOS and LPV)**

- **Encouragement of validation teams, capacity building and training**
  - **Community best practises**
  - **Uncertainty estimation and analysis**

- **Fourth in ~ 5 yrly (Miami) series of CEOS SST comparisons (Miami 3 also organised by NPL (in UK and USA)**
  - **First for LST field campaign (some instruments included in Miami 3)**

fiducial reference temperature measurements

(13 participants / 4 Continents)

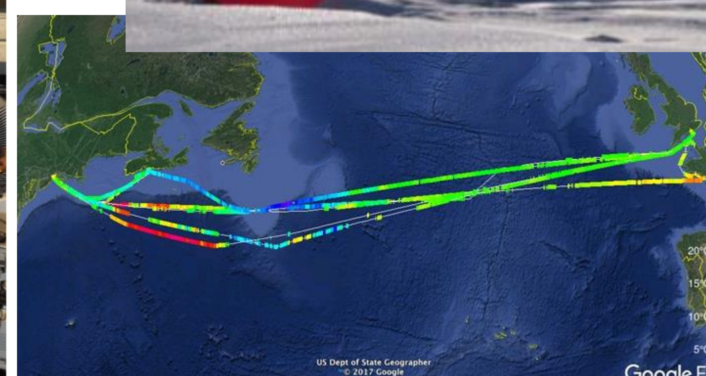
NPL National Physical Laboratory

CEOS esa

1. Miami University (USA)
2. ONERA (France)
3. University of Valencia (Spain)
4. University of Southampton (UK)
5. Qing Dao (China) -1
6. Qing Dao (China) -2
7. RAL (UK)
8. CSIRO (Australia)
9. KIT (Germany)
10. DMI (Denmark)
11. GOTA (Canary Islands
12. JPL NASA (USA)
13. Ian Barton (Australia)

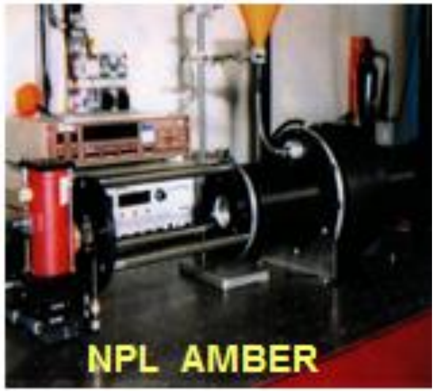







SI traceability: LCE (June 2016)

Necessary for all participants to assess biases to SI under Laboratory conditions



ITS-90

T= ~250 – 325 K
Non-vacuum

NPL BB

PTB BB

NPL Rad (AMBER)

PTB Rad

Rad 1 | Rad 2 | Rad 3 | Rad 4 | Rad n

BB1 | BB 2 | BB 3 | BB 4 | BB n

Room Environment with variable T

The 2016 blackbody lab comparison

20th to 24th June 2016

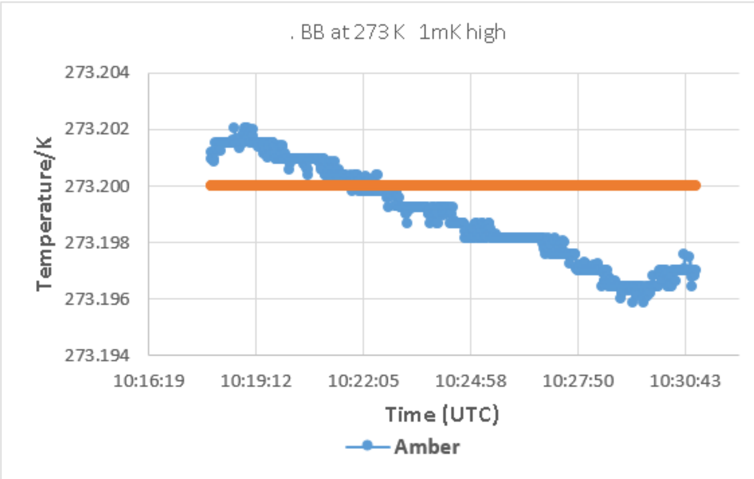
BB comparison (June 2016)

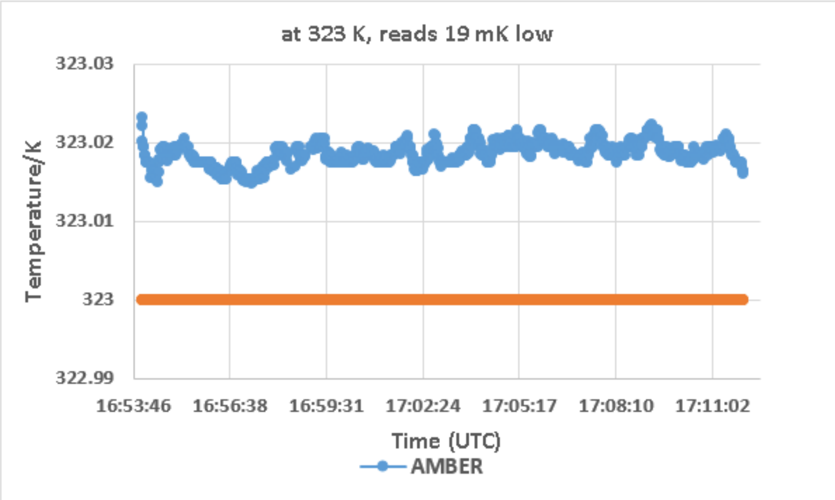
NPL National Physical Laboratory

1. Miami University - USA
2. ONERA - France
3. University of Valencia- Spain
4. University of Southampton - UK
5. Qing Dao -China
6. RAL - UK
7. CSIRO - Australia

8. KIT- Germany

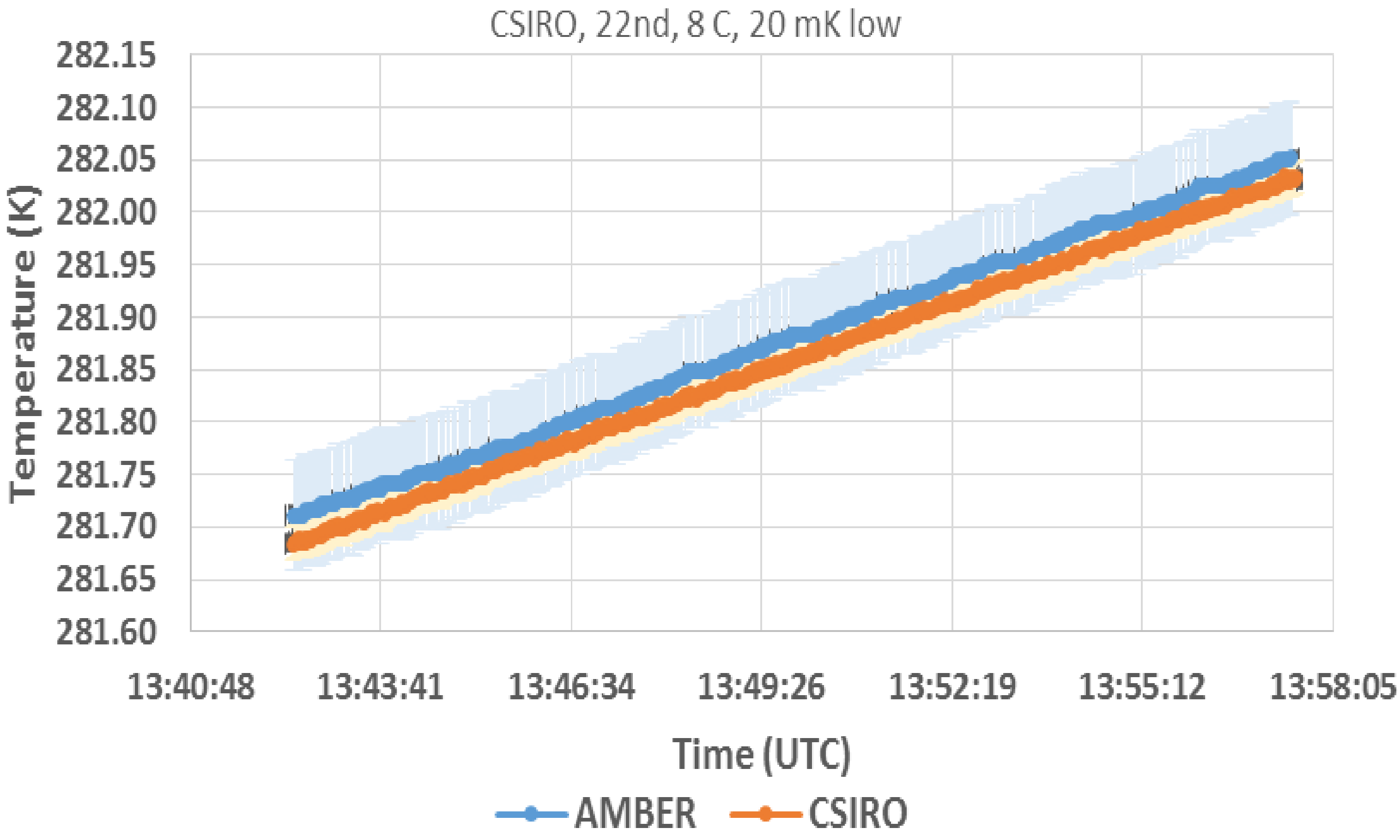
273 K to 323 K   (0 to 50 °C)



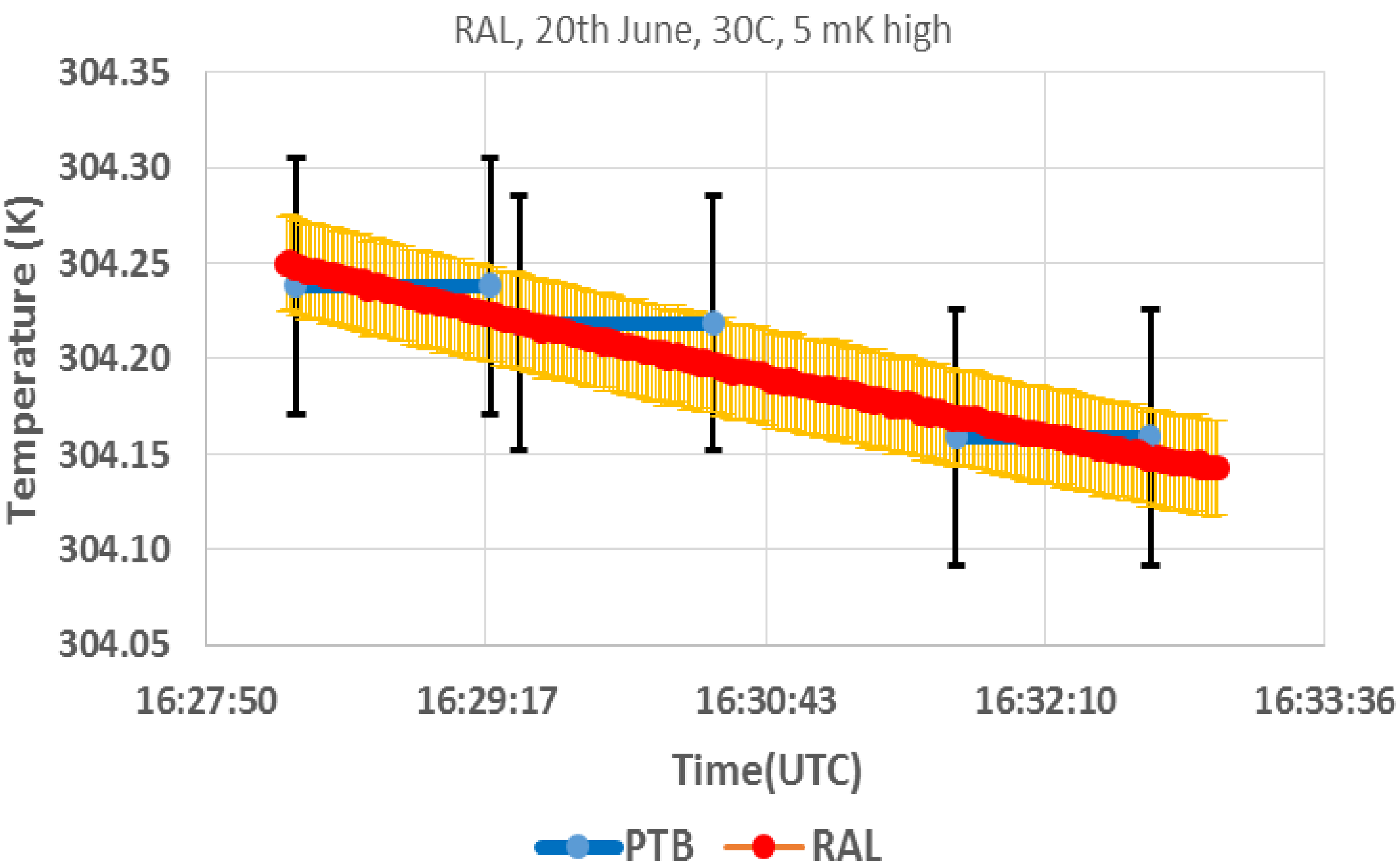


fiducial reference temperature measurements

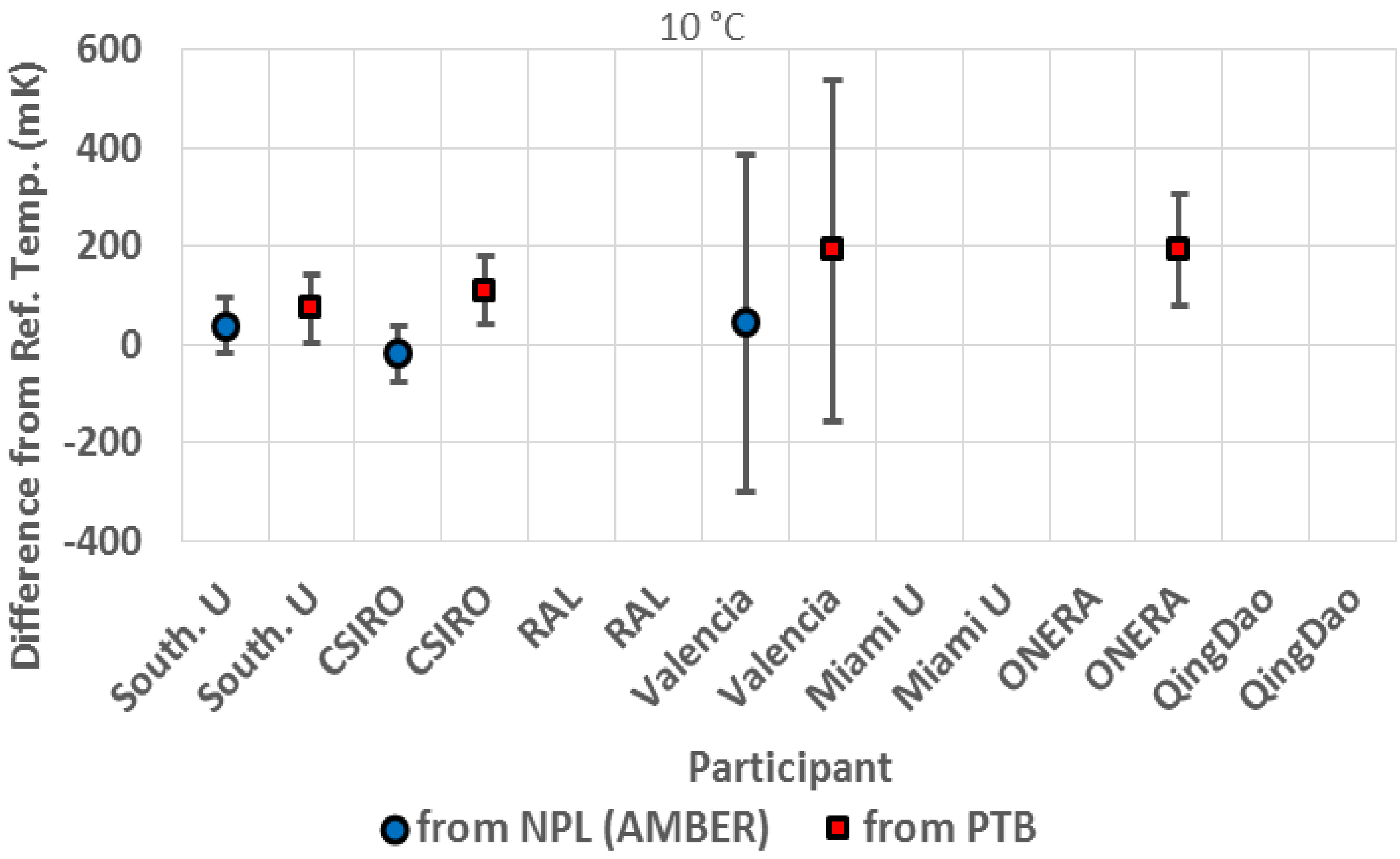
Measurements (as a function of time) reported by the CSIRO blackbody as well as the temperature of the same blackbody measured by the AMBER radiometer.



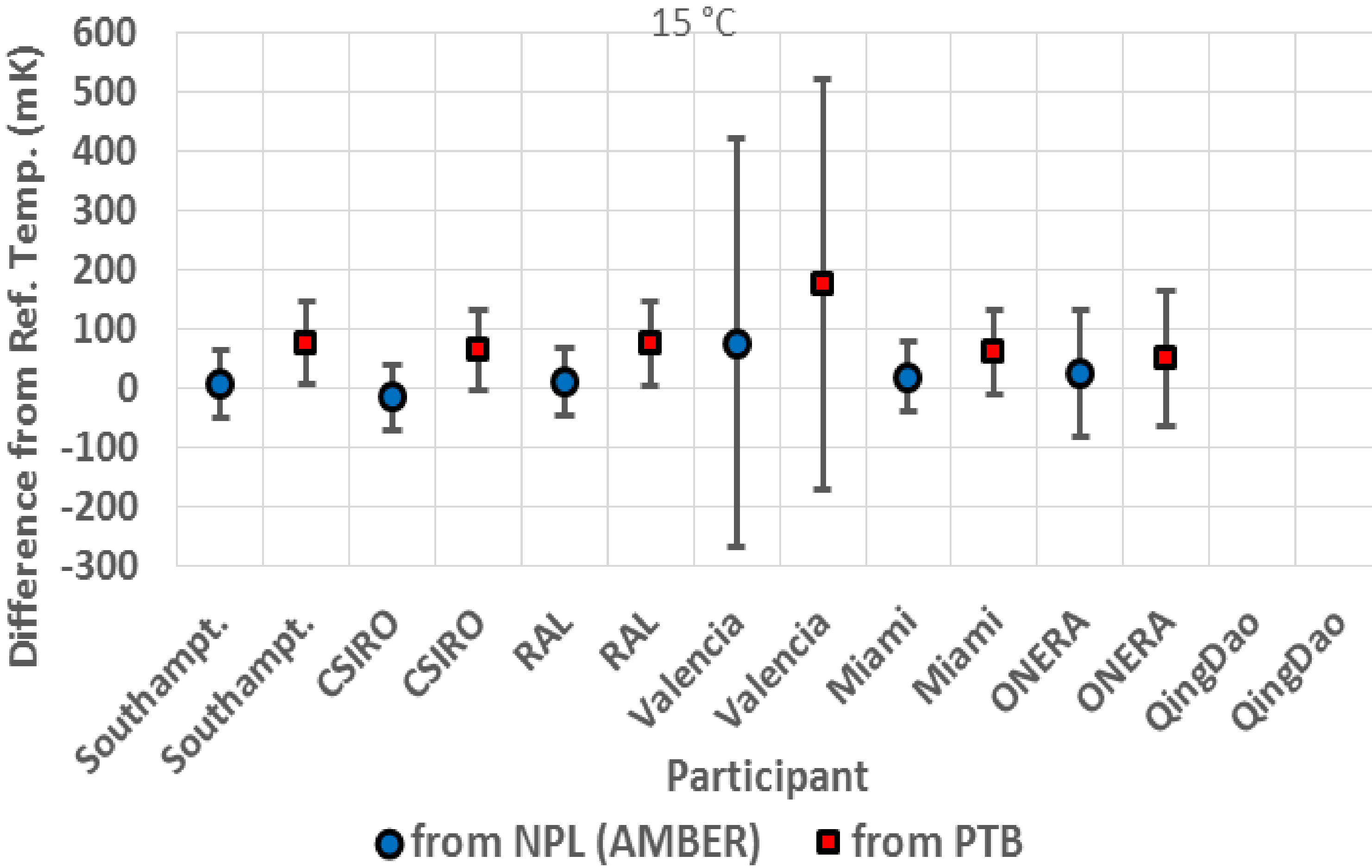
Measurements (as a function of time) reported by the RAL blackbody as well as the temperature of the same blackbody measured by the PTB IR radiometer.



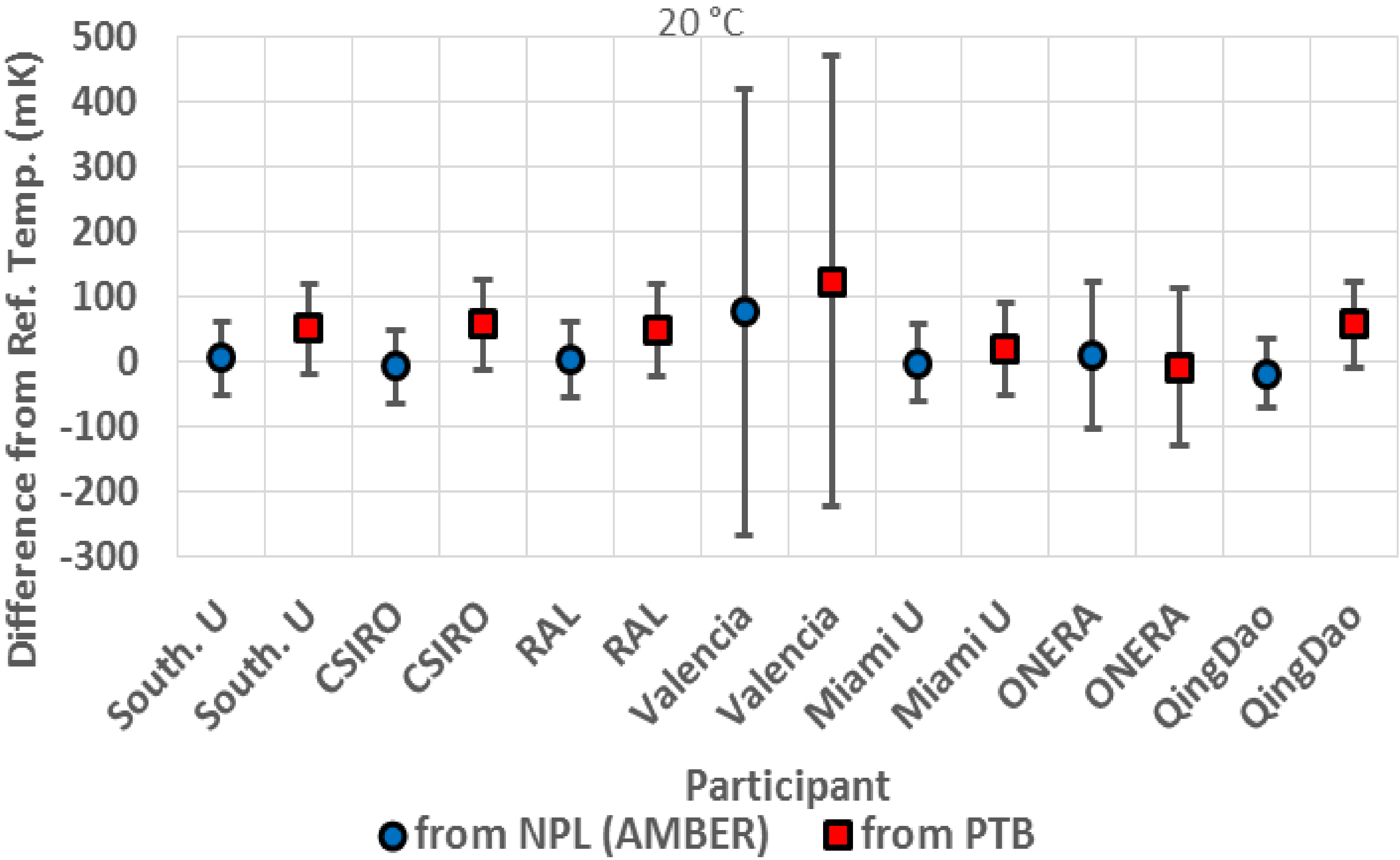
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 10 ºC.



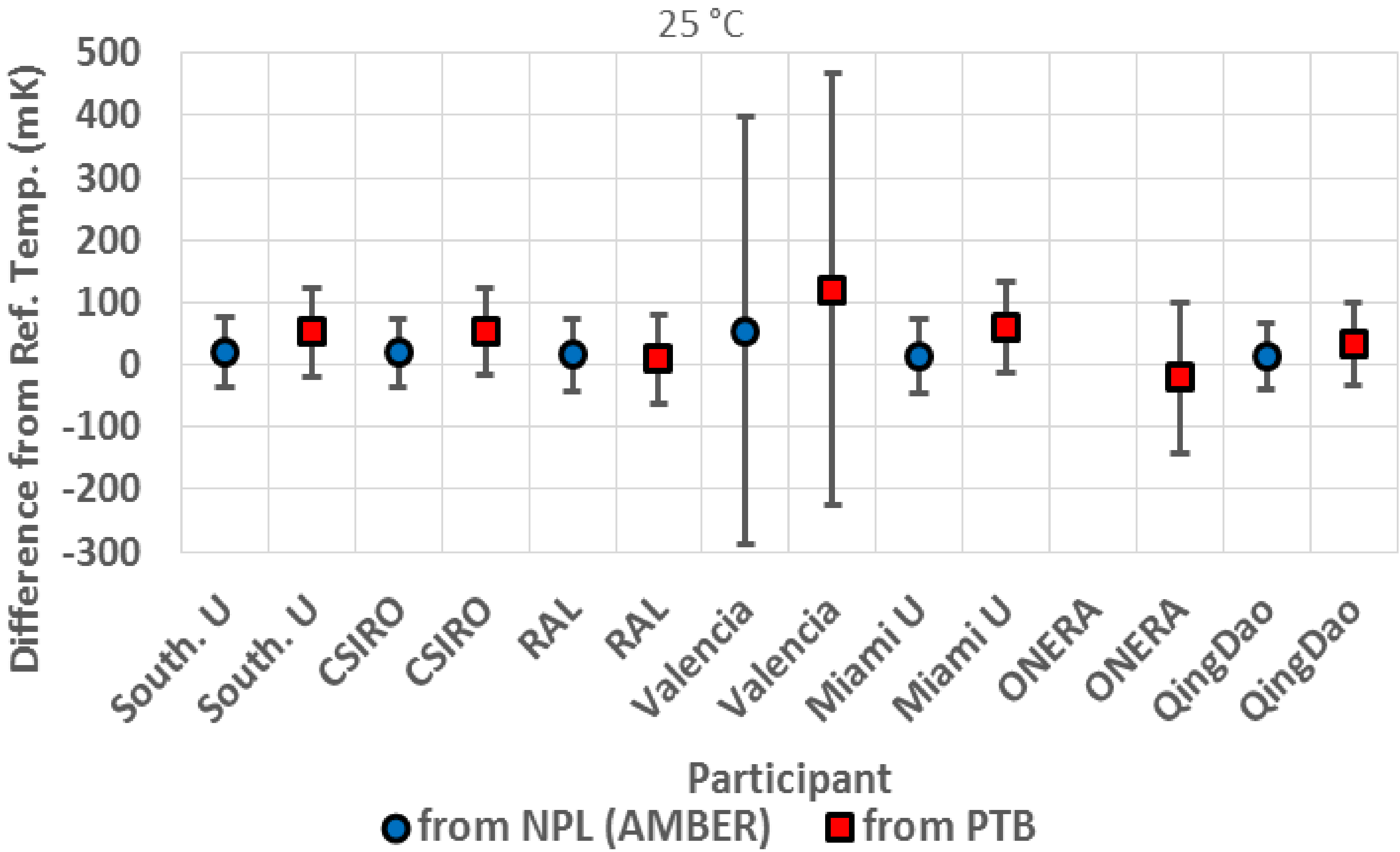
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 15 ^{o}C.



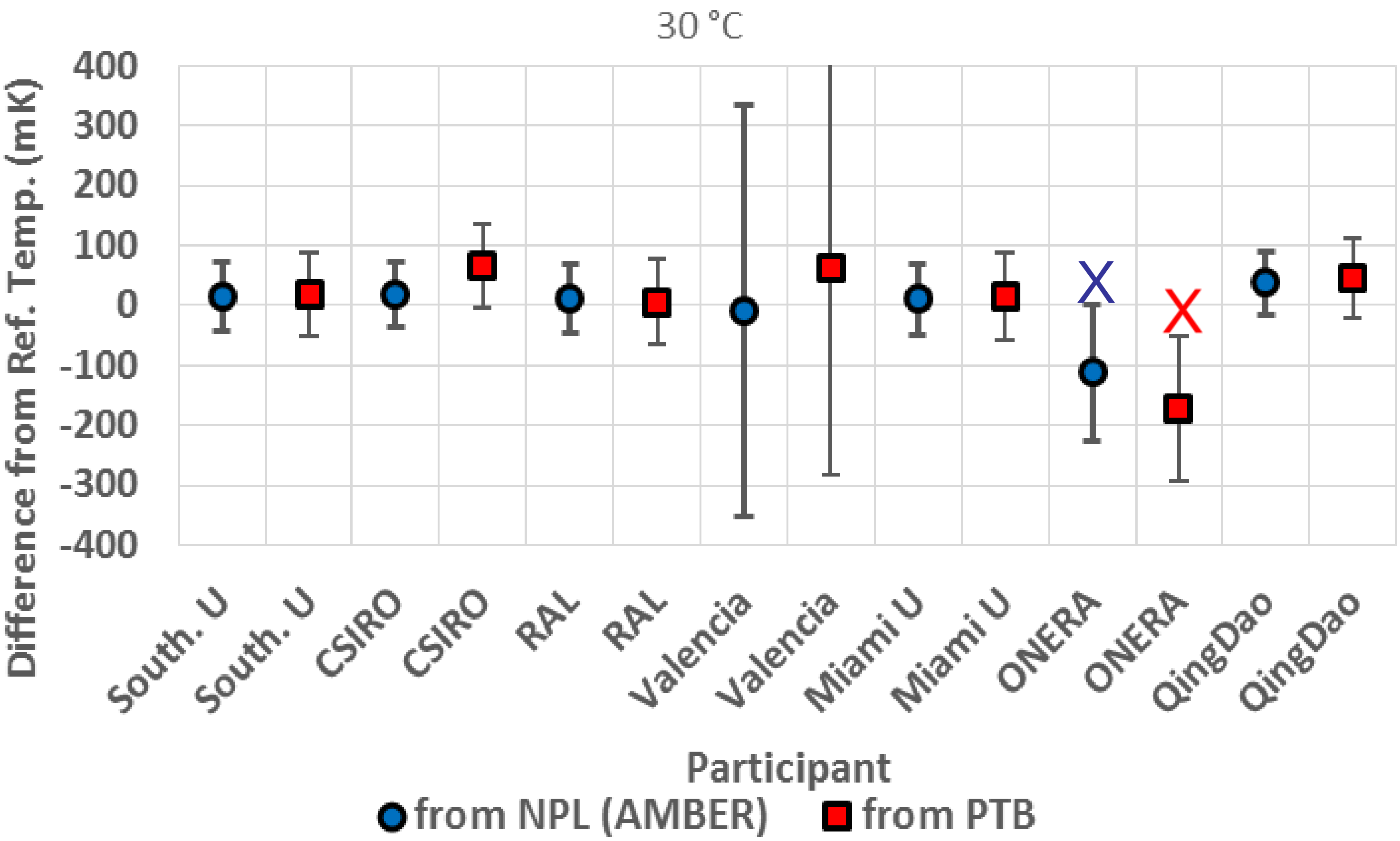
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 20 ºC.



Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 25 °C.

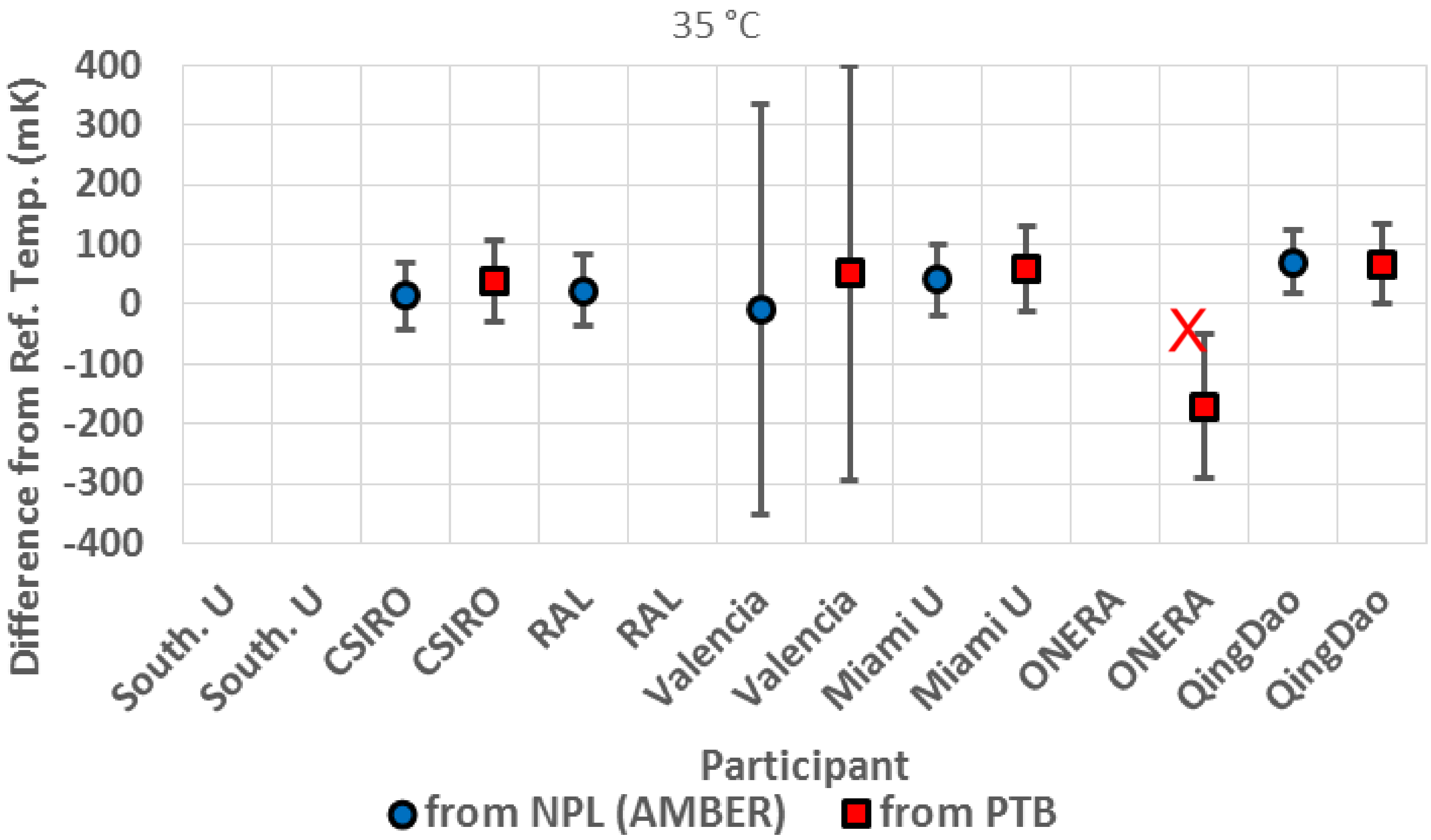


Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 30 °C.

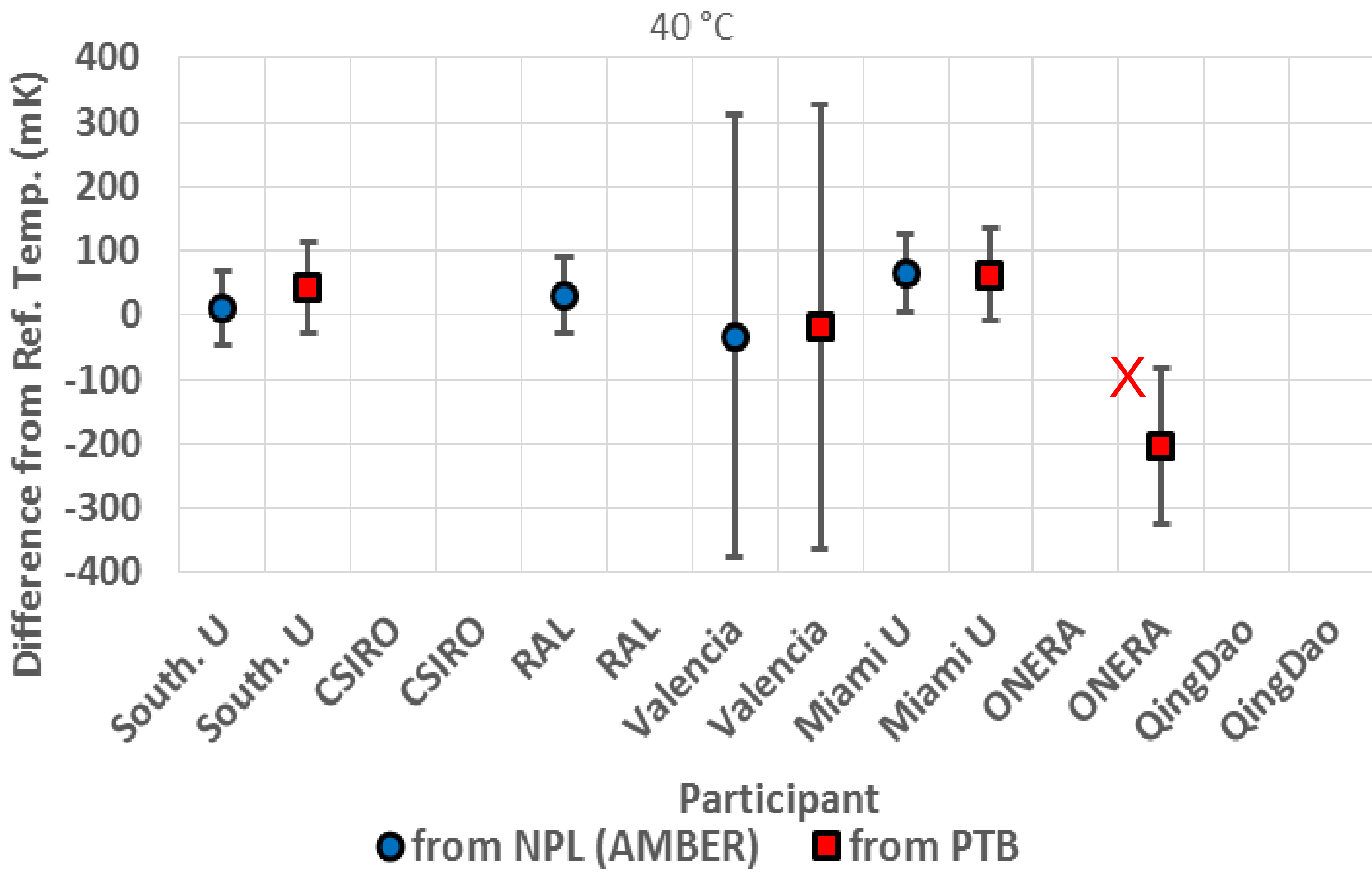


Note initial error in interpretation of manufacturers calibration of ONERA BB

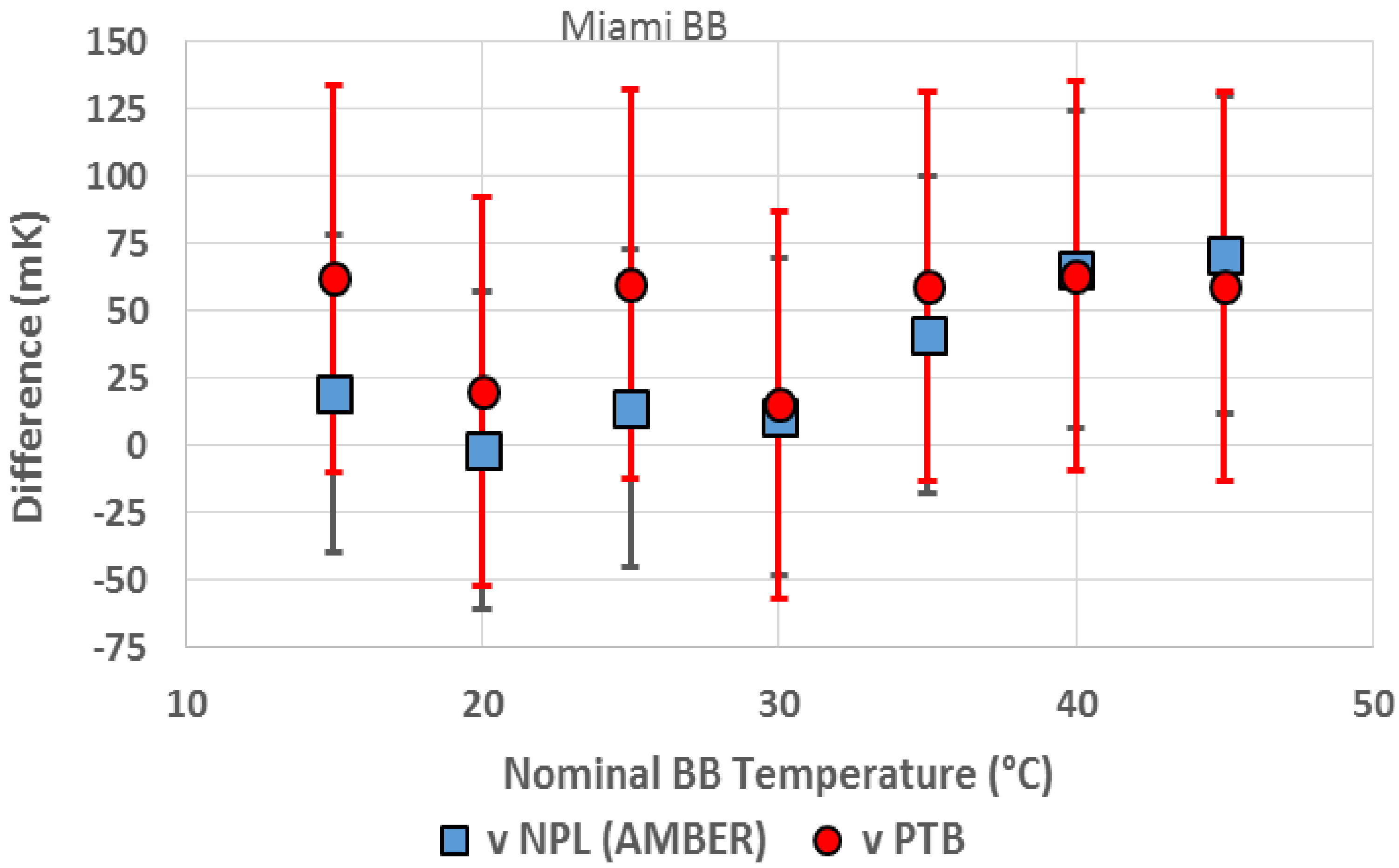
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 35 ºC.



Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 40 °C.



Difference between the mean of the measurements reported by the Miami University blackbody and the mean of the temperatures measured by AMBER (shown in blue) and PTB (shown in red) at nominal blackbody temperatures.



The 2016 radiometer lab comparison

20th to 24th June 2016

Radiometer comparison

NPL
National Physical Laboratory

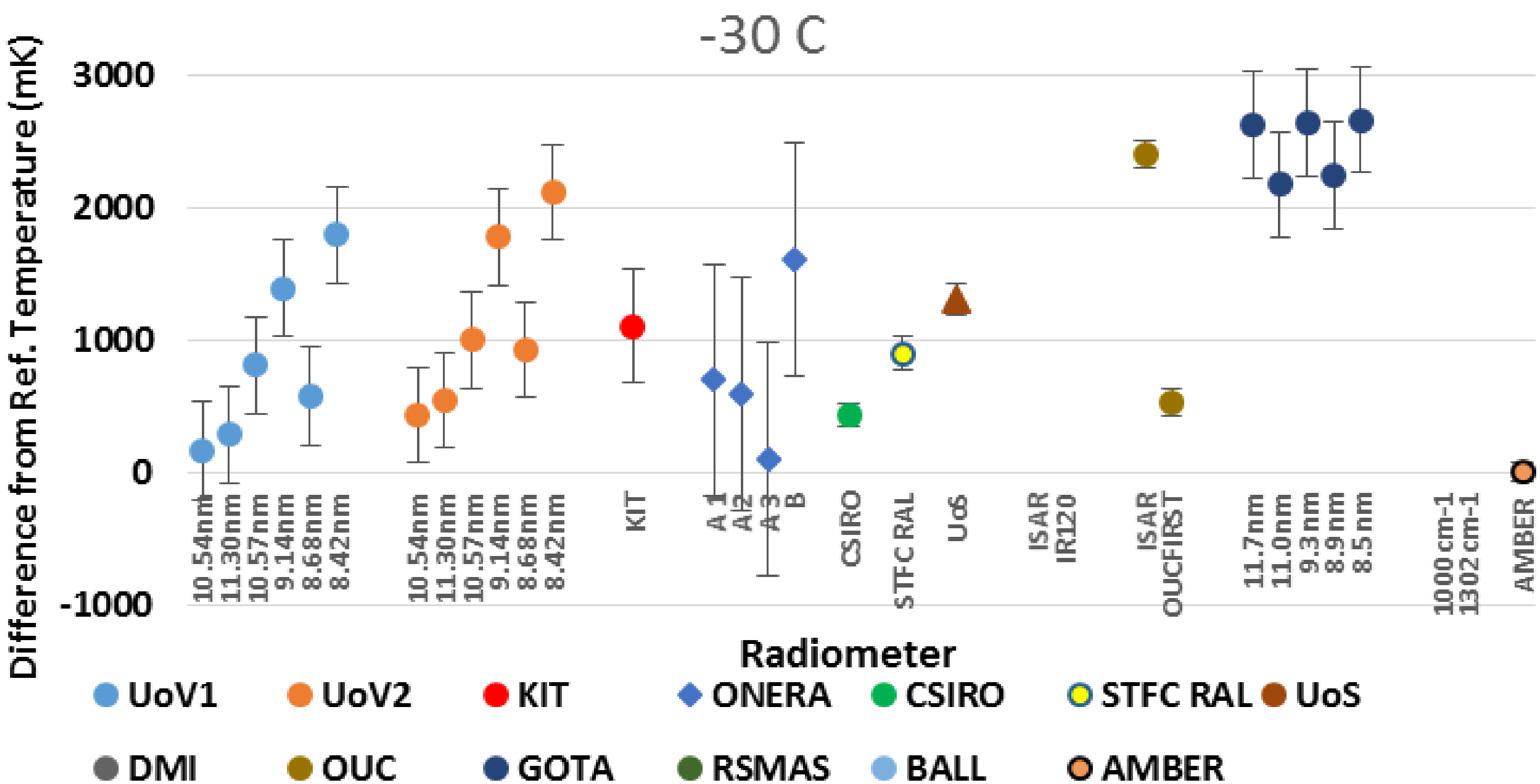
1. Miami University (USA)
2. ONERA (France)
3. University of Valencia (Spain)
4. University of Southampton (UK)
5. Qing Dao (China) -1
6. Qing Dao (China) -2
7. RAL (UK)
8. CSIRO (Australia)
9. KIT (Germany)
10. DMI (Denmark)
11. GOTA (Canary Islands
12. JPL NASA (USA)
13. Ian Barton (Australia)

MAERI (UofM) viewing NPL ammonia Heat pipe

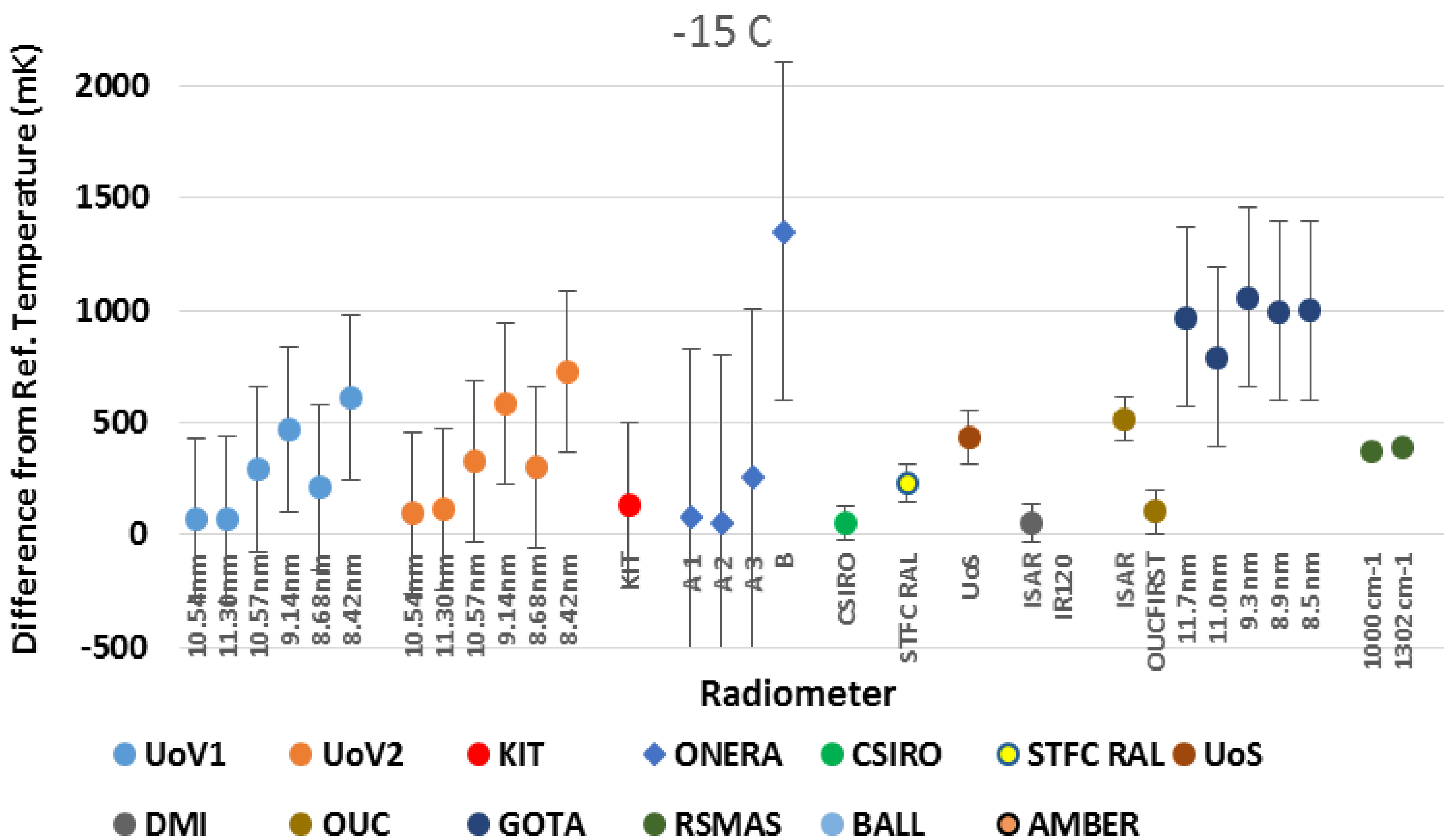
SISTER (RAL) viewing NPL ammonia Heat pipe

240 K to 318 K

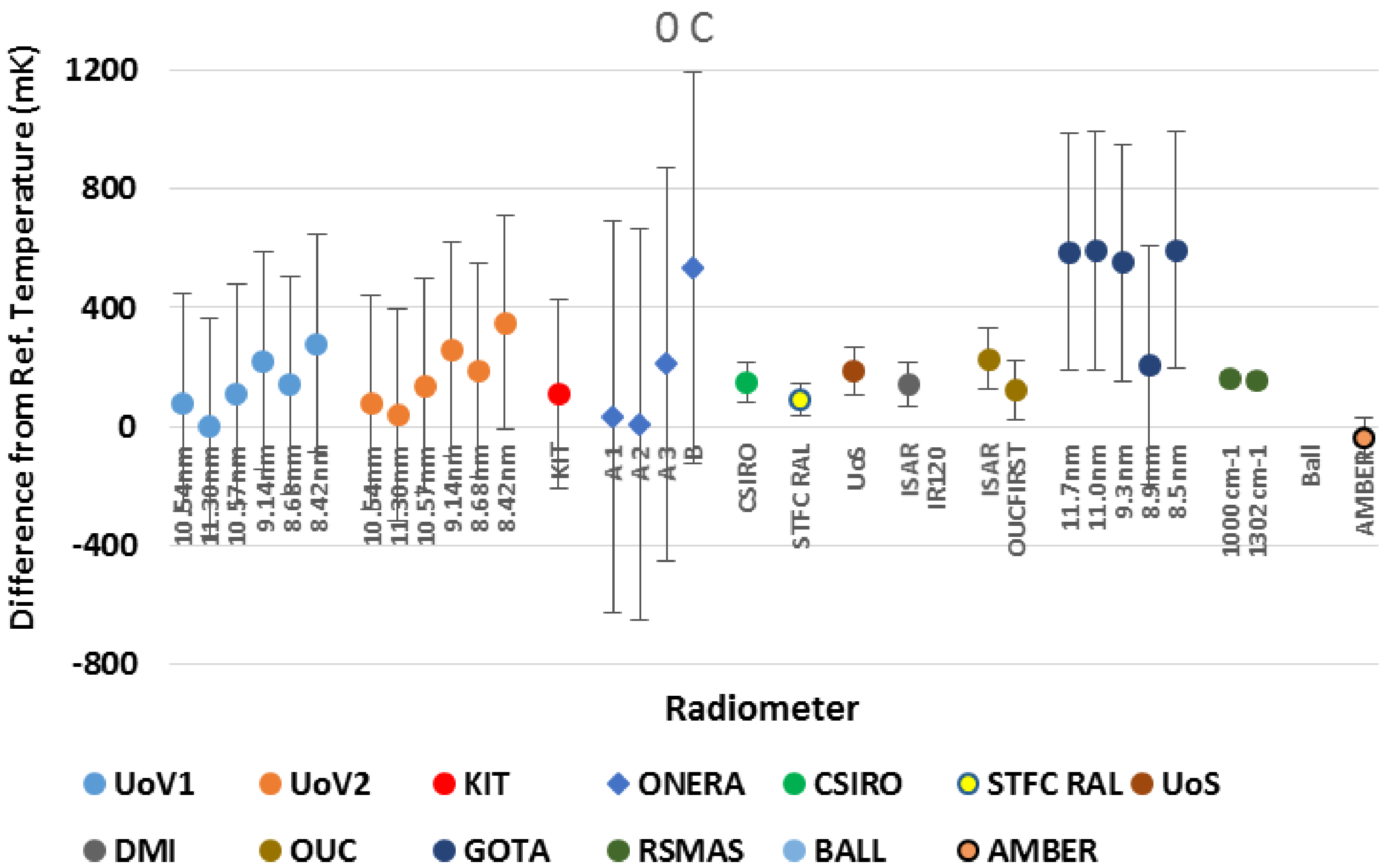
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of -30°C.



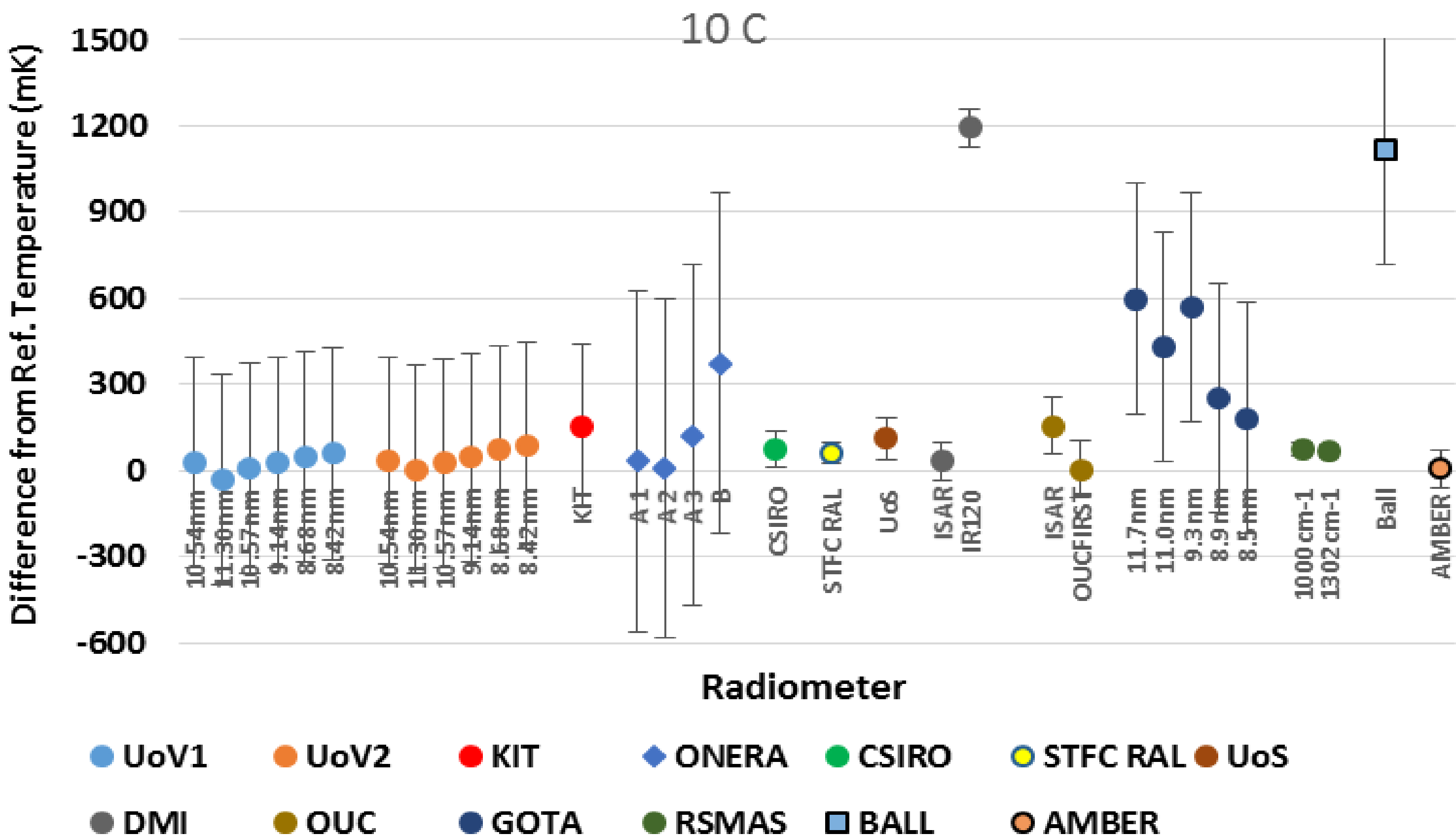
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of -15°C.



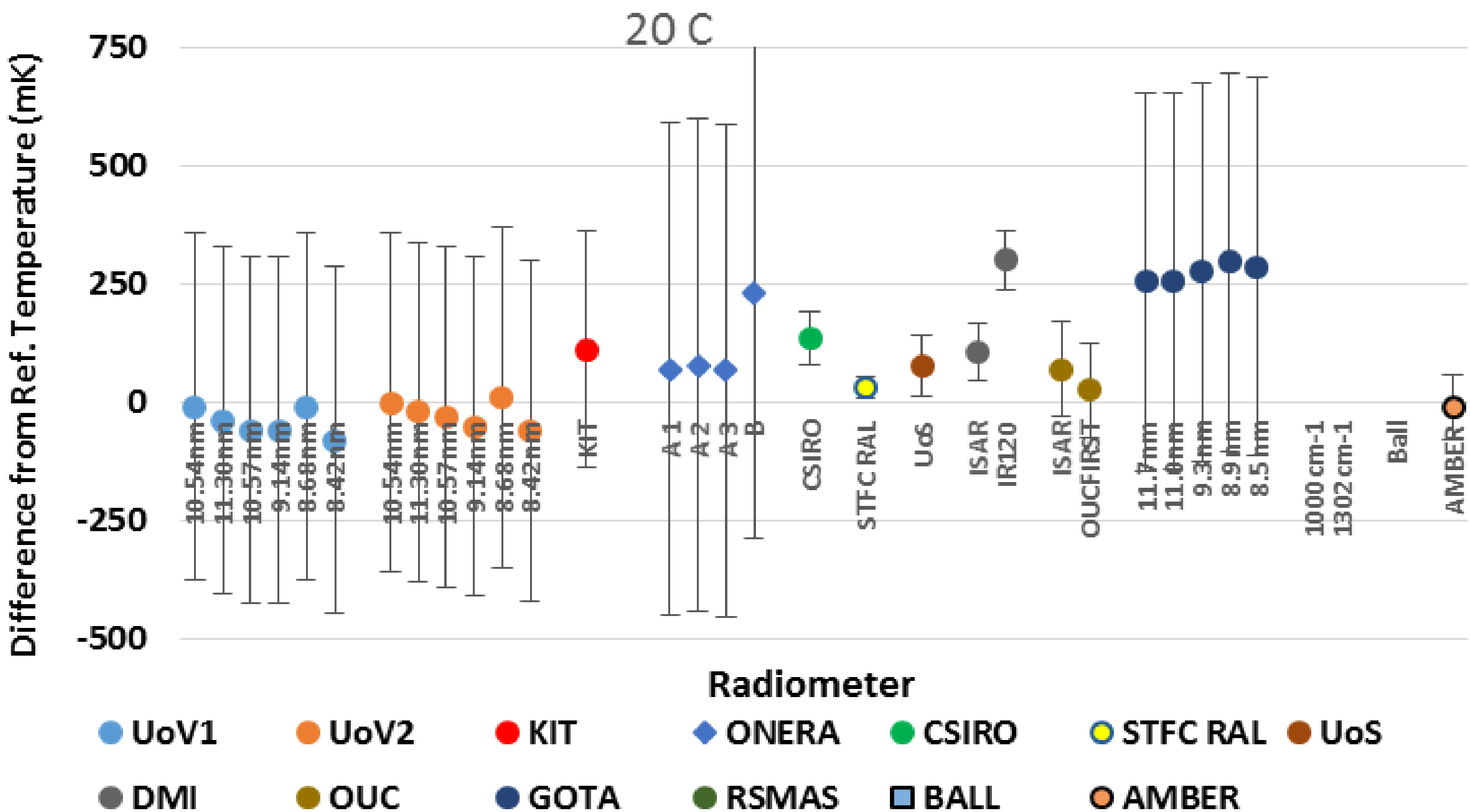
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 0°C.



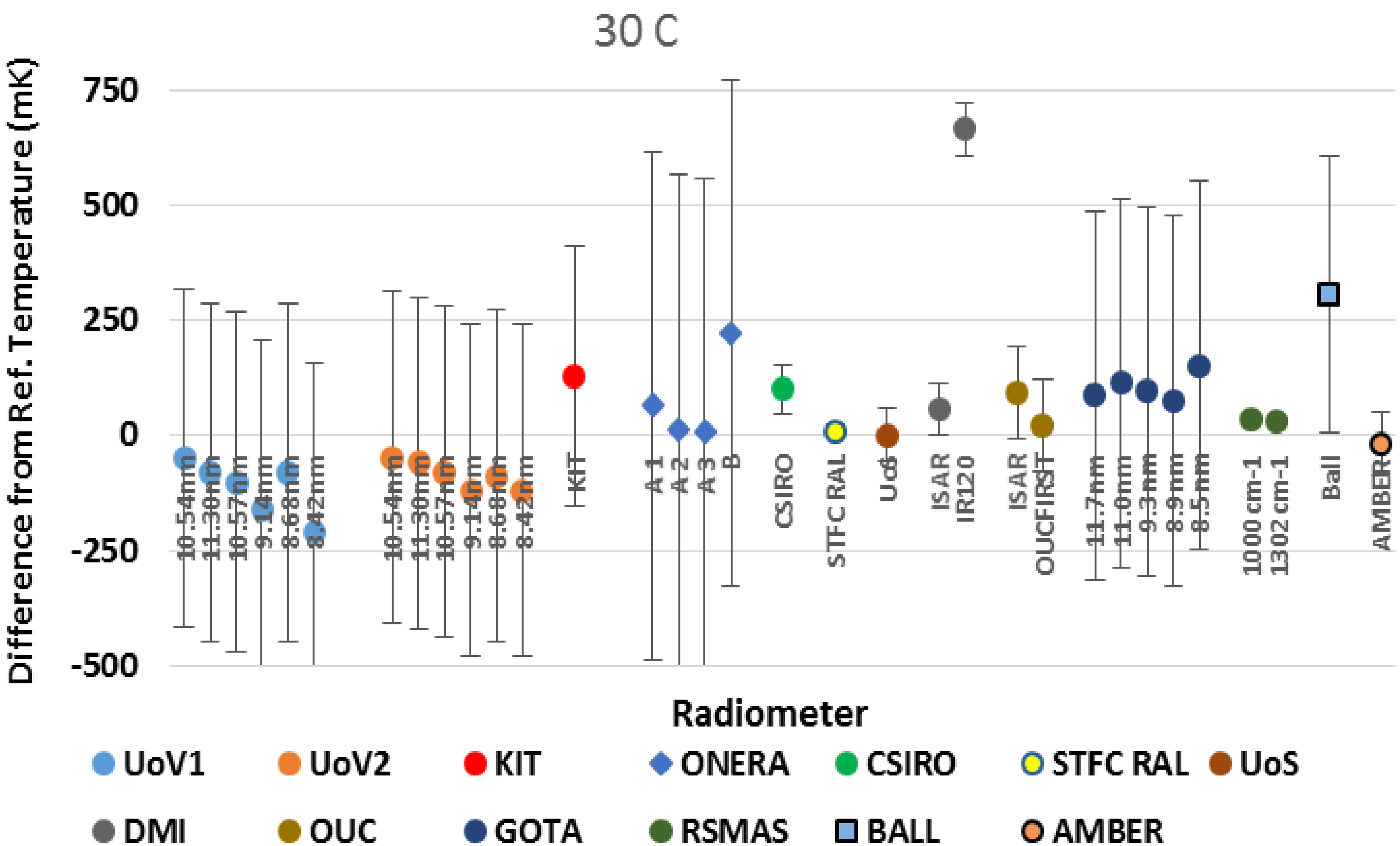
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 10°C.



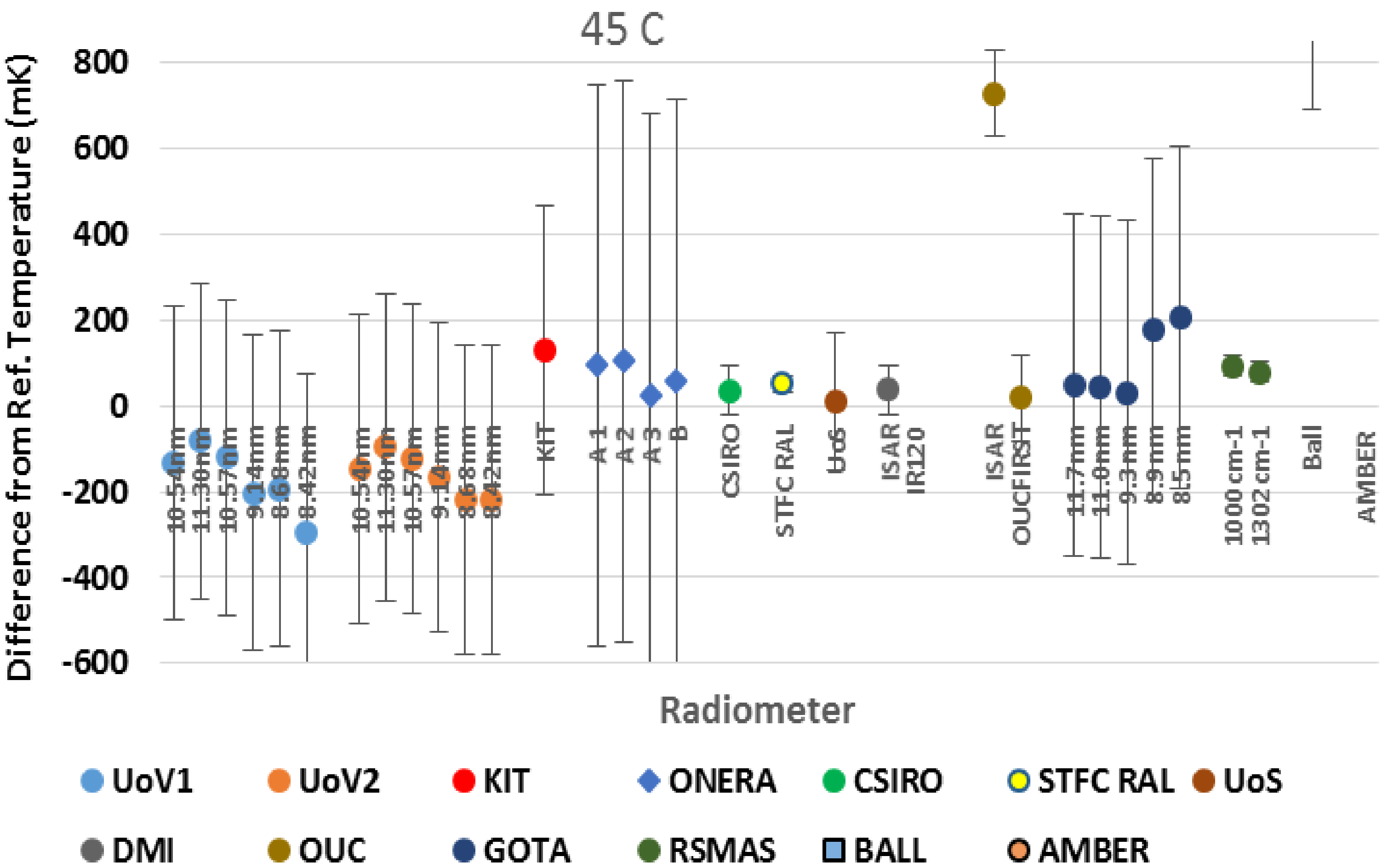
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 20°C.



Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 30°C.



Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 45°C.



The 2016 WST comparison at Wraysbury reservoir

27th June to 1st July 2016

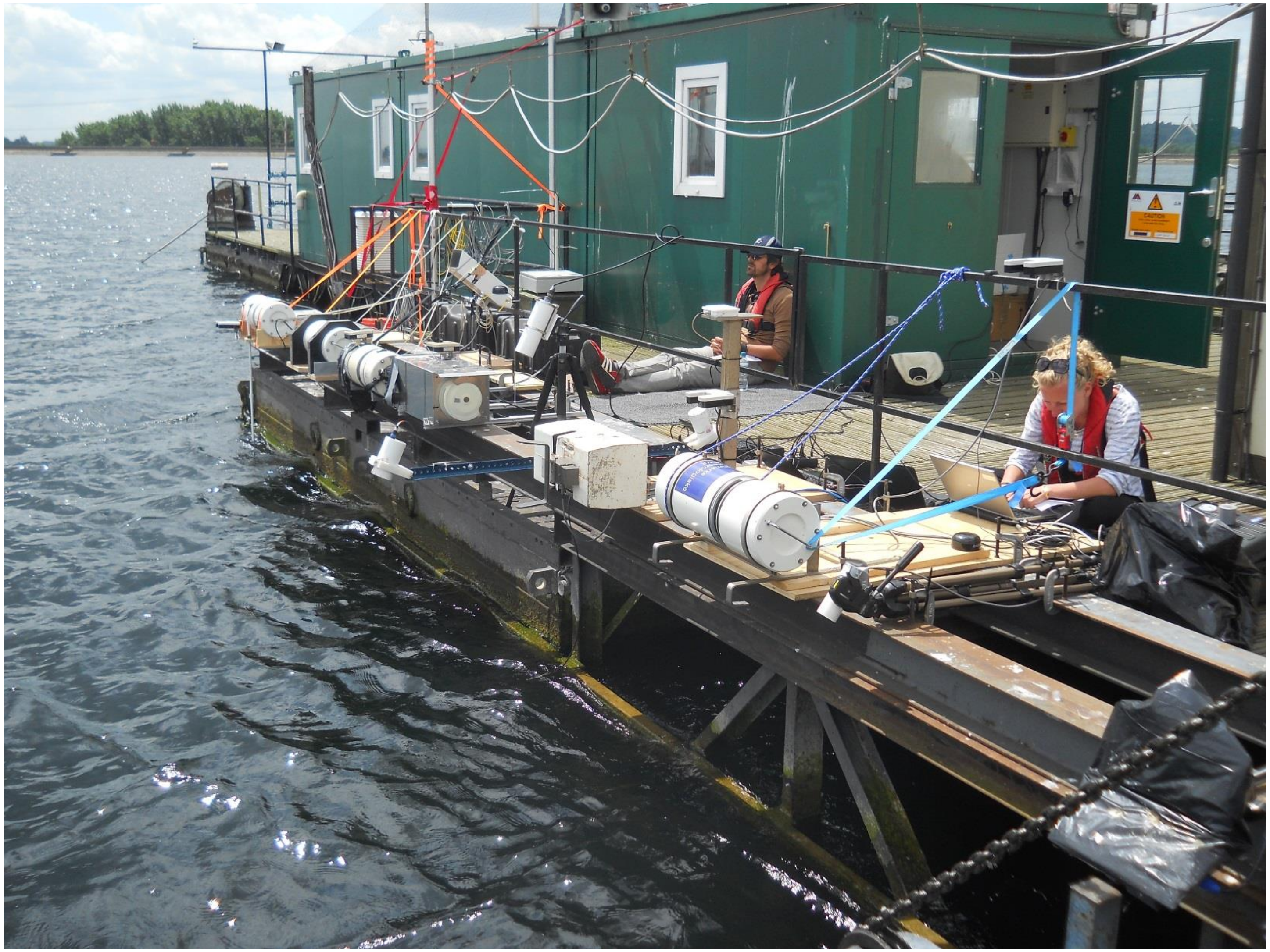
NPL National Physical Laboratory

WST comparison

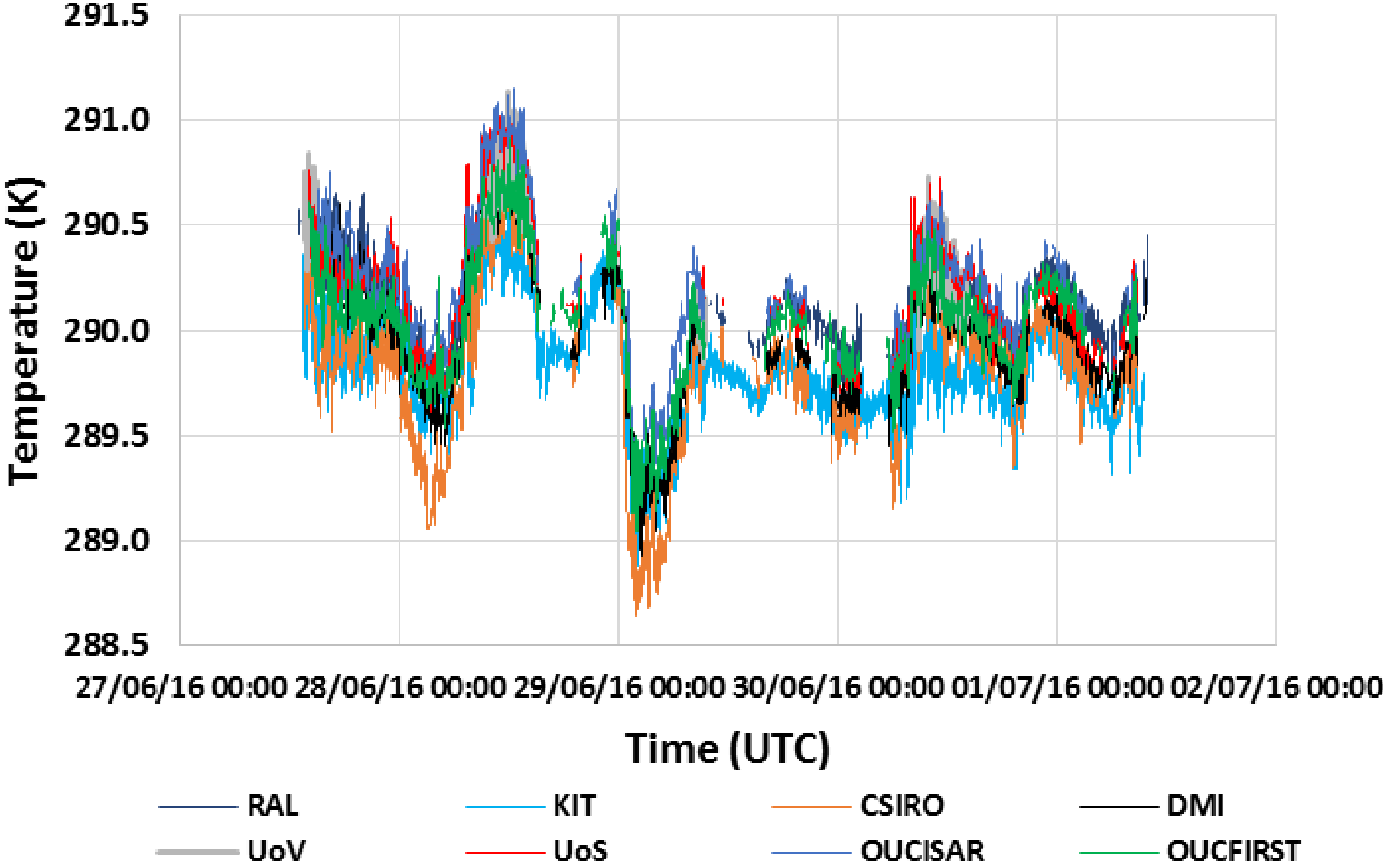
1. University of Valencia (Spain)
2. University of Southampton (UK)
3. Qing Dao (China) -1
4. Qing Dao (China) -2
5. RAL (UK)
6. CSIRO (Australia)
7. KIT (Germany)
8. DMI (Denmark)
9. GOTA (Canary Islands)
10. JPL NASA (USA)

Wraysbury reservoir with the platform on which the radiometers were mounted located in the middle of the reservoir

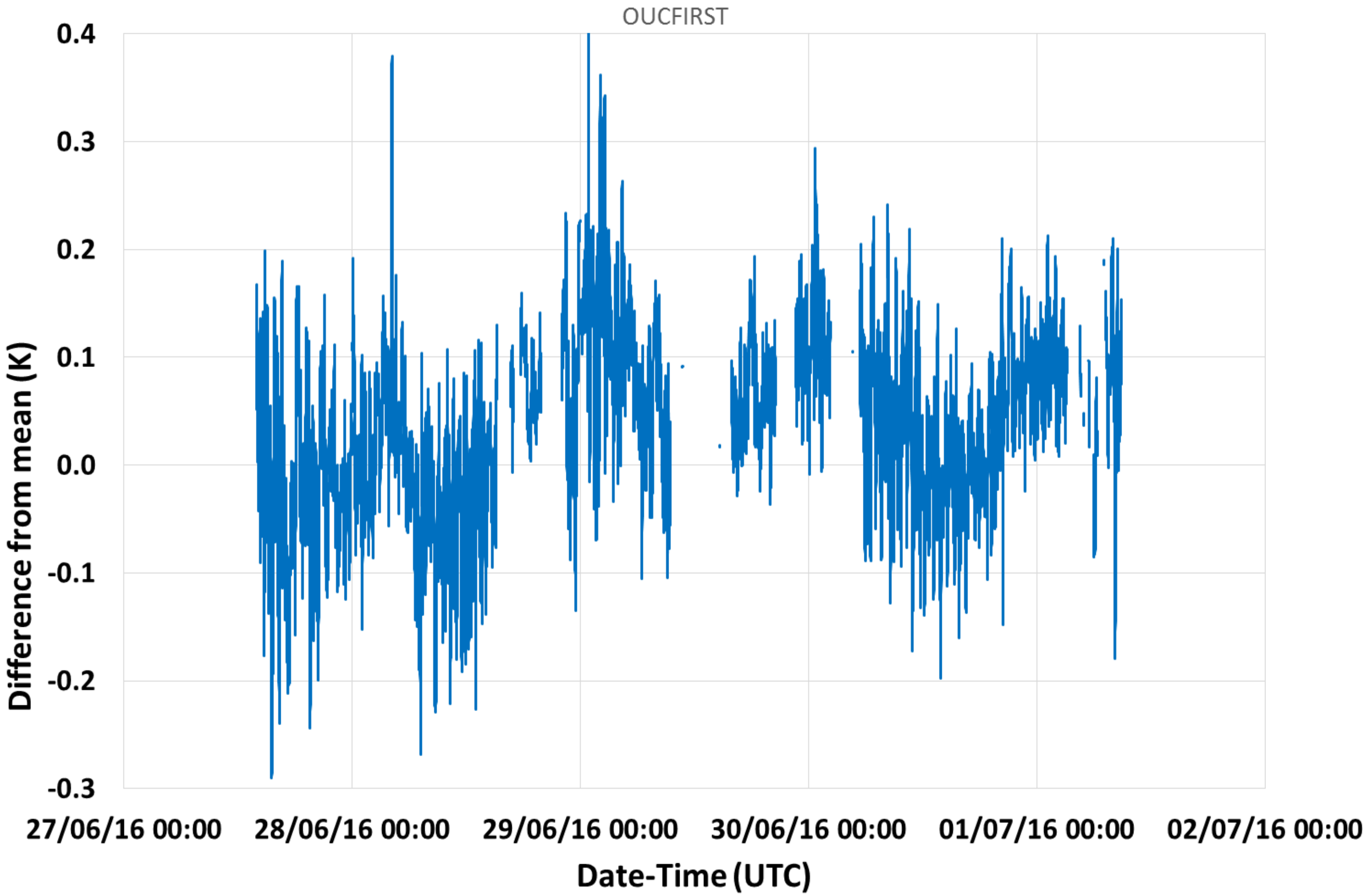
Radiometers measuring WST during the 2016 comparison



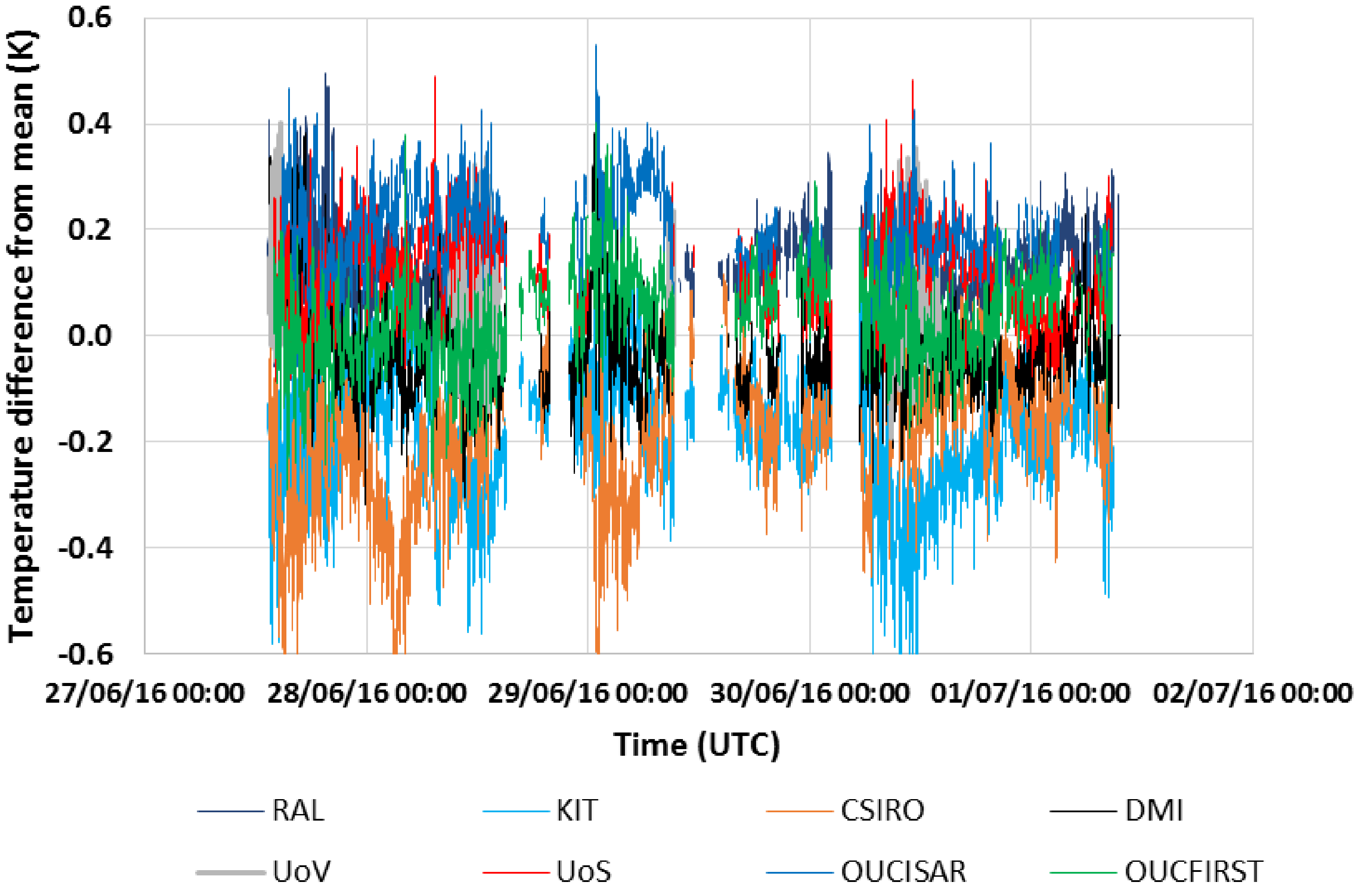
WST measurements of the various participants, over the five-day comparison period



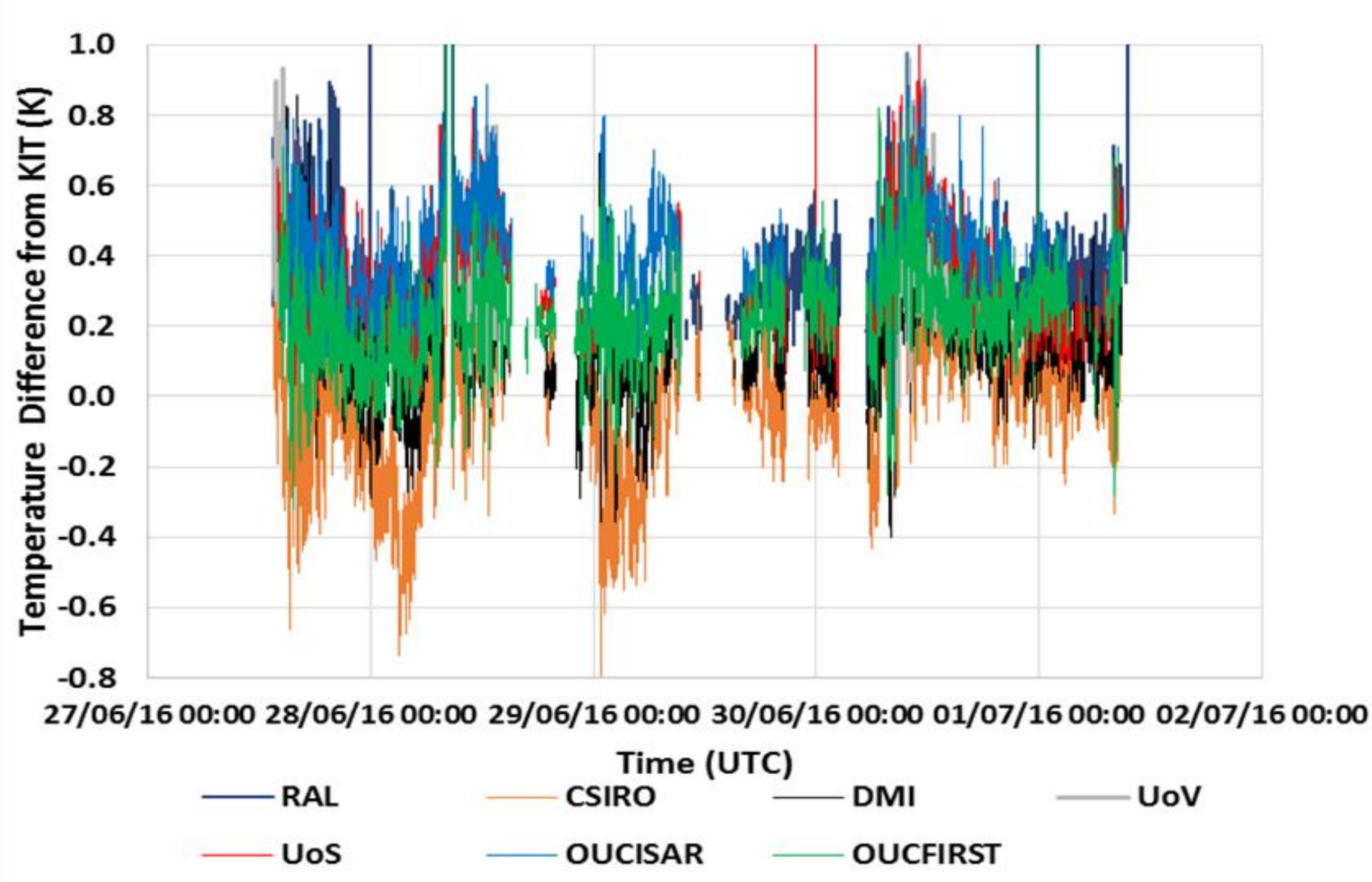
Difference of the measurements of the water surface temperature of Wraysbury reservoir made by the OUCFIRST radiometer and the mean of all measurements made over the five day period



Plot of the difference of the WST measurements of the various participants from their arithmetic mean, over the five-day comparison period.



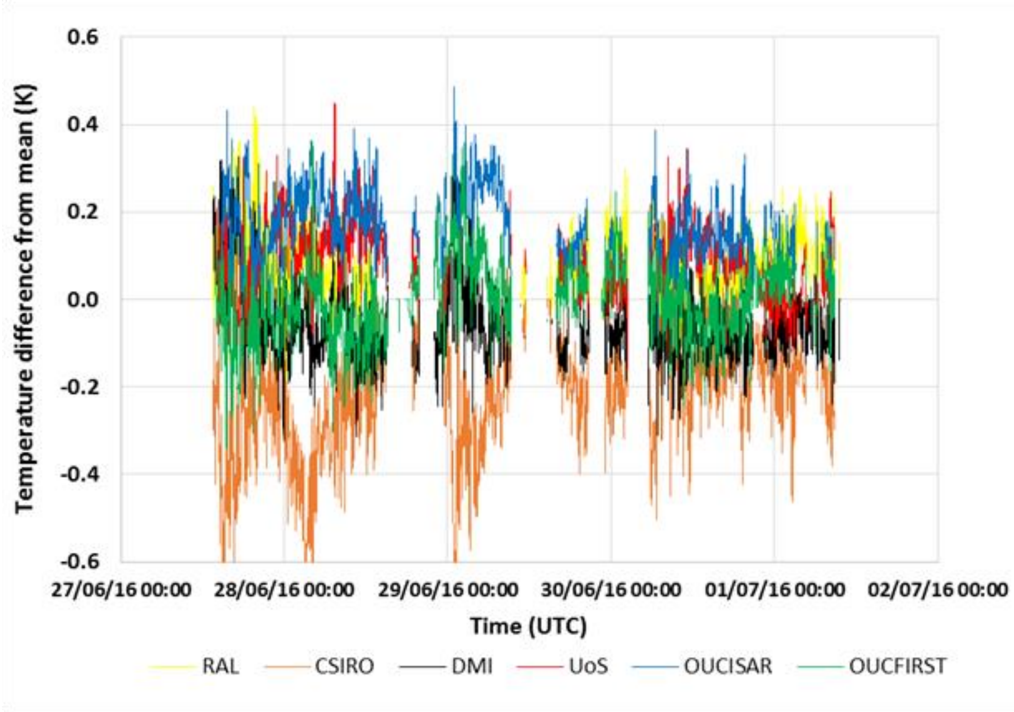
Plot of the difference of the WST measurements of the various participants, from the measurements provided by KIT, over the five-day comparison period.



Difference of the mean of the average of the 10 radiometers who participated in the WST comparison averaged over the five-day measurement period from the mean of the measurements of each radiometer averaged over the same five day period.

Radiometer	Mean difference from the mean (^{o}C)
STFC RAL	0.123
KIT	-0.159
CSIRO	-0.189
DMI	-0.020
UoV	0.117
UoS	0.125
OUCFIRST	0.033
OUC-ISAR	0.206
GOTA	0.593
JPL	-0.109

Difference from mean for SST designed radiometers only



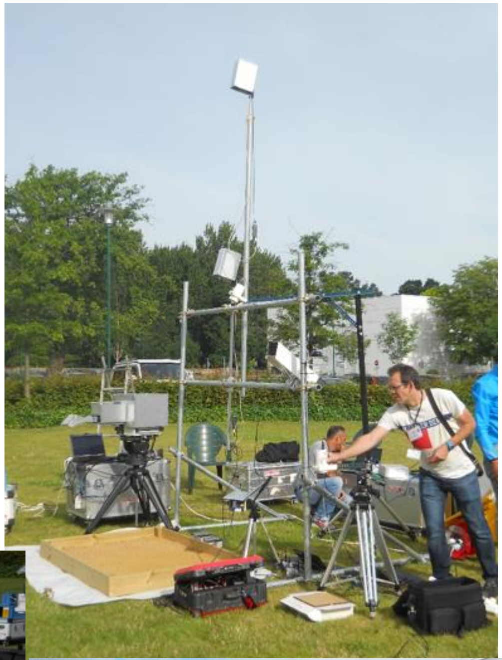
	mean difference from mean (°C)		
Radiometer	All radiometers	SST-Measuring	SST-Measuring
	Included	Radiometers Only	Radiometers excl. CSIRO
	°C	°C	°C
RAL	0.123	0.084	0.037
KIT	-0.159		
CSIRO	-0.189	-0.228	
DMI	-0.020	-0.053	-0.106
UoV	0.117		
UoS	0.125	0.090	0.044
OUCFIRST	0.033	-0.002	-0.054
OUC-ISAR	0.206	0.174	0.119
GOTA	0.593		
JPL	-0.109		

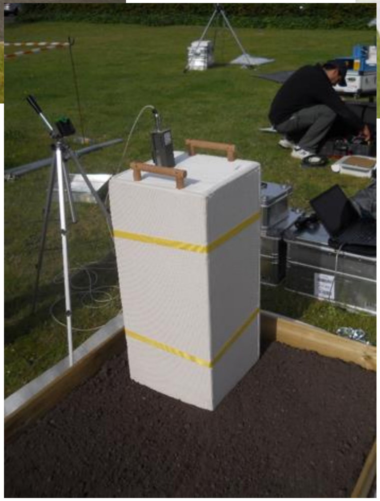
The 2016 LST comparison at NPL

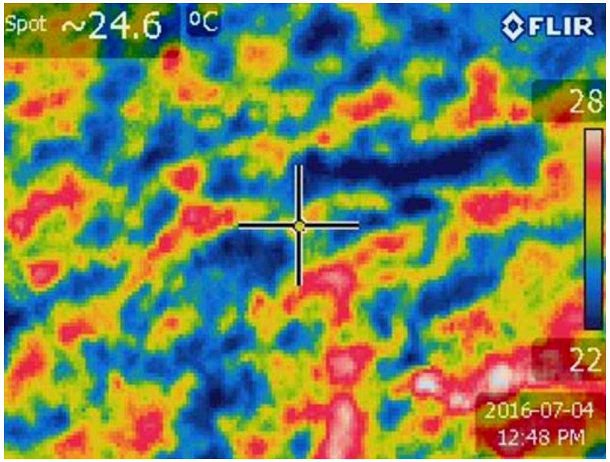
4th to 7th July 2016

LST (Sun & Cloud)

1. University of Valencia (Spain)
2. KIT (Germany)
3. JPL NASA (USA)
4. ONERA (France)







Emissivity

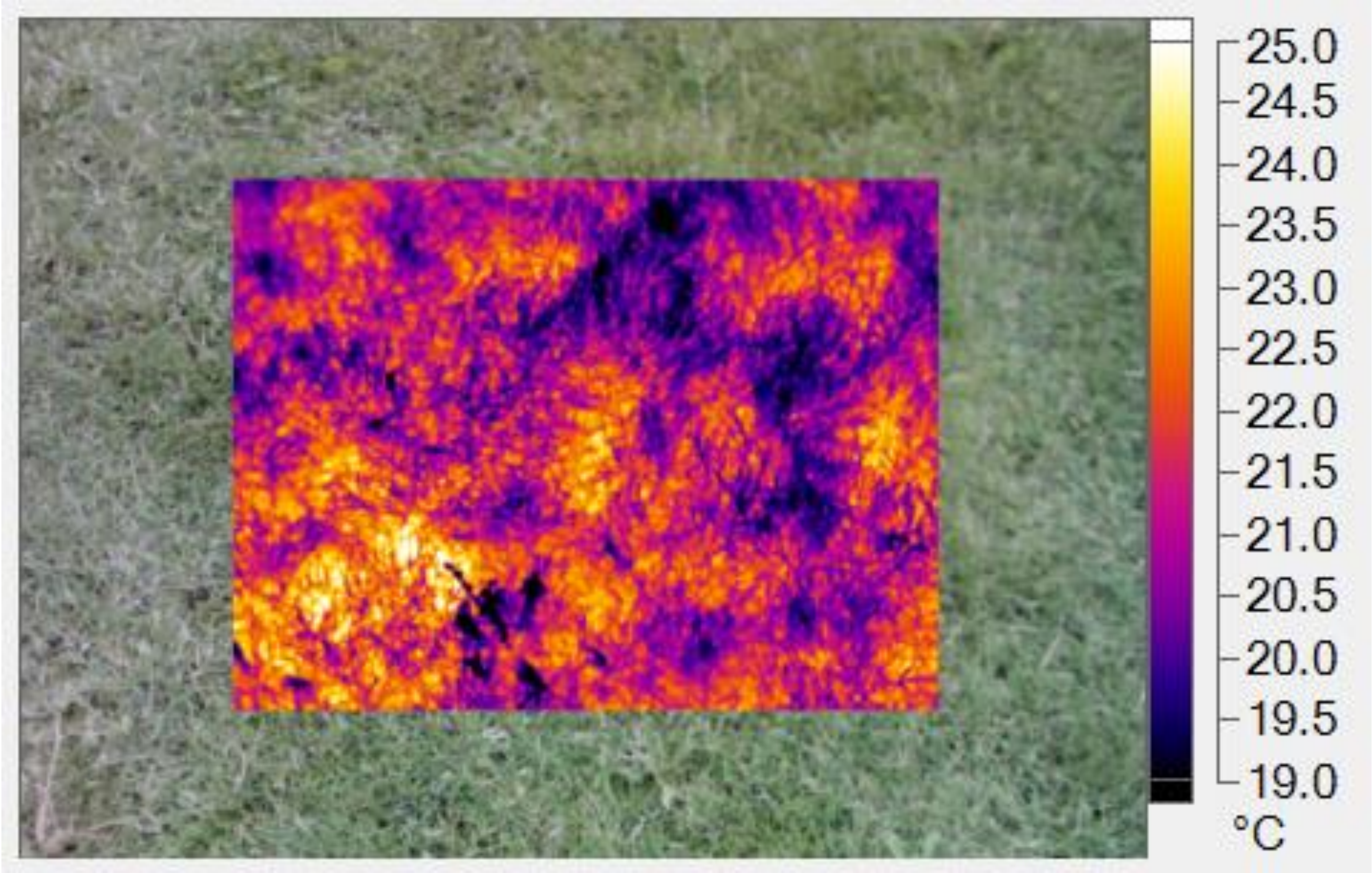
fiducial reference temperature measurements

Land samples studied:

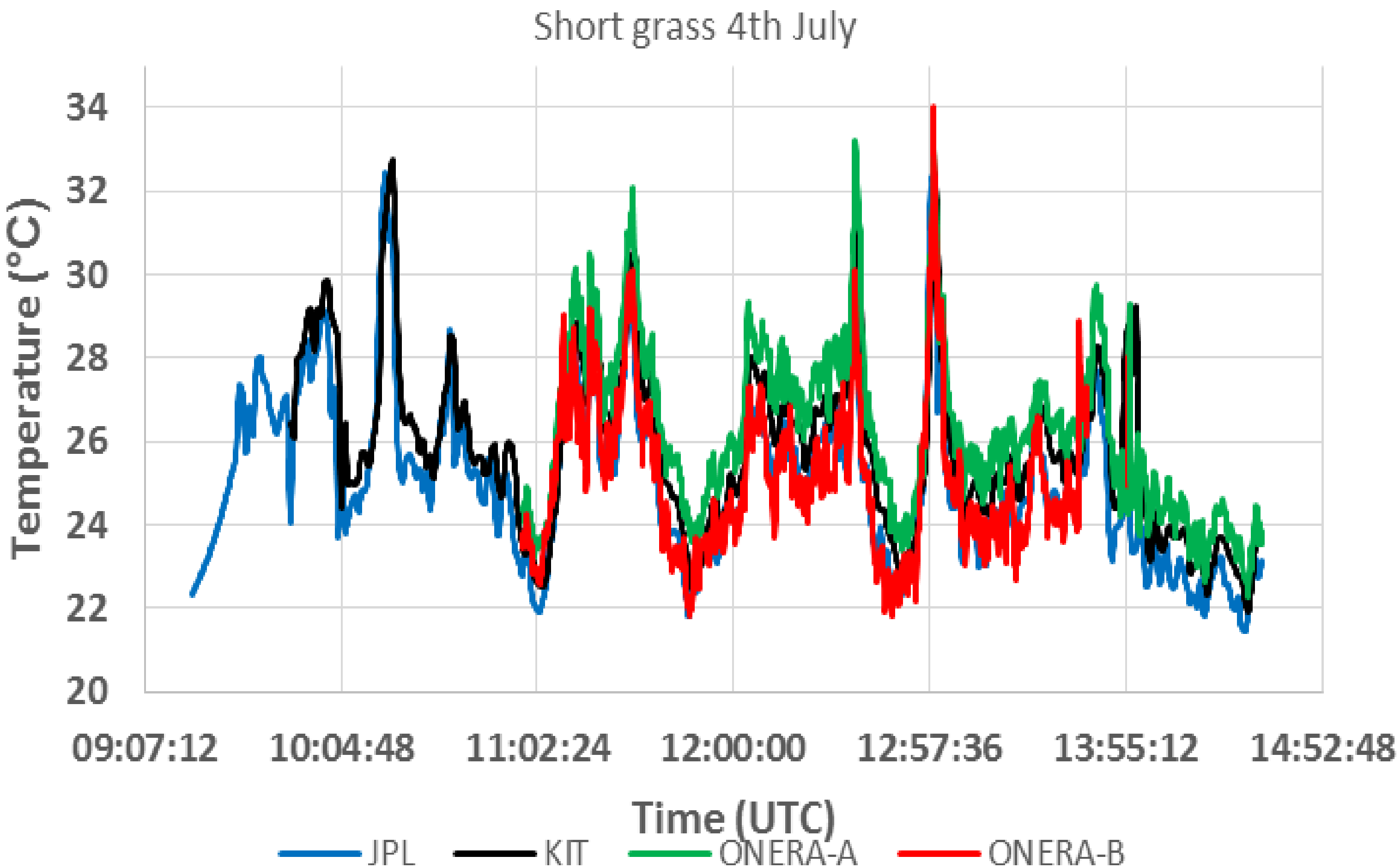
- Short grass
- Clover
- Sand
- “Dark” soil
- Gravel
- Tarmac

Some of the targets used for the 2016 LST comparison.

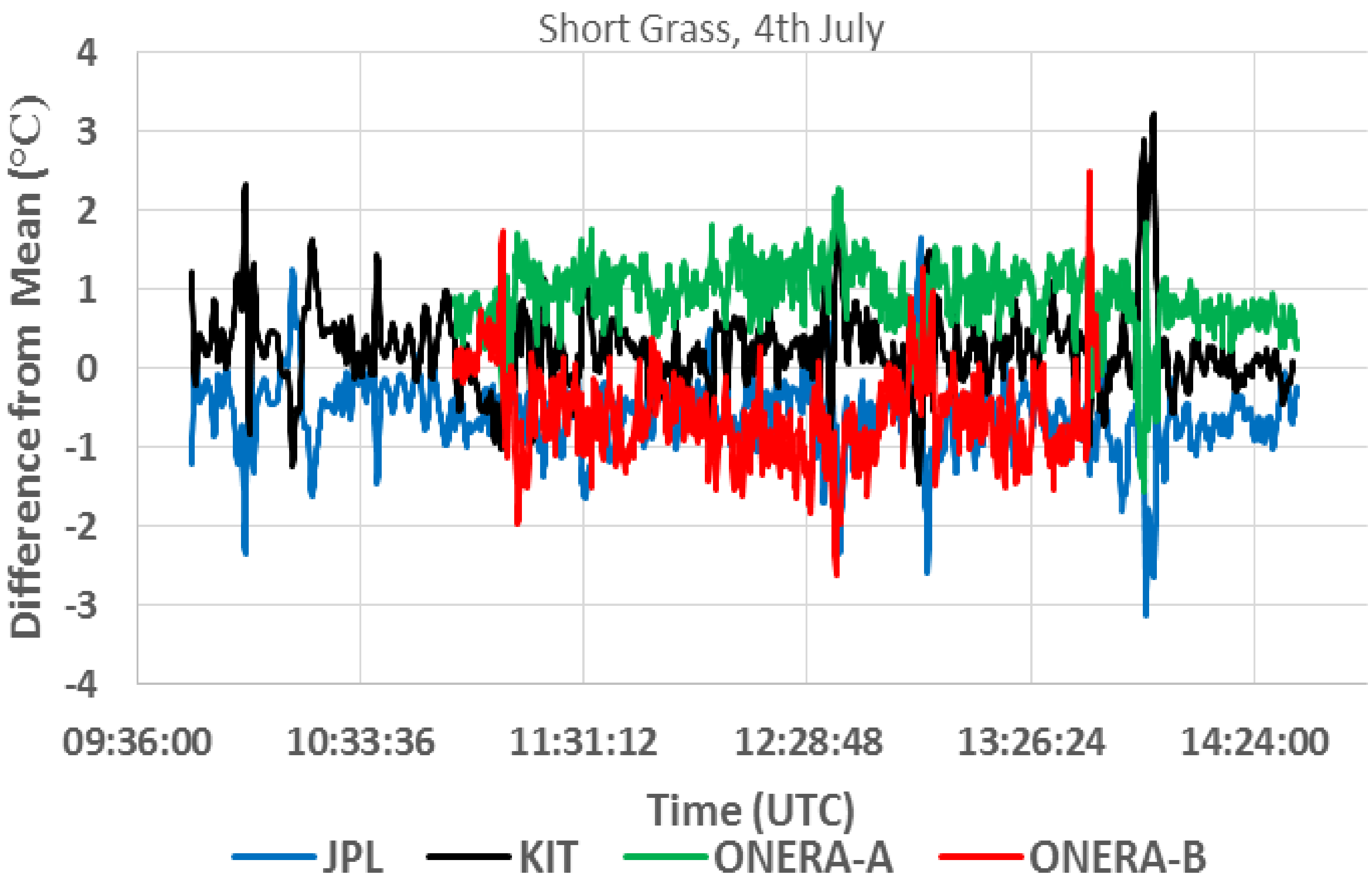
Image of the combination of a thermal image of the short grass sample with a black and white, visible image of the same target. The Figure shows that the apparent surface temperature of the sample was varying by about 5 ºC over the measured area.



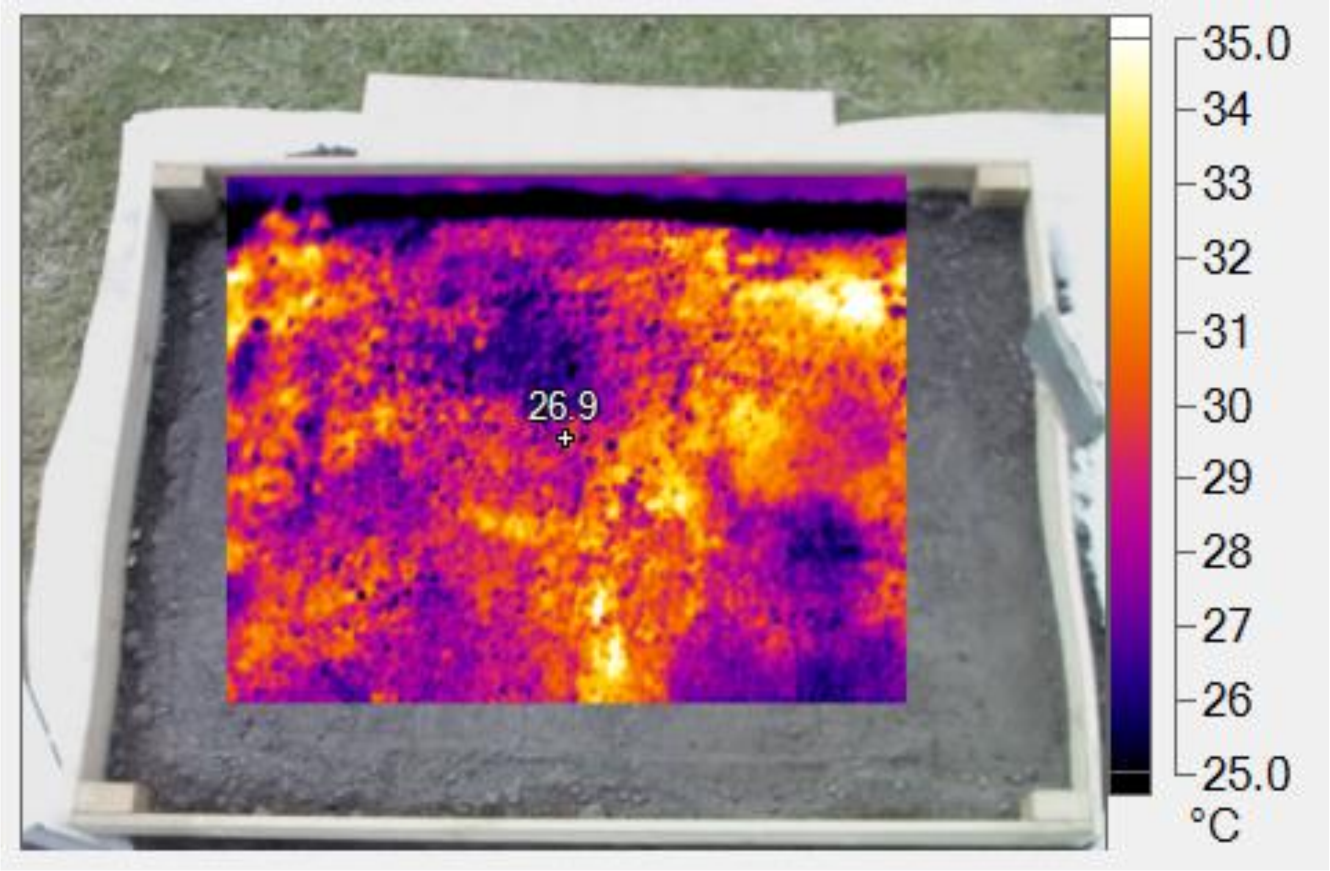
Surface temperature of short grass sample measured by the participating radiometers on the 4th July 2016.



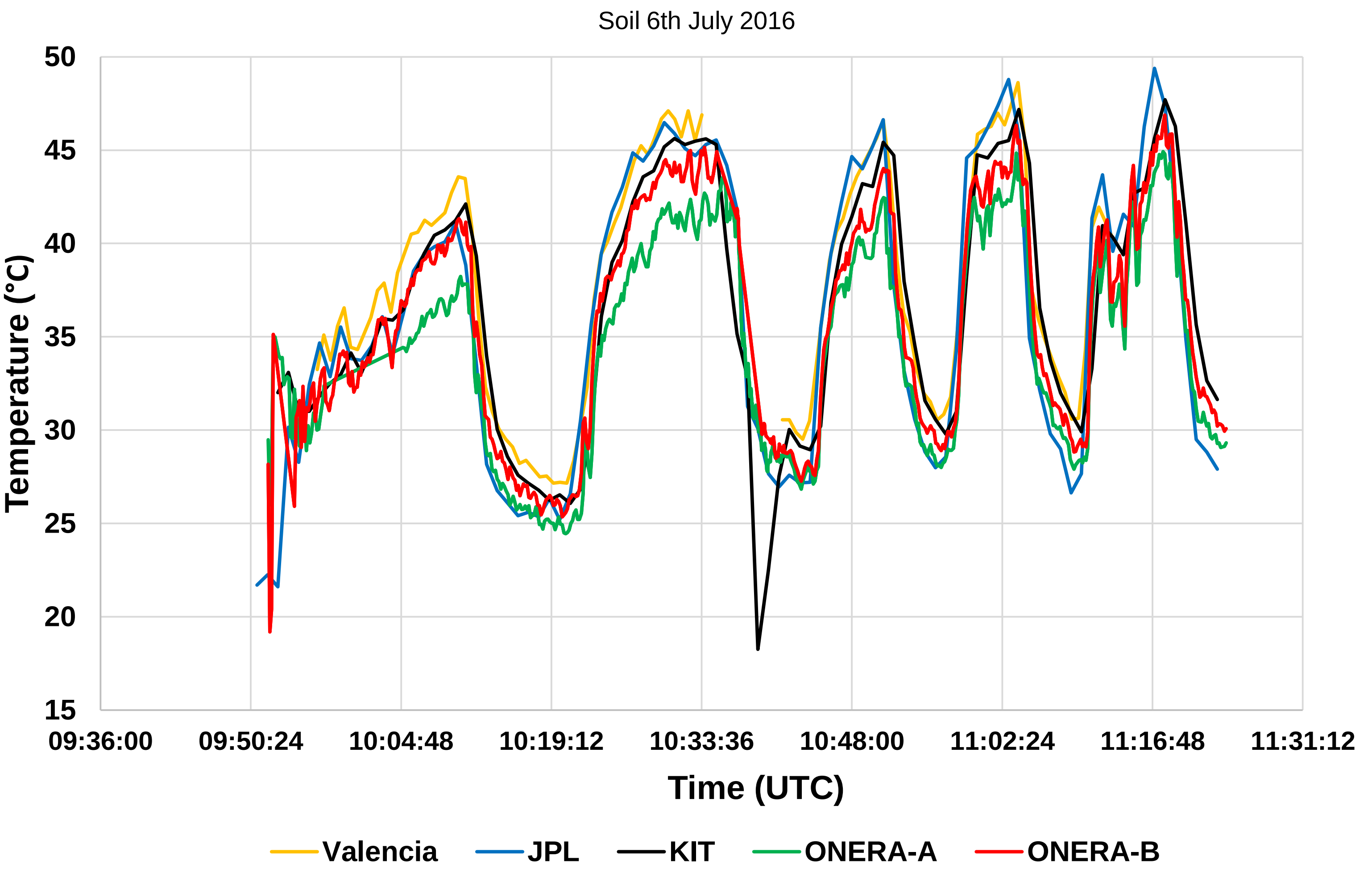
Difference of the measurements of measuring radiometers on the short grass sample from their mean. This Figure shows that the difference is within ±3 ºC throughout the monitoring period (mostly within ±2 ºC).



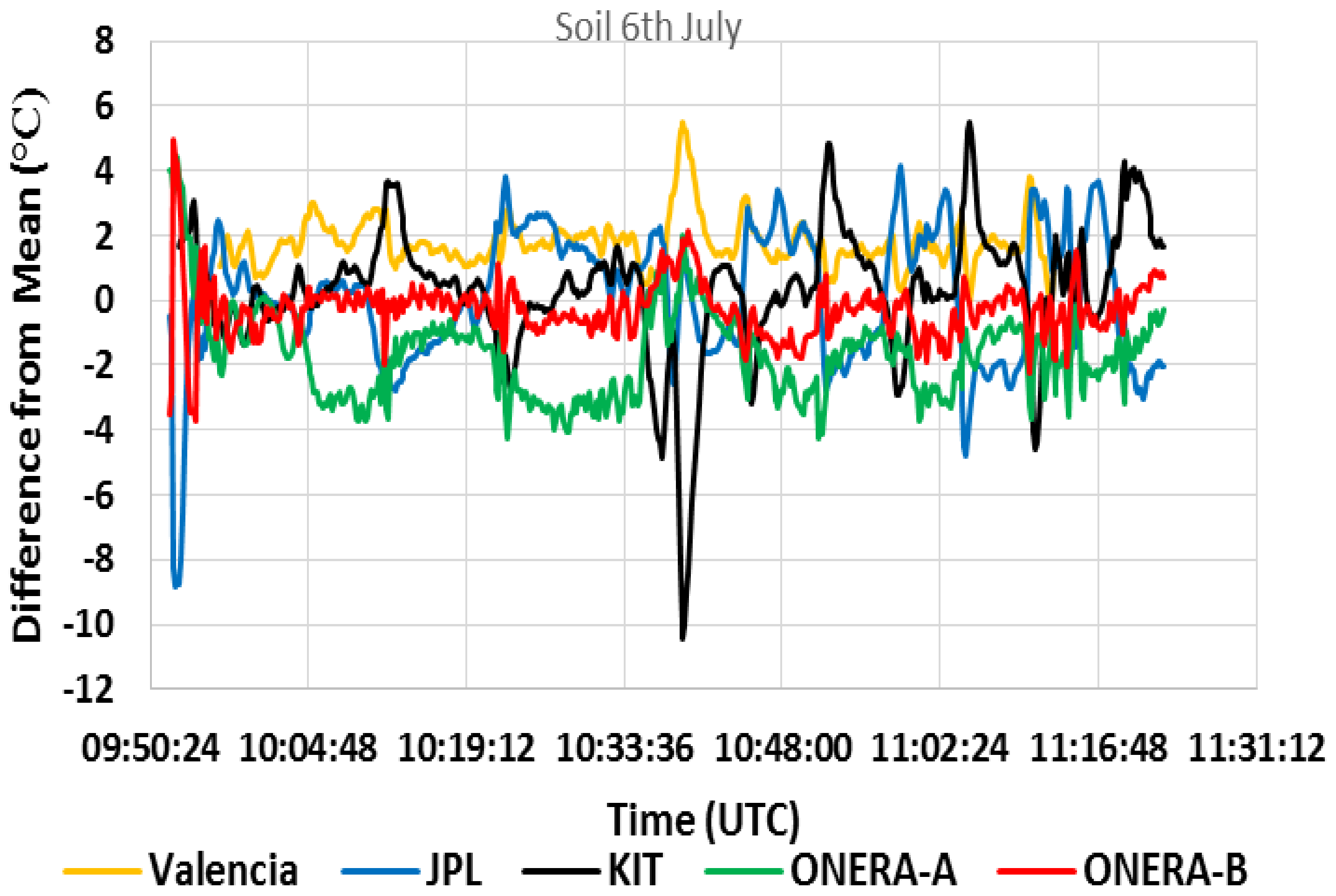
Combination of a thermal image of the dark soil sample with a black and white, visible image of the same target. The Figure shows that the apparent surface temperature of the sample was varying by about 10 °C over the measured area.



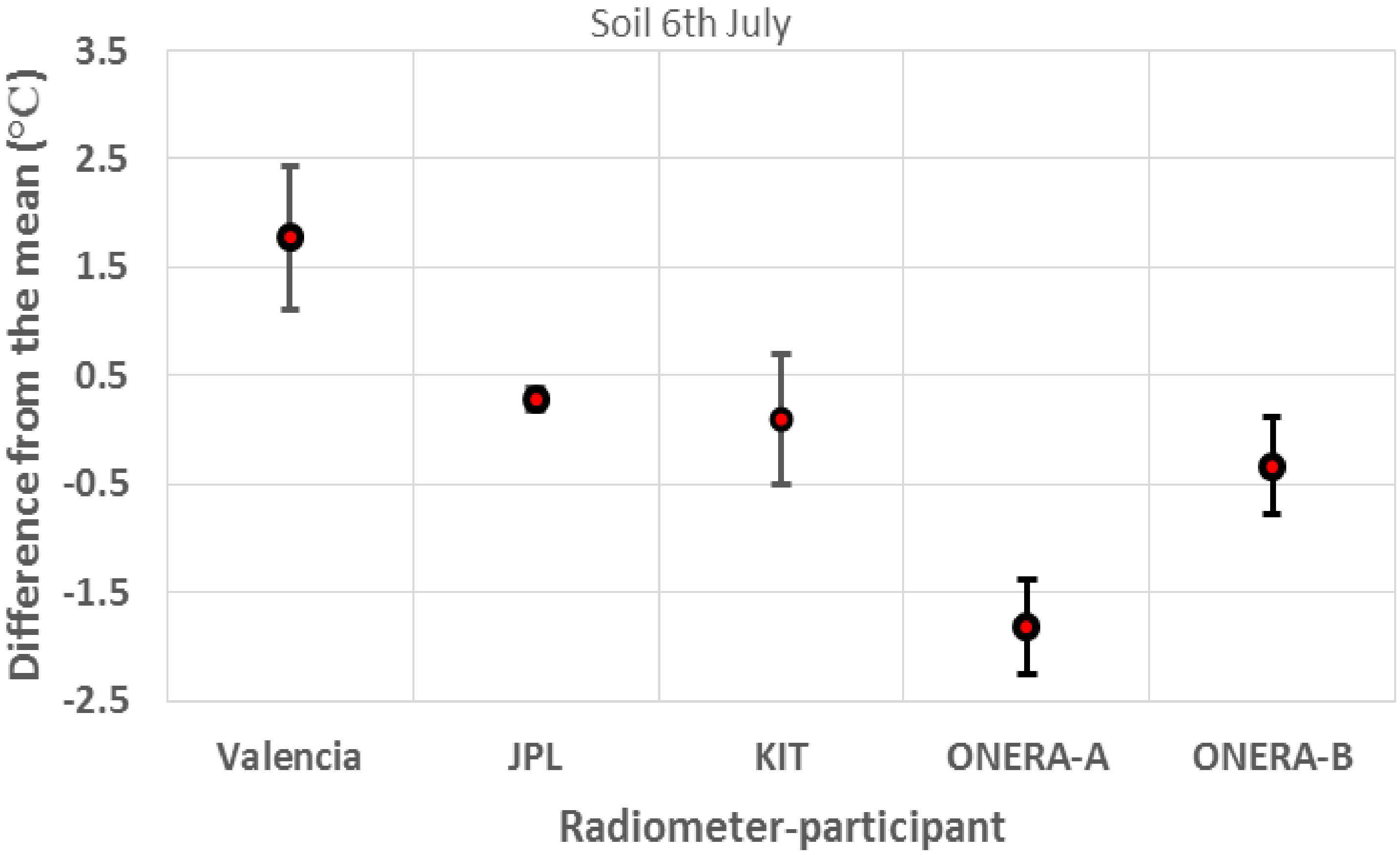
Surface temperature of dark soil measured by the participating radiometers on the 6th July 2016



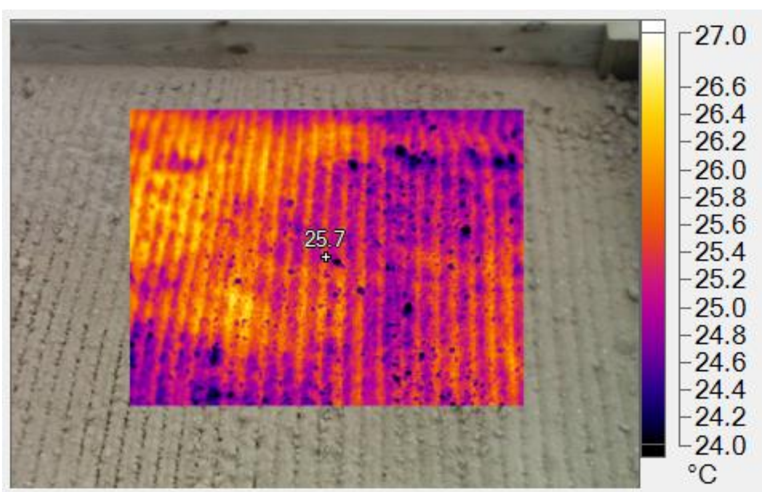
Difference of the measurements of the five measuring radiometers made on the 6th July on the dark soil sample from their mean.

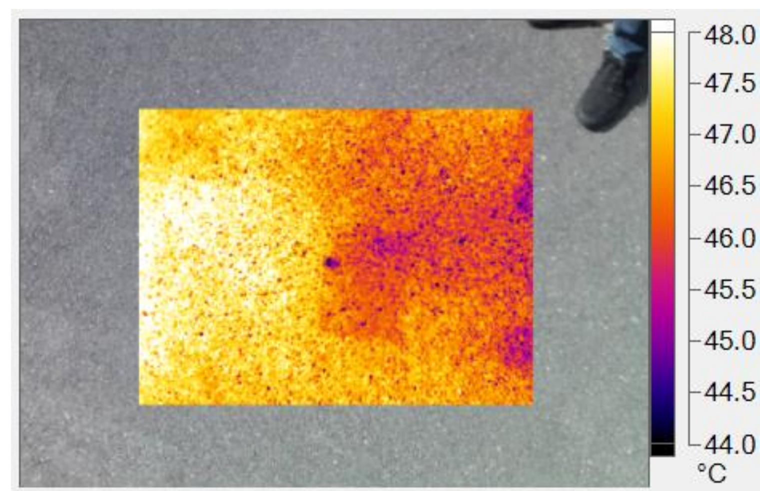


Difference of the mean surface temperature of the dark soil sample measured by participants from the mean of the measurements of all the participants.

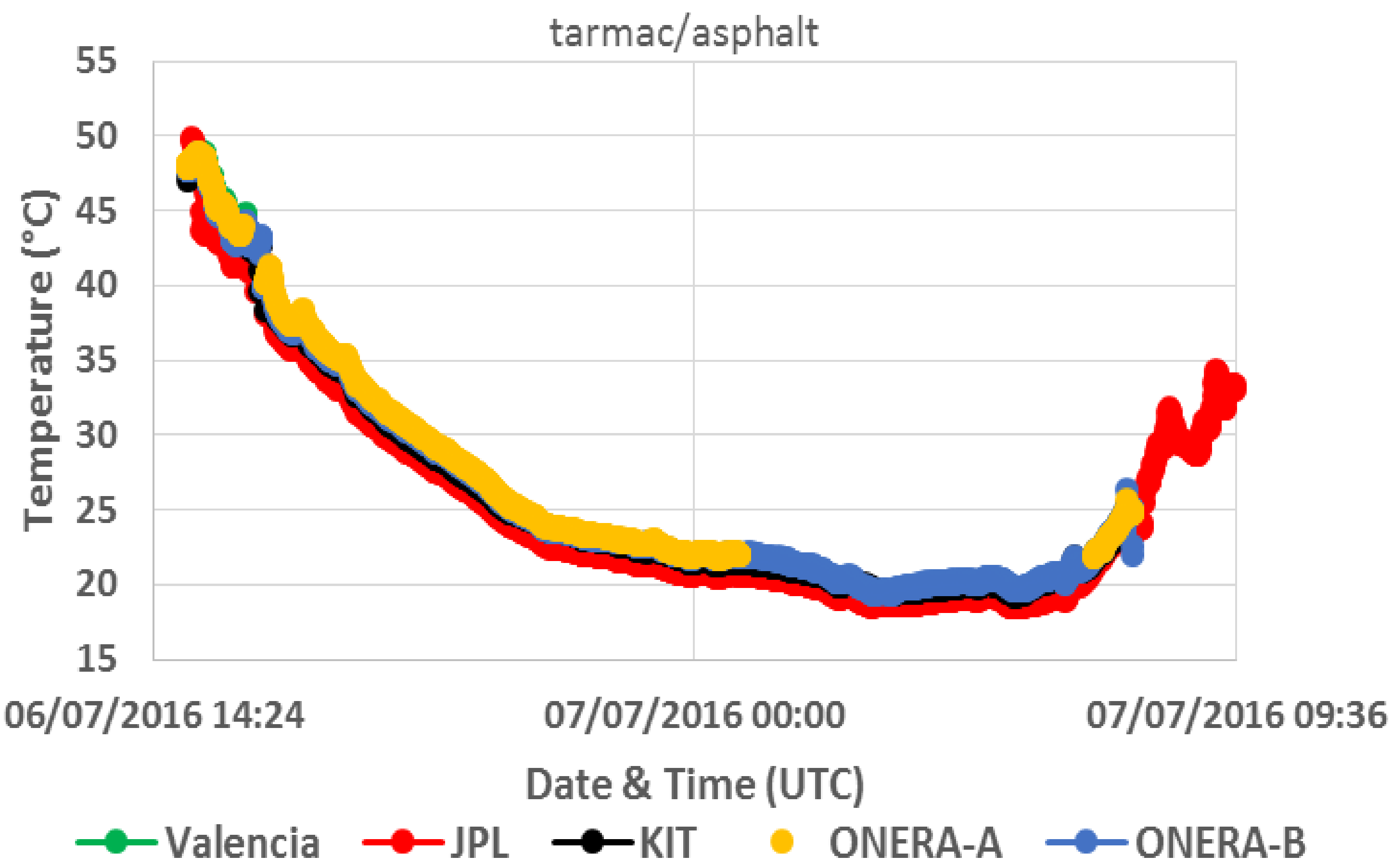


The "smoothness" of the sand sample was critical in determining the variations in temperature on the surface of the sample.

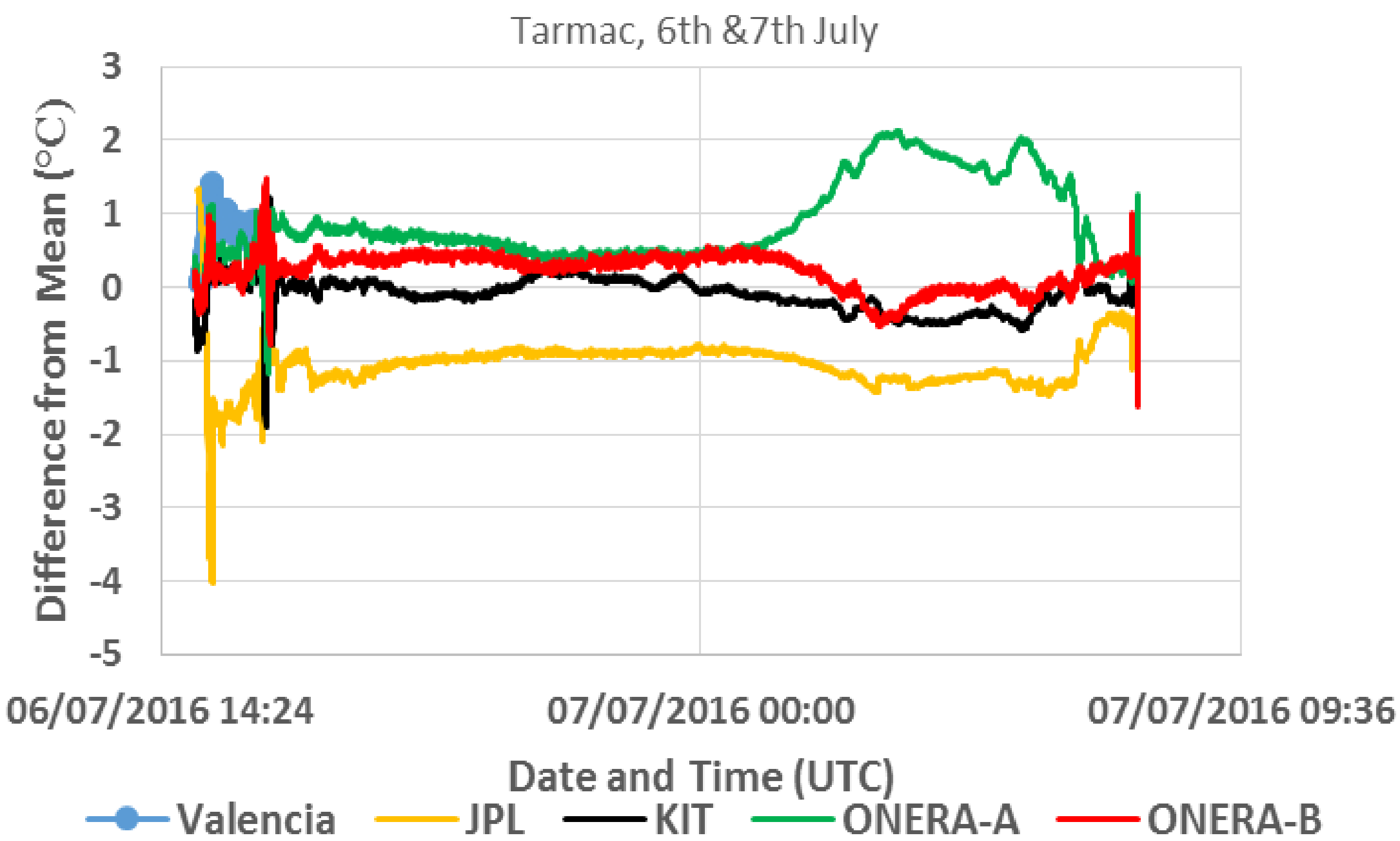




Surface temperature of tarmac measured by the participating radiometers on the 6th & 7th July 2016



Difference of the measurements of the five measuring radiometers made on the 6th July on the tarmac sample from their mean. The bulk of the difference of all five radiometers from their mean is within ±2 ºC throughout the monitoring period



Thank you to all participants

QUESTIONS TO CONSIDER

- What are likely needs (Surface Temp) in 5, 10, 20 yrs? (Land Water & Ice)?
  - Uncertainty @ satellite and surface (validation)
  - Sampling
- What are the technical challenges to overcome to allow us to achieve?
- What are priorities to tackle?
- How to achieve? Existing/new projects?, technology? Coordination? ……
  - Brightness T (radiometers)   or Contact T (thermometers   or ?
  - A few high accuracy measurements or lots of lower accuracy
- Are community comparisons important? How often?
  - What improvements/evolutions
- Building a community strategy, roadmap and resources to implement