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

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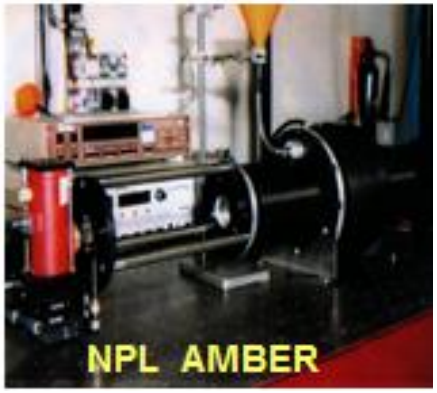
NPL

Working Group on Calibration and Validation

SI traceability: LCE (June 2016)

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

NPL National Physical Laboratory



ITS-90

NPL BB

PTB BB

T= ~250 – 325 K
Non-vacuum

NPL Rad (AMBER)

PTB Rad

Rad 1

Rad 2

Rad 3

Rad 4

Rad n

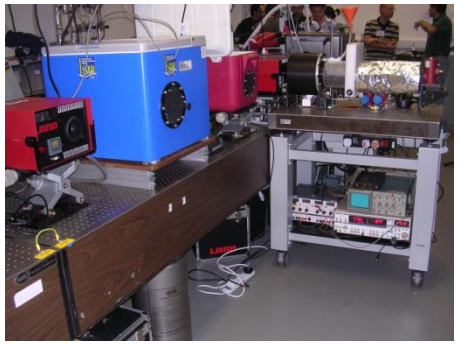
BB1

BB 2

BB 3

BB 4

BB n



Room Environment with variable T

fiducial reference temperature measurements

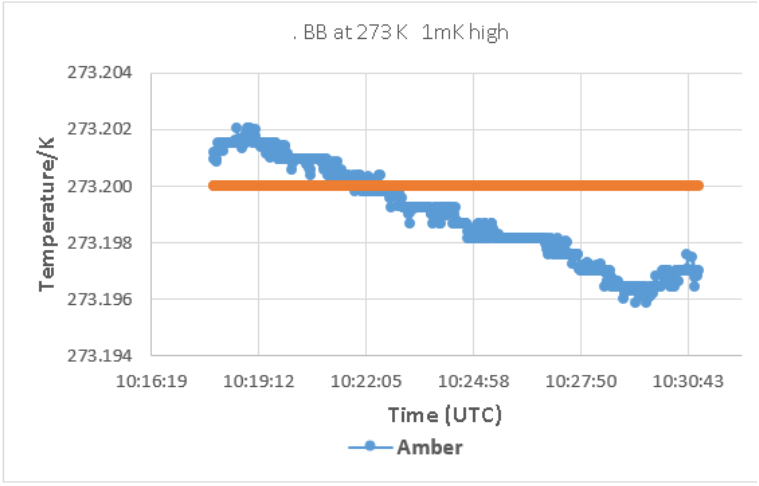
The 2016 blackbody lab comparison

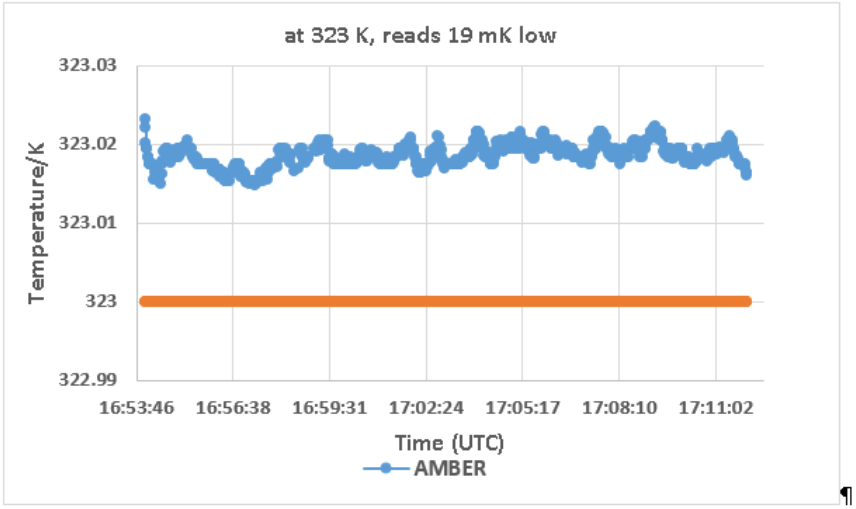
20th to 24th June 2016

BB comparison (June 2016)

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)



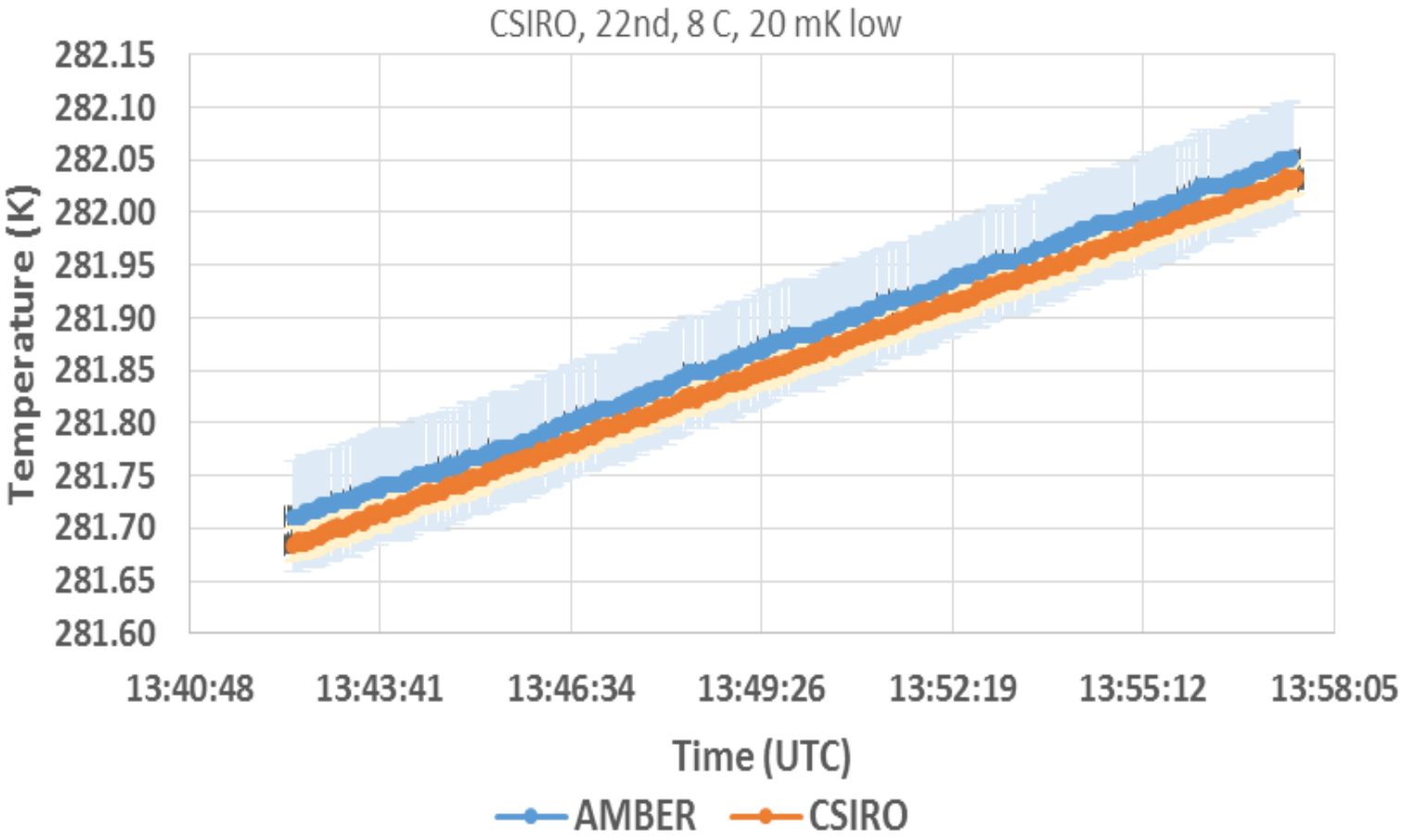


fiducial reference temperature measurements

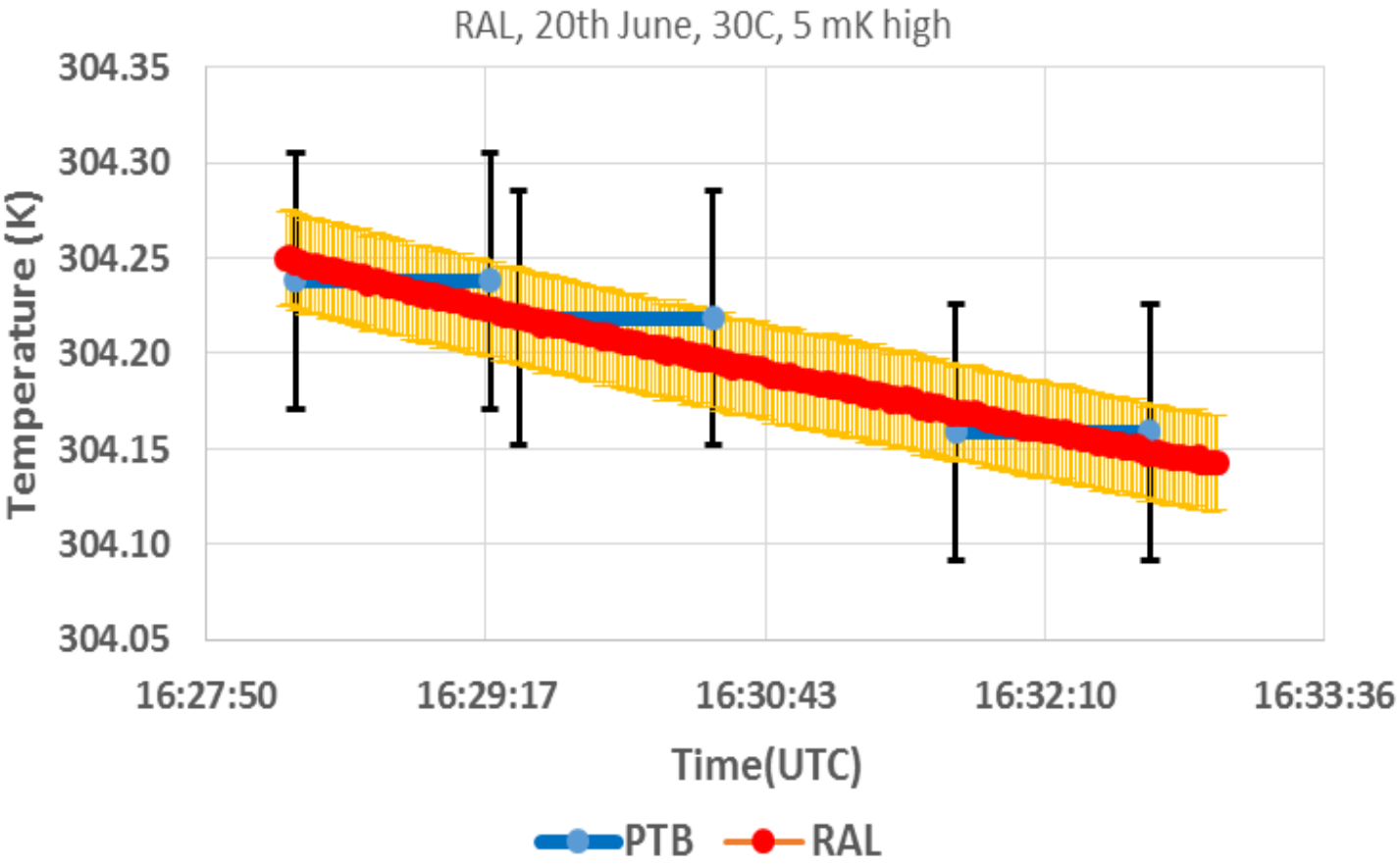
Blackbody lab comparison at NPL

- All participants have provided data for their comparisons with the AMBER and PTB radiometers.
- The detail in the uncertainty budgets provided by different participants varied considerably.
- All the data provided by participants have been analysed.
- A draft report for the BB lab comparison was prepared and circulated to all participants.
- Data and copy of the report have also been uploaded on the FTP server and can be accessed by participants.
- The bulk of the measurements agree with the NPL and PTB scales within the combined uncertainties.

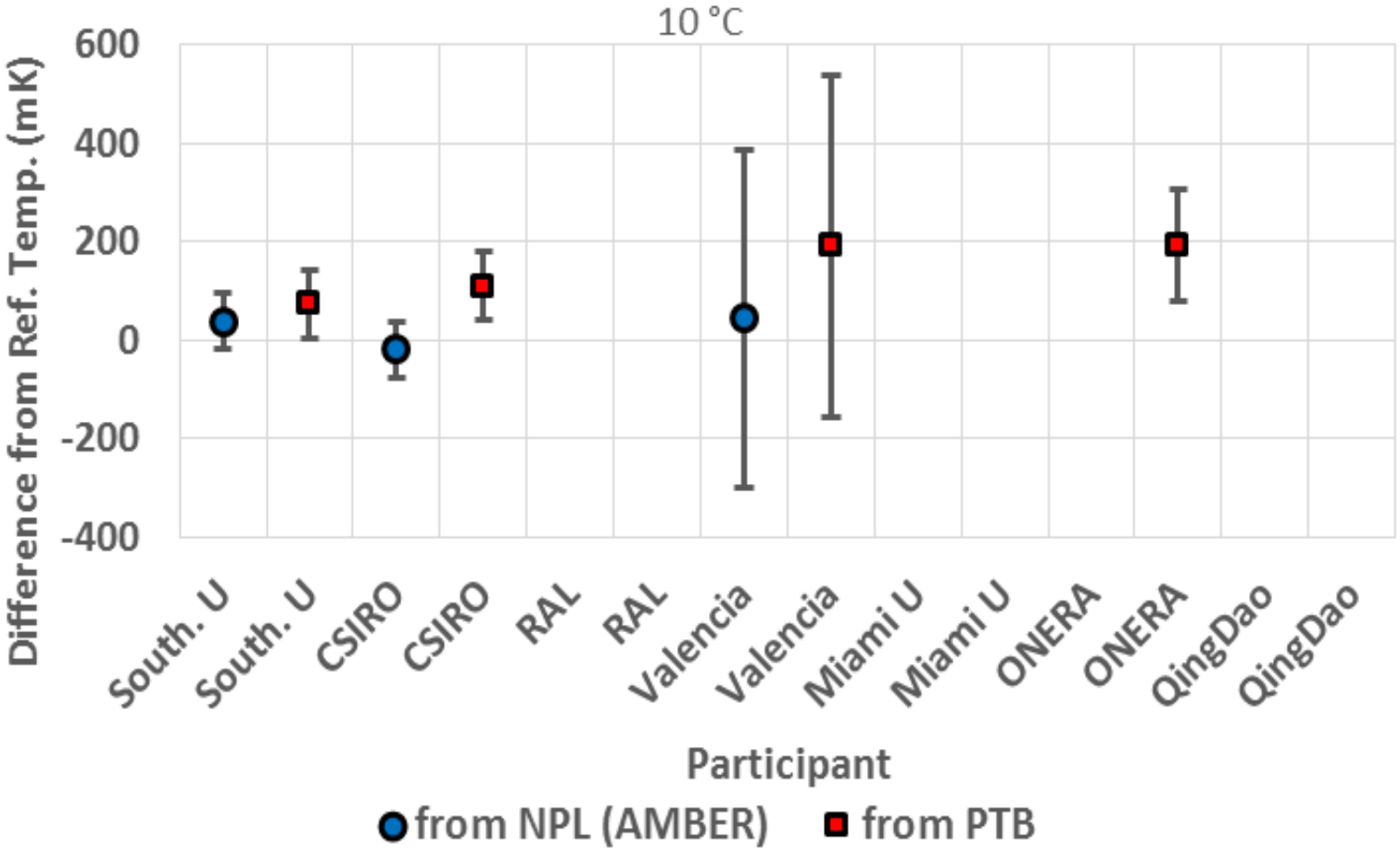
Measurements (as a function of time) reported by the CSIRO blackbody as well as the temperature of the same blackbody measured by the AMBER radiometer.



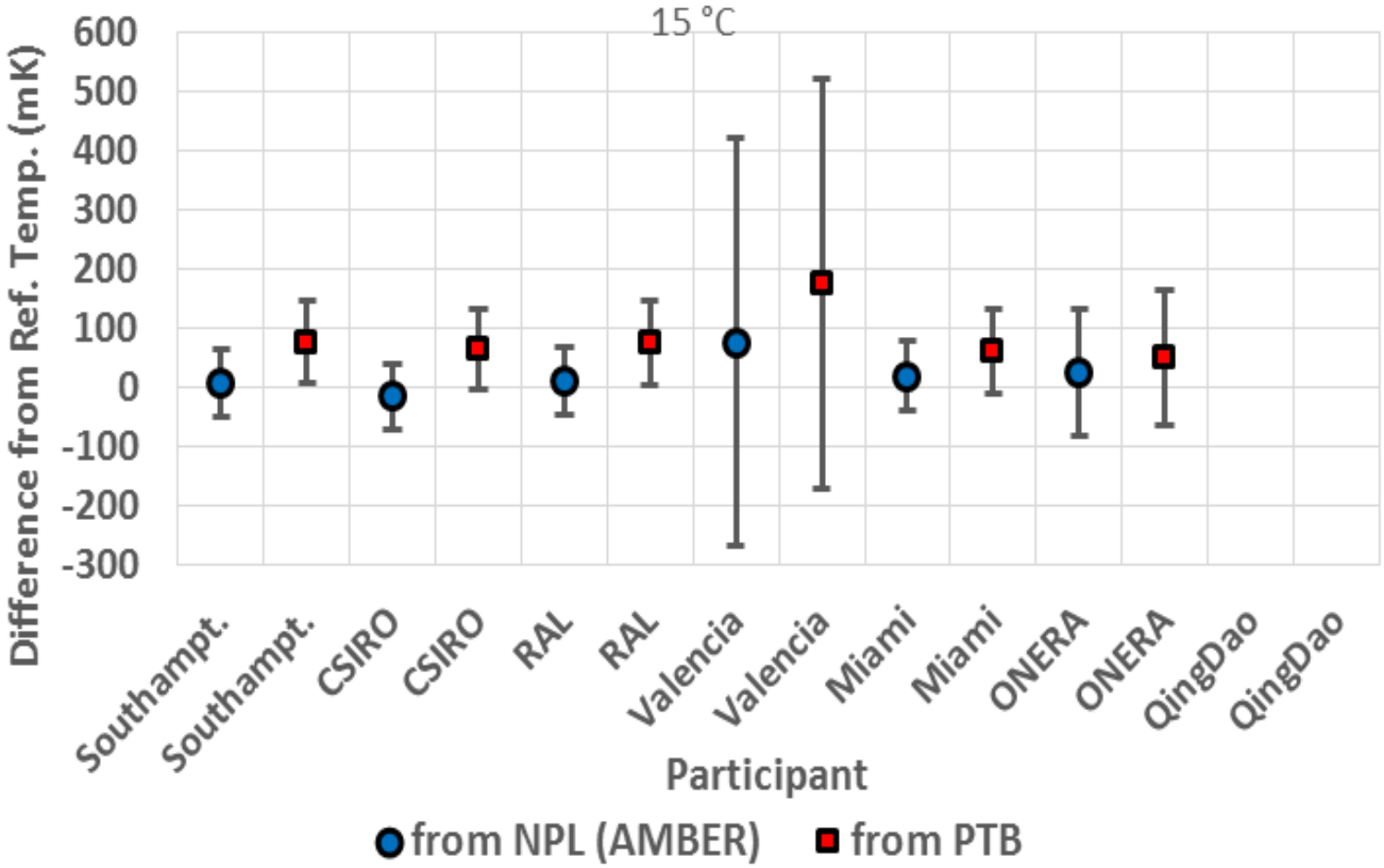
Measurements (as a function of time) reported by the RAL blackbody as well as the temperature of the same blackbody measured by the PTB IR radiometer.



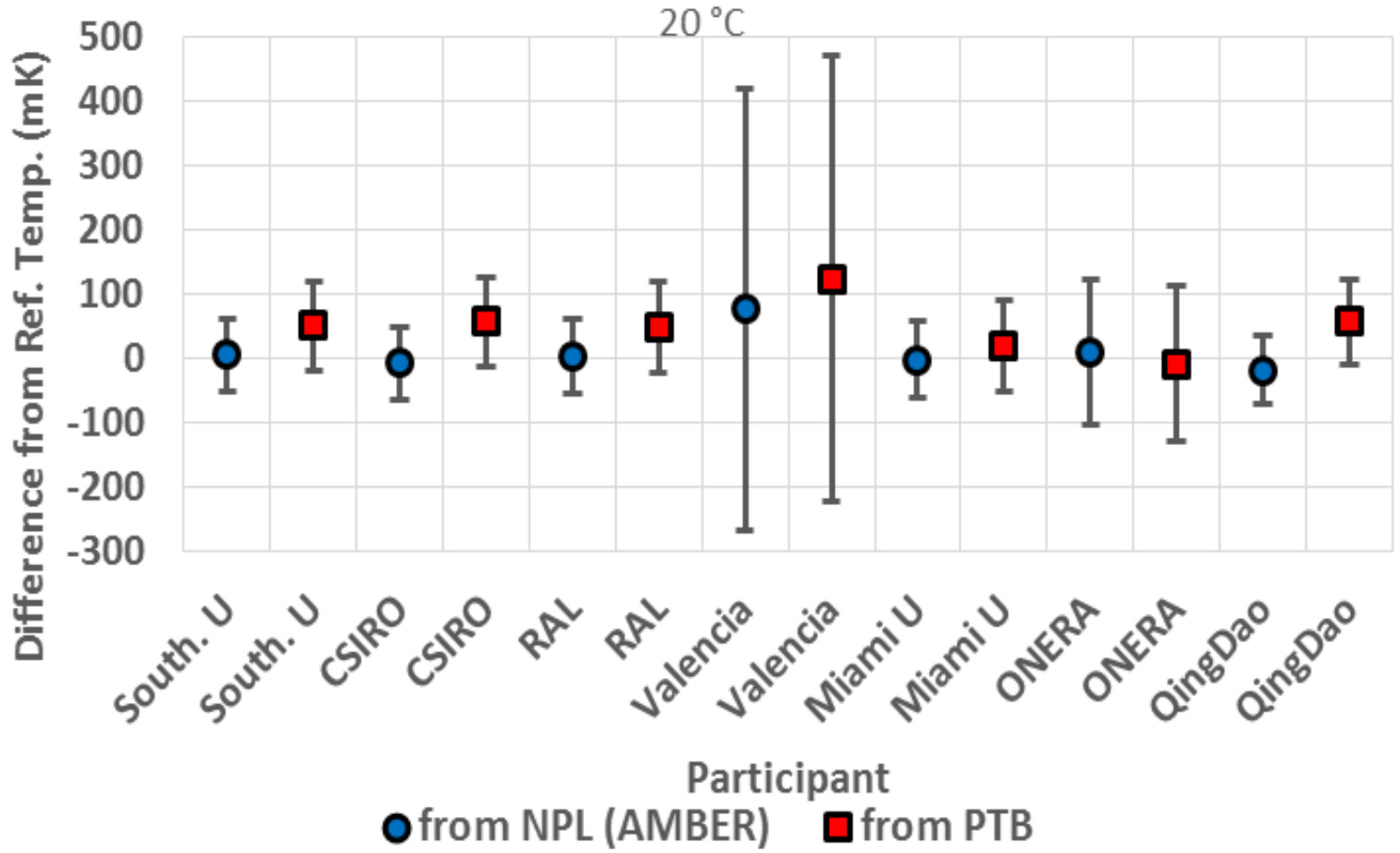
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 10 °C.



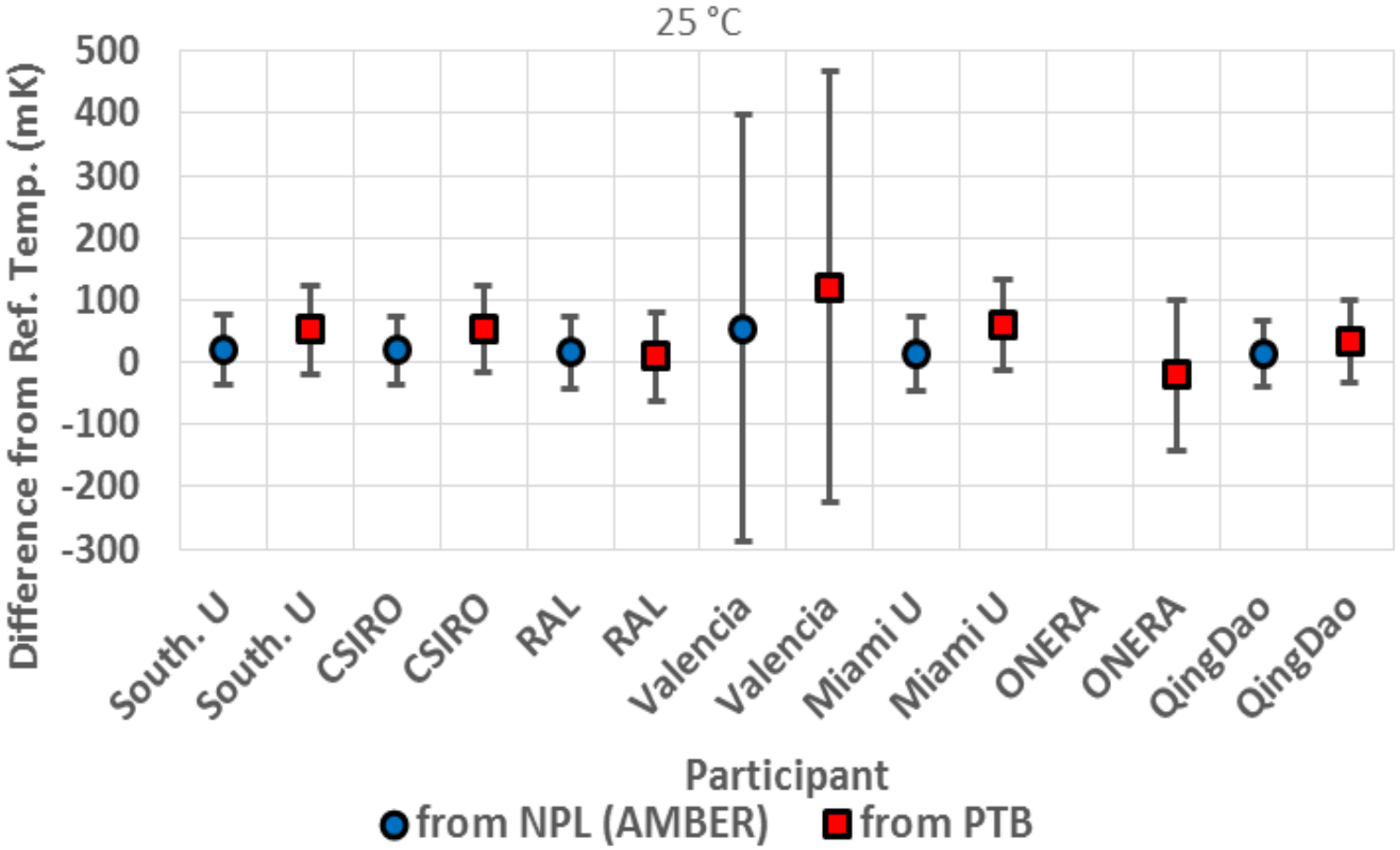
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 15 °C.



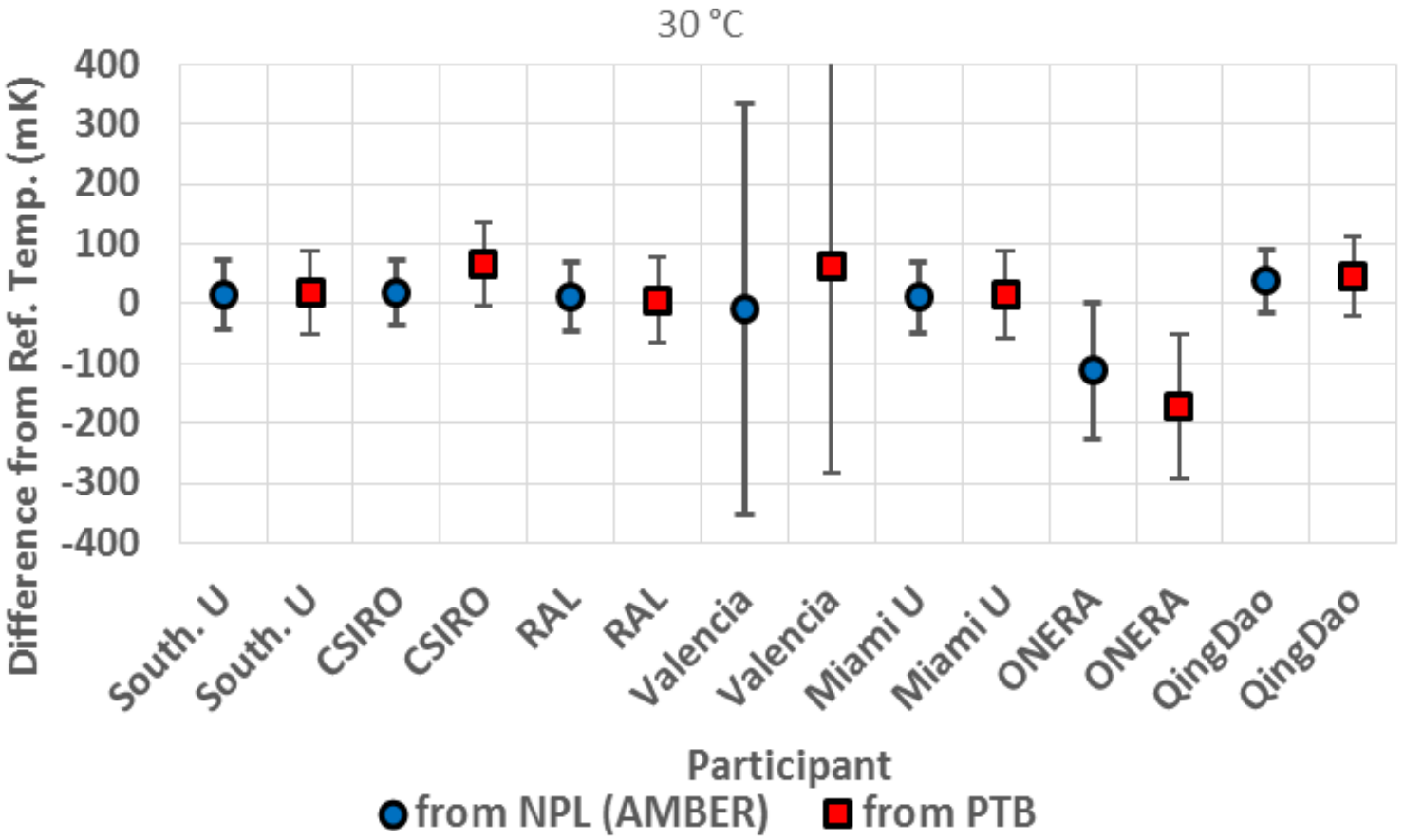
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 20 °C.



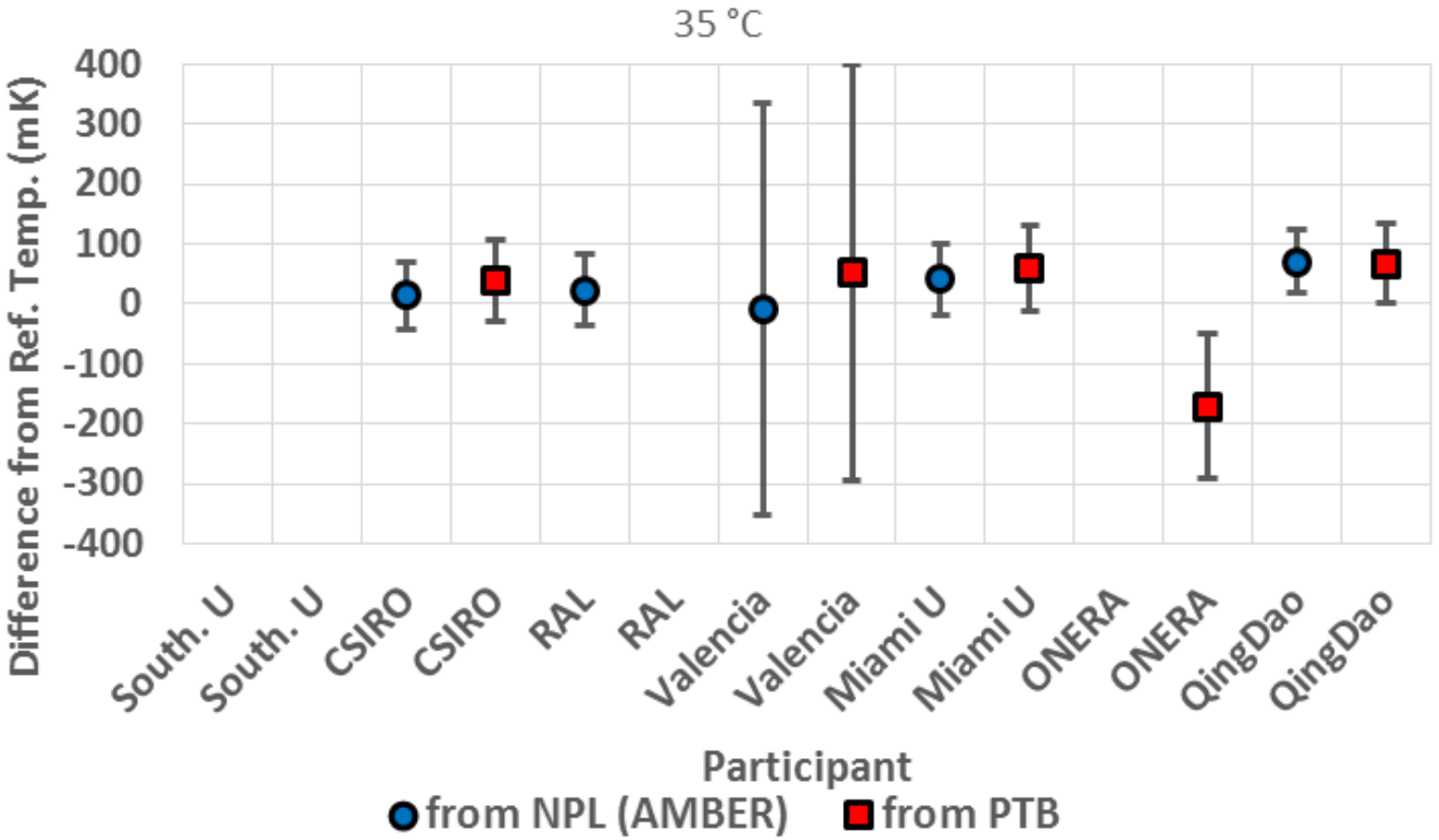
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 25 °C.



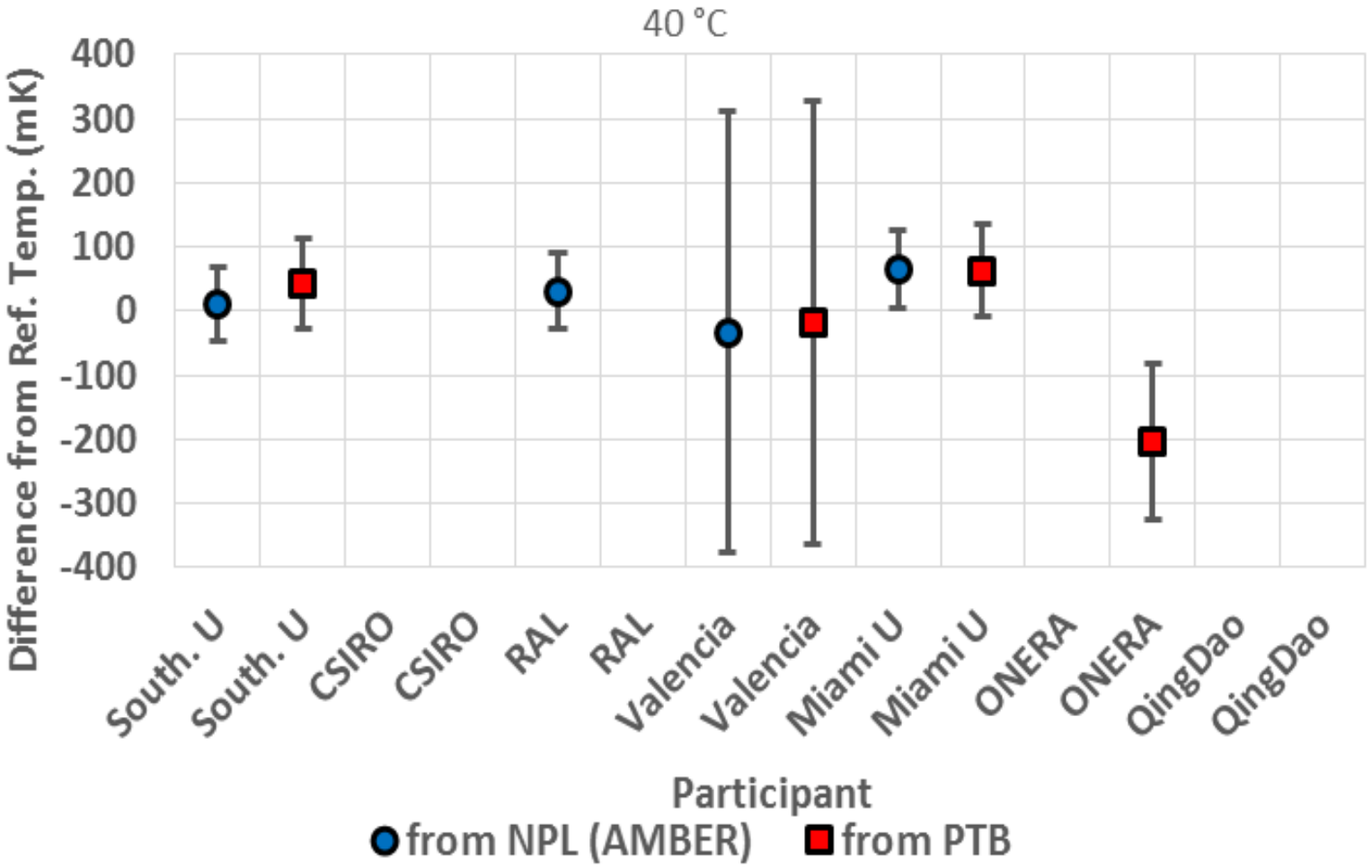
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 30 °C.



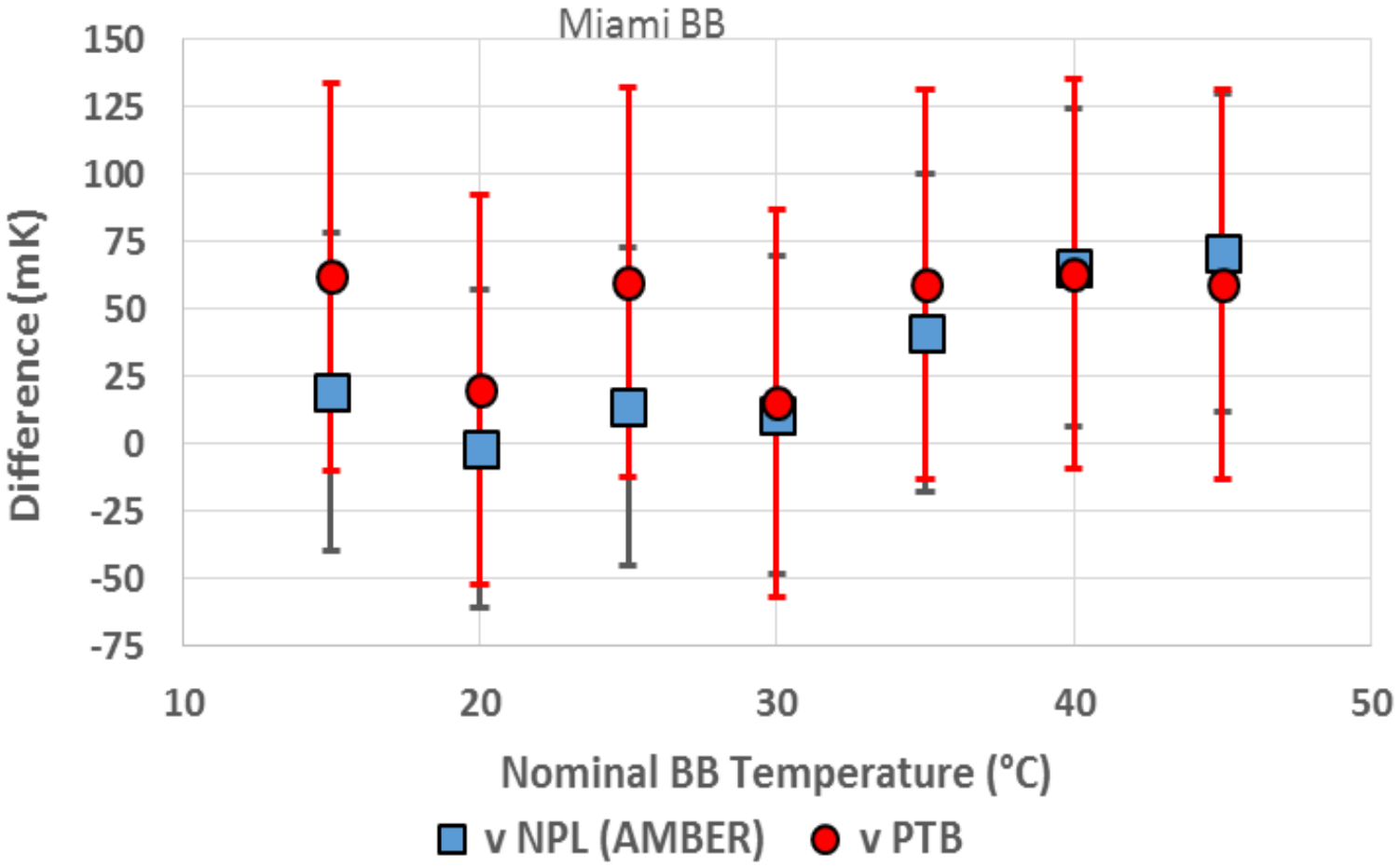
Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 35 °C.



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 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.



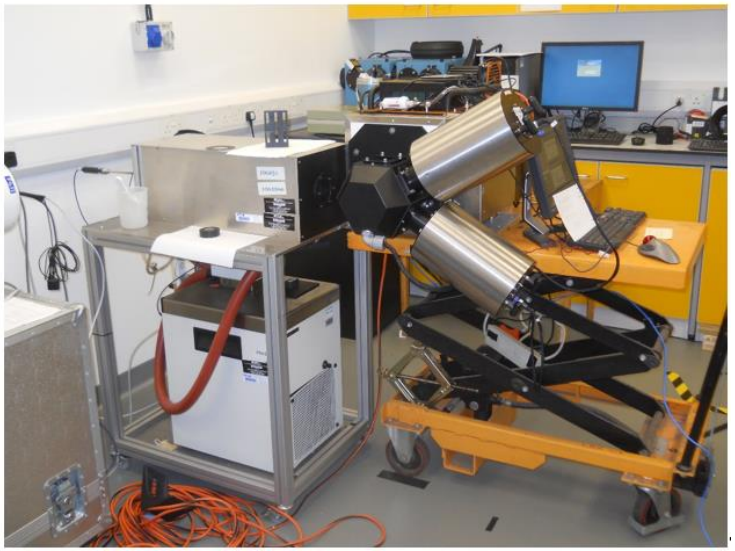
The 2016 radiometer lab comparison

20th to 24th June 2016

Radiometer comparison

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)

240 K to 318 K



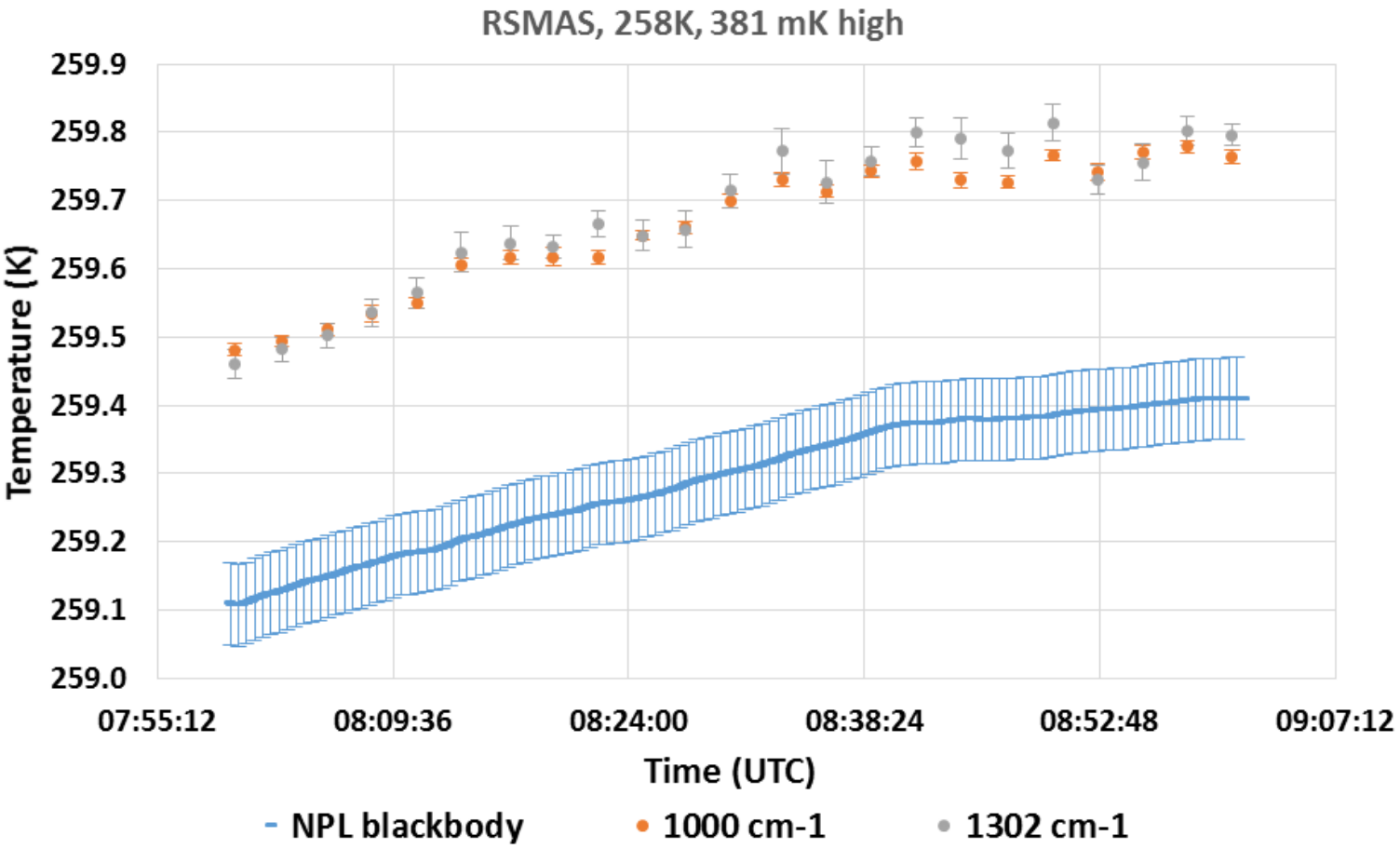
MAERI (UofM) viewing NPL ammonia Heat pipe

SISTER (RAL) viewing NPL ammonia Heat pipe

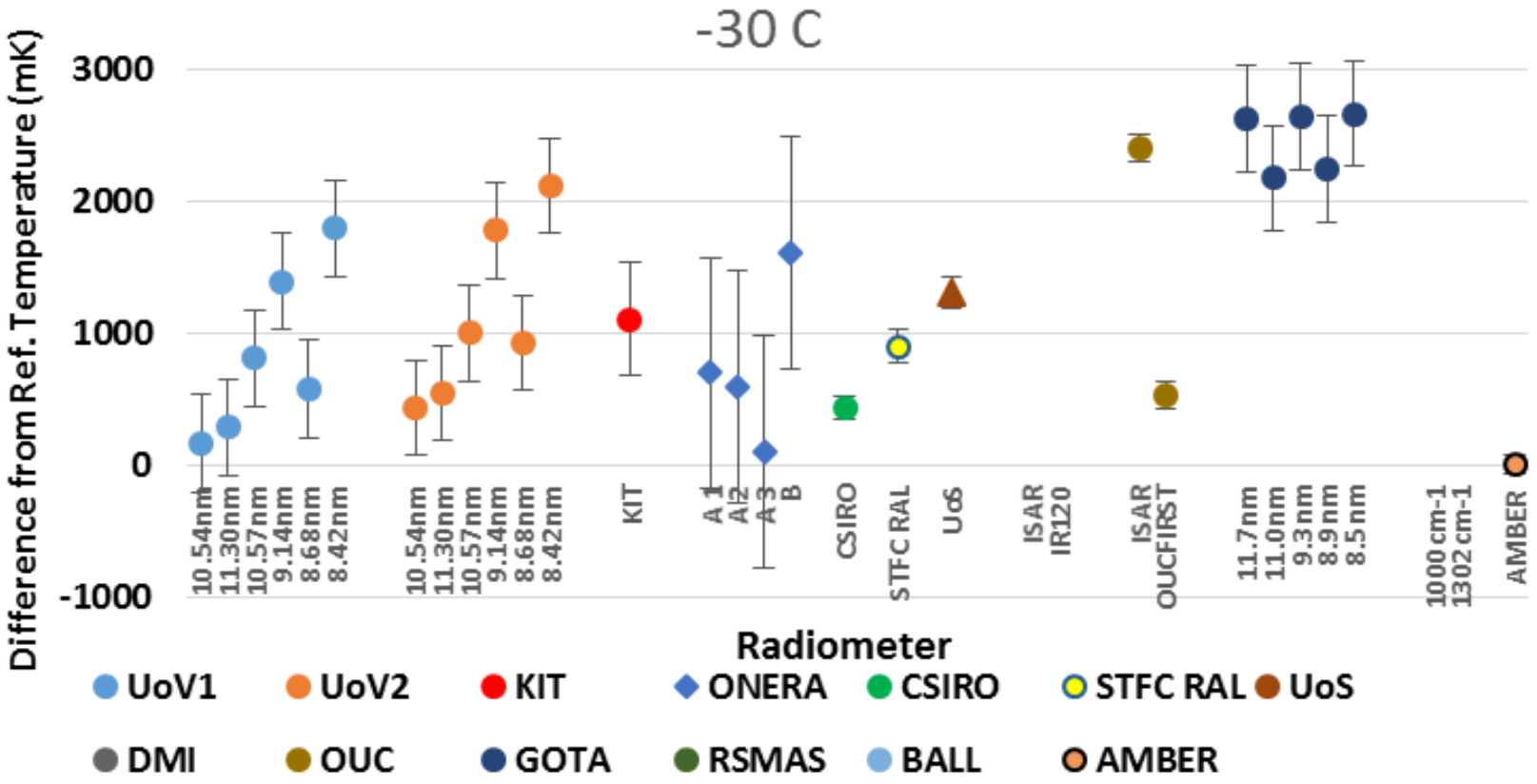
Summary of Radiometer lab comparison work

- **All participants have provided data for their comparisons with NH3 heat-pipe blackbody.**
- **The detail in the uncertainty budgets provided by different participants varied considerably.**
- **All the data provided have been analysed.**
- **A draft report for this part of the work was prepared and was been circulated to all participants.**
- **All data and a copy of the report have been uploaded on the FTP server.**

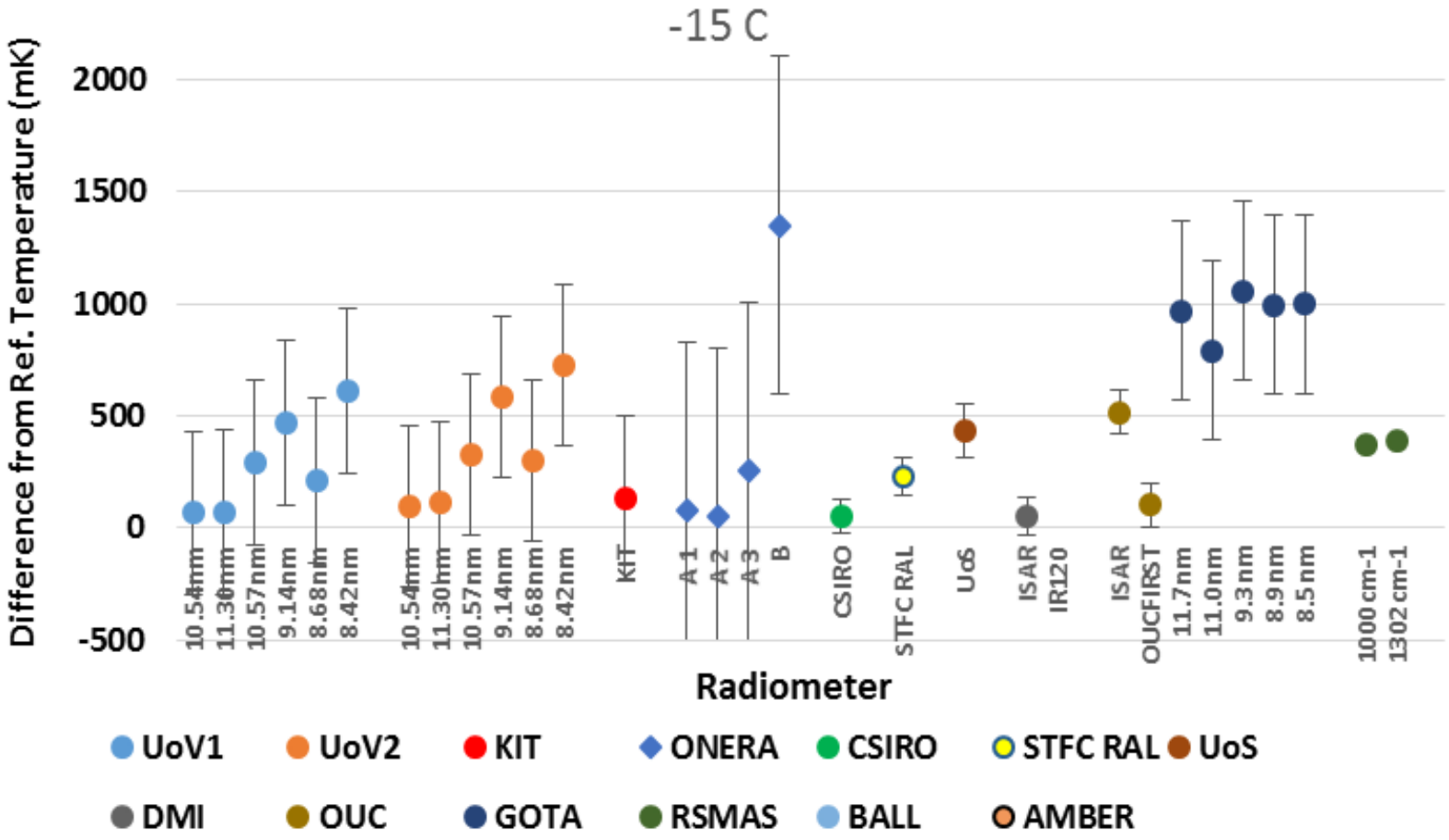
Temperature of the NH3 reference blackbody at about -15°C (shown in blue) and the corresponding measurements of the test radiometer.



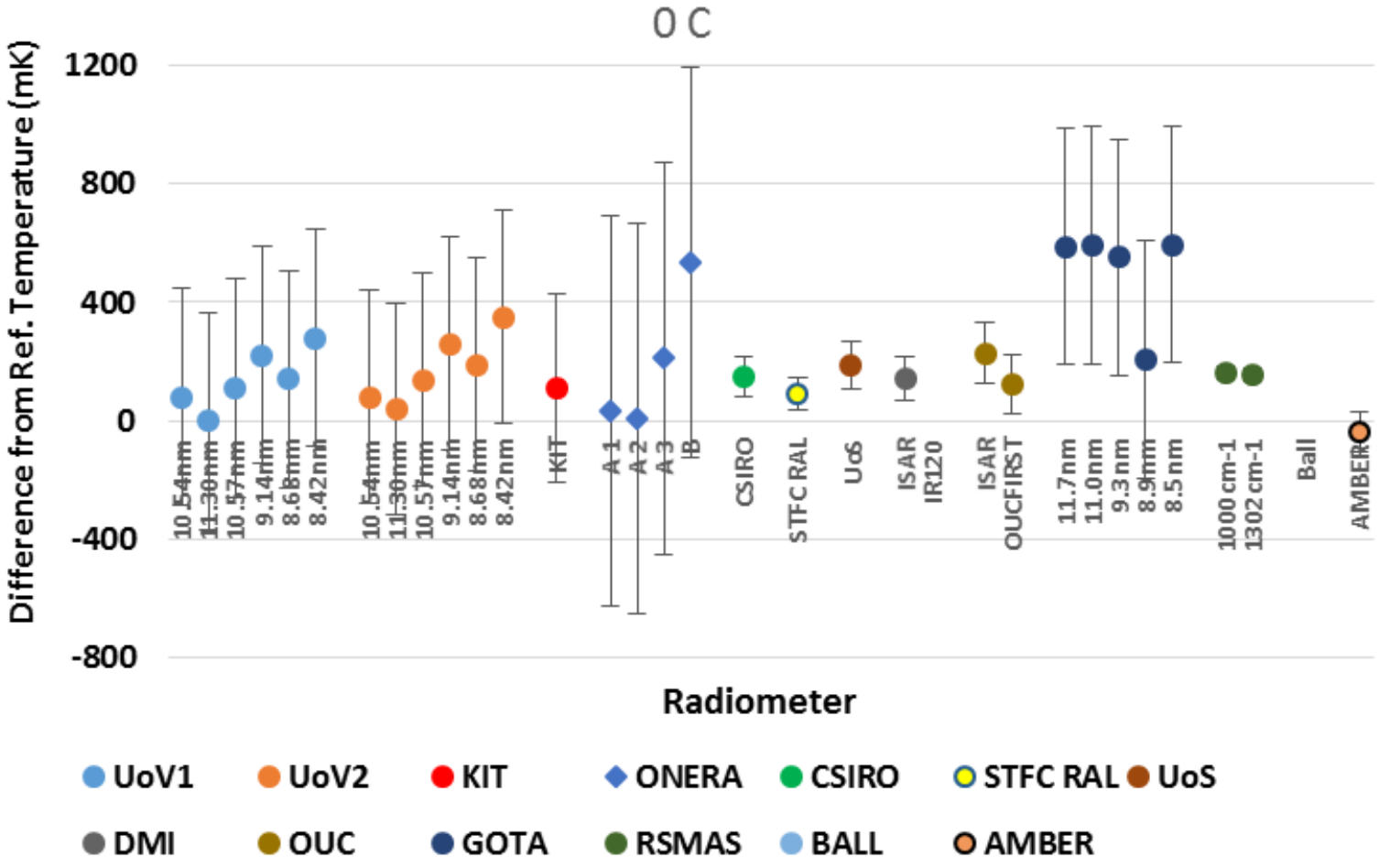
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of -30°C.



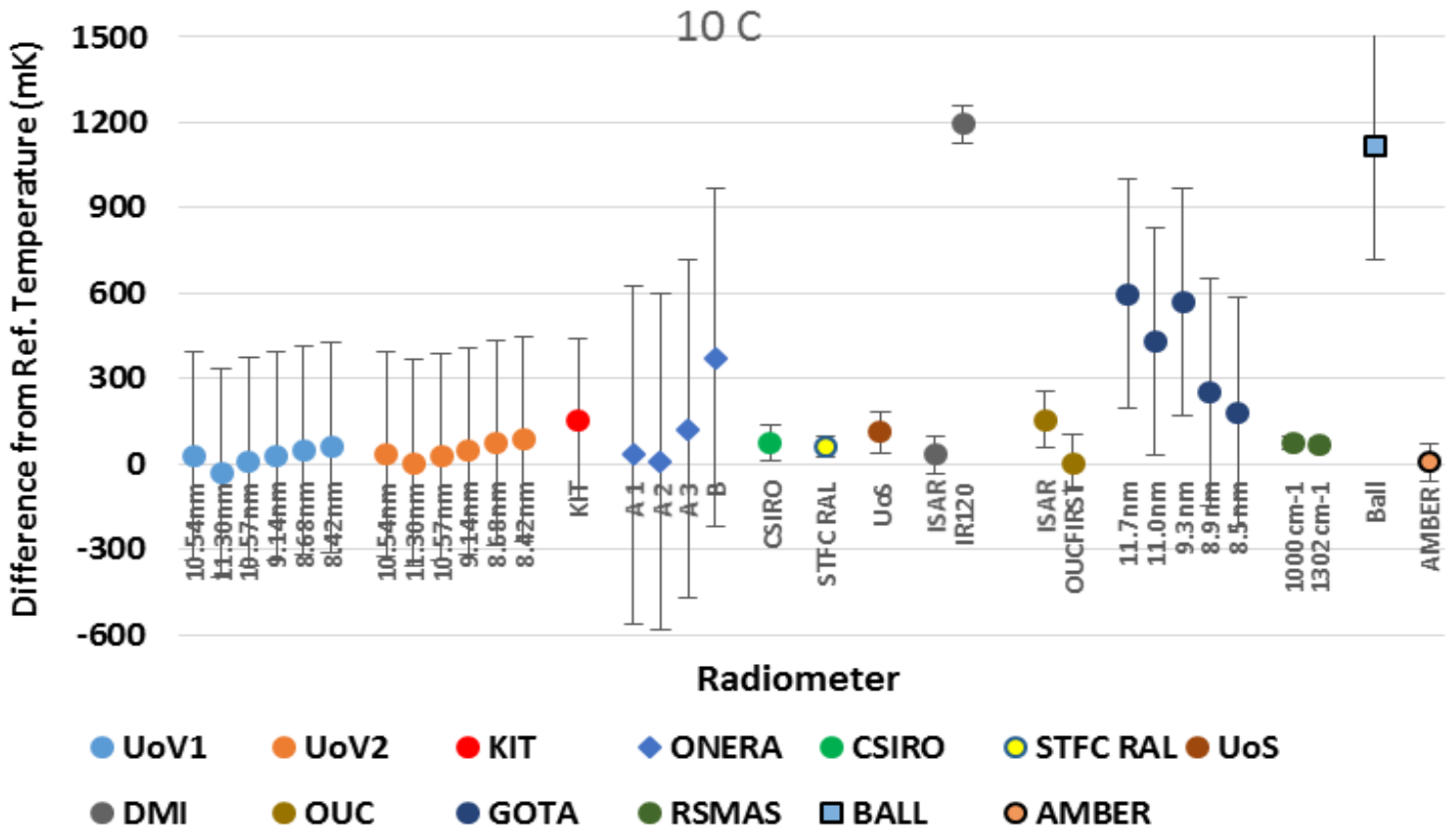
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of -15°C.



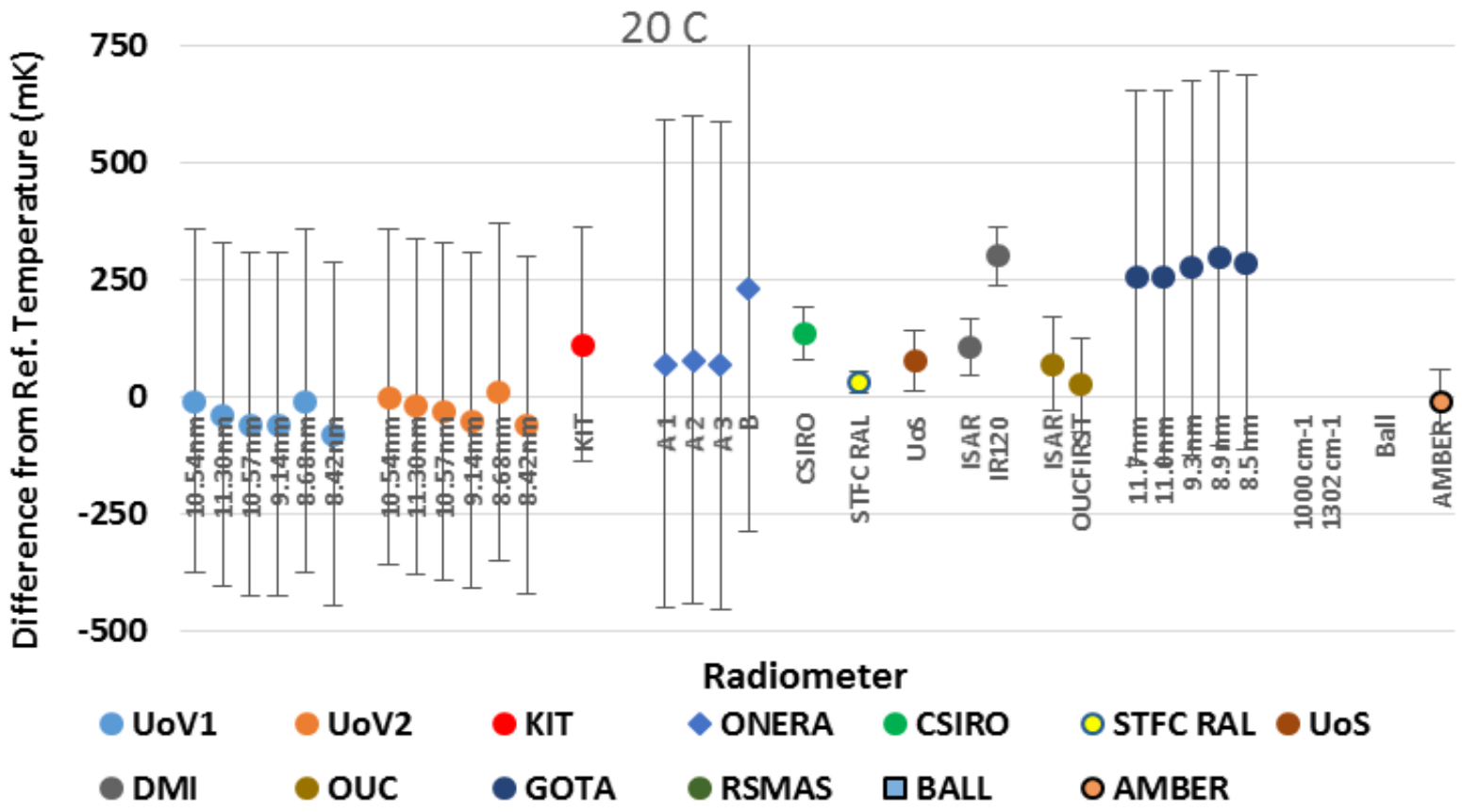
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 0°C.



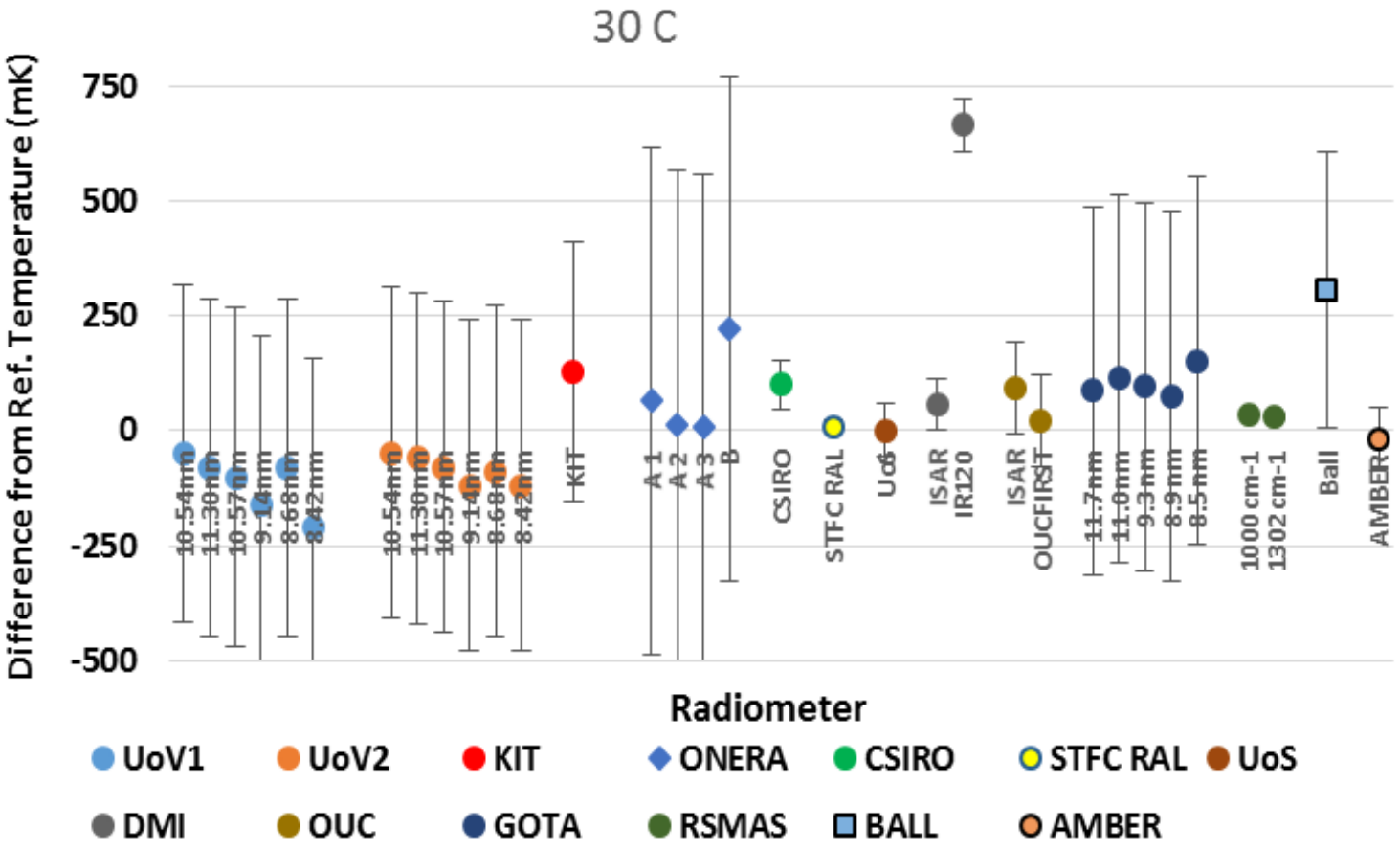
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 10°C.



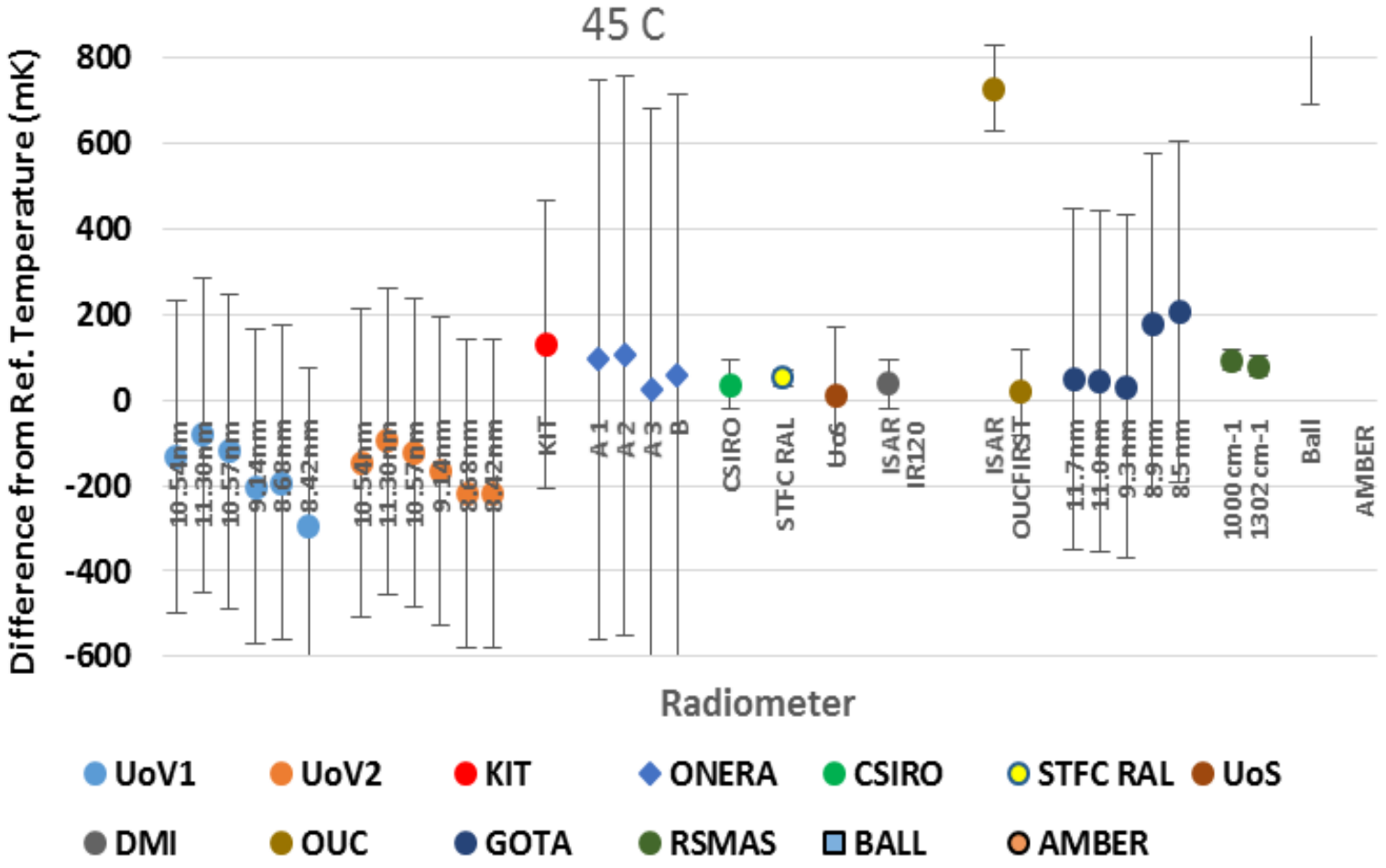
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 20°C.



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.



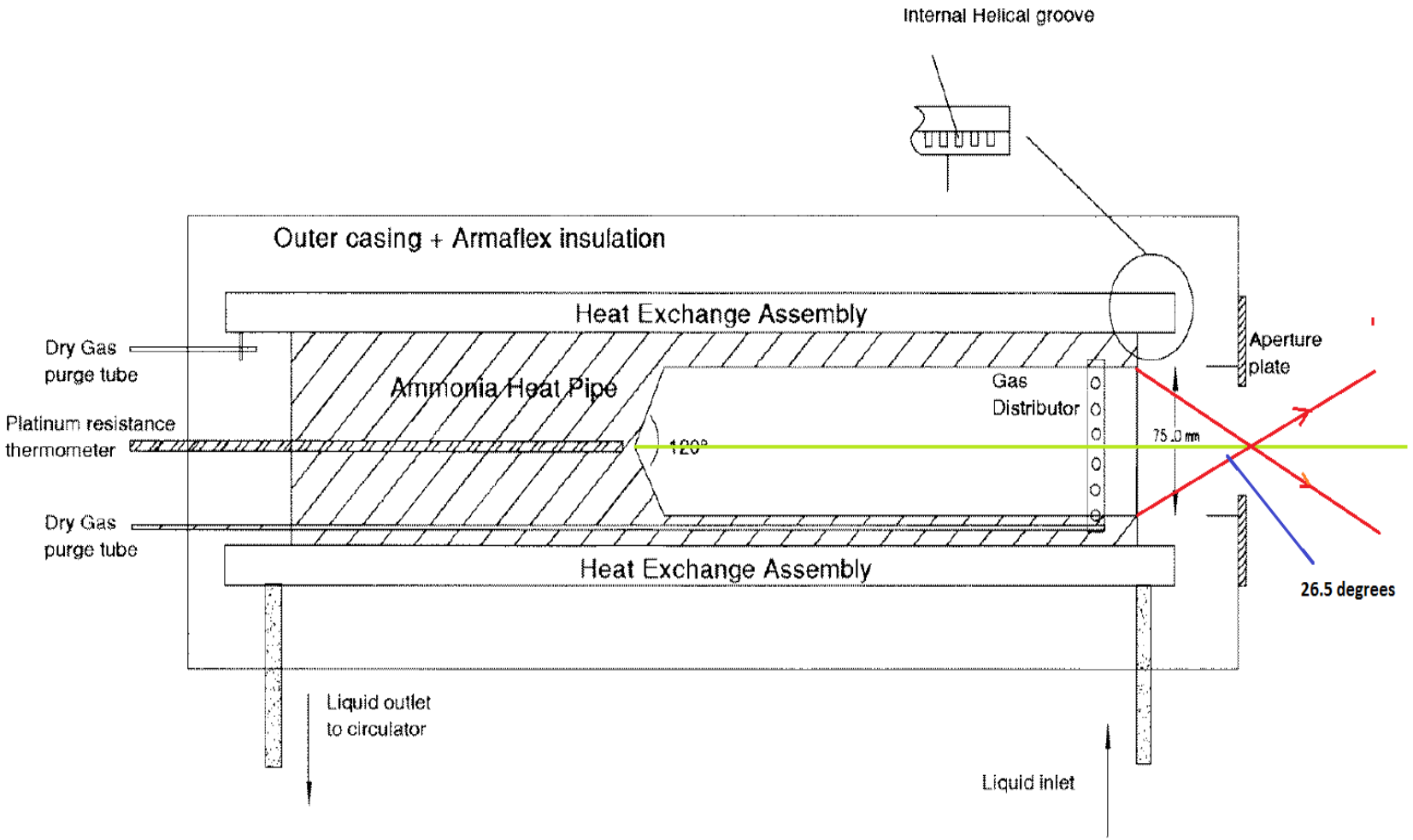
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 45°C.



Summary of the radiometer lab comparison

- The results indicate that, for measurements corresponding to the reference blackbody operating at temperatures above 0 ^{o}C, the difference of the radiometer measurements from those of the ammonia heat-pipe blackbody cavity temperature is within the uncertainty of the measurements, with some exceptions.
- However, these differences become progressively larger as the reference blackbody temperature decreased to -15 ^{o}C and -30 ^{o}C.
- What gives rise to these differences at low temperatures?
  - Radiometer FoV effects
  - Radiometer Out-of-Band response
  - Extrapolation effects

The NPL NH3 Heat-pipe Blackbody



FoV of participating radiometers

Organisation	FoV	Full/Half angle
	degrees	
Valencia U	10	Not specified
RAL	13	Full
Southampton U	12	Full
RSMAS MAERI	2.6	Full
RSMAS ISAR	10	full
JPL	36	full
QingDao	Not specified	
ONERA	4	Full
GOTA	Not specified	
KIT	8.3	Full
DMI	10	Not specified
CSIRO	Not specified	
Ball Aero	18	Not specified

The BB cavity can support radiometers with a 26.5° half angle (53° full angle) FoV

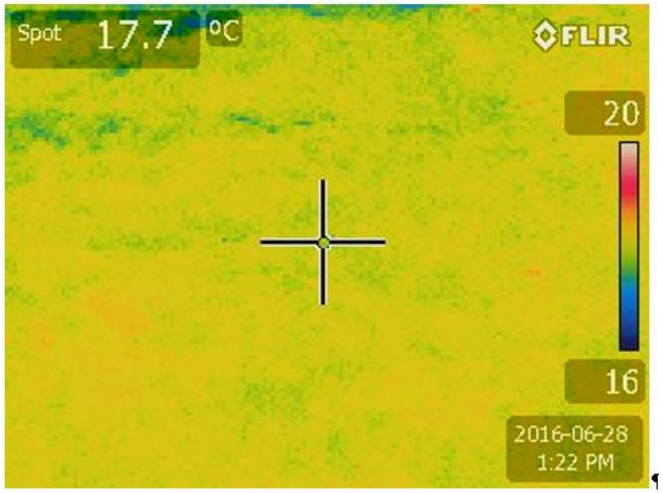
The BB cavity can support radiometers with a 12° half angle (24° full angle) FoV when placed at a distance of 100 mm from aperture.

The 2016 WST comparison at Wraysbury reservoir

27th June to 1st July 2016

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)



The WST comparison at Wraysbury reservoir.

- WST measurements were completed between Monday 27th of June and Friday 1st July.
- They involved continuous **Day-time** and **Night-time** WST measurements.
- They involve measurements under "**clear sky**" and under "**cloudy**" and **"rainy"** conditions.
- Although some radiometers could provided WST measurements at more than one angle, participants were asked to provide the "best" WST measurements they could.
- Due to some rainy periods**,** not all radiometers were able to operate continuously, hence there are gaps in the WST measurements of some participants.

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

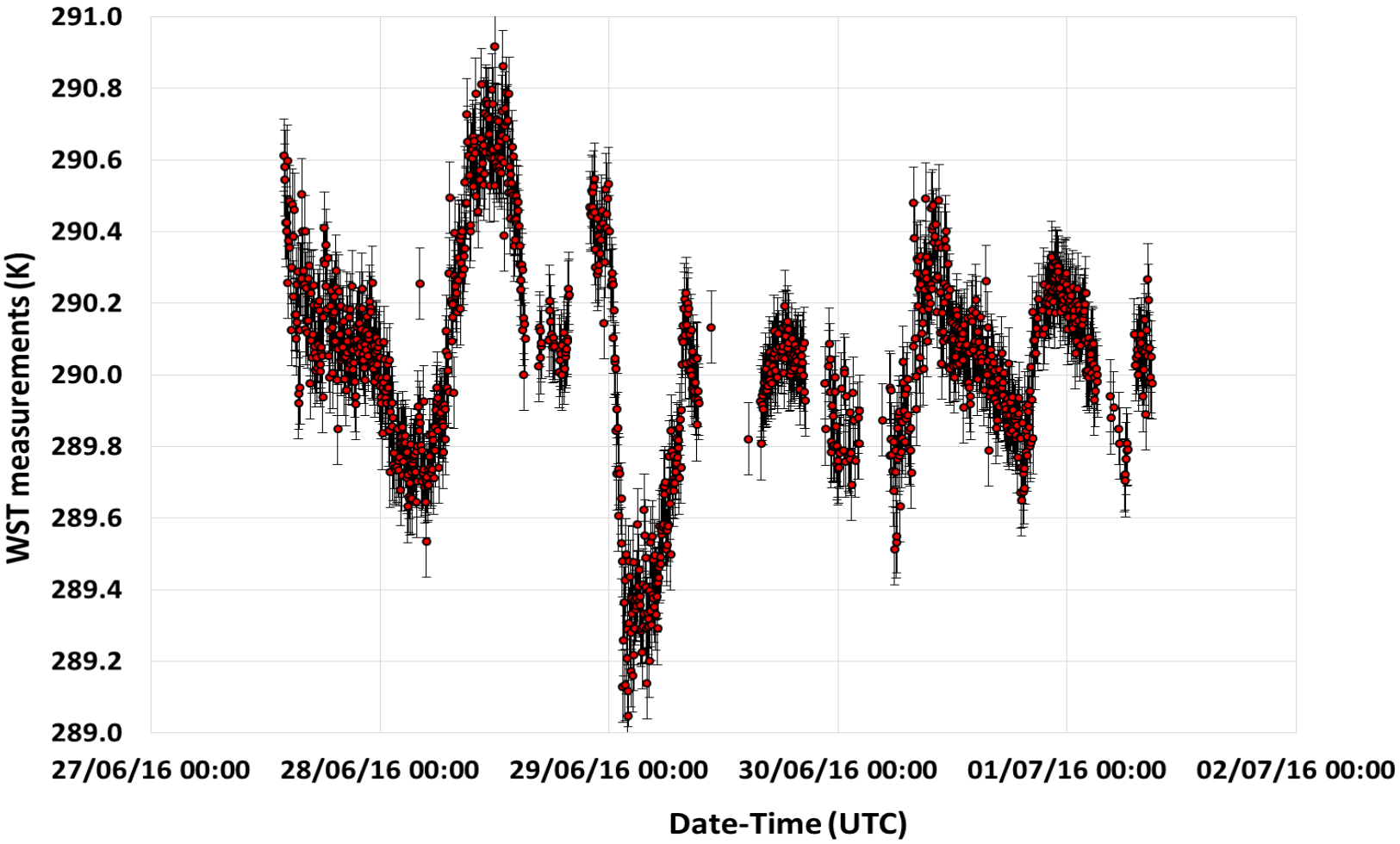
Radiometers were installed with the aid of a boat

Radiometers measuring WST during the 2016 comparison

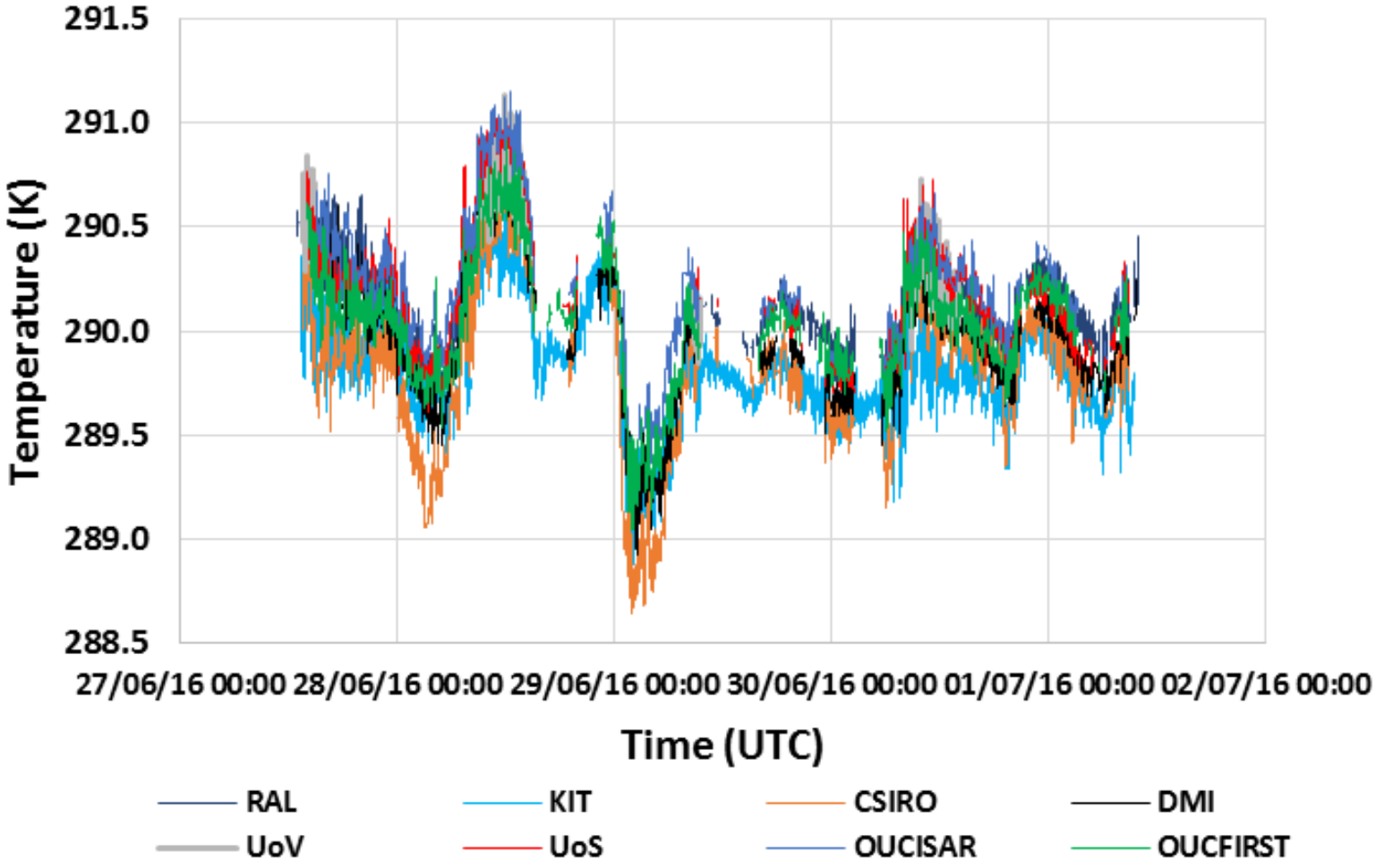
Summary of the WST comparison at Wraysbury reservoir

- **All participants provided measurements for their radiometer WST comparison at Wraysbury reservoir.**
- **The detail in the uncertainty budgets provided by different participants varied considerably.**
- **All the data provided have been analysed.**
- **A report for this part of the work was prepared and circulated to all participants.**
- **The data and a copy of the report have been uploaded on the FTP server.**

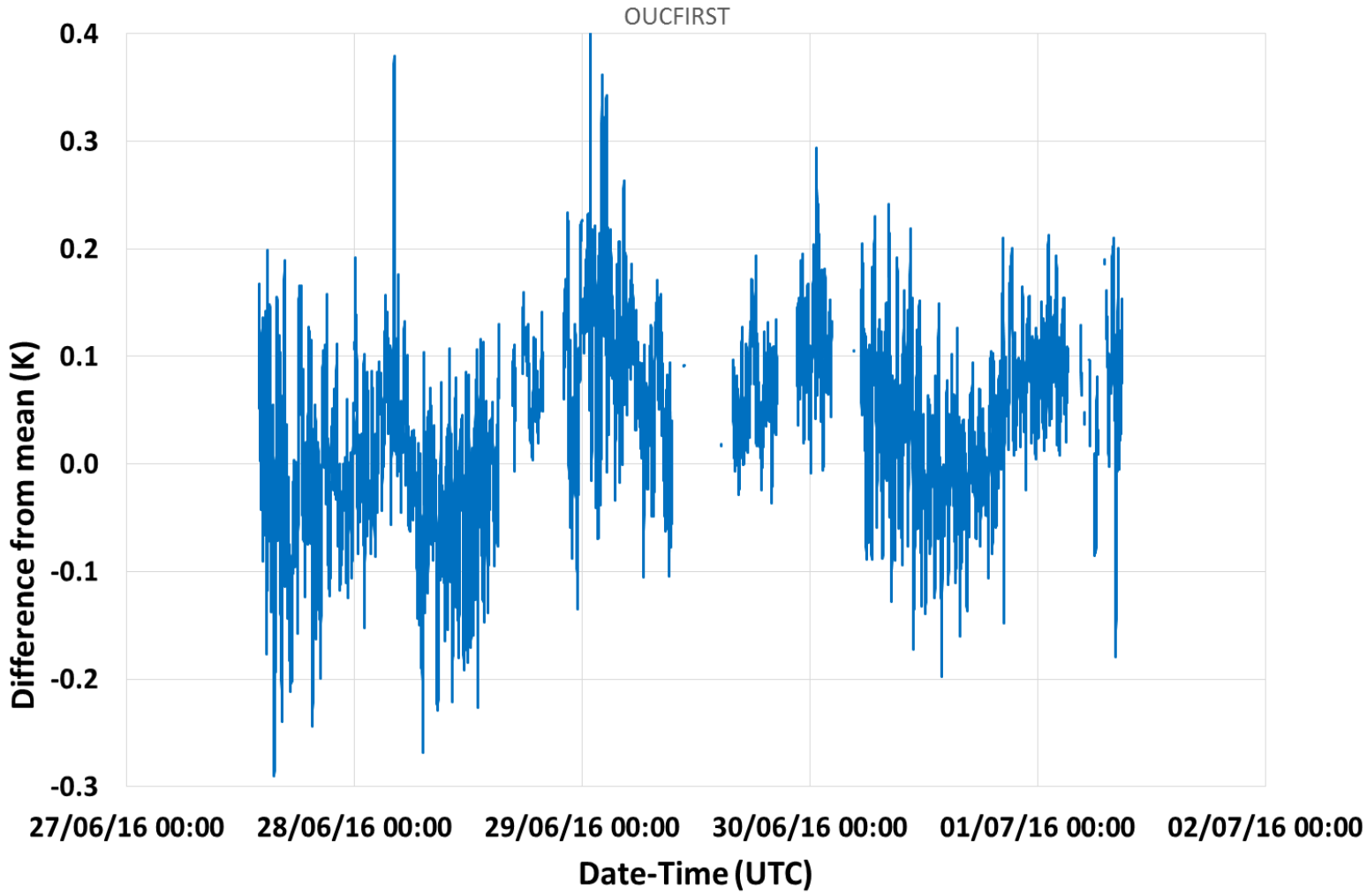
Measurements of the water surface temperature of Wraysbury reservoir made by the OUCFIRST



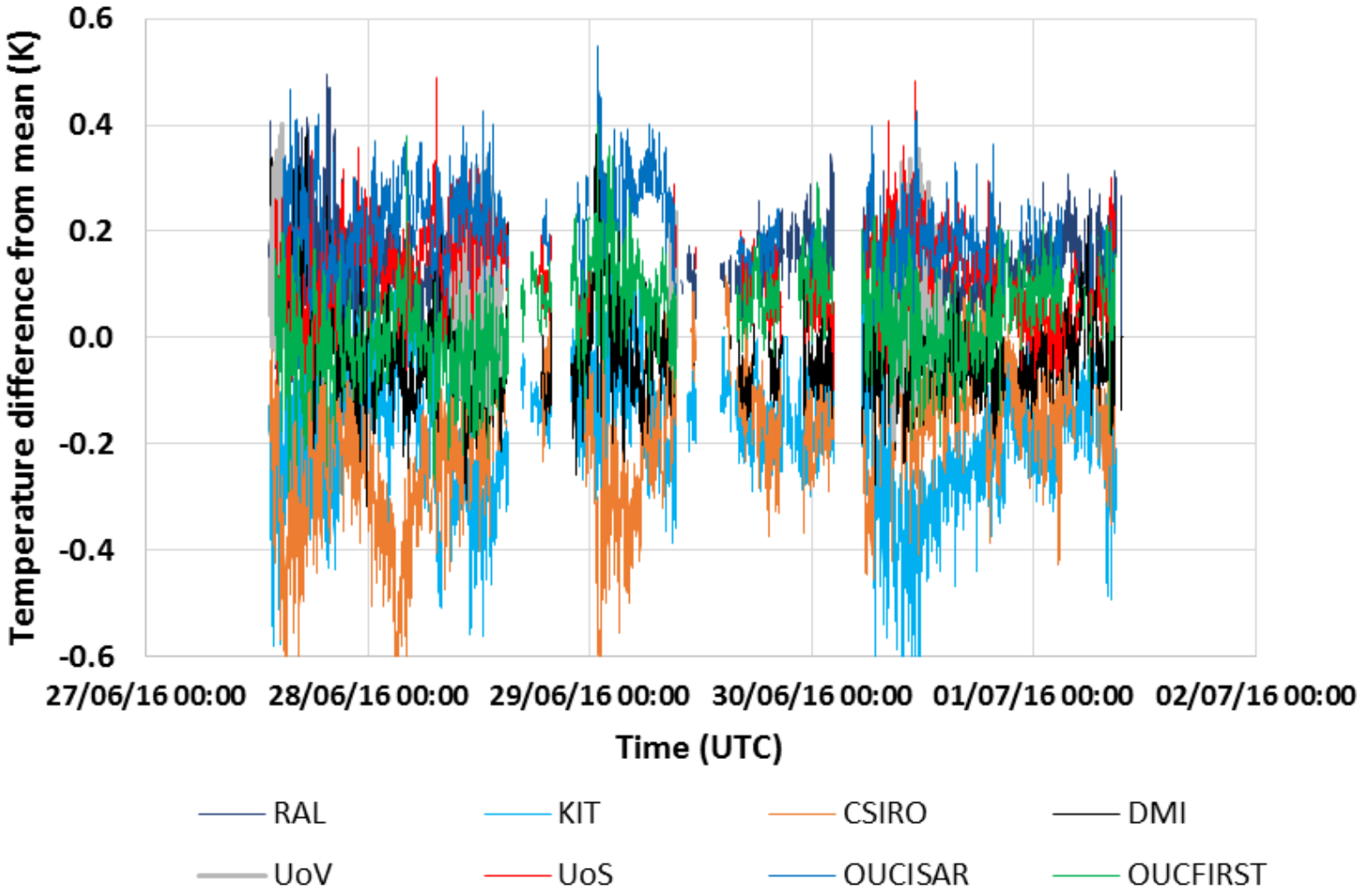
WST measurements of the various participants, over the five-day comparison period



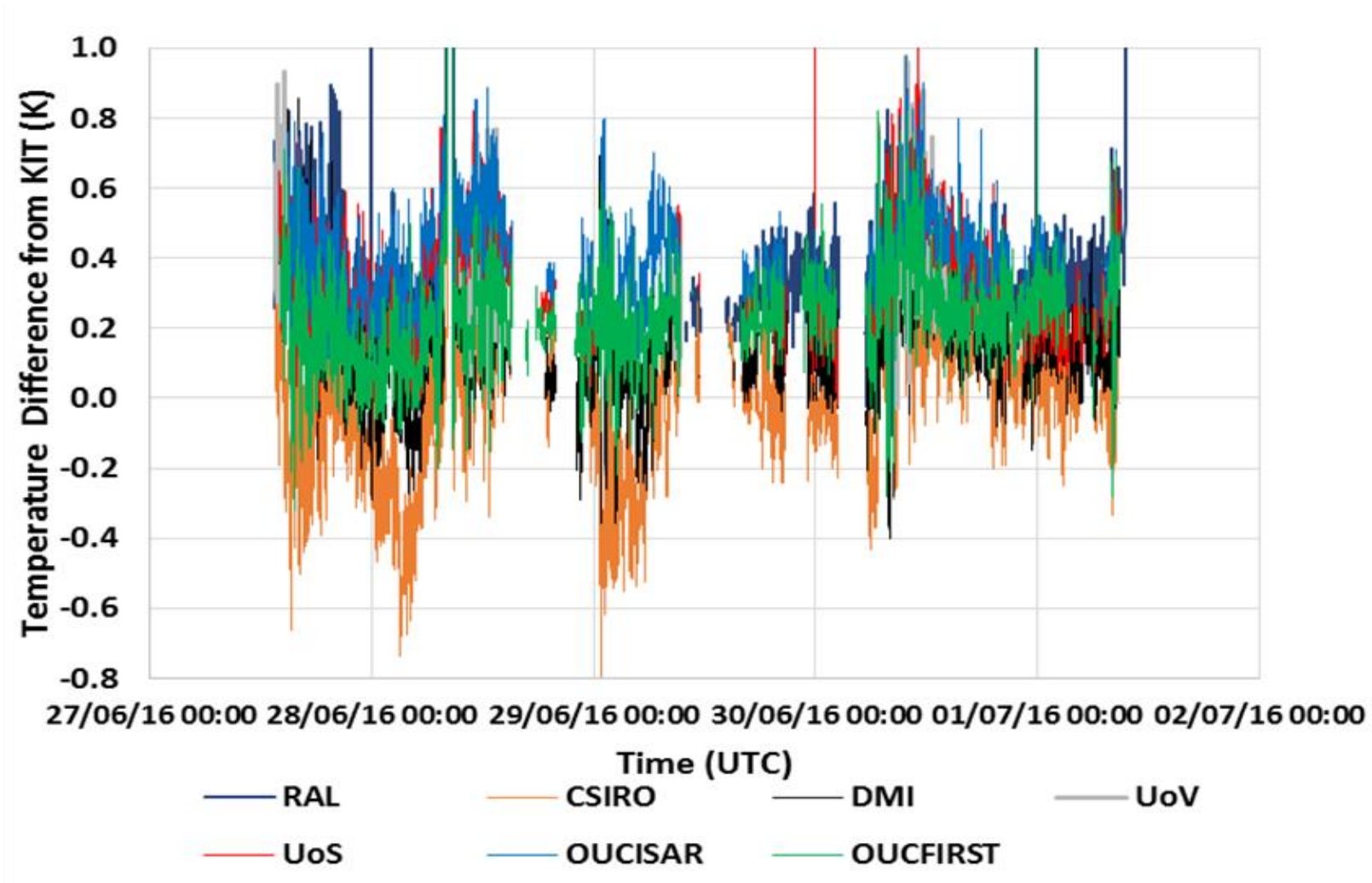
Difference of the measurements of the water surface temperature of Wraysbury reservoir made by the OUCFIRST radiometer and the mean of all measurements made over the five day period



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

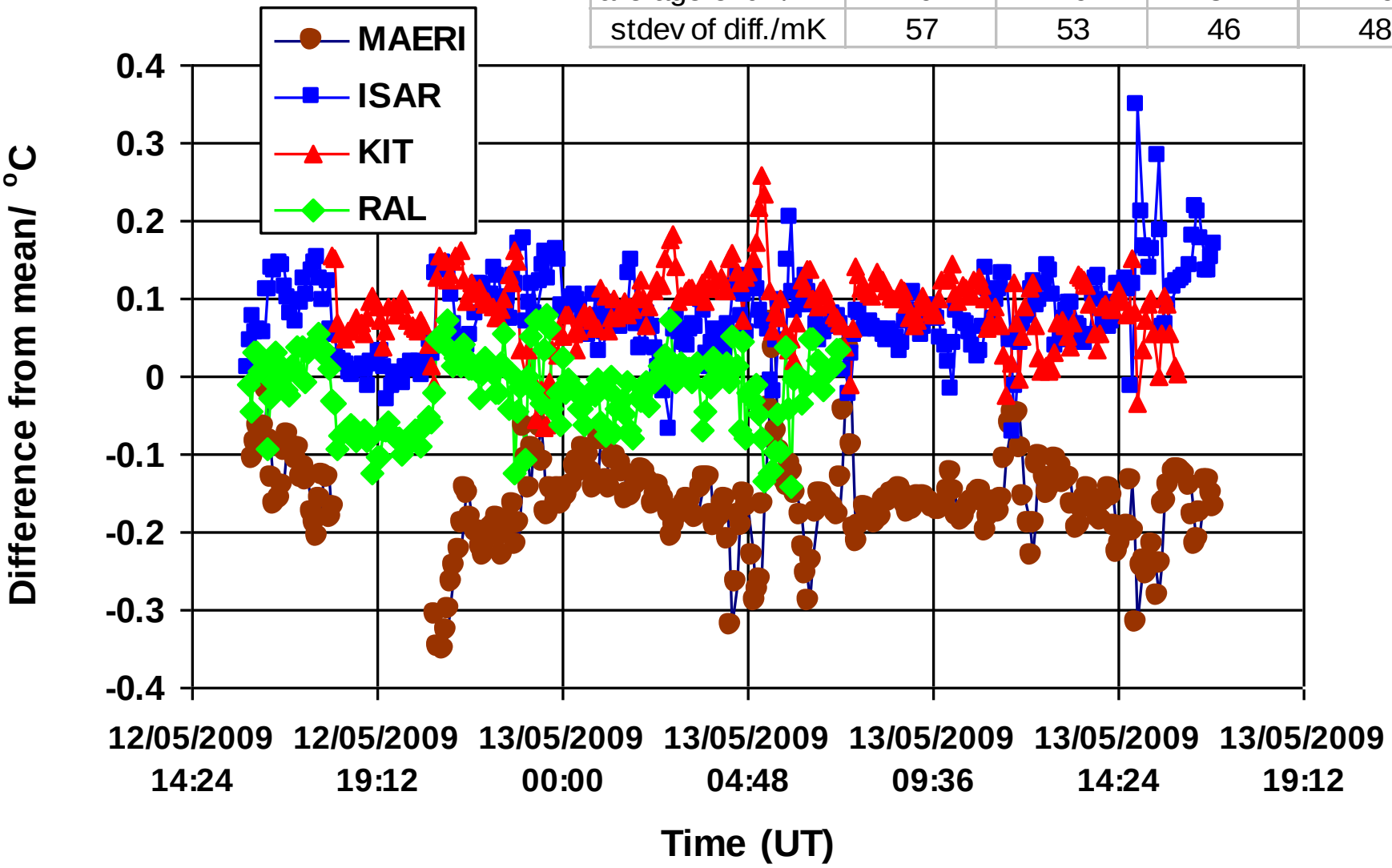


Plot of the difference of the WST measurements of the various participants, from the measurements provided by KIT, over the five-day comparison period.



Difference from mean, 2009 comparison

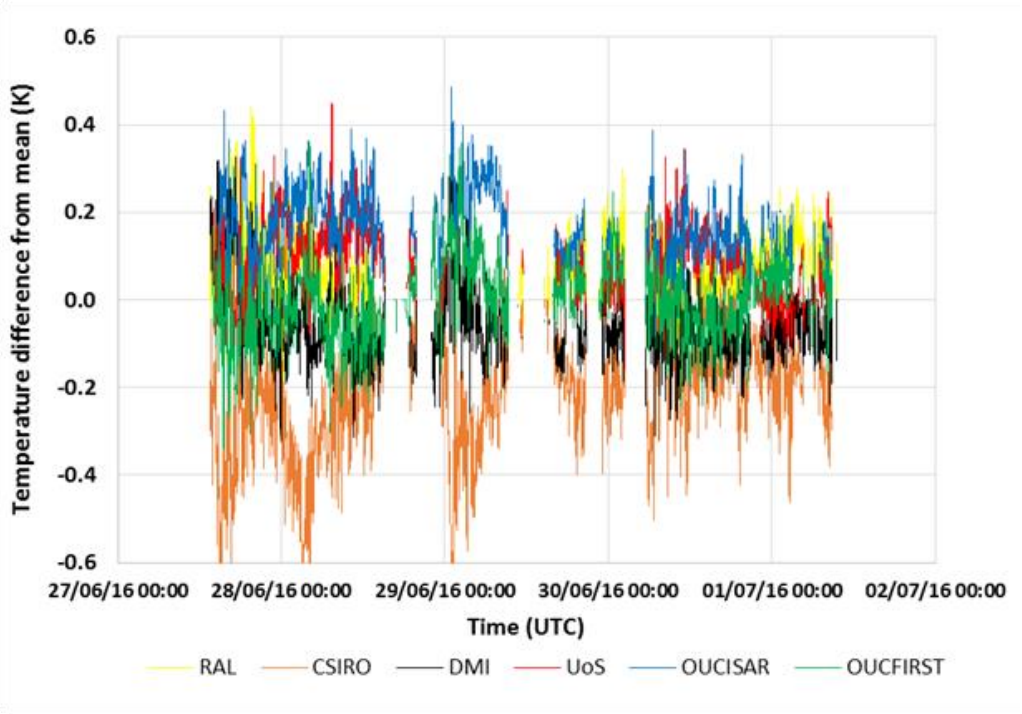
	MAERI	ISAR	KIT	RAL
average of diff/mK	-161	79	87	-19
stdev of diff./mK	57	53	46	48



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 (°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 Included	SST-Measuring Radiometers Only	SST-Measuring 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		

SISTeR / ISAR inter-comparison

- The ISAR SISTeR side by side inter-comparison on the *QM2* ran 11th Sept. 2015 to 5th Nov. 2015
  - Issues with the Rain Gauges limited the usable data to 20th Sept. to 5th Nov.
  - Early results look promising. Arial
  - More work needed on understanding the uncertainties

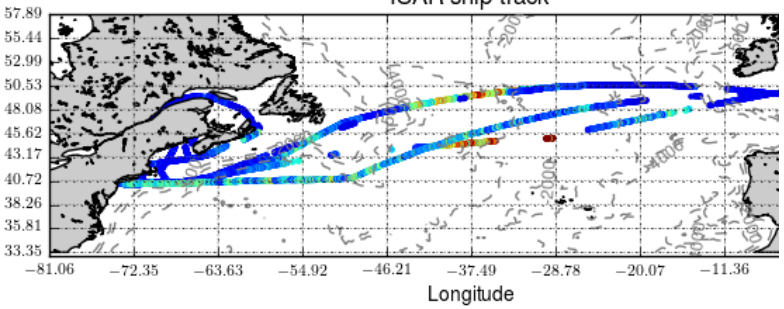
Infrared sea surface temperature autonomous radiometer

ISAR

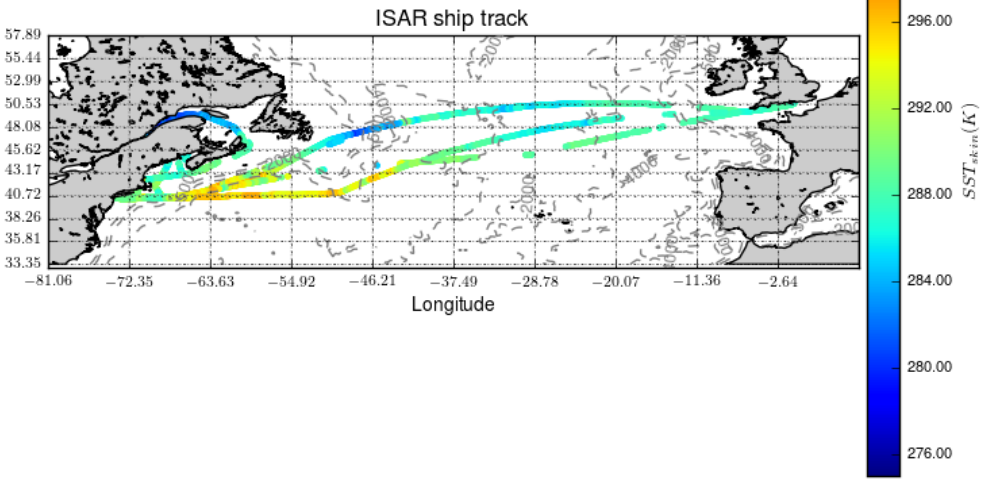
www.isar.org.uk

SISTeR / ISAR inter-comparison

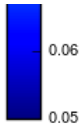
ISAR time: 20150920 11:35:03 to to 20151105 09:11:31



ISAR time: 20150920 11:35:03 to to 20151105 09:11:31

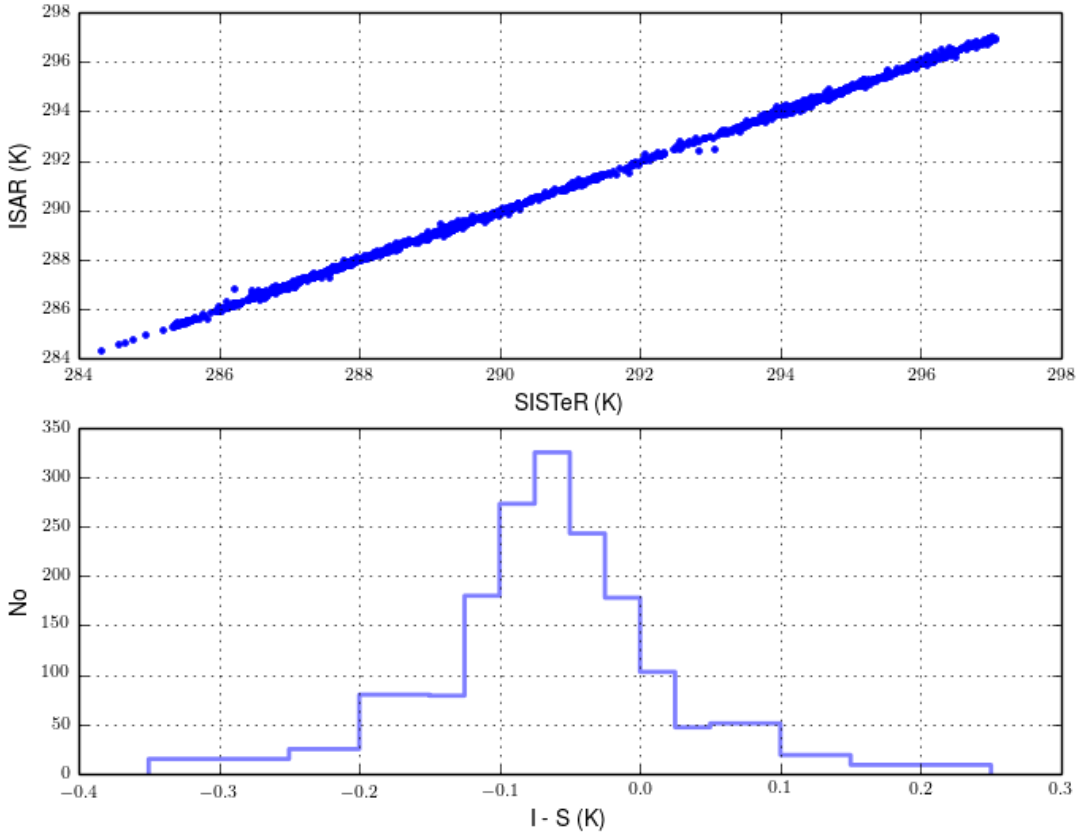


processed 20151207 17:45:20 (c) 2015 ISAR team



processed 20151207 17:45:17 (c) 2015 ISAR team

ISAR – SISTeR data



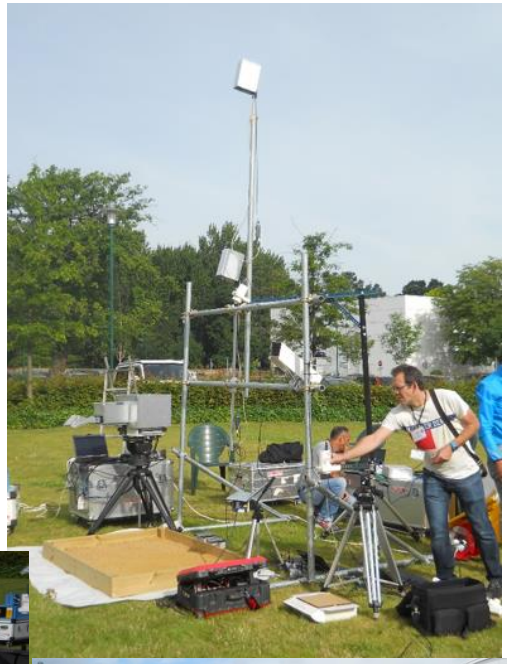
Filtered data:
Only data where QM2 was faster than 5 kts used

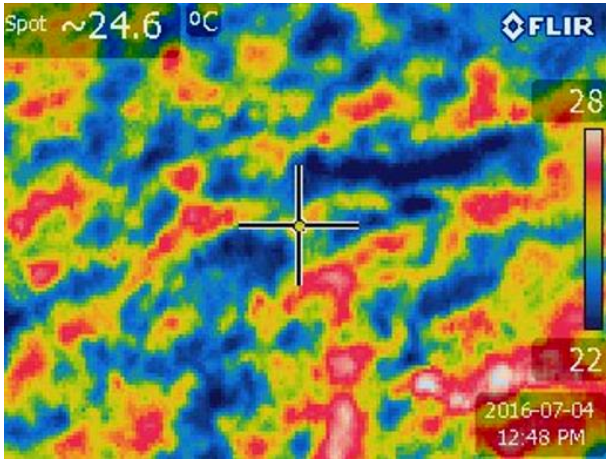
The 2016 LST comparison at NPL

4th to 7th July 2016

LST (Sun & Cloud)

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





Emissivity

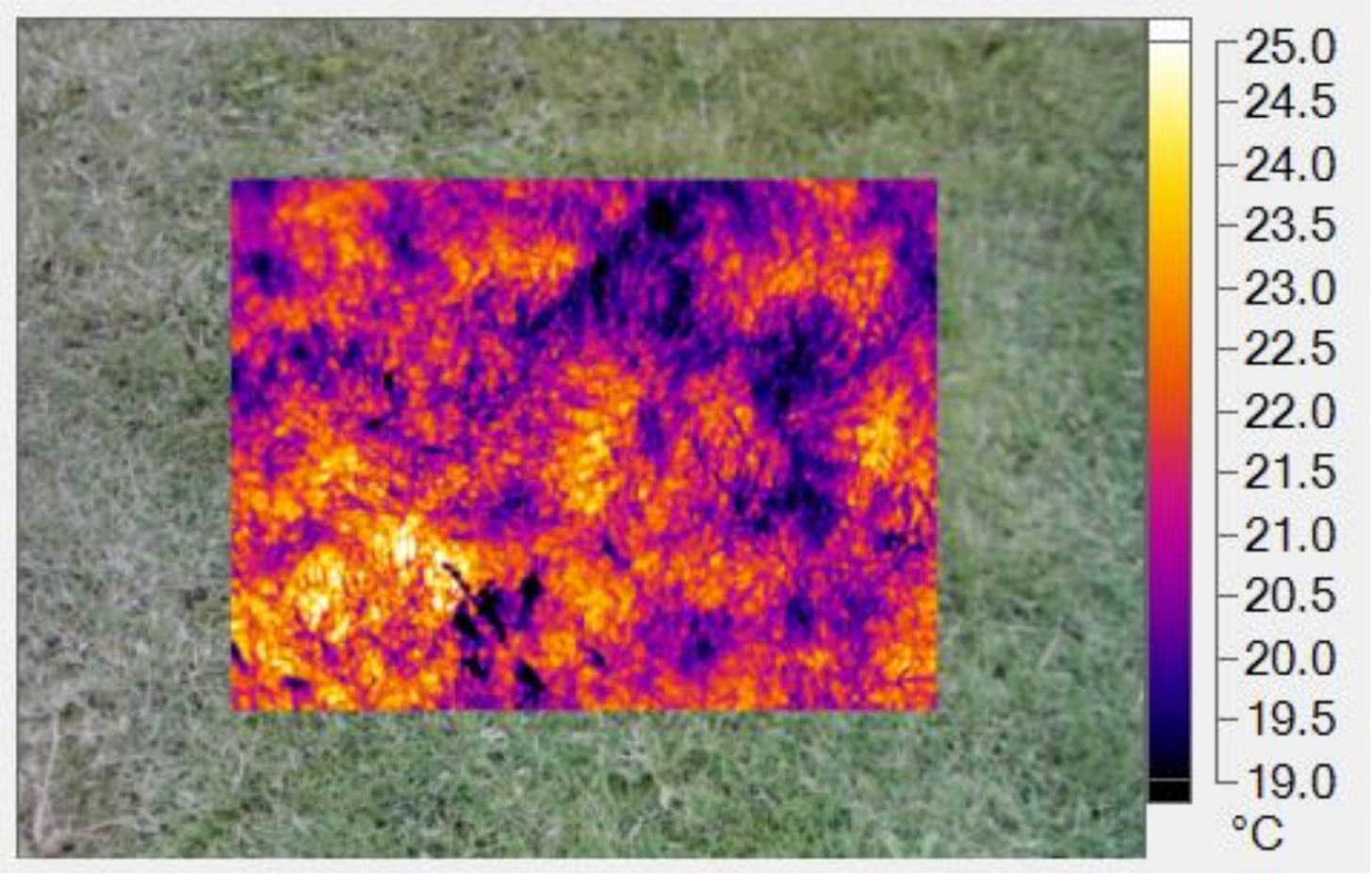
fiducial reference temperature measurements

Land samples studied:

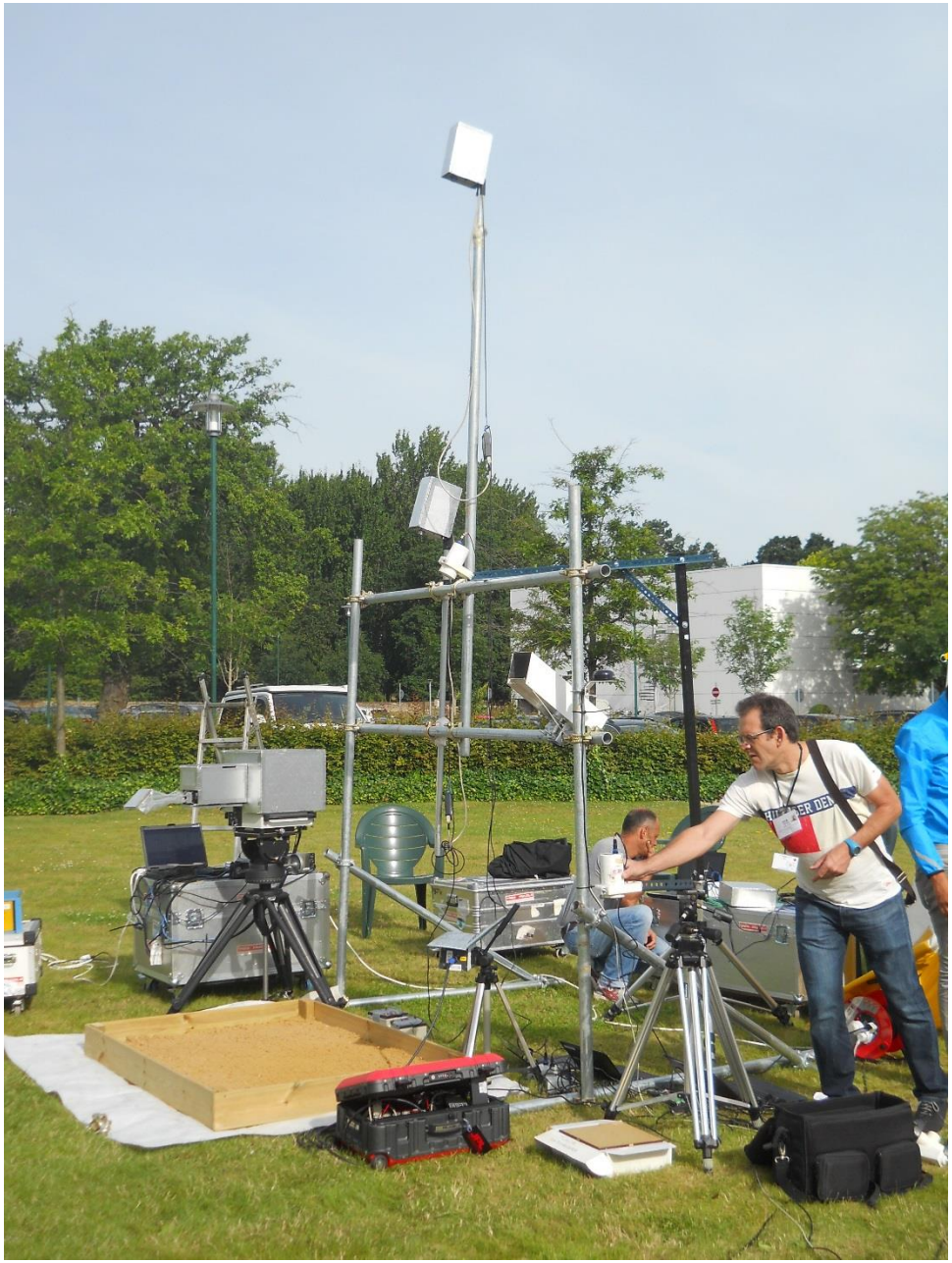
- Short grass
- Clover
- Sand
- “Dark” soil
- Gravel
- Tarmac

Some of the targets used for the 2016 LST comparison.

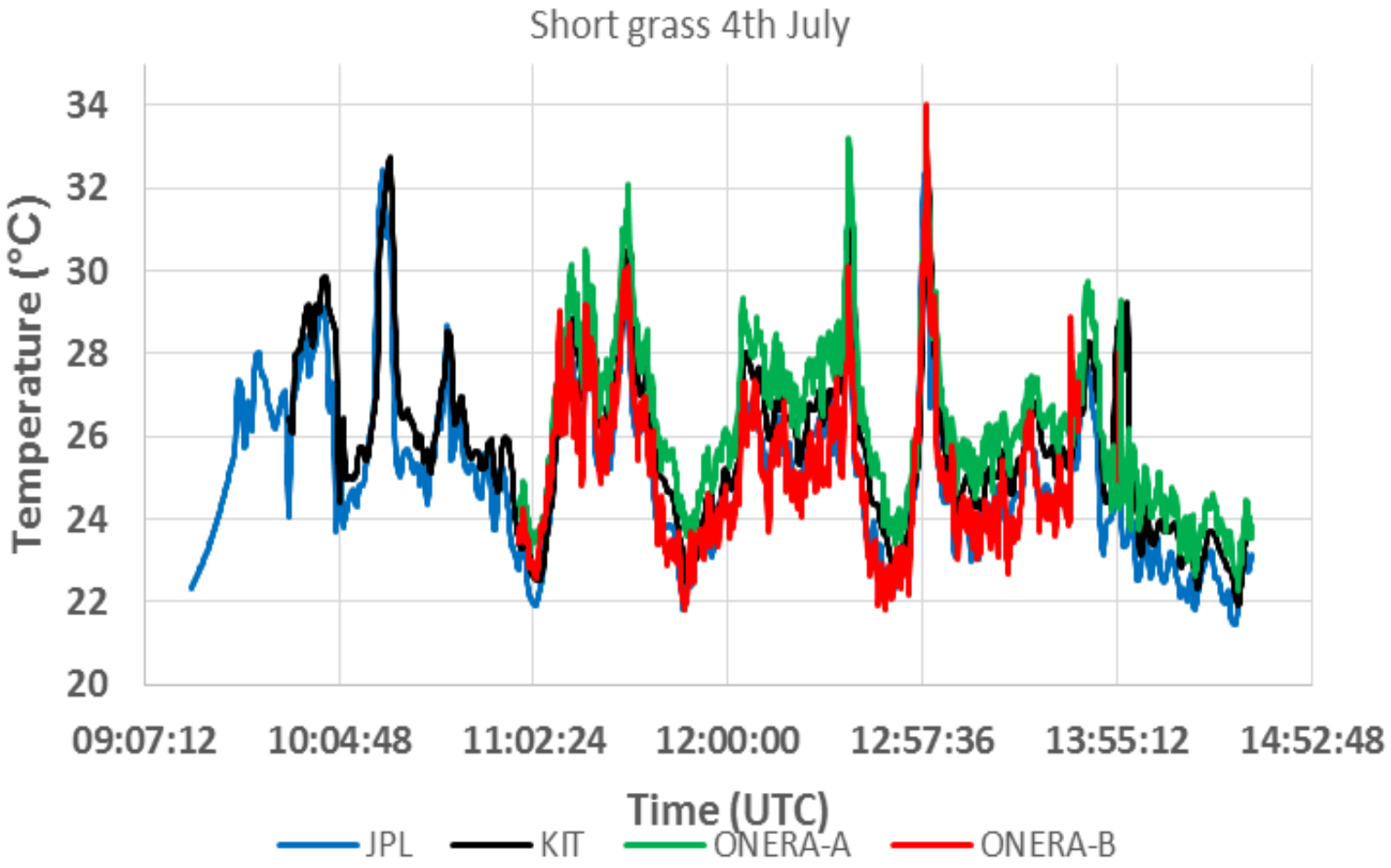
Image of the combination of a thermal image of the short grass sample with a black and white, visible image of the same target. The Figure shows that the apparent surface temperature of the sample was varying by about 5 ^{o}C over the measured area.



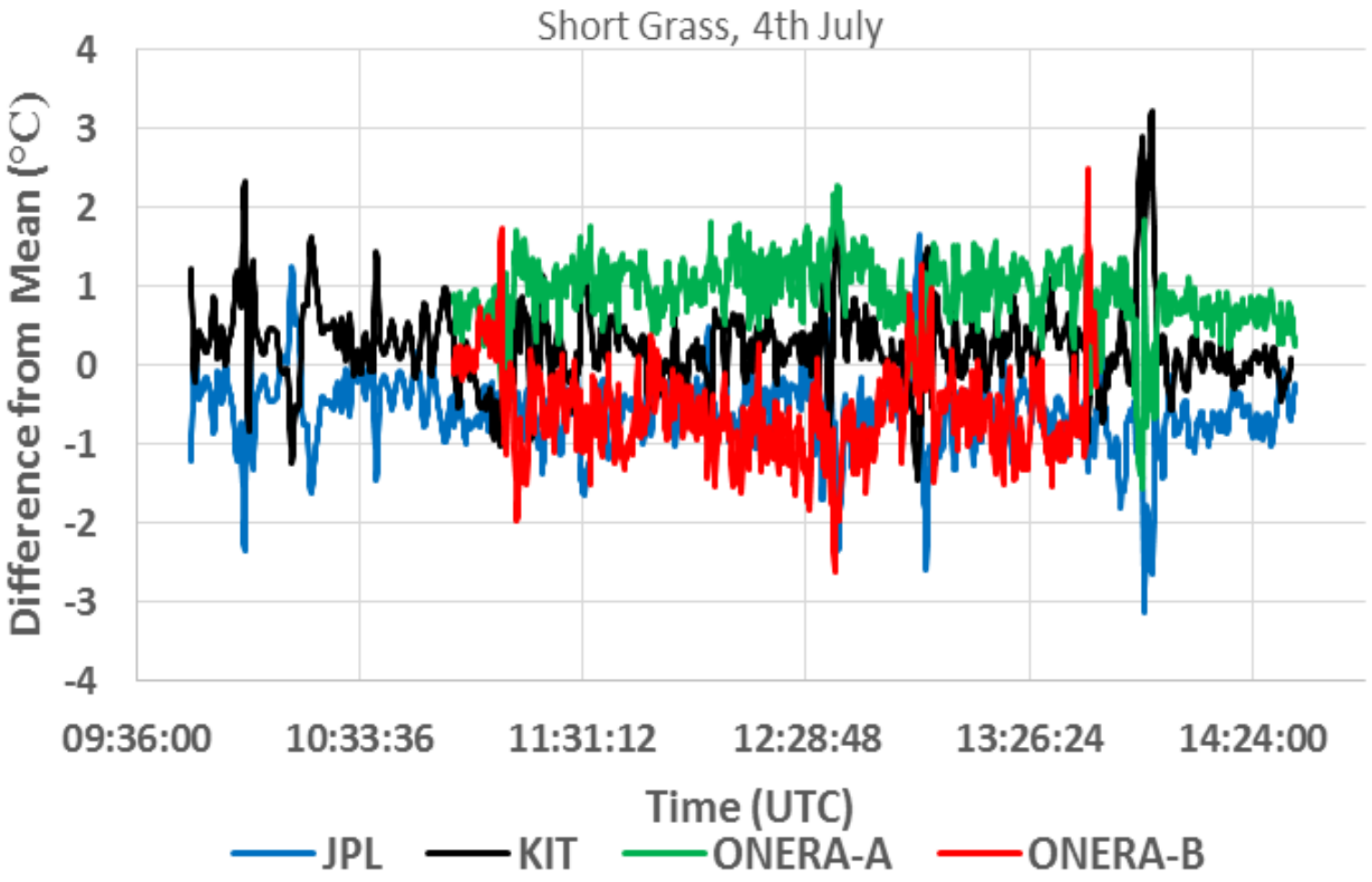
Radiometers measuring the surface temperature of the sand sample, with one of the radiometers placed at a height of approximately 4 m



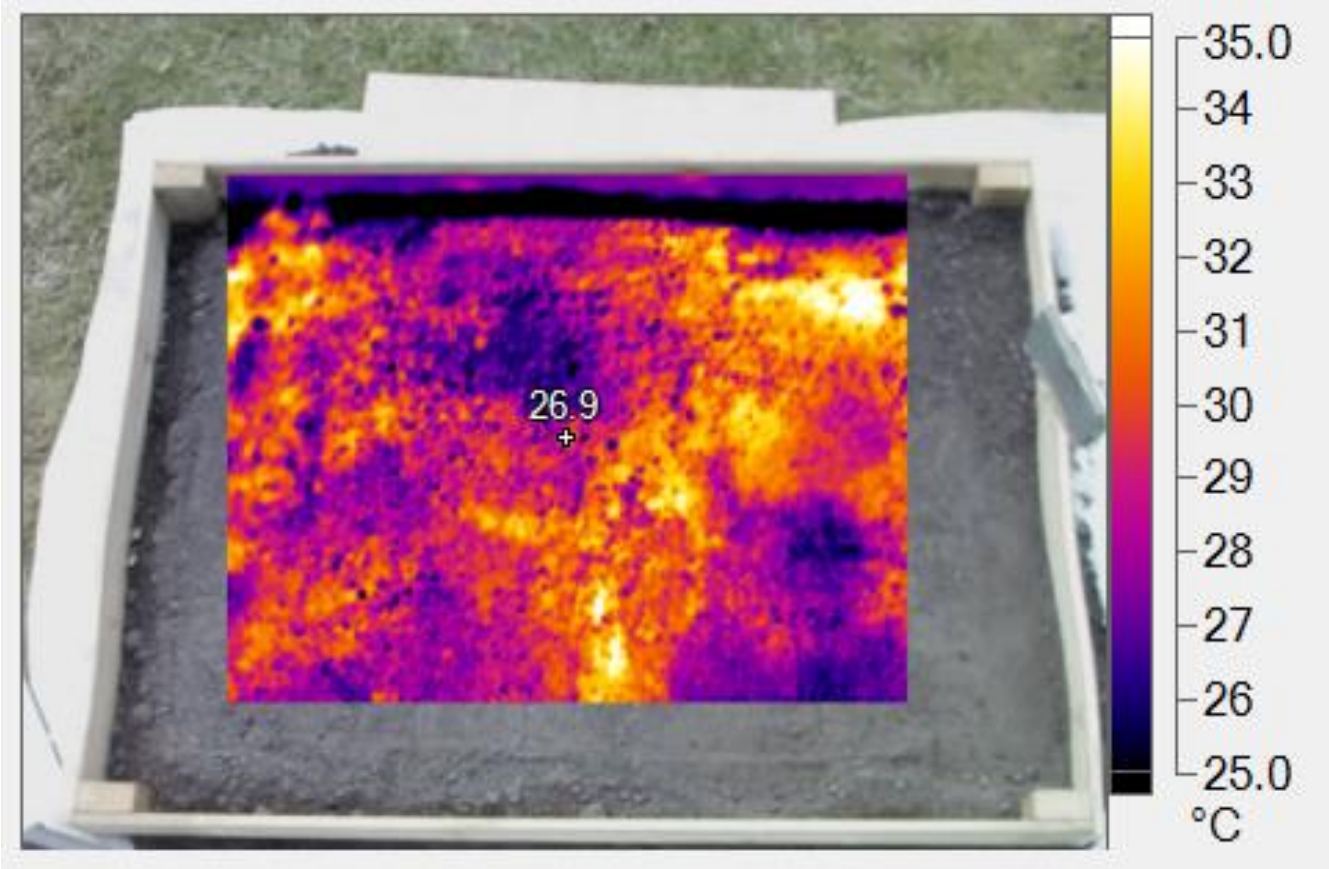
Surface temperature of short grass sample measured by the participating radiometers on the 4th July 2016.



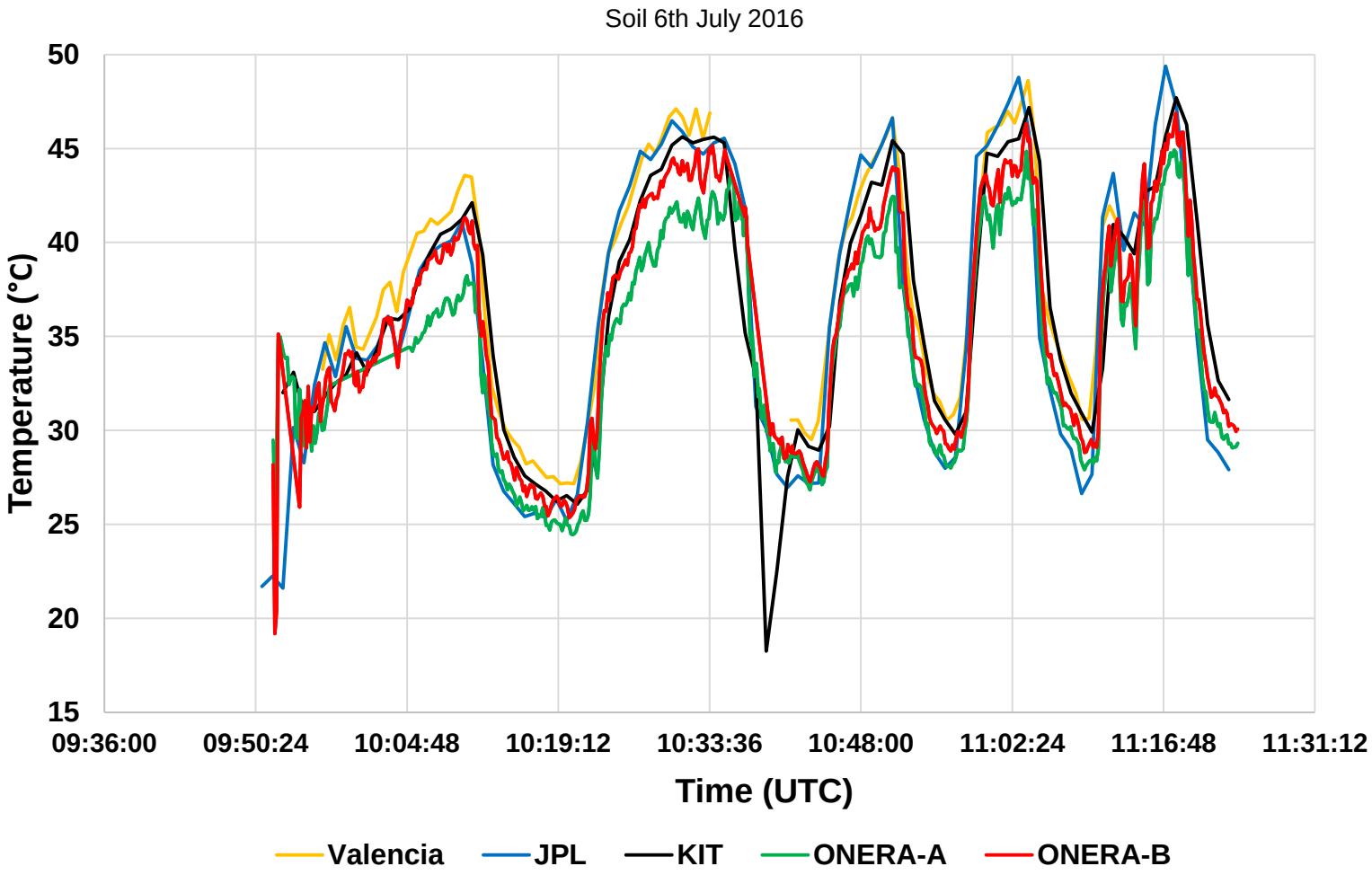
Difference of the measurements of measuring radiometers on the short grass sample from their mean. This Figure shows that the difference is within ±3 °C throughout the monitoring period (mostly within ±2 °C).



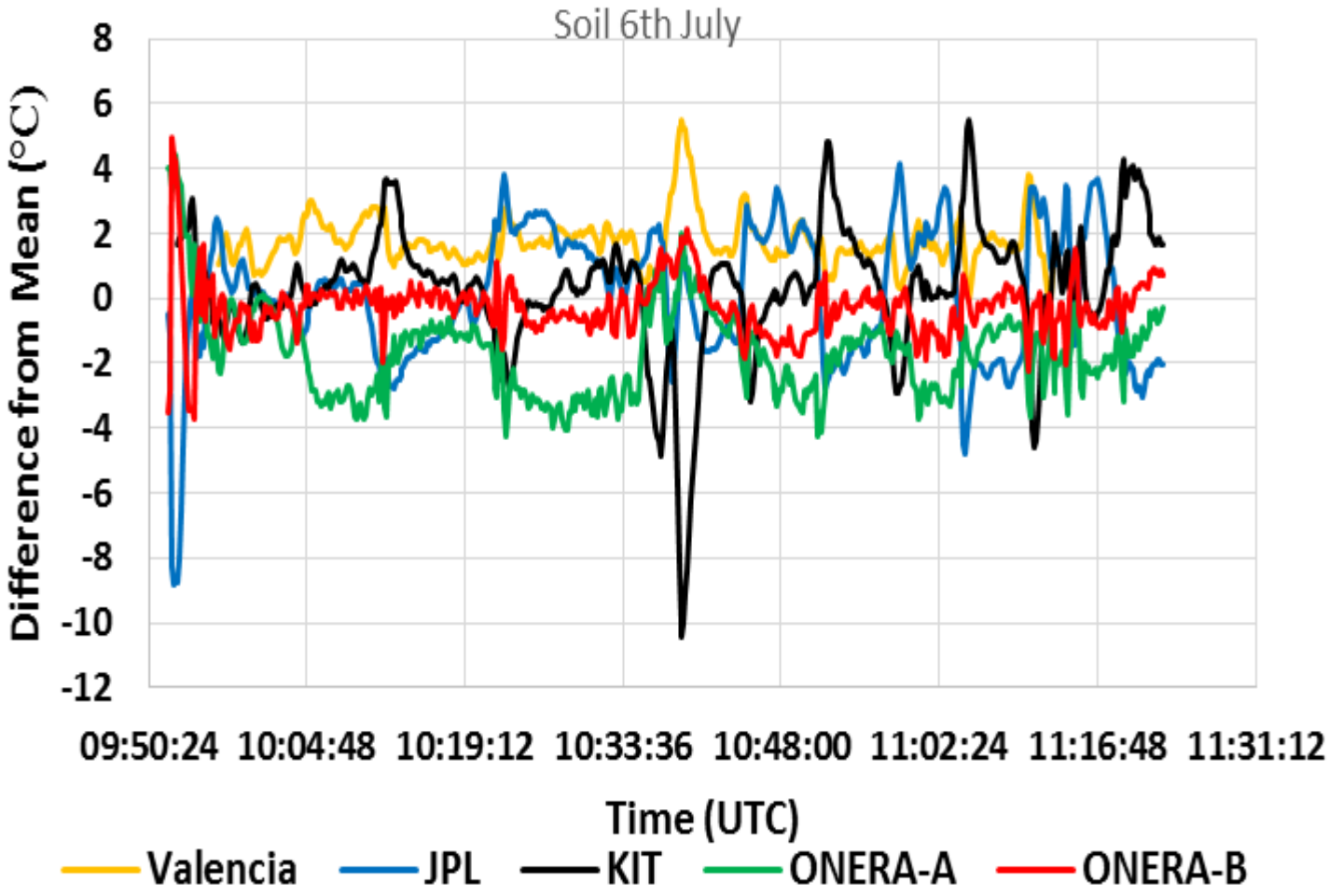
Combination of a thermal image of the dark soil sample with a black and white, visible image of the same target. The Figure shows that the apparent surface temperature of the sample was varying by about 10 ºC over the measured area.



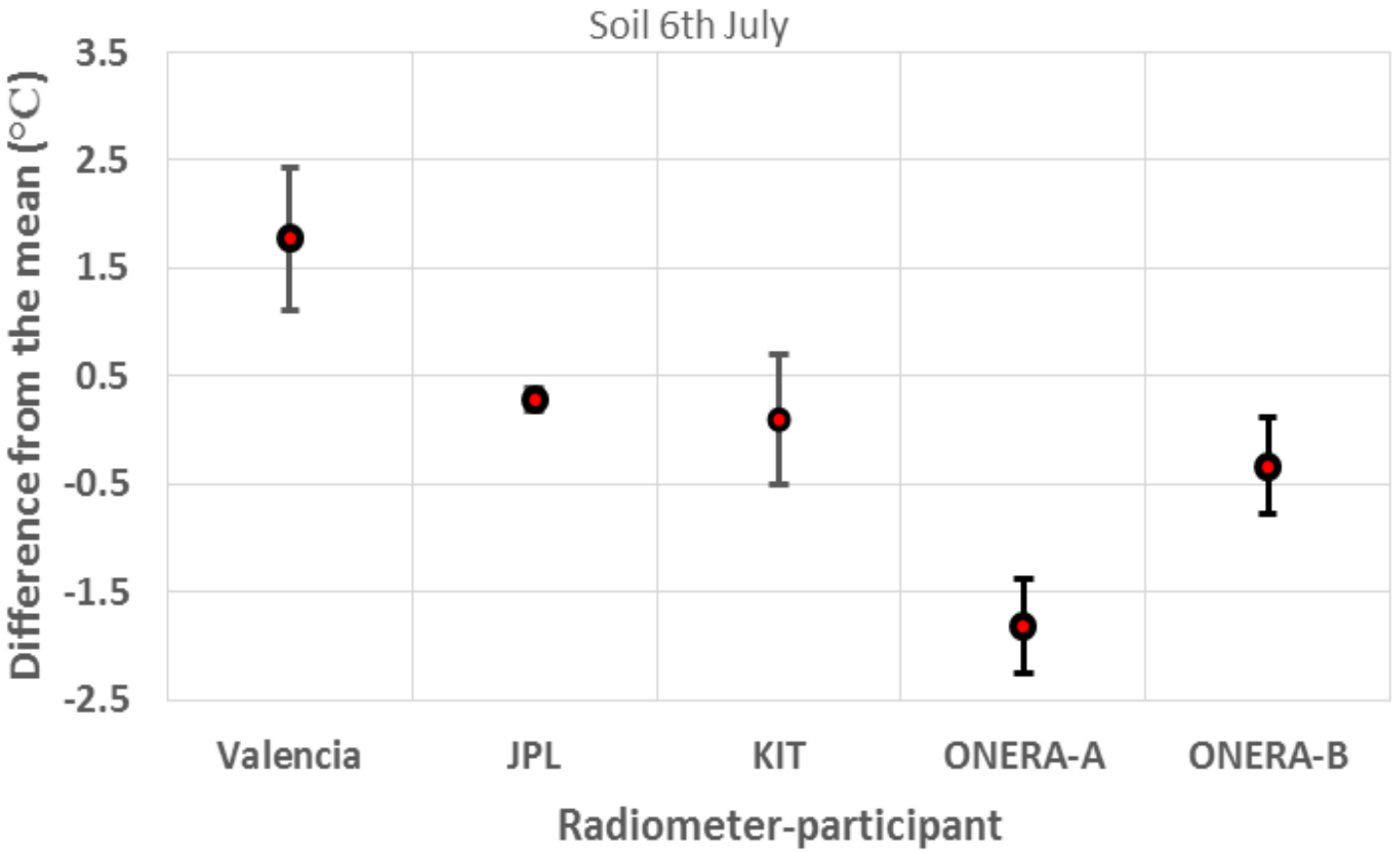
Surface temperature of dark soil measured by the participating radiometers on the 6th July 2016



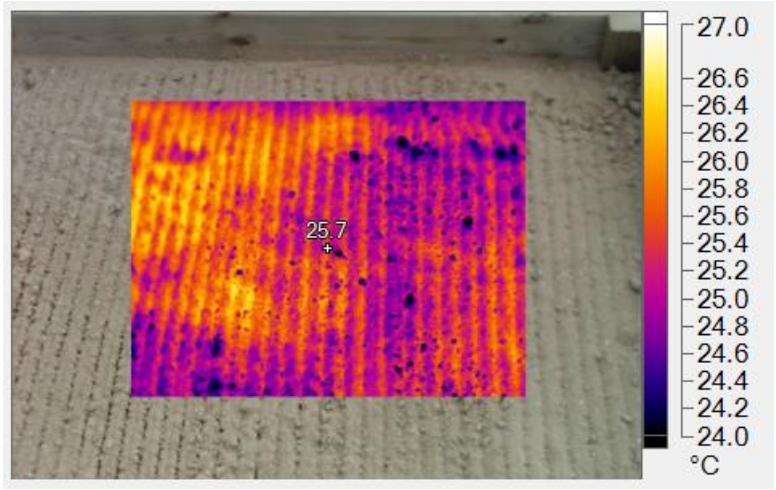
Difference of the measurements of the five measuring radiometers made on the 6th July on the dark soil sample from their mean.

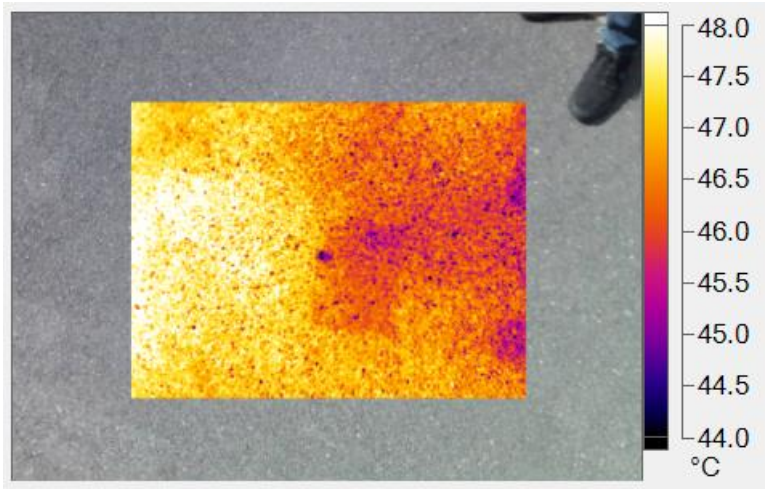


Difference of the mean surface temperature of the dark soil sample measured by participants from the mean of the measurements of all the participants.

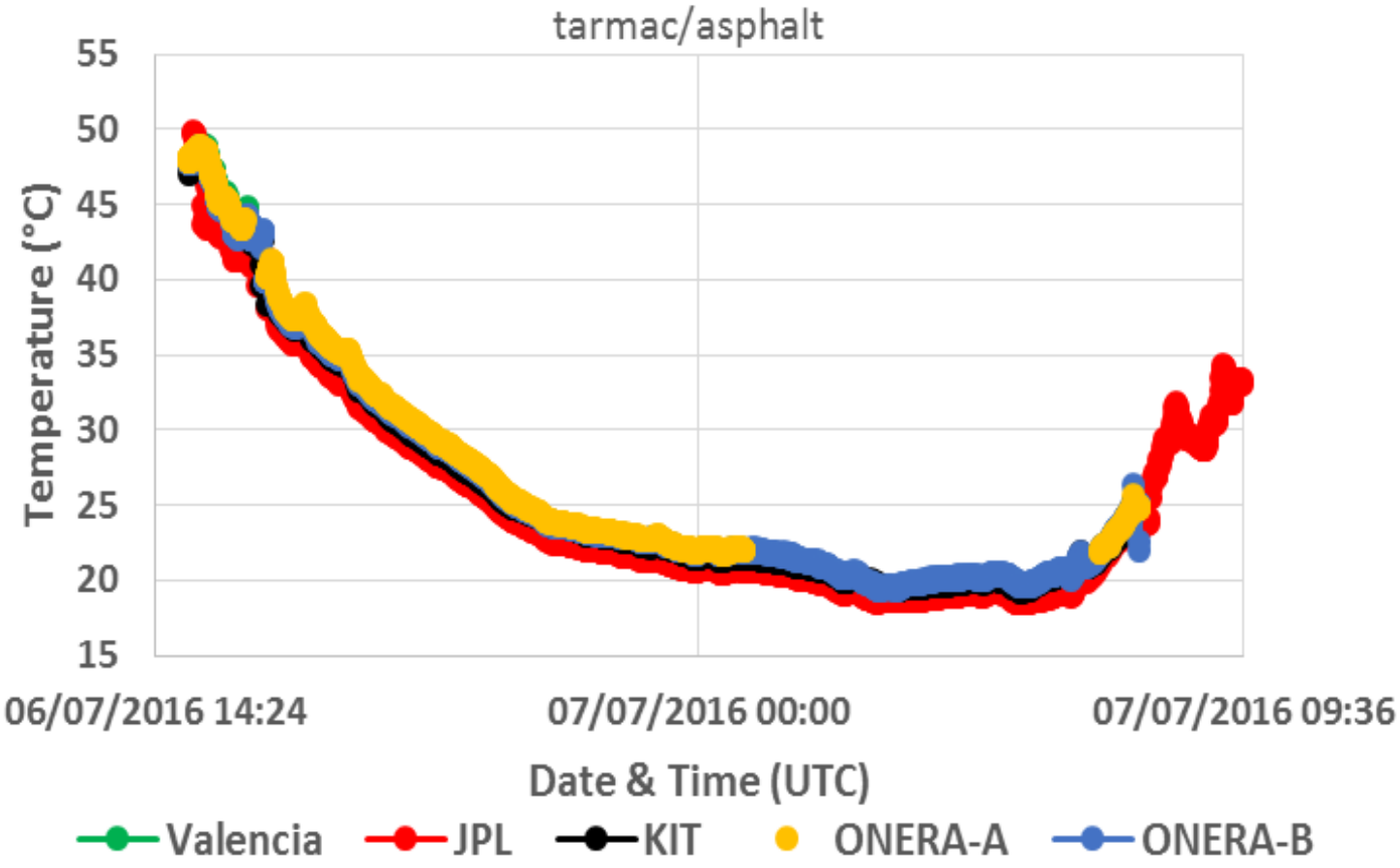


The “smoothness” of the sand sample was critical in determining the variations in temperature on the surface of the sample.

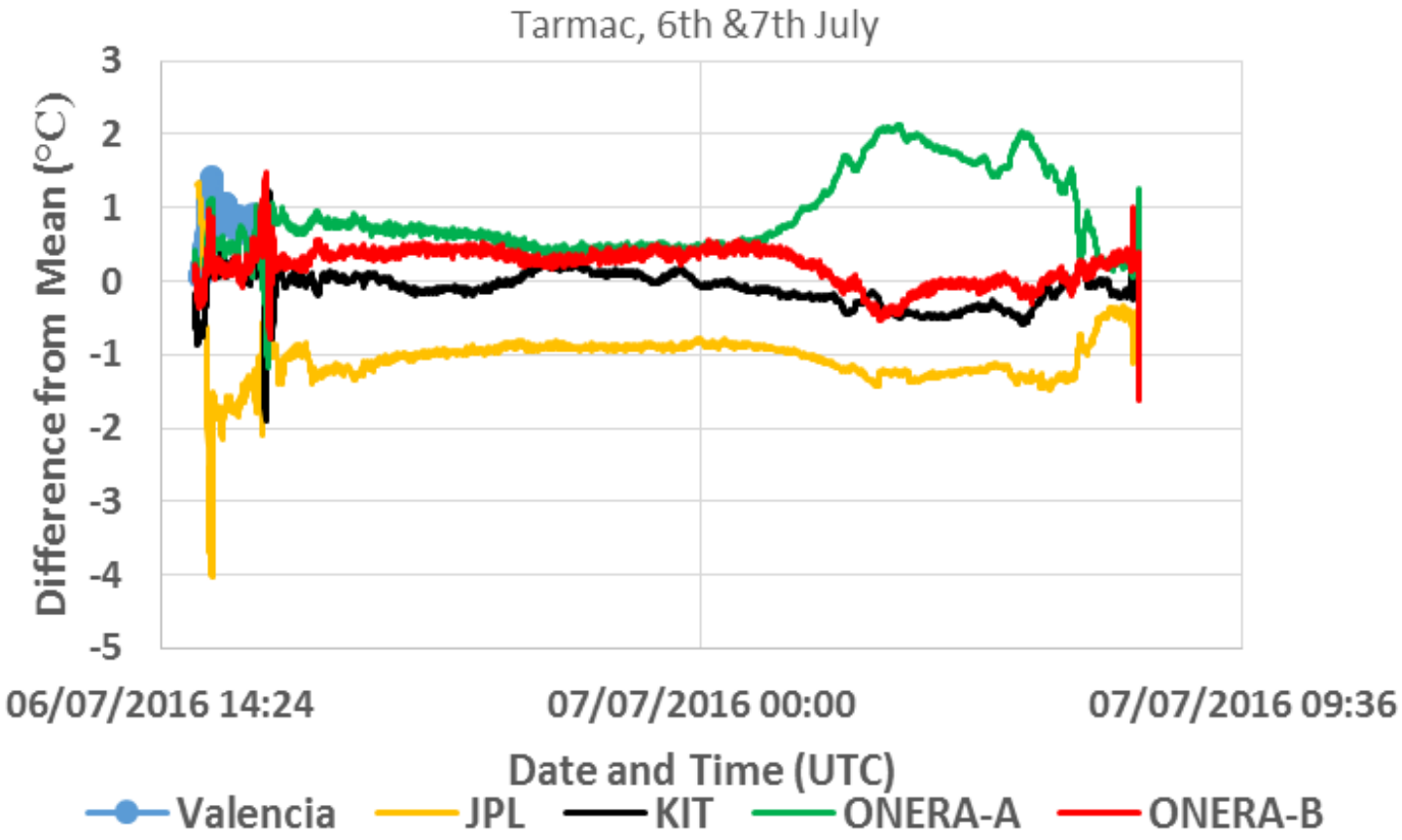




Surface temperature of tarmac measured by the participating radiometers on the 6th & 7th July 2016

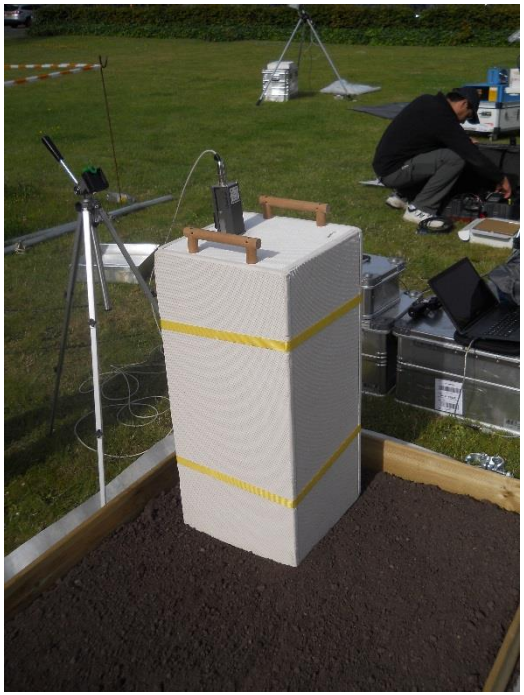


Difference of the measurements of the five measuring radiometers made on the 6th July on the tarmac sample from their mean. The bulk of the difference of all five radiometers from their mean is within ±2 °C throughout the monitoring period

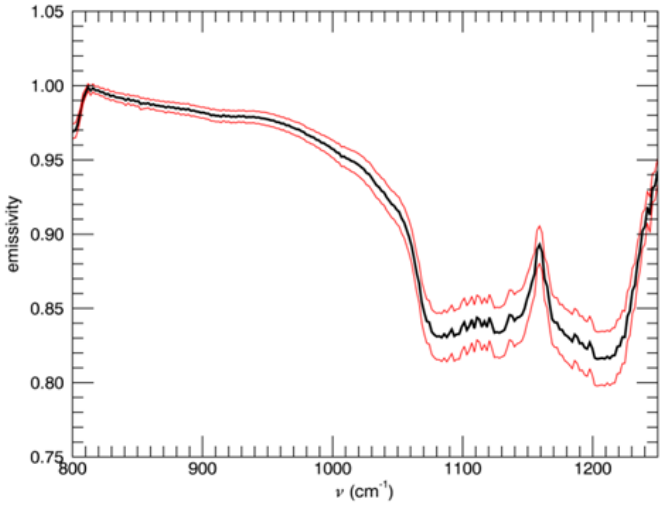


Emissivity issues

- Knowledge of the emissivity of its sample is critical.
- Three of the participants measured the emissivity of at least some of the samples during the LST measurement campaign.
- This also allowed the uncertainty contribution due to the emissivity to be calculated.



The emissivity of the sand sample in the 800 cm^{-1} to 1250 cm^{-1} region, as measured by ONERA during the 2016 FRM4STS comparison activity.



- The emittance of samples depends on wavelength. Unfortunately, the spectral responsivity of the participating radiometers is different. This meant that there would be differences in the measurement of the surface temperature of a target, if the participants used the same emissivity value for that particular sample.
- Rather than insist that participants use the same emissivity for a particular sample, it is far better to allow the participants to use what they consider as their best estimate of the emissivity of the target for their radiometer under the conditions which prevailed when the measurements were done. In fact this is the approach which they would have to use in the field during a measurement campaign.
- For this reason, no guidance was given as to which emissivity value participants should use for particular targets during the 2016 LST comparisons at NPL.

Summary

1. The 2016 FRM4STS comparisons at NPL and Wraysbury were completed.
2. All participants provided their measurements for all activities.
3. All data provided by participants have been analysed.
4. Some participants have been asked to provide further information regarding their treatment of uncertainties.
5. Reports describing the blackbody lab comparison activities, the radiometer lab comparison activities, the WST comparison activities at Wraysbury reservoir and the LST comparison activities at NPL have been prepared and circulated to participants for comment.
6. Data of all four comparison activities, along with copies of the reports have been uploaded on the FTP server and can be accessed by all participants.

Summary (cont.)

1. The blackbody lab comparison shows that the bulk of the participants' measurements are in agreement with NPL and PTB measurements for all temperatures investigated.

2. The radiometer lab comparison shows that, for temperatures above 0 °C, the bulk of the participants' measurements are in agreement with the reference BB measurements. However, significant discrepancies become evident for -15 °C and particularly -30 °C. This was assigned to radiometer spectral responsivity issues(out of band response), in combination with the extrapolation schemes used by participants.

3. The WST comparison showed some discrepancies between the measurements of different participants, with differences of ±0.4 °C evident from the average of all measurements.

4. The LST comparison showed some discrepancies between the measurements of different participants, with differences being typically less than ±2 °C from the average of all participant measurements. The exception appears to be the soil sample where measurements were within ±4 °C from the average of all participant measurements This is partly due to the large surface temperature variations (up to 10 °C) present on the soil surface temperature.

Thank you for listening

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NPL National Physical Laboratory

LST @ Namibia Jun 2017

NPL National Physical Laboratory

KIT Karlsruhe Institute of Technology

fiducial reference temperature measurements esa KIT

Implementation plan for the FRM4-CEOS field Inter-comparison Experiments (FICE) in Namibia

ESA Contract No. 4000113848_15I-LG

Prepared by Folke Olesen (KIT)

Gobabeb
'station dune'

30 m high
'Wind Tower'
in the Namib

NPL National Physical Laboratory

Proposed structure

- **Session 1: Science requirements for LST, IST and SST applications: Climate, meteorology, oceanography…**
- **Session 2: The space based element: current and future sensors capabilities and challenges**
- **Session 3: Metrological framework: Traceability and uncertainty, sampling and scaling, Representativeness ….**
- **Session 4: Post-launch validation: performance, traceability and uncertainty** of **field/aircraft deployed radiometers**
- **Session 5: Post-launch validation: non-returnable measurement systems**
- **Session 6: Establishing a sustainable framework of measurements to ensure fit for purpose data to meet the needs of society.**