Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS)

ESA Contract No. 4000113848_15I-LG

D110: Archive of FRM TIR radiometer calibration and verification data

Evangelos Theocharous & Nigel Fox

AUGUST 2018

Reference	OFE-D-110-V1-Iss-1-Ver-1
Issue	1
Revision	1
Date of Issue	22 August 2018
Document Type	ARCH

Digitally signed by Device Identity 9c6f8ccd4f5eaa531db70b0929b3d2a06f1e6010
Reason: I am approving this document
Location: Noordwijk, The Netherlands
Date: 2018.09.29 19:01:55 +01'00'

INTENTIONALLY BLANK

Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS)

D110: Archive of FRM TIR radiometer calibration and verification data

Evangelos Theocharous & Nigel Fox

National Physical Laboratory
Hampton Road, Teddington, Middlesex, TW11 0LW

CONTENTS

DOCUMENT MANAGEMENT

Issue	Revision	Date of Issue/revision	Description of Changes
1	1	22.08.2018	Complete draft submitted for review

DOCUMENT APPROVAL

Contractor Approval

Name	Role in Project	Signature & Date (dd/mm/yyyy)
Dr Nigel Fox	Technical Leader	
Dr Andrew Brown	Project Manager	 Andrew Brown, NPL 22 August 2018

CUSTOMER APPROVAL

Name	Role in Project	Signature	Date (dd/mm/yyyy)
C Donlon	ESA Technical Officer		

APPLICABLE DOCUMENTS

AD Ref.	Ver. /Iss.	Title
EOP-SM/2642	1	Fiducial Reference Measurements for Thermal Infrared Satellite Validation (FRM4STS) Statement of Work

ACRONYMS AND ABBREVIATIONS

CEOS	Committee on Earth Observation Satellites
DMI	Danish Meteorological Institute
EO	Earth Observation
FTP	File Transfer Protocol
IR	Infra-Red
ISO	International Organization for Standardization
KIT	Karlsruhe Institute of Meteorology
LST	Land Surface Temperature
NMI	National Metrology Institute
NPL	National Physical Laboratory
PTB	Physikalisch Technische Bundesanstalt
SST	Sea Surface Temperature
SI	Système Internationale
WGCV	Working Group for Calibration and Validation
WST	Water Surface Temperature

1. INTRODUCTION

The measurement of the Earth's surface temperature is a critical product for meteorology and an essential parameter/indicator for climate monitoring. Satellites have been monitoring global surface temperature for some time, and have established sufficient consistency and accuracy between in-flight sensors to claim that it is of "climate quality". However, it is essential that such measurements are fully anchored to SI units and that there is a direct correlation with "true" surface/in-situ based measurements.

The most accurate of these surface based measurements (used for validation) are derived from field deployed IR radiometers. These are in principle calibrated traceably to SI units, generally through a reference radiance blackbody. Such instrumentation is of varying design, operated by different teams in different parts of the globe. It is essential for the integrity of their use, to provide validation data for satellites both in-flight and to provide the link to future sensors, that any differences in the results obtained between them are understood. This knowledge will allow any potential biases to be removed and not transferred to satellite sensors. This knowledge can only be determined through formal comparison of the instrumentation, both in terms of its primary "lab based" calibration and its use in the field. The provision of a fully traceable link to SI ensures that the data are robust and can claim its status as a "climate data record".

The "IR Cal/Val community" is well versed in the need and value of such comparisons having held highly successful exercises in Miami and at NPL in 2001 [1, 2] and 2009 [3, 4]. However, six years had passed and it was considered timely to repeat/update the process, which was started in 2016. The 2016 comparison consisted of five stages:

i. Laboratory comparisons of the radiometers and reference radiance blackbodies of the participants.
ii. Field comparisons of Water Surface Temperature (WST) held at Wraysbury fresh water reservoir, near NPL.
iii. Field comparisons of Land Surface Temperature (LST held on the NPL campus.
iv. Field comparisons of Land Surface Temperature (LST) held at the Research Centre on the Namib plain, Gobabeb in Namibia in 2017.
v. Field comparisons of Ice Surface Temperature (IST) held in the Arctic.

During the 2016 comparison, NPL served as the pilot laboratory, supported by PTB, and provided traceability to SI units during laboratory and field comparisons at and around NPL. This document describes how the calibration and verification data of the laboratory FRM TIR radiometers and blackbodies will be collected and archived, following good data stewardship practices, which will provide access to records of research on request.

NPL, the UK national metrology institute (NMI) as pilot for the 2016 laboratory comparisons was responsible for inviting participants and for the analysis of data, following appropriate processing by individual participants. NPL, as pilot, was the only organisation to have access and to view all data from all participants. This data remained confidential to the individual participants and NPL at all times, until the publication of the report showing results of the comparison to participants.

2. HOW TO SAVE THE MEASUREMENTS OF THIS COMPARISON

The aim of this report is to describe how to archive the FRM TIR radiometer and blackbody calibration and verification data. The archive should follow good data stewardship practices and provide access to the records on request or by authentication using a sign-in protocol, in the form of a username and a password.

The activity of maintaining and providing access to EO datasets is widespread. There are a number of professional bodies such as UK NEODC and Ifremer of France which offer this service, thus ensuring data integrity, managed access, etc. However, the data which will be acquired and stored under the current project is limited compared to those which are available from EO instruments. The number of participants is relatively small so this task should be considerably simpler compared to the storage and the provision of access of satellite EO data.

After considering the various methods of storing and retrieving the data, it was concluded that this task can be successfully addressed using a File Transfer Protocol (FTP) server. This has the advantage of being simpler to control and administered compared to using a professional data storage organization. It will also be considerably less expensive. NPL already has FTP servers aiding a number of different projects. The data will be regularly backed up and the maintenance of the server will be done by people familiar with the files stored and their contents.

It is proposed that a summary of all the results of measurements which are made as part of the comparison will be included on the comparison website http://www.frm4sts.org/ under the “Data Resources” menu, and in the “FRM4STS – Results Database” directory, with links to the underpinning full raw data set saved on the FTP, the latter being password protected to the participants of the comparison. The data will be saved under an FTP server which will allow the transfer of data files from the host to another host over the internet. Data can be accessed after the FTP user authenticates himself using a sign-in protocol, in the form of a username and a password.

There are alternative ways of saving the data/results of this comparison such as using SharePoint. Office 365 provides SharePoint as a service, however, the installation of SharePoint typically requires multiple virtual machines, at least two separate physical servers and requires a somewhat significant installation and configuration effort. Some of the participants may not have the required software to access the data stored on a SharePoint platform.

Data stored on an FTP server will be easy to find and accessed by authorized users. Data stored on an FTP server will be available to authorized users free of charge.

The database which will be saved under this directory will be divided into five main sections corresponding to the five main activities of this comparison. These sections are:

i. Laboratory comparison of radiometers and blackbodies of participants.
ii. Water Surface Temperature (WST) comparison at Wraysbury reservoir.
iii. Land Surface Temperature (LST) comparison at NPL.
iv. Land Surface Temperature (LST) comparison in Namibia.
v. Ice Surface Temperature (IST) comparison in the Arctic
vi. Land Surface Temperature comparison in Namibia

Each Section will have its own directory which will be populated with the results of the current round of comparisons relevant to that Section. So there will be a directory containing the results of the laboratory comparison of the blackbodies and radiometers of the participants, another containing the results of the WST comparison at Wraysbury reservoir, etc. When the button representing the measurements of the laboratory comparison of radiometers of the participants is selected, the list of all the participants which took part in this comparison will be shown in alphabetical order (see Figure 1).

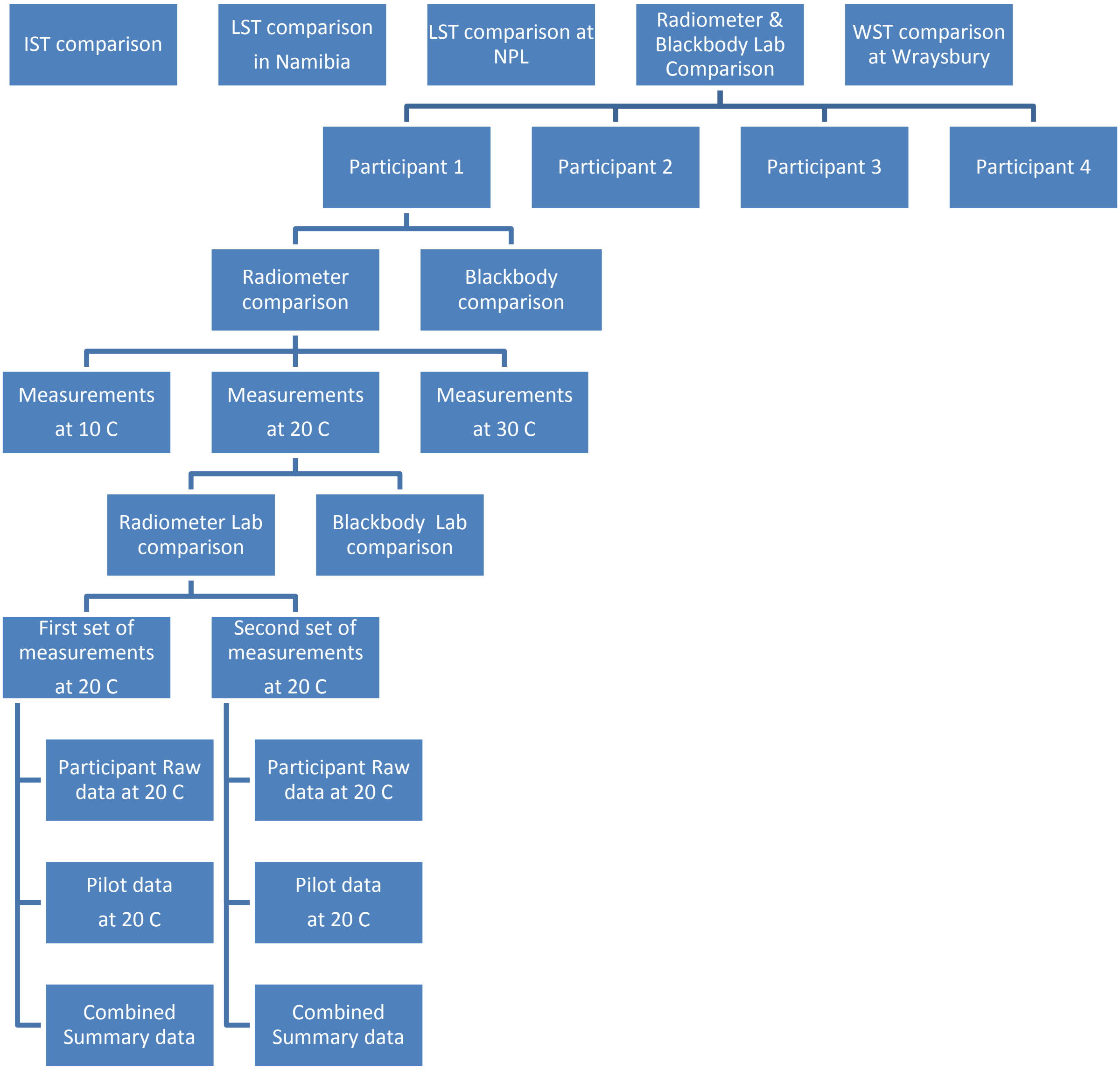

Figure 1: Layout of the database showing how the measurements of the comparison will be stored.

When a particular participant option is selected, it will open a directory which will show the measurements of the comparison associated with that particular participant. This directory will be sub-divided into two directories, the first dedicated with the results of the laboratory comparison of the radiometer of that particular participant, while the second deals with the results of the laboratory comparison of the blackbody of the same participant (see Figure 1). Participants which do not take part in the blackbody laboratory comparison, will not have any data under the blackbody laboratory comparison option. Selection of one of these two options (radiometer or blackbody laboratory comparison) will show sub-directories corresponding for the different temperatures under which the laboratory comparison of the radiometers or the blackbodies were done. For example, selection of the radiometer laboratory comparison option will show three (or more, depending on the number of blackbody temperatures measured) directories, the first containing the measurements corresponding to the reference blackbody operating around 10 ºC, the second containing the measurements corresponding to 20 ºC, the third contains the measurements corresponding to 30 ºC, etc. Similarly, selection of the blackbody laboratory comparison option will also show three (or more) directories, the first containing the measurements corresponding to 10 ºC, the second containing the measurements corresponding to 20 ºC, the third contains the measurements corresponding to 30 ºC etc.

Selection of the radiometer laboratory comparison option containing the measurements corresponding to a particular blackbody temperature, e.g. 20 ºC, will show two or more options, depending on how many measurements were repeated by that radiometer monitoring the reference blackbody at 20 ºC. Selection of the first option will show a list of excel files associated with first set of measurements done by that radiometer monitoring the reference blackbody at 20 ºC. These files will include:

i. The raw data (provided by the participant) of the first set measurements which they did on the reference blackbody at 20 ºC. This file will consists of a table with at least three columns. The first column will be showing the UTC time at which the measurement was done, the second column will show the brightness temperature of the blackbody as measured by the test radiometer and the third column will show the combined uncertainty of the measurements, estimated by the participant. The average value of the measurements of the brightness temperature made by the test radiometer will also be given in this file. The title of this file will include information such as the date on which the measurements were done, the temperature and humidity prevailing in the lab while these measurements were being acquired, etc. This file will also show graphical plots of the measurements made by the participant as a function of time.

ii. The corresponding measurements of the brightness temperature of the reference blackbody made by the pilot. This file will also consists of a table with three columns. The first column will be showing the UTC time at which the measurement was done, the second column will show the brightness temperature of the reference blackbody as measured by the pilot, while the third column will show the combined uncertainty of the measurements shown in the second column, estimated by the pilot. The average value of the measurements of the brightness temperature of the reference blackbody over the measurement period will also be given in this file. This file will also show graphical plots of the blackbody brightness temperature made by pilot, as a function of time.

iii. The files shown in the same directory will also include a summary file which shows the first set of measurements made by the participant at 20 ºC, alongside the corresponding measurements of the reference blackbody reported by the pilot, along with the associated uncertainties of the two measurements. This file will also show graphical plots of the measurements made by the participant, as well as the actual brightness temperature of the reference blackbody, as measured by the pilot. Figure 2 shows a typical plot of the measurements made by a participant radiometer along with the actual brightness temperature of the reference blackbody which was being monitored. The average value of the measurements made by the test radiometer and the corresponding average value of the actual blackbody temperature will also be given. The difference between the two average values will also be given, to indicate the “error” with which the test radiometer measures the brightness temperature of the reference blackbody at that particular temperature setting.

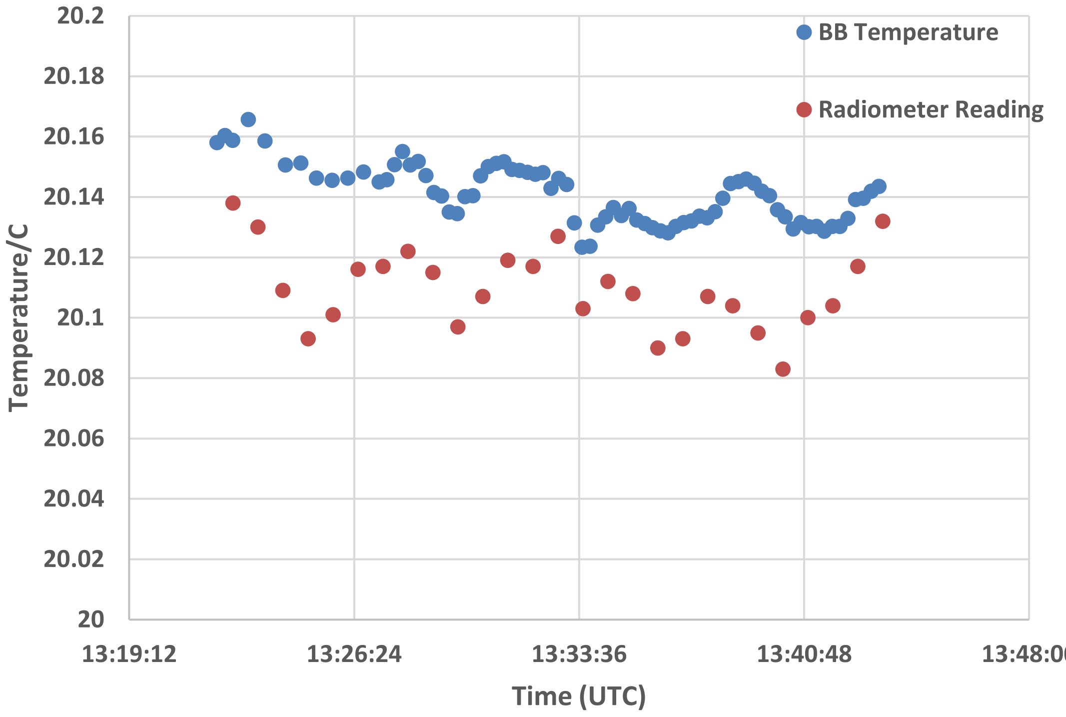

Figure 2: Typical plots of the measurements made by every participant radiometer along with the actual brightness temperature of the blackbody which was being monitored. Figure 2 shows how the measurements will be presented graphically.

The website reports will show tables which summarise the differences/“errors” of the measurements made by participating radiometers of the brightness temperature of the reference blackbody at different temperatures from the actual blackbody cavity temperature and provide reports also peer reviewed publications of the various comparisons. Table 1 shows an example of such a Table from the 2009 radiometer comparison which was completed at NPL [3]. Finally the website will show these differences in a graphical presentation; Figure 3 shows the plot of the differences of the mean of the radiometer readings from the mean of the temperature of the NPL reference blackbody during the same period (blue circles). The blackbody was maintained at a nominal temperature of 10 ºC during the acquisition of the measurements shown in Figure 3. The red squares in the same Figure show the points corresponding to when the University of Miami blackbody (also maintained at a nominal temperature of 10 ºC) was being viewed by the same radiometers.

Table 1: Difference of the mean of the measurement of the brightness temperature of the NPL reference blackbody completed by the participants during the 2009 comparison at NPL from the actual blackbody temperature. Similar tables will be created for the 2016 laboratory comparison activities.

	Set Temperature °C	NPL VTBB 1st measur. mK	NPL VTBB 2nd measur. mK
GOTA	30	1147	
8-14 µm	20	9	79
	10	-1276	-1165
	5	-2137	
GOTA	30	67	
11.35 µm	20	189	189
	10	254	235
	5	293	
GOTA	30	87	
10.65 µm	20	199	139
	10	204	185
	5	243	
GOTA	30	-43	
9.1 µm	20	169	109
	10	54	185
	5	253	
GOTA	30	-93	
8.7 µm	20	169	129
	10	74	185
	5	253	
Canary	30	47	
8.3 µm	20	149	169
	10	44	125
	5	133	
IPL	30	-393	-298
CE312-2	20	162	190
10.54 µm	10 (uncorrected)	691	683
	10 (corrected)	40	14
	5 (uncorrected)	956	
	5 (corrected)	-104	
IPL	30	-278	-283
CE312-2	20	136	154
11.29 µm	10 (uncorrected)	644	633
	10 (corrected)	74	62
	5 (uncorrected)	860	
	5 (corrected)	30	
IPL	30	-333	-178
CE312-2	20	150	240
10.57 µm	10 (uncorrected)	716	655
	10 (corrected)	26	-40
	5 (uncorrected)	888	
	5 (corrected)	-16	
IPL	30	-438	-507
CE312-2	20	74	228
9.15 µm	10 (uncorrected)	881	934
	10 (corrected)	80	125
	5 (uncorrected)	1434	
	5 (corrected)	206	
IPL	30	-492	-413
CE312-2	20	169	225
8.69 µm	10 (uncorrected)	896	773
	10 (corrected)	-93	-223
	5 (uncorrected)	1502	
	5 (corrected)	238	
IPL	30	-402	-197
CE312-2	20	173	296
8.44 µm	10 (uncorrected)	983	809
	10 (corrected)	291	127
	5 (uncorrected)	1538	
	5 (corrected)	486	

	Set Temperature °C	NPL VTBB 1st measur. mK	NPL VTBB 2nd measur. mK
Valencia DEPT	30	-108	
CE312-1-Unit 1	20	118	79
10.7 µm	10	321	292
	5	416	
Valencia DEPT	30	-160	
CE312-1-Unit 1	20	221	160
12 µm	10	464	442
	5	701	
Valencia DEPT	30	66	
CE312-1-Unit 1	20	82	101
10.8 µm	10	140	145
	5	208	
Valencia DEPT	30	372	
CE312-1-Unit 1	20	83	104
8.8 µm	10	-179	-154
	5	-209	
Valencia DEPT	30	-57	
CE312-1-Unit 2	20	189	134
10.7 µm	10	423	366
	5	529	
Valencia DEPT	30	14	
CE312-1-Unit 2	20	233	243
12 µm	10	467	383
	5	557	
Valencia DEPT	30	104	
CE312-1-Unit 2	20	204	168
10.8 µm	10	289	237
	5	328	
Valencia DEPT	30	-12	
CE312-1-Unit 2	20	225	153
8.8 µm	10	514	392
	5	605	
RAL	30	-24	
SISTER	20	-25	-33
	10	-16	-19
Southampton	30	6	
ISAR	20	126	28
	10	87	69
	5	77	
OUC	30	59	48
ISAR	20	94	64
	10	145	136
	5	237	279
KIT	30	190	152
Heidronics	20	30	
KT - 15	10	-208	
	5	-632	

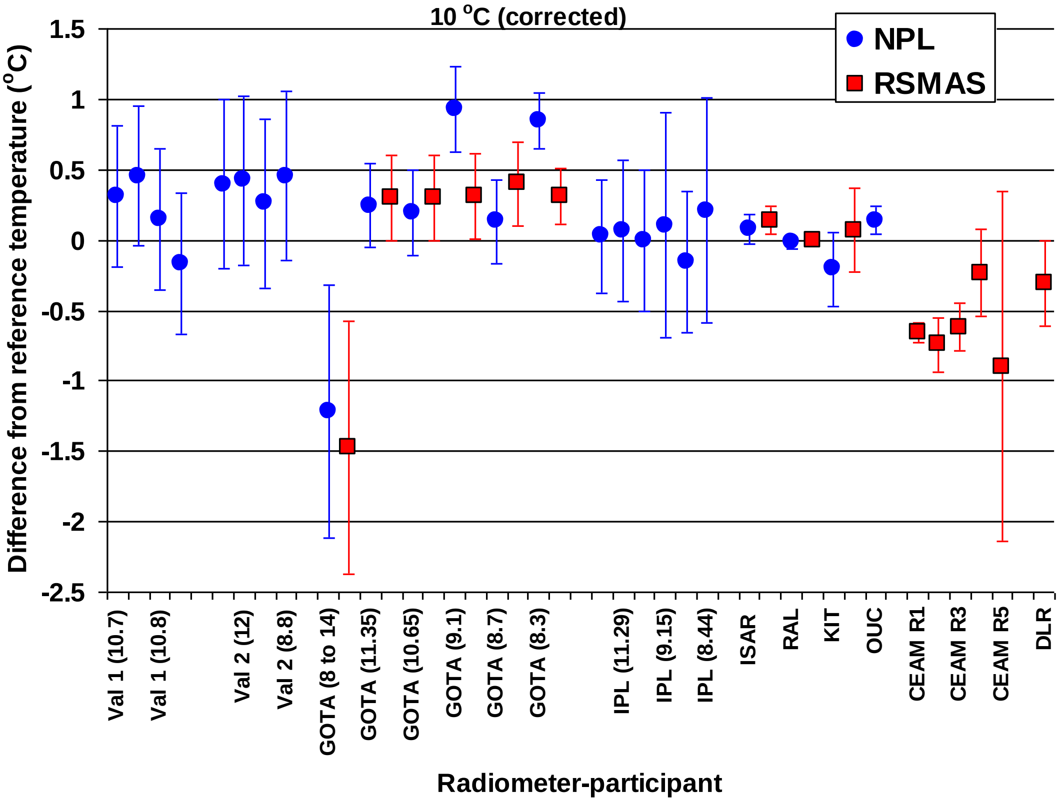

Figure 3: Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody (blue circles), maintained at a nominal temperature of 10 °C, obtained during the 2009 comparison. The red squares show the points corresponding to the University of Miami blackbody. Similar plots corresponding to the 2016 comparison will be shown on the comparison website.

3. REFERENCES

1. Barton, I. J., Minnett, P. J., Maillet K. A., Donlon, C. J., Hook, S. J., Jessup, A. T. and Nightingale, T. J., 2004," The Miami 2001 infrared radiometer calibration and intercomparison: Part II Shipboard results", *Journal of Atmospheric and Oceanic Technology*, **21**, 268-283.

2. Rice, J. P., Butler, J. I., Johnson, B. C., Minnett, P. J., Maillet K. A., Nightingale, T. J, Hook, S. J., Abtahi, A., Donlon, and. Barton, I. J., 2004, "The Miami 2001 infrared radiometer calibration and intercomparison. Part I: Laboratory characterisation of blackbody targets", *Journal of Atmospheric and Oceanic Technology*, **21**, 258-267.

3. Theocharous, E., Usadi, E. and Fox, N. P., "CEOS comparison of IR brightness temperature measurements in support of satellite validation. Part I: Laboratory and ocean surface temperature comparison of radiation thermometers", NPL REPORT OP3, July 2010.

4. Theocharous E. and Fox N. P., "CEOS comparison of IR brightness temperature measurements in support of satellite validation. Part II: Laboratory comparison of the brightness temperature comparison of blackbodies", NPL Report COM OP4, August 2010.