CEOS

fiducial reference
temperature
measurements

FRM4STS: Fiducial Reference measurements for validation of Surface Temperature from Satellites (ceos cv8)

Nigel Fox (Chair CEOS WGCV IVOS)

NPL (ESA Project)

WGCV Plenary # 40

esa
European Space Agency

NPL National Physical Laboratory | Centre for Carbon Measurement

DML

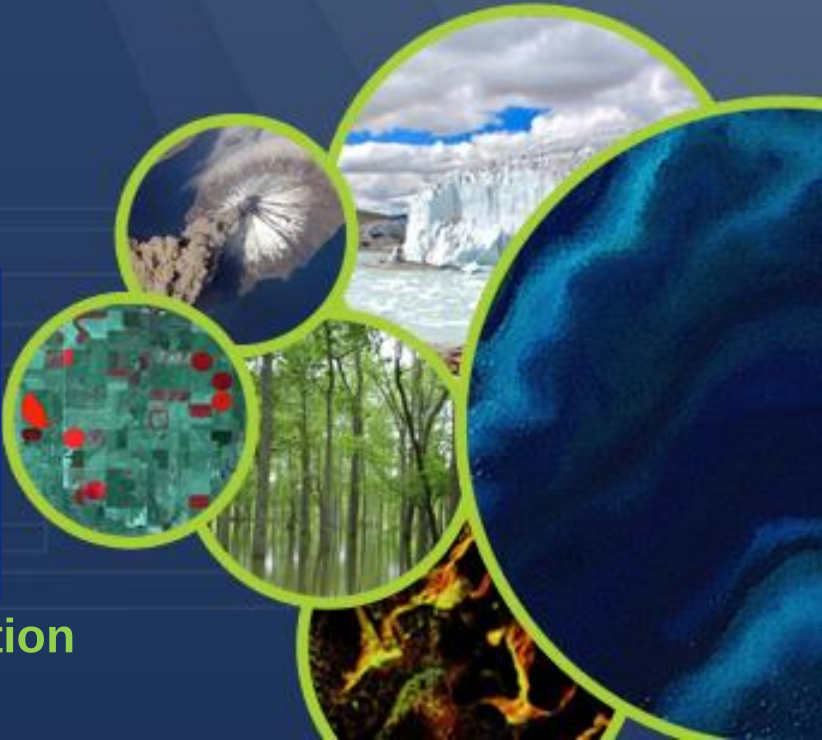
UNIVERSITY OF Southampton

DMI

Science & Technology Facilities Council

PTB

KIT Karlsruhe Institute of Technology



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

Requires:

- Comparisons to ensure consistency between measurement teams
- Accessible common descriptions and evaluation of uncertainties
- Robust links to SI
- Experiments to evaluate sources of bias/uncertainty under differing operational conditions
- International community buy-in (customer and supplier) of added value and how to achieve – through provision of guidance and best practises and access to standards and comparisons

Context: CEOS plenary (2014) endorsed a project to carry out a series of comparisons of instrumentation & methods used to validate satellite IR measurements of surface (Ocean, Land) Temp to ensure international harmonisatio

(an extension of previous ‘Miami series’)

ESA sponsored project (FRM4STS) to:

- Design and implement a laboratory-based comparison of the results of participants calibration processes for FRM TIR radiometers (SST, LST, IST)
- Design and implement a laboratory-based comparison to verify TIR blackbody sources used to maintain calibration of FRM TIR radiometers.
- Conduct external comparison ‘experiments’ of LST and WST to evaluate environmental effects e.g. sky radiance
- 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 yrs
- Conduct field-campaigns for FRM TIR of LST and IST to assess environmental effects in real world sites.
- Develop a set of best practise protocols for the calibration, operation and performance of FRM of Surface temperatures.
- Carry out comparisons and analysis to SI standards with full metrological rigour (e.g. detailed uncertainty breakdown).
- 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.

Activities and participation

All teams making satellite validation measurements (particularly for S3, are strongly encouraged to participate)

- Registration still open to new potential participants laboratory and LST in Namibia
  - But need input urgently
- Responses to questionnaires on instrumentation/Uc etc
- Draft protocols to be commented on/accepted
- Any questions (this webinar) or email or telephone

- Date for Diary MARCH 7 to 9 2017 @ NPL

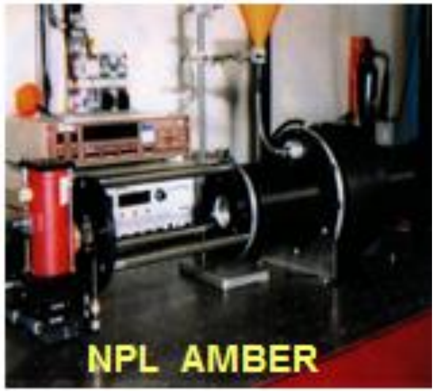
‘international workshop on satellite surface temperature measurements, their validation and strategies to ensure quality for the future’ **(including all the results from this exercise)**

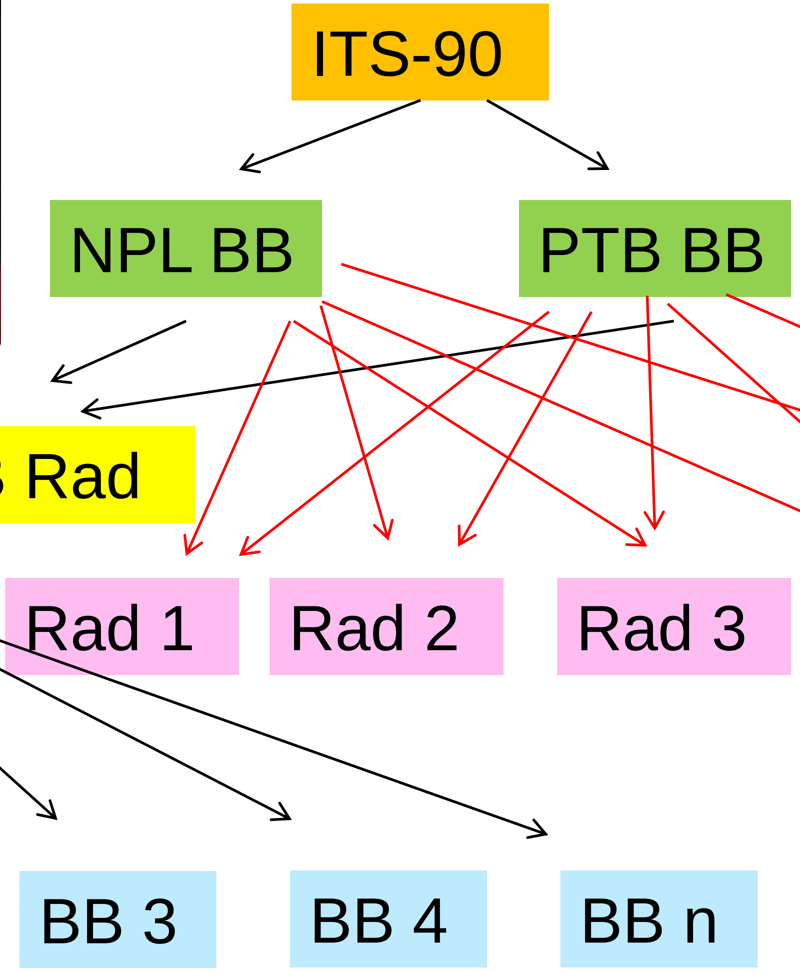
fiducial reference temperature measurements

For info on the project: www.FRM4STS.org

SI traceability: LCE (June 2016)

Necessary for all participants to assess biases to SI under Laboratory conditions **19 participants**





ITS-90

NPL BB

PTB BB

NPL Rad (AMBER)

PTB Rad

Rad 1

Rad 2

Rad 3

Rad 4

Rad n

BB1

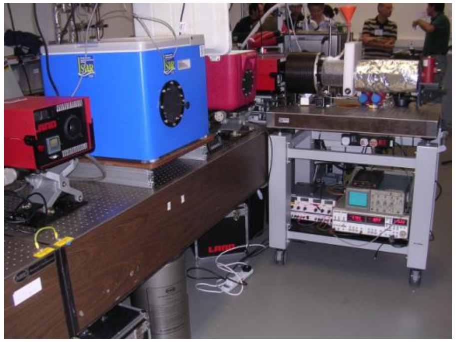
BB 2

BB 3

BB 4

BB n

T= ~223 – 325 K
Non-vacuum



Room Environment with variable T

Water Surface Temp (near NPL) (Jun/Jul 2016)

The floating platform from which WST measurements are due to take place is in the middle of the Wraysbury reservoir. The depth of the reservoir is 20 m.

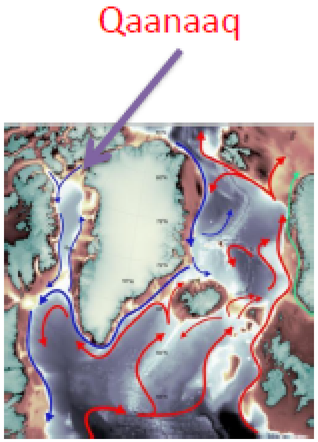
LST measurements @ NPL (impact of environment e.g. sky in context of ε) July 2016

Planned LST measurement targets

- The following “targets” are being planned (on the advice of KIT):
- Short green grass (high emissivity at 10 µm).
- Short dry grass (low emissivity at 10 µm).
- Sand / gravel with different SiO_2 contents and grain sizes
- “Dark soil”.
- Tarmac.

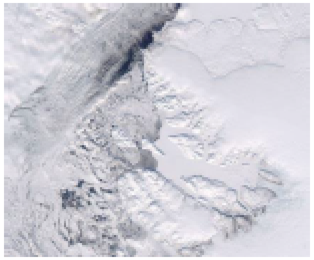
IST ‘pilot’ comparison (April 2016)

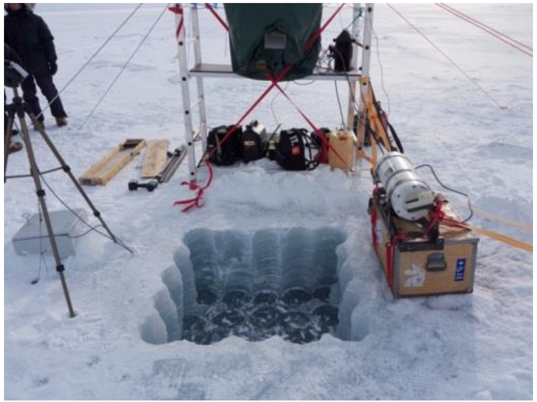
The aim with this study is to evaluate potential variances (non-equivalences) in FRM of TIR radiometers under high latitude sea ice field conditions.



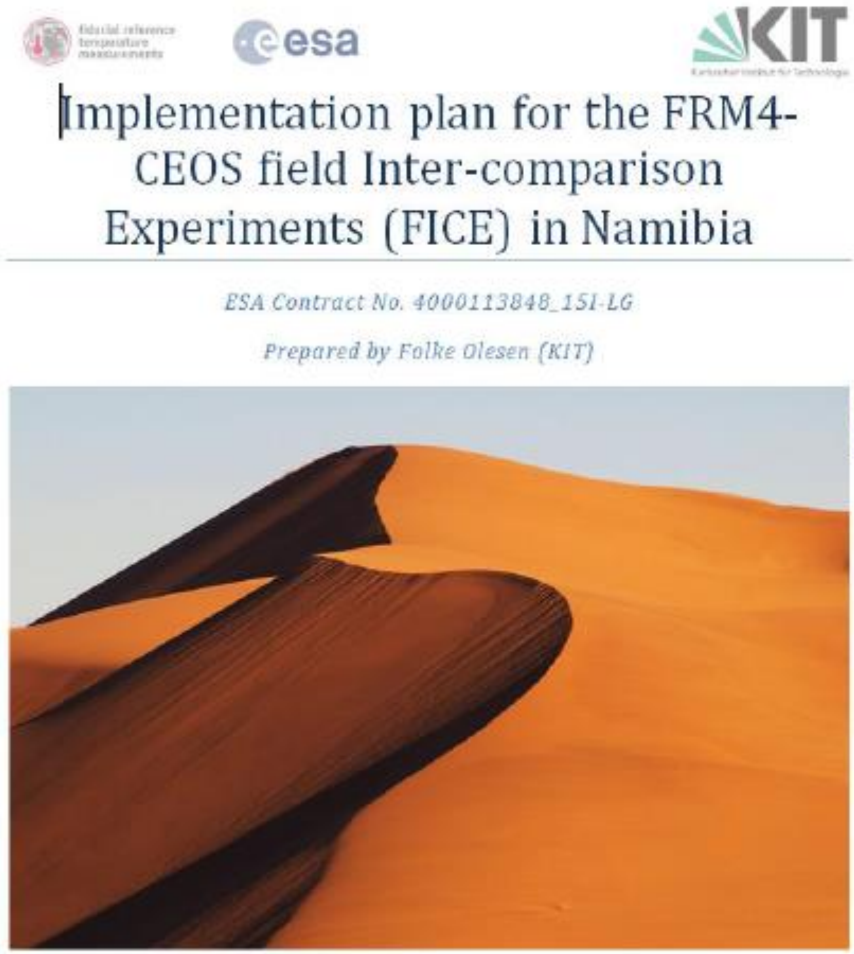
This option will be conducted as four main tasks:

- *Plan and arrange a FICE with focus upon FRM for Ice surface temperature*
- *Conduct an IST FICE in Qaanaaq, Greenland with at least 2 independent FRM TIR radiometers*
- *Process the field campaign data with focus upon SI traceability*
- *Report the results in a technical report/publication*





LST @ Namibia Nov 2016



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

Detailed Preparation of the 2016 Laboratory Comparison

E. Theocharous (Theo), N.P. Fox

Earth Observation, Climate & Optical Group

NPL, UK

e.theo@npl.co.uk

28th April 2016

CONTENTS

Directory of external participants 2016 comparison

S.No	Contact person	Organisation	Institute	Phone No.	Email id	Comments	Initial Invitation sent (28Oct15)? (Y/N)	Confirmed Attending? (1/0)	1A: Laboratory	1B: WST @ NPL	1C: LST @ NPL	2A: Shipborne comparisons	2B: LST @ Gobabeb	2C: IST @ Greenland	Funding assistance required? (Y/N/M)	CEOS Agency	Blackbody	What Radiometer?
1	Michael Reynolds	RMRCo, Seattle	Remote Measurement & Research Co., 214 Euclid Av., Seattle WA 98122	Tel: +1 631-374-2537	michael@rmrco.com	Developed a new instrument called ROSR. Also ISAR	Y	1	Y	Y	Y	Y	N	N	M	TBC	BB	ISAR & RORSR
2	Jacob Høyer	DMI	Danish Meteorological Institute (DMI), Centre for Ocean and Ice, Lyngbyvej 100, 2100 København Ø	Tel: +4539157203	jlh@dmi.dk	ISAR?	Y	1	Y	Y	N	N	N	Y	N			ISAR?
3	Frank-M. Göttsche / Folke Olesen	KIT	IMK-ASF, Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany	+49 721 608-23821	frank.goettsche@kit.edu, folke.olesen@kit.edu	Heidronics KT15.85	Y	1	Y	Y	Y	N	Y	M	N	CEOS WGCV (LPV subgroup)	BB	Heidronics KT15.85
4	Nicole Morgan, (Helen Beggs)	Bureau of Meteorology, Australian Govt.	Ocean Modelling Research Team, Research and Development Branch, Bureau of Meteorology GPO Box 1289 Melbourne VIC 3001, Level 11, 700 Collins Street, Docklands VIC 3008	Nicole +613 6232 5222 Helen: +61 3 9669 4394	Nicole.Morgan@csiro.au h.beggs@bom.gov.au	http://www.bom.gov.au- ISAR	Y	1	Y	Y	M	Y	N	N	N		Casots II	ISAR
5	Manuel Arbelo	GOTA	Grupo de Observacion de la Tierra y la Atmosfera (GOTA), ULL, Spain		marbelo@ull.es	Cimel CE312 (5_channels)	Y	1	Y	Y	Y	M	M	N		CDIT_Spain	BB	Cimel CE312 (5 channels)
6	Gerardo Rivera (Simon Hook)	JPL-NASA	Carbon Cycle and Ecosystems, MS 183-501, Jet Propulsion Laboratory,4800 Oak Grove Drive ,Pasadena, CA 91109		gerardo.rivera@jpl.nasa.gov simon.j.hook@jpl.nasa.gov	has a new generation nulling radiometer	Y	1	Y	Y	Y	Y	M	M	N	NASA		Nulling radiometer
7	J. A. Sobrino	Imaging Processing Laboratory (IPL) Universitat de Valencia	Imaging Processing Laboratory (IPL), Parque Científico Universitat de Valencia, Poligono La Coma s/n ,	Tel: +34 96 354 3115;	sobrino@UV.es		Y	1	y	m	n	M	N	N	M			
8	Tim Nightingale	STFC	STFC Rutherford Appleton Laboratory,Chilton, Didcot Oxon OX11 0QX,United Kingdom	Tel: +44 1235445914;	Tim.Nightingale@stfc.ac.uk	Has a SISTeR Radiometer	Y	1	Y	Y	N	Y	N	N	M	UKSA	BB Casots I	SiSTER
9	Caroline Sloan	MOD, NAVY SHIPS-HM FEIO	SHIPS-HM FEIO | Navy Command Headquarters, MP 2.3, Leach Building, Whale Island, Portsmouth, Hampshire, PO2 8B	Tel: 023 9262 5958 | Mil: 93832 5958;	caroline.sloan104@mod.uk ; NAVYSHIPS-HMFEIO@mod.uk;	ISAR	Y	1	y	M	N	M	N	N	M			ISAR
10	Ian Barton	CSIRO Australia	Head office, PO Box 225,Dickson ACT 2602, Australia	Tel: +61 3 9545 2176;	ian.barton@ozemail.com.au	TASCO THI-500	Y	1	Y	N	N	N	N	N	N			TASCO THI-500
11	Dr. César Coll Raquel Niclòs Vicente Garcia Santos	UV-ES	Faculty of Physics,University of Valencia,Dr. Moliner, 50. 46100 Burjassot, Spain		raquel.niclos@uv.es cesar.coll@uv.es vicente.garcía-santos@uv.es	5 radiometers in total	Y	1	Y	Y	Y	M	Y	N	N	110 cm	BB	CIMEL plus other four
12	Peter J Minnett Goshka or Miguel	RSMAS	Rosenstiel School, University of Miami,4600 Rickenbacker Causeway,Miami, FL 33149,USA		pminnett@rsmas.miami.edu	MaERI and ISAR	Y	1	Y	N	N	Y	N	M	M	NASA & NOAA	BB	MaERI and ISAR
13	Steinar Eastwood	Norwegian Meteorological Institute	P.O.Box 43 – Blindern N-0313 Oslo, Norway		s.eastwood@met.no	Campbell Science IR120 with Apogee for sky measurement	Y	1	Y	Y	N	M	N	Y	N	Norwegian Space Centre		Campbell Science IR120
14	Laurent Poutier	ONERA	2, avenue Edouard Belin – 31055 Toulouse Cedex4 -		laurent.poutier@onera.fr	Heidronics & BOMEM	Y	1	Y	M	Y	N	Y	N	Y	ESA	Mikrom M345	Heidronics & BOMEM
15	Dr. Werenfrid Wimmer	Southampton Univerity			w.wimmer@soton.ac.uk	ISAR	Y	1	Y	Y	N	Y	N	Y	N	UKSA	BB	ISAR
16	Rasmus Tonboe	DMI	Lyngbyvej 100, DK-2100 Copenhagen, Denmark		rtt@dmi.dk	ISAR, KT15, CS	Y	1	M	M	M	M	N	Y	N	ESA		ISAR, KT15, CS
17	William Good Bill Emery	Ball Aerospace EDU-USA	1600 Commerce Street, Boulder, CO 80301,		wgood@ball.com emery@colorado.edu	Two radiometers: CIRiS-demonstrator and BESST	Y	1	Y	M	M	M	N	N	Y	NASA		Two radiometers: CIRiS-demonstrator and BESST
18	Kailin Zhang	Qingdao	Ocean University of China 238 Songling Road, Qingdao		zhangkl@ouc.edu.cn ;	own radiometer	Y	1	y	y	N	N	N	N			BB	own radiometer
19	Minglun Yang	Qingdao	Ocean University of China Qingdao, China		minglunyang@163.com ;	ISAR	Y	1	y	y	N	N	N	N				ISAR
									18Y + 1M	12Y + 5M	6Y + 3M		3Y + 2M	4Y + 2M				

Summary of preparations for blackbody comparisons so far

- Planning has continued.
- Protocol for the laboratory blackbody comparison was prepared and published on the project's website.
- Blackbody Lab Comparison takes place during the week beginning 20th June.
- There will be 10 participants bringing 10 blackbodies to the 2016 blackbody comparison.
- Blackbodies being compared range from the RSMAS blackbody (which is a copy of the NIST water-bath blackbody), to CASOTS type I and II, and to small blackbodies (Landcal and Mikron).

Laboratory Blackbody Comparison

- The test blackbodies will be compared relative to two well-characterised transfer standard radiometers. The transfer radiometers used will be:

  the NPL AMBER radiometer which measures the brightness temperature of the blackbodies for a wavelength of 10.1 μm, and

  the PTB infrared broadband radiometer which measures the brightness temperature of the blackbodies in the 8 μm to 14 μm wavelength range.

- The test blackbodies which are used to support sea/water surface temperature measurements will be compared at a minimum of three nominal temperatures of **283 K, 293 K and 303 K.**

- The blackbodies which are used to support land surface temperature measurements, the comparison will be extended **down to 273 K and up to 323 K.**

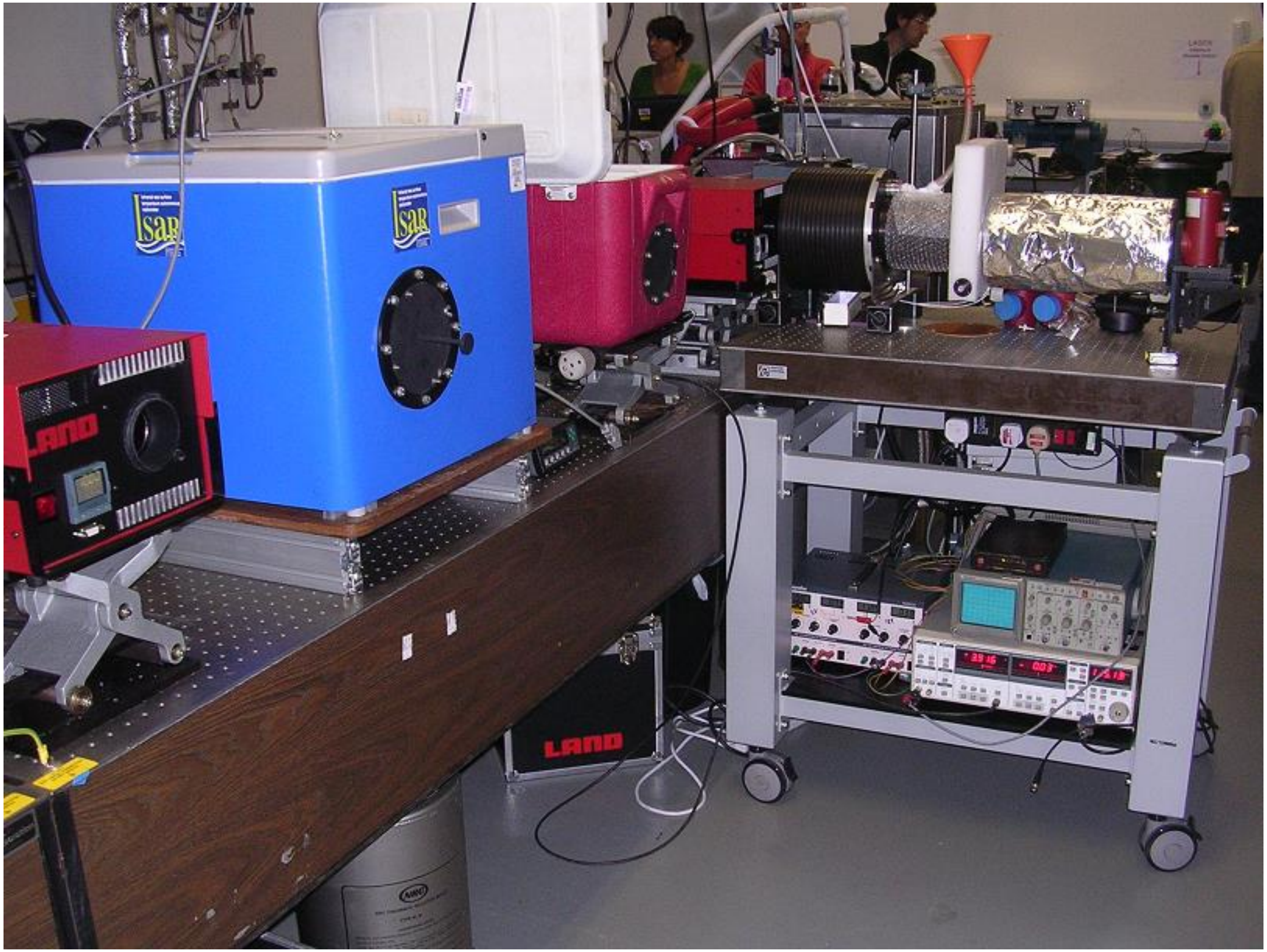
- The blackbodies which are used to support ice surface temperature measurements, the comparison can be over the **253 K to 278 K** temperature range.

Preparations for the blackbody comparisons so far

- The comparison of the participants’ blackbodies was extensively discussed with PTB. (Christian Monte visited NPL in March).
- PTB will be using their Heitronics 19 radiometer for the 2016 blackbody lab comparison.
- The calibration of the PTB radiometer will be frequently checked using one of the PTB portable blackbodies.
- NPL will be using the AMBER radiometer for the blackbody comparison.
- The calibration of the AMBER radiometer will be calibrated using the new NPL Ga blackbody.

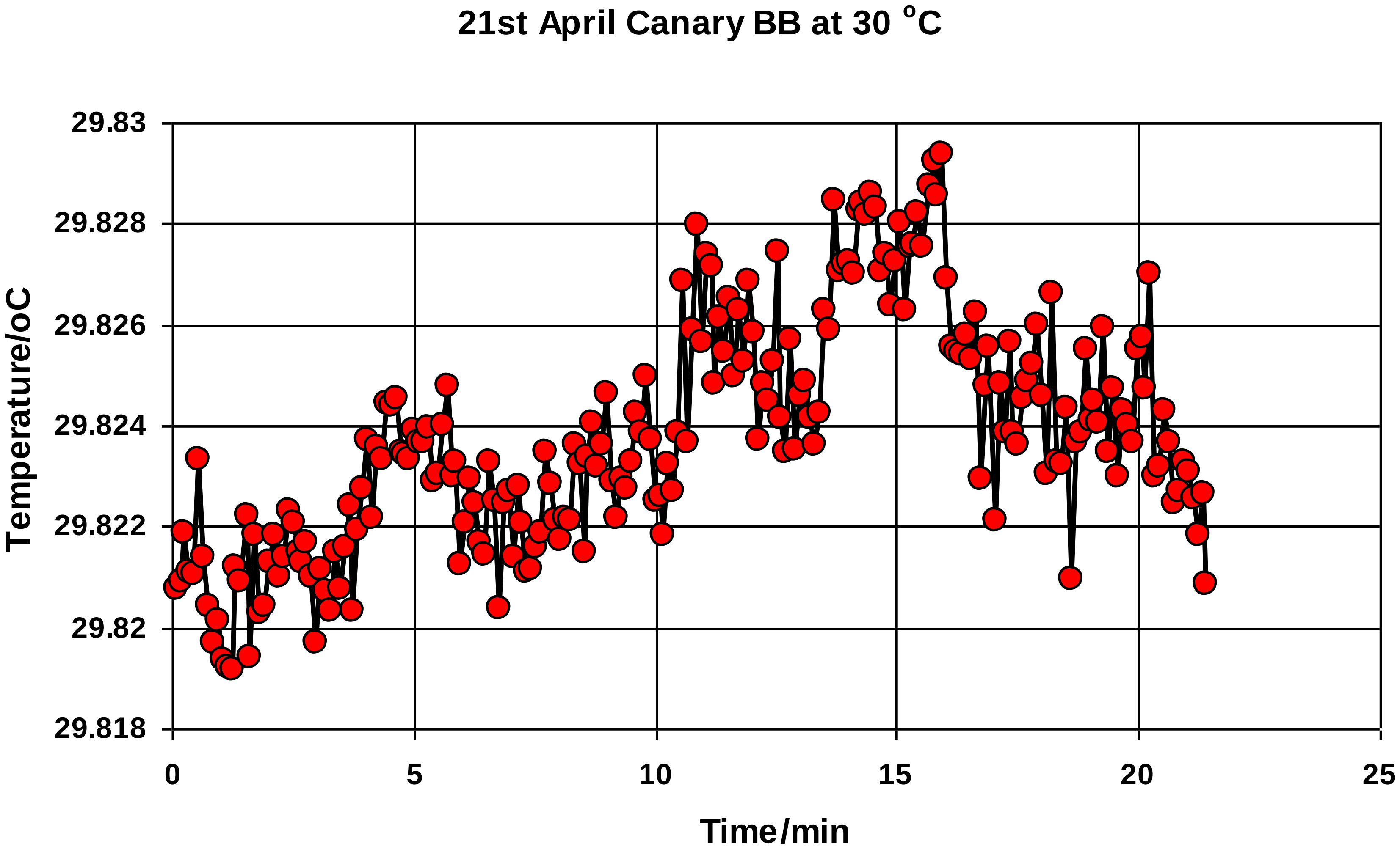
The AMBER radiometer measuring the radiance temperature of blackbodies during the 2009 Workshop at NPL.

AMBER will be assisted by the PTB IR filter radiometer.



4 metre bench where the blackbodies will be positioned

Blackbody set to 30 ^{o}C. Mean 29.824 ^{o}C
“Error” = -176 mK, p/p = 10 mK



National Physical Laboratory

Difference between the temperature of the blackbody cavity provided by the participants and the brightness temperature of the same blackbody measured by the AMBER radiometer at different blackbody set temperatures.

Participant	Set temperature °C	Temperature "error" 21st April run mK	Temperature "error" 22nd April run mK
RAL	30	14	6
SISTeR BB	20	-8	-5
	10	-15	-14
Southampton	30	-7	3
ISAR BB	20	-16	-14
	10	-19	-18
GOTA	30	-176	-188
La Laguna Univ.	20	-152	-181
Canary Island	10	-164	-177
DEPT	30	-167	-185
Valencia University	20	-143	-166
LAND P80P	10	-74	-87

Summary of preparations for radiometer comparisons so far

- Planning has continued.
- Protocol for the laboratory radiometer comparison was prepared and is published on the project’s website.
- Lab radiometer Comparison takes place during the week beginning 20th June.
- We estimate that there will be 19 participants bringing 29 radiometers to the 2016 radiometer comparison (one participant is bringing 5 radiometers, another 3 and some 2 radiometers).
- Radiometers being compared range from the MAERI (FT spectrometer based), to seven ISARs, to small radiometers (Heitronics, CIMEL) and at least one “home-made” radiometer.

Laboratory Radiometer Comparison

- All participating radiometers will be compared to a reference radiance ammonia heat-pipe blackbody calibrated traceable to SI.

- The reference blackbody is:

  a variable temperature BB,

  it is well-characterised

  has a high spectral emissivity and

  has a 75 mm diameter aperture, which is sufficiently large to accommodate the field of view of any participating radiometer.

- The ammonia reference radiance blackbody will be set to a fixed "known" temperature and then viewed by all participating radiometers.

Laboratory Radiometer Comparison

- Radiometers will be invited to measure the temperature of the reference blackbody in the -50 °C to +50 °C temperature range in 10 °C step.

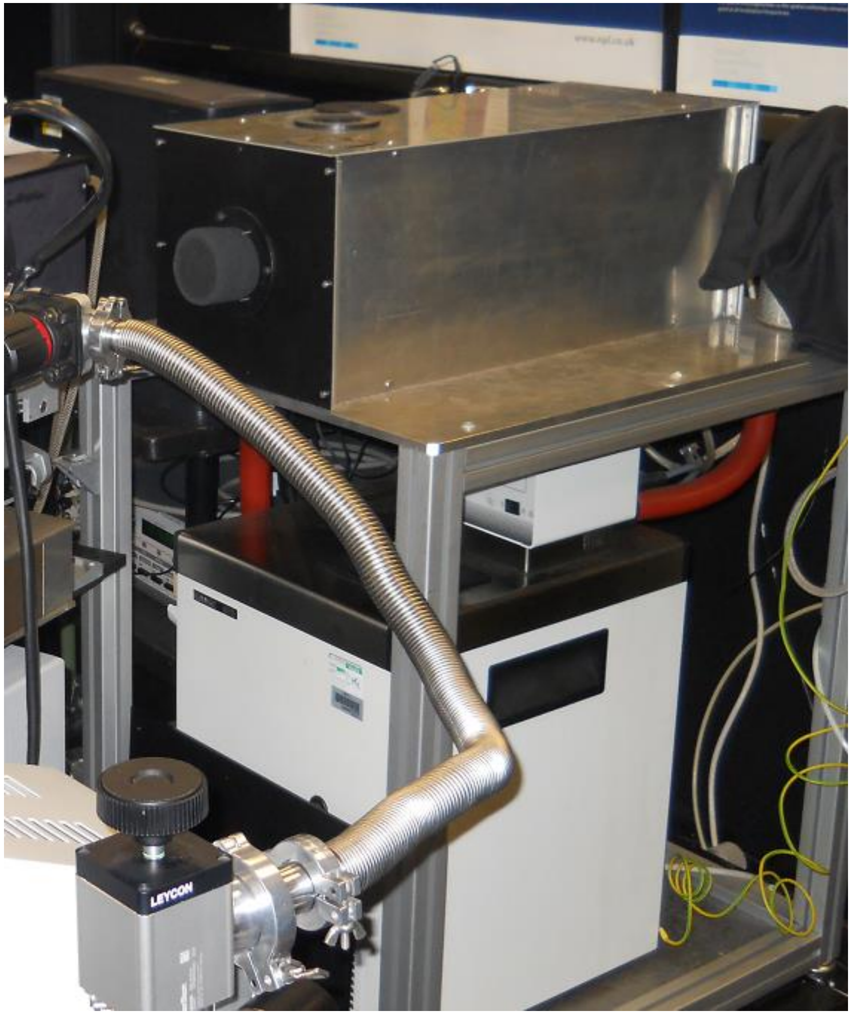
- Radiometers which are used to measure sea/water surface temperature will perform measurements of the reference radiance blackbody at at least four nominal temperatures of **278 K, 283 K, 293 K and 303 K**.

- Radiometers which are used to measure land surface temperatures will perform measurements of the reference blackbody in the range **273 K to 323 K**.

- Radiometers which are used to measure ice surface temperatures will perform measurements of the blackbody in the range **253 K to 293 K**.

- The ammonia heat-pipe reference blackbody will also be set to a temperature lower than **233 K** so the response of all radiometers can also be tested at this temperature.

NPL ammonia heat-pipe blackbody will be the reference blackbody during the 2016 radiometer lab comparison.

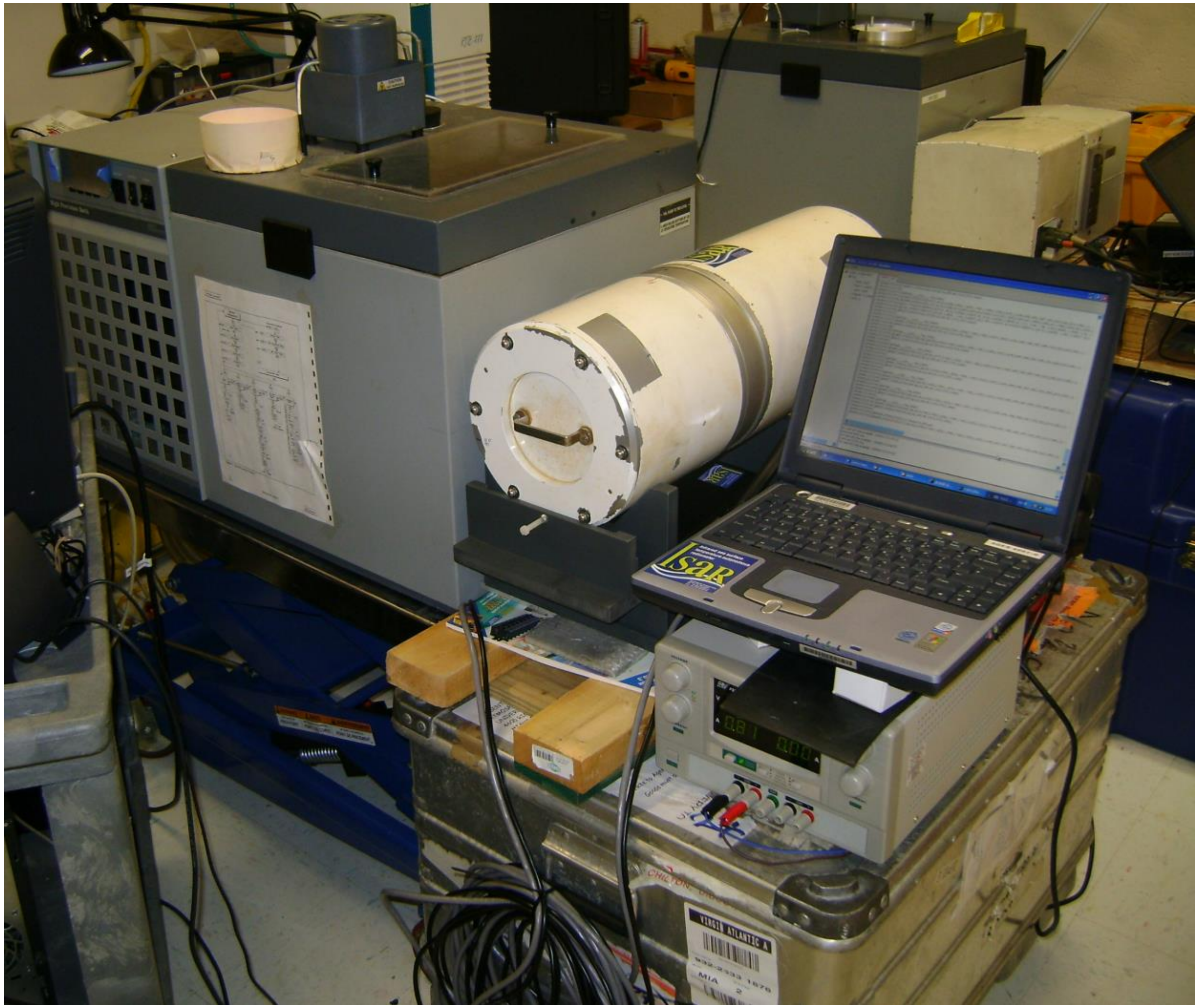


Heat-pipe blackbodies offer much better spatial uniformity in heating the cavity.

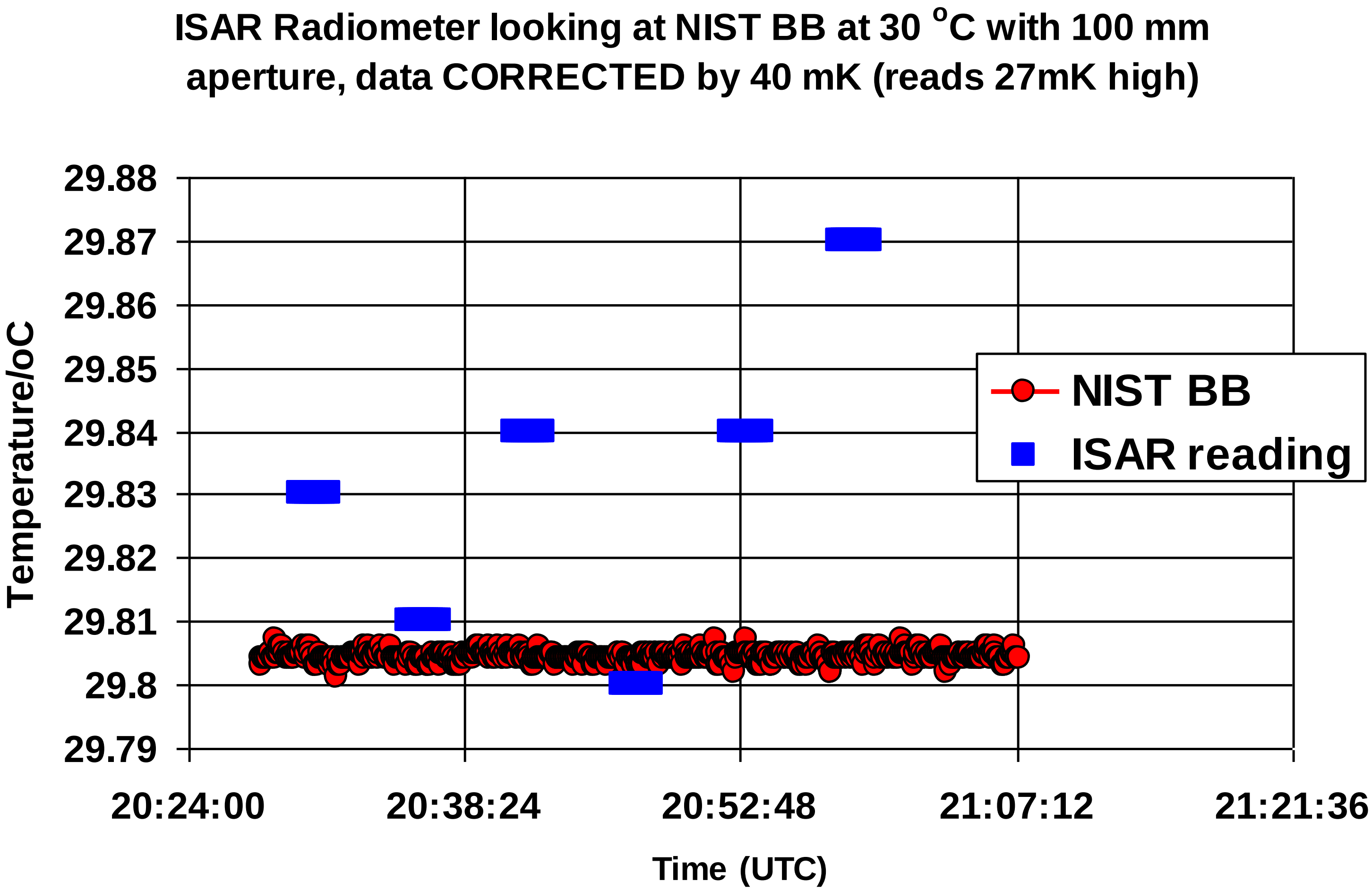
The BB can cover the
-50 °C to +50 °C range.

Cavity size: 75 mm in diameter and 300 mm long.

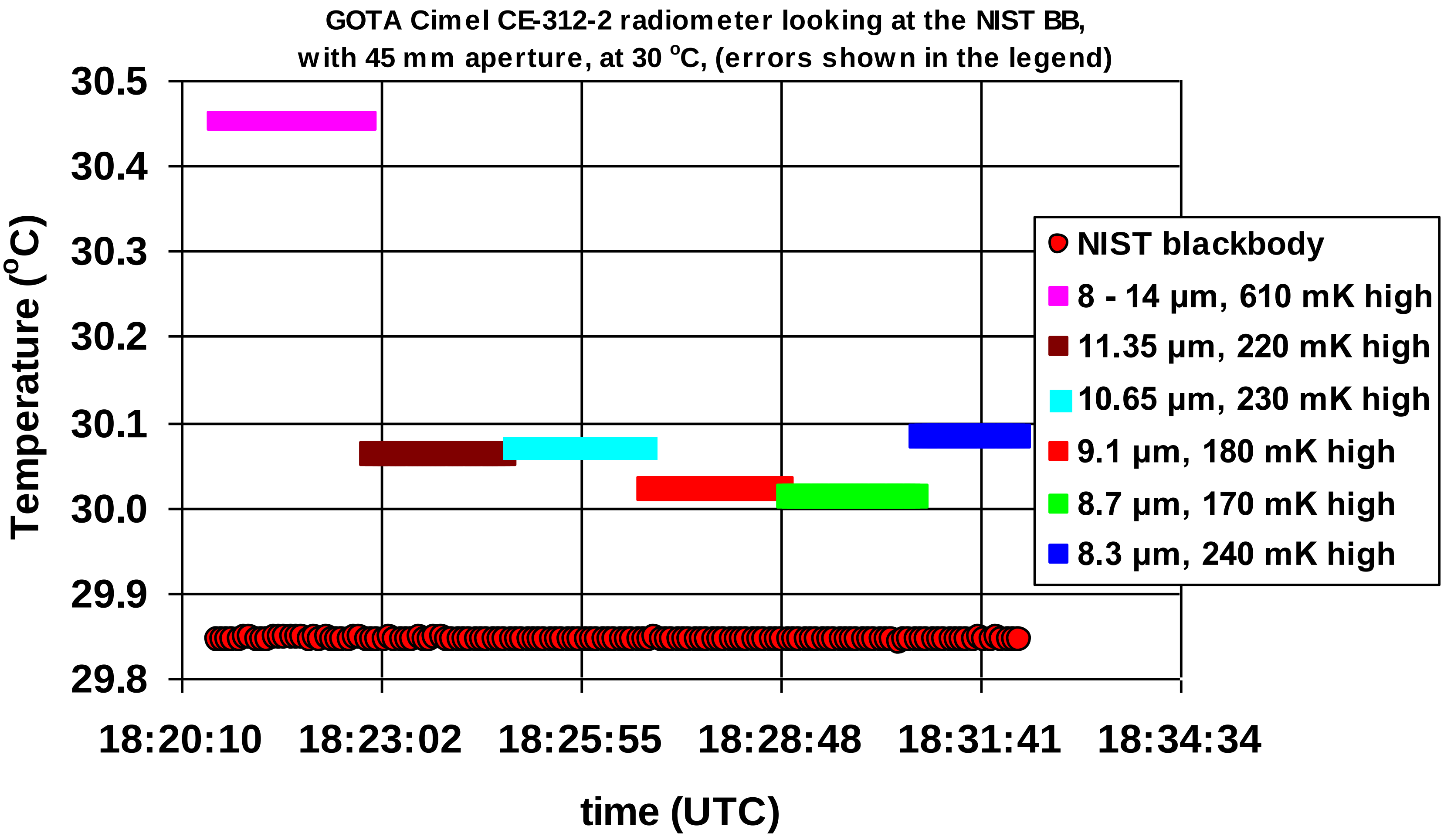
The ISAR and SISTER radiometers being tested during the 2009 Workshop



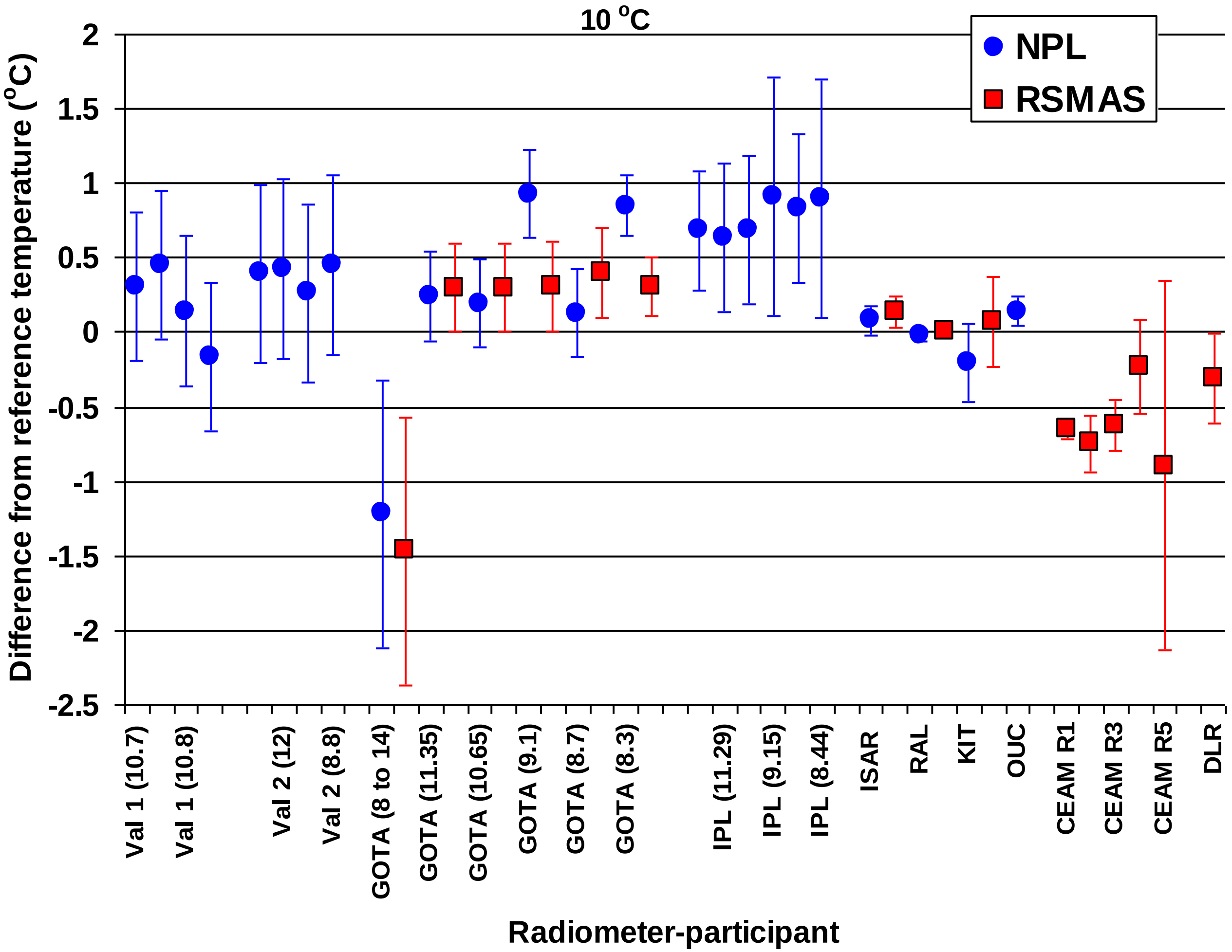
ISAR radiometer viewing the NIST blackbody at 30 °C, 100 mm aperture, <Radiometer measurement> – <NIST blackbody temp> = 0.027 K, (brackets indicate average over time interval shown)



Radiometer viewing blackbody at 30 °C. The figure legend indicates the deviation of the different radiometer channels from the average blackbody temperature, over the measurement interval.



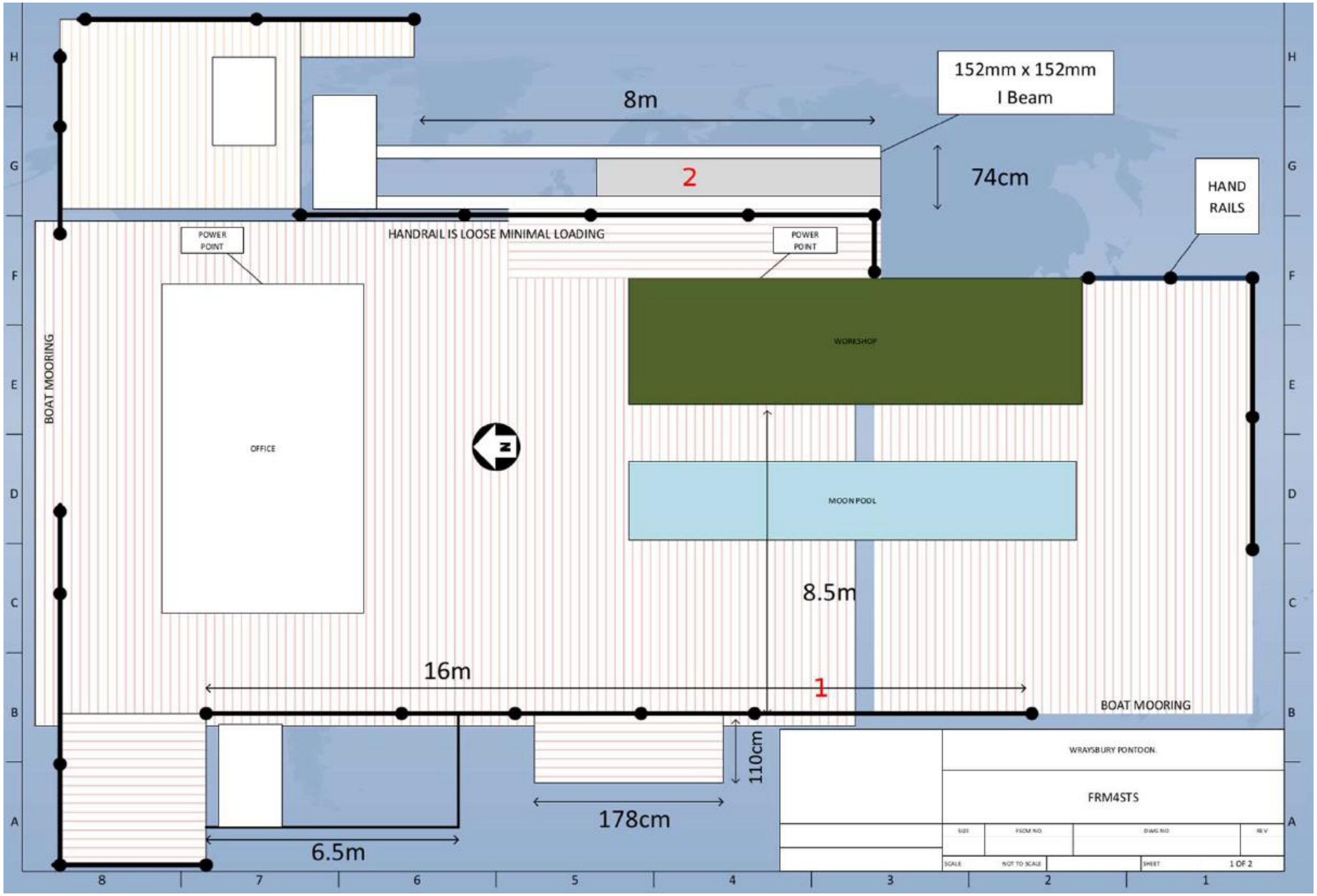
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL variable temperature blackbody (blue circles), maintained at a nominal temperature of 10 °C. The red squares show the points corresponding to the RSMAS blackbody.



WST measurements: 92 steps to the top!

Wraysbury reservoir with platform in background

Schematic of the Wraysbury reservoir platform

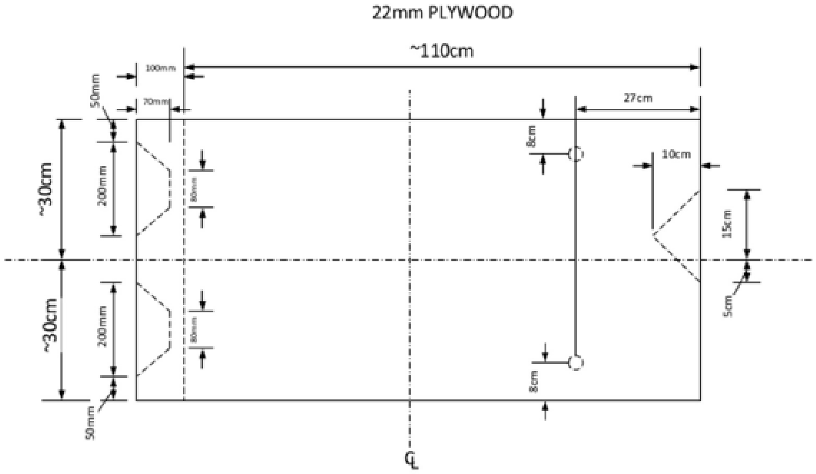


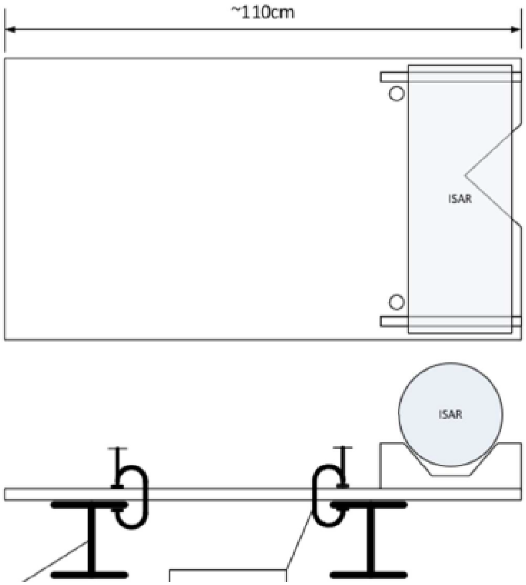
“Normal side” 10 m with railings and 9 m without railings

Alternative side, 8 m length

The alternative side of the platform

Mounting board for ISARs suggested by Fred Wimmer

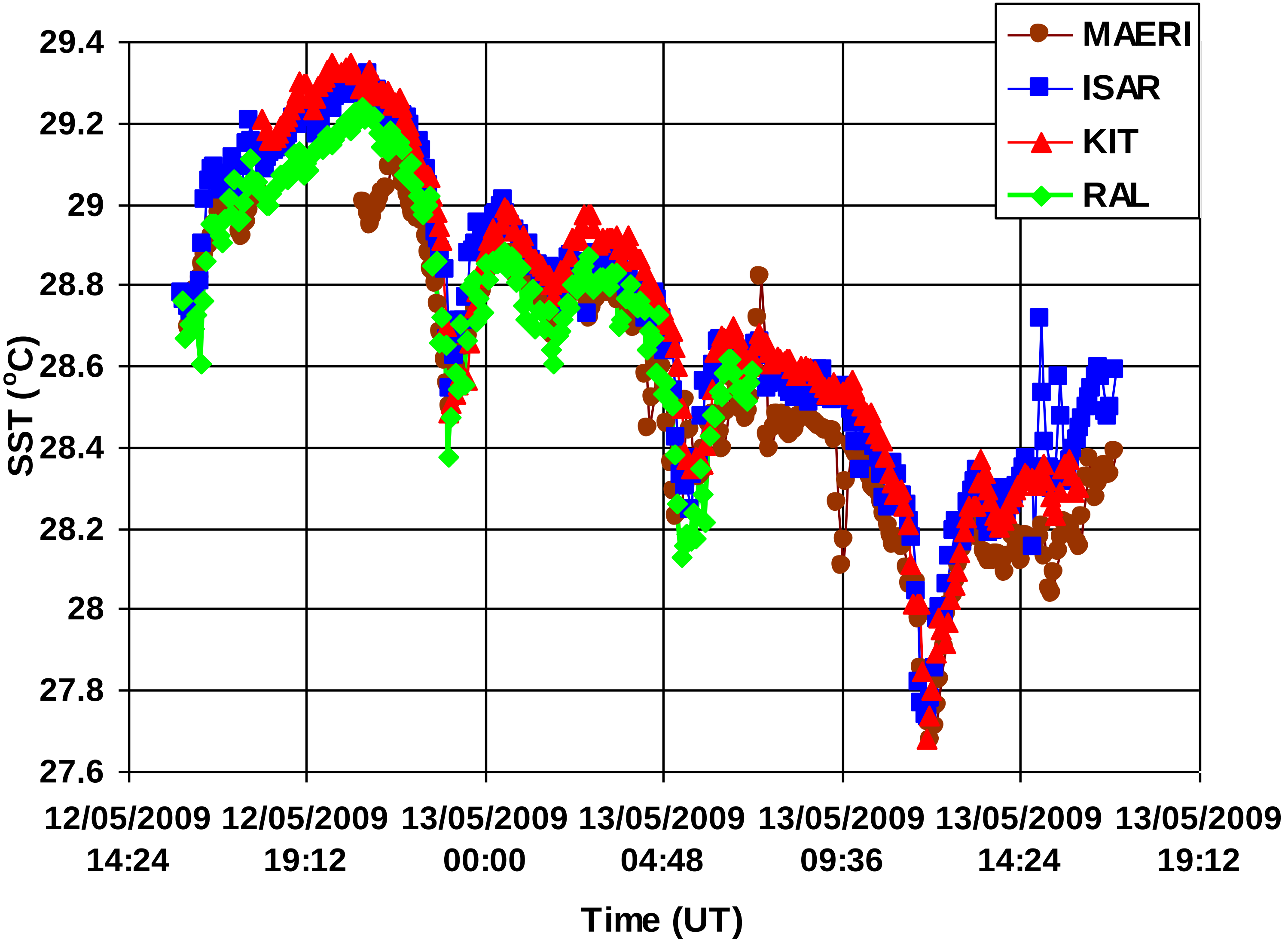




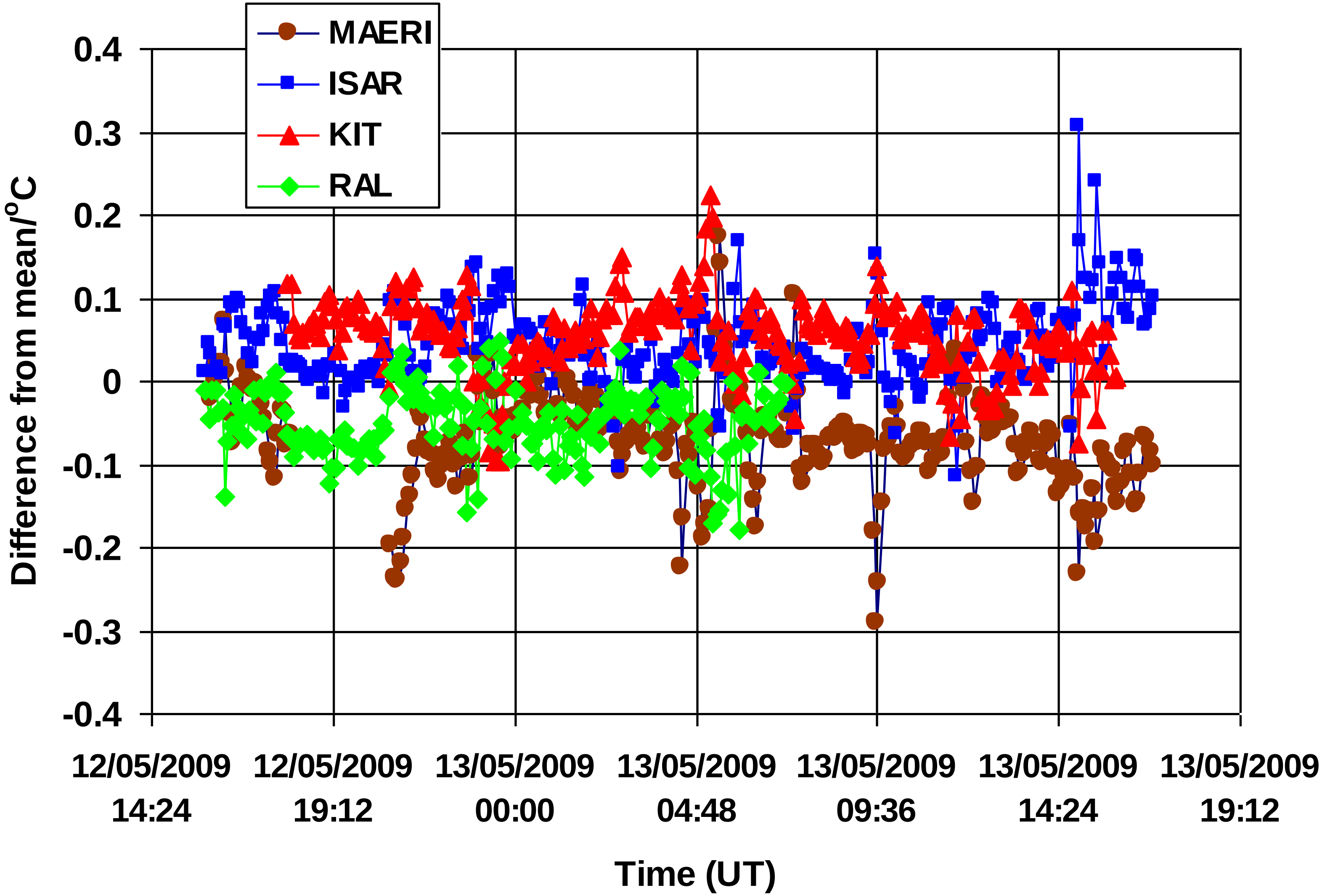
Information about the Wraysbury platform

- Plenty of mains electricity sockets.
- 4 m long extensions are required.
- The outside ambient temperature and humidity will be continuously monitored and recorded.
- Toilets on the “shore”. A boat trip is needed!
- Tea/coffee is available on platform.
- Lunch has to be brought to the platform.
- Radiometers can stay on platform over-night and operated unattended.
- All measurements should be time-stamped with UTC.

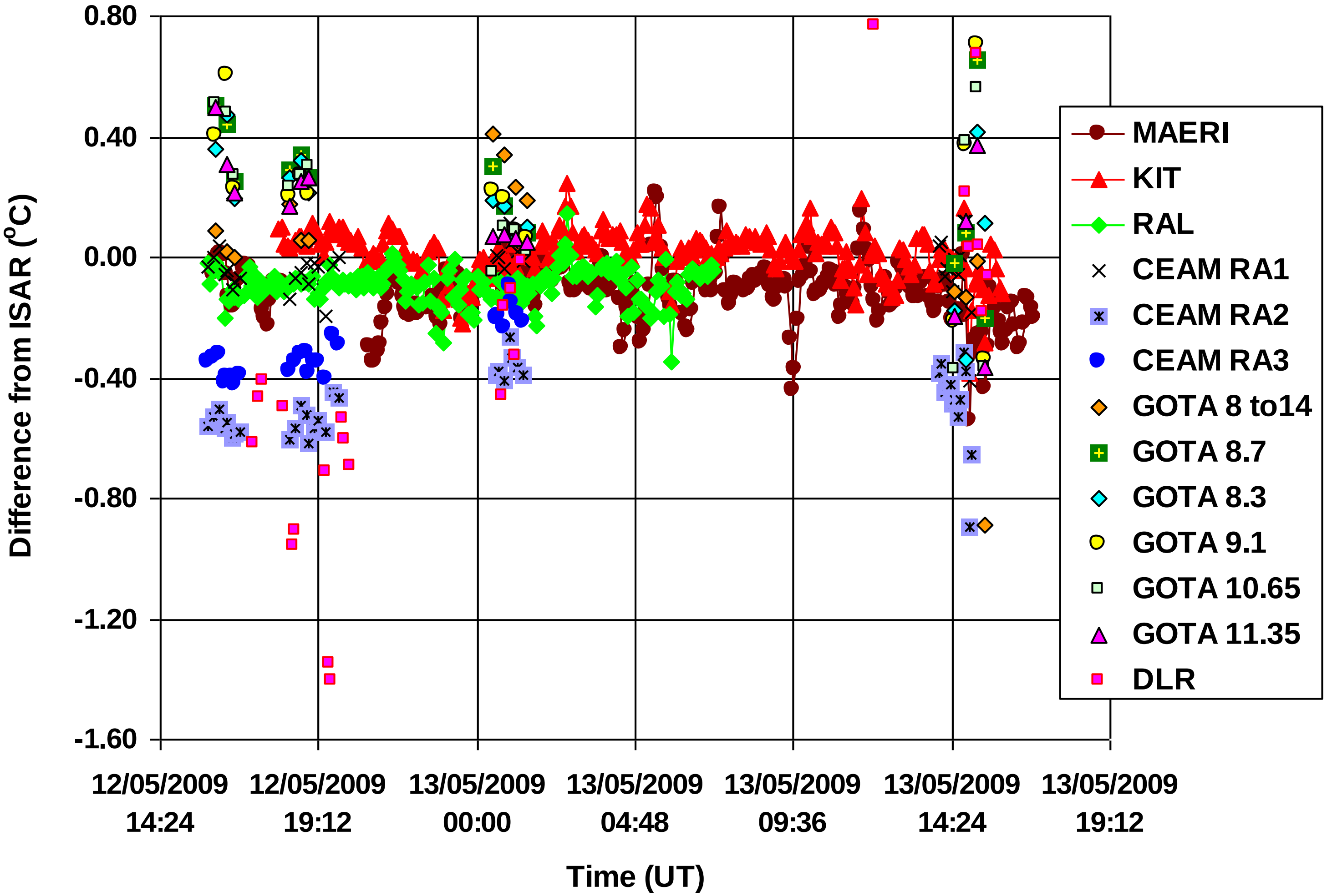
SST measured by the continuously-reading radiometers at the2009 comparison



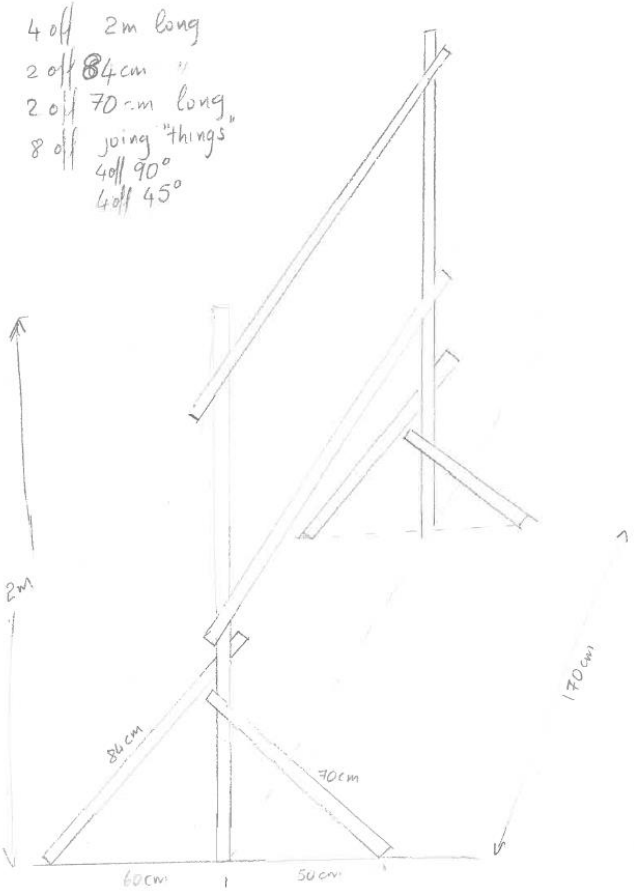
Difference of the continuously-reading radiometers (MAERI, ISAR, KIT and RAL-SISTeR) from their mean



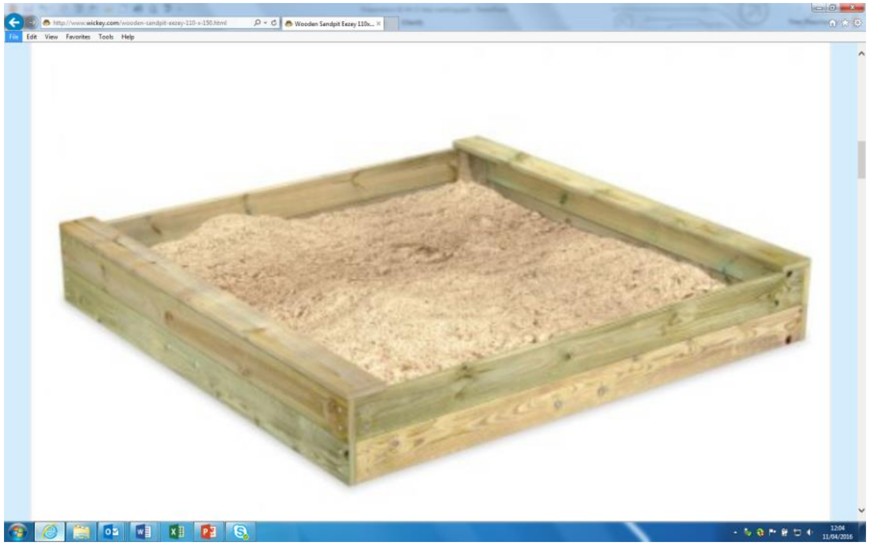
Difference of the ocean surface temperature measurements of the radiometers which participated at the 2009 comparison compared to the measurements completed by the ISAR radiometer



1.5 m by 1.1 m sandpits 30 cm high



4 off 2m long
2 off 84cm "
2 off 70cm long
8 off joing "things"
4off 90°
4off 45°



Land samples to be "looked at":

- Tall grass
- Short grass
- Sand
- "Brown soil"
- Gravel
- Tarmac

Information on the NPL LST measurements

- There are mains sockets (230 V AC) in the cabin.
- 50 m long extensions will be provided.
- Ambient temperature and humidity will be monitored.
- Toilets in Bushy house or the sports pavilion.
- Tea/coffee in sports pavilion.
- Lunch in sports pavilion, Teddington or back in NPL main restaurant.
- All measurements should be time-stamped with UTC.
- Radiometers can stay outside and run overnight but it is best if they are stored in the cabin for safety.

How measurements will be stored:

- After considering the various methods of storing and retrieving data from the FRM4STS comparison, it was concluded that this task can be addressed using a File Transfer Protocol (FTP) server.
- An FTP server will be simpler to control and administered and considerably less expensive compared to using a professional data storage organization.
- NPL is well versed with using FTP servers for the storage and retrieval of data of a number of different projects. The data saved under the FTP server will be regularly backed up following common practices of the NPL IT support team.
- The maintenance of the server will be done by people familiar with the files stored and their contents.

How measurements will be stored

- A report on how to archive calibration and verification data (D110) was prepared.
- A report which describes how to document and store measurements in an appropriate database so they can be retrieved and used by groups having an interest in scrutinising the performance of the different radiometer systems used to collect FRM data for use in satellite validation activities (D140) was prepared.
- NPL’s IT unit has started “building” the FTP server for the 2016 comparison.

WHERE THE DATA WILL BE STORED

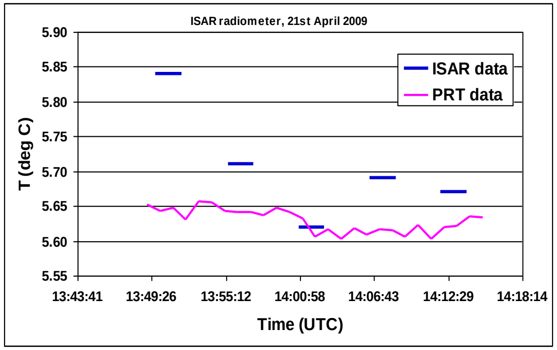
All the measurements which will be made as part of the current FRM4STS comparison will be included on the comparison website http://www.frm4sts.org/ under the “Data Resources” menu and in the “FRM4STS – Results Database” directory.

The FTP server will allow the access of stored data files (read only) to users which can authenticate themselves using a username and a password.

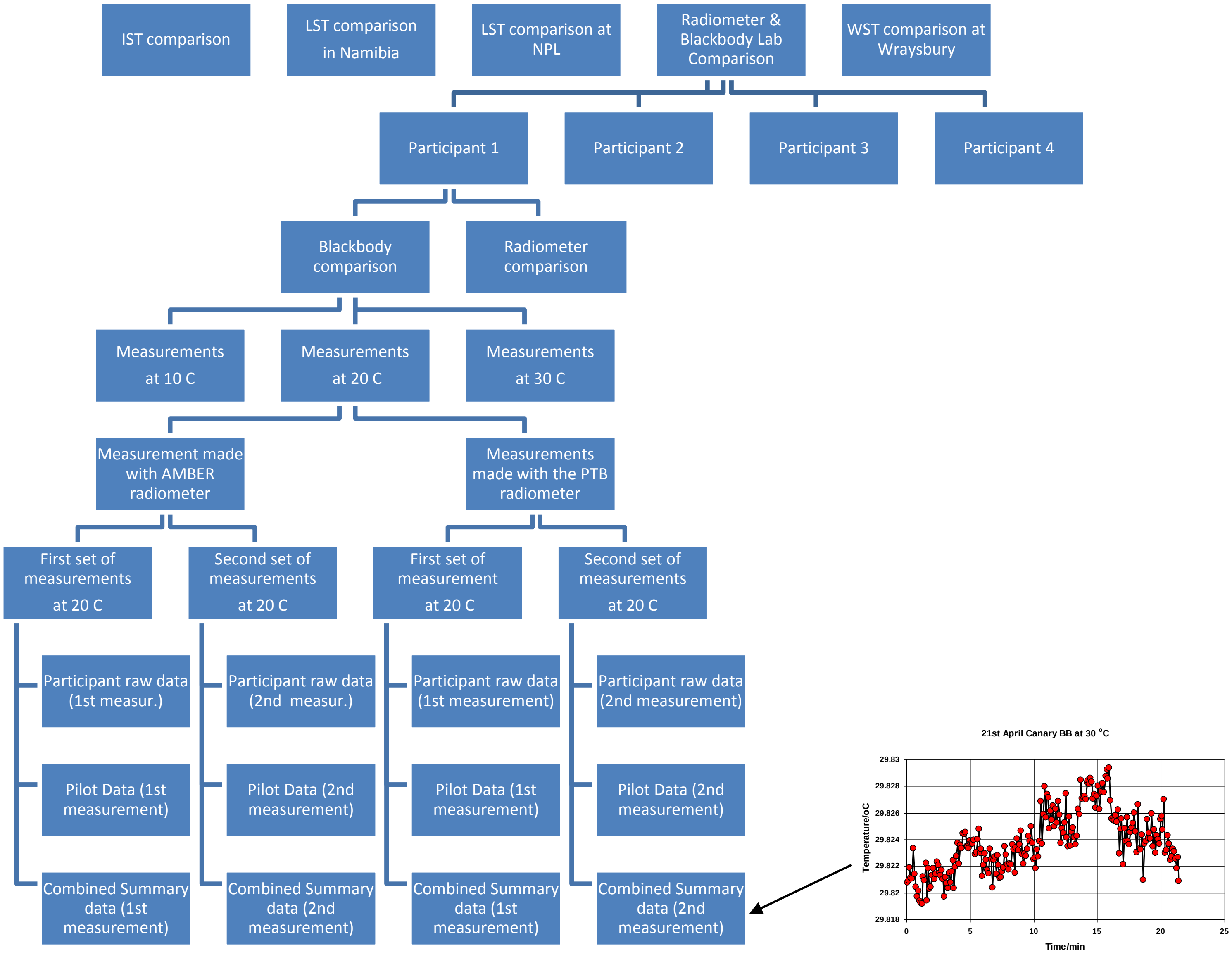
NPL will be the only organisation able to change the contents of the FTP server.

Layout of the database showing how the measurements of the participants’ laboratory radiometer comparison will be stored

- IST comparison
- LST comparison in Namibia
- LST comparison at NPL
- Radiometer & Blackbody Lab Comparison
  - Participant 1
    - Radiometer comparison
      - Measurements at 10 C
      - Measurements at 20 C
        - First set of measurements at 20 C
          - Participant raw data at 20 C
          - Pilot data at 20 C
          - Combined Summary data at 20 C
        - Second set of measurements at 20 C
          - Participant raw data at 20 C
          - Pilot Data at 20 C
          - Combined Summary data at 20 C
      - Measurements at 30 C
    - Blackbody comparison
  - Participant 2
  - Participant 3
  - Participant 4
- WST comparison at Wraysbury



Layout of the database showing how the measurements of the participants' laboratory blackbody comparison will be stored.

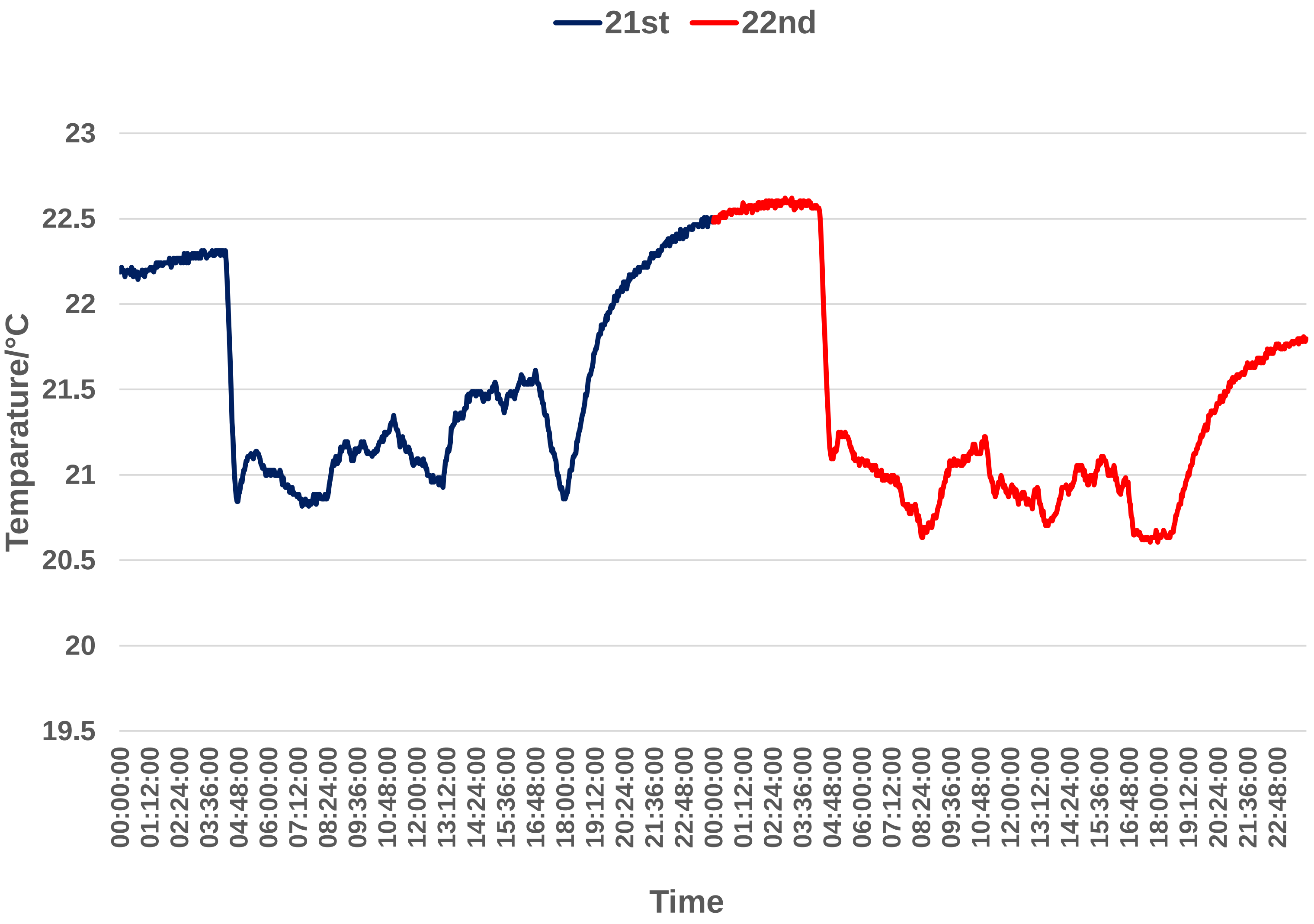


- IST comparison
- LST comparison in Namibia
- LST comparison at NPL
- Radiometer & Blackbody Lab Comparison
  - Participant 1
    - Blackbody comparison
      - Measurements at 10 C
      - Measurements at 20 C
        - Measurement made with AMBER radiometer
          - First set of measurements at 20 C
            - Participant raw data (1st measur.)
            - Pilot Data (1st measurement)
            - Combined Summary data (1st measurement)
          - Second set of measurements at 20 C
            - Participant raw data (2nd measur.)
            - Pilot Data (2nd measurement)
            - Combined Summary data (2nd measurement)
        - Measurements made with the PTB radiometer
          - First set of measurement at 20 C
            - Participant raw data (1st measurement)
            - Pilot Data (1st measurement)
            - Combined Summary data (1st measurement)
          - Second set of measurements at 20 C
            - Participant raw data (2nd measurement)
            - Pilot Data (2nd measurement)
            - Combined Summary data (2nd measurement)
      - Measurements at 30 C
    - Radiometer comparison
  - Participant 2
  - Participant 3
  - Participant 4
- WST comparison at Wraysbury

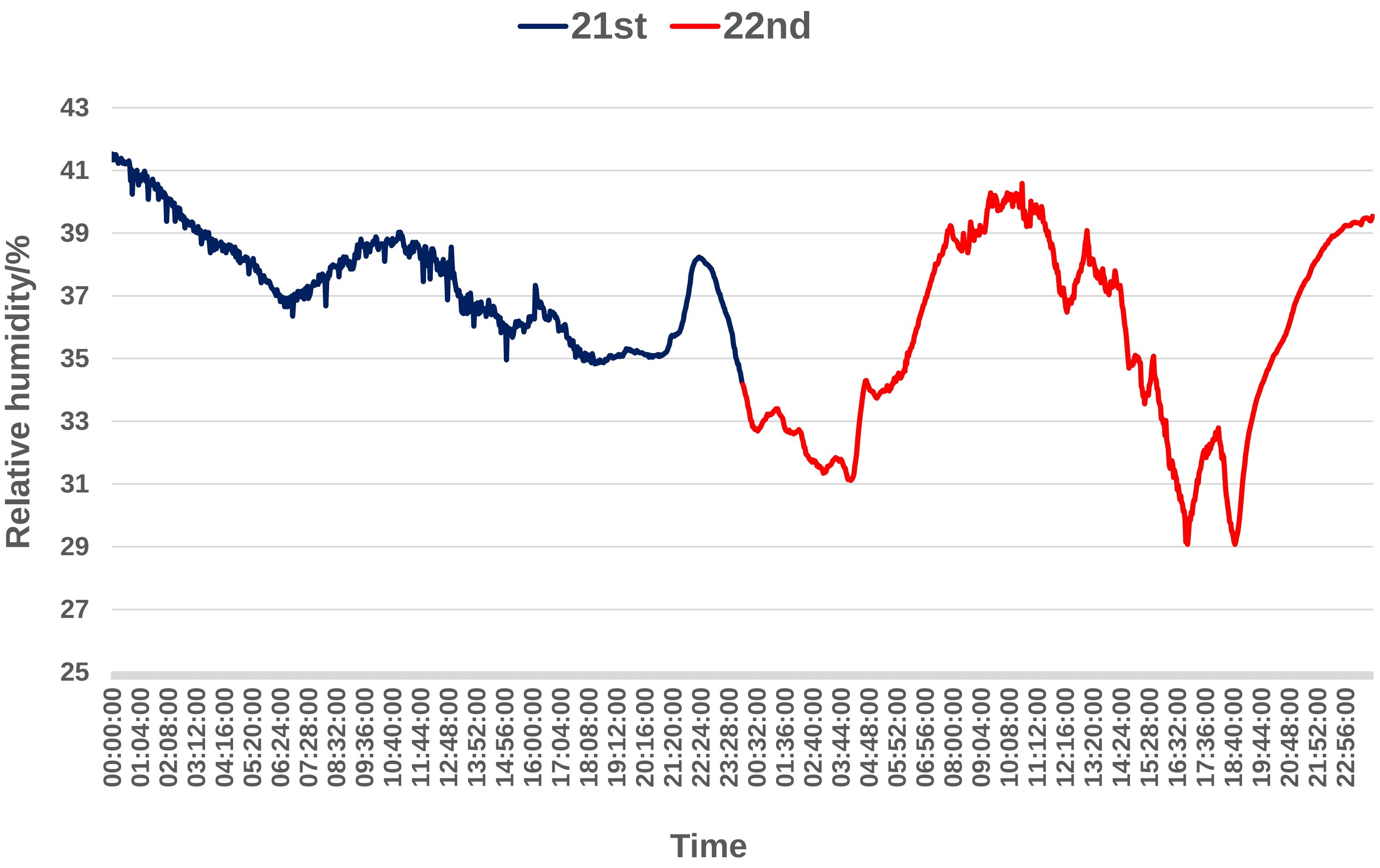
What information will the data files include:

- The title of these files will include information such as:
    1. the type of test radiometer used and its unique ID,
    2. the date on which the measurements were done,
    3. the temperature and humidity prevailing while these measurements were being acquired, etc.
- For the lab radiometer comparisons, the average value of the measurements made by the test radiometer and the corresponding average value of the actual reference blackbody temperature will also be given.
- The difference between the two average values of the same measurement will also be given, to indicate the drift in the test radiometer responsivity at that particular temperature setting.

Air temperature of lab during 2009 comparison



Relative humidity in lab during the 2009 comparison



Uncertainties

- A copy of an NPL report which deals with the measurement of the uncertainties in SST measurements was circulated to the participants.
- Alternative methods of treating uncertainties were also highlighted.
- Lists of the parameters which could contribute to the uncertainty of the measurements which the 2016 comparison deals with, were also given in the protocols of the various measurements.

When using blackbodies you have to consider:

Blackbody emissivity: Even a small deviation from unity results in tens (or even hundreds) of mK of change in the measured radiance temperature of the blackbody.

Emissivity depends on the cavity coating, shape of the cavity and cavity aperture.

The BB **emissivity must be calculated** (or measured?) and the “temperature error” introduced by the non-unity emissivity estimated.

This “error” should be used as a correction to the temperature measured by the PRT, e.g. changing the emissivity of a BB at 30°C from 0.9993 to 0.9999 changes the radiance temperature by 50mK!

The appropriate uncertainty contribution due to emissivity should be added in the uncertainty budget.

Other blackbody uncertainty contributions

Consider the **position of thermometer** relative to cavity. Does it represent the temperature of the inside of the cavity?

If not, then the **temperature drop** due to thermal resistance between thermometer position and inside of the cavity should be estimated. One of our Ga reference blackbodies suffers from a 22 mK temperature drop!

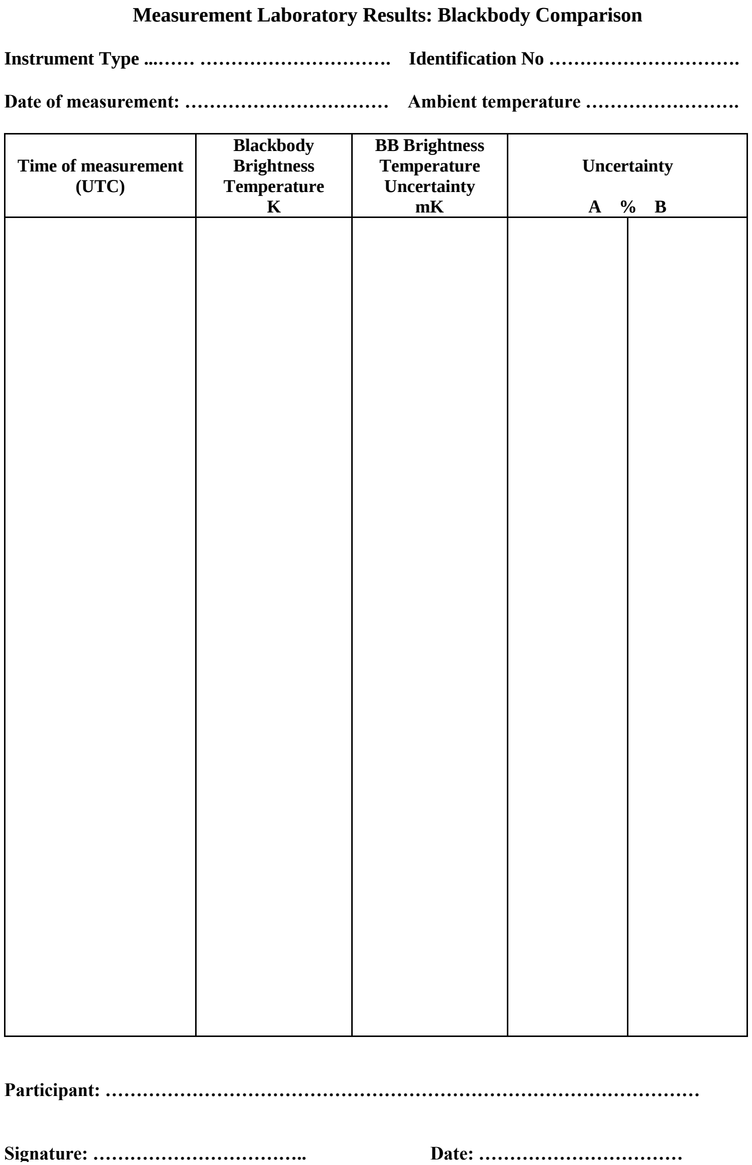
Correction/uncertainty due to **radiative heating/cooling** of the blackbody cavity to the environment (small for BBs operating at ambient temperatures, but significant at other temperatures).

Correction/uncertainty due to **convection** heating/cooling of the blackbody cavity to the environment (small for BBs operating at ambient temperatures).

Cavity temperature uniformity: Uncertainty due to the temperature variation within the blackbody cavity.

Stability of the blackbody temperature.

Measurement Laboratory Results: Blackbody Comparison



Measurement Laboratory Results: Blackbody Comparison

Instrument Type ...…… …………………………. Identification No ………………………….

Date of measurement: …………………………… Ambient temperature …………………….

Time of measurement (UTC)	Blackbody Brightness Temperature K	BB Brightness Temperature Uncertainty mK	Uncertainty	
			A %	B

Participant: ………………………………………………………………………………

Signature: …………………………….. Date: ……………………………

Measurement Laboratory Results: Radiometer Comparison

Instrument Type ...…. …………………………. **Identification No** ………………………….

Date of measurement: ………………………….. **Ambient temperature** …………………….

Time of measurement (UTC)	Measured Brightness Temperature	Combined Measurement Uncertainty	Wave-length	Band-width	Uncertainty		No. of
	K	mK	µm	nm	A %	B	Runs

Participant: ……………………………………………………………………………….

Signature: …………………………….. **Date:** ……………………………

Uncertainty Contributions: Radiometer Comparison

Uncertainty Contribution	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperatur K
Repeatability of measurement	U_{Repeat}		U_{Repeat}
Reproducibility of measurement	U_{Repro}		U_{Repro}
Primary calibration		U_{Prim}	U_{Prim}
Linearity of radiometer		U_{Lin}	U_{Lin}
Drift since calibration		U_{Drift}	U_{Drift}
Ambient temperature fluctuations		U_{amb}	U_{amb}
Size-of-Source Effect		U_{SoS}	U_{SoS}
Atmospheric absorption/emission		U_{atm}	U_{atm}
RMS total	$((U_{repeat})^2+(U_{Repro})^2)^{½}$		

Uncertainty Contributions: Blackbody Comparison

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperatur K
Repeatability of measurement	U_{Repeat}		U_{Repeat}
Reproducibility of measurement	U_{Repro}		U_{Repro}
Blackbody emissivity		U_{emis}	U_{emis}
BB Thermometer Calibration		U_{therm}	U_{therm}
BB cavity temperature non-uniformity		U_{Unif}	U_{Unif}
BB temperature stability		U_{stab}	U_{stab}
Reflected ambient radiation		U_{Refl}	U_{Refl}
Radiant heat/loss gain		$U_{Radiant}$	$U_{Radiant}$
Convective heat/loss gain		$U_{Convect}$	$U_{Convect}$
Primary Source		U_{Prim}	U_{Prim}
RMS total	$((u_{Repeat})^2+(u_{Repro})^2)^{\frac{1}{2}}$		

WST measurements results sheet

WST Measurement Results at Wraysbury Reservoir

Instrument Type ...………… Identification Number ……… Ambient temperature …………

Date of measurement: …………………… View angle from nadir (degrees)………………

Wavelength (µm) …………………………… Bandwidth (µm) ……………………………..

Time (UTC)	Measured WST K	Combined WST Uncertainty K	Measured sky temperature K	Uncert. in sky temperature K	Uncertainty %		No. of Runs
					A	B	

Participant: ………………………………………………………………………………………

Signature: …………………………….. Date: ……………………………

Uncertainty Contributions: WST Comparison

Uncertainty Contribution	**Type A Uncertainty in Value / %**	**Type B Uncertainty in Value / (appropriate units)**	**Uncertainty in Brightness temperatur K**
Repeatability of measurement	U_{Repeat}		U_{Repeat}
Reproducibility of measurement	U_{Repro}		U_{Repro}
Primary calibration		U_{Prim}	U_{Prim}
Water emissivity		U_{emiss}	U_{emiss}
Water surface "roughness"		U_{rough}	U_{rough}
Angle of view to nadir		U_{angle}	U_{angle}
Linearity of radiometer		U_{Lin}	U_{Lin}
Drift since last calibration		U_{Drift}	U_{Drift}
Ambient temperature fluctuations		U_{amb}	U_{amb}
Atmospheric absorption/emission		U_{atm}	U_{atm}
RMS total	$((U_{repeat})^2+(U_{Repro})^2)^{\frac{1}{2}}$		

Summary

1. The preparation of the laboratory radiometer comparison was described.
2. The preparation of the lab blackbody comparison was described.
3. The preparation for the WST comparison at Wraysbury reservoir was described.
4. The preparation of the LST comparison at NPL was described.
5. How and where measurements will be treated and stored.
6. Analysis of uncertainties
7. Summary

Thank you for listening

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