Date 24/03/09
Issue 0.95

QA4EO-CEOS-IVO-CL-C-001

Protocol for the CEOS WGCV Comparison of techniques/instruments used for surface IR radiance/brightness temperature measurements

Originator: Nigel Fox

Function: Lead Scientist for Earth Observation, National Physical Laboratory and chair of CEOS WGCV IVOS sub-group

---

The National Physical Laboratory

Hampton Road
Teddington
Middlesex TW11 0LW

CHANGE RECORD

Change Number	Issue	Date	Description
	0.1	16/03/09	First draft prepared
	0.2	23/03/09	Mods to include SST as a measurand, include Brightness temp in title and request for info on applications use of instruments.
	0.9	24/03/09	Incorporate comments from RSMAS
	0.95	5/5/09	Modify results forms and update participants list

APPROVAL RECORD:

ISSUE 1, approved by:	
Name	**Date of approval**

TABLE OF CONTENTS

1 Introduction........5
2 Objectives........6
3 Organization........6
3.1 Pilot........6
3.2 Participants........6
3.3 Participants' details........7
3.4 Form of comparison........8
3.5 Comparison overview........9
3.5.1 Comparison 1: black bodies........9
3.5.2 Comparison 2: Radiometers (laboratory)........9
3.5.3 Comparison 3: Radiometers (Ocean view)........9
3.5.4 Comparison transatlantic linkage........10
3.6 Timetable........10
3.7 Transportation of instrumentation........10
4 Measurement instructions........11
4.1 Traceability........11
4.2 Measurement wavelengths........11
4.3 Measurand........11
4.4 Measurement instructions........11
4.4.1 Comparison 1: black bodies........11
4.4.2 Comparison 2: Radiometers (laboratory)........12
4.4.3 Comparison 3: Radiometers (Ocean view)........13
4.4.4 General........14
5 Measurement uncertainty........14
6 Reporting of results........15
7 Comparison analysis........16
8 Appendix A: Measurement results........16
9 Appendix B: Description of Instrumentation and route of traceability........21
10 Appendix C: Uncertainty of measurement........22

1 Introduction

In an era when the number of Earth observation satellites is rapidly growing and measurements from satellite sensors are used to answer increasingly urgent global issues, often through synergistic and operational combinations of data from multiple sources, it is imperative that scientists and decision-makers be able to rely on the accuracy of Earth observation data products. The characterization and calibration of these sensors, particularly their relative biases, are vital to achieve the developing integrated GEOSS for coordinated and sustained observations of the Earth. This can only reliably be achieved in the post-launch environment through the careful use of observations by multiple sensor systems over common, well-characterized terrestrial targets. In some cases e.g. the Oceans such "sites" can be transient in nature and are thus better defined by the methodology of their use and the instrumentation used to characterise them. Through greater access to and understanding of these vital vicarious methods, the validity and utility of information gained from Earth remote sensing will continue to improve.

The measurement of the Earth's surface temperature and more fundamentally, its temporal and spatial variation is a critical operational product for meteorology and an essential parameter/indicator for climate monitoring. Satellites have been monitoring global surface temperature for some time, with good precision and through activities like GODAE High Resolution Sea Surface Temperature pilot project (GHRSST-pp) have established sufficient consistency and accuracy between in-flight sensors to claim that it is of "climate quality". However, it is essential for long-term records and the avoidance of any potential data gaps 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 Cal/Val) are derived from field deployed IR radiometers. These are in principle calibrated traceably to SI units, generally through a blackbody radiator. 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 Cal/Val 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 (or in this case Ocean). If a fully traceable link to SI can also be established and demonstrated this will ensure that the data will be 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 a previous highly successful exercise in Miami in 2001 [2,3]. This comparison was also organised through CEOS with organisational sponsorship from a number of CEOS agencies: ESA, EUMETSAT, NASA and NOAA/NESDIS. However, eight years will have passed and it is considered timely to repeat/update the process, particularly as many of the satellite sensors originally supported are now nearing their end of life, and in readiness for new sensors.

This protocol describes the set of comparison activities that will be carried out as part of this exercise and the necessary generic details of the procedures that will be followed. Readers are encouraged to also read QA4EO-CEOS-DQK-004 for more details and background on the generic comparison process itself.

2 Objectives

The overarching objective of this comparison is *"To establish the "degree of equivalence" between surface based IR Cal/Val measurements made in support of satellite observations of the Earths surface temperature and to establish their traceability to SI units through the participation of national standards laboratories"*.

The objective can be sub-divided into the following:

1) Evaluate differences in IR radiometer primary calibrations (laboratory based)
   a. Reference standards used (Black bodies) and traceability
   b. Radiometers response to common black body target
   c. Evaluate differences in radiometer response when viewing ocean target
2) Establish formal traceability for participant black bodies and radiometers

3 Organization

3.1 Pilot

NPL will serve as pilot for this comparison supported by the University of Miami Rosenstiel School of Marine and Atmospheric Science (RSMAS) as hosts. In this role they will jointly be responsible for the organisation of the comparison ensuring that the logistics and any support equipment is available. NPL, the pilot, will also be responsible for inviting participants and for the analysis of data, following appropriate processing by individual participants. NPL, as pilot, will be the only organisation to have access and to view all data from all participants. This data will remain confidential to the participant and NPL at all times, until the publication of Draft A. (report showing results of the comparison to participants).

3.2 Participants

The list of participants is given in the Section 3.3.

All participants should be able to demonstrate independent traceability to SI of the instrumentation that they use, or make clear the route of traceability via another named laboratory. n.b if participants route of traceability is not fully established their results may not be used to determine a comparison reference value although their results relative to it will be visible. They will then be able to use this comparison in the future as evidence of traceability.

By their declared intention to participate in this key comparison, the participants accept the general instructions and the technical protocols written down in this document and commit themselves to follow the procedures strictly.

Once the protocol and list of participants has been agreed, no change to the protocol or list of participants may be made without prior agreement of all participants.

Where required demonstrable traceability to SI will be obtained through participation of NIST and NPL as pilot.

3.3 Participants' details

Contact person	Institute	Contact details	Short version
Nigel Fox	National Physical Laboratory Hampton Road Middlesex TW11 0LW United Kingdom	Tel: +44 20 8943 6825 Email: Nigel.fox@npl.co.uk	NPL
Manuel Arbelo	Grupo de Observacion de la Tierra y la Atmosfera (GOTA) ULL Spain	E-Mail: marbelo@ull.es	GOTA
Dr. César Coll	Dept. of Earth Physics and Thermodynamics Faculty of Physics University of Valencia Dr. Moliner, 50. 46100 Burjassot Spain	Tel: E-mail: Cesar.Coll@uv.es	UV-ES
Raju Datla	NIST 100 Bureau Drive Gaithersburg, MD 20899 USA	E-mail: rdatla@nist.gov	NIST
William (Bill) Emery	Univ of Colorado Aerospace Eng. Sci. Dept CB 431, Boulder CO, 80309-0431 USA	E-mail: emery@colorado.edu	EDU-USA
Dr. Frank-M. Goettsche	Forschungszentrum Karlsruhe Institute of Meteorology and Climate Research Atmospheric Trace Gases and Remote Sensing Meteorological Satellite-Data Analysis Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen Germany	Tel: +49-(0)7247-82-3821 E-mail: frank.goettsche@imk.fzk.de	IMK-FZK
Dr. Lei Guan	Ocean Remote Sensing Institute Ocean University of China 5 Yushan Road Qingdao, 266003 China	Email: leiguan@ouc.edu.cn	OUC-CN
Dr Raquel Niclos	Mediterranean Center for Environmental Studies,	Tel: +34 961318227 Email: niclos@ceam.es	CEAM

	14 Charles Darwin 46890 Paterna Valencia Spain		
Peter J Minnett	University of Miami 4600 Rickenbacker Causeway Miami, FL 33149 USA	E-Mail: pminnett@rsmas.miami.edu	RSMAS
Tim Nightingale	STFC Rutherford Appleton Laboratory Chilton, Didcot Oxon OX11 0QX United Kingdom	Email: tim.nightingale@stfc.ac.uk	STFC RAL
J. A. Sobrino	Imaging Processing Laboratory (IPL) Parque Científico Universitat de Valencia Poligono La Coma s/n 46980 Paterna Spain	Tel: +34 96 354 3115 E-mail: sobrino@uv.es	IPL-ES
Werenfrid Wimmer	National Oceanography Centre, Southampton European Way, Southampton, SO19 9TX United Kingdom	E-mail: w.wimmer@soton.ac.uk	SOTON

3.4 Form of comparison

This protocol covers a number of individual comparisons. Each comparison will have its own specific characteristics but will all in principle take the same form i.e. they will all seek to observe a common entity, (surface/artefact), and analysis will be made by reference to the mean value observed by all participants. In some cases, to remove potential systematic biases from the measurand under evaluation, results will undergo a normalisation.

In the case of the black body radiator comparison, traceability to SI will also be established through the direct participation of black bodies characterised at national standards laboratories, NIST and NPL. Although these black bodies will not be viewed directly by all participants robust linkage to them will be established. Viewing of these black bodies by participant radiometers will allow that traceability to be extended to the radiometers.

The measurement aspects of the comparison will take place in two stages to allow maximum participation and also to enable a traceability chain to be established to both NPL and NIST. Stage 1 will take place at NPL and will only involve laboratory based measurements of black bodies and radiometers. Stage 2 will take place at RSMAS, where, in addition to the laboratory-based activities replicating those of Stage 1, there will be direct measurements of the Ocean.

Linkage between the two Stages will be established through participant radiometers used in both stages, serving as transfer standards.

3.5 Comparison overview

The comparison exercise consists of three separate comparisons two of which take place in two linked stages. The following sections outline the principle scope of each comparison, specific details will be described in section 4.

3.5.1 Comparison 1: black bodies

In this comparison, any portable black bodies provided by participants will be compared relative to a reference black body using a well-characterised transfer standard radiometer. In Miami the reference black body will be from NIST and in the UK from NPL.

The transfer radiometer used in Miami will be the TXR radiometer of NIST operating in two spectral bands (centred at 5 and 10 μm) and at NPL the AMBER facility will be used but in this case only at 4 μm.

The comparison will be performed at three nominal temperatures: 283 K, 293 K and 303 K.

3.5.2 Comparison 2: Radiometers (laboratory)

For this comparison all participant radiometers will be compared to a reference blackbody calibrated traceable to SI through NIST or NPL. The reference black body will be variable in temperature, have a well-characterised and high spectral emissivity and have an aperture sufficiently large to accommodate the field of view of any participant radiometer.

In Miami, the RSMAS reference black body will be used, which has been traceably calibrated to NIST. In the UK the NPL reference black body will be used directly.

The reference black body will be set to a fixed known temperature and then viewed by all radiometers. Measurements will be performed at nominal temperatures of: 278 K, 283 K, 293 K and 303 K, or a subset of these determined by time or other constraints.

3.5.3 Comparison 3: Radiometers (Ocean view)

For this comparison all radiometers will simultaneously view the same part of the Ocean from the pier at RSMAS, Miami for a variety of view angles: 40º, 45º,50º and 55°.

This comparison will only take place in the USA.

Measurements will be performed during both day and night time conditions.

3.5.4 Comparison transatlantic linkage

Because the reference transfer radiometer (AMBER) and variable temperature black body of NPL are not readily portable, linkage of the comparisons performed in the UK and USA will be through participant radiometers. This will be supplemented by a portable single temperature black body, which will serve to confirm stability of the radiometers.

3.6 Timetable

There are three main phases to the comparison activity. The first phase prepares for the measurements; the second phase is the measurements themselves and takes place in two stages and the third phase the analysis and report writing. The timescale for the third phase has a compressed element to allow analysis in near real time during the comparison process.

PHASE 1: PREPARATION	
Invitation to participate	July 2008
Preparation and formal agreement of protocol	Jan - March 2009
PHASE 2: MEASUREMENTS	
Participants measure primary Black body (UK)	April 2009
Comparison of black bodies (UK)	April 2009
Participants measure black bodies (USA)	May 2009
Comparison of black bodies (USA)	May 2009
Participants measure Ocean	May 2009
Participants send all data and reports to pilot	May 2009
Additional opportunity for measurements at NPL	June 2009
PHASE 3: ANALYSIS AND REPORTS	
Participants send preliminary report of measurement system and uncertainty to pilot and forwarded to all	April 2009
Receipt of comments from participants	May 2009
Draft A (results circulated to participants)	May 2009
Final draft report circulated to participants	August 2009
Draft B submitted to CEOS WGCV	Sep 2009
Final Report published	October 2009

3.7 Transportation of instrumentation

It is the responsibility of all participants to ensure that any instrumentation required by them is shipped with sufficient time to clear any customs requirements of the host country. This includes transportation from any port of entry to the site of the comparison and any delay could result in them being excluded from the comparison.

It is recommended that where possible any fragile components should be hand carried to avoid the risk of damage.

The pilot and host laboratory have no insurance for any loss or damage of the instrumentation during transportation or whilst in use during the comparison, however all reasonable efforts will be made to aid participants in any security.

Electrical power will be available to all participants, although the nature of this, including interface sockets will reflect that of the host country and participants should not anticipate that adaptors will be available. The host laboratory (RSMAS) can provide a small number of transformers to provide 220Vac.

4 Measurement instructions

4.1 Traceability

All participant instruments should be independently traceable to SI units with documentary evidence of the route and associated uncertainty. If this traceability is provided as part of a "calibration" from the instrument manufacturer then the manufacturer should be contacted and asked to supply the appropriate details.

Temperature measurements should be made by reference to the International Temperature Scale of 1990 (ITS-90) or thermodynamically.

4.2 Measurement wavelengths

The comparison will be analysed as a set of separate comparisons for each wavelength where appropriate or as wavelength band e.g. 3 to 5 µm and 8 to 12 µm. Participants must inform the pilot laboratory prior to the start of the comparison which wavelengths the participant will be taking measurements at.

4.3 Measurand

The principle measurand in all three comparisons is brightness temperature.

4.4 Measurement instructions

4.4.1 Comparison 1: black bodies

- The transfer radiometer used to view the participants black bodies should be calibrated traceable to NPL or NIST primary scales (likely to be via a black body) as appropriate prior to use. This may occur as part of the comparison exercise, or at some alternative time (which could be several weeks) before or after, providing the stability of the reference transfer standard radiometer is known. Ideally this radiometer should be calibrated before and after its use in this comparison to demonstrate its stability.

- The transfer radiometer should be mounted so that it can be easily aligned to be coaxial to the participant black bodies. Care needs to be taken to avoid significant reflections or emissions from the transfer radiometer into the black body under test or at least so that any interaction is such that its impact on any measurements is minimised.

- Participants will set their black body to the nominal temperature specified by the pilot. They will indicate to the pilot when they have reached equilibrium. They will declare to the pilot their brightness temperature together with any uncertainty and/or short-term drift (which may occur during the time of measurement by the reference transfer radiometer).

- The operator of the transfer radiometer will record the reading of the radiometer relative to an appropriate dark reading for ten measurements, together with the identity of the participant and the information supplied by the participant.

- The participant will not be informed of the result at this stage.

- The process will be repeated for each of the three nominal temperatures. In practise it is expected that other participants black bodies will be measured sequentially whilst black bodies re-stabilise to any new temperature.

- The sequence should then be repeated for all temperatures to assess reproducibility.

4.4.2 Comparison 2: Radiometers (laboratory)

- The variable temperature black body used for this comparison should be well characterised with demonstrable traceability to SI.
- Each participant radiometer should be mounted so that it can be easily aligned to the reference black body.
- The reference black body should then be set to one of the nominal temperatures specified in this protocol. (n.b. this should not necessarily be the exact temperature, so as to ensure "blindness" to participants).
- Each participant radiometer should then be aligned to view the reference black body and when they are ready make ten measurements of the brightness temperature or spectral radiance of the blackbody at all wavelengths of their radiometer. This information should be recorded and unless it needs further processing should be provided to the pilot at this time. If further processing is needed this should be done with urgency and the results provided to the pilot within 2 hrs of completing the measurements.
- The pilot will record the actual temperature of the reference black body and any drift, which may occur during the time period of each participant's measurements, together with the results from the participant.
- The above process should be repeated for all four temperatures specified in this protocol.
- The complete sequence should be repeated for all temperatures, including realignment of radiometers, to assess repeatability.

4.4.3 Comparison 3: Radiometers (Ocean view)

This will involve a set of measurements at a range of angles in two stages i.e. day and night.

4.4.3.1 Day

- Each participant radiometer should be mounted on the pier at RSMAS and aligned to view the area indicated by the pilot. This target location will be chosen to allow comparisons to be made at a range of view angles.
- The "clock" of each participant should be synchronised to that of UTC.
- Following an indication from the pilot, each participant will then measure the target and record its viewed brightness temperature (Ocean and Sky as correction) and at all wavelengths at time intervals to suit each radiometer during a 30 minute period. The effective time of each observation should be clearly indicated.
- The host will collect measurements of meteorological data and bulk sea temperature, time stamped during this process.
- Participants will then be asked to change viewing angle and the process repeated.
- This process will be repeated for all view angles.
- The complete above sequence will then again be repeated, with all instruments realigned.
- After completing the above measurement sequence, participants will have 3 hrs to carry out any necessary post processing e.g. sky brightness correction etc before submitting final results to the pilot, which will include processed Sea Surface Temperature (SST) values.
- The results should not be discussed with any participant other than the pilot until the pilot gives permission.

4.4.3.2 Night

- The above process should be repeated following sundown.

4.4.3.3 Declaration of Comparison completion

The above process should ideally be considered as a single comparison and the results analysed. Before declaring the results to the participants the pilot will consult with all participants about the nature of the meteorological conditions of the comparison and with additional knowledge of the variance between declared results determine if a repeat should be carried out. At this stage participants, may be told the level of variance between all participants but no information should be given to allow any individual result or pair of results to be determined. If the participants consider that the process should be repeated, as a result of poor conditions, then the results of that "day-night" will remain blind to the pilot.

The comparison process will be repeated until all participants are happy that meteorological conditions are good or that time has run out. At this point the comparison will be considered final and the results provided to all participants. This will constitute the final results and no changes will be allowed, either to the values or uncertainties associated with them unless they can be shown to be an error of the pilot.

However, if a participant considers that the results that they have obtained are not representative of their capability and they are able to identify the reasons and correct it, they can request of the pilot (if time allows) to have a new comparison. This comparison, would require participation of at least one other participant and ideally two and sufficient time.

If the above conditions can be met then the above comparison process can be repeated.

4.4.4 General

No other measurements are to be attempted by neither the participants nor any modification to the operating conditions during the course of this comparison. The transfer standards used in this comparison should not be used for any purpose other than described in this document nor given to any party other than the participants in the comparison during or following the comparison.

Any information obtained relating to the use or any results obtained by a participant during the course of the comparison shall be sent only to the pilot laboratory who will be responsible for co-ordinating how the information should be disseminated to other participants. No communication whatsoever regarding any details of the comparison other than the general conditions described in this protocol shall occur between any of the participants or any party external to the comparison without the written consent of the pilot laboratory. The pilot laboratory will in turn seek permission of all the participants. This is to ensure that no bias from whatever accidental means can occur.

5 Measurement uncertainty

The uncertainty of measurement shall be estimated according to the *ISO Guide to the Expression of Uncertainty in Measurement* (QA4EO-CEOS-DQK-006). In order to achieve optimum comparability, a list containing the principal influence parameters for the measurements and associated instrumentation are given below. An example table which should be completed by participants is included as Appendix C The participating laboratories are encouraged to follow this breakdown as closely as possible, and adapt it to their instruments and procedures. Other additional parameters may be felt appropriate to include dependent on specific measurement facilities and these should be added with an appropriate explanation and/or reference. As well as the value associated with the uncertainty, participants should give an indication as to the basis of their estimate. All values should be given as standard uncertainties, in other words for a coverage factor of $k = 1$.

Type A

Repeatability of measurement - repeatability of measurement process without re-alignment of the participants instrument. This component should be largely caused by the instrumentation stability/resolution related to the output from the reference standard and any associated measuring instrument. In effect the standard deviation of a single set of measurements made on the reference standard. This should be presented as a relative quantity.

Reproducibility of measurement - reproducibility (run to run) following re-alignment of the instrument with the comparison transfer standard. This should be, largely caused by the measurement set-up related to the output from the transfer standard. This should be presented in terms of percentage of the assigned result.

Type B

Participants disseminated scale - This is the total uncertainty of the participant's instrument. This includes its traceability to any primary reference standard, underpinning scale as disseminated by them. This should include the uncertainty in the primary SI realisation, or in the case of a scale originating from another laboratory, the uncertainty of the scale disseminated to it by that laboratory. It should of course reference the originating laboratory. All uncertainties contributing to this parameter should be itemised as part of the report, or if published a copy of this publication attached. These should include spectral emissivity and its uniformity in the case of the black body, together with any thermometry.

Wavelength - This is the uncertainty in the absolute value of the wavelength used for the comparison. This should only be taken account of in terms of the instrumentation being used and should include details relating to bandwidth where appropriate.

6 Reporting of results

On completion of each set of results as, indicated above, they should be reported to the pilot. Where possible, these should be sent in electronic form as well as hard copy.

The measurement results are to be supplied in the Template provided by the pilot laboratory at the beginning of the comparison (see Appendix A) with the final draft of the protocol. The measurement report is to be supplied in the Word Template as a .doc file provided by the pilot. This will simplify the combination of results and the collation of a report by the pilot and reduce the possibility of transcription errors.

Understanding that not all participants are likely to have a native English speaker on their staff, the pilot offers to review and advise on the English of the supplied reports. To simplify the job of the pilot, however, if you have the opportunity to have the report checked separately by someone with good English, please do so.

The measurement report forms and templates will be sent by e-mail to all participating laboratories. It would be appreciated if the report forms (in particular the results sheet) could be completed by computer and sent back electronically to the pilot. **A signed report must also be sent to the pilot in paper form by mail or as a scanned document, receipt will be acknowledged, see appendix D.** In case of any differences, the paper forms are considered to be the definitive version.

If, on examination of the complete set of provisional results, the pilot institute finds results that appear to be anomalous, all participants will be invited to check their results for numerical errors without being informed as to the magnitude or sign of the apparent anomaly. If no numerical error is found the result stands and the complete set of final results is sent to all participants, subject to the discussion in section 4.4.4.3. Note that once all participants have been informed of the results, individual values and uncertainties may be changed or removed, or the complete comparison abandoned, only with the agreement of all participants and on the basis of a clear failure of instrumentation or other phenomenon that renders the comparison or part of it invalid.

Following receipt of all measurement reports from the participating laboratories, the pilot laboratory will analyse the results and prepare a first draft report on the comparison, draft A. This will be circulated to the participants for comments, additions and corrections. Subsequently, the procedure outlined in QA4EO-CEOS-DQK-004 will be followed.

7 Comparison analysis

Each comparison will be analysed by the pilot according to the procedures outlined in QA4EO-CEOS-DQK-004. In some cases, analysis will be carried out based solely on results declared by the participant, in others there will be further analysis based on modifications of the instrument calibration as a result of previous comparisons. In this way all available information will be presented and the final results will be transparent to all readers of the report.

Unless an absolute traceable reference to SI of sufficient accuracy is a-priori part of the comparison and accepted as such by all participants, all participants will be considered equal. All results will then be analysed with reference to a common mean of all participants weighted by their declared uncertainties.

In this comparison primary standard sources of both NIST and NPL will be used. The participation of these sources will allow a direct linkage and the consequential establishment of formal traceability to be established for all measurements. The nominally independent scales from NPL and NIST will be linked through participant radiometers.

8 Appendix A: Measurement results

The attached measurement summary should be completed by each participant for each completed set of laboratory/Ocean measurements. A complete set being one, which may include multiple measurements on, or using the same instrument but does not include any realignment of the instrument. For each realignment a separate measurement sheet should be completed. Therefore for each Laboratory based comparison there should be 2 complete measurements sheets.

For clarity and consistency the following list describes what should be entered under the appropriate heading in the table.

Wavelength	The assigned centre wavelength of the measured brightness temperature. For the case of Fourier Transform spectrometers, the wavelength range, and wavelength resolution should be specified.
Bandwidth	The spectral bandwidth of the instrument used for the comparison defined as the Full Width at Half the Maximum.
Brightness temperature	Measured or predicted brightness temperature by participant
Std Deviation	The standard deviation of the number of measurements made to obtain the assigned brightness temperature without realignment
Number of Runs	The number of independent measurements made to obtain the specified std deviation.
Uncertainty	The total uncertainty of the measurement of brightness temperature separating this into Type A and B for a coverage factor of k=1.

Emissivity	The average spectral emissivity within the bandwidth
View angle from Nadir	The angle of view of the radiometer to the Ocean from Nadir

A1. Measurement results: Laboratory Blackbody

Laboratory……………………………….

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

Time UTC	Blackbody Brightness Temperature K	Bandwidth nm	Std Dev.	Num of Runs	Uncertainty A	% B	Emissivity

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

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

A2. Measurement results: Laboratory: Radiometer

Laboratory…………………………………

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

Time UTC	Wavelength µm	Measured Brightness Temperature K	Bandwidth nm	Std Dev.	Uncertainty A	% B	Number of runs

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

Date: ………………Time (UTC)……………**Signature:**………………………….

A3. Measurement results: Ocean view

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

Wavelength	Brightness Temp Ocean	Std Dev Ocean	Brightness Temp Sky	Std Dev sky	Bandwidth	SST	Num of	Uncertainty SST		View angle from nadir	Time
µm	K	K	K	K	nm	K	Runs	A %	B	Degrees	UTC

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

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

9 Appendix B: Description of Instrumentation and route of traceability

This template should be used as a guide. It is anticipated that many of the questions will require more information than the space allocated.

Make and type of Instrument (Radiometer and/or black body)...

....

Outline Technical description of instrument: *this could be a reference to another document but should include key characteristic: type of detector, spectral selecting component(s), field of view, type of black coating (and its spectral characteristics), model used to determine emissivity, location, number and type of thermometers….* ....

....

....

....

....

....

Establishment or traceability route for primary calibration including date of last realisation and breakdown of uncertainty: *this should include any spectral characterisation of components/instruments*..

....

....

Operational methodology during measurement campaign; *method of alignment, sampling strategy, data processing methods* ....

....

....

Radiometer useage (deployment) (previous use of instrument, locations regularity, and planned applications, if activities have targeted specific mission please indicate………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

....

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

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

10 Appendix C: Uncertainty of measurement

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K
Repeatability of measurement	u_{Repeat}		u_{Repeat}
Reproducibility of measurement	u_{Repro}		u_{Repro}
Stability of source	$u_{Sourcestab}$		$u_{Sourcestab}$
Emissivity		u_{emis}	u_{emis}
BB Thermometer cal		u_{therm}	u_{therm}
BB Isothermal variance		u_{Iso}	u_{Iso}
Primary Source		u_{Prim}	u_{Prim}
RMS total	$((u_{ref})^2+(u_{Trans})^2+(u_{Sourcestab})^2)^{½}$		

The above table is a suggested layout for the presentation of uncertainties for the calibration of blackbodies. It should be noted that some of these component may sub-divide further depending on their origin. For example emissivity may have a modelling term, a measurement term of the coating and/or a measurement term for the cavity as a whole. Similarly the Type A uncertainties here assume that some intermediate radiometer has been used to transfer a scale from a primary black body to this one. If the basis of traceability for this black body is independent in nature then only source stability is likely to be important. In this example it is assumed that the source varies in a random way, if it is more of a drift then a correction can be applied and only the uncertainty in this included here. There will of course be repeatability components etc when used in this comparison but these are part of the comparison and will be added separately and should not be included in this table. In principle this table should exist for each individual wavelength and so any spectral variance should be indicated.

In a similar way the table below is indicative of the uncertainties on a radiometer.

The RMS total refers to the usual expression i.e. square root of the sum of the squares of all the individual uncertainty terms as shown in the example for Type A uncertainties.

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K
Repeatability of measurement	u_{Repeat}		u_{Repeat}
Reproducibility of measurement	u_{Repro}		u_{Repro}
Linearity of radiometer		u_{Lin}	u_{Lin}
Primary calibration		u_{Prim}	u_{Prim}
Drift since calibration		u_{Drift}	u_{Drift}
RMS total	$((u_{ref})^2+(u_{Trans})^2))^{½}$		

11 Appendix D Data receipt confirmation

All data should be sent to the pilot NPL. The details of the contact person for this are:

To: **(participating laboratory, please complete)**

From: **Dr Theo Theocharous**
National Physical Laboratory
Hampton Road
Teddington
Middlesex
United Kingdom
TW11 0LW

Tel: ++44 20 8943 6977
e-mail: theo.theocharous@npl.co.uk

We confirm having received your data resulted from the CEOS key comparison of "techniques/instruments used for surface IR radiance/brightness temperature measurements" on ....(date).

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