Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS) – Ice Surface Temperature Comparison of Participants Radiometers

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Protocol for the FRM4STS LCE (LCE-IP)

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Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS): Ice Surface Temperature Comparison of Participants Radiometers

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Contractor Approval

Name	Role in Project	Signature & Date (dd/mm/yyyy)
Dr Nigel Fox	Technical Leader	
Mr David Gibbs	Project Manager	

CUSTOMER APPROVAL

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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

AMBER	Absolute Measurements of Black-body Emitted Radiance
CEOS	Committee on Earth Observation Satellites
DMI	Danish Meteorological Institute
IST	Ice Surface Temperature
IR	Infra-Red
KIT	Karlsruhe Institute of Meteorology
LST	Land Surface Temperature
NMI	National Metrology Institute
NPL	National Physical Laboratory
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 will have passed and it is considered timely to repeat/update the process. Plans are in place for the comparisons to be repeated in 2016. The 2016 comparison will include:

i. Laboratory comparisons of the radiometers and reference radiance blackbodies of the participants.
ii. Field comparisons of Water Surface Temperature (WST) scheduled to be held at Wraysbury fresh water reservoir, near NPL.
iii. Field comparisons of Land Surface Temperature (LST) scheduled to be held on the NPL campus.
iv. Field comparisons of Land Surface Temperature (LST) scheduled to be held at two sites (Gobabeb Training and Research Centre on the Namib plain and the "Farm Heimat" site in the Kalahari bush) in Namibia in 2016.
v. Field comparisons of Ice Surface Temperature (IST) scheduled to be held in the Arctic during 2016.

This document describes the protocol which is proposed for the Ice Surface Temperature comparisons of the participants' radiometers during the 2016 comparison activities to be held in the Laboratory and on the Sea ice Off Qaanaaq, Greenland. Note that, following an initial review by participants and an assessment of by a number of participants, some of the introductory sections of this protocol will be revised and made more generic to allow the protocol to be a standalone document for future use.

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 Earth's 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) Evaluation of the differences in IR radiometer primary calibrations

a. Reference standards used (blackbodies) and traceability (laboratory based).
b. Radiometers response to common blackbody targets (laboratory based).
c. Evaluation of differences in radiometer response when viewing Water/Land/Ice surface targets, in particular the effects of external environmental conditions such as sky brightness.

2) Establishment of formal traceability for participant blackbodies and radiometers

The purpose of this document is to describe the protocol which is proposed for the Ice Surface Temperature comparisons of the participants' radiometers during the 2016 comparison activities.

3. ORGANIZATION

3.1 PILOT

NPL, the UK national metrology institute (NMI) will serve as pilot for this comparison supported by the PTB, the NMI of Germany. NPL, the pilot, will 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 the report showing results of the comparison to participants.

3.2 PARTICIPANTS

The list of the potential participants, based on current contacts and expectation who will be likely to take part is given in the Section 3.3. Dates for the comparison activities are provided in Section 3.6. A full invitation to the international community through CEOS and other relevant bodies will be carried out to ensure full opportunity and encouragement is provided to all. 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.

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 have been reviewed and agreed, no change to the protocol may be made without prior agreement of all participants. Where required, demonstrable traceability to SI will be obtained through participation of PTB and NPL as pilot.

3.3 PARTICIPANTS' DETAILS

Table 1. Contact Details of Participants

Contact person	Short version	Institute	Contact details
Nigel Fox	NPL	National Physical Laboratory	email: nigel.fox@npl.co.uk; Tel: +44 20 8943 6825
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Jacob Høyer	DMI	Danish Meteorological Institute (DMI), Centre for Ocean and Ice, Lyngbyvej 100, 2100 København Ø	email: jlh@dmi.dk; Tel: +4539157203
Frank Goettsche	KIT	Institute for Meterology and Climate Research (IMK-AF), Kaiserstr. 12, 76131, Karlsruhe, Germany	email: frank.goettsche@kit.edu; +49 721 608-23821
Helen Beggs	Bureau of Meteorology, Australian Govt.	Ocean Modelling Research Team Research and Development Branch Bureau of Meteorology	email: h.beggs@bom.gov.au;

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Leiguan Ouc	OUC-CN	Ocean Remote Sensing Institute Ocean University of China 5 Yushan Road,Qingdao, 266003 China	email: leiguan@ouc.edu.cn
Manuel Arbelo	GOTA	Grupo de Observacion de la Tierra y la Atmosfera (GOTA), ULL, Spain	email.: marbelo@ull.es
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Caroline Sloan	MOD, NAVY SHIPS-HM FEIO	Fleet Environmental Information Officer NAVY SHIPS-HM FEIO | Navy Command Headquarters, MP 2.3, Leach Building, Whale Island, Portsmouth, Hampshire, PO2 8B	Tel: 023 9262 5958 | Mil: 93832 5958; NAVYSHIPS-HMFEIO@mod.uk; caroline.sloan104@mod.uk
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Dr. Frank-M. Goettsche	IMK-FZK	Forschungszentrum Karlsruhe Institute of Meteorology and Climate Research, Atmospheric Trace Gases and Remote Sensing, Meteorological Satellite-Data Analysis, Hermann-von-Helmholtz-Platz 1,	email: frank.goettsche@imk.fzk.de; Tel: +49-(0)7247-82-3821

Contact person	Short version	Institute	Contact details
		76344 Eggenstein-Leopoldshafen Germany	
Peter J Minnett	RSMAS	University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149 USA	email: pminnett@rsmas.miami.edu

3.4 OVERVIEW OF THE FORM OF COMPARISONS

This protocol covers the comparison of the responsivity of the radiometers of participants, when the radiometers are observing a common entity. In the case of the IST comparison activity, the radiometers will be located on the Sea ice off Qaanaaq, Greenland and will be measuring the skin temperature of the snow and sea ice surface.

3.5 COMPARISON OVERVIEW

The ice surface temperature calibration comparison exercise ideally consists of all radiometers simultaneously viewing the same part of the sea ice from racks and scaffolds which are located about 4 to 5 km out on the ice from the coasts, for a variety of view angles: 25, 35º, 45º and 55°. Measurements will be performed during both daytime and night-time conditions.

3.6 TIMETABLE

There are three main phases to the 2016 comparison activity. The first phase prepares for the measurements; the second phase is the execution of the measurements themselves and the third phase is the analysis and report writing.

Table 2. Comparison activity- Phases

PHASE 1: PREPARATION	
Invitation to participate	October 2015
Preparation and formal agreement of protocol	Jan - March 2016
PHASE 2: MEASUREMENTS	
Field comparison experiment	March-April, 2016
Participants measure primary blackbody	June 2016
Comparison of participants' blackbodies	June 2016
Participants send all data and reports to pilot	July 2016
PHASE 3: ANALYSIS AND REPORT WRITING	
Participants send preliminary report of measurement system and uncertainty to pilot and forwarded to all	April 2016
Receipt of comments from participants	May 2016
Draft A (results circulated to participants)	July 2016
Final draft report circulated to participants	August 2016
Draft B submitted to CEOS WGCV	September 2016
Final Report published	October 2016

Table 3 below shows the top-level plan for the comparison activity at NPL during 2016. The first week starting on Monday 20th June 2016 has been allocated to laboratory measurements of the reference blackbody using the participants' radiometers as well as the measurement of the participants' blackbodies using the reference radiometers of NPL and PTB. These measurements are expected to last for the whole of that week.

The second week starting in on Monday 27th June 2016 has been allocated to field measurement of the Water Surface Temperature (WST) of the large water reservoir at Wraysbury, near NPL. Measurements will be done from the platform located in the middle of the reservoir. These measurements are expected to finish by the end of that week (Friday 1st July 2016).

The third and final week of the comparison has been allocated to field measurements of Land Surface Temperature (LST). These will be done at a site on the NPL campus. The plan is to start the LST measurements on Monday 4th July 2016. The LST measurements are expected to finish on Friday 8th July.

This protocol deals with the IST comparison activities which are due to take place in late March, beginning of April, 2016.

Table 3. Comparison Activity Plan

Week No.	Experiment No.	Start Date	End Date	Experiment	Venue
1	1	30 March, 2016	7 April, 2016	Ice Surface Temperature measurement intercomparison of radiometers	Inglefield Bredning, Qaanaaq, Greenland
2	2	20 JUNE 2016	24 JUNE 2016	Laboratory calibration of participants' radiometers against reference blackbody. Simultaneously, laboratory calibration of participants' blackbodies using the NPL AMBER facility and PTB's IR radiometer.	NPL, UK
3	3	27 JUNE 2016	1 JULY 2016	Water surface temperature measurement inter-comparison of participants' radiometers.	Wraysbury reservoir, near NPL, UK
4	4	04 JULY 2016	08 JULY 2016	Land Surface Temperature measurements comparison of radiometers.	Near NPL, UK

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, in this case Greenland/Denmark. 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. DMI can provide some guidance on the local processes needed for this activity. 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. Any queries should be directed to Jacob Høyer at jlh@dmi.dk .

Electrical power (220 V ac) from a mobile generator on the ice, will be available to all participants. In addition, 24 V dc batteries will be available at the site on the ice. Participants who require a 110 V ac supply should provide their own adaptor.

3.8 PRELIMINARY INFORMATION

Three months prior to the start of the comparison participants will be required to supply to the pilot a description of the instrumentation that they will bring to the comparison. This will include any specific operational characteristics where heights/mountings may be critical as well as a full description of its characterisation, traceability and associated uncertainties under both laboratory and field conditions. These uncertainties will be reviewed by NPL for consistency and circulated to all participants for comment and peer review. Submitted uncertainty budgets can be revised as part of this review process but only in the direction to increase the estimate in light of any comments. No reduction will be allowed for the purpose of this comparison but post the comparison process, participants may choose to re-evaluate their uncertainties using methods and knowledge that they may acquire during the review process.

4. MEASUREMENT INSTRUCTIONS

4.1 TRACEABILITY

All participant radiometers 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.

4.2 MEASUREMENT WAVELENGTHS

The comparison will be analysed as a set of 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 comparisons is brightness temperature.

4.4 MEASUREMENT INSTRUCTIONS FOR ISTCOMPARISON

4.4.1 Day-time IST measurements

- The radiometers must have a pre and post deployment calibration/verification in order to demonstrate traceability. The description of each participant's radiometer and its route of traceability should be provided by completing the form shown in Appendix B.

- The radiometers should be mounted securely on a rack or scaffold next to the observation area using an appropriate mounting frame which allows the easy installation and removal of the radiometer. If the radiometer requires alignment within the frame, then alignment marks or a self-aligning frame should be used.

- The radiometers should be mounted in such a way that the ice surface view and the sky view are clear of any physical obstructions as well as exhaust and other effluents.

- Each participant radiometer should be mounted and aligned to view the area of the ice indicated by the pilot. This target location will be chosen to allow comparisons to be made at a range of view angles.

- The radiometers need to have their optical components, such as the mirrors, windows or blackbodies, protected from the environment. This can partially be done using a water and snow-proof enclosure to protect the radiometer components. A better protection is provided by using a rain or snow sensor that can trigger a protective response.

- Under conditions of high wind, the mounting position should be chosen to avoid any snow piles from reaching the radiometer.

- If a radiometer requires specialized wiring to operate (e.g. for real time data transmission), the pilot should be informed early enough so that the required specialized wiring can be installed prior to the beginning of the comparison.

- 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 (Ice and Sky as correction) at time intervals which suit each radiometer. The effective time of each observation should be clearly indicated.

- Measurements can be repeated for different wavelengths.

- The host will collect measurements of meteorological data such as air temperature, in and outgoing radiation, relative humidity and wind speed during the measurement period and make these available to the participants.

- Participants will be encouraged to change viewing angle during the measurements period.

- The view angle from the vertical should be selected to be in the 15^{o} to 55^{o} range. This should prevent the radiometer from viewing reflections from the mounting rack as well as having to deal low ice emissivities which occur for large view angles.

- After completing the above measurement sequence and upon returning to the Qaanaaq settlement, participants will have 3 hours to carry out any necessary post processing e.g. sky brightness correction etc. before submitting final results to the pilot, which will include processed Ice Surface Temperature (IST) values.

- The results should not be discussed with any participant other than the pilot until the pilot gives permission.

- Data should be given to the Pilot on the form given in Appendix A, which will also be available electronically.

4.4.2 Night-time IST measurements

- The same procedure can be used to acquire measurements during night-time.

- Please note that night time measurements will be made under unattended operation of the radiometers.

4.5 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 determined 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 except to the pilot.

The comparison process will continue 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.

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. Example tables corresponding to radiometer uncertainty contributions are given in Appendix C. The participating laboratories should complete this table and 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 $k = 1$. Note this table largely refers to the uncertainties involved in making the measurement during the comparison process, and as such includes the summary result of the instruments primary traceability etc. It is expected that the uncertainty associated with the full characterisation of the instrument will be presented in a separate document and evaluated as part of the laboratory comparison. Any corrections due to potential biases from this exercise will be evaluated in the final report. Guidance on establishing such uncertainty budgets can be obtained by review of the NPL training guide which can be found at http://www.emceoc.org/documents/uaeo-int-trg-course.pdf.

5.1 TYPE A UNCERTAINTY CONTRIBUTIONS

5.1.1 Repeatability of measurement

This describes the repeatability of measurement process without re-alignment of the participants’ radiometer. 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 it is the standard deviation of a single set of measurements made on the reference standard. This should be presented as a relative quantity.

5.1.2 Reproducibility of measurement

This describes the 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.

5.2 TYPE B UNCERTAINTY CONTRIBUTIONS

5.2.1 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 should be attached.

5.2.2 Wavelength

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

5.2.3 ICE and snow emissivity

This uncertainty contribution arises due to the uncertainty in the knowledge of the emissivity of the snow and ice at the appropriate wavelength.

5.2.4 Angle of view to nadir (angle of incidence)

The snow and ice emissivity decreases as the angle of incidence increases, hence any uncertainty in the angle of incidence will manifest as an uncertainty in the emissivity of the snow and ice.

5.2.5 Drift in the radiometer responsivity.

The responsivity of all instruments is known to change with time. The responsivity of a radiometer is expected to drift since it was last calibrated. The amount of drift in the responsivity of the radiometer should be quantified and used to introduce an uncertainty contribution due to this drift in the uncertainty budget.

5.2.6 Ambient temperature/relative humidity fluctuations

Changes in ambient temperature can affect the output of a radiometer as well as the transmittance of the atmosphere. Although corrections can be added to account for the fluctuations in the ambient temperature, an uncertainty is also required to account for the uncertainty of the corrections. Similarly changes in the atmospheric humidity can affect the responsivity of the radiometer as well as the transmittance of the atmosphere at the operating wavelength, hence an uncertainty contribution is also required in the uncertainty budget to account for this effect.

6. REPORTING OF RESULTS

On completion of the acquisition of measurements, as indicated above, they should be reported to the pilot. Where possible, these should be sent in electronic form as well as hard copy at the time of the comparison. In this way any immediate anomalies can be identified and potentially corrected during the course of the comparison, whilst still keeping results blind.

The measurement results are to be supplied in the Template provided by the pilot laboratory at the beginning of the IST comparison (see Appendix A for the Templates for reporting the results of the radiometer IST field comparisons). The measurement results should also be provided in an Excel format. 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.

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 of the report will be acknowledged using the form shown in 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, ideally during the course of the comparison, 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 will be sent to all participants. 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.

7. COMPARISON ANALYSIS

Each comparison will be analysed by the pilot according to the procedures outlined in QA4EO-CEOS-DQK-004. In every case, analysis will be carried out based solely on results declared by each participant.

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.

8. REFERENCES

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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.

APPENDIX A: REPORTING OF MEASUREMENT RESULTS

The attached measurement summary should be completed by each participant for each completed set of IST field 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. A separate measurement sheet should also be completed if a different view angle from nadir, or a different wavelength or bandwidth is used by the same radiometer.

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

Time	The time of the measurements should be UTC.
Measured Ice Surface Temperature	Brightness temperature measured or predicted by participant.
Measurement uncertainty	Combined/total uncertainty of the measurement.
Measured Sky Temperature	Brightness sky temperature measured or predicted by participant.
Uncertainty	The total uncertainty of the measurement of brightness temperature separated into Type A and Type B. The values should be given for a coverage factor of k=1.
Wavelength	This describes the assigned centre wavelength used for the measured brightness temperature. For the case of Fourier Transform spectrometers, the wavelength range and wavelength resolution should be specified.
Bandwidth	This is the spectral bandwidth of the instrument used for the comparison, defined as the Full Width at Half the Maximum.
Standard 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 standard deviation.
View angle from Nadir	The angle of view of the radiometer to the surface of the ice from Nadir.

IST Measurement Results at Inglefield Bredning, off Qaanaaq, Greenland

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

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

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

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

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

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

APPENDIX B: DESCRIPTION OF RADIOMETER 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 Radiometer ....

....

Outline technical description of instrument: *this could be a reference to another document but should include key characteristics for radiometers such as type of detector used, spectral selecting component(s), field of view etc.:* ....

....

....

....

....

....

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

....

....

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

....

....

Radiometer usage (deployment), previous use of instrument and planned applications. If activities have targeted specific mission please indicate: ....

....

....

....

....

....

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

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

APPENDIX C: UNCERTAINTY CONTRIBUTIONS ASSOCIATED WITH IST MEASUREMENTS AT INGLEFIELD BREDNING, OFF QAANAAQ, GREENLAND

The table shown below is a suggested layout for the presentation of uncertainties for the measurement of the IST at Inglefield Bredning off Qaanaaq, Greenland. It should be noted that some of these components may sub-divide further depending on their origin. 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.

Uncertainty Contribution	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}
Primary calibration		U_{Prim}	U_{Prim}
Ice/snow emissivity		U_{emiss}	U_{emiss}
Ice/snow 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	$((U_{repeat})^2+(U_{Repro})^2))^{½}$		

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 that we have received your data which resulted from the CEOS key comparison of "techniques/instruments used for surface IR radiance/brightness temperature measurements" on ....(date).

....
....
....

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

-END OF DOCUMENT-