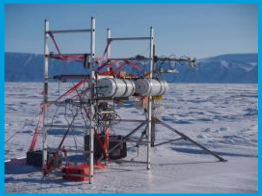
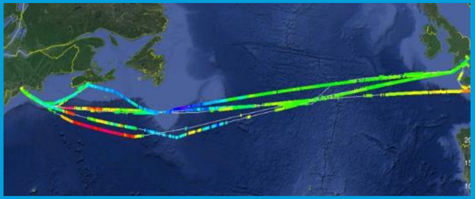
NPL National Physical Laboratory | Centre for Carbon Measurement

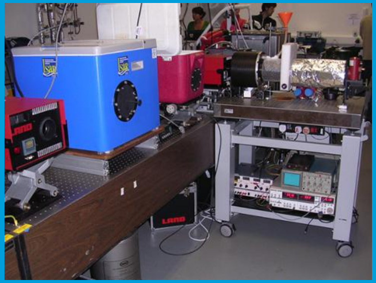
Supporting climate research and a low carbon future

Fiducial Reference Measurements For validation of Surface Temperature of Satellites (FRM4STS)





Dr Nigel Fox (project Lead)
Head of Science EO, Climate & Optical



fiducial reference temperature measurements

PTB

KIT Karlsruhe Institute of Technology

CEOS

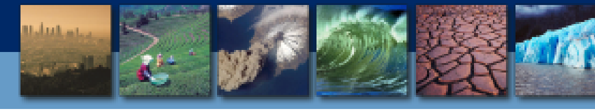
DMI

Science & Technology Facilities Council

DML DAVID MELDRUM LTD

University of Southampton

Project 1: SST/LST Comparison Campaign



Cal/Val sensor comparison campaign in support of SST and LST measurements from space (support action for VC-SST and WGC)

(follows similar highly successful Tuz Golu campaign for surface reflectance and Miami 3 (2009) for SST (10 global participants) using QA4EO guidelines

Proposal

4th of ~5 yearly ('Miami' 1,2,3) WGCV comparisons for radiometers including black bodies

- **Phase1 (2014-2015): Laboratory based vs. SI traceable standards (radiometers and black bodies) (Land and Ocean applications)**
- **Phase 2A (2014 – 2018): Series of ship/ocean based radiometer campaigns**
- **Phase 2B (2015 – 2017): Field-based calibration of radiometers**
- **Participation open to all**

Background

- **Essential Climate Variables Sea Surface Temperature (SST) and Land Surface Temperature (LST) are both dependent on global satellite observations of surface emitted thermal radiation**
    - **Heritage long-time series of data from multiple sensors exists**
    - **New sensors soon to be launched e.g. Sentinel 3, JPSS-1**
- **International comparisons are essential to provide confidence in data, test innovation and facilitate capacity building and training**

Project 1: SST Comparison Campaign

- **ESA have agreed to provide funding to support the organisation, logistics and analysis of the comparison (For all phases 1 through to 2B)**

  It will require:

  - CEOS member agencies to support the participation (travel/subsistence ~2-3 wks to UK) and instruments transport of appropriate Cal/Val teams from their region of influence.
  - For Phase 2A, this will require radiometers to be deployed on ships for a few months (no cost for ship but for radiometer transport).
  - For Phase 2B, this will require support for radiometers and personnel (travel/subsistence ~2 wks) for appropriate teams from their region of influence to be deployed) to a field-site potentially in Namibia.

- **Benefits to CEOS agencies:**
  - Knowledge to remove and correct instrument biases enabling harmonised global satellite Cal/Val
  - Potential to learn and improve from peer interactions
  - Establishment of best-practises for instrument and product Cal & Val

Project 2: SST (pilot) 'Operational Validation Project' Proposal

Background:

- For SST validation (Operational and Climate) require network of high performance drifting Ocean Buoys for continuous monitoring of Ocean Temps, in addition to Ship borne radiometers analogous to 'test-sites' such as Aeronet and new LandNET
  - Key part of strategy to bridge 'data gaps' between sensors for climate
  - White paper drafted by VC-SST, GHRSST, WGCV-IVOS detailing background available
  - Existing networks not sufficient in number for necessary coverage

Request to agencies

- Agency (or group of) to provide resources to launch a set of high performance well-calibrated SI traceable drifting Ocean Buoys as an initial demonstration pilot project. Buoys can be built nationally to meet community defined specification
- Agencies to allocate resources to continue and where possible extend number of ocean borne radiometer cruises for SST validation - independent of specific satellite missions to facilitate improved management of 'data gaps' between missions for Climate.

QA4EO
A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

- The Quality Assurance framework for Earth Observation (QA4EO)
- Looks to make the GUM accessible to the EO community

Community-specific guidelines Click to close

QA4EO Principle:
'All data and derived products shall have associated with them a fully traceable indicator of their quality', documented and quantitatively tied to an international standard ideally SI

Identifier	Description
QA4 CLP	
QA4 CLP	
QA4 CLP	
QA4 CLP	
QA4 CLP-005	applications
QA4EO-WGCV-IVO-CLP-006	Methodologies that should be applied to determine immersion factors for both radiance and irradiance underwater sensors
QA4EO-WGCV-IVO-CLP-007	Absolute Calibration using Rayleigh Scattering
QA4EO-WGCV-IVO-CLP-008	Protocol for the CEOS WGCV pilot Comparison of techniques/instruments used for vicarious calibration of land surface imaging through a ground reference standard test site

Fiducial Reference measurements (FRMs)

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What are Fiducial Reference Measurements?

"The suite of independent ground measurements that provide the maximum return on investment for a satellite mission by delivering, to users, the required confidence in data products, in the form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission" (Sentinel-3 Validation Team)

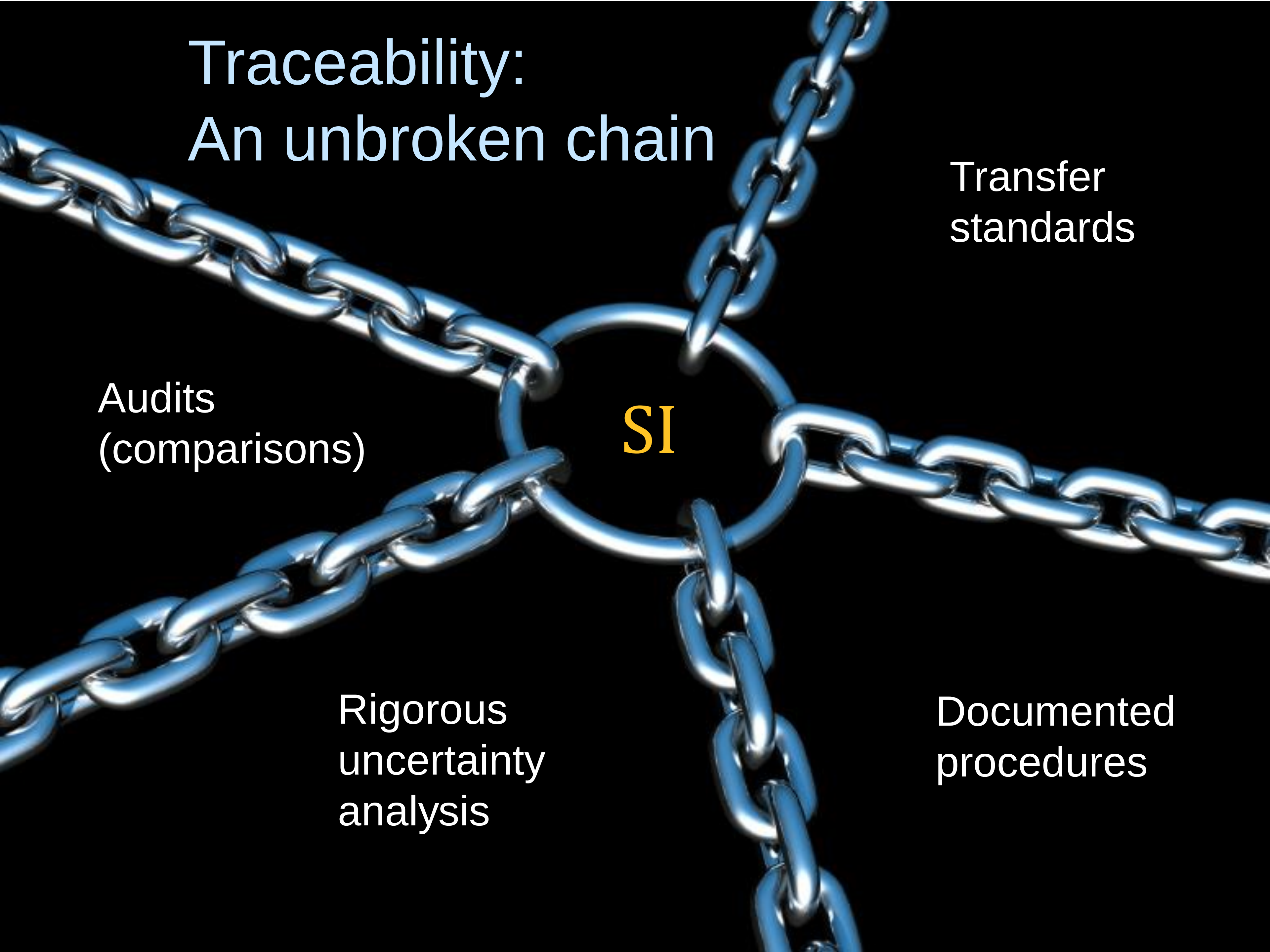
An FRM must:

- Have documented evidence of its degree of consistency for its traceability to SI through the results of round robin inter-comparisons and calibrations using formal metrology standards
- Be independent from the satellite geophysical retrieval process
- Have a detailed uncertainty budget for the instrumentation and measurement process for the range of conditions it is used over.
- Adhere to community agreed measurement protocols, and management practises.

& have Uc levels fit for the application they are used for

esa

Traceability: An unbroken chain



Importance of comparisons

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Need for comparisons:

- Must be blind with open and unconstrained reporting of result (even if cause of any error identified, unless not due to participant).
- Should be established to evaluate range of quantity being measured, its potential operational environment, and not bias any method/sensor.
- Provide the means to identify biases and unknown unknowns
- An independent validation of estimated uncertainties of instrument and its use
- A check on robustness of methods to use instrument
- Evaluation of 'state of the art' of community
- If includes references which are a-priori higher accuracy and SI traceable (ideally primary standards of an NMI) it establishes consistency with 'truth'
- Enables participants to learn from each other in terms of uncertainty evaluation and enable peer based challenge where significant variances exist.
- Gives confidence to participants and their users of the quality of their data.

Use guidance and best practises of NMIs

FRM4STS.org

The home for surface T validation info

fiducial reference temperature measurements

Home | News | About | Project Documents | Data Resources | Activities | International Workshop | Contact | Drifter SST Measurements

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Home

Project Documents

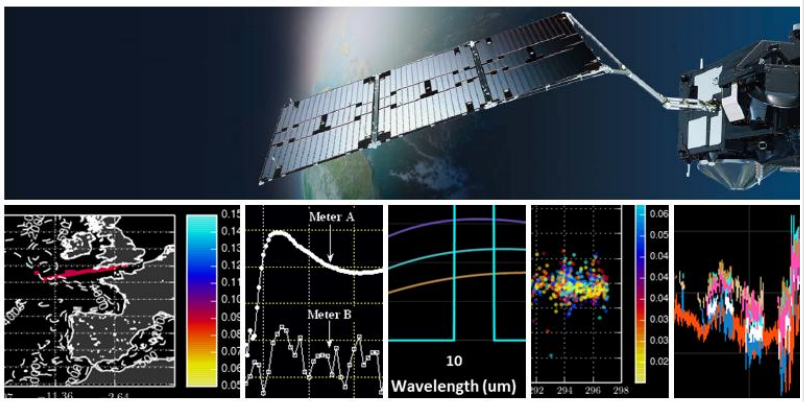
Deliverable documents

This section of the page corresponds to the FRM4STS Statement of Work. For other documents such as **Guides**, **Protocols**, **Papers**, **Meetings**, **Presentations** and **Posters** – please scroll further down the page.

Ref	Deliverable title and description
D-10	FRM4STS Directory
D-20	FRM4STS web portal
D-30	Project Brochure
D-40	High quality graphics (FIG) that can be used by the FRM4STS project and ESA to promote the outcomes of the project throughout the project.
D-50	Web Stories for the project and ESA web site based on the activities of the project
D-60	Preparation and submission of at least one peer review journal article based on the project results.
D-80	Technical Report 1: "Procedures and Protocols for the verification of TIR FRM Field Radiometers and Reference Blackbody Calibrators"
D-90	Implementation plan for the FRM4STS LCE
D-100	Technical Report 2: "Results from the 4th CEOS TIR FRM Field Radiometer Laboratory Inter-comparison Exercise" • Part 1 of 4: Blackbody laboratory comparison • Part 2 of 4: Laboratory comparison of radiation thermometers • Part 3 of 4: Water surface temperature comparison of radiation thermometers • Part 4 of 4: Land surface temperature comparison of radiation thermometers
D-110	Archive of FRM TIR radiometer calibration and verification data
D-120	Technical Report (TR-3) "A Framework to Verify the Field Performance of TIR FRM"

Home › FRM4STS – Results Database

FRM4STS – Results Database



The database will be divided by the main project phases which will initially be populated from the results of the current round o… below:

- Phase 1: Laboratory Intercomparison
- Phase 2A: Shipborne Comparison
- Phase 2B: Land Surface Temperature
- Phase 2C: Ice Surface Temperature – data available
- Non-Recoverable IST Observations – data available

fiducial reference temperature measurements

NPL esa DML KIT PTB CEOS

Protocols for traceability and comparisons

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

Technical Report 1
Procedures and Protocols for the verification of TIR FRM Field Radiometers and Reference Blackbody Calibrators

ESA Contract No. 4000113848_15I-LG

Evangelos Theocharous, NPL
Nigel Fox, NPL
Frank Göttsche, KIT
Jacob L. Høyer, DMI
Werenfred Wimmer, Soton
Tim Nightingale, STFC

Contents:- 10 individual protocols

- How to establish and maintain traceability for: land, Ocean and Ice radiometric validation measurements
  - Developed by world experts

- Comparison protocols for laboratory: radiometers, blackbodies
- “ “ for water bodies
  for land surfaces
  for Ice
  for on-board ships
  for Land campaigns

Include templates for Uc etc

Uncertainty budgets developed for each radiometer

Uncertainty Contribution	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K
Repeatability of measurement	0.12		0.024
Reproducibility of measurement	0.12		0.024
Primary calibration		0.250 K	0.250
Linearity of radiometer		0.070 K	0.070
Drift since calibration		0.176 K	0.176
Temperature resolution		0.050 K	0.050
Ambient temperature fluctuations		0.035 K	0.035
Atmospheric absorption/emission		0.035 K	0.035
RMS total	0.173		0.323

Uncertainty Contribution	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K	Comment (D. Osterman, 090916)
Repeatability of measurement	U_{Repeat}		0.095	Lab calibration 08/10/16
Repeatability of measurement	U_{Repro}		0.19	Lab calibrations 07/27/16 and 08/10/16
Primary calibration temperature		U_{prim}	0.086 (10 °C) 0.064 (20 °C) 0.086 (30 °C) 0.160 (45 °C)	Electro-Optical Industries CES 200-04-MG; combines temperature accuracy, stability, uniformity
Primary calibration emissivity		+/-0.004 (emissivity)	0.44 (10 °C) 0.46 (20 °C) 0.50 (30 °C) 0.54 (45 °C)	Electro-Optical Industries CES 200-04-MG
Linearity of radiometer		U_{Lin}	0.29 (10 °C) 0.14 (20 °C) 0.15 (30 °C) 0.03 (45 °C)	Deviation from best fit line to 08/10/16 lab measurements, 12 ºC to 45 ºC
Drift since calibration		0	0	Accounted for in reproducibility
Ambient temperature fluctuations		1.67 (ºC room temp pk-pk)	0.08	Assume max ambient temperature pk-pk fluctuation 3 F = 1.67 ºC
Atmospheric absorption/emission		0	0	Negligible absorption in 38 mm path length
RMS Total			**0.59 (10 °C) 0.54 (20 °C) 0.58 (30 °C) 0.63 (45 °C)**	

- Still work to be done! Improved from Miami 3
- Training given & desire to move forward
- More case studies required particularly in Uc related to use

SI traceability: LCE (June 2016)

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

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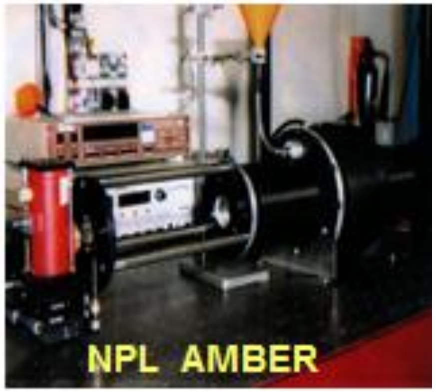
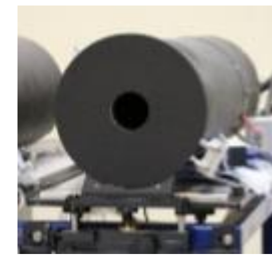


ITS-90

T= ~250 – 325 K
Non-vacuum

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

fiducial reference temperature measurements

Room Environment with variable T

BB comparison (June 2016)

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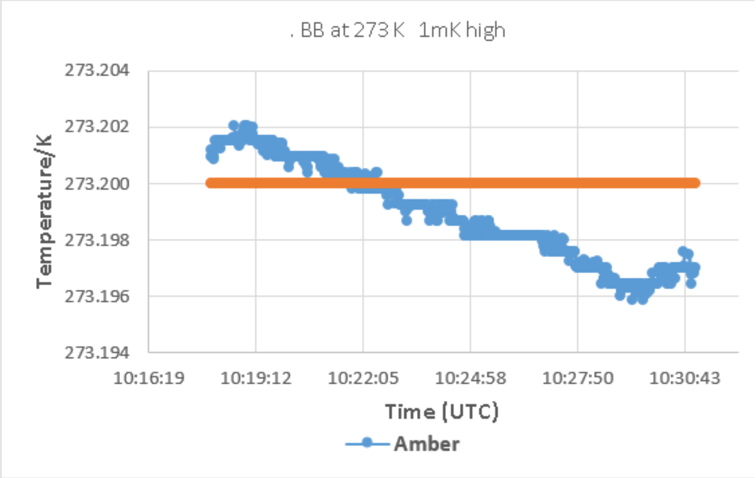
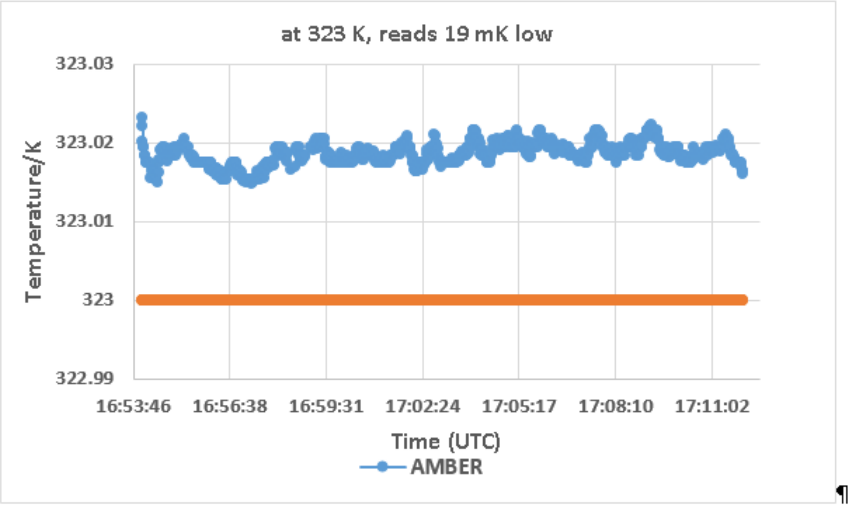
1. Miami University - USA
2. ONERA - France
3. University of Valencia- Spain
4. University of Southampton - UK
5. Qing Dao -China
6. RAL - UK
7. CSIRO - Australia
8. KIT- Germany

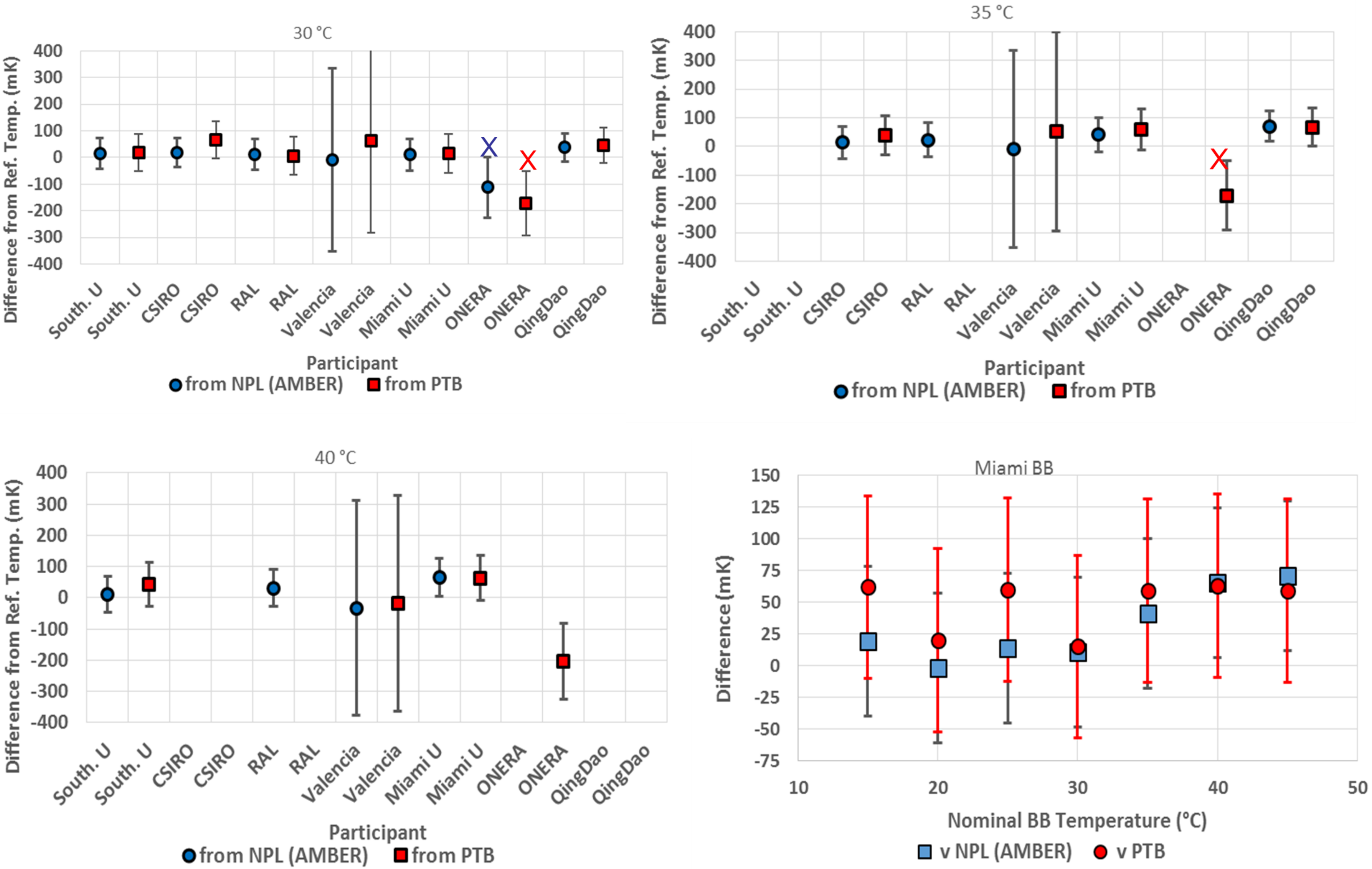
273 K to 323 K (0 to 50 °C)





fiducial reference temperature measurements

Difference of Participant BB T from NPL AMBER (blue) and PTB (Red)



2016 Radiometer comparison

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National Physical Laboratory

1. Miami University (USA)
2. ONERA (France)
3. University of Valencia (Spain)
4. University of Southampton (UK)
5. Qing Dao (China) -1
6. Qing Dao (China) -2
7. RAL (UK)
8. CSIRO (Australia)
9. KIT (Germany)
10. DMI (Denmark)
11. GOTA (Canary Islands
12. JPL NASA (USA)
13. Ian Barton (Australia)

240 K to 318 K

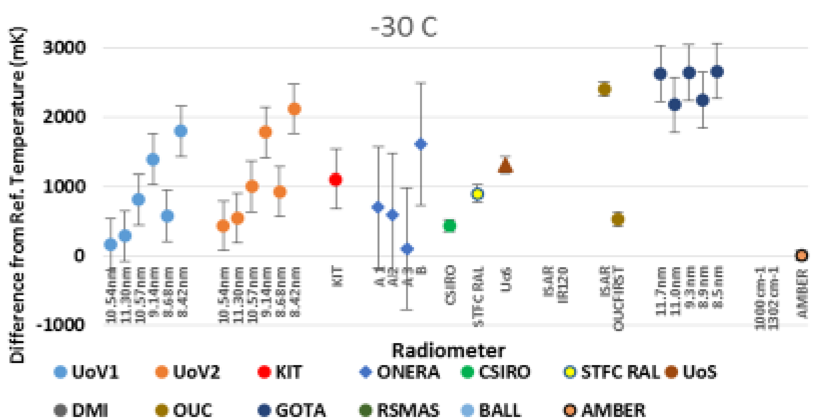
MAERI (UofM) viewing NPL ammonia Heat pipe

SISTER (RAL) viewing NPL ammonia Heat pipe

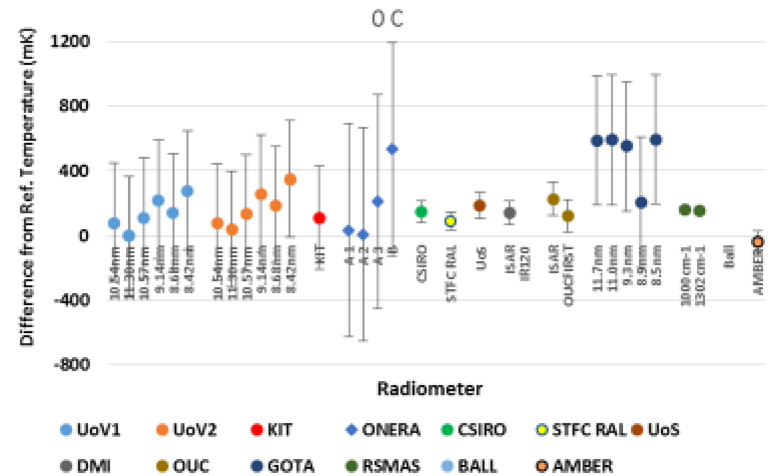
Selection of Results of Lab Radiometer comparison to SI

National Physical Laboratory

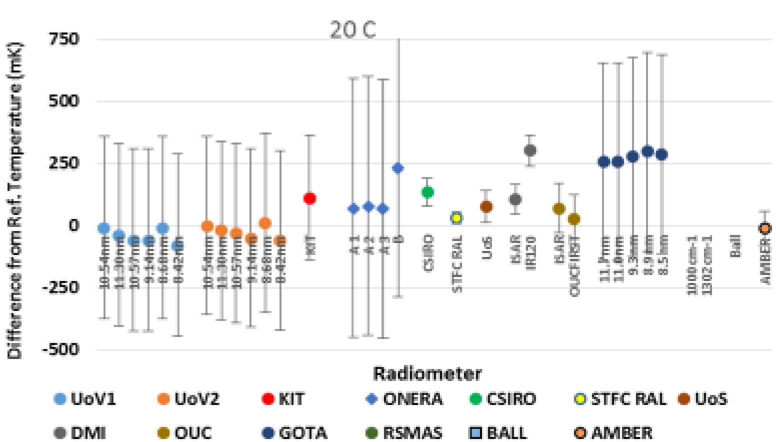
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of -30°C.



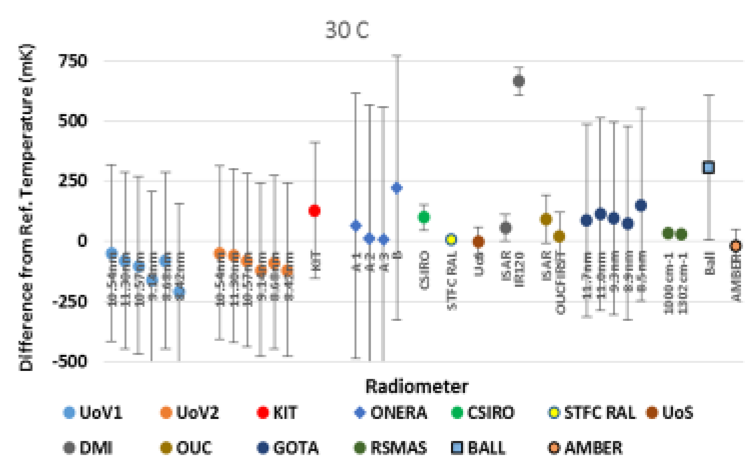
Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 0°C.



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



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

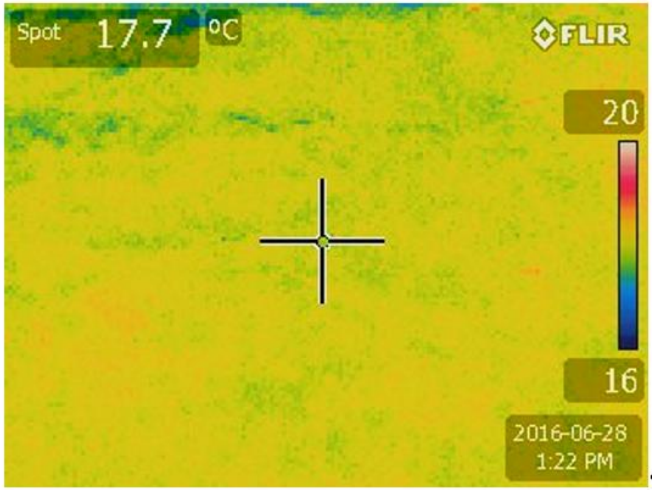


WST comparison

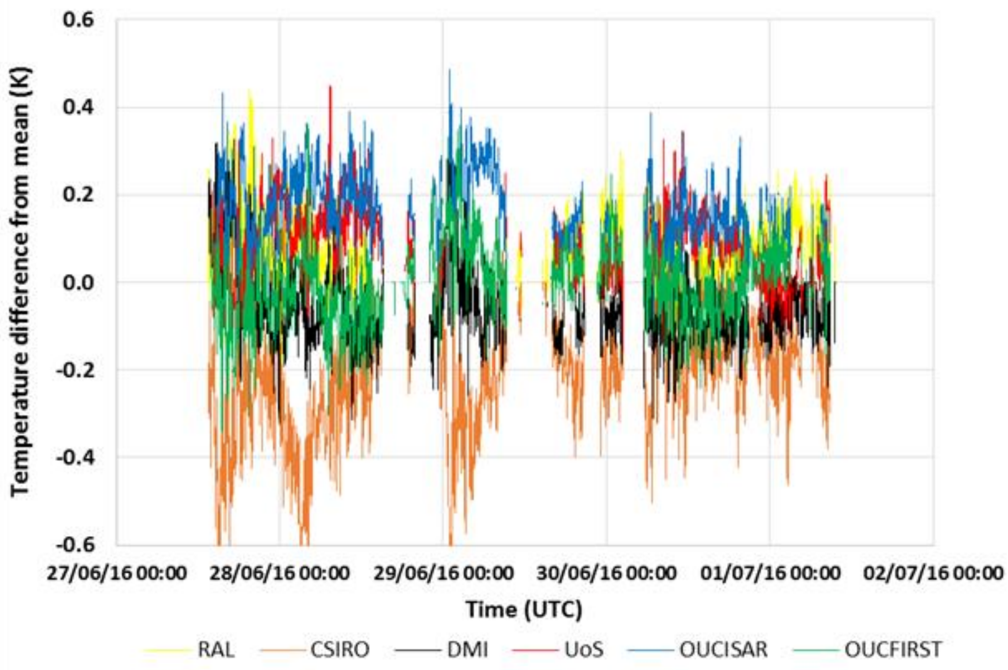
1. University of Valencia (Spain)
2. University of Southampton (UK)
3. Qing Dao (China) -1
4. Qing Dao (China) -2
5. RAL (UK)
6. CSIRO (Australia)
7. KIT (Germany)
8. DMI (Denmark)
9. GOTA (Canary Islands)
10. JPL NASA (USA)

Day & night measurements

Vagaries of UK weather!



Difference from mean for SST designed radiometers only



	mean difference from mean (°C)		
Radiometer	All radiometers Included °C	SST-Measuring Radiometers Only °C	SST-Measuring Radiometers excl. CSIRO °C
RAL	0.123	0.084	0.037
KIT	-0.159		
CSIRO	-0.189	-0.228	
DMI	-0.020	-0.053	-0.106
UoV	0.117		
UoS	0.125	0.090	0.044
OUCFIRST	0.033	-0.002	-0.054
OUC-ISAR	0.206	0.174	0.119
GOTA	0.593		
JPL	-0.109		

fiducial reference temperature measurements

Technical Report 2: Results of 'lab' comparisons

NPL National Physical Laboratory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Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS)

ESA Contract No. 4000113848_15I-LG

D100 - Technical Report 2: Results from the 4
CEOS TIR FRM Field Radiometer
Laboratory Inter-comparison Exercise

Part 1 of 4: Blackbody laboratory comparison

JUNE 2017

Reference	OFE-D100(Part 1)-V1-Iss-1-Ver-1-Draft
Issue	1
Revision	1
Date of Issue	23 June 2017
Document Type	TR-2

Approval/Acceptance

ESA Craig Donlon Technical Officer — Signature

NPL Andrew Brown Project Manager — Signature

NPL - Commercial


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

ESA Contract No. 4000113848_15I-LG

D100 - Technical Report 2: Results from the 4th CEOS TIR FRM Field Radiometer Laboratory Inter-comparison Exercise

Part 2 of 4: Laboratory comparison of radiation thermometers

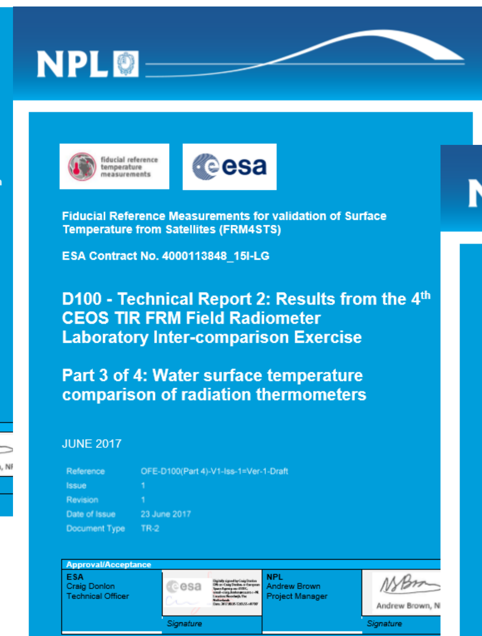
JUNE 2017

Reference	OFE-D100(Part 2)-V1-Iss-1-Ver-1-Draft
Issue	1
Revision	1
Date of Issue	23 June 2017
Document Type	TR-2

Approval/Acceptance

ESA Craig Donlon Technical Officer — Signature

NPL Andrew Brown Project Manager — Signature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Fiducial Reference Measurements for validation of Surface Temperature from Satellites (FRM4STS)

ESA Contract No. 4000113848_15I-LG

D100 - Technical Report 2: Results from the 4th CEOS TIR FRM Field Radiometer Laboratory Inter-comparison Exercise

Part 3 of 4: Water surface temperature comparison of radiation thermometers

JUNE 2017

Reference	OFE-D100(Part 4)-V1-Iss-1=Ver-1-Draft
Issue	1
Revision	1
Date of Issue	23 June 2017
Document Type	TR-2

Approval/Acceptance

ESA Craig Donlon Technical Officer — Signature

NPL Andrew Brown Project Manager — Signature


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

ESA Contract No. 4000113848_15I-LG

D100 - Technical Report 2: Results from the 4th CEOS TIR FRM Field Radiometer Laboratory Inter-comparison Exercise

Part 4 of 4: Land surface temperature comparison of radiation thermometers

JUNE 2017

Reference	OFE-D100(Part 4)-V1-Iss-1-Ver-1-Draft
Issue	1
Revision	1
Date of Issue	22 September 2017
Document Type	TR-2

Approval/Acceptance

ESA Craig Donlon Technical Officer — Signature

NPL Andrew Brown Project Manager — Signature

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4 peer review pubs submitted

International workshop of Experts Oct 16-18 2017 @ NPL, UK

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DRAFT

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

ESA Contract No. 4000113848_15I-LG

FRM4STS International Workshop: Fiducial Reference Measurements (FRM) for satellite derived surface temperature product validation

Nigel Fox

DECEMBER 2017

Reference	OFE-D160/170 -V1-Iss-1-Ver-1
Issue	1
Revision	3
Date of Issue	14 DECEMBER 2017
Status	DRAFT
Document Type	FRM4STS International Workshop Report

---------Page Break---------

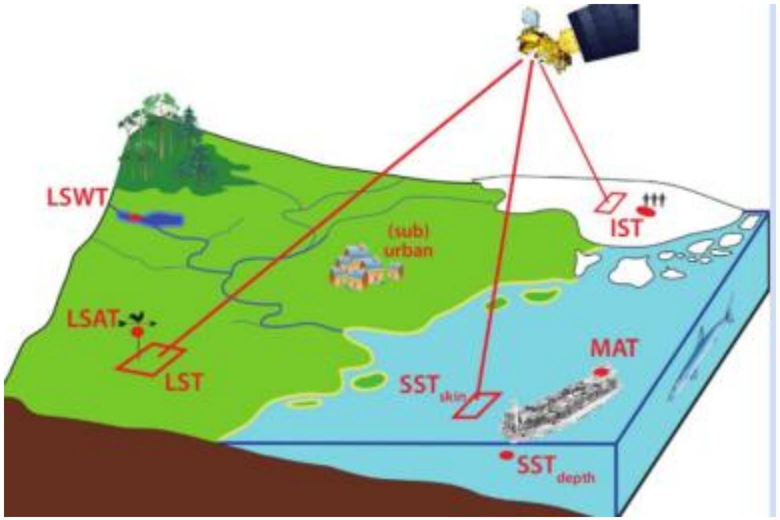
- 40 + experts from across the globe (land, Ocean, Ice
- Invited scoping presentations
- Facilitated discussion - recommendations and priorities

fiducial reference temperature measurements

Some Key Recommendations

National Physical Laboratory

- **FRMs should be encouraged need more sites, more match-ups and more comparisons**
  - **Super-sites with WMO? particularly over land (also urban, mountains. Polar …)**



- **Research to look at scaling – point to satellite, heterogeneity, global representativeness**
- **Research to look at effects of T skin to depth – water, snow, Ice**
- **Training / Case studies on Uc estimation and analysis + good practice guides on measurements and instruments**
- **Comparisons designed to account for operational conditions (low/high ambient T)**
  - **Ship based multi laterals for oceans**
- **Cloud detection/masking (day/night) Satellite and Validation**

Some Key Recommendations

- **Link Satellites to Validation – compare traceability and reference standards (not rely on models)**
- **Compare retrieval algorithms (using standardised data)**
- **More (traceable Buoys) consider triple sensors for redundancy, recoverability?**
- **Look for synergy in other observations e.g. passive microwave and IR uld be encouraged need more sites, more match-ups and more comparisons**
  - **Super-sites with WMO? particularly over land (also urban, mountains. Polar …)**

Science Drivers Recommendations: Ocean

From KENT (BAMS 2017)

- Add more data and metadata to ICOADS
- Reprocess existing ICOADS records
- Improve information on observational methods.
- Improve physical models of SST bias.
- Improve statistical models of SST bias.
- Maintain and extend the range of different estimates of SST bias
- Expand data sources for validation and extend use of measures of internal consistency in validation.

Which require:

- Quantified fully broken down uncertainties and sources of error in respect to SI (traceability)
  -With validated detail on their std deviations. Correlations, distributions, stabilities
- The means to propagate information (including uncertainties) to all spatial and temporal scales (particularly from point samples to satellite pixels)
- Documented statement of limitations of use/analysis
- Depth models

Roadmap: Oceans priorities

Imp				
ACTIVITY/REQUIREMENT	**JUSTIFICATION/COMMENTS**	**Impact**	**DEGREE OF DIFFICULTY**	
DV Model Verification / Validation	• Useful for historical analysis • New buoys with depth	5	5	CEOS WGCV
Study sampling errors	• Historical use • Find historic minimum • Plan future deployment	4	3	XXXXX CEOS GHRSST
Additional buoy development for passive microwave		5	5	DBCP GHRSST
Sampling of coastal variability		5	5 Political geophysical small scale	APRS WMO CEOS CEMS
Improve buoy technology		5	3	DBCP
• Algorithm round-robin including cloud mask • Generate validation dataset		4	2	GHRSST
Traceability of validation data, require subset to BF traceability		5	4	CEOS FRM

Conclusion

- Concept of FRMs encouraging good practise
- Comparisons key to ensure robustness
  - Important results are transparent
- International consistency in ‘controlled’ conditions good
  - Still work to evaluate extremes of observations
- Training still needed in Uncertainty evaluation
- More specific comparisons tailored to real world observation conditions to be encouraged
- Start planning for next CEOS comparison (2020/21)