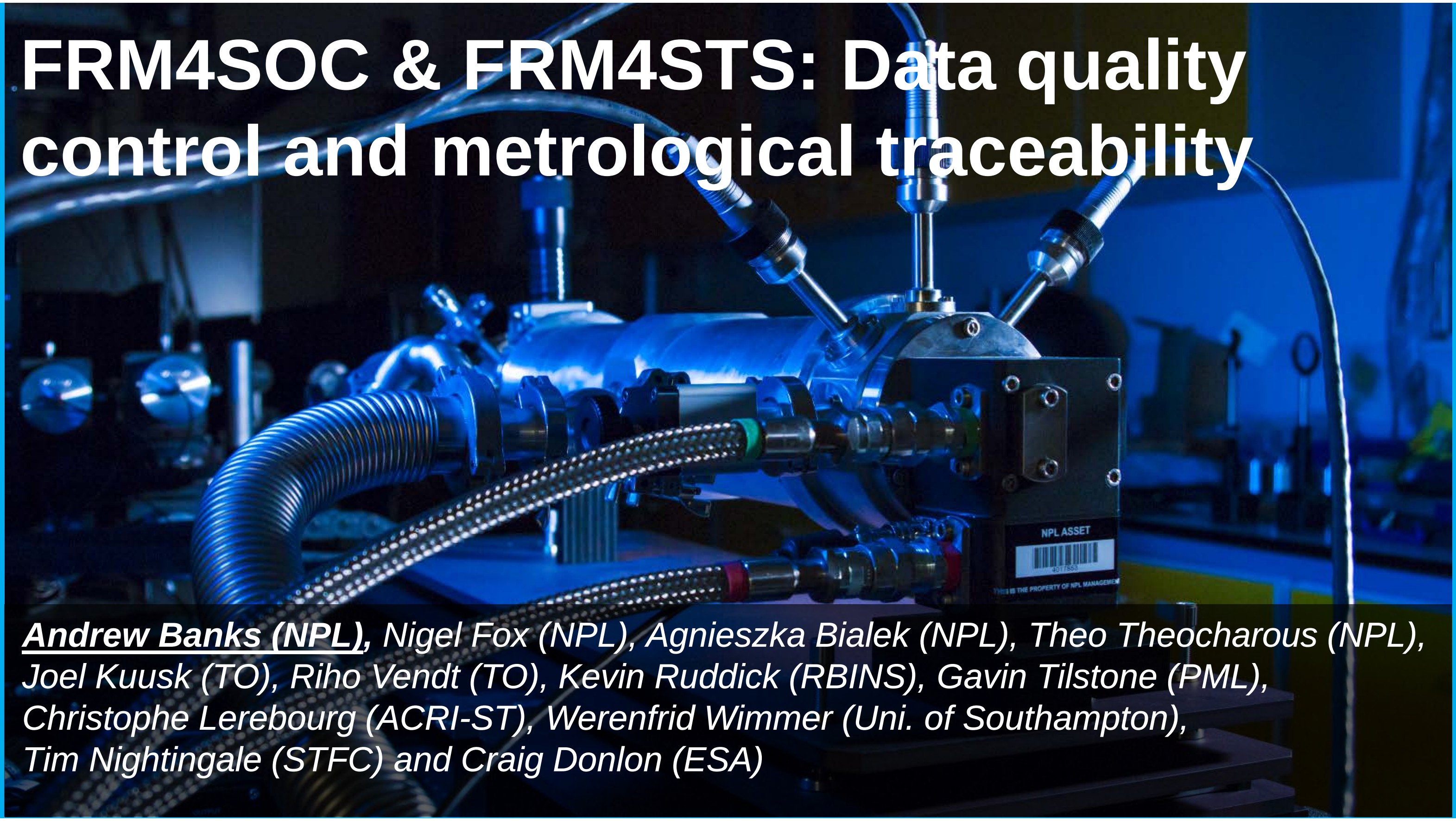

FRM4SOC & FRM4STS: Data quality control and metrological traceability

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fiducial reference measurements for satellite ocean colour

fiducial reference temperature measurements

Summary of the presentation

1. Context

- Fiducial Reference Measurements (FRM)
- Metrological foundation

2. The FRM4SOC Project

- Project outline
- Data quality and metrological traceability

3. The FRM4STS Project

- Project outline
- Data quality and metrological traceability

1. Context

Fiducial Reference Measurements (FRM) are a suite of independent, fully characterized, and traceable ground measurements that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO)

fi·du·cial (adj) *Regarded or employed as a standard of reference, as in surveying*
`[Late Latin fiducialis, equivalent to fidi(a) trust, from fidere, to trust.]`

fiducial reference measurements for satellite ocean colour

BOUSSOLE
Buoy for the acquisition of long-term optical time series

fiducial reference temperature measurements

FIDUCIAL REFERENCE MEASUREMENTS FOR ALTIMETRY
FRM4ALT

Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations
FRM4DOAS

Fiducial Reference Measurements for Greenhouse Gases

pandonia

FRM4ALT COASTAL
FIDUCIAL REFERENCE MEASUREMENTS FOR ALTIMETRY

FRM4VEG

1. Context:

Metrological Foundation – key terminology (simplified)

Metrological Traceability: *property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty* (*Vocabulary International Metrology (VIM ISO guide 99)*)

- **Error –** **difference from a "true" value or a "bias" that can often be corrected for.**
- **Uncertainty –** **how well we believe we know the value**
  - **"Type A" or random** – **statistically determinable by experiment**
  - **"Type B" –** **any other means of estimating uncertainty (can be educated guess)**
- **Quality Indicator (QI) –** **an indicator of performance or quality of the result of a process/activity derived from an uncertainty estimate but can be a text descriptor / flag / numeric value. Can be binary**
- **Traceability (document link)** **– Archived and accessible, complete documentary linkage of all steps in a process chain tied to a result**
- **Standard (reference)** **– "reference" against which performance can be determined**

1. Context:
Metrological Foundation - Uncertainty

National Physical Laboratory

- **Follow the GUM – Guide to the expression of Uncertainty in Measurement**
  - ✓ The foremost authority and guide to the expression and calculation of uncertainty in measurement science
  - ✓ Written by the JCGM and BIPM (NPL input)

http://www.bipm.org/en/publications/guides/gum.html

- **Law of propagation of uncertainties**

$$u_c^2(y) = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i) + 2\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \frac{\partial f}{\partial x_i} \frac{\partial f}{\partial x_j} u(x_i, x_j)$$

Adding in quadrature

Sensitivity coefficient times uncertainty

Correlation term

Sensitivity coefficients times covariance

$u(a,b) = u(b,a)$

2 because symmetrical:

N.B. Can be done analytically or using Monte Carlo analysis

1. Context: Metrological Foundation

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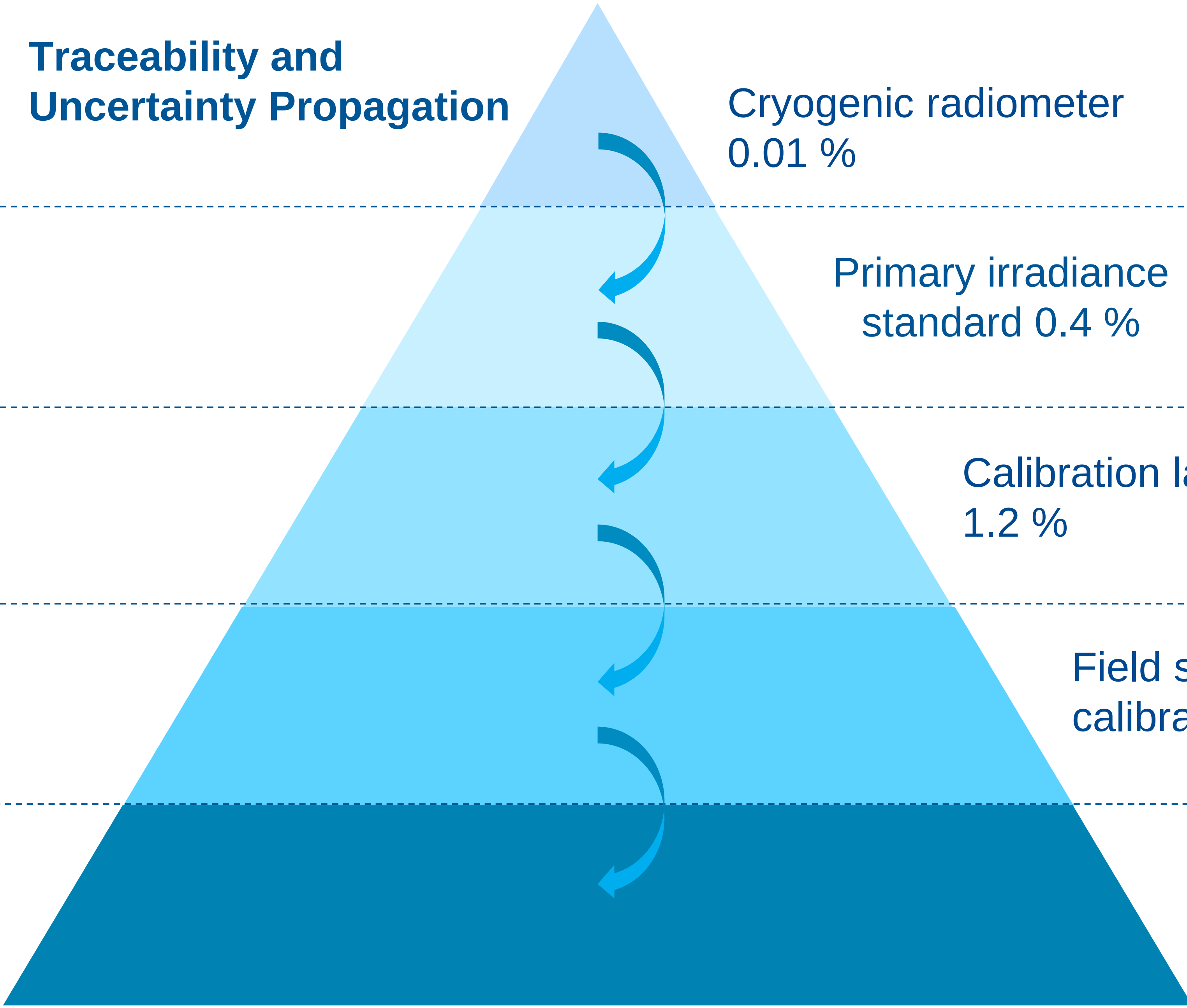
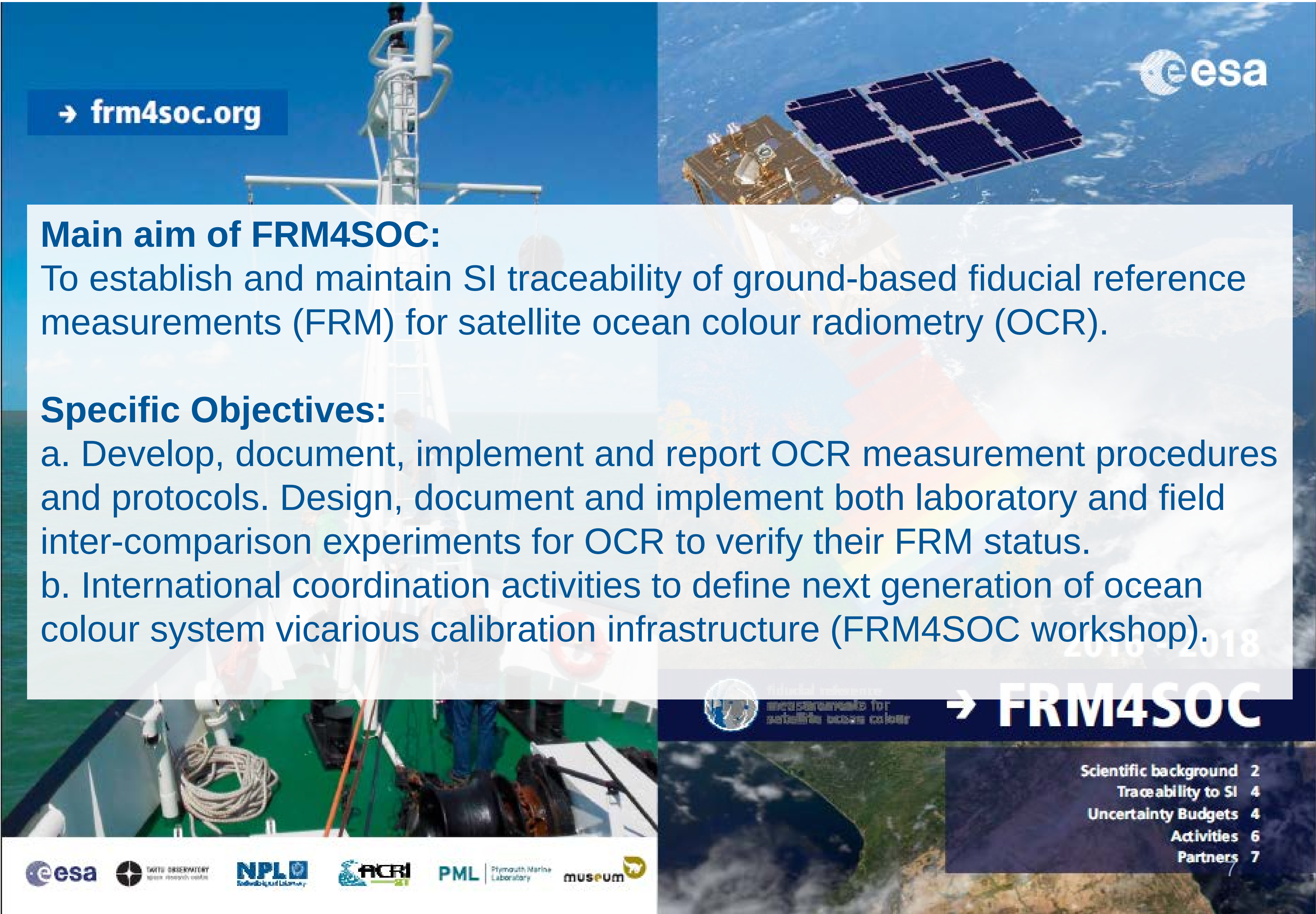
Traceability and Uncertainty Propagation



2. The FRM4SOC Project

Main aim of FRM4SOC:
To establish and maintain SI traceability of ground-based fiducial reference measurements (FRM) for satellite ocean colour radiometry (OCR).

Specific Objectives:
a. Develop, document, implement and report OCR measurement procedures and protocols. Design, document and implement both laboratory and field inter-comparison experiments for OCR to verify their FRM status.
b. International coordination activities to define next generation of ocean colour system vicarious calibration infrastructure (FRM4SOC workshop).



2. The FRM4SOC Project

NPL National Physical Laboratory

International context:

- Under the auspices of **CEOS** WGCV and in support of the CEOS OCR virtual constellation.
- Helping fulfil the **IOCCG** in situ OCR white paper objectives and contribute to the relevant IOCCG WGs and task forces (e.g. uncertainty, future of OC-SVC, satellite sensor calibration).
- Contributing to **Copernicus** and the success of the **Sentinel** series of satellite sensors.

Three types of international intercomparison exercises:

Comparison 1 for OCR radiance and irradiance calibration sources
Comparison 2 for OCR calibration, lab & “controlled” outdoor measurements
Comparison 3 for OCR field measurements (AMT & AAOT)
(End-to-end uncertainty evaluation for FRM4SOC carried out by NPL)

fiducial reference measurements for satellite ocean colour

2. The FRM4SOC Project

Comparison 1: Reference Irradiance and Radiance Sources

fiducial reference measurements for satellite ocean colour

- NPL (UK pilot) with 11 participants from around the world, including:
  - Tartu (Estonia)
  - JRC (EC)
  - NOAA (USA)
  - Satlantic (Canada)
  - CSIRO & IMO (Australia)
  - NIVA (Norway)
  - NERC (UK)
  - LOV & Cimel (France)
  - DLR (Germany)
- Aimed at verifying the performance of irradiance and radiance sources used to calibrate ocean colour radiometers (OCRs)
- Part 1- Irradiance. Took place 03-07 April 2017 at NPL. Participant labs supplied their irradiance sources to NPL for SI traceability check , measurement using the NPL Spectral Radiance and Irradiance Primary Scales (SRIPS) facility & Reference Spectroradiometer System (RefSpec) and performance intercomparison
- Part 2 – Radiance. Between June 2017 and February 2018 transfer radiometers are being sent to each participant lab for radiance source measurements with periodic checks against the NPL derived radiance scale

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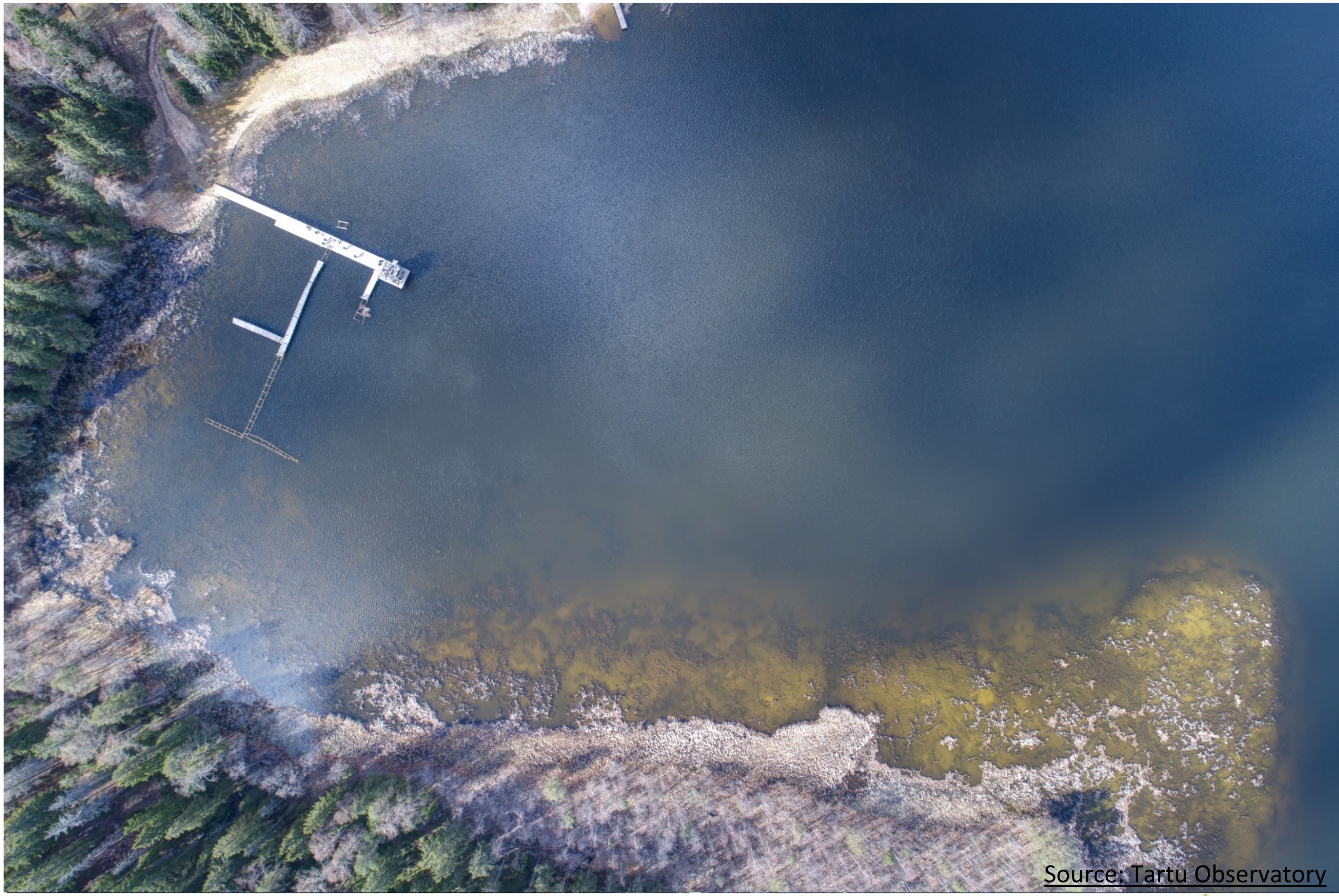
2. The FRM4SOC Project:

Comparison 2: Lab and “controlled” outdoor OCR measurements

- Took place at Tartu Observatory, Estonia 08-13 May, 2017

- Aimed at verifying the performance (i.e., absolute radiometric calibration and characterization) of FRM Field Ocean Colour Radiometers (OCR) used for Satellite Validation

- ~40 OCRs calibrated and used to measure irradiance and radiance in the lab and simultaneouslyin a “controlled” outdoor environment



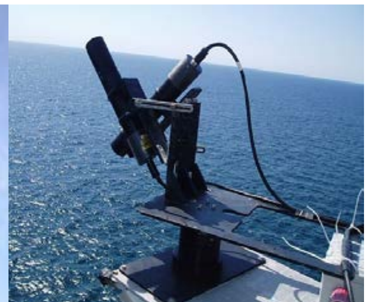
Source: Tartu Observatory

fiducial reference measurements for satellite ocean colour

2. The FRM4SOC Project:

Comparison 3: OCR field measurements

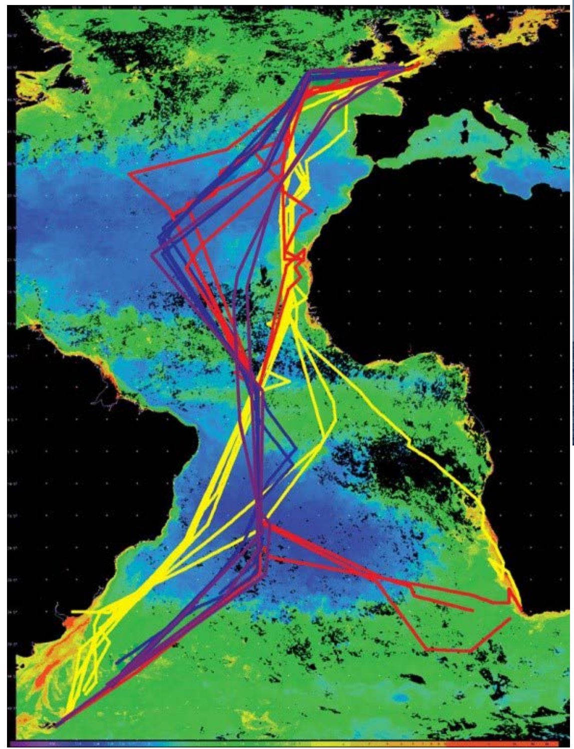
1. The **Acqua Alta Oceanographic Tower (AAOT),** Gulf of Venice, Italy.
8 days, in ***July 2018*** (date tbc).



Purpose built steel tower with instrument house platform to conduct optical measurements under stable conditions to tilt and roll and illumination geometry.

2. The **Atlantic Meridional Transect (AMT)** No.27. ***Sept-Oct 2017***.

AMT cruises are conducted between UK & South Atlantic on a NERC ship.



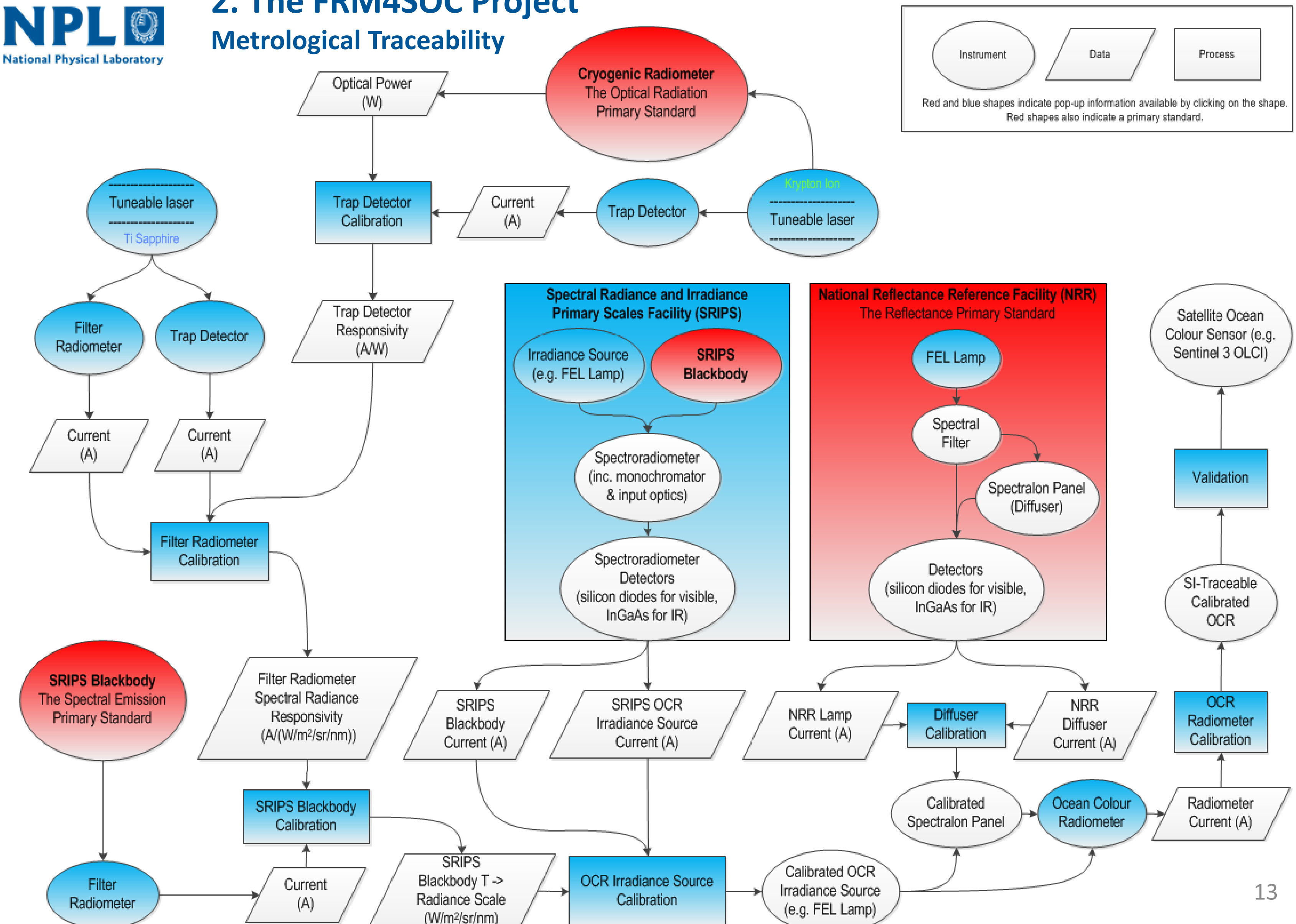
AMT passes through a wide range of environmental conditions and biogeochemical provinces.

FRM4SOC International Workshop on Options and Approaches to the Long-term Vicarious Adjustment of Sentinel- OLCI & MSI A/B/C and D Instruments

- Took place at ESA-ESRIN, Frascati, Italy, 21-23 Feb, 2017
- 30+ participants from Europe, USA, Canada, Australia & S.Korea
- Included many of the world's leading experts in the field
- Consensus reached on many key points

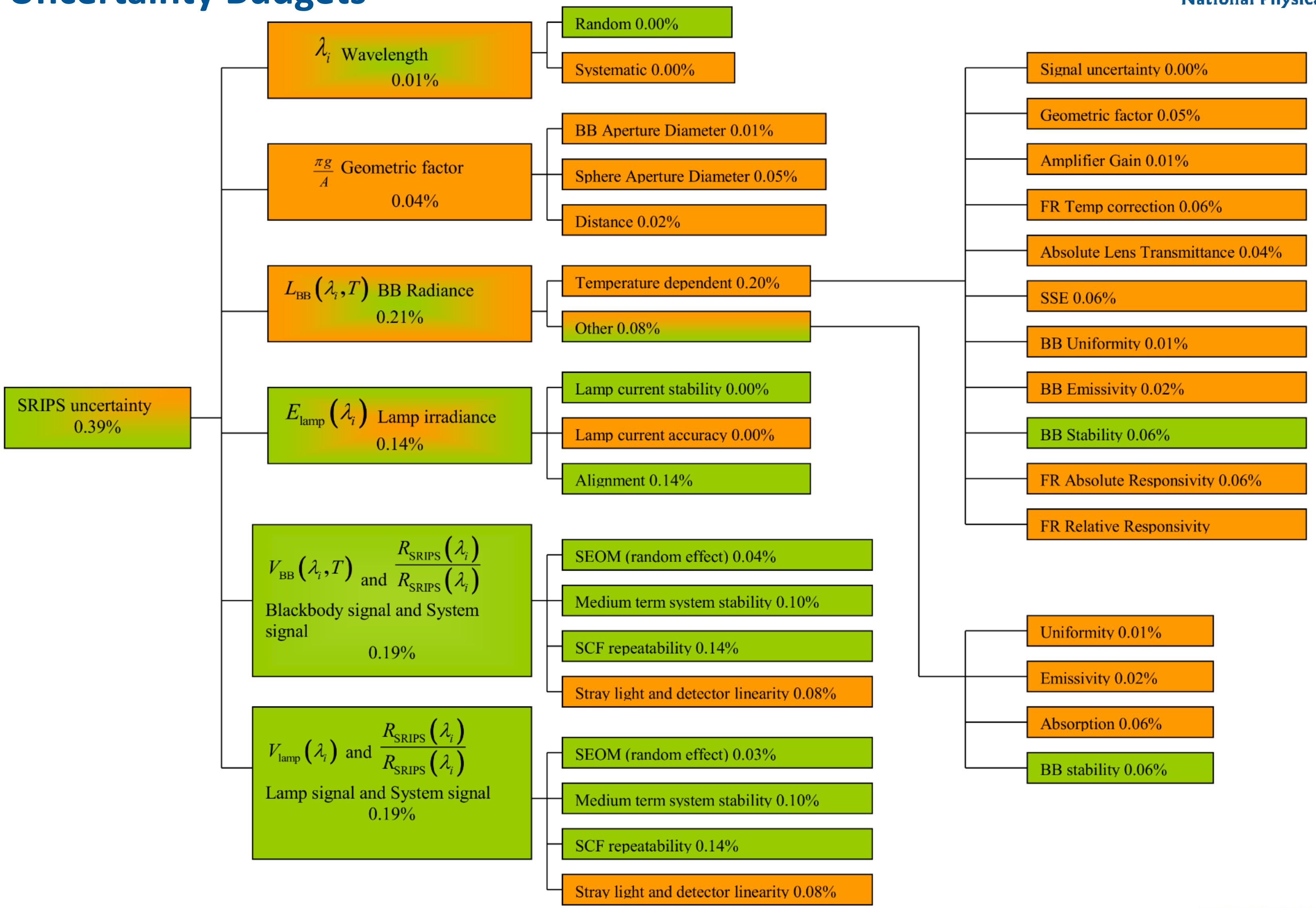
2. The FRM4SOC Project

Metrological Traceability



2. The FRM4SOC Project

Uncertainty Budgets



fiducial reference measurements for satellite ocean colour

2. The FRM4SOC Project

Uncertainty Budgets

		400 nm	442.5 nm	490 nm	560 nm	665 nm	778.8 nm	865 nm
Radiometer	Certificate	0.89	0.74	0.74	0.74	0.74	0.76	0.83
	Instability	0.5	0.3	0.3	0.3	0.5	0.7	0.9
	Alignment	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Temperature	0.02	0.01	0.01	0.03	0.09	0.2	0.38
	Signal, uA	0.074	0.025	0.023	0.016	0.017	0.024	0.04
	Non-Linearity	0.1	0.06	0.05	0.04	0.07	0.08	0.18
	Stray light	0.3	0.4	0.4	0.2	0.2	0.2	0.4
FEL source	Shunt	0.002	0.002	0.002	0.002	0.002	0.002	0.002
	Current	0.15	0.14	0.12	0.11	0.09	0.08	0.07
	Distance	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	Alignment	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Combined (k=1)	1.09	0.92	0.92	0.85	0.94	1.09	1.37
	Expanded (k=2)	2.2	1.8	1.8	1.7	1.9	2.2	2.7

Source: Tartu Observatory

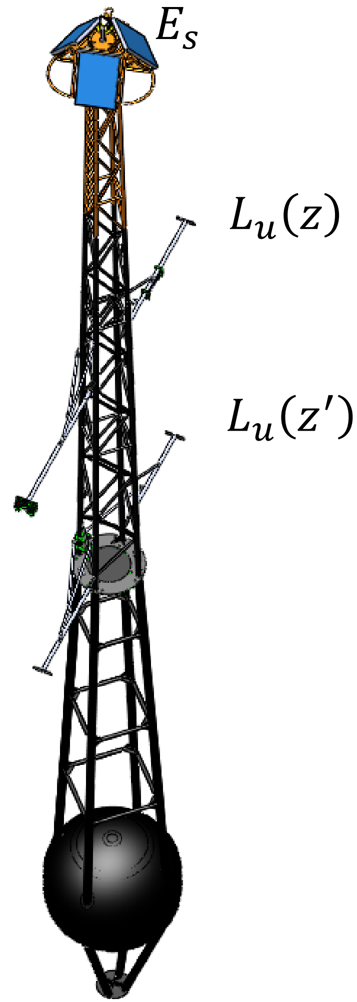
2. The FRM4SOC Project

Uncertainty Budgets

BOUSSOLE

$$R_{rs} = {}^{L_w}/_{E_s}$$

$$R_{rs} = \frac{\overline{L_{u4}} f_{cal} f_s \exp\left[z_4 \left(\frac{-\ln\left(\overline{L_{u9}} f_{cal} f_s / \overline{L_{u4}} f_{cal} f_s \right)}{z_9 - z_4} \right) \right] f_H f_{\rho n}}{\overline{E_s} f_{cal} f_{cos} f_{tilt} f_{dir} + (1 - f_{dir}) \overline{E_s} f_{cal}}$$



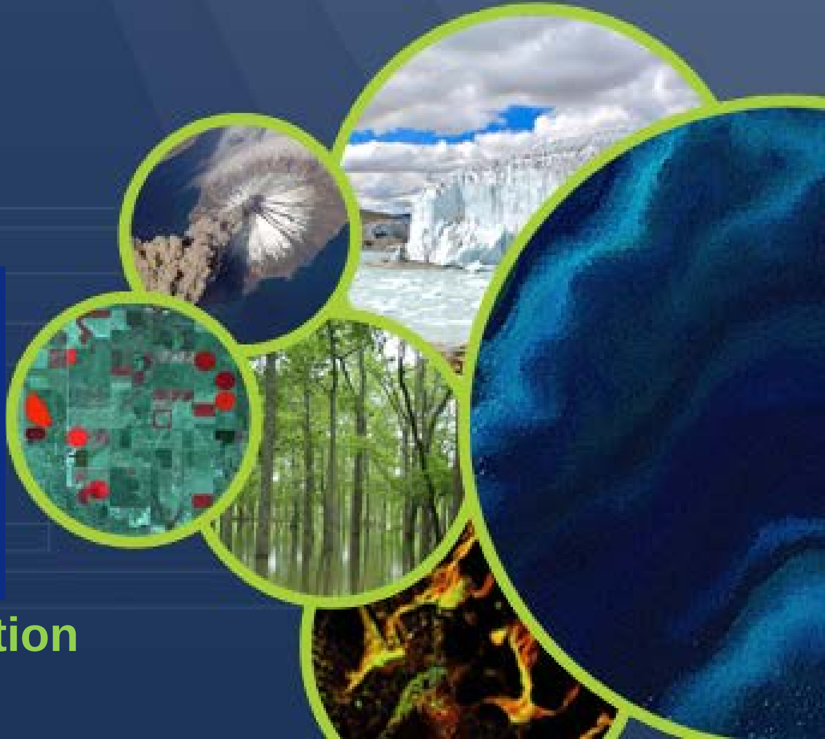
Sources of uncertainty in current data set	
INSTRUMENT RELATED	absolute radiometric calibration (f_{cal}), diffuser cosine response (f_{cos}),
ENVIRONMENTAL	shading (f_s), buoy tilt (f_{tilt}), z_4 and z_9 are the actual instruments depths corrected for buoy tilt,
MODELLING	extrapolation to surface correction using *Hydrolight* simulation (f_H), the constant for water-air interface fraction of the direct to total solar irradiance (f_{dir})

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

Nigel Fox (Chair CEOS WGCV IVOS)

NPL coordinating ESA Project

WGCV Plenary # 40



Working Group on Calibration and Validation

3. The FRM4STS Project:

Main Aim of FRM4STS: to establish and maintain SI traceability of global Fiducial Reference Measurements (FRM) for satellite derived surface temperature product validation and help develop a case for their long term sustainability

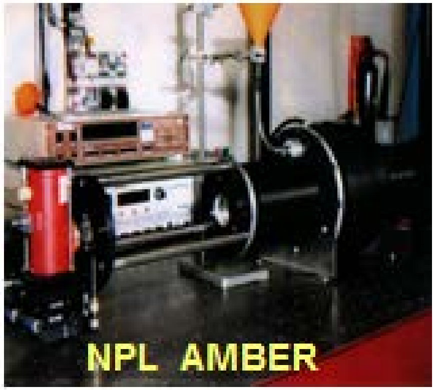
Specific Objectives:

- Design and implement a laboratory-based comparison of the results of participants calibration processes for FRM TIR radiometers (SST, LST, IST)
- Design and implement a laboratory-based comparison to verify TIR blackbody sources used to maintain calibration of FRM TIR radiometers.
- Conduct outdoor comparison 'experiments' of LST and WST to evaluate environmental effects e.g. sky radiance
- Design and implement field inter-comparisons of SST using pairs of FRM TIR radiometers on board ships to build a database of knowledge over several years
- Conduct field-campaigns for FRM TIR of LST and IST to assess environmental effects in real world sites.
- Develop a set of best practise protocols for the calibration, operation and performance of FRM of Surface temperatures.
- Carry out comparisons and analysis to SI standards with full metrological rigour (e.g. detailed uncertainty breakdown).
- Perform a study of means to establish traceability and potential benefits to satellite validation and CDRs of high accuracy ocean temperature measurements using buoys and similar floating systems.

3. The FRM4STS Project:

SI traceability lab comparison (June 2016 at NPL)

19 participants assessed biases to SI under Laboratory conditions



ITS-90

T= ~223 – 325 K
Non-vacuum

NPL BB

PTB BB

NPL Rad (AMBER)

PTB Rad

Rad 1

Rad 2

Rad 3

Rad 4

Rad n

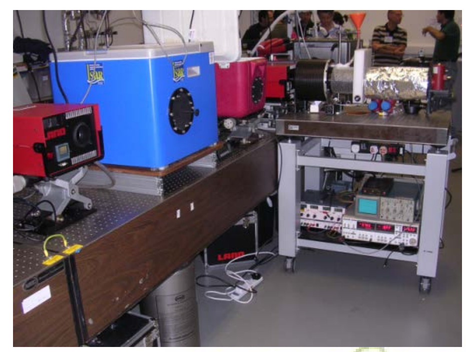
BB1

BB 2

BB 3

BB 4

BB n



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fiducial reference temperature measurements

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3. The FRM4STS Project:

Water Surface Temp – “controlled” outdoor comparison (near NPL - Jun/Jul 2016)

fiducial reference temperature measurements

3. The FRM4STS Project:
Uncertainty Contributions

National Physical Laboratory

Blackbody Comparisons

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperatur K
Repeatability of measurement	U_{Repeat}		U_{Repeat}
Reproducibility of measurement	U_{Repro}		U_{Repro}
Blackbody emissivity		U_{emis}	U_{emis}
BB Thermometer Calibration		U_{therm}	U_{therm}
BB cavity temperature non-uniformity		U_{Unif}	U_{Unif}
BB temperature stability		U_{stab}	U_{stab}
Reflected ambient radiation		U_{Refl}	U_{Refl}
Radiant heat/loss gain		$U_{Radiant}$	$U_{Radiant}$
Convective heat/loss gain		$U_{Convect}$	$U_{Convect}$
Primary Source		U_{Prim}	U_{Prim}
RMS total	$((u_{Repeat})^2+(u_{Repro})^2)^{½}$		

Radiometer Comparisons

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

WST Comparisons

Uncertainty Contribution	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperatur K
Repeatability of measurement	U_{Repeat}		U_{Repeat}
Reproducibility of measurement	U_{Repro}		U_{Repro}
Primary calibration		U_{Prim}	U_{Prim}
Water emissivity		U_{emiss}	U_{emiss}
Water surface “roughness”		U_{rough}	U_{rough}
Angle of view to nadir		U_{angle}	U_{angle}
Linearity of radiometer		U_{Lin}	U_{Lin}
Drift since last calibration		U_{Drift}	U_{Drift}
Ambient temperature fluctuations		U_{amb}	U_{amb}
Atmospheric absorption/emission		U_{atm}	U_{atm}
RMS total	$((U_{repeat})^2+(U_{Repro})^2))^{½}$		

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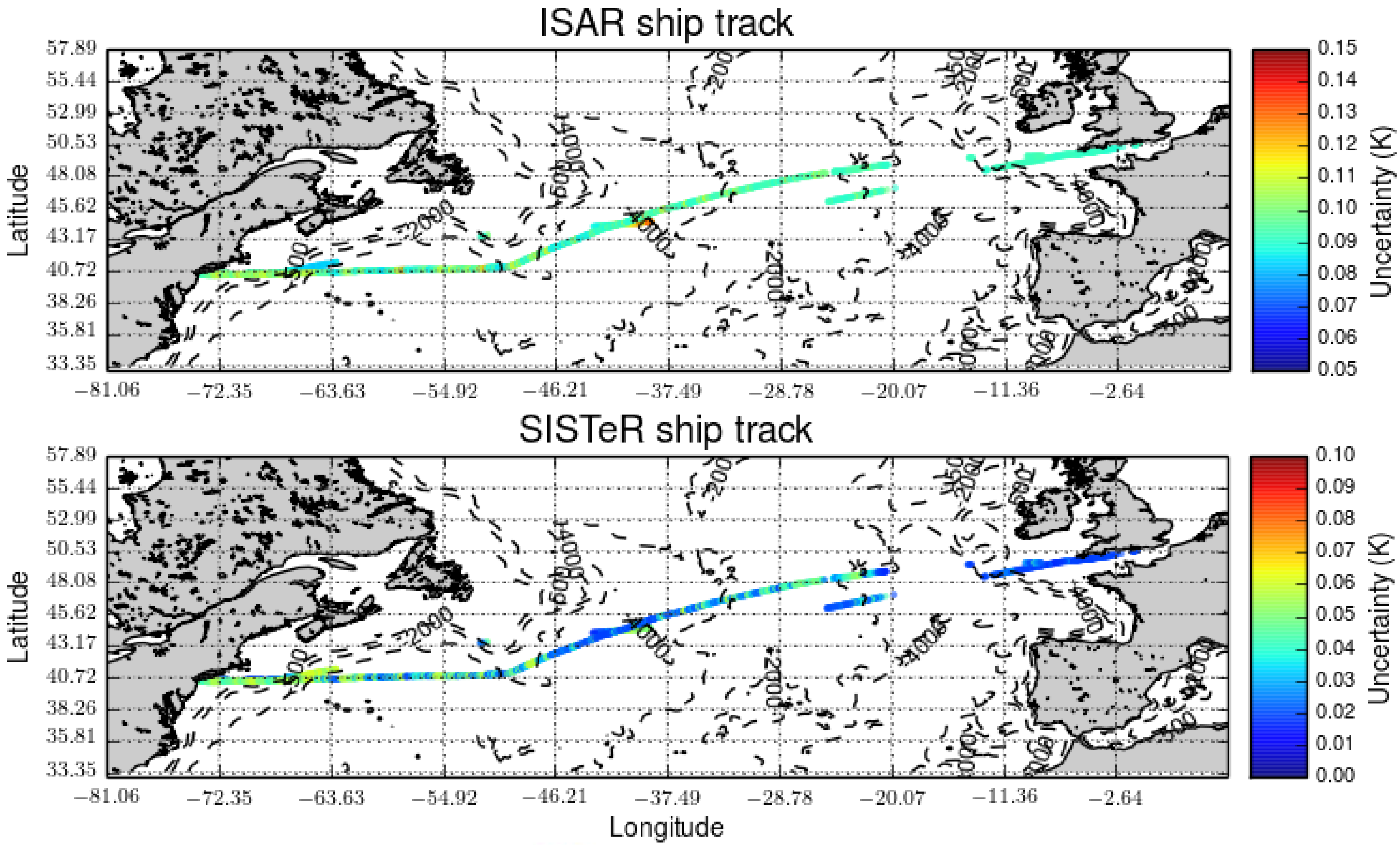
3. The FRM4STS Project:

SST radiometer field comparison – Queen Mary 2 cruise Sep-Nov 2015



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3. The FRM4STS Project:
SST Comparisons – Total uncertainty

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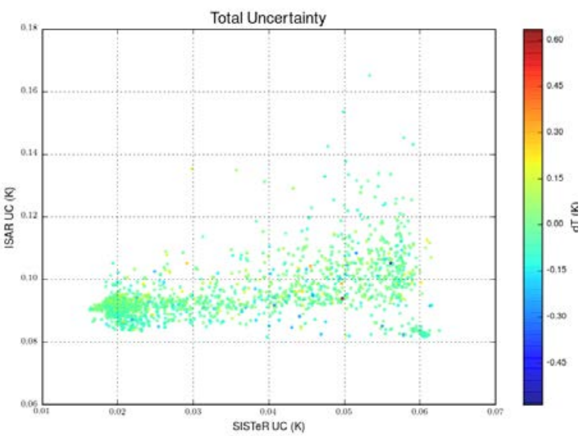

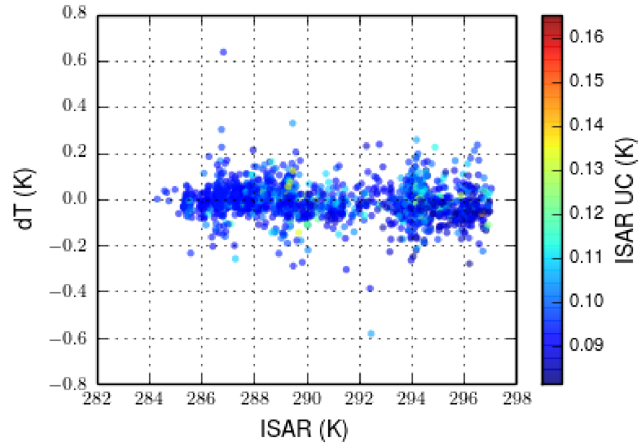

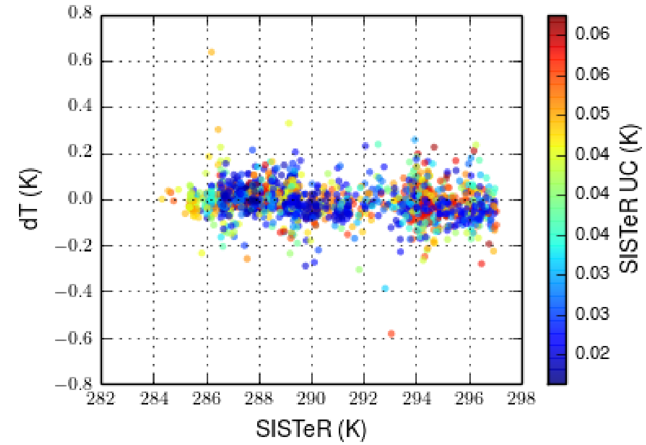

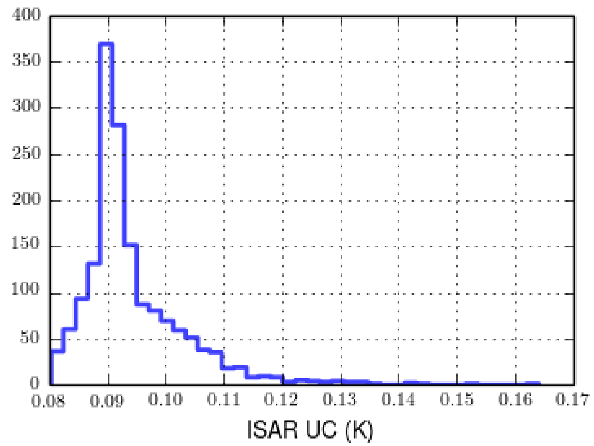

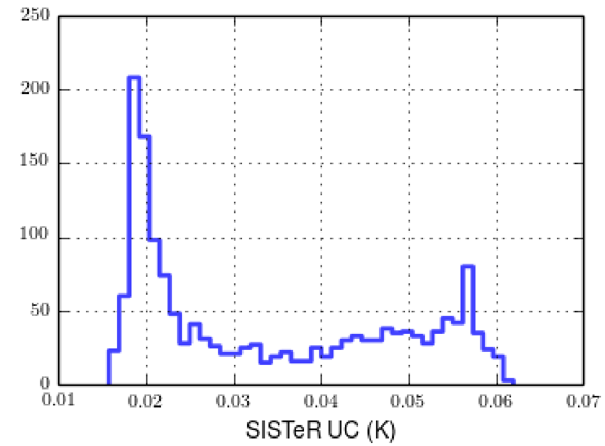

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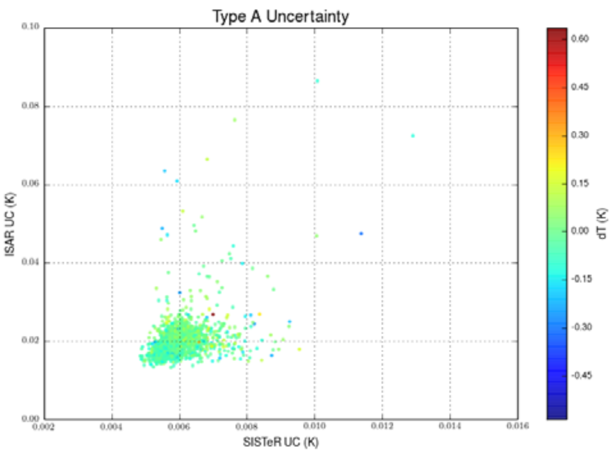
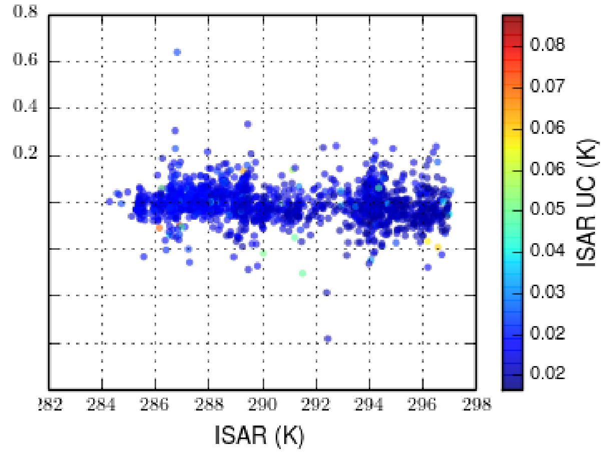
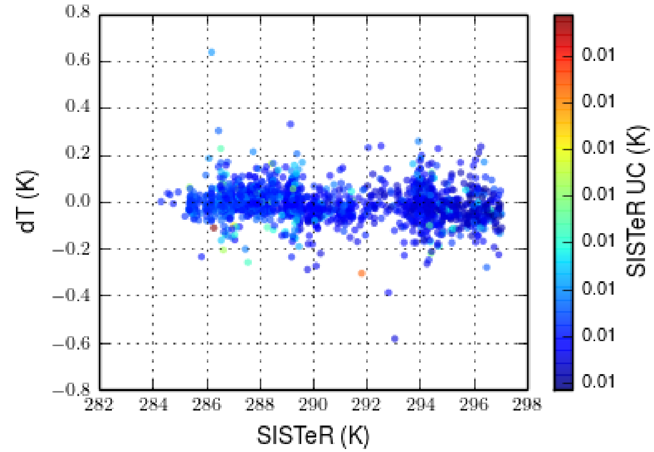
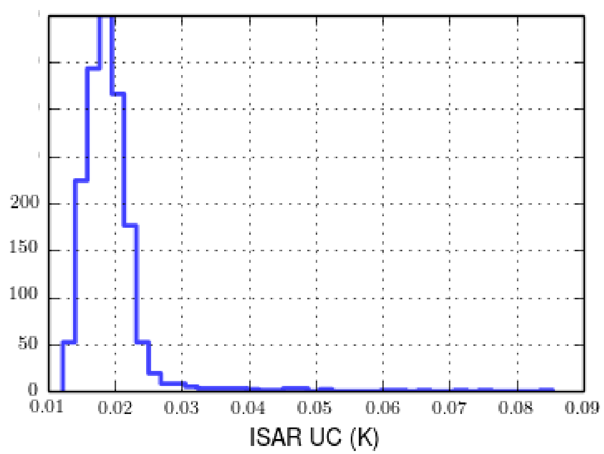
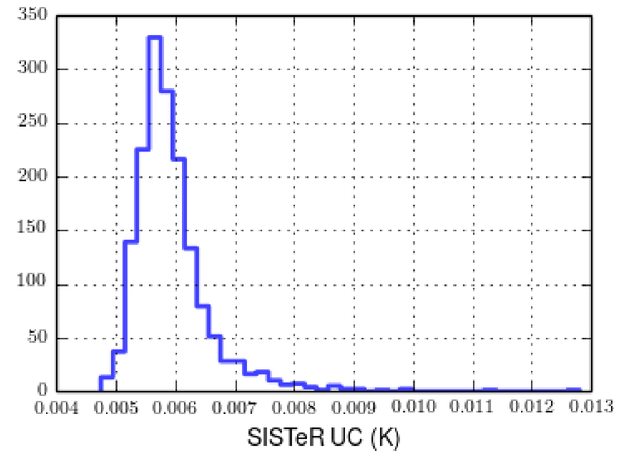
3. The FRM4STS Project:
SST Comparisons – Type A uncertainty



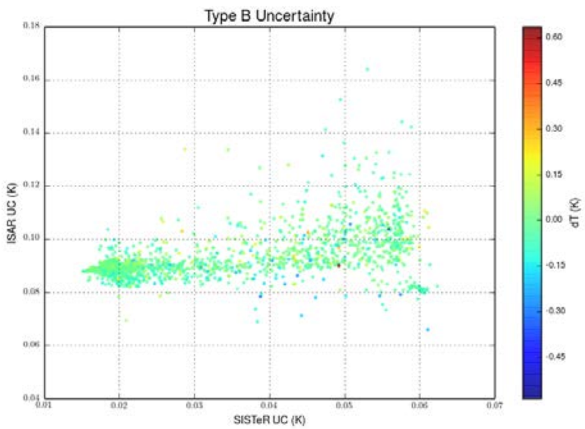


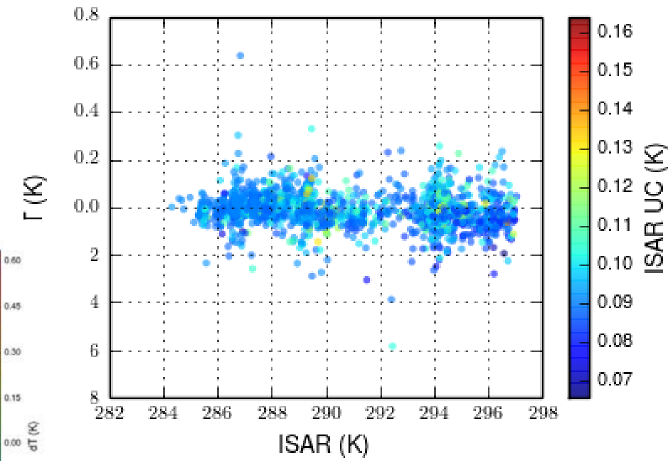


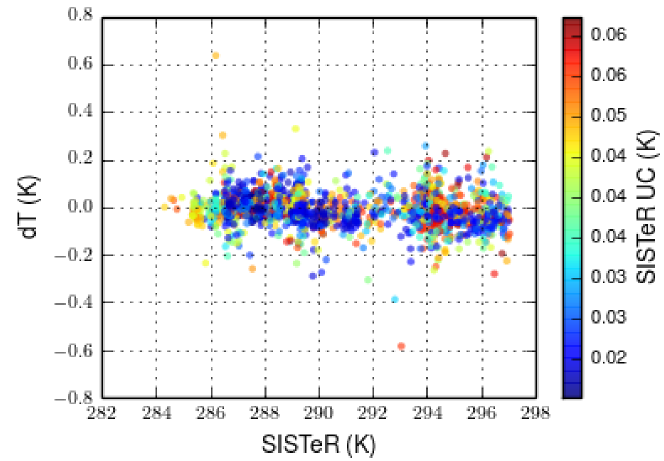


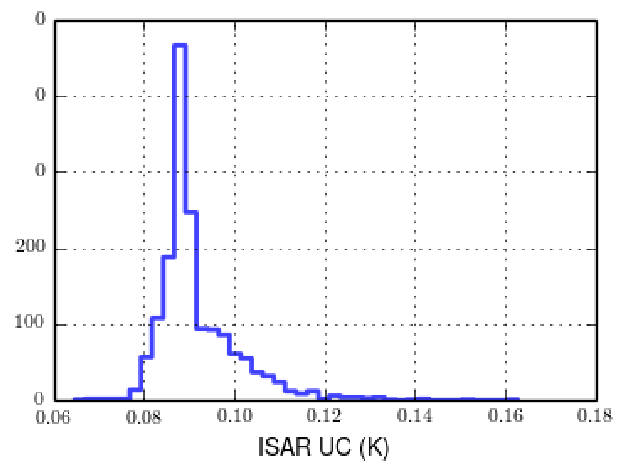


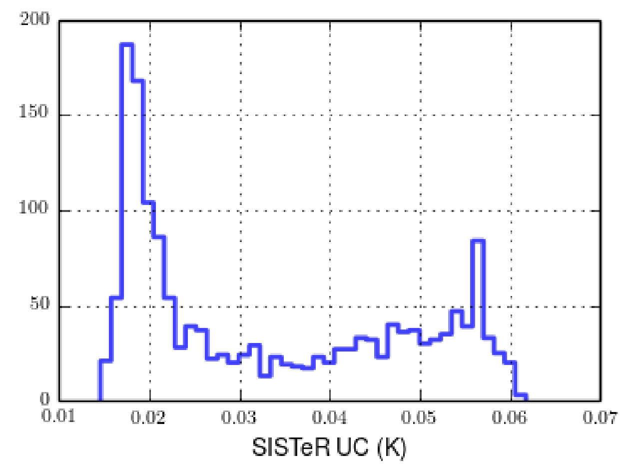
3. The FRM4STS Project:
SST Comparisons – Type B uncertainty











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Summary of the presentation – key points

1. Metrological traceability is a key component in making fiducial reference measurements. Through SI traceability and uncertainty evaluation at each step it ensures the measurement is trustworthy, coherent and reliable. The resultant uncertainty budget also provides a means of obtaining a quantifiable quality indicator for the data.

2. The ESA FRM projects and NPL under the auspices of CEOS are helping to embed metrological principles and methods in satellite validation and calibration in order to provide more robust and reliable EO measurements

3. As well as FRM4SOC and FRM4STS, NPL is actively engaged in a number of long-term research projects on the complex task of providing metrological traceability for satellite products of the ocean - open to further collaboration

Thank you

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