International Space Science Institute

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International Teams in Space Science

Generation of Climate Data Records of Sea-Surface Temperature from Current and Future Satellite Radiometers

Report of the Second Workshop

October 1-5, 2012

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Abstract

This report summarizes the presentations and discussions at the Second Workshop of the International Team on the *Generation of Climate Data Records of Sea-Surface Temperature from Current and Future Satellite Radiometers*. The Workshop was held at the ISSI from October 1 to 5, 2012. The purpose of the presentations was to ensure that all of the Team Members were all aware of developments since the First Workshop irrespective of their own specialties. The discussions were focused on how best to move forward with establishing the justification of the term Climate Data Record when applied to Sea-Surface Temperatures derived from measurements of satellite radiometers. A number of particular research areas that need attention were discussed.

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The mention here of the names of manufacturers or of instruments is for illustrative purposes only, and does not represent endorsement of the International Space Science Institute, or of the authors of this document, or of any institution or agency with which they are affiliated.

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1 Workshop Participants

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Dr Gary Corlett (Co-leader)	University of Leicester, UK
Dr Sandra Castro	University of Colorado, USA
Dr Craig Donlon	ESA ESTEC, NL
Dr Lei Guan	Ocean University of China, CN
Dr Andy Jessup	University of Washington, USA
Dr Tim Nightingale	Rutherford Appleton Laboratory, UK
Dr Theo Theocharous	National Physical Laboratory, UK
Dr Gary Wick	NOAA Earth System Research Laboratory, USA
Mr Werenfrid Wimmer	University of Southampton, UK

Participants (left to right): Gary Wick, Sandra Castro Lei Guan, Craig Donlon, Gary Corlett, Tim Nightingale Andy Jessup, Werenfrid Wimmer, Theo Theocharous and Peter Minnett.

2 Introduction

The Second Workshop of the ISSI Study Project on the *Generation of Climate Data Records (CDRs) of Sea-Surface Temperature (SST) from current and future satellite radiometers* was held at the ISSI in Bern, Switzerland on October 1-5, 2012. The goals of this ISSI Study Project are to:

1. Review the results of the three Miami infrared workshops and lay the groundwork for the next series of workshops to be held in the USA or Europe.
2. Review the current "state of the art" of satellite SST retrieval uncertainties, and identify the contributions to the satellite-derived uncertainty budget from the validating radiometers, and from the method of validation.
3. Revisit the specifications for future SST validation radiometers.
4. Establish and publish a Best Practices Handbook for validation of satellite-derived SSTs.
5. Ensure the steps to establishing SST CDRs are rigorous and well-understood by those involved in this activity.
6. Make longer term, coordinated plans to validate new satellite radiometers – VIIRS on NPP and JPSS, and SLSTR on Sentinel-3.
7. Coordinate the validation of the satellite-derived SSTs within the framework of the CEOS QA4EO.
8. Examine the initial validation results of the VIIRS on NPP.
9. Finalize publications arising from the Study Projects.

Much of the fundamental research and field programs that provide the framework of the ISSI Study Project are funded from national sources. The research and the transition of results into the operational community is facilitated through the Group for High Resolution SST (GHRSST; Donlon et al., 2009) in which any of the participants in the Study Project are active. A newly constituted SST Science Team, formed under aegis of the NASA Physical Oceanography Program, provides a loose framework and discussion forum for a large group of active researchers. The role of this ISSI Study Project is to coordinate the effort and facilitate activities of a small subgroup of the satellite SST community concerned with the generation of CDRs of SST. Further background information can be found in the report of the First Workshop (Minnett and Corlett, 2012)[1].

3 Workshop Objectives

The main Workshop Objectives were to continue to the work begun in the First Workshop that addresses the list of the Study Project objectives, listed above, and to formulate the contents of the Best Practices Handbook for validation of satellite-derived SSTs using ship based radiometers. The meeting was held partially in plenary, during which presentations were made with open discussions involving all, and partially in break-out groups for more specialized discussions and writing. The workshop agenda is given in the Appendix.

The plenary sessions were intended to ensure all participants were aware of the current state of the field with presentations on the characteristics of satellite radiometers, including those recently launched, and scheduled for launch in the next several years, of ship-board radiometers,

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[1] Available at http://www.issibern.ch/teams/satradio/documents/ISSI_Sat_SST_CDR_Workshop1_FinalReport.pdf

and of in situ, sub-surface thermometers. The plenary sessions also included a discussion of the requirements of a CDR, and specifically an SST CDR.

4 Discussions

4.1 New satellite radiometers: Suomi-NPP VIIRS

The Suomi-NPP (National Polar-orbiting Partnership) satellite was launched on October 28, 2011, and the initial cool-down of the focal plane containing the infrared detectors began in early 2012. Using SSTs derived using the at-launch atmospheric correction algorithm and the VIIRS Cloud Mask (VCM), matchups with drifting and mooted buoys were begun soon afterwards. In addition comparisons with global SST fields derived from other satellite sensors and SST L4 analyses were also conducted. Ship radiometers from RSMAS, University of Miami, were also deployed to gather skin SST measurements for the validation of the VIIRS SST retrievals.

The initial impression of the VIIRS infrared measurement and the derived SSTs is that the instrument is not introducing significant artifacts into the infrared data streams and the derived SSTs are of good quality, and moderate accuracy: all are very promising for the first model of a new instrument design in orbit. As is to be expected of a new instrument, there were a number, relatively small, of interruptions to the instrument data flow in the early commissioning phase, and as a result, the assessment of accuracies is very preliminary and limited to global matchups with drifters.

	v5.3 iQuam buoys	**v5.3 GHRSST buoys**
IDPS SST2b night		
median	-0.292K	-0.543K
sd	0.601K	0.702K
count	50561	2404
IDPS SST3b night		
median	-0.156K	-0.363K
sd	0.531K	0.590K
count	50561	2404

Table 1. Preliminary assessment of VIIRS SST uncertainties from comparisons with drifting buoys.

IDPS is the Interface Data Processing Systems, which is the VIIRS processing system; iQuam is the “in situ SST quality monitor” program at NOAA/STAR; GHRSST buoys refer to the new generation of drifting buoys that have 0.01K resolution in the SST values in the data transmission; SST2b is the two-band (λ= 10.8, 12.0 µm) SST retrieval; SST3b is the three-band (λ= 3.7, 10.8, 12.0 µm).

Table 1 shows the preliminary assessment of VIIRS SST retrievals, using two night-time algorithms. The validation data are the subsurface temperatures measured from drifting buoys. The larger set comes from those having passed the iQuam[2] quality assurance test. The GHRSST (Group for High Resolution SST) buoys are a new generation of drifters that have 0.01K SST resolution in transmitted data, even though they do not yet have thermometers with calibration accuracies matching the resolution. Thus, the discrepancies between the VIIRS and in situ temperatures are not smaller for the GHRSST than for the iQuam buoys. The two sets of buoys, do not sample the global oceans very well, so there is likely a contribution to these discrepancies

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[2] http://www.star.nesdis.noaa.gov/sod/sst/iquam/about.html

from sampling uncertainties. Nevertheless, these statistics are very encouraging for the potential of VIIRS SSTs to contribute to the SST CDR.

Despite this very promising start to the VIIRS mission, the deployment of successive VIIRS on the Joint Polar Satellite System (JPSS) orbiters has been recently put on doubt by a report submitted to NOAA recommending the replacement of VIIRS by AVHRR on the JPSS satellites. In the discussion here, it was believed by all that this would be a very undesirable, regressive development and not likely to be of benefit to the SST user community.

4.2 New satellite radiometers: GCOM-W1 AMSR2

The Japanese earth observation satellite Shizuku (also known as GCOM-W1: Global Change Observation Mission – Water 1) was launched on 18 May, 2012 into the A-Train orbit, which it entered in late June. The main instrument on board is the Advanced Microwave Scanning Radiometer 2 (AMSR2) which is a development of the very successful AMSR-E (Advanced Microwave Scanning Radiometer for the Earth Observing System) on the NASA Aqua satellite, and which was powered down in October 2011. AMSR2 has the low frequency channels necessary for SST measurement. Further information about AMSR2, including examples of products, are shown in the PowerPoint file provided by Dr Misako Kachi that is included in the Annex of this report.

4.3 Mitigating the effects of the AATSR/SLSTR data gap

The AATSR sensor was the third in a series of instruments designed to provide global SST to an accuracy and stability suitable for climate change detection from 1991 onwards. The ATSR SST ECV CDR is provided by the ARC dataset (Merchant et al., 2012) and it can be demonstrated from independent measurements that for at least the period from 1993 to date, the uncertainty of the dataset is < 0.1 K (90% confidence) and the stability in the tropics is of order 0.03 K/decade (stability has so far only be assessed in the tropics as this is where the longest *in situ* records are).

The loss of Envisat prior to the launch of SLSTR, now not expected to fly until early-2015 at the earliest, creates an enforced break in the ATSR SST CDR. This raises two fundamental SST data continuity questions:

1. Gap-bridging: How can SST data from Sentinel 3 be traced to the same absolute temperature reference as the ARC SST data record?

2. Gap-filling: How might the data gap between Envisat and Sentinel 3 be filled using alternative sources of SST data that supports:
    a. The maximum achievable homogeneity with both AATSR and SLSTR (minimum artifacts in SST across the sensor transitions for all regions globally);
    b. Continuation of ‘climate quality’ levels of long-term stability (changes in absolute bias <5 mK/year);
    c. Continuation of the independence of the ARC record into the Sentinel era.

From a long-term (25-30 year) ECV perspective, both are critical questions, as climate scientists need to be assured that there are no biases between SST data derived from AATSR on Envisat and SLSTR on Sentinel 3, and that any observed change in temperature during the data gap is real. Here we focus solely on question 1 as it is most relevant to this series of workshops at ISSI.

4.3.1 Proposed Solution

Comparisons of AATSR and SLSTR to ship-borne radiometers, which are periodically calibrated against international (SI) reference standards, provide traceability to SI of the skin retrievals of the satellite. To ensure the best possible AATSR-to-SLSTR traceability, the geographical and seasonal sampling of available radiometric matches made for the final years of AATSR should be broadly replicated for the early years of SLSTR. (SST biases are region and season-dependent, and these dependencies cannot be assumed to be the same for AATSR and SLSTR. Thus, radiometric matches that are not consistent in this regard would have an additional component of uncertainty when used for AATSR-SLSTR comparison). The observations for any given region should also ideally be undertaken with the same ship-borne radiometers, to minimize differences in the trace to the standard reference arising from technological differences.

However, comparison with ship-borne radiometry alone is not likely to be enough to establish the necessary stability between AATSR and SLSTR in the event that SLSTR does not meet its predicted performance (I) because of the limited statistical power of relatively small samples per ship-borne radiometer and (ii) because the limited number of regions of the global ocean that have been sampled with ship-borne radiometry matched to AATSR. Therefore, ship-borne radiometer measurements would then need to be supplemented by the more numerous *in situ* measurements that are available.

Also, in order to build confidence in the tie between AATSR and SLSTR, it is desirable to have verification of the brightness temperatures (BTs) measured by both instruments through a common intermediary. This in itself will not be enough to bridge the SST gap but will demonstrate the quality of the common fundamental CDR of related level 1 BTs. In order to do this, AATSR and SLSTR BTs should be compared to BTs measured by IASI on METOP (since IASI is also the tie for the AVHRR on METOP). The launch of METOP-B will ideally allow two IASI instruments to be compared to SLSTR. It also gives some redundancy to the system since IASI-A will be intercompared to IASI-B.

4.3.2 Summary

The longer than anticipated data gap between AATSR and SLSTR poses a greater challenge to SST data continuity than anticipated. However, by exploiting all the alternative sources of SST - calibrated ship-borne radiometers, *in situ* thermometry and alternative satellite instruments - it should be possible to provide a baseline set of measurements against which to adequately compare the AATSR and SLSTR biases to achieve the goal of an ATSR-SLSTR CDR (gap-bridging). To achieve the best results will require additional analyses of the satellite data sources and assumes that no protracted Pinatubo-like event will occur before SLSTR has been commissioned. Continuity of ship-borne radiometry from the end of AATSR to the start of SLSTR is vital for the SST CDR gap-bridging function.

4.4 Shipboard radiometry update

The M-AERI Mk 2 has successfully completed sea-trials on the NOAA S *Ronald H Brown* (Figure 1). The cruise was planned to be much longer, including the refurbishment of the

PIRATA moorings at 24°W off West Africa, but was curtailed due to problems with the ship's engines. Plans are being developed to mount two M-AERIs, an original version next to the Mk2, on a long Atlantic Section from Woods Hole, USA, to Cape Town, South Africa. The two RSMAS ISARs are mounted on ships that cross the Pacific Ocean and the SISTeR is continuing a long-term deployment on the Cunard Liner *Queen Mary II*. The NOCS ISAR has been installed on the *Pont Aven* of Brittany Ferries that plies between Portsmouth and Santander, Plymouth and Roskoff, and Cobh and Roskoff. The Ocean University of China ISAR has been deployed on the R/V *Dong Fang Hong 2* operating in the China Seas.

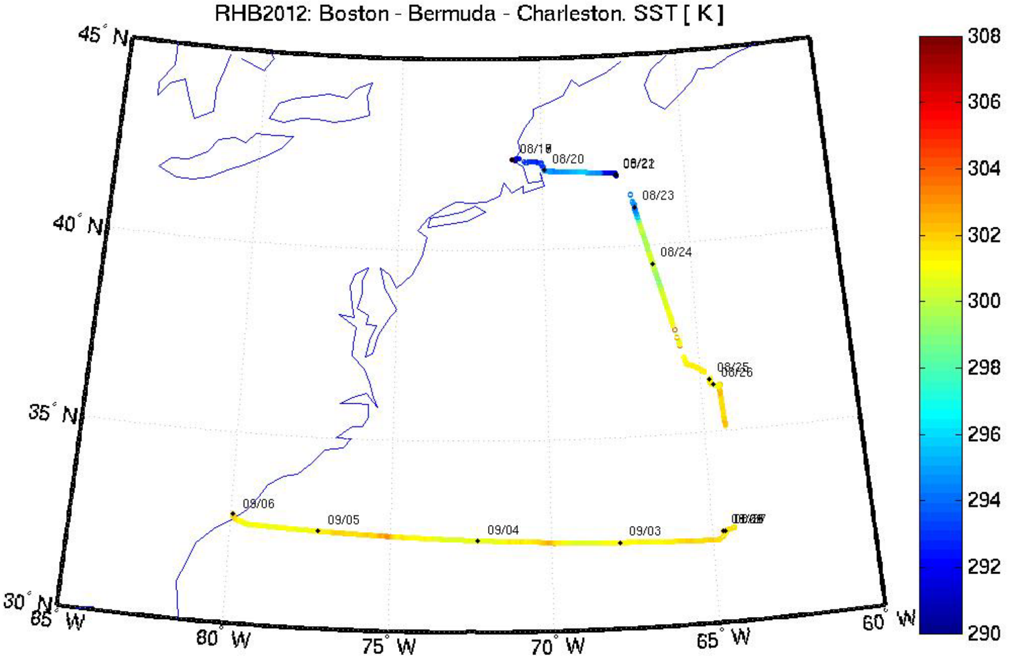

Figure 1. Measurements of skin SST by the M-AERI Mk2 from NOAA Ship *Ronald H Brown*, 18 August – 6 September, 2012.

4.5 CDR generation

As in the First Workshop, considerable time was spent discussing the conceptual and practical approaches to deriving a CDR based on satellite-derived skin SST retrievals. This is fundamental to the objectives of this Study Group. Starting with the flow charts derived during the First Workshop (Figures 2 and 3), the discussion was focused on the two distinct components of ensuring traceability to SI-standards through an unbroken chain of comparisons; one that takes place in the laboratory and the other at sea. Each link in the chain introduces uncertainties that have to be propagated through the process of deriving uncertainties in the satellite SSTs by comparison with ship-board radiometric measurements. The scheme for producing SI-traceable skin temperature measurements is shown in Figure 4. The operations depicts in the upper part of the figure occur in the laboratory during episodic comparisons with a transfer standard of a National Metrology Institute, such as the TXR (Transfer Radiometer; Rice and Johnson, 1998) that have taken place in a series of workshops at the University of Miami (Rice et al., 2004) and

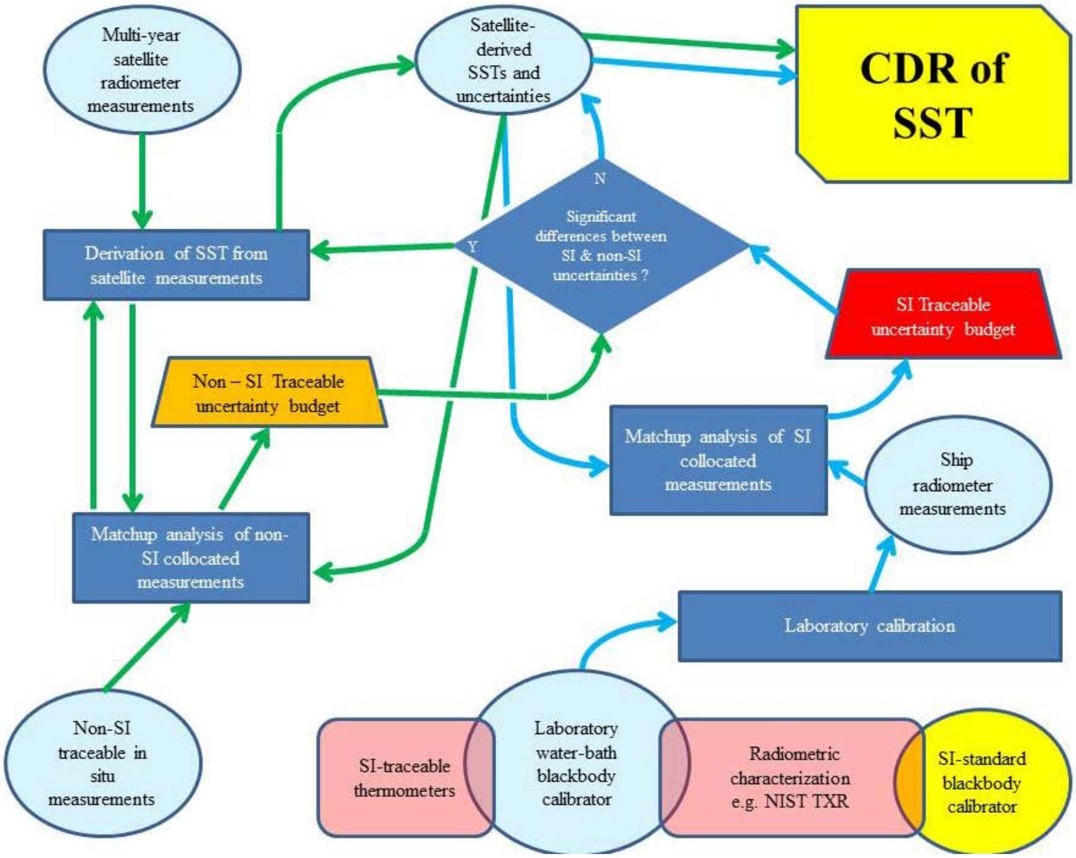

Figure 2. Form of the schematic for generating SST CDRs from satellite and in situ data derived during the First Workshop.

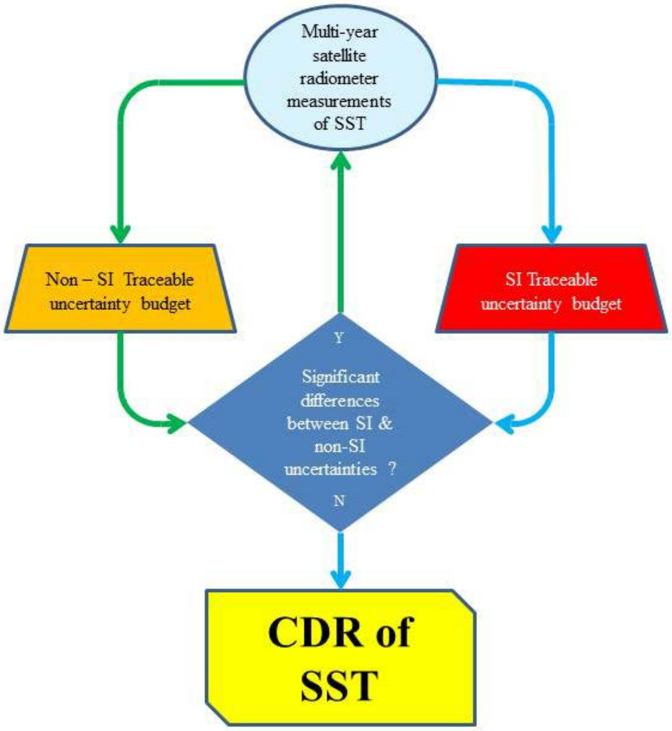

Figure 3. Simplified schematic for the generation of SST CDRs.

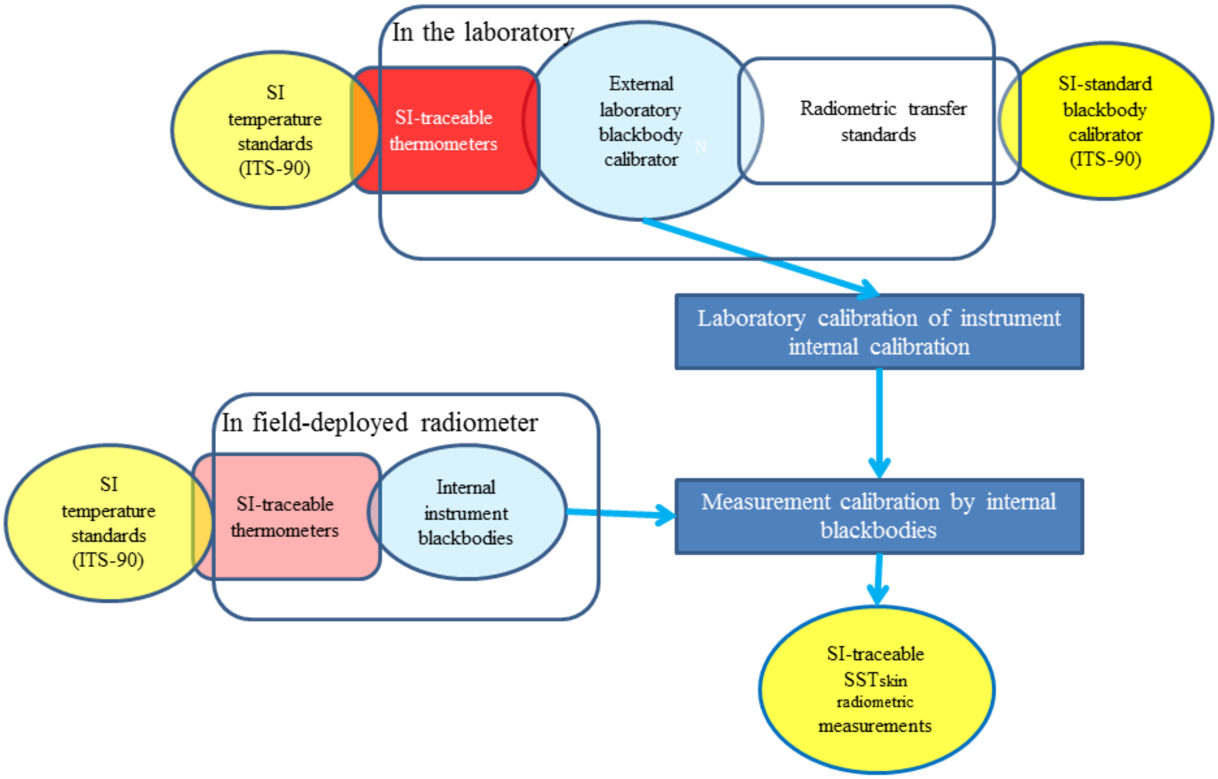

Figure 4. Schematic representation of the traceability of skin SST measurements taken by radiometers on ships.

the National Physical Laboratory (Theocharous and Fox, 2010). The lower part of the figure portrays the at-sea component of the exercise.

Figure 5 shows the part of the process of taking the matchups between the satellite-derived SSTs and SI-traceable measurements of skin SST made by ship-board radiometers and with non-SI-traceable measurements of subsurface temperatures made by thermometers mounted on drifting buoys. The set of matchups with the ship radiometers provides traceability to SI-standards, and ideally this would be all that is required. However, the use of the SST CDR requires each measurement to be accompanied by an uncertainty budget and estimates of the characteristics of the uncertainties, such as the dependences of the uncertainties on environmental parameters. The number of ship-board radiometers is regrettably too small for an adequate sampling of the parameter space that influences the satellite-SST retrieval uncertainties, and thus the much larger data set of matchups with subsurface measurements from buoys has also to be used (Figure 3 and Figure 5). The process pivots on whether the uncertainty budgets derived from comparisons with SI-traceable and non-SI-traceable measurements are equivalent. If yes, it can be argued that the uncertainties derived from the much larger set of non-SI-traceable matchups can be used in the characterization of the SST CDR. If not, it implies that the satellite-derived SSTs have uncertainties that are not well characterized in either sets of matchups, and the algorithms used in deriving the satellite SSTs should be improved. The metrics for the equivalence in the characteristics of the two uncertainty budgets have to be determined taking into account the properties of the two data sets and the methods used to generate the matchups.

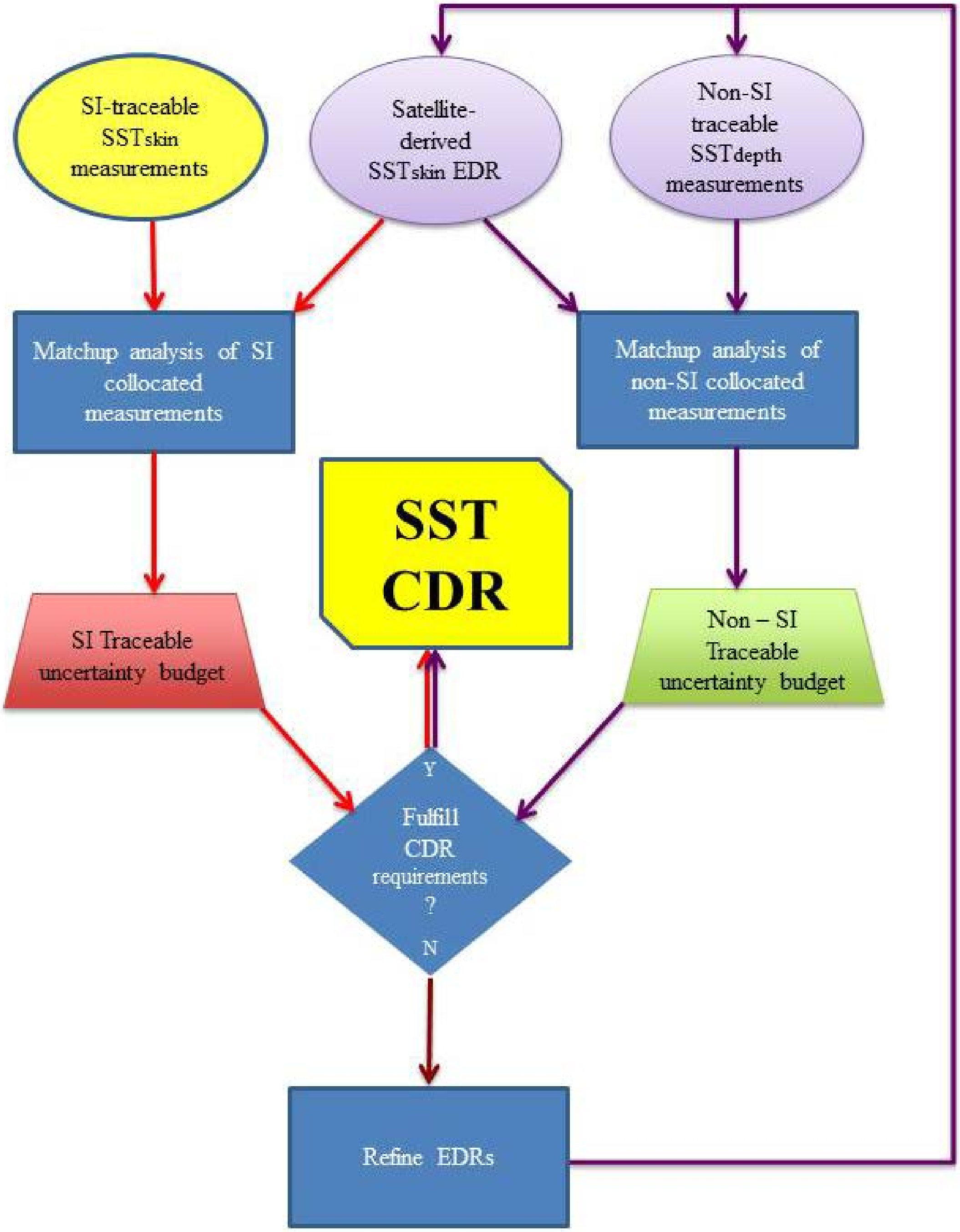

Figure 5. Schematic diagram of the process of generating SST CDRs from satellite SST retrievals using matchup-ups from SI-traceable skin SST measurements from ship radiometers, and non-SI-traceable subsurface temperatures from drifting buoys.

4.6 Data Archive and distribution

An important aspect of adherence to the guidelines of the CEOS QA4EO is the provision of appropriate documentation of a satellite-derived CDR, and of ease of accessibility to the data set(s) comprising the CDR. In the case of a satellite-derived SST CDR, this also applies to the ship-based radiometer data that underpin the legitimacy of the CDR. The details of the contents of the Data Base to hold these and associated measurements were further discussed, building on the conclusions reached during the First Workshop (Minnett and Corlett, 2012). The contents of a document to define the format of ship-board radiometer data were discussed. The lead author of this is Dr Tim Nightingale and when completed, the documents will be a joint ISSI and GHRSST report.

5 Research Areas

Several research areas requiring urgent attention were identified and discussed in the Breakout Groups, and in plenary.

5.1 Estimating Measurement Uncertainty in SST from Shipboard Radiometry

Optimal use of ship-based SST from improving the accuracy of satellite-based SST requires that an uncertainty associated with each shipboard radiometer measurement be reported. The overall measurement uncertainty for ship-based SST derived can be divided into uncertainties associated with the instrument and those associated with the environment, which includes the sea surface and its surroundings. In general, instrument uncertainty can be adequately determined by evaluation of the radiometer in the laboratory using calibration techniques that conform to standard practices (e.g. Rice et al., 2004). Environmental uncertainty is dominated by the dependence of sea surface emissivity and reflectivity on incidence angle and includes effects due to wind-induced surface roughness, wave slope, ship roll, and sky conditions. Over the past 25 years, a significant body of research parameterizing the dependence of emissivity and reflectivity on wind speed has been established (see Nalli et al., 2008 for a recent survey). Thus a potential approach to estimating the environmental uncertainty for individual ship-based measurements is to use such parameterizations with simultaneous measurements of environmental conditions. In order to assess the adequacy of this approach, research that examines and quantifies the separate and combined effects of the primary factors contributing to environmental uncertainty is required.

5.2 Validation of uncertainties

The goal is to define and implement a method for validating uncertainties.

The provision of pixel level uncertainties with satellite SSTs is a key requirement for the construction of a satellite SST CDR. One way of generating such uncertainties is to compare the satellite SSTs to a set of reference measurements from non-satellite instruments. Owing to significant changes in the type, accuracy and coverage of available reference measurements, an alternate approach is to develop an uncertainty model for the satellite SSTs from the comparisons to the reference measurements. An advantage of this latter approach is that a consistent set of uncertainties can then be provided to every pixel in the satellite SST data record (included those with no corresponding reference measurements); a consequence is the requirement to then validate the uncertainties (actually the uncertainty budget) as well as the SSTs themselves.

The approach taken to validate the uncertainties should determine whether the calculated uncertainties are generally of the correct magnitude, and whether the measurements with higher (or lower) reported uncertainty are, in fact, less (or more) certain than others – i.e. how much confidence is there in the uncertainties. It is possible to infer such knowledge from the statistics of discrepancies between the satellite and reference measurements if (1) the uncertainty distributions of the reference measurements are well understood, and (2) the number of cases is large enough to stratify the data along various dimensions while ensuring the sample size is sufficient to provide a statistically significant estimates of standard deviation.

The quality of the uncertainties can be provided as a quality indicator for each uncertainty as well as maps of the *degree of equivalence* or *degree of confirmation.*

The issues to be addressed are:

1. How do we differentiate reference measurements?
2. Are the uncertainty distributions of the reference measurements well understood?
3. Are the uncertainties of comparing satellite and reference measurements understood?
4. How do we define a statistically significant sample?
5. How do we provide uncertainty confidence to users?

5.3 Extending the SST CDR before the deployments of ship-board radiometers

The overall approach is to work backwards from periods of traceability using overlap periods as the primary means of transferring traceability. Quantifying differences during an overlap period of two or more satellites provides a framework for propagation of absolute accuracy, and transfers uncertainty from more recent “known” period to previous “unknown” period lacking SI traceable in situ collocations. General questions to be addressed include:

- What is minimum period of overlap required?
- What duration/number of collocations are required to transfer accuracy?
- Is this met as we go back in time?

Constructing collocations of observations from the two satellites can be done in terms of brightness temperature (radiance) or SST.

The first option is to construct collocations of brightness temperature in situations of satellite overpasses in the overlap period. The advantages are:

- More physical: closer to what is measured by the satellite
- Independent of uncertainties associated with the retrieval process
- Can do with collocations close in time.

But the disadvantages are:

- Subject to differences in spectral response of different satellites
- Collocations constrained to higher latitude regions

Which give rise to the following questions:

- What are constraints on matchup criteria?
- Are specular/angular differences between satellites sufficiently small?
- Do collocations in limited regions capture all of the potential differences between the satellites?
- Are there differences in satellite instrument response over different portions of the orbit?

The second option is to construct collocations in SST space. This confers the following advantages:

- In principle, can be extend to broader geographic regions

- Differences in spectral response are already incorporated

But this has the disadvantages of being:

- Less fundamental
- Subject to differences in the SST retrievals

Whichever approach is used, the uncertainty budget/error statistics have to be complied.

Extending the results back over the lifetime of a satellite radiometer involves determining if and how the uncertainty characteristics change with time, and constructing uncertainty estimates as functions of time (as well as location or other identified dependencies). This can be achieved with two approaches.

The first is to incorporate available in situ SST measurements, which involves assuming that while individual in situ measurements are subject to significant uncertainties, in the mean the record is not biased. Comparing mean in situ and satellite SST measurements identifies any trend in differences. This is a proven method which captures direct variations in SST, but it is not independent: Any trends are tied to the in situ record, and there may be significant contributions that arise from comparisons between skin and subsurface SSTs.

The second approach is to deduce change in satellite characteristics from available sensor data, which would have the advantage of rendering any conclusion independent of the in situ record, but it is unclear that known characteristics capture all aspects of the degradation of the satellite radiometer, and neither is it clear that all relevant information is available. This gives rise to the question of the sufficiency of the onboard satellite parameters to capture and characterize drift in the satellite radiometer performance. The work being done by Jon Mittaz and Jack Xiong can be a good starting point.

The processes can be repeated in principle backwards in time through the overlap periods with earlier satellites as required.

An important research task is to conduct a feasibility study using data from a period where in situ data are available to validate, attempting to answer the multiple questions cited above.

6 Acronyms

AATSR	Advanced Along-Track Scanning Radiometer
ATSR	Along-Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CDR	Climate Data Record
CEOS	Committee on Earth Observation Satellites
IASI	Infrared Atmospheric Sounding Interferometer
ISAR	Infrared Sea surface temperature Autonomous Radiometer
JPSS	Joint Polar Satellite System
M-AERI	Marine-Atmospheric Emitted Radiance Interferometer
NIST	National Institute of Standards and Technology (USA)
NOAA	National Oceanic and Atmospheric Administration
QA4EO	Quality Assurance Framework for Earth Observation
SI	Système International d'Unités
SISTeR	Scanning Infrared Sea Surface Temperature Radiometer
SLSTR	Sea and Land Surface Temperature Radiometer
S-NPP	Suomi-National Polar-orbiting Partnership
TXR	(NIST) Thermal-infrared Transfer Radiometer
VIIRS	Visible Infrared Imager Radiometer Suite
WGCV	(CEOS) Working Group on Calibration and Validation

7 References

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8 Appendices

8.1 Meeting agenda

Monday, 1 October, 2012

Welcome
Local Arrangements
Review Objectives of the Workshop
Discuss & modify agenda

Satellite radiometers
New developments:
Suomi-NPP VIIRS Instrument characteristics and SST Accuracies - Peter Minnett
AMSR-2 on GCOM-W1 - Peter Minnett
Chinese HY satellites and sensors - Lei Guan
Consequences of loss of Envisat and AATSR; progress towards SLSTR - Gary Corlett
New results of note - All

Shipboard radiometers
Update on past and future deployment plans.
Radiometer calibration workshop – developments?

In situ measurements
Updates on results using drifting or moored buoys.
New developments?

Discussion of SST CDRs
Uncertainty budgets and SI traceability - Theo Theocharous
Improvements on the flow diagram developed at the First Workshop?
How can the satellite-derived SST CDR be extended back before the deployments of ship-board radiometers? - Gary Wick
How can satellite SST CDRs be merged with in situ SST time series?
Ocean reference sites – is this concept one to follow for radiometric skin SST measurements?
Alignment with QA4EO; involvement of CEOS

Data Archiving and distribution
Refine the user requirements for a data archive
Discuss and agree upon the initial radiometer data format, including metadata for archival data - Tim Nightingale

Tuesday, 2 October, 2012

Definition of Breakout Groups – Ship-board radiometry, in situ measurements and (other suggestions?) ….

Each group to consider, amongst other things:

- Minimum and optimal accuracy requirements and how these can be achieved and demonstrated
- Revision of contents of "Best Practices Handbooks" for measurements to be used to validate satellite-derived SSTs
- Discuss research areas that need urgent attention.

Wednesday, 3 October, 2012

Updates in Sentinel-3 and SST_cci - Craig Donlon
Reports of Breakout Groups
Breakout sessions

Thursday, 4 October, 2012

Reports of Breakout Groups
Breakout sessions
Reports of Breakout Groups

Friday, 5 October, 2012

Future plans
Identify problems to be addressed, gaps to be filled
Requirements of future calibration workshops
Opportunities for coordinated ship radiometer deployments
Outline of peer-reviewed publications arising from this ISSI Study Project
Dates for next ISSI Workshop

Adjourn 12:30

8.2 Presentations

This section provides the slides used during the workshop. They are presented on six per page, to be read vertically.

The sequence of presentations is:

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Generation of Climate Data Records of Sea-Surface Temperature from current and future satellite radiometers

Goals and Outcomes

Goal 1

Review of the results of the three Miami infrared workshops and lay the groundwork for the next series of workshops to be held in the USA or Europe.

Published papers (Miami 2):

- Rice, Jet al, 2004: The Miami2001 Infrared Radiometer Calibration and Intercomparison: 1. Laboratory Characterization of Blackbody Targets. *Journal of Atmospheric and Oceanic Technology,* ***21, 258-267.***
- Barton, I. J., P. J. Minnett, C. J. Donlon, S. J. Hook, A. T. Jessup, K. A. Maillet, and T. J. Nightingale, 2004: The Miami2001 infrared radiometer calibration and inter-comparison: 2. Ship comparisons. *Journal of Atmospheric and Oceanic Technology,* ***21, 268-283.***

Published Reports (Miami 3):

- Theocharous, E., E. Usadi, and N. P. Fox, 2010: CEOS comparison of IR brightness temperature measurements in support of satellite validation. Part I: Laboratory and ocean surface temperature comparison of radiation thermometers, National Physical Laboratory, Teddington, Middlesex, UK, 130 pp.
- Theocharous, E. and N. P. Fox, 2010: CEOS comparison of IR brightness temperature measurements in support of satellite validation. Part II: Laboratory comparison of the brightness temperature of blackbodies, National Physical Laboratory, Teddington, Middlesex, UK, 43 pp.

The goals of the ISSI Study Project- as proposed

1. Review of the results of the three Miami infrared workshops and lay the groundwork for the next series of workshops to be held in the USA or Europe.
2. Review the current “state of the art” of satellite SST retrieval uncertainties, and identify the contributions to the satellite-derived uncertainty budget from the validating radiometers, and from the method of validation.
3. Revisit the specifications for future SST validation radiometers.
4. Establish and publish a Best Practices Handbook for validation of satellite-derived SSTs.
5. Ensure the steps to establishing SST CDRs are rigorous and well-understood by those involved in this activity.
6. Make longer term, coordinated plans to validate new satellite radiometers – VIIRS on NPP and JPSS, and SLSTR on Sentinel-3.
7. Coordinate the validation of the satellite-derived SSTs within the framework of the CEOS QA4EO.
8. Examine the initial validation results of the VIIRS on NPP.
9. Finalize publications arising from the Study Projects.

Goal 2

Review the current “state of the art” of satellite SST retrieval uncertainties, and identify the contributions to the satellite-derived uncertainty budget from the validating radiometers, and from the method of validation.

This is a moving target……

Outcomes

- A handbook of Best Practices
- Web pages for conveying results and progress
- Papers submitted to the peer-reviewed literature - potential titles are:
  - “Demonstrating traceability to SI in deriving climate data records: An example using sea-surface temperature”
  - “Accuracy of satellite-derived sea-surface temperatures derived from multi-decadal time series from multiple satellite sensors”

Goal 3

Revisit the specifications for future SST validation radiometers.

Are there new radiometers envisioned?

Goal 4

Establish and publish a Best Practices Handbook for validation of satellite-derived SSTs.

Contents assessed during last meeting and first draft distributed; focus of this meeting

---

Goal 5

Ensure the steps to establishing SST CDRs are rigorous and well-understood by those involved in this activity.

To be determined through this series of meetings.

Several approaches may be feasible, desirable, or simply necessary. Assess uncertainty budgets of radiometer-derived SST CDR route.

Goal 6

Make longer term, coordinated plans to validate new satellite radiometers – VIIRS on NPP and JPSS, and SLSTR on Sentinel-3.

- On a person-to-person basis, avoid unnecessary duplication, but still allow comparative measurements.
- How to identify areas or conditions needing attention?
- Include AMSR-2 on GCOM-W; AVHRR on MetOps, Geostationaries?
- Data sharing
- Quality assurance
- Data bases (on-line?)

Goal 7

Coordinate the validation of the satellite-derived SSTs within the framework of the CEOS QA4EO.

- Outcome of these workshops

Goal 8

Examine the initial validation results of the VIIRS on NPP.

- Results will be presented here

Goal 9

Finalize publications arising from the Study Projects.

- Outcome of these workshops

Requirements of a Climate Data Record

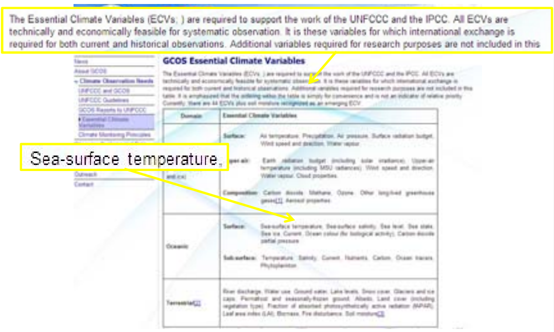
Essential Climate Variables

GCOS Essential Climate Variables

The Essential Climate Variables (ECVs;) are required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this table. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority. Currently, there are 44 ECVs plus soil moisture recognized as an emerging ECV.

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour. **Upper-air:** Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties. **Composition:** Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[1], Aerosol properties.
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial[2]	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance, Soil moisture[3].

Essential Climate Variables



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Sea-surface temperature

Reference to SI-standards

Although it seems self-evident, it was only in 1995 at the 20th Conférence Générale des Poids et Mesures that it was recommended that *"those responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programs are in terms of well-characterized SI units so that they are reliable in the long term, are comparable world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Mètre"* (BIPM 1995).

This lays the foundation for relating environmental measurements to SI (Système International d'Unités) standards, which, in the USA, are maintained by the National Institute of Standards and Technology (NIST) and in the UK by the National Physical Laboratory (NPL).

This recommendation is the basis of the feasibility Climate Data Records of SST as by following it, temperature measurements from different sources taken over a period of time can be combined in a meaningful manner.

(http://www.bipm.org/en/CGPM/db/20/1/)

Satellite-derived CDRs

- National Academy of Sciences Report (*NRC, 2000*): "***a data set designed to enable study and assessment of long-term climate change***, *with 'long-term' meaning year-to-year and decade-to-decade change. Climate research often involves the* ***detection of small changes against a background of intense, short-term variations****."*
- *"Calibration and validation should be considered as a process that encompasses the entire system, from the sensor performance to the derivation of the data products. The process can be considered to consist of five steps:*
  - *instrument characterization,*
  - *sensor calibration,*
  - *calibration verification,*
  - *data quality assessment, and*
  - *data product validation."*

NIST Traceability

Long-term validation, by a suite of sensors, can best be achieved if each has traceability to a National Reference Standard

- Satellite radiometers require validation traceability to radiometric as well as thermometric references.
- NIST traceable thermometers are off-the-shelf items - not so for radiometers.

Desired SST CDR uncertainties

- The useful application of all satellite-derived variables depends on a confident determination of uncertainties.
- CDRs of SSTs require most stringent knowledge of the uncertainties:
  - Target accuracies:

    0.1K over large areas,

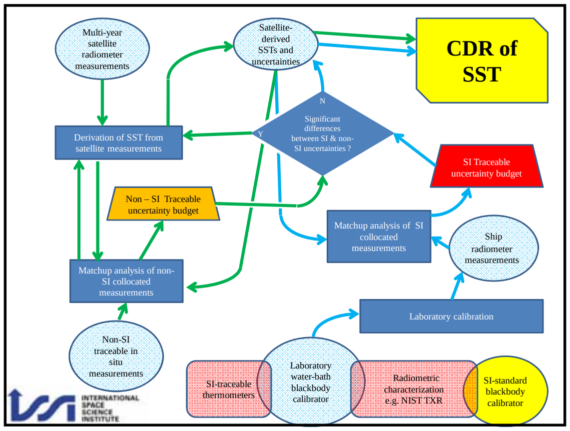
    stability 0.04K/decade

Ohring et al. (2005) Satellite Instrument Calibration for Measuring Global Climate Change: Report of a Workshop. *Bulletin of the American Meteorological Society* **86**:1303-1313

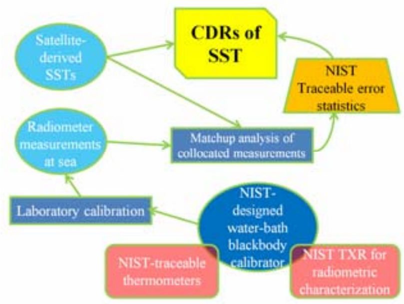
Revised at Workshop 1

CDR of SSTs

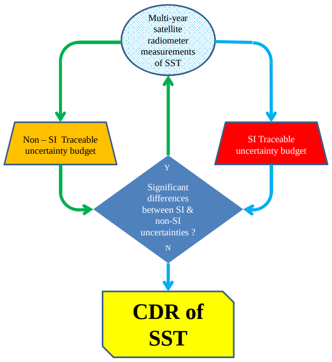
- Climate Data Records of SST require an **unbroken chain between the satellite measurement and an SI Temperature standard**.
- Prior to launch, the satellite radiometers are calibrated using SI-traceable standards, but post launch it is not currently feasible to check calibration drift using SI-standards.
- Drifting buoys are currently not sufficiently well calibrated for this purpose, and very few are recovered to check for calibration drift during deployment .
- A calibration chain can be established using ship-based radiometers to validate the skin SST retrievals, provided the ship-based radiometers have SI-traceable calibration.
- This is achieved using the NIST TXR or NPL AMBER to characterize the laboratory black-body calibration targets to check the internal calibration of the ship-based radiometers.

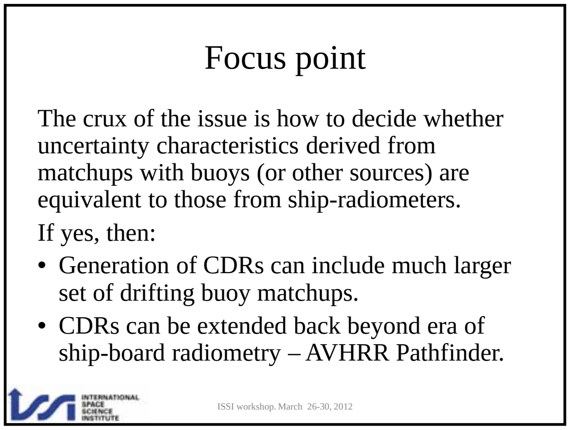


Unbroken traceability



Minnett, P. J. and G. K. Corlett, 2012: A Pathway to Generating Climate Data Records of Sea-Surface Temperature from Satellite Measurements. *Deep-Sea Research II*, **77–80**(0): 44-51





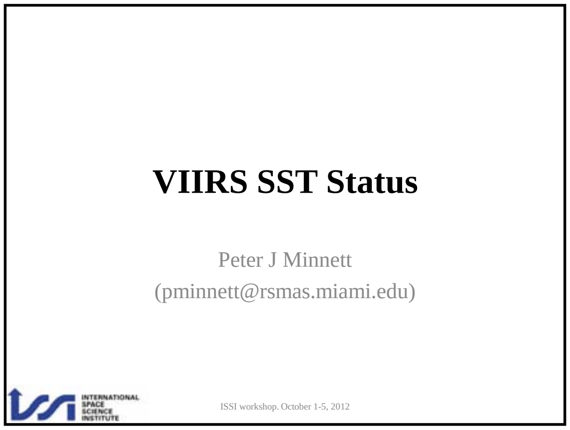
Focus point

The crux of the issue is how to decide whether uncertainty characteristics derived from matchups with buoys (or other sources) are equivalent to those from ship-radiometers.

If yes, then:

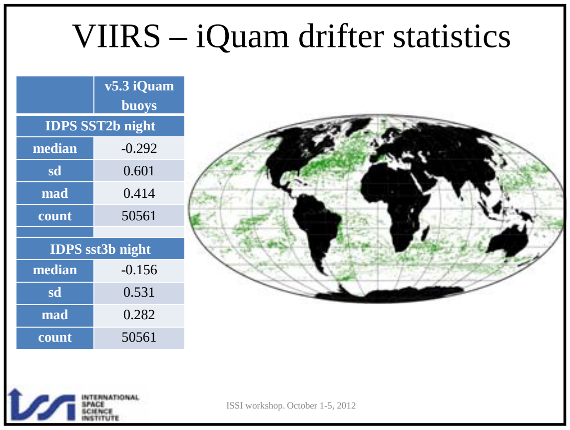
- Generation of CDRs can include much larger set of drifting buoy matchups.
- CDRs can be extended back beyond era of ship-board radiometry – AVHRR Pathfinder.

ISSI workshop. March 26-30, 2012



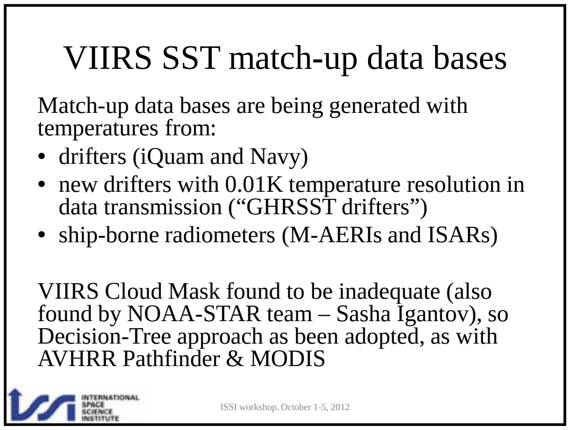
VIIRS SST Status

Peter J Minnett
(pminnett@rsmas.miami.edu)



VIIRS – iQuam drifter statistics

	v5.3 iQuam buoys
IDPS SST2b night	
median	-0.292
sd	0.601
mad	0.414
count	50561
IDPS sst3b night	
median	-0.156
sd	0.531
mad	0.282
count	50561

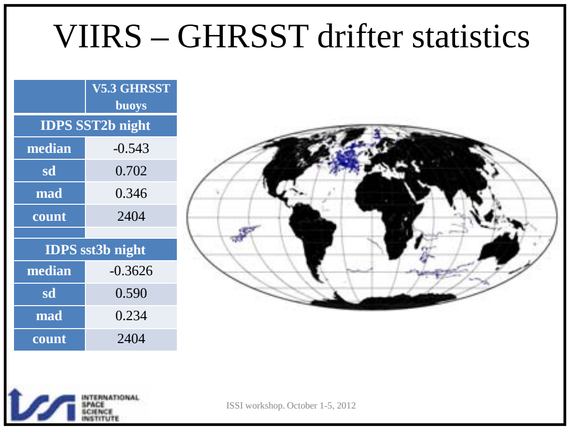


VIIRS SST match-up data bases

Match-up data bases are being generated with temperatures from:

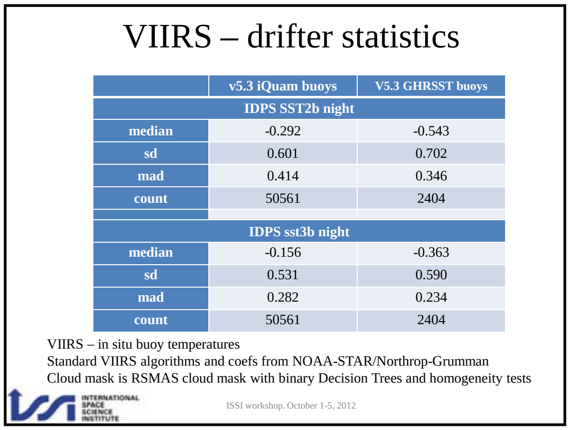
- drifters (iQuam and Navy)
- new drifters with 0.01K temperature resolution in data transmission (“GHRSST drifters”)
- ship-borne radiometers (M-AERIs and ISARs)

VIIRS Cloud Mask found to be inadequate (also found by NOAA-STAR team – Sasha Igantov), so Decision-Tree approach as been adopted, as with AVHRR Pathfinder & MODIS



VIIRS – GHRSST drifter statistics

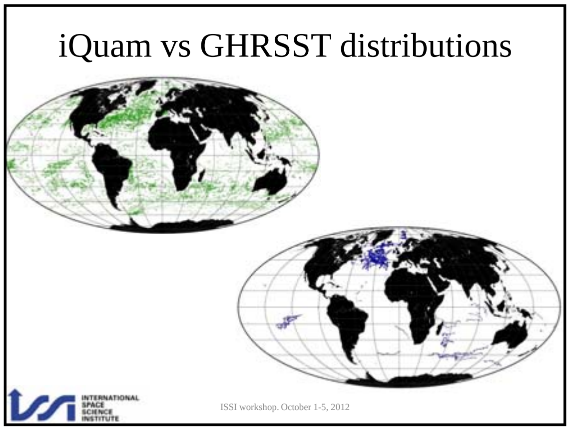
	V5.3 GHRSST buoys
IDPS SST2b night	
median	-0.543
sd	0.702
mad	0.346
count	2404
IDPS sst3b night	
median	-0.3626
sd	0.590
mad	0.234
count	2404



VIIRS – drifter statistics

	v5.3 iQuam buoys	V5.3 GHRSST buoys
IDPS SST2b night		
median	-0.292	-0.543
sd	0.601	0.702
mad	0.414	0.346
count	50561	2404
IDPS sst3b night		
median	-0.156	-0.363
sd	0.531	0.590
mad	0.282	0.234
count	50561	2404

VIIRS – in situ buoy temperatures
Standard VIIRS algorithms and coefs from NOAA-STAR/Northrop-Grumman
Cloud mask is RSMAS cloud mask with binary Decision Trees and homogeneity tests



iQuam vs GHRSST distributions

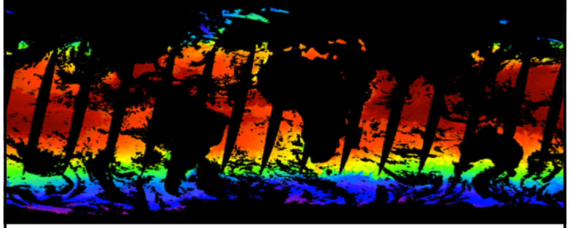
VIIRS – GHRSST Buoy matchups. Monthly and zonal distributions

Month	<40S	40S to 20S	20S to Eq	Eq to 20N	20N to 40N	>40N
4	18	23	99	3	17	171
5	29	46	112	6	21	144
6	41	30	101	0	28	113
7	51	38	100	1	38	164
8	36	46	81	9	61	284
9	5	4	10	3	8	52

- But VIIRS is under threat…..

VIIRS (night-time 3-band) SST

June 14, 2012



VIIRS SSTs derived using the SST Team atmospheric correction algorithm with monthly, latitudinally dependent coefficients derived using temperatures from quality-controlled drifting buoys, including those from iQuam.

Fri, 21 September, 2012

Report: Scale Back JPSS Satellite Effort

WASHINGTON — The U.S. National Oceanic and Atmospheric Administration (NOAA) should delete some climate sensors from its next-generation polar-orbiting weather satellite program and streamline its management to save money, an independent report said.

NOAA's JPSS. Credit: Ball Aerospace artist's concept

The report, delivered to NOAA July 21 and made public Sept. 21, said the Joint Polar Satellite System (JPSS) should not be responsible for flying two climate-change instruments that are now part of the program: the Clouds and Earth's Radiant Energy System sensor and the Total Solar Irradiance Sensor. The energy system sensor is aboard the first JPSS spacecraft, launched last October, and slated for inclusion on the second satellite, dubbed JPSS-1; the solar irradiance sensor is supposed to fly on a so-called Free Flyer satellite in 2016.

The report, chaired by former Lockheed Martin executive A. Thomas Young, said these two sensors should be part of a separate NOAA program or, better yet, be transferred to NASA.

In addition, the report said NOAA should explore replacing the JPSS's Visible and Infrared Imager Suite, which had a troubled development history, with a legacy alternative from an earlier generation of civilian polar-orbiting weather satellites.

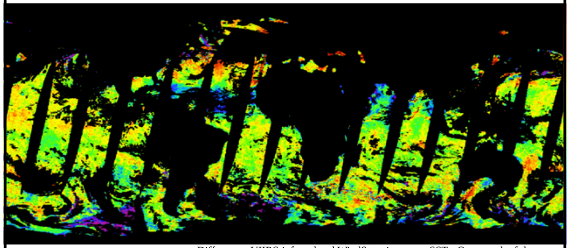
Retired U.S. Navy Rear Adm. David Titley, NOAA's deputy undersecretary for operations, said the agency was giving these suggestions serious consideration. "We are looking at if we simplify the JPSS program to be a basically a weather-only mission," he said in a Sept. 21 interview.

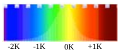
Titley identified the Advanced Very High Resolution Radiometer, which flew aboard NOAA's earlier-generation weather satellites, as a possible replacement for the Visible Infrared Imager Radiometer Suite.

The report largely gave the Geostationary Operational Environmental Satellite (GOES)-R program a pass, saying it is going "reasonably well" and has a less complicated management structure than the JPSS program. That first of those satellites is scheduled for a 2015 launch, although the report put the chances of meeting that timetable at 48 percent.

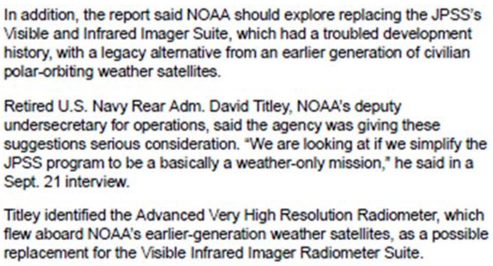
The JPSS joint NOAA-NASA management structure, on the other hand, "unnecessarily increases management costs and decreases the probability of mission success," according to the report.

SST Differences: VIIRS(3band night) – WindSat





Differences VIIRS infrared and WindSat microwave SSTs. Over much of the ocean the differences are small and uniform. Large negative differences (purple colors) in the Southern Ocean are likely due to cloud contamination in the VIIRS SSTs. The negative differences in the Atlantic (blue) are where we expect to see the effects of Saharan dust aerosols. Standard Deviation for SST derived from monthly coefficients, full IR mission are order 0.3K. The color scale is given at left.



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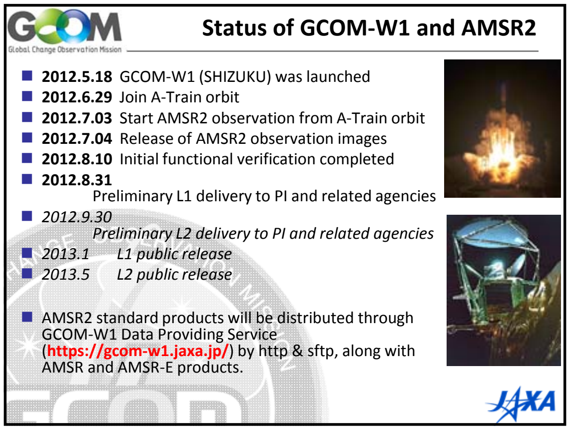
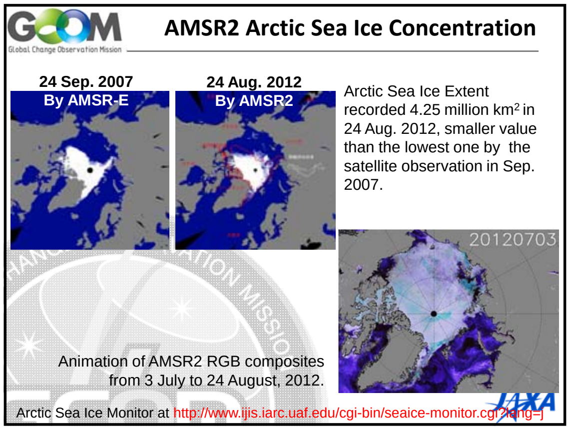


Status of GCOM-W1 and AMSR2

- **2012.5.18** GCOM-W1 (SHIZUKU) was launched
- **2012.6.29** Join A-Train orbit
- **2012.7.03** Start AMSR2 observation from A-Train orbit
- **2012.7.04** Release of AMSR2 observation images
- **2012.8.10** Initial functional verification completed
- **2012.8.31**
  Preliminary L1 delivery to PI and related agencies
- *2012.9.30*
  Preliminary L2 delivery to PI and related agencies
- *2013.1 L1 public release*
- *2013.5 L2 public release*
- AMSR2 standard products will be distributed through GCOM-W1 Data Providing Service (**https://gcom-w1.jaxa.jp/**) by http & sftp, along with AMSR and AMSR-E products.

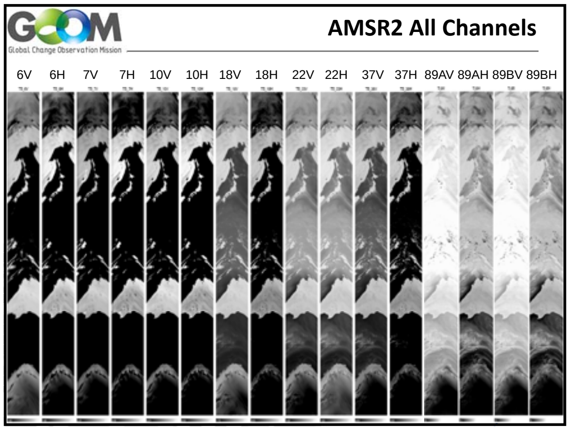


AMSR2 Arctic Sea Ice Concentration

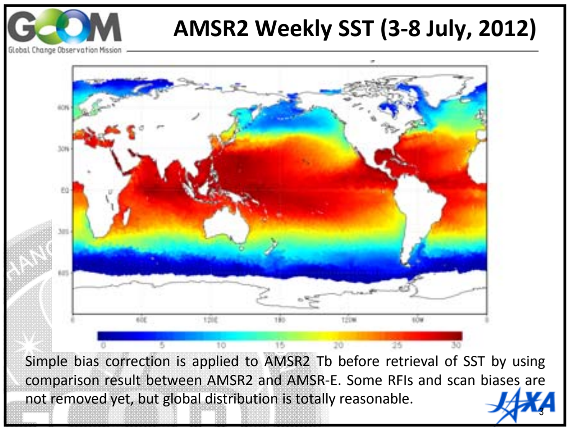
Arctic Sea Ice Extent recorded 4.25 million km^2 in 24 Aug. 2012, smaller value than the lowest one by the satellite observation in Sep. 2007.

Animation of AMSR2 RGB composites from 3 July to 24 August, 2012.

Arctic Sea Ice Monitor at http://www.ijis.iarc.uaf.edu/cgi-bin/seaice-monitor.cgi?lang=j



AMSR2 All Channels



AMSR2 Weekly SST (3-8 July, 2012)

Simple bias correction is applied to AMSR2 Tb before retrieval of SST by using comparison result between AMSR2 and AMSR-E. Some RFIs and scan biases are not removed yet, but global distribution is totally reasonable.

Updates from EUMETSAT

Peter J Minnett
(pminnett@rsmas.miami.edu)

Status - Metop-B - EUMETSAT http://www.eumetsat.int/metop-B

Metop-B Commissioning

METOP-B in Commissioning

Following a successful handover to EUMETSAT from ESA/ESOC, on 20 September, Metop-B is now in commissioning.

The timeline below gives details of the commissioning activities.

Last Updated: Friday, 28 September, 2012 14:40

Timeline

Key milestones for the post-launch commissioning phase, including details on when instruments are switched on and tested, and when data starts to become available for users

---

Notable developments at EUMETSAT

- METOESAT-10 launched
- MetOp-B launched
- MOU signed with China State Oceanic Administration’s (SOA’s) National Satellite Ocean Application Service (NSOAS)

Commissioning milestones

Title	Activity	Date/Status
Handover	Handover of Metop-B to EUMETSAT	**Completed** 20 September
SIOV Start	Satellite In-Orbit Verification (SIOV) begins	**Started**
	Final orbit phasing achieved	**Completed**
Payload verification	Solid State Recorder	**Completed**
	HRPT switch on	**Completed**
	HRPT verification	**Completed**
	Search & Rescue on	L+ 1.5 weeks
	ADCS Receiver and Transmitter on	**Completed**
	AVHRR & HIRS doors opening	L+ 4 weeks
	IASI mechanisms release	L+ 4.5 weeks
	IASI, HIRS & AVHRR outgassing	L+ 5 weeks
Direct Readout Available	Service continuously available according to the schedule below	
	AVHRR visible channel	**Available**
	GOME	**Available**
	First [illegible]	**Available**
	AMSU A1& A2	**Available**
	ASCAT	**Available**
	MHS	**Available**
	GRAS	**Available**
	ADCS	**Available**
	SEM	L+ 3 weeks
	HIRS	L+ 4 weeks
	AVHRR/3 IR	L+ 4 weeks
	IASI	L+ 6 weeks
SIOV ends	End of Satellite In-Orbit Verification (SIOV) phase	L+ 6 weeks
Global Data to Cal/Val Partners	AMSU-A1, A2	L+ 2-6 weeks
	AVHRR/3 VIS	L+ 2 weeks
	GRAS	L+ 3 weeks
	MHS	L+ 4 weeks
	HIRS/4	L+ 4 weeks
	ASCAT	L+ 5 weeks
	AVHRR/3 IR	L+ 5 weeks
	GOME-2	L+ 12 weeks
	IASI	L+ 17 weeks
Global Data to all users	Pre-operational data progressively made available per product processing facility	L+ 2-7 months
Regional Data to all users	EARS-AVHRR	L+ 9 weeks
	EARS-ATOVS	L+ 13 weeks
	EARS-ASCAT	L+ 23 weeks
	EARS-IASI	L+ 25 weeks
Satellite Operational	Metop-B becomes prime satellite	L+ 7.5 Months

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CEOS EO HANDBOOK – MISSION SUMMARY - Meteosat-10 http://database.eohandbook.com/database/missionsummary.aspx?missio

CEOS EO HANDBOOK – MISSION SUMMARY - Meteosat-10

Full Name	Meteosat Second Generation-3	**Status**	Approved
Mission Agencies	EUMETSAT, ESA	**Launch Date**	Jun 2012
Mission Links	mission site | data access portal	**EOL Date**	Jun 2020
EO Portal Info			
Orbit Type	Geostationary	**Orbit Period**	
Orbit Sense	N/A	**Orbit Inclination**	
Orbit Altitude	36000 km	**Orbit Longitude**	0 deg
Orbit LST		**Repeat Cycle**	
Objectives and Applications	Meteorology, climatology, atmospheric dynamics/water and energy cycles Meteosat 1-7 are first generation. Meteosat 8-11 are second generation and known as MSG in the development phase.		
Mission Instruments	GERB - Geostationary Earth Radiation Budget MSG Comms - Communications package for MSG SEVIRI - Spinning Enhanced Visible and Infra-Red Imager		

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Cooperation agreement with China State Oceanic Administration

August 30, 2012

EUMETSAT signs cooperation agreement with China State Oceanic Administration

Today’s signature of a cooperation agreement on the exchange of oceanographic satellite data between EUMETSAT and the China State Oceanic Administration’s (SOA’s) National Satellite Ocean Application Service (NSOAS) will further increase cooperation with China and create new opportunities for the oceanography user community.

Under the agreement, EUMETSAT will provide data from the Advanced Scatterometer (ASCAT) instruments flying on the Metop satellites as well as from the Jason-2 and Jason-3 ocean topography missions. In return, NSOAS/SOA will provide data from the HY-1 and HY-2 satellites, adding Chinese altimeter, radiometer, and scatterometer data to EUMETSAT’s portfolio of third party data. The cooperation will consolidate the position of EUMETSAT as a key data provider for the oceanography user community.

The agreement also covers cooperation on data processing, scientific activities, calibration and validation.

See http://www.eumetsat.int/Home/Main/News/Press_Releases/821834?l=en

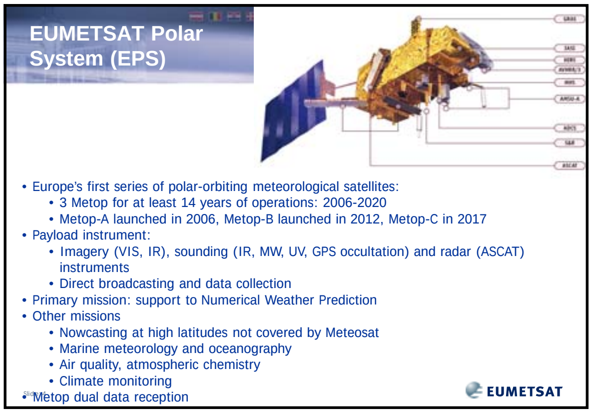
EUMETSAT

Monitoring weather and climate from space

EPS/Metop and MSG

www.eumetsat.int

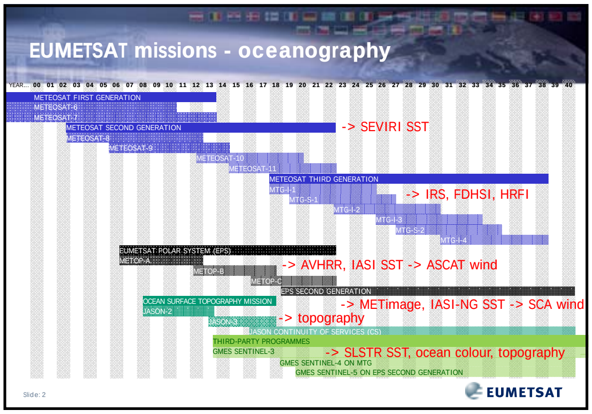
EUMETSAT



EUMETSAT Polar System (EPS)

- Europe's first series of polar-orbiting meteorological satellites:
  - 3 Metop for at least 14 years of operations: 2006-2020
  - Metop-A launched in 2006, Metop-B launched in 2012, Metop-C in 2017
- Payload instrument:
  - Imagery (VIS, IR), sounding (IR, MW, UV, GPS occultation) and radar (ASCAT) instruments
  - Direct broadcasting and data collection
- Primary mission: support to Numerical Weather Prediction
- Other missions
  - Nowcasting at high latitudes not covered by Meteosat
  - Marine meteorology and oceanography
  - Air quality, atmospheric chemistry
  - Climate monitoring
- Metop dual data reception

EUMETSAT



EUMETSAT missions - oceanography

-> SEVIRI SST

-> IRS, FDHSI, HRFI

-> AVHRR, IASI SST -> ASCAT wind

-> METimage, IASI-NG SST -> SCA wind

-> topography

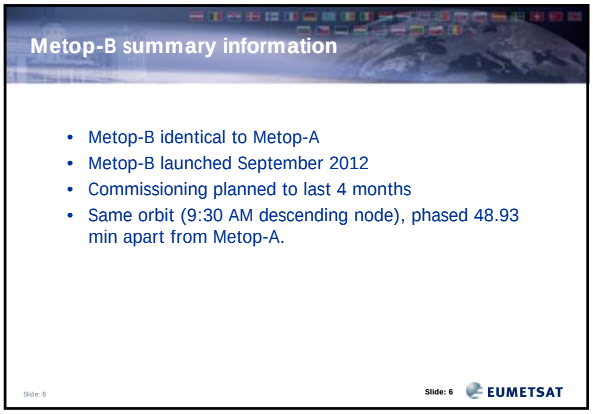
-> SLSTR SST, ocean colour, topography

EUMETSAT

Launch Metop-B
17 September 2012 16:28:40 UTC

Baikonur Cosmodrome

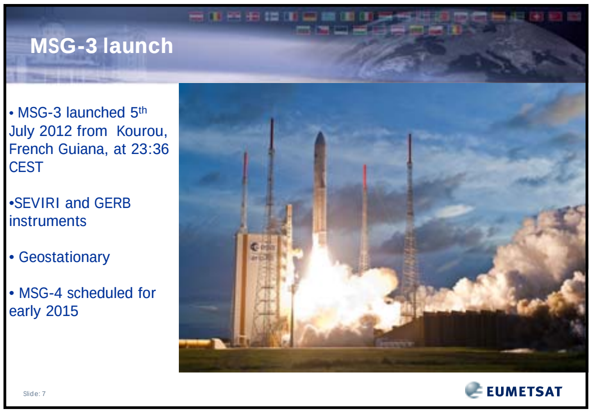
The EPS space component is the Metop-satellite



Metop-B summary information

- Metop-B identical to Metop-A
- Metop-B launched September 2012
- Commissioning planned to last 4 months
- Same orbit (9:30 AM descending node), phased 48.93 min apart from Metop-A.

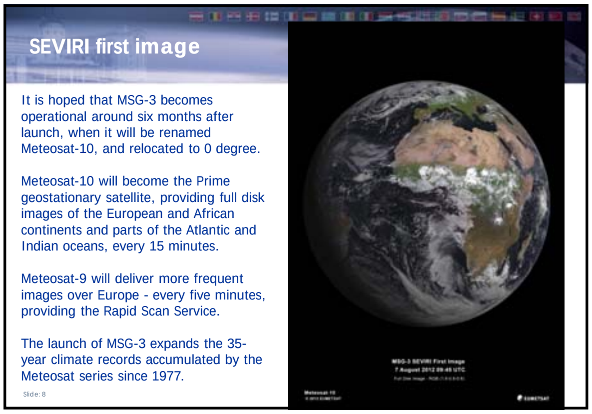
EUMETSAT



MSG-3 launch

- MSG-3 launched 5th July 2012 from Kourou, French Guiana, at 23:36 CEST
- SEVIRI and GERB instruments
- Geostationary
- MSG-4 scheduled for early 2015

EUMETSAT



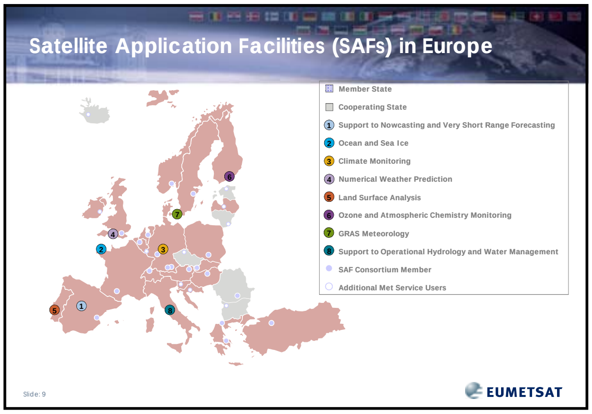
SEVIRI first image

It is hoped that MSG-3 becomes operational around six months after launch, when it will be renamed Meteosat-10, and relocated to 0 degree.

Meteosat-10 will become the Prime geostationary satellite, providing full disk images of the European and African continents and parts of the Atlantic and Indian oceans, every 15 minutes.

Meteosat-9 will deliver more frequent images over Europe - every five minutes, providing the Rapid Scan Service.

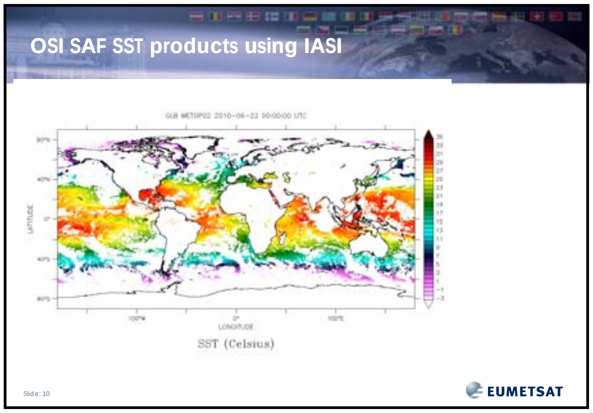
The launch of MSG-3 expands the 35-year climate records accumulated by the Meteosat series since 1977.



Satellite Application Facilities (SAFs) in Europe

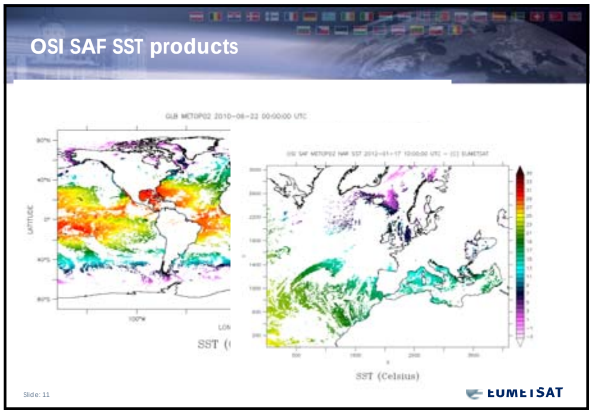
- ▨ Member State
- ☐ Cooperating State
- ① Support to Nowcasting and Very Short Range Forecasting
- ② Ocean and Sea Ice
- ③ Climate Monitoring
- ④ Numerical Weather Prediction
- ⑤ Land Surface Analysis
- ⑥ Ozone and Atmospheric Chemistry Monitoring
- ⑦ GRAS Meteorology
- ⑧ Support to Operational Hydrology and Water Management
- ● SAF Consortium Member
- ○ Additional Met Service Users

EUMETSAT



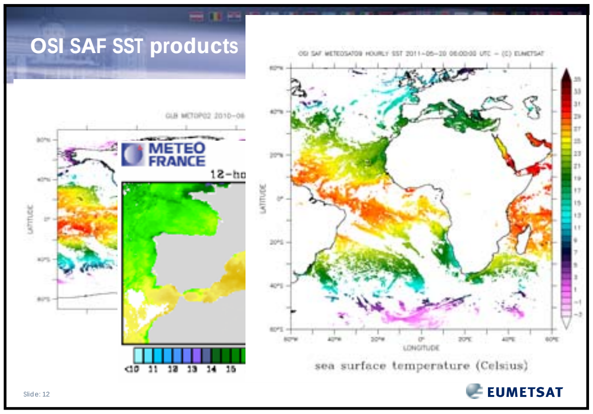
OSI SAF SST products using IASI

EUMETSAT



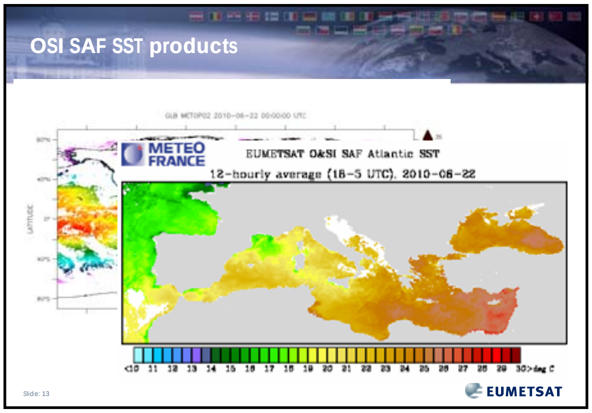
OSI SAF SST products

EUMETSAT



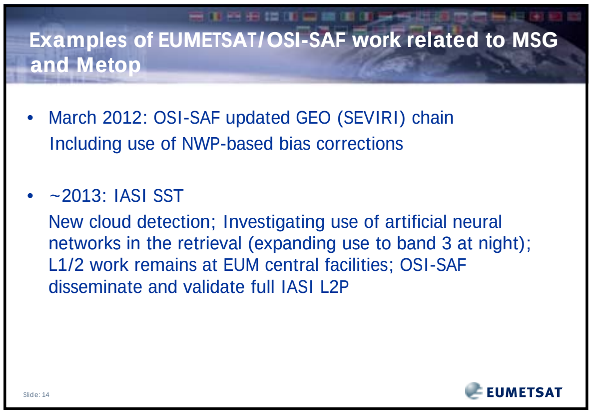
OSI SAF SST products

EUMETSAT



OSI SAF SST products

EUMETSAT



Examples of EUMETSAT/OSI-SAF work related to MSG and Metop

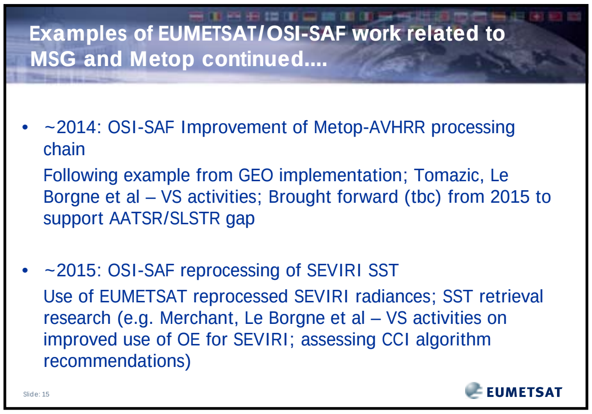
- March 2012: OSI-SAF updated GEO (SEVIRI) chain

  Including use of NWP-based bias corrections

- ~2013: IASI SST

  New cloud detection; Investigating use of artificial neural networks in the retrieval (expanding use to band 3 at night); L1/2 work remains at EUM central facilities; OSI-SAF disseminate and validate full IASI L2P

EUMETSAT



Examples of EUMETSAT/OSI-SAF work related to MSG and Metop continued....

- ~2014: OSI-SAF Improvement of Metop-AVHRR processing chain

  Following example from GEO implementation; Tomazic, Le Borgne et al – VS activities; Brought forward (tbc) from 2015 to support AATSR/SLSTR gap

- ~2015: OSI-SAF reprocessing of SEVIRI SST

  Use of EUMETSAT reprocessed SEVIRI radiances; SST retrieval research (e.g. Merchant, Le Borgne et al – VS activities on improved use of OE for SEVIRI; assessing CCI algorithm recommendations)

EUMETSAT

ESA Climate Change Initiative Phase 1

Sea Surface Temperature (SST)

Bridging the ENVISAT Gap: Preferred approach

Chris Merchant, Gary Corlett, Nick Rayner

Preferred option for bridging sensors

- Combination of:

  Metop-A AVHRR and IASI

  and Metop-B AVHRR and IASI

  - 0930/2130 h is close to SST_CCI reference local time
  - Long overlap of Metop-A AVHRR and AATSR
  - Expect Metop-A AVHRR to continue to 2016 (launch of Metop-C)
  - Stability of Metop-A AVHRR can be assessed relative to
    - AATSR for 6 years
    - Metop-A IASI on board
    - Metop-B AVHRR and Metop-B IASI
  - Retains independence from in situ
  - Retains independent validation and traceability to SI

Strengths of SST-CCI dataset

- Independence from in situ
  - Physics-based, referenced to AATSR D2* for both ATSRs and AVHRR
- Continuity 1991 - 2012
  - ~6 month global overlaps for ATSRs
- Excellent stability
  - 95% confidence interval on false trends expected within 5 mK yr^{-1}
    - Assessed for tropics
  - Consistent local time
    - ERS1/2 at 1030/2230h
    - Envisat at 1000/2200h
- Provide both SST-skin and SST-depth (at 1030/2230h)

Step 1: AVHRR-A / AATSR cross-referencing

- Developed and demonstrated within SST_CCI
- Utilises Multi-sensor Match-up System (MMS)
  - Double matches of AVHRR-A and AATSR to a common in situ reference
  - Method on next slide
- 'Best quality' AVHRR-A is bridge
  - Using SST CCI uncertainty model, select low-uncertainty data as bridging dataset
  - May be noisier than AATSR
  - But it is bias and stability that are paramount
- Once SLSTR is within the MMS, exploit overlap in same way

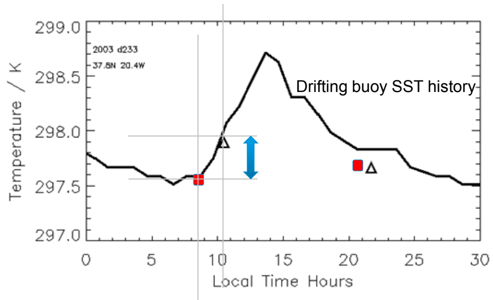
Can this be continued?

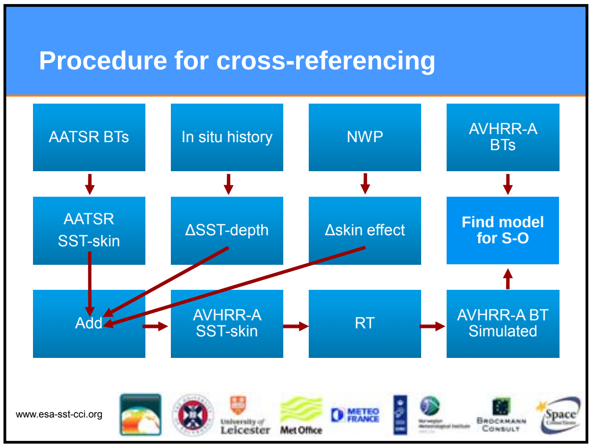
- Need to link to future of Sentinel 3 and SLSTR
- Minimum gap is 2 years

- What can bridge this gap?
  - 'Bridge' means to provide SST between AATSR and SLSTR …
  - … AND to overlap AATSR and SLSTR at either end
  - … in order to get homogeneity/stability from overlaps

- Can independence be preserved?
- Can stability be assessed and controlled?

Multi-sensor Match with *in situ* history





Procedure for cross-referencing

AATSR BTs

In situ history

NWP

AVHRR-A BTs

AATSR SST-skin

ΔSST-depth

Δskin effect

Find model for S-O

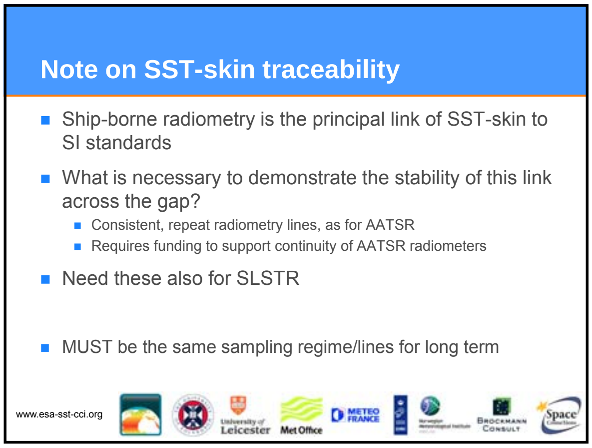
Add

AVHRR-A SST-skin

RT

AVHRR-A BT Simulated

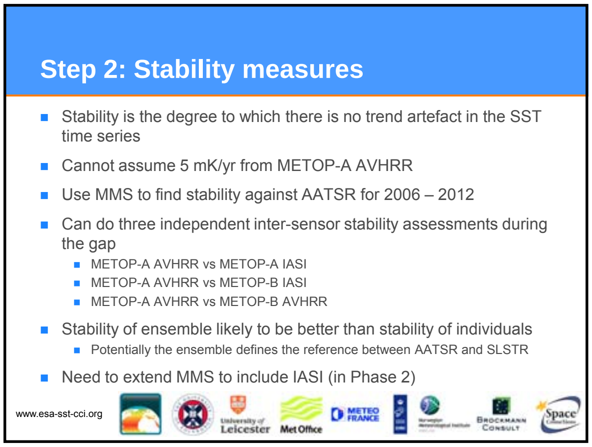
www.esa-sst-cci.org



Note on SST-skin traceability

- Ship-borne radiometry is the principal link of SST-skin to SI standards
- What is necessary to demonstrate the stability of this link across the gap?
  - Consistent, repeat radiometry lines, as for AATSR
  - Requires funding to support continuity of AATSR radiometers
- Need these also for SLSTR
- MUST be the same sampling regime/lines for long term

www.esa-sst-cci.org



Step 2: Stability measures

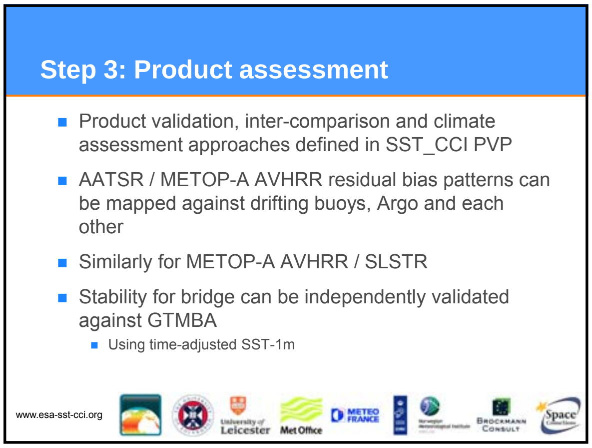
- Stability is the degree to which there is no trend artefact in the SST time series
- Cannot assume 5 mK/yr from METOP-A AVHRR
- Use MMS to find stability against AATSR for 2006 – 2012
- Can do three independent inter-sensor stability assessments during the gap
  - METOP-A AVHRR vs METOP-A IASI
  - METOP-A AVHRR vs METOP-B IASI
  - METOP-A AVHRR vs METOP-B AVHRR
- Stability of ensemble likely to be better than stability of individuals
  - Potentially the ensemble defines the reference between AATSR and SLSTR
- Need to extend MMS to include IASI (in Phase 2)

www.esa-sst-cci.org

Step 4: Pray

- Specifically, for *none* of these:

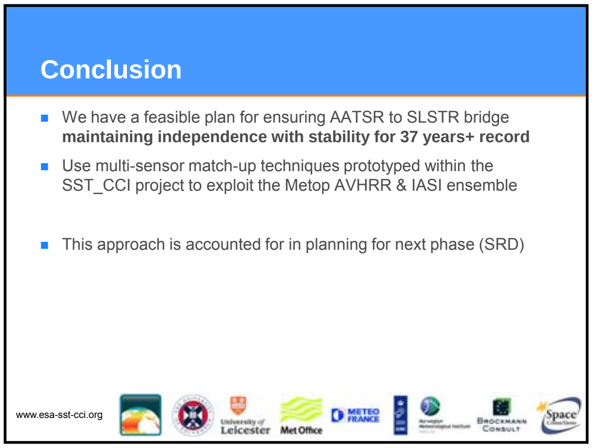
www.esa-sst-cci.org



Step 3: Product assessment

- Product validation, inter-comparison and climate assessment approaches defined in SST_CCI PVP
- AATSR / METOP-A AVHRR residual bias patterns can be mapped against drifting buoys, Argo and each other
- Similarly for METOP-A AVHRR / SLSTR
- Stability for bridge can be independently validated against GTMBA
  - Using time-adjusted SST-1m

www.esa-sst-cci.org



Conclusion

- We have a feasible plan for ensuring AATSR to SLSTR bridge **maintaining independence with stability for 37 years+ record**
- Use multi-sensor match-up techniques prototyped within the SST_CCI project to exploit the Metop AVHRR & IASI ensemble
- This approach is accounted for in planning for next phase (SRD)

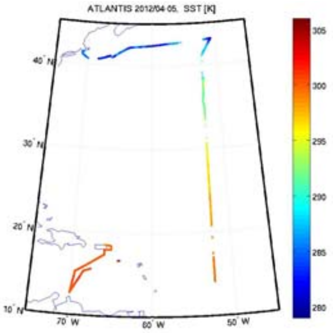
www.esa-sst-cci.org

Update on ship-based radiometer deployments

Peter J Minnett

M-AERI on R/V *Atlantis*

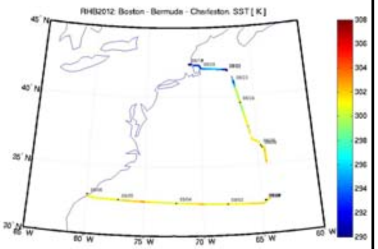
Skin SSTs measured by an M-AERI, along the track of the R/V *Atlantis*, in April and May, 2012. These data are included in VIIRS SST matchup data bases.



Both RSMAS ISARs at sea

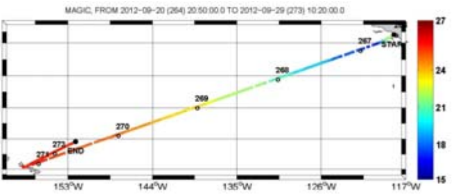
- NYK Lines ship *Andromeda Leader* deployment continues
- ISAR installed on *Horizon Spirit* as part of a year-long project of the DoE ARM program, called MAGIC.

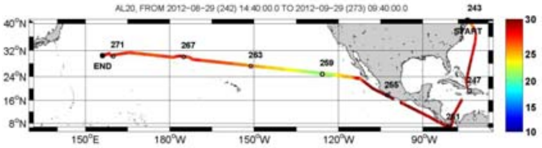

M-AERI Mk-2 on *Ronald H Brown*

Skin SSTs measured by a M-AERI Mk2 along the track of the NOAA Ship *Ronald H Brown*, August 19 – September 6, 2012. Main cruise, Bermuda to Barbados via PNE moorings off W. Africa was cancelled, and rescheduling is under discussion.

These are preliminary data and after quality assurance will be included in VIIRS SST matchup data bases.

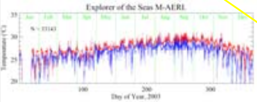




Royal Caribbean Cruise Lines

Use of commercial cruise liners provides a cost-effective mechanism for generating long time-series of radiometric measurements of skin SST, often along repeating tracks.





M-AERI on:
Allure of the Seas, starting 2012;
Explorer of the Seas, 2000-2006, restarting in 2012.

The treatment of uncertainties in SST measurements using radiation thermometers for the validation of satellite SST measurements

E. Theocharous (Theo)

Optical Metrology Group, NPL, UK

e.theo@npl.co.uk

4th October 2012

TREATMENT OF UNCERTAINTIES

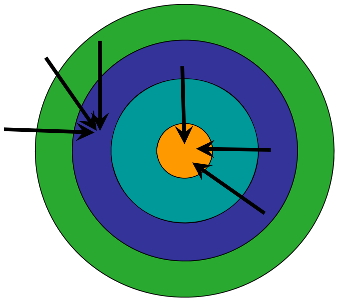
- **The acquisition of CDR requires traceability to SI units.**
- **Traceability is required to an internationally agreed reference standard (ideally SI)**
- **Traceability is the property of a measurement whereby it is related to a reference standard through an unbroken chain of calibration steps, each with its own stated measurement uncertainty** (ISO 1995, “Guide to the expression of uncertainty in measurement (GUM)”, ISBN number: 92-67-10188-9)

CONTENTS

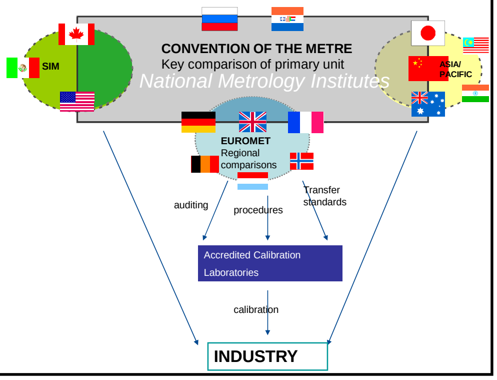
1. Introduction – importance of Traceability.
2. Treatment of uncertainties.
3. The steps required for the development of an uncertainty budget..
4. Uncertainties in SST measurements.
5. Conclusions

- Traceability **requires** the correct treatment of measurement uncertainties.
- Each calibration step has to have its own, appropriate, uncertainty budget.
- Unfortunately the interpretation of traceability by some instrument manufacturers and users who declare the calibration of their instruments as being traceable to National Standards Laboratories is not always as rigorous as the true definition requires.

Precision: measurement repeatability Accuracy: closeness to true value



Traceability requires a true value of whatever is measured



CONVENTION OF THE METRE
Key comparison of primary unit
National Metrology Institutes

SIM

ASIA/ PACIFIC

EUROMET
Regional comparisons

auditing

procedures

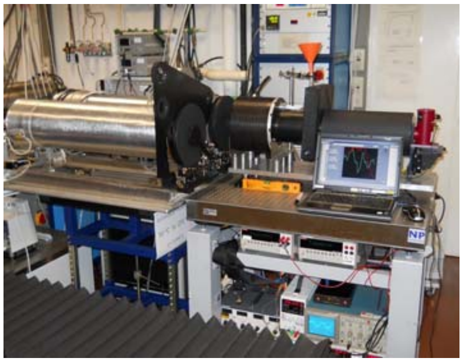
Transfer standards

Accredited Calibration Laboratories

calibration

INDUSTRY

Comparison of the radiation temperature scales of the PTB and NPL in the temperature range from -57 °C to 50 °C



Simplest traceability root

Reference Blackbody

Radiation thermometer

Transfer standard blackbody

Calibrated SST-measuring radiation thermometer

Measurement of the SSTs using the calibrated radiation thermometer

---

Comparison of the radiation temperature scales of the PTB and NPL in the temperature range from -57 °C TO 50 °C

B. Gutschwager, E. Theocharous et al.

Submitted for publication in
Measurement Science and Technology

Guidance on how to prepare an uncertainty budget for each of the three calibration steps highlighted above

Reference Blackbody

Radiation thermometer

Transfer standard blackbody

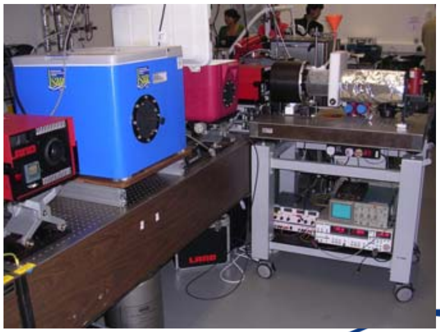
The traceable measurement of SST using radiation thermometers such as SISTER, ISAR or MAERI should include of the following <u>minimum</u> calibration steps:

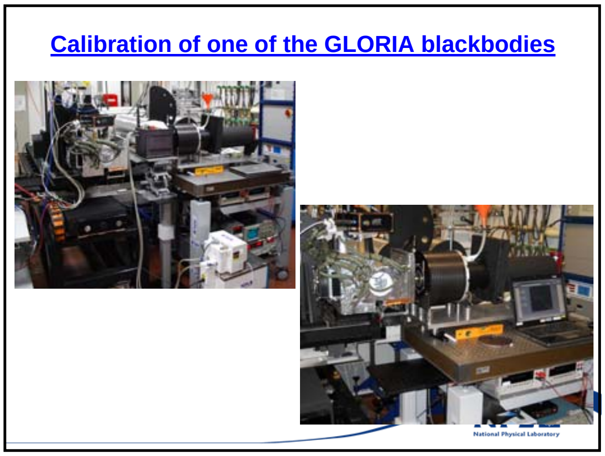
i. Calibration of the radiance temperature (related to spectral radiance via Planck' equation) of a transfer standard blackbody against SI units (a reference blackbody). The transfer standard blackbody will be used to calibrate the radiation thermometer (see next step).

ii. Calibration of the responsivity of the radiation thermometer against the calibrated transfer standard blackbody (which was calibrated under step (i)).

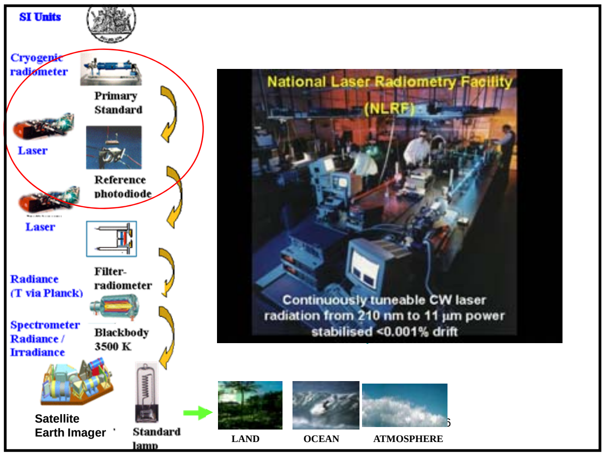
iii. Measurement of the SST of the ocean using the calibrated radiation thermometer (calibrated under step (ii)).

AMBER calibrating “transfer standard” blackbodies



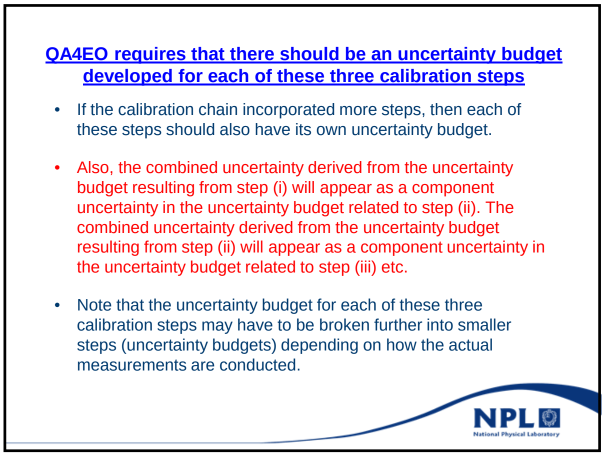


Calibration of one of the GLORIA blackbodies



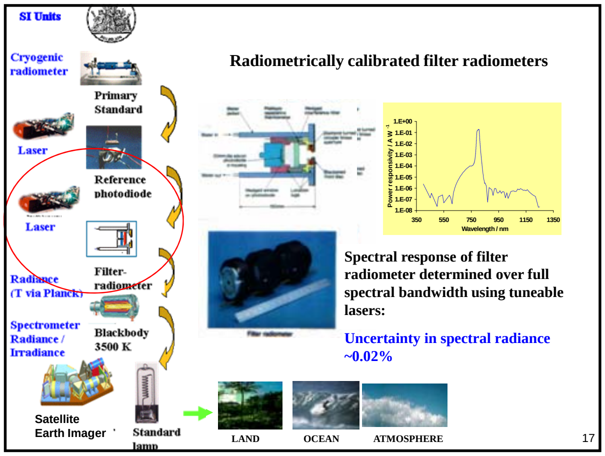
National Laser Radiometry Facility (NLRF)

Continuously tuneable CW laser radiation from 210 nm to 11 µm power stabilised <0.001% drift



QA4EO requires that there should be an uncertainty budget developed for each of these three calibration steps

- If the calibration chain incorporated more steps, then each of these steps should also have its own uncertainty budget.
- Also, the combined uncertainty derived from the uncertainty budget resulting from step (i) will appear as a component uncertainty in the uncertainty budget related to step (ii). The combined uncertainty derived from the uncertainty budget resulting from step (ii) will appear as a component uncertainty in the uncertainty budget related to step (iii) etc.
- Note that the uncertainty budget for each of these three calibration steps may have to be broken further into smaller steps (uncertainty budgets) depending on how the actual measurements are conducted.

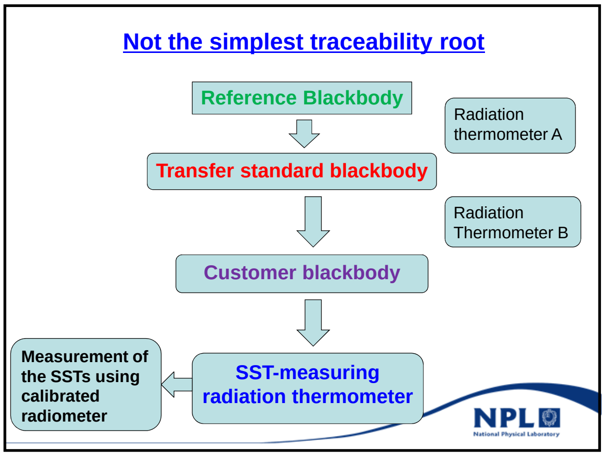


Radiometrically calibrated filter radiometers

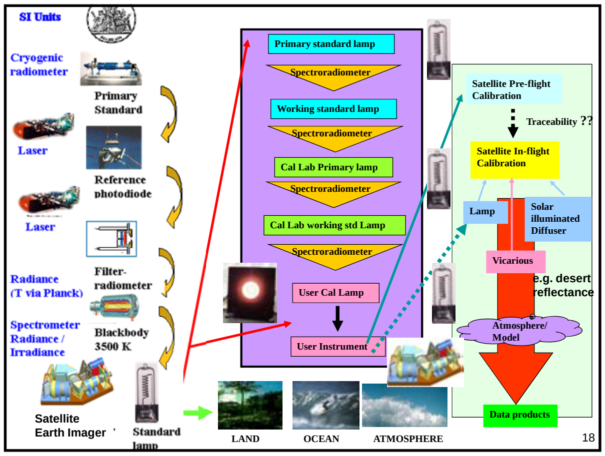
Spectral response of filter radiometer determined over full spectral bandwidth using tuneable lasers:

Uncertainty in spectral radiance ~0.02%

17



Not the simplest traceability root



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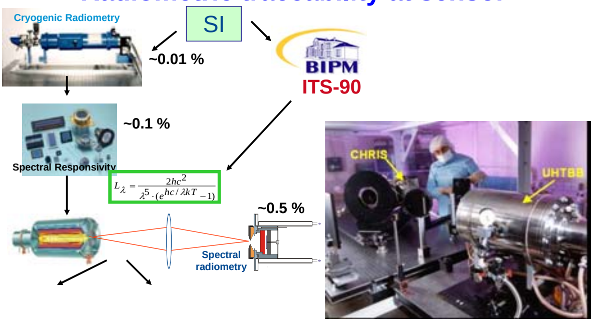
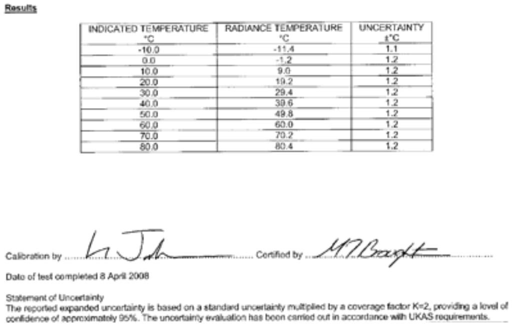
Radiometric traceability at sensor



Certificate of calibration of a P80P blackbody



Results

INDICATED TEMPERATURE °C	RADIANCE TEMPERATURE °C	UNCERTAINTY ±°C
-10.0	-11.4	1.1
0.0	-1.2	1.2
10.0	9.0	1.2
20.0	19.2	1.2
30.0	29.4	1.2
40.0	39.6	1.2
50.0	49.8	1.2
60.0	60.0	1.2
70.0	70.2	1.2
80.0	80.4	1.2

Calibration by .... Certified by ....

Date of test completed 8 April 2008

Statement of Uncertainty
The reported expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor K=2, providing a level of confidence of approximately 95%. The uncertainty evaluation has been carried out in accordance with UKAS requirements.

"Typical value of difference between radiometer brightness temperature and Landcal Blackbody Source P80P temperature"

Parameter	Type A Uncertainty in Value / %	Type B Uncertainty in Value / (appropriate units)	Uncertainty in Brightness temperature K
Repeatability of measurement(1)	0.009K / 0.003%		0.009
Reproducibility of measurement(2)	0.03K / 0.010%		0.03
Linearity of radiometer(3)		0.02 K	0.02
Primary calibration(4)		0.06 K	0.06
Drift since calibration		-	-
RMS total	0.03K / 0.011%	0.06 K	0.07

Impossible!

- The participant ignored the calibrated values shown by the certificate.
- The participant quoted a combined uncertainty of a measurement using his radiometer as 0.07 ºC.
- However, the calibration certificate shows that the uncertainty in the blackbody calibration was an order of magnitude (0.6 ºC).
- Not quite possible!

Calibration Requirements

The use of "Substitution" method is highly desirable.

In the infrared, **blackbodies** provide superior standards compared to photo-detectors (radiometers) because of their superior long term stability.

However, you cannot rely on just the PRT (thermometer) reading alone to provide the radiance temperature of the blackbody!!!!!!!

With blackbodies you have to consider:

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

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

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

This "error" is added as a correction to the temperature measured by the PRT. e.g. changing the emissivity of a BB at 30 C from 0.9993 to 0.9999 changes the radiance temperature by 50 mK!

Add uncertainty contribution due to emissivity

Other blackbody issues

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

Estimate **temperature drop** due to thermal resistance between thermometer position and inside of the cavity. One of our Ga reference blackbodies suffers from a 22 mK temperature drop! This should be added as a correction (and as an uncertainty).

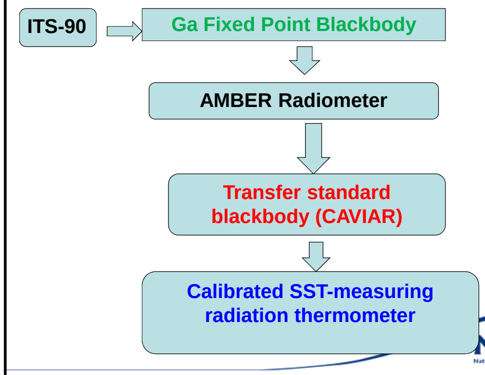
Correction/uncertainty due to **radiative heating/cooling** of the blackbody cavity to the environment. (small for BB operating at ambient temperatures, but significant).

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

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

Stability of the blackbody temperature.

NPL traceability root at 10 um



ITS-90

Ga Fixed Point Blackbody

AMBER Radiometer

Transfer standard blackbody (CAVIAR)

Calibrated SST-measuring radiation thermometer

Definition of "zero"

1. The substitution method works best when the SST reading is equal to the reference blackbody reading (null effect).
2. If the temperatures of the two BB differ, one has to consider corrections due to the "Zero radiance reference". Using two BB helps!
3. At NPL we use a "77 K" blackbody to define "zero". We have to because we operate down to -70 C.
4. Our calculations indicate that working at around 10 um wavelength, we require a cold blackbody of temperature less than 110 K to ensure errors below 10 mK.

Standard uncertainty budget of the radiance temperature of a Ga fixed-point blackbody

Contribution	Standard Uncertainty / mK	Comment
Uncertainty due to the Ga blackbody emissivity	29	Difference of cavity emissivity (0.9993) from unity is taken to be the uncertainty contribution (with rectangular distribution). The standard uncertainty is provided in mK.
Uncertainty due to Ga blackbody temperature "drop"	13	Estimated from the temperature drop between the Ga metal and the inside surface of the Ga blackbody cavity.
Stability of the Ga blackbody radiance temperature (as indicated by a high resolution radiometer such as AMBER). This is type A uncertainty.	4	Standard deviation of measurements over the measurement period e.g. 5 minutes.
Uncertainty due to radiation heat loss to the environment	2	Small since the Ga blackbody is operating just above ambient.
Uncertainty due to convective heat loss to the environment	2	Small since the Ga blackbody is operating just above ambient.
Uncertainty due to (spatial) temperature variation inside the cavity	3	
Uncertainty due to ambient temperature fluctuations	2	
Uncertainty due to the purity of the Ga metal	1	The Ga metal used to fill the blackbody cavity was 99.9999% pure.
Combined uncertainty (k=1)	32 mK	

Spectral issues

N.B. Considerations should be given to atmospherics absorption/humidity.

If you can tolerate the poorer signal-to-noise ratio, then use a narrow band radiometer.

Measure spectral response profile of radiometer and use it in calculations (rather than using single wavelength approximation)

Systematic standard uncertainties when AMBER is used to measure the radiance temperature of a test blackbody in the 10 ˚C to 40 ˚C temperature range by comparison to a gallium fixed-point blackbody.

Contribution	Standard Uncertainty / mK	Comment
Uncertainty in the Ga blackbody radiance temperature	32	Taken from Ga blackbody uncertainty budget (see Table 3)
Uncertainty due to the lock-in amplifier non-linearity (Theocharous, 2008)	36	0.1% non-linearity in the lock-in amplifier (maximum in the -50 °C to 30 °C temperature range). Depends on the difference between the Ga melting point temperature and the temperature of the target being measured.
Uncertainty in the relative spectral responsivity calibration of 10.1 µm filter radiometer	6	From the calibration of the relative spectral responsivity of the 10.1 µm filter radiometer
Uncertainty due to the definition of the "radiometric zero"	4	From monitoring the AMBER output when the 77 K blackbody is being viewed
Uncertainty in the measurement of the ZnSe AMBER window transmission	1	Common to all blackbody measurements, hence the uncertainty due to this window is small.
Uncertainty in the measurement of the ZnSe AMBER lens transmission	1	Common to all blackbody measurements, hence the uncertainty due to this window is small.
AMBER stability/drift over the period of a measurement	18	based on 0.05% drift over a measurement period i.e. 5 minutes
Uncertainty due to ambient temperature fluctuations	12	See reference (Theocharous and Theocharous, 2006)
Uncertainty due to chopper frequency fluctuations	2	Based on a 0.2 Hz drift in the chopper frequency during a measurement cycle.
Combined uncertainty (k=1)	53 mK	

The steps required for the development of an uncertainty budget

- Determine the mathematical relationship between input and output quantities (if it exists).
- List the parameters which can potentially affect the measurement. These are potential sources of uncertainty!
- Assign uncertainty values and probability distributions to the parameters identified.
- Convert to Standard Uncertainty for each parameter.
- Determine Sensitivity Coefficients (partial derivatives, if a functional relationship exists) for each parameter. If a functional relationship does not exists, then change variable by small amount , while keeping the others the same and noting the change in output.

Sensitivity coefficients – the options

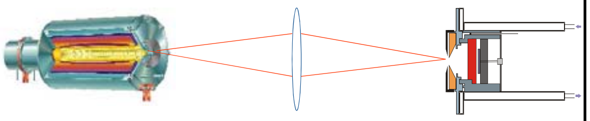
Differential Calculus	Numerical Trial and Error	Experimental Trial and Error
Simple relationships	Complex expressions	Unknown relationship

The steps required for the development of an uncertainty budget (cont.)

- Are the different uncertainties correlated? If yes, then determine correlation coefficients.
- Combine uncertainty contributions using standard techniques to determined the **combined standard uncertainty**.
- Determine Degree of Freedom, Coverage Factor and Expanded Uncertainty.

In radiometer Planck's law is used extensively

$$\boxed{L_\lambda = \frac{2hc^2}{\lambda^5 \cdot (e^{hc/\lambda kT} - 1)}}$$

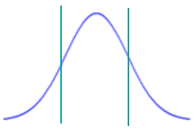


$$y = f(x_1, \quad x_2, \quad x_3, \quad ....)$$

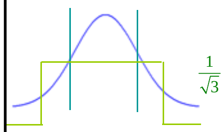
$$c_i = \frac{\partial y}{\partial x_i}$$

$$U_c(y) = \sqrt{c_1{}^2 * U^2(x_1) + c_2{}^2 * U^2(x_2) + c_3{}^2 * U^2(x_3) ....}$$

Convert to standard uncertainties



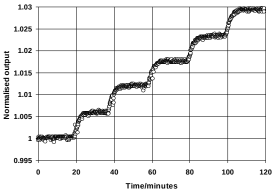
- •Normal distribution



- •Rectangular distribution
- •You know it's in a range

Temperature Coefficient of Response

- It is defined as the percentage change in the responsivity of the instrument, resulting from an increase of the ambient temperature of 1 °C.
- It is calculated by measuring the output of the radiation thermometer while it is sequentially maintained at a number of temperatures around ambient. Figure 1 shows the output of a radiometer located in an enclosure, as the temperature of the enclosure was increased every 20 minutes in steps of 2 °C, from 20 °C to 30 °C.



How to deal with the temperature coefficient of response

- From the slope of the plot of the radiometer output at different ambient/enclosure temperatures, the temperature coefficient of response of the radiometer can be estimated (+0.29% $^{o}C^{-1}$).
- The ambient temperature should be recorded during the entire period during which a set of measurements is acquired using this radiometer.
- The maximum deviation of the ambient temperature during that period should be calculated (say 2 °C).
- The maximum percent fluctuation on the radiometer output during the monitoring period (2 °C at 0.29% per °C means a maximum deviation of 0.58%) is estimated.
- This is treated as an uncertainty contribution with a rectangular profile which is equivalent to a standard uncertainty contribution equal to 0.58% divided by the square root of 3.
- This uncertainty contribution is added to the other uncertainty components to arrive at the combined uncertainty of the measurement completed with that radiometer.

Temperature Coefficient of Response (cont.)

- One way of reducing the uncertainty contribution due to the temperature coefficient of response of the radiation thermometer is to actively stabilise the temperature around the instrument.
- However, this may not be practically feasible due to the extra power requirements which will be necessary. At least stabilise the most sensitive components of the instrument. The DLATGS used in SISTER changes by 2.5% per °C.
- Another method would be to reduce the period of data acquisition to ensure that the drift in the ambient temperature during that period is minimised

Other sources of uncertainty

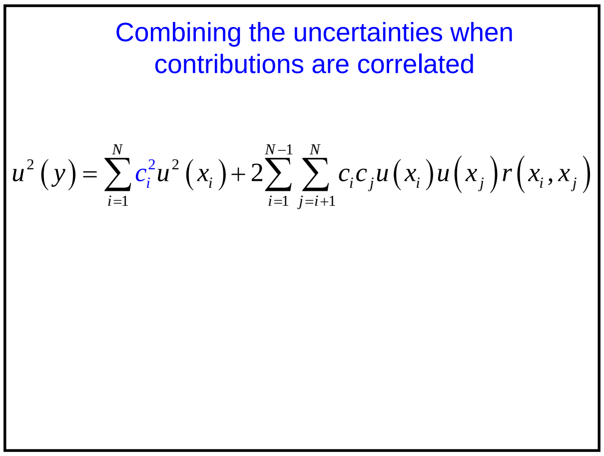
- **Ambient Humidity fluctuations**: Treatment similar to temperature coefficient of response.
- **Linearity of response**: Null measurement aids linearity.
- **"Dark" or "zero reading" measurements**: Only an issue for SST very different from the temperature of the internal blackbodies.
- **Out-of-band response:** Only an issue for SSTs very different from the temperature of the internal blackbodies.
- **Stability/Ageing**: Drift of internal blackbodies between calibrations? Degradation of components?
- **Polarisation**: Characterise response to polarised light.
- **Temporal Response**
- **Repeatability, Type A uncertainty**

Other sources of uncertainty (continued)

- **Out-of-field stray light**: Important when bright sources (e.g. the sun) are near the FoV of the radiometer.
- **Uncertainty in the viewing angle**; the water emissivity is a function of the "angle of incidence". The observation angle of the radiation thermometer will depend on the tilting of the ship. The level of tilting of the ship should be recorded and the corresponding change in the observation angle should be estimated. The corresponding change in the water emissivity (due to changes in the observation angle) should then be calculated, from which the corresponding uncertainty in the SST can be calculated.
- **Uncertainty contribution due to the water emissivity**.
- **Uncertainty contribution due to the "state of the sea surface"**.
- **Uncertainty contribution due to the "wind speed**".

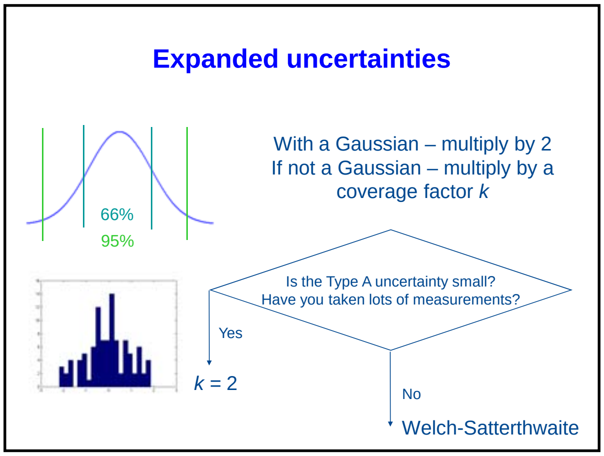
Other sources of uncertainty (continued)

- Uncertainty contribution due to the measurement of the sky radiance.
- Uncertainty contribution due to the delay between readings of the SST, the internal blackbody and the sky radiance temperature.
- Uncertainty contribution due to relative spectral responsivity of the radiation thermometer response (partly covered by out of band response)
- Uncertainty contribution due to the "Size of Source" effect
- Responsivity



Combining the uncertainties when contributions are correlated

$$u^2(y) = \sum_{i=1}^{N} c_i^2 u^2(x_i) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} c_i c_j u(x_i) u(x_j) r(x_i, x_j)$$



Expanded uncertainties

With a Gaussian – multiply by 2
If not a Gaussian – multiply by a coverage factor *k*

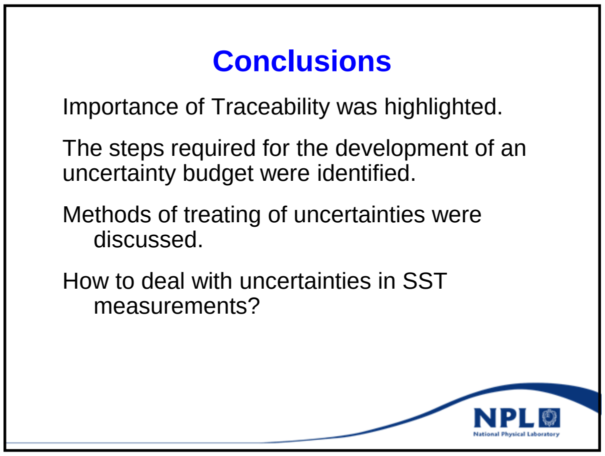
Is the Type A uncertainty small?
Have you taken lots of measurements?

Yes

$k = 2$

No

Welch-Satterthwaite



Conclusions

Importance of Traceability was highlighted.

The steps required for the development of an uncertainty budget were identified.

Methods of treating of uncertainties were discussed.

How to deal with uncertainties in SST measurements?