Report to IVOS 24: Surface Temperature

Gary Corlett

Content

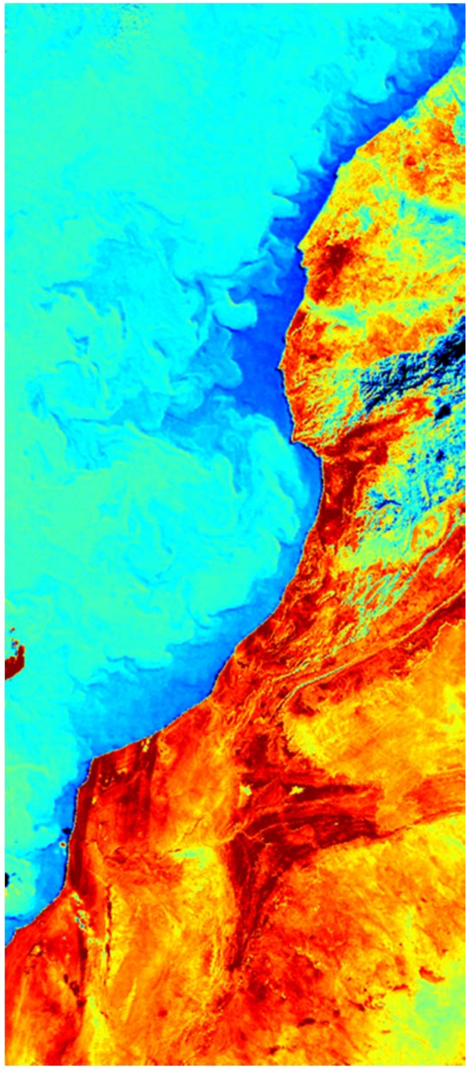
- Virtual constellation on sea surface temperature
- A pathway to generating an SST CDR
- SST val needs for a climate
- GHRSST progress
  - ARC time series homogenisation and stability
- Pre-launch calibration of SLSTR

Recommendations

- Recommendation for next IR intercomparison
- Recommendation for common approach to stability assessment across domains

LST&E validation

- Not as easy as SST
  - But tractable
- Four main methods for LST&E validation
  - Compare to in situ
  - Radiance based
  - Intercomparison
  - Time series
- Multi-sensor approach is preferred
  - Aids interpretation of results
- Best practice document drafted
  - Under funding from ESA
  - Then to be iterated with LPV (Hook, Sobrino) and rest of community



The CEOS Sea Surface Temperature Virtual Constellation (SST-VC)

Dr. Craig Donlon, European Space Agency

and

Dr. Kenneth S. Casey, NOAA National Oceanographic Data Center

Committee on Earth Observation Satellites

SST-VC Background

- The SST-VC is implemented through the long-standing Group for High Resolution SST (GHRSST)
- Since its inception in 2000, GHRSST has included not just operational, near-real time data streams, but also climate data records in its scope
- A Technical Advisory Group for reprocessed data was established at the start
- “Climate thinking” was factored into GHRSST Data Product Specifications (GDS) from the beginning
- Data products were brought together physically and archived
- Intercomparison systems were developed AND used
- User feedback was solicited and acted upon

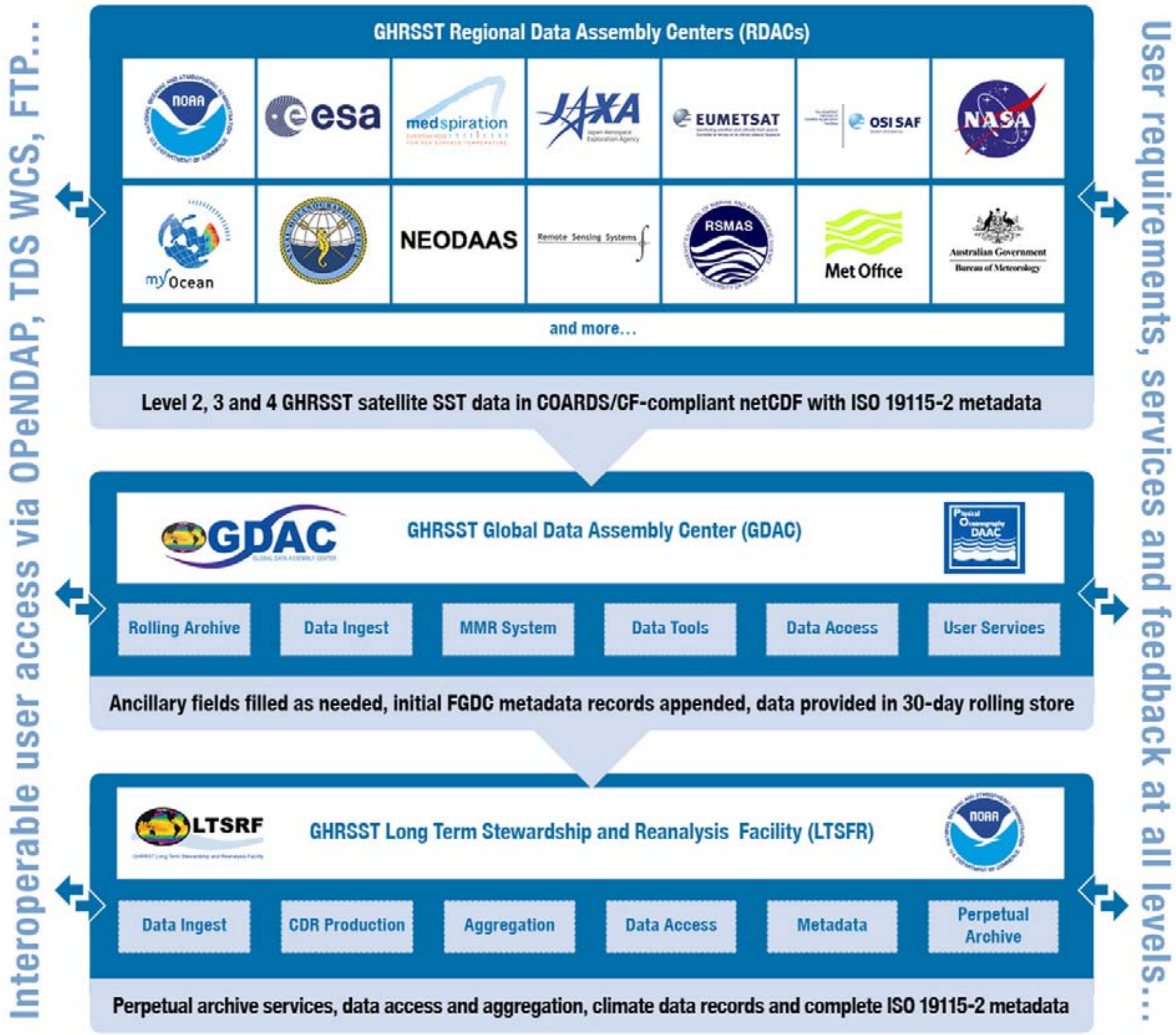
SST-VC Lessons Learned

- **Define a product specification and <u>require</u> its use**
  - Don't be afraid of large volumes
  - Use CF/ACDD-compliant netCDF-4 (within internal compression and chunking)
  - Develop tools and teams to help your Producers get it into that format
  - Standardize what you can – and what you can't, standardize the container and the description of it
  - Use ISO 19115-2 collection-level metadata
- **Make sure the operational products are archived and accessible, even if not "climate quality"**
  - Needed to demonstrate how much better reprocessed data sets
  - You may need them as first guesses in your climate-quality algorithms
- **Define an ECV Product Framework and be inclusive (at first)**
- **Then when you really understand the playing field…**
  - Define a more rigorous ECV Data Processing Framework that sets a higher standard for products to be considered vetted and community consensus climate data records
- **Remember you will likely need multiple climate data records**
  - No one product will typically be able to fill all user needs

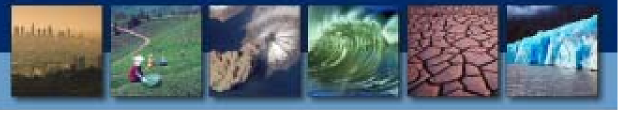
SST-VC: Implementation

We propose to implement the SST-VC building on the existing *Group for High Resolution SST* framework.

GHRSST
Group for High Resolution Sea Surface Temperature

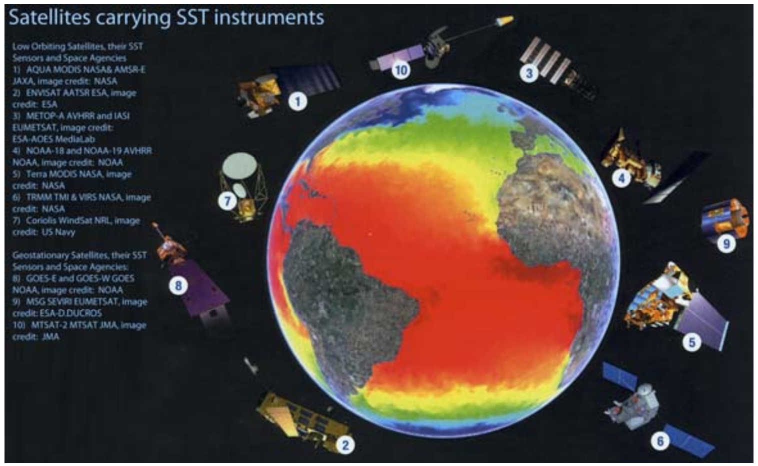


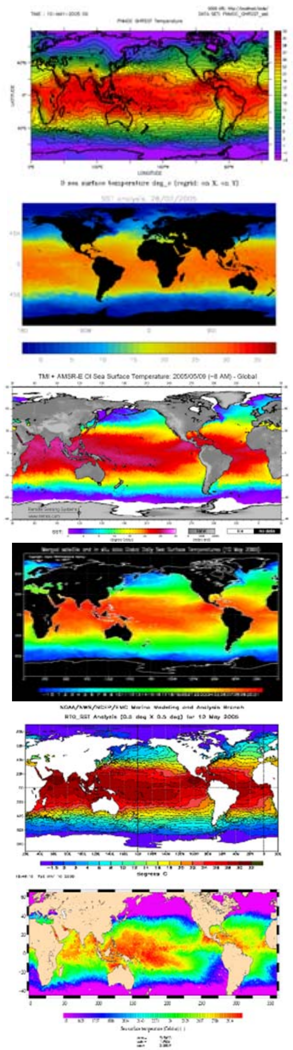
SST-VC: Implementation



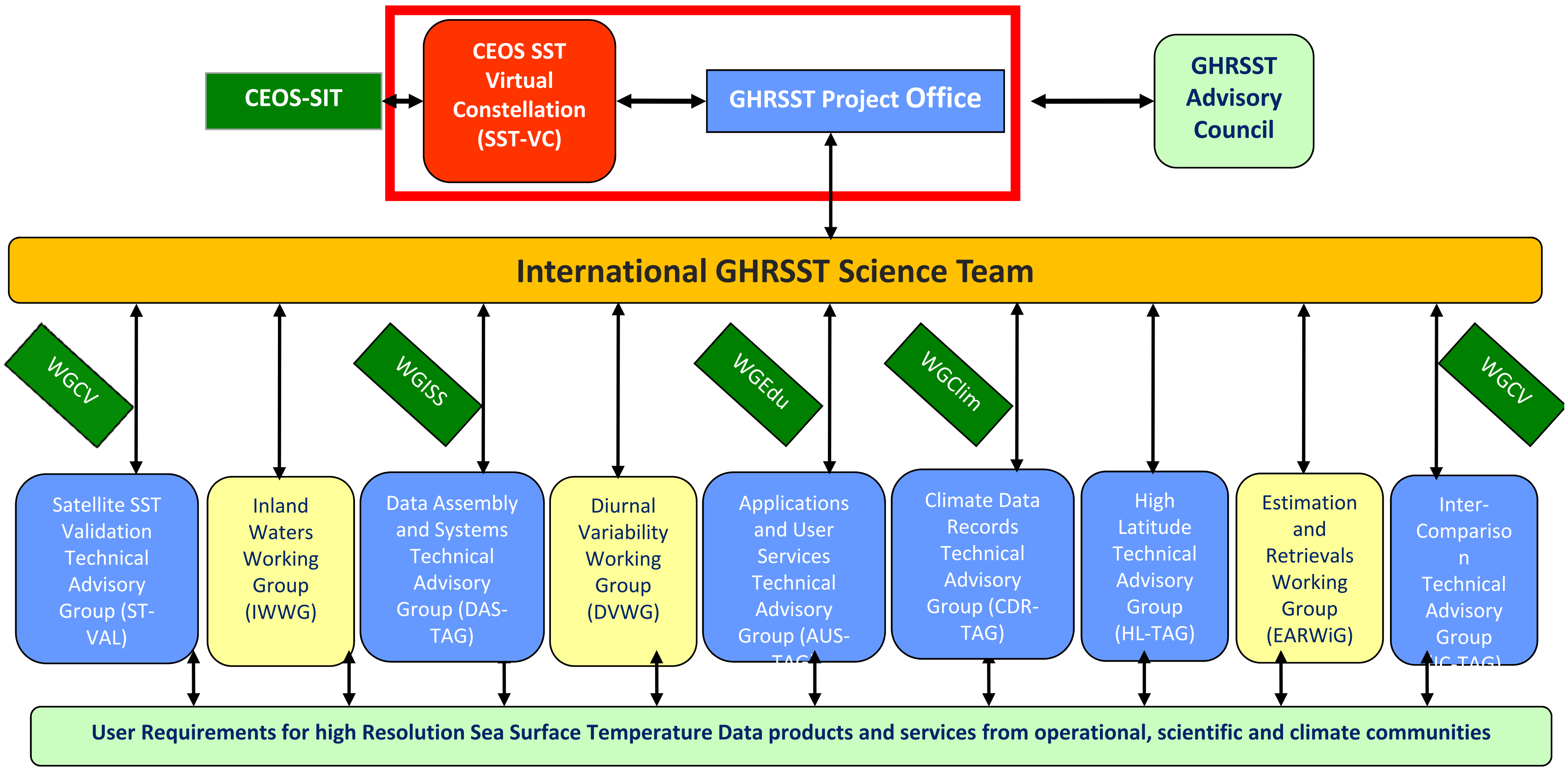
Using this approach, the CEOS SST-VC has instant access to:

- **A baseline SST virtual constellation system of systems**
- **Internationally agreed SST products and services (data access, user support services)**
- **Initial consensus technical documentation for the constellation**
- **A functional coordination mechanism active at the international level (Science Team, Advisory Council, Project Office)**



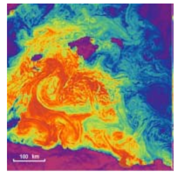


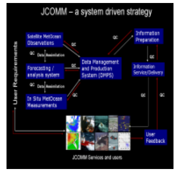
CEOS Interfaces to GHRSST

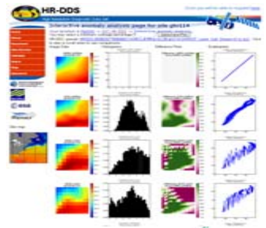


Benefits of the Proposed Approach

- Strengthen CEOS Agency SST activities through better synergy and communication
- Nurture a global framework and through CEOS, encourage wider participation of all Agencies
- Better SST product and service interoperability building on the strengths of CEOS Agencies
- Facilitate better data access and product applications
- Provide value for money by capitalising on the investments already committed to GHRSST
- Allow a rapid spin up of SST-VC activities with minimal overhead



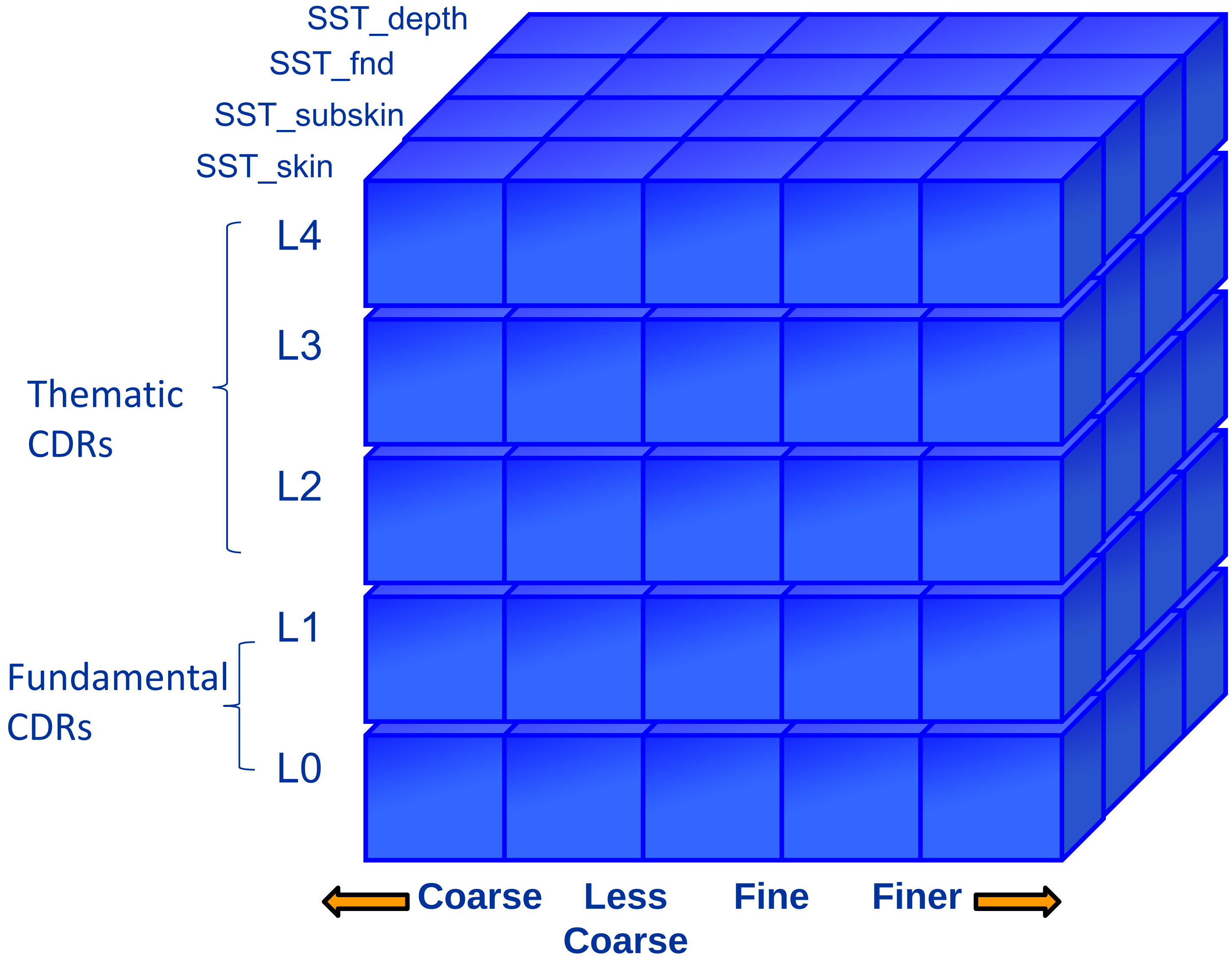




SST-VC: Activities

Activity	Status
1. Minimize duplication of existing activities	Initiated through VC proposal
2. Develop and optimize the SST constellation	OceanObs '09 White Paper
3. Develop and implement metrics for SST services, products, and users	User Requirements Document published
4. Coordinate consensus SST reference documents	GDS2 published
5. Encourage timely access to products	Ongoing
6. Develop and improve the satellite SST ECV	Ongoing (see next slide)
7. Improve SST calibration, inter-calibration, and validation	Ongoing
8. Improve user feedback to CEOS Agencies	Ongoing
9. Develop training activities for satellite SST practitioners	New activity leveraging existing capabilities
10. Liaise with the other VCs	New activity

Develop and Improve the SST ECV



GHRSST has defined a conceptual "cube" of related SST products climate data records – NO SINGLE SST PRODUCT CAN MEET ALL USER NEEDS! – and is working on a CDR Data Processing Framework (DPF) to define the SST CDR vetting procedures

SST-VC: Current Membership

SST-VC Co-leads:

1. Kenneth S. Casey, National Oceanic and Atmospheric Administration (NOAA), USA
2. Craig Donlon, European Space Agency (ESA), Netherlands

SST-VC Members:

1. Hans Bonekamp, European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Germany
2. Andrew Bingham, Jet Propulsion Laboratory, National Aeronautics and Space Administration (NASA), USA
3. Misako Kachi, Japan Aerospace Exploration Agency (JAXA), Japan
4. Peter Minnett (GHRSST Science Team Chair), University of Miami, USA

SST-VC: Desired Membership

We specifically identify the following Space Agencies and other entities whose participation could be solicited:

- **Comision Nacional de Actividades Espaciales (CONAE), Argentina**
- **Indian Space Research Organisation (ISRO)**
- **Korea Aerospace Research Institute (KARI)**
- **Chinese Academy of Space Technology (CAST)**
- **National Remote Sensing Center of China (NRSCC)**
- **National Satellite Meteorological Center/Chinese Meteorological Administration (NSMC/CMA)**
- **Russian Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET)**
- **Russian Aviation and Space Agency (Roskosmos)**
- **Global Climate Observing System (GCOS)**
- **Group for Earth Observation (GEO)**
- **Other CEOS members with an interest in SST**

CEOS

Summary

- A CEOS SST-VC has now been developed and approved according to the CEOS VC Process Paper
- The SST-VC and GHRSST work together
- An SST-VC Implementation plan has been developed and approved
- A first SST-VC meeting will be held 6-7th June 2012 in room 203 at Sanjo Conference Hall, the University of Tokyo - Hongo Campus, Tokyo, Japan, kindly hosted by JAXA.

A pathway to generating an SST CDR

Peter Minnett

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

News
About GCOS
Climate Observation Needs
UNFCCC and GCOS
UNFCCC Guidelines
GCOS Reports to UNFCCC
Essential Climate Variables
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Sea-surface temperature,

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
and ice)	**Surface:** Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour. **pper-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].

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."*

Traceability to SI

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/NPL 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: 0.1 K over large areas, stability 0.04 K/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

CDR of SSTs

•Climate Data Records of SST require an **unbroken chain between the satellite measurement and an SI Temperature standard**.

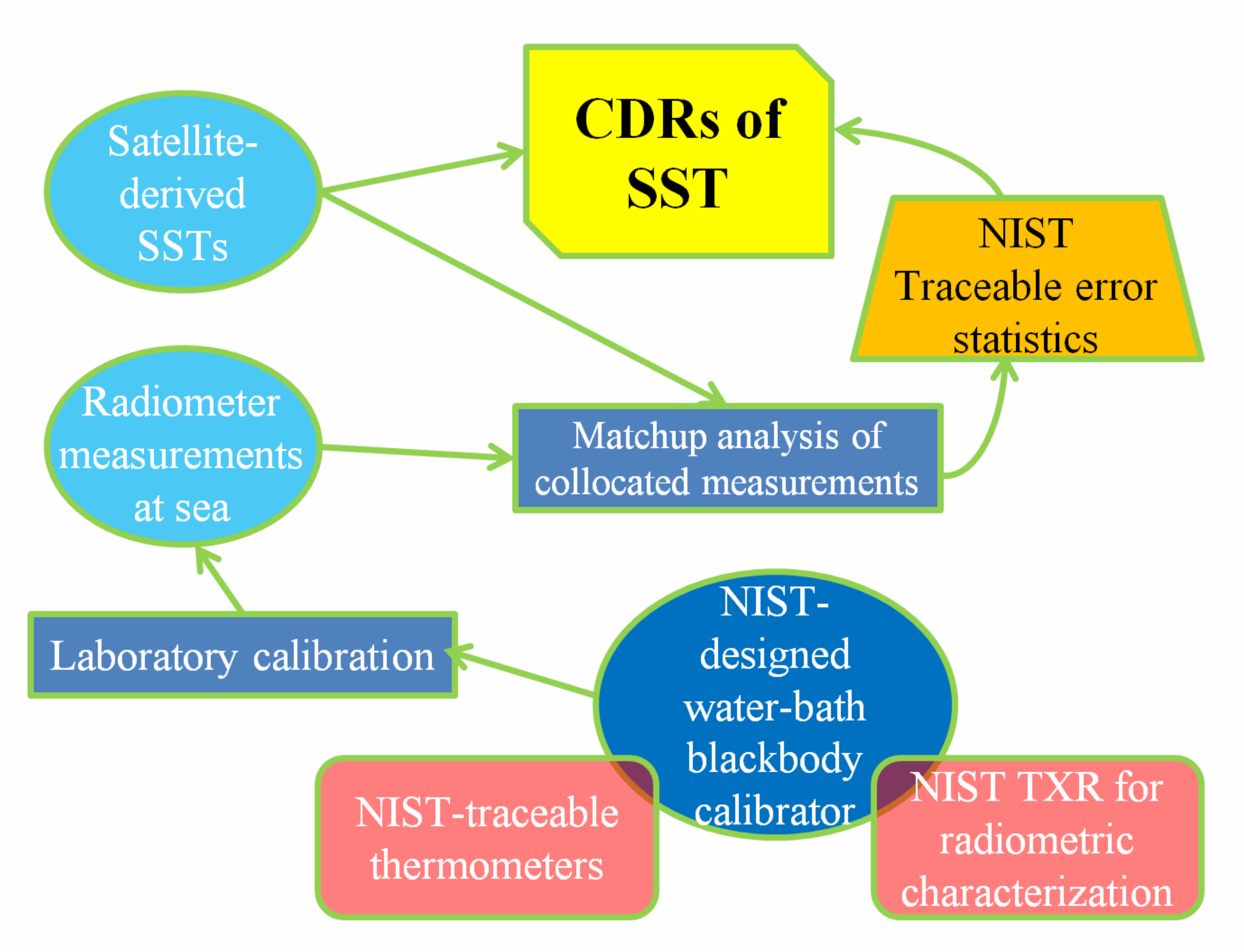
•Prior to launch, the satellite radiometers are calibrated using SI-traceable standards, but post launch it is not currently feasible to check calibration drift using SI-standards.

•Drifting buoys are currently not sufficiently well calibrated for this purpose, and very few are recovered to check for calibration drift during deployment .

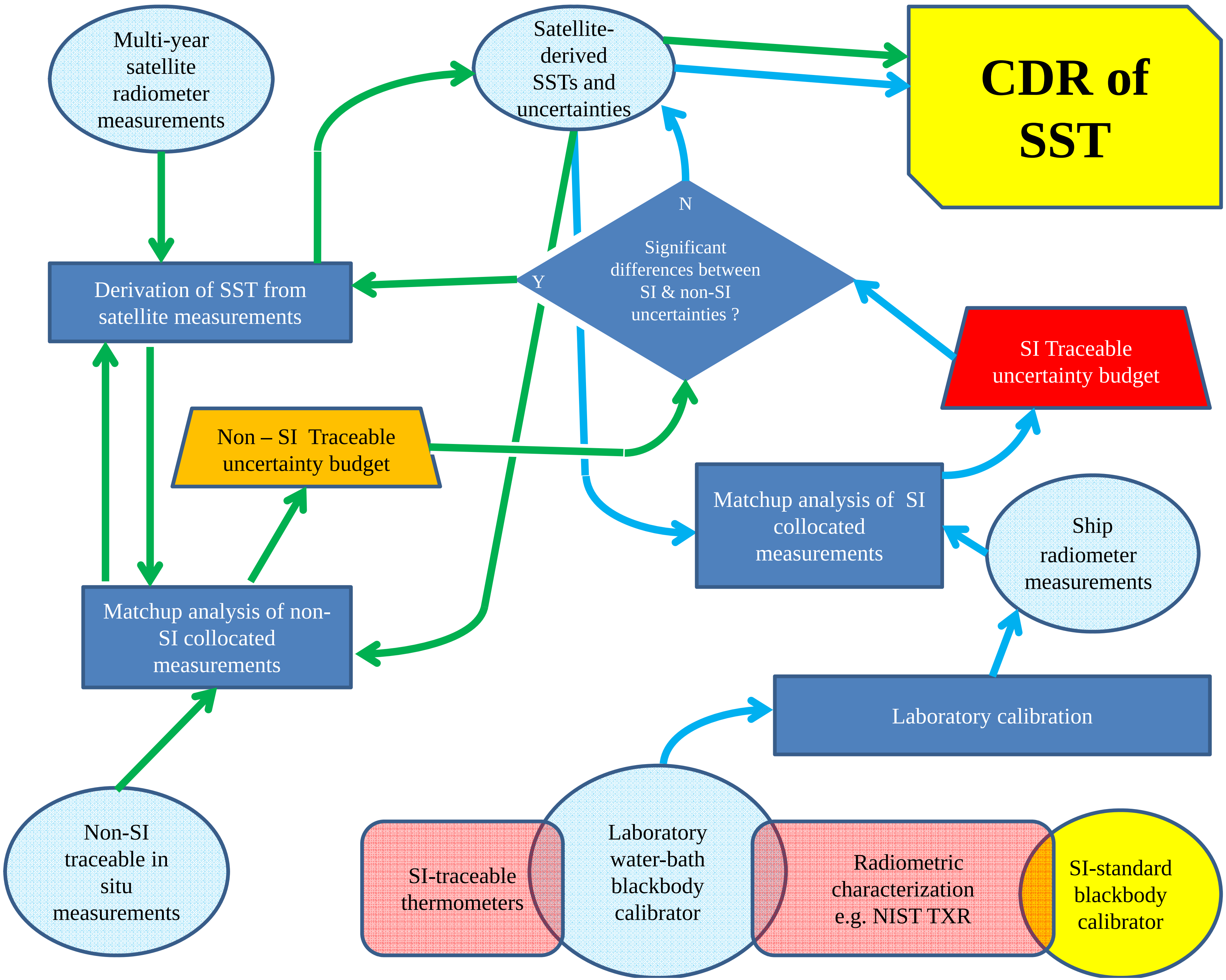
•A calibration chain can be established using ship-based radiometers to validate the skin SST retrievals, provided the ship-based radiometers have SI-traceable calibration.

•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.

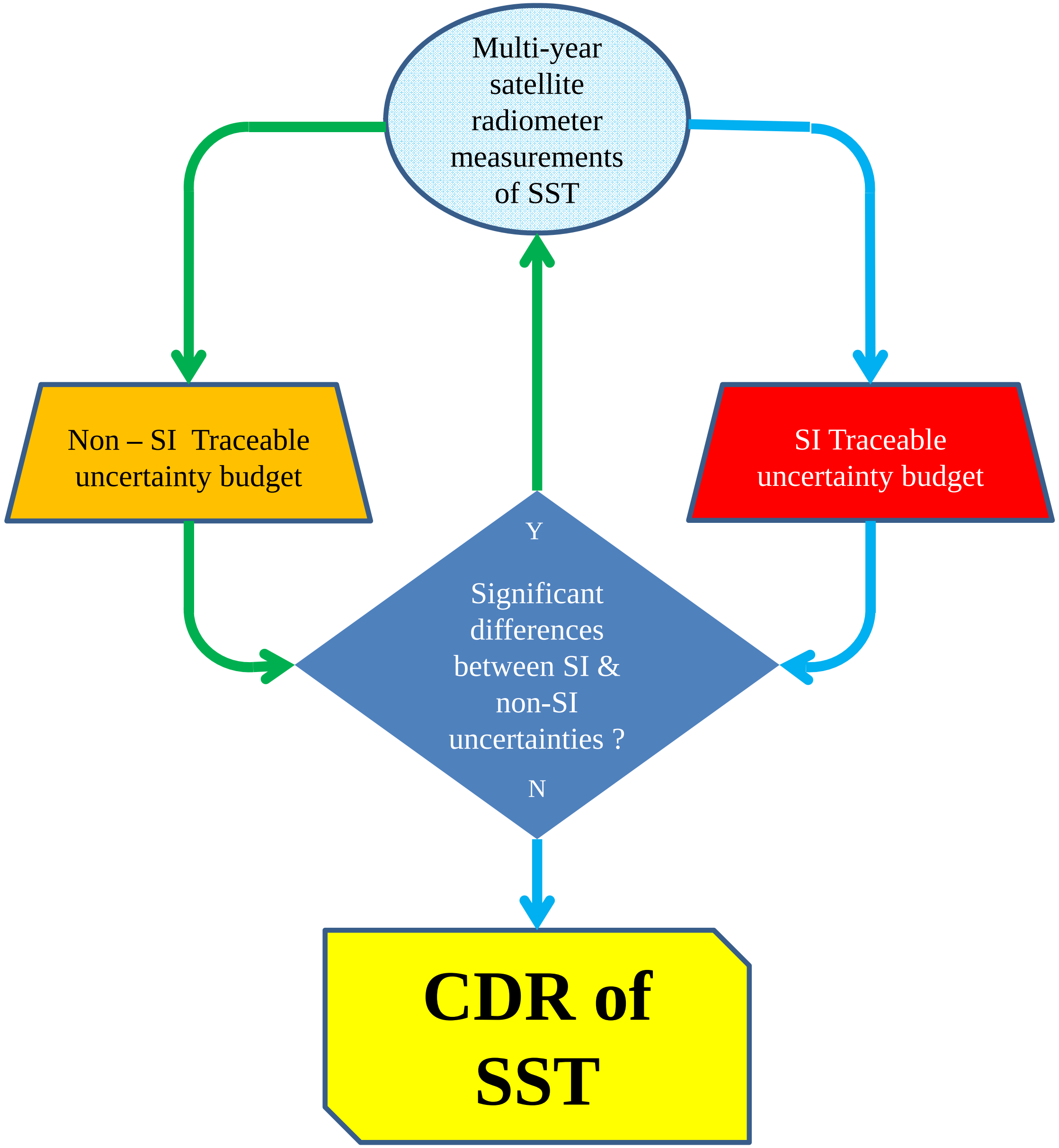
Unbroken traceability



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,* in press.



Multi-year satellite radiometer measurements
Satellite-derived SSTs and uncertainties
CDR of SST
Derivation of SST from satellite measurements
N
Y
Significant differences between SI & non-SI uncertainties ?
SI Traceable uncertainty budget
Non – SI Traceable uncertainty budget
Matchup analysis of SI collocated measurements
Ship radiometer measurements
Matchup analysis of non-SI collocated measurements
Laboratory calibration
Non-SI traceable in situ measurements
SI-traceable thermometers
Laboratory water-bath blackbody calibrator
Radiometric characterization e.g. NIST TXR
SI-standard blackbody calibrator


Multi-year satellite radiometer measurements of SST
Non – SI Traceable uncertainty budget
SI Traceable uncertainty budget
Y
Significant differences between SI & non-SI uncertainties ?
N
CDR of SST

SST val needs for climate

Summary of non-satellite SSTs

- Drifting buoys
  - Unknown calibration; global data; SST-depth; good coverage in recent ~decade
- GTMBA
  - Better calibration; SST-1m; acceptable coverage (influenced by data collection)
- Ship-borne radiometers
  - Traceable to SI; SST-skin; very-high accuracy; very-poor coverage
- VOS and VOSclim
  - Generally poor coverage; very high uncertainty on single sample
- Coastal moorings
  - Questionable uncertainty; tough areas to validate
- Argo 4m
  - Global; acceptable sampling; very-low uncertainty (calibration method to be analysed)

Interaction with in situ: DBCP (1)

- SST algorithm development, selection and independent validation requires match-ups to drifting buoys
  - They're essential for exploring biases at regional scales
- GHRSST has been in discussion with the DBCP with the aim of improving drifting buoy accuracy and precision for SST, time and location
- In response the DBCP created the HRSST drifter pilot project
  - Stage 1: Improved time and locations – first deployments started in DATE; SST reported to 0.01 °C; data currently being evaluated; led by ESURFMAR.
  - Stage 2: Calibration - first deployments started in DATE; data currently being evaluated; accuracy to < 0.05 °C; led by Met Office.

Interaction with in situ: DBCP (2)

- Initial deployments not in optimal locations for satellite SST validation
- Resources (300 k€) requested from space agencies to
  - Deploy additional drifters (in high value areas)
  - Host a workshop
- Benefits
  - Relatively low cost; High scientific return
  - Demonstrate value first. Other operators would continue after successful demonstration; transition to standard operational drifters.
  - Model for closer interaction/synergy between satellite and in situ communities; integrated observing system.
  - DBCP doing its bit – difficult to get support from space agencies.

Requirements: SST reference data

- Stability
  - Establish long-term radiometric and sub-surface ocean reference sites for SST
- Traceability to SI
  - Ship-borne radiometers (skin)
  - Argo near surface measurements (depth)
- Regional uncertainties
  - Drifters and moorings
  - Other ship data
- Continue interaction with in situ communities

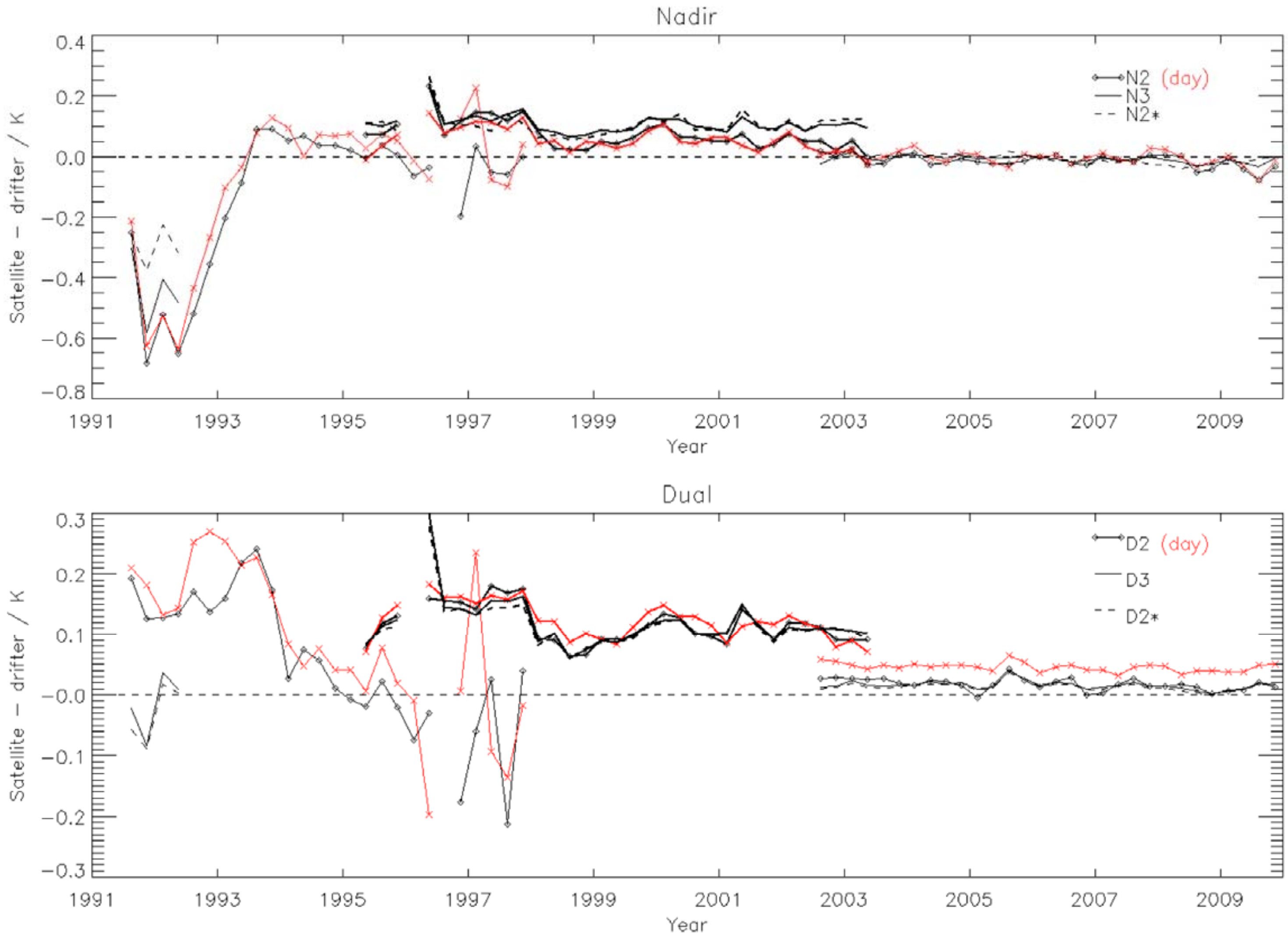
CEOS IR radiometer inter-comparison

- Third in a series of inter-comparisons establish degree of equivalence (biases) between participant's took place in 2009
  - Reference black bodies
  - IR radiometers under lab conditions
  - IR radiometers as used viewing Ocean (SST)
- Time to prepare for next one
  - Loss of AATSR
  - Launch of VIIRS
  - Future launch of SLSTR
- Need to sort out funding
  - Update protocol

Homogenisation of BTs in ARC and inferences about ATSR calibrations

Owen Embury, Chris Merchant

Need to homogenise to get CDR



Overview of homogenisation

ATSR-2-ATSR-1 overlap
Reconcile 11 & 12 BTs

AATSR

- 3.7 & 11 only (D2*) reference retrieval
- N2, N3, D2, D3 offsets adj'd to D2*

ATSR-2

- D2* for ATSR-2 is then consistent with AATSR
- N2, N3, D2, D3 offsets adj'd to D2*

ATSR-1

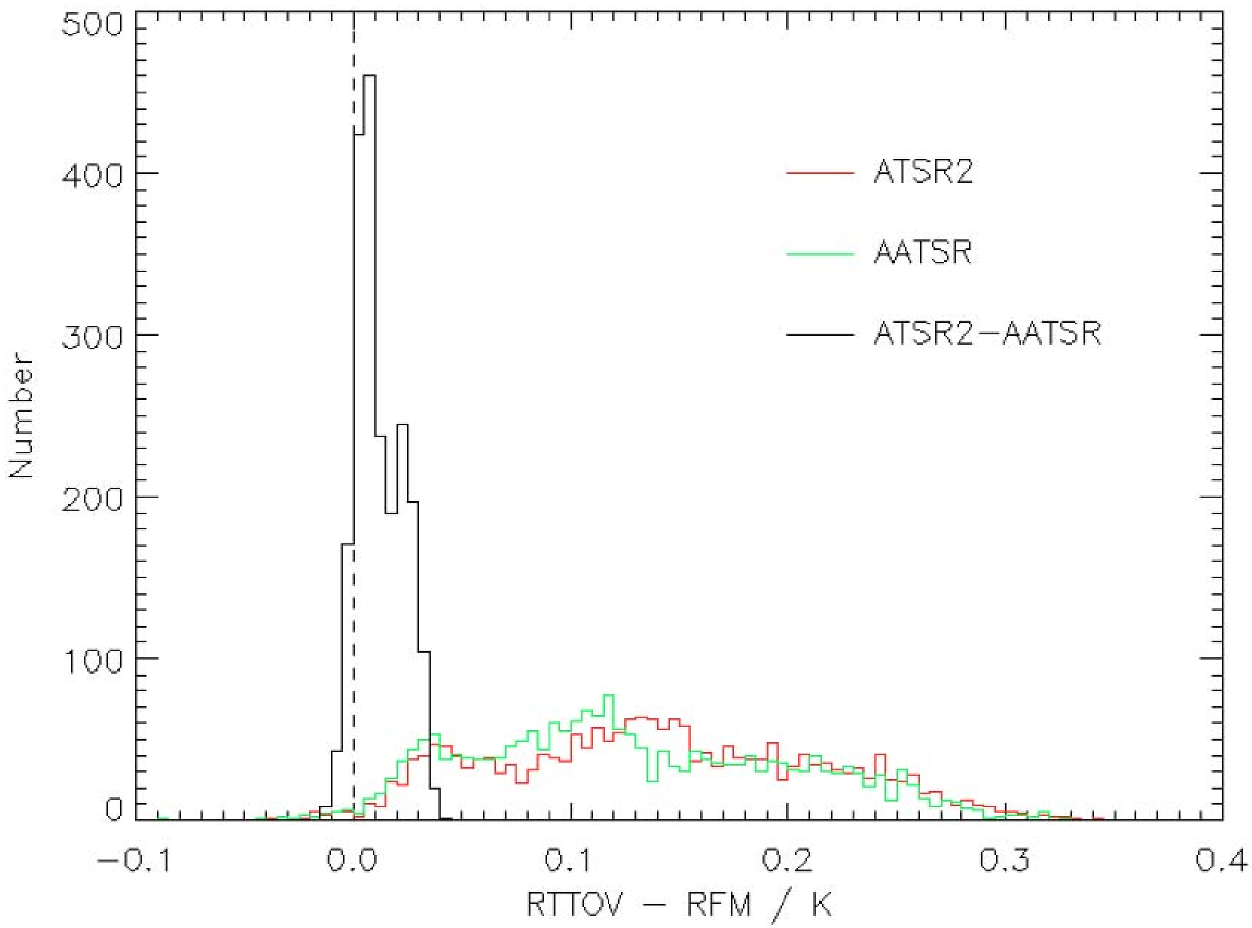
- No 3.7, so ATSR-2 D2* is ref. for offsets at end
- ATSR-1 D2* (untied) is ref. at start
- Detector temp. trend

AATSR-ATSR2 overlap
Adjusted BT calibration for 3.7 & 11
(accounting for spectral responses)

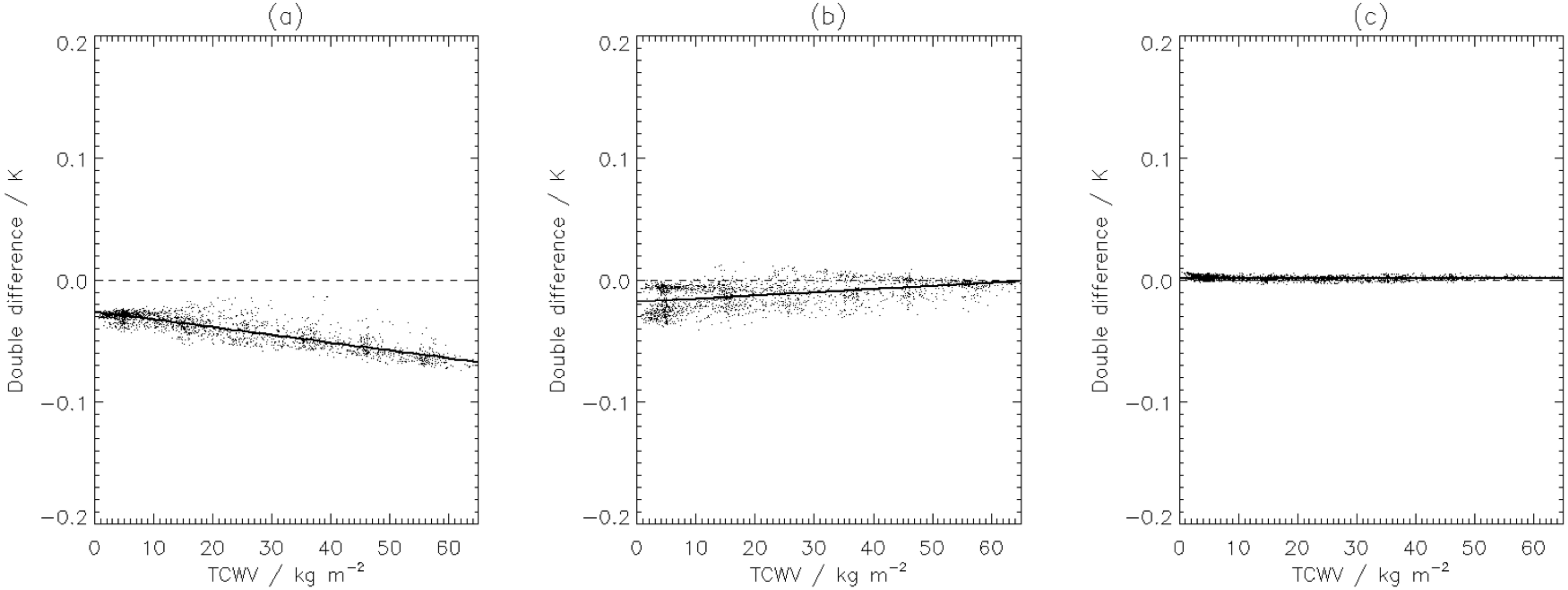
AATSR / ATSR-2 overlap

- Half an hour difference
- Find matches where clear sky in both, using conservative assumptions (high clear-sky probability, large areas with high fraction of clear)
- Extract NWP and use RTTOV to forward model expected BTs, accounting for diurnal cycle of sea surface using surface heating model
- Would rather use RFM (which was used for the coefficients), but was too expensive. Is RTTOV good enough?

RTTOV models ATSR2/AATSR 11 um differences to *O*(0.03 K)

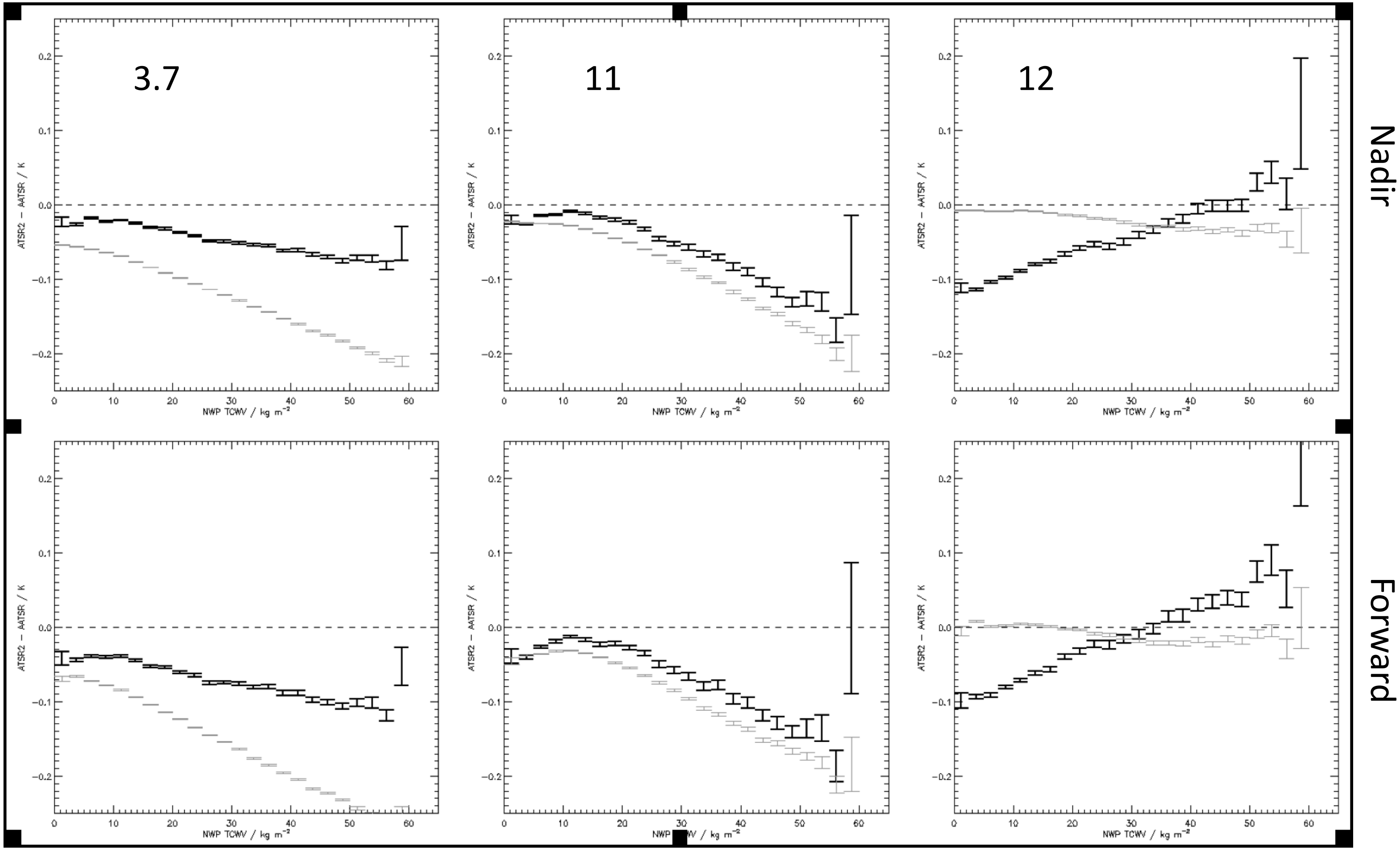


Parameterise RTTOV(AATSR-ATSR2) to match RFM(AATSR-ATSR2)



Left to right: 3.7, 11 and 12 um
Double difference = RTTOV(ATSR2-AATSR) – RFM(ATSR2-AATSR) = "mx + c"
Hence, estimate of RFM-equivalent BT difference is
        = RTTOV(ATSR2-AATSR) – "mx + c"

Simulated and **observed** ATSR2-AATSR



ATSR-2 to AATSR adjustment parameterisation = c + m*TCWV

	Nadir offset	Nadir slope	Forward offset	Forward slope
3.7	0.03	0.0016	0.02	0.0022
11	0.009	0.00064	0.011	0.00066
12	-0.12	0.0033	-0.11	0.0039

ARC V1.0 Stability assessment

Dave Berry

Assessment of stability

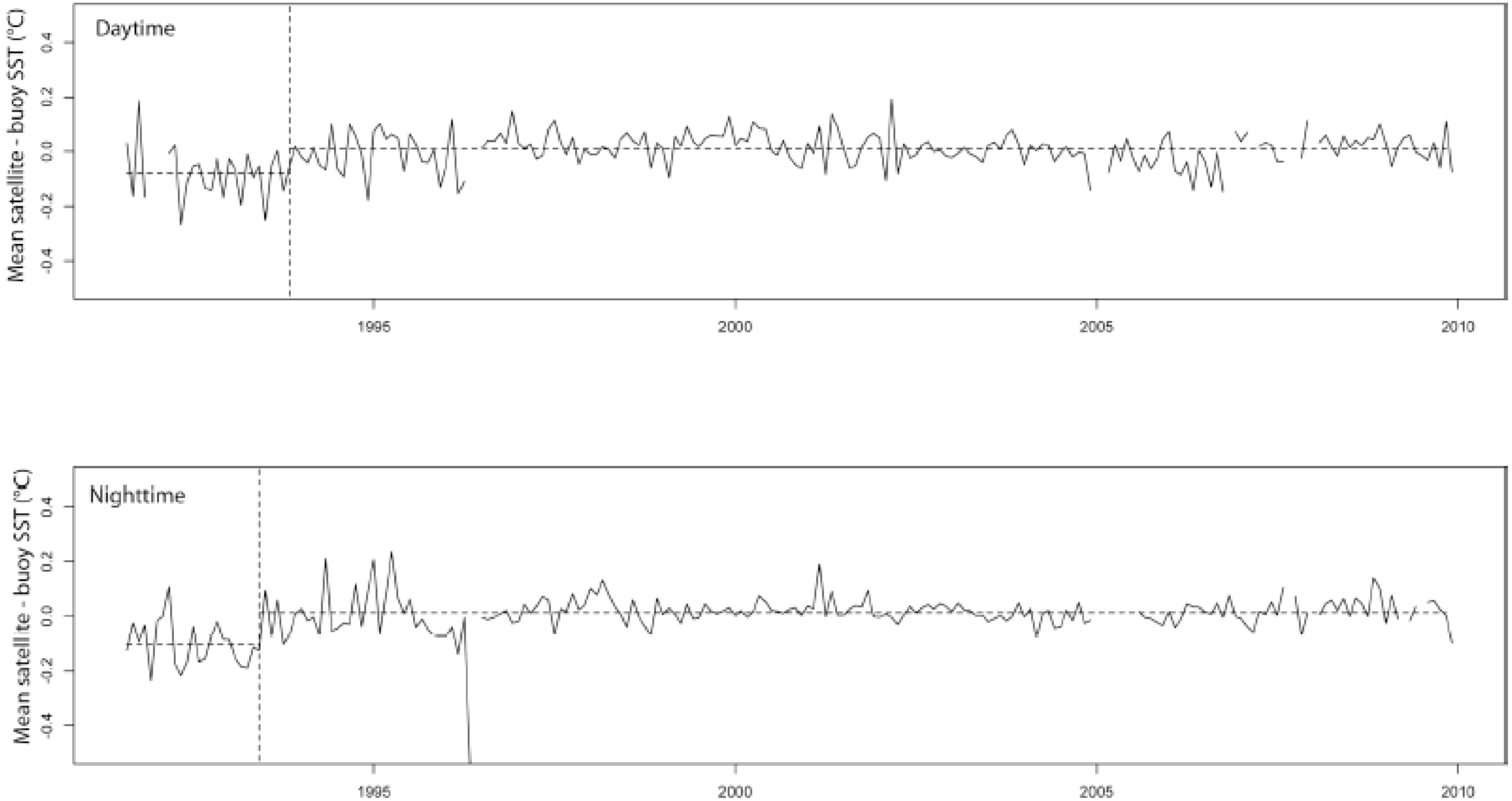
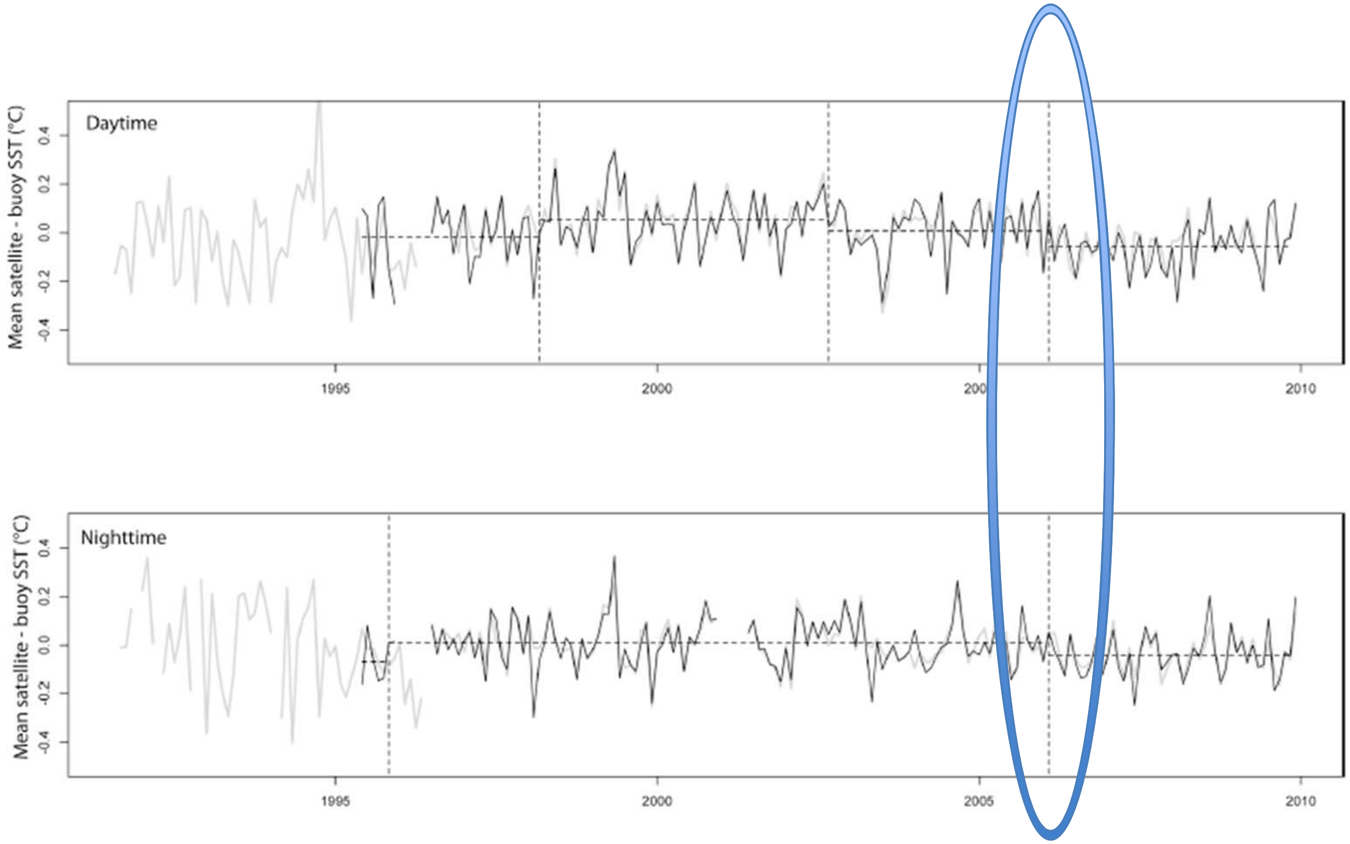


Figure 5. Analysis of stability of the full series of ARC observations against tropical moored buoys, using a technique for identifying step changes objectively. Upper panel: daytime monthly mean discrepancies; lower panel, night time. The early step change is apparently associated with the dissipation of the post-Pinatubo stratospheric aerosol.

Penalized Maximal *t* Test (PMT; Wang et al., 2007).

Against US coastal moorings



-0.04 K step same time as ECMWF upgrade from 60 to 91 model levels

Figure 11: As Figure 10 but for the US Coastal region and the combined ATSR1 / ATSR2 / AATSR record (grey) and combined ATSR2 / AATSR record (black).

Penalized Maximal *t* Test (PMT; Wang et al., 2007).

Stability: 0.03 K/dec for 1993-2009*

Region	Period	Time of day	Trend ($^{\circ}$C decade^{-1})	95% confidence interval ($^{\circ}$C decade^{-1})
Tropics	*All (1991 – 2009)*	*Day*	*0.026*	*0.006 < trend < 0.045*
Tropics	*All (1991 – 2009)*	*Night*	*0.044*	*0.020 < trend < 0.069*
Tropics	> 1993	Day	-0.006	-0.026 < trend < 0.015
Tropics	> 1993	Night	0.010	-0.014 < trend < 0.034

Table 3. Trends and their significance in the full ARC timeseries (D2 SSTs).

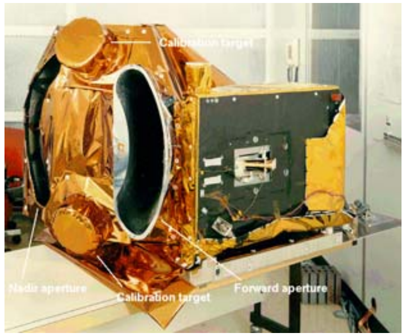
*in the tropics – which is the only place we can make an assessment

Status of Sentinel-3 SLSTR calibration facility

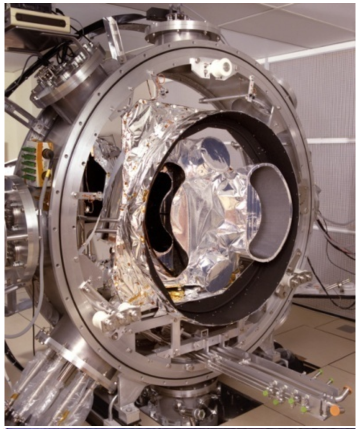
Dave Smith

ATSR Series

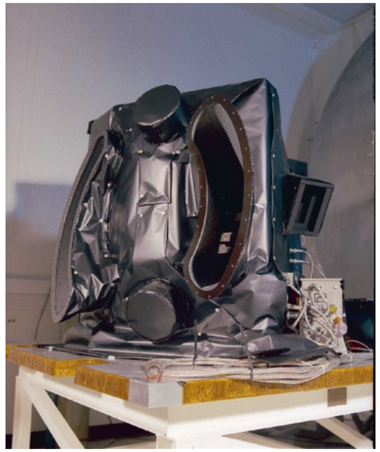
1991-2000 ATSR-1



1995-2008 ATSR-2



2002- AATSR

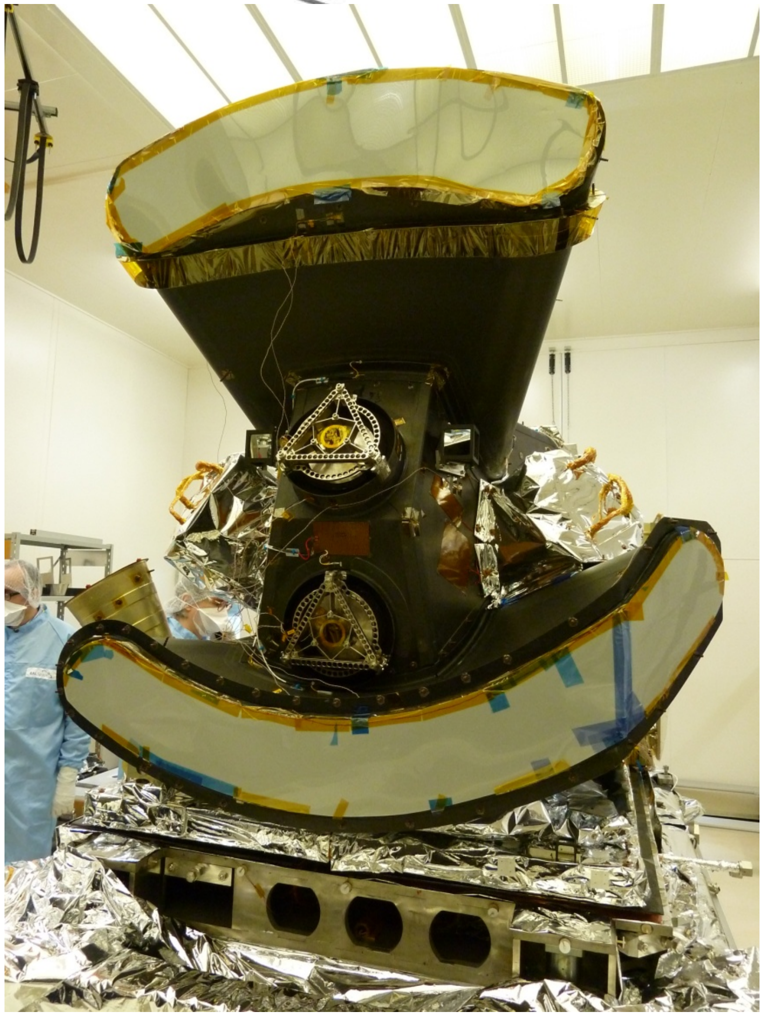


Sea and Land Surface Temperature Radiometer

RAL Space

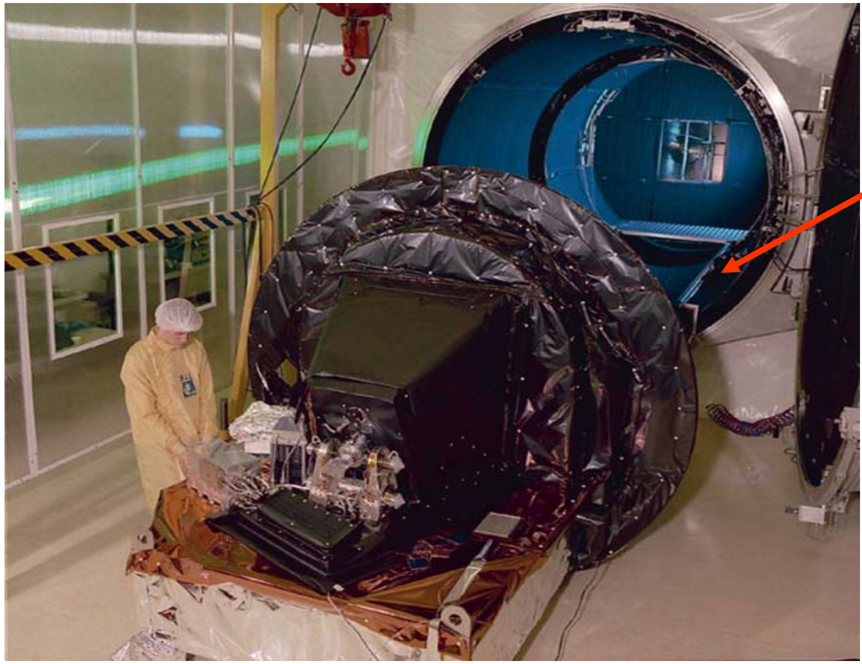
Nadir swath	>74°	(1300 km min up to 1800 km)
Dual view swath	49°	(750 km)
Two telescopes	Φ110 mm / 600mm focal length	
Spectral bands	TIR : 3.74µm, 10.85µm, 12µm SWIR : 1.38µm, 1.61µm, 2.25 µm VIS: 555nm, 659nm, 859nm	
Spatial Resolution	1km at nadir for TIR, 0.5km for VIS/SWIR	
Radiometric quality	NEΔT 30 mK (LWIR) – 50mK (MWIR) SNR 20 for VIS - SWIR	
Radiometric accuracy	0.2K for IR channels 2% for Solar channels relative to sun	

AATSR Performance is Maintained!



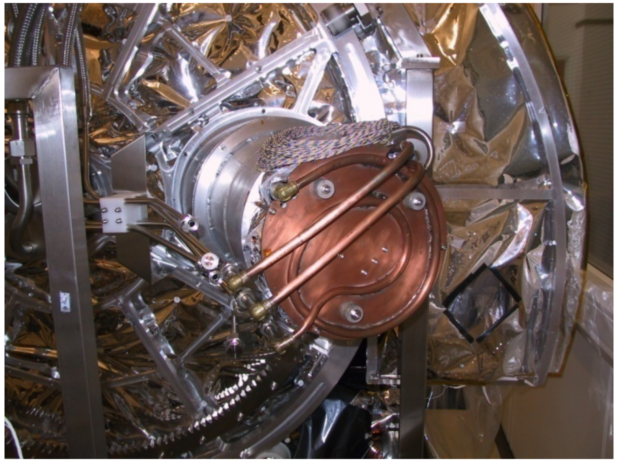
Test Facility – AATSR

RAL Space



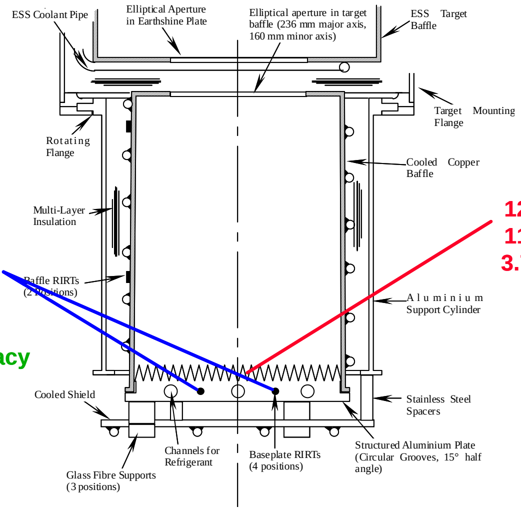
Calibration tests performed under representative thermal environment to control stray light

Radiometric Test Equipment previously used for ATSR-1/2 & AATSR-2



Precision RIRTs Calibrated to ITS90 < 0.01K

Radiometric Accuracy < 0.05K



Emissivity
12µm = 0.99871
11µm = 0.99870
3.7µm = 0.99911

Standards

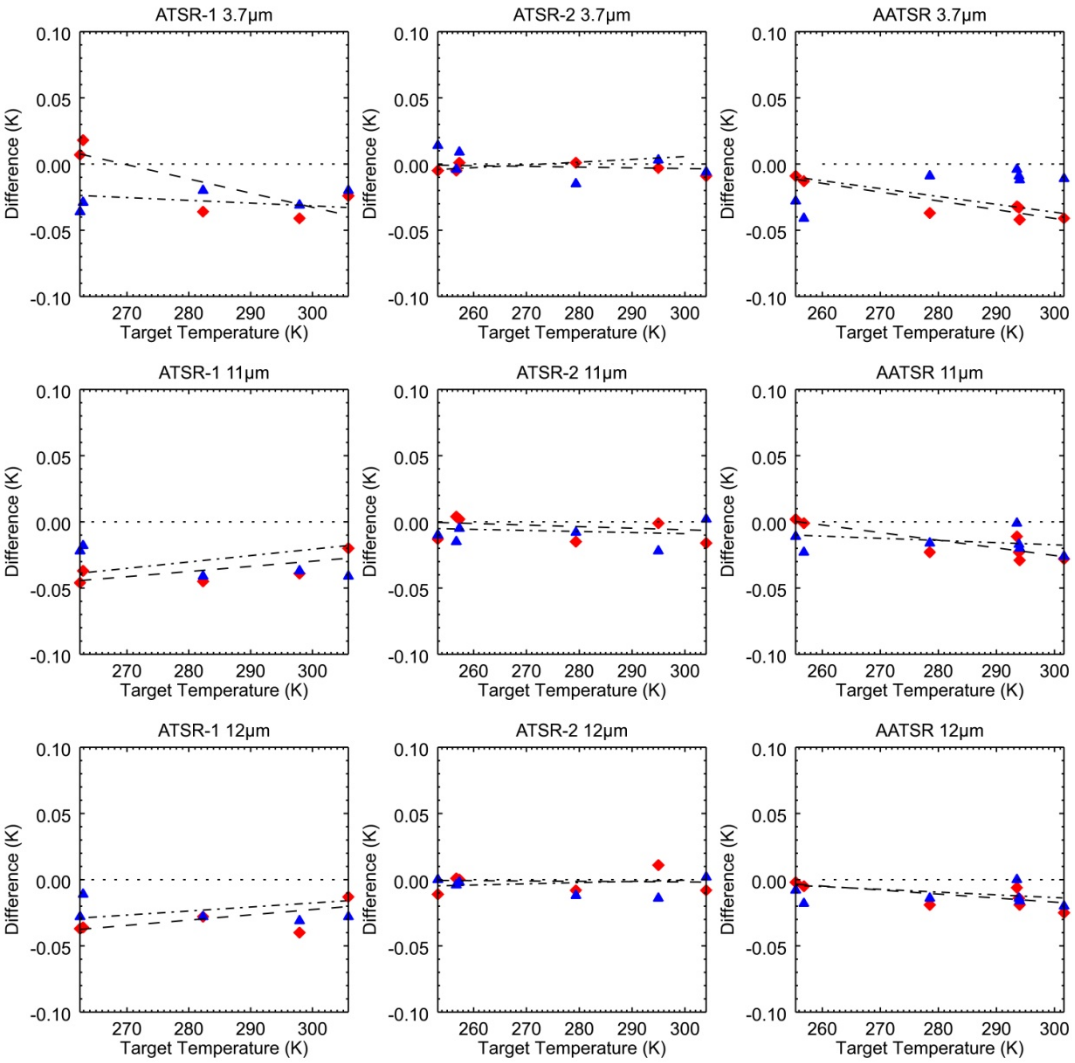
ATSR

ATSR-2

AATSR

SLSTR

Comparison of ATSR BBs with external BBs



- For each of the calibration runs, measurements were taken with the external blackbody temperatures matched to the on-board target temperatures.

- Effect of non-linearity is negligible at these points

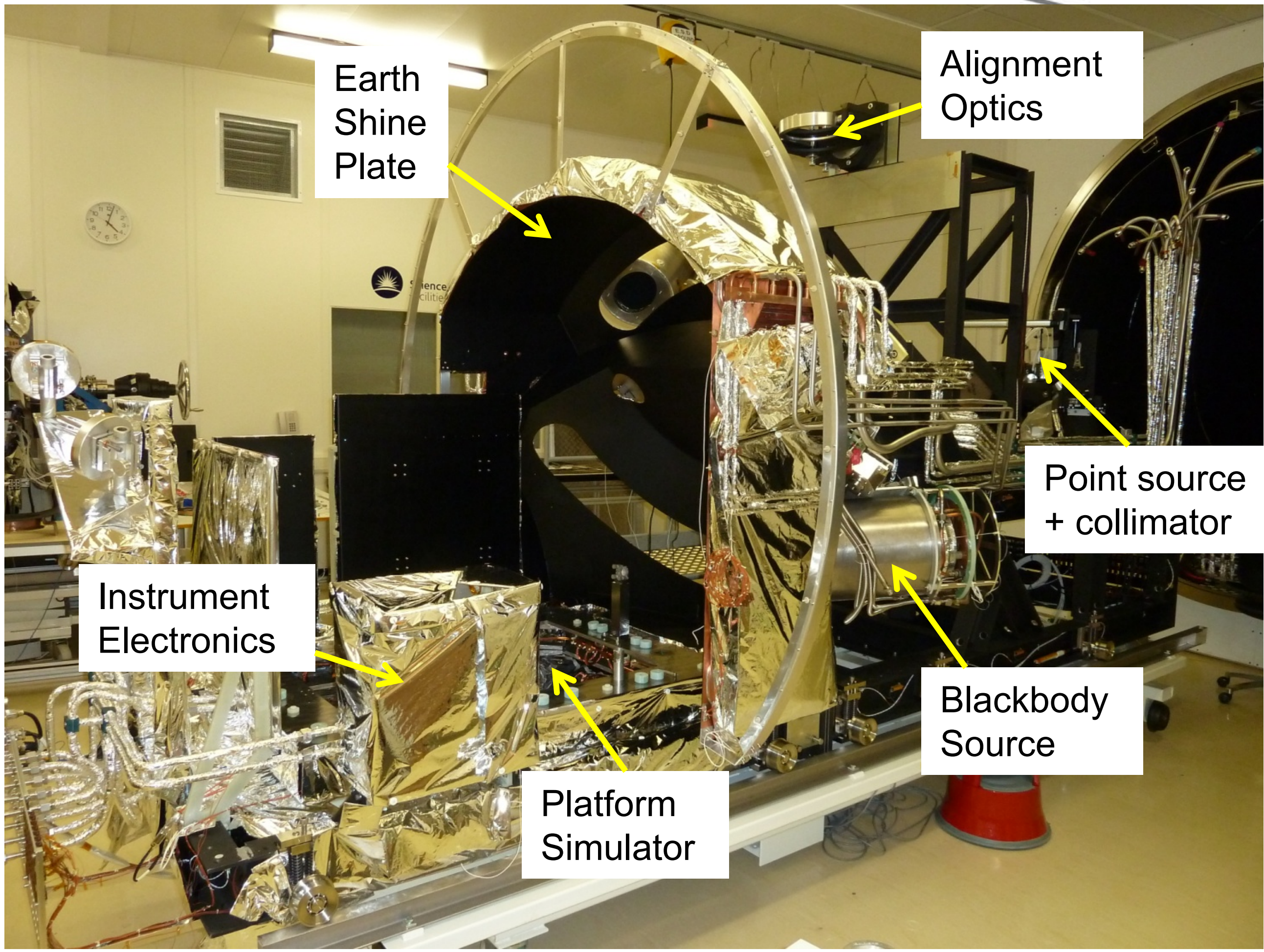
- Provides a ‘direct’ comparison of the flight blackbodies against external sources.

Key Measurements for IR Radiometric Calibration at Instrument level

RAL Space

- Demonstrate that the 'on-board' radiometric calibration works under flight representative thermal conditions.
  - BOL and EOL conditions
  - Simulated orbital transient thermal conditions
- Perform the 'on-board' radiometric calibration for a range of target temperatures between 210K and 320K.
  - Verify the absolute accuracy of the on-board calibration against external targets
  - Verify that each IR channel produces self consistent results in both views
  - Measurement of radiometric noise vs. scene temperature
  - Measurement of signal channel non-linearity to provide appropriate corrections
- Verify the calibration around the full instrument field-of-view
  - Determine and measure any scan dependent variation in the radiometric performance.
  - Determination of swath width to verify required clearance at ends of swath
- Measure the effect on the radiometric calibration vs. detector temperature.
- Verify the calibration with the on-board black-bodies set at different power levels.

SLSTR Calibration Facility



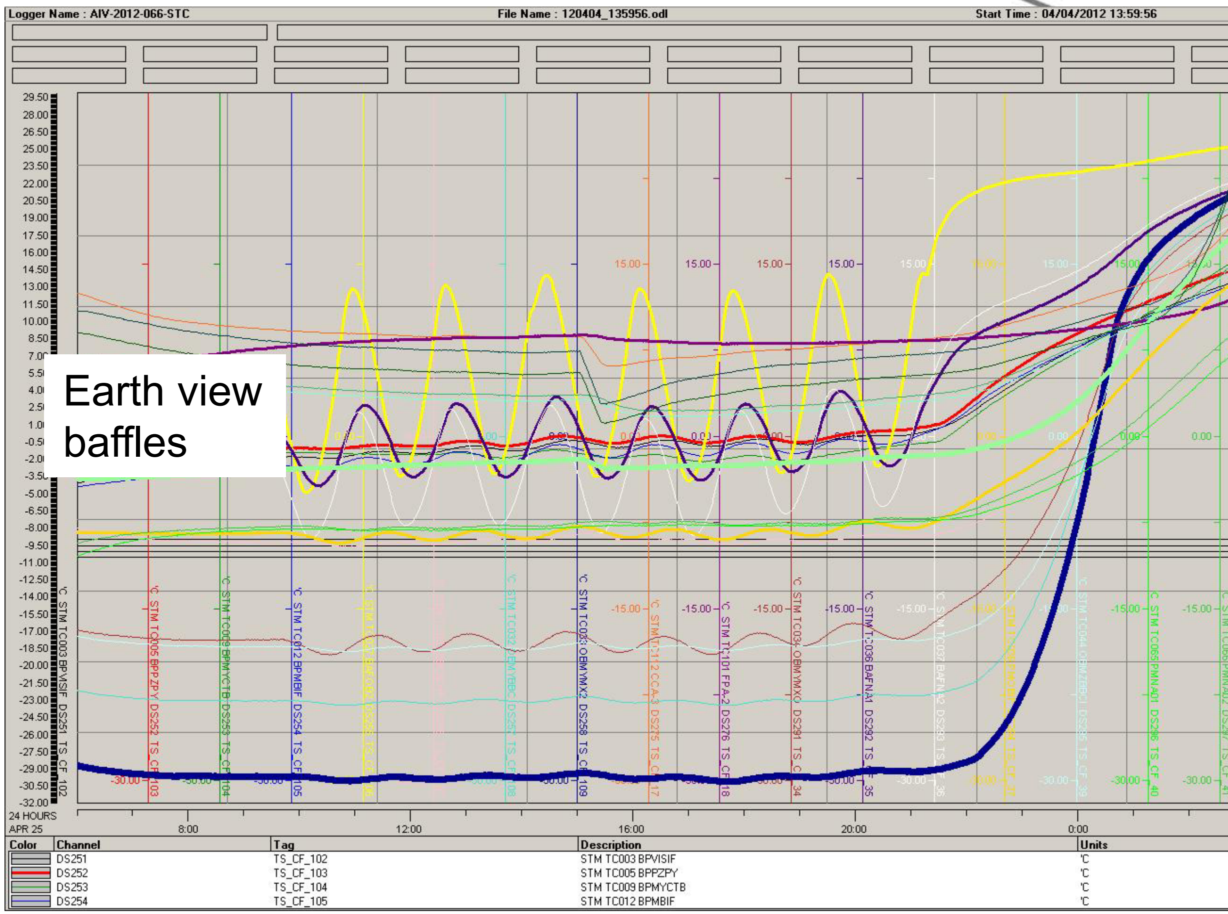
- Facility commissioning completed 19th March 2012
- STM Integrated & MLI fitted 28th March
- Tests with STM in progress
- PFM Testing scheduled for Q2 2013?

- ESA requirement to perform calibration tests under flight representative conditions.
  - *Thermal balance*
  - *Steady State*
  - *Instrument fully operational*

Orbital Simulation

Calibration tests have to demonstrate that the on-board calibration is robust against orbital transients in instrument temperatures.

Orbital simulations are performed with external sources at different TB tests



Source Calibration

- Blackbody radiances are dependent on two key parameters
  - Temperatures
  - Emissivity

- Temperature calibration is achieved by calibrating thermometer systems to ITS-90
  - Well established procedures

- Emissivity is more difficult to achieve for large targets
  - Has to be done in a temperature controlled environment
  - For the SLSTR operating temperatures, the ratio of signal to background is small – hence measurement uncertainties are large
  - Radiometric accuracy required <0.1% for SLSTR
  - Most reliable figures for emissivity are obtained by calibration of witness samples + modelled geometry.

Issues for CEOS to Consider

RAL Space

- Currently link between space based and ship-borne IR radiometers is via 'on-board' blackbodies – traced to ITS-90.

- So far there is no 'direct' comparison between BBs used for space and ship-borne radiometers.
  - Ship BBs have been measured at NPL using Amber
  - A similar measurement should be performed on RAL ground targets – what about targets used for VIIRS etc?

- Although Miami type inter-comparisons are useful – the environment is not controlled (i.e. It's hot and humid).
  - Not easy to determine real instrument effects that give rise to apparent biases

- Tests under controlled environmental conditions have not been performed
  - SLSTR calibration activities presents an opportunity to perform an intercomparison to test ship radiometers against ground calibration sources used for flight instrumentation.