Pre-Launch Calibration of the Sea and Land Surface Temperature Radiometer

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Along-Track Scanning Radiometers

- Designed in the early 1980’s by UK and Australian scientists – who were then ahead of their time in recognizing climate change as an important issue.

- **Specifically** designed to measure sea surface temperature (SST) for:
  - Climate change detection – the first sensor aimed at this task!
  - to support a range of oceanography studies
  - Later capabilities added for land, cloud, and aerosol remote sensing

- **Three** instruments have been flown between 1991 to 2012 on ESA EO missions:
  - ATSR(-1) on ERS-1– initial experimental instrument (1991-1996)
  - AATSR on ENVISAT (2002-2012)
Copernicus

- Copernicus is an European programme to deliver near-real-time data derived from satellite and in situ observations for understanding our planet and sustainably manage the environment we live in.

- Copernicus is served by a set of dedicated satellites (the Sentinel families) and contributing missions (existing commercial and public satellites).

- The Sentinel satellites are specifically designed to meet the needs of the Copernicus services and their users. Since the launch of Sentinel-1A in 2014, the European Union set in motion a process to place a constellation of almost 20 more satellites in orbit before 2030.
Sentinel-3

- Forms part of the Copernicus Space Segment
- Designed for monitoring ocean and land surface parameters
- 3 Main Instruments
  - SLSTR – Sea and Land Surface Temperatures
  - OLCI – Ocean Colour and Vegetation
  - SRAL – Altimetry
- 2 Satellites to provide daily global coverage
  - S3A Launched Feb 2016
  - S3B Launch April 2018 – Commissioning Ongoing
  - Orbits at 140°
SLSTR Instrument

Nadir swath >74° (1400km swath)

Dual view swath 49° (750 km)

Two telescopes Φ110 mm / 800mm 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
Thermal InfraRed Blackbodies

- Effective Emissivity >0.998
- T non-uniformity < 0.02 K
- T Abs. Accuracy 0.07 K
- T stability < 0.3 mK/s
- 8 PRT sensors + 32 Thermistors

VIS-SWIR Channels Diffuser Based VISCAL

- Zenith diffuser + relay mirrors
- Uncertainty <2%

On Board Calibration Sources
Calibration Topics

Solar Channel Radiometry
- Calibration of VISCAL system
- Radiometric response over dynamic range
- Linearity
- Radiometric noise performance
- Polarisation

IR Radiometry
- Blackbody calibration
- Radiometric accuracy over dynamic range
- Linearity
- Radiometric noise performance
- Orbital Stability
- Polarisation

Geometric Calibration
- Pointing Direction (LoS)
- Spatial Sampling
- Co-Registration
- Image Quality (MTF)

Spectral Response Calibration
- In-band response
- Out of band response
- Temperature dependency of response
Spectral Response Calibration

• Measurement technique:
  • Operated the SLSTR focal plane array as the detector in a Michelson Fourier transform spectrometer
  • Derived spectral responses from time-resolved interferograms collected by the FPA detectors

• Characterised:
  • Spectral responses of all standard channels (S1 – S9) at FPA temperatures of 87K, 92K, 100K
  • Spectral polarisation (depth, plane and unpolarised response) of longwave channels (S7 – S9) at an FPA temperature of 87K
Spectral Response Profiles

S1 0.555µm

S2 0.660µm

S3 0.868µm

S4 1.375µm

S5 1.612µm

S6 2.253µm

S7 3.742µm

S8 10.82µm

S9 12.05µm

LW edge

Sensitive to Temperature

All channels meet requirements and agree well with predictions

Measurements show expected sensitivity of spectral responses to optics temperatures
VIS/SWIR Calibration

• SLSTR VIS/SWIR channels are calibrated via a diffuser based calibration VISCAL system – based on (A)ATSR concept
  – VISCAL is illuminated once per-orbit by the Sun

• Pre-Launch Calibration is to characterise key instrument performance
  – Radiometric response of each detector
  – Signal-to-Noise performance of each detector
  – Reflectance factor of VISCAL system
  – Polarisation sensitivity
Source Setup

• Integrating sphere used for calibration of SLSTR
  • Labsphere U2000C

• 6 lamps, one (lamp 3) has a variable aperture.

• Three spectrometers mounted on the sphere to monitor source output and provide traceability to UK’s National Physical Laboratory calibration
  • 2 SWIR
  • 1 for VIS-NIR
Integrating Sphere Cross-Comparisons

• An exercise is in progress to compare spectral radiances of integrating sphere sources used for SLSTR (RAL Space) and OLCI (Thales Alenia Space, France) calibrations.

• NPL have performed measurements using spectroradiometers and reference source at host institution.

• Final results soon to be issued
Radiometric Response

Radiometric responses as function of scene radiance measured in both earth views for all channels and detectors.

Note dispersion of responsivity of SWIR Channels.
• Results showed dispersion of measured reflectance factors.
  • Confirmed by on orbit measurements

• Particularly pronounced in SWIR channels.
  • Root cause identified as due to non uniform response across main aperture

• With exception of S6, average values in good agreement with predictions.

• Comparable results for Oblique view and SLSTR-B
IR Instrument Calibration – Objectives

• Does the end-to-end instrument calibration scheme work?
  • New optical design – 2 telescopes not 1, multiple detectors per channel
  • OME thermal design – not based on AATSR heritage

• Does the instrument calibration work over the full field of view and dynamic range?
  • Wider instrument swath compared to AATSR
  • Nonlinearity, Noise performance, Dynamic range

• Does calibration work in flight representative environment?
  • Nominal BOL – is this defined?
  • EOL (Hot)
  • Orbital temperature variations
Calibration facility was designed to perform the radiometric calibration and optical alignment checks under flight representative thermal vacuum conditions with the instrument fully operational in its flight configuration.

Initial Trials with STM completed April 2012
S3A March-May 2015
S3B Oct 2016 – Feb 2017
S3C Spring 2019
S3D 2020...
External Blackbody Calibration Sources

- **Precision RIRTs**
  - Calibrated to ITS90
  - < 0.01K

- **Radiometric Accuracy**
  - < 0.05K

**Identical sources for both nadir/oblique earth views**

**Temperatures controlled by refrigerant loops**

- Emissivity
  - $12\mu m = 0.99871$
  - $11\mu m = 0.99870$
  - $3.7\mu m = 0.99911$

**Sources previously used for all ATSR instruments**

- ATSR
- ATSR-2
- AATSR
- S3 SLSTR
TIR Calibration Procedure

• Measurements are performed at different thermal environment conditions and for different instrument configurations

• Data are processed using calibration algorithms and subsystem characterisation data as used for flight

• Raw data provides input to verify L0-L1 processing chains
Measured - Actual BT SLSTR-A

Plots show the differences between the BT measured by SLSTR and the BT derived from the BB thermometry.

Uncertainties are combined uncertainty estimates – $k=1$

Only S7-S9 shown for clarity.
Plots show the differences between the BT measured by SLSTR and the BT derived from the BB thermometry.

Uncertainties are combined uncertainty estimates – $k=1$

Only S7-S9 shown for clarity.
Why the differences?

**Non-Blackness of optical stops** (i.e. \( \varepsilon < 0.9 \)) causing non-uniform thermal background

Measurements by PTB confirm issue with black coatings

Hence modification to stop coatings

**Temperature gradients in flight BBs**
Thermal modelling shows asymmetry of baseplate temperatures
Analysis of BB radiances in progress
Modelling Calibration Error

• A small team was set up to investigate possible causes of the discrepancies in the calibration results
  • I.e. what are the additional terms in the calibration model.

• An analysis suggested a non-uniform background radiance which varied around the scan.
  • BB radiance errors
  • Non-Black coating on optical baffles

• The effects were modelled and a correction was tested with the data.
  • Model is has several free parameters and is an approximation

• Early inter-comparsions with IASI performed by EUMETSAT suggest that on-orbit stray-light error correction is not necessary.
On-Going Activities

• SLSTR-B commissioning phase is in progress

• Sentinel-3A and Sentinel-3B are now in tandem phase with 30s separation between two spacecraft
  • Allows ‘direct’ comparison between two spacecraft

• Results of integrating sphere comparison to be used for re-analysis of pre-launch calibration of VIS/SWIR channels

• Preparations in full-swing for SLSTR C calibration
  • Spectral response in July 2018
  • Instrument in Spring 2019
Conclusions

• Pre-launch calibration testing under flight representative is essential:
  • For TIR instruments this is particularly true since vicarious calibration – extremely challenging
  • Necessary for demonstrating end-to-end instrument calibration model
  • Allows identification, analysis and correction of measurement errors
  • Provides reference data that are needed for validating data processors and for post-launch activities

• Calibration testing takes time and resources to perform and process data in timely manner
  • As usual calibration is the last activity in an instrument build .... Huge pressure on schedule, budgets ... pressure to descope calibration activities.
Thank You for your attention

Preliminary S3B vs S3A Comparisons from Tandem Phase – Hot Scene

Scatter due to scene non-uniformity + clouds
• Leonardo (formerly Selex ES), Instrument prime contractor, supply of Detector Assembly (the Focal Plane Assembly (FPA), the Front End electronics (FEE) and the Cryocooler (CCS)).
• JOP, supplier of opto-mechanical enclosure.
• RAL, responsible for calibration and systems design consultancy under ThalesAlenia as Sentinel 3A prime contractor.