Calibration and In-Flight Performance of the Sentinel-3 Sea and Land Surface Temperature Radiometer

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The Remote Sensing Problem
A very indirect measurement

Uncertainties are introduced at ALL levels and will affect the final physical quantity of interest

Noise
Responsivity
Spectral Response
Resolution
Coverage
Stability…

Atmosphere (absorption, scattering, emission), surface state, geometry, illumination…

‘Real world’
e.g. SST, cloud…

Validation
\( x_v \) and \( S_v \)

Retrieved parameters
and uncertainty
\( x \) and \( S_x \)

Understanding of what was missed

Instrument measurements \( (y_m) \)
and uncertainty \( (S_y) \)

A priori information \( (x_a) \)
And uncertainty \( (S_a) \)

Knowledge
of environment

Instrument
Calibration
Parameters

Retrieval
Forward model \( y(x) \)

\[
J(x) = (y(x) - y_m)S_y^{-1}(y(x) - y_m)^T + (x - x_a)S_a^{-1}(x - x_a)^T
\]

Accurate
Physics and
Environment

Cost
function
ATSR Series

1991-2000 ATSR-1

1995-2008 ATSR-2

2002-2012- AATSR
SLSTR Key Requirements

- Continuity of Sea and Land Surface Temperature datasets derived from (A)ATSR

- Additional bands for fire radiative power measurements and improved cloud detection

- Dual-View Capability

- On-board calibration sources

- Daily global coverage (with 2 satellites)

AATSR Level-3 product at user-defined spatial resolution Europe daytime Feb 2011 at 0.25°

Global SST ENVISAT AATSR monthly composite

ENVISAT AATSR hot spot fires and world fire atlas
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

On-Board Calibration  Blackbody Sources for TIR
                    VISCAL for solar channels
On-Board Calibration systems

Thermal InfraRed Blackbodies

- Effective $e > 0.998$
- $T$ 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 VISCAL

- Zenith diffuser +
- relay mirrors
- Uncertainty $<2\%$
SLSTR-A

Calibration at RAL - Jan-June 2015

Sentinel-3A launch - Feb 2016

First Image - March 2016

In-Orbit Commissioning Review – July 2016

Hurricane Ophelia 15/10/2017
SLSTR-B

Arrived at RAL for calibration – Oct 2016
In-Air Tests – October – Nov 2016
In-Vacuum Tests – Nov 2016 – Feb 2017
S3B Launch – Spring 2018

SLSTR-B = Refurbished Proto-Flight Model (PFMr)

Refurb includes:
Rebuilt BB1
New flight BB2
Recoated telescope aperture stop to reduce internal strays
The Goal

To ensure the interoperability of satellite datasets it is a requirement for their measurements to be calibrated against standards that are traceable to SI units.

For temperature this is the International Temperature Scale of 1990.

For IR instruments such as SLSTR the traceability is achieved via internal BB sources.

- Instrument
- Blackbody Source
- S-PRT
- Fixed Point Cells
Typically DN will be some function of scene radiance

\[ \text{DN}_{\text{scene}} = F_{\text{ADC}} \cdot (V \{ A\Omega (\tau_{\text{opt}} L_{\text{scene}} + (1 - \tau_{\text{opt}}) L_{\text{inst}}) \} + V_{\text{off}}) \]

which reduces to

\[ \text{DN}_{\text{scene}} = g(L_{\text{scene}}) + \text{offset} \]

We invert this to get scene radiance as a function of DN

\[ L_{\text{scene}} = g^{-1}(\text{DN}_{\text{scene}} - \text{DN}_{\text{offset}}) \approx a_0 + a_1 \text{DN}_{\text{scene}} \text{ (assuming linear function)} \]

\[ (uL_{\text{scene}})^2 = \sum_{i=0}^{n} (uL_i)^2 \]

We obtain calibration coefficients via reference to known calibration sources.
SLSTR L1 Processing

Processing specification defined by

ATBD -> DPM
L0 and L1 Product Specifications

Each spectral band (5 thermal bands) and detector element (2x2) for each for each earth view (separate for nadir and oblique) has unique set of calibration coefficients

= 40 for IR channels alone

Contained in Satellite Characterisation and Calibration Database Document (S-CCDB)
Configuration controlled by MPC
SLSTR IR Traceability Tree

Thermometer Calibration Uncertainties

- Noise
- Thermometer drift
- Drift of readout electronics

Uncertainty in spectral response measurement
Temperature dependence

\[ u(R(\lambda)) \]

\[ \frac{\partial T_{BA1}}{\partial T_i} \]

\[ T_{BA1} = \sum_{i=1}^{n_{BA1}} w_i T_i \sum_{i=1}^{n_{BA1}} w_i \]

Temperature Gradients
Temperature Stability

\[ \frac{\partial L(T_{BA1})}{\partial R(\lambda)} \]

\[ L(T_{BA1}) = \int R(\lambda) B(T_{BA1}, \lambda) d\lambda \]

\[ \frac{\partial L_{BA1}}{\partial T_{BA1}} \]

\[ \frac{\partial L_{BA1}}{\partial L_{BA1}} \]

Reflectance of black coating
Cavity modelling

\[ u(\varepsilon) \]

\[ \frac{\partial L_{BA1}}{\partial \varepsilon} \]

\[ L_{BA1} = L(T_{BA1}) + (1 - \varepsilon) L_{back} \]

Uniformity around scan
Stray Light

\[ \frac{\partial L_{scene}}{\partial L_{BA1}} \]

\[ L_{scene} = L(T_{BA1}) + (1 - \varepsilon) L_{BA1} + \Theta \]

Effective temperature of instrument
Temperature stability during calibration

\[ u(T_{back}) \]

\[ \frac{\partial L_{BA1}}{\partial T_{BA1}} \]

\[ \frac{\partial L_{BA2}}{\partial L_{BA2}} \]

\[ \frac{\partial L_{BA2}}{\partial \varepsilon} \]

\[ \frac{\partial L_{BA2}}{\partial \varepsilon} \]

Effective temperature of instrument
Temperature stability during calibration

\[ u(X) \]

\[ \frac{\partial X}{\partial L_{scene}} \]

\[ L_{scene} = \frac{(C_{scene} - C_{BA2})}{(C_{BA1} - C_{BA2})} \]

Non-Linearity Measurement
Noise

\[ u(NL) \]

\[ \frac{\partial C_{scene}}{\partial NL} \]

\[ u(C_{scene}) \]

\[ \frac{\partial C_{scene}}{\partial C_{BA1}} \]

\[ C_{BA1} = \frac{1}{N} \sum_{i=1}^{N} C_{BA1i} \]

\[ \frac{\partial C_{BA1}}{\partial C_{BA1}} \]

\[ u(C_{BA1}) \]

Non uniformity of source

\[ u(C_{BA2}) \]

\[ \frac{\partial C_{BA2}}{\partial C_{BA2}} \]

\[ C_{BA2} = \frac{1}{N} \sum_{i=1}^{N} C_{BA2i} \]

Noise

\[ \frac{\partial C_{BA2}}{\partial C_{BA2}} \]

\[ u(C_{BA2}) \]

\[ \frac{\partial C_{BA2}}{\partial C_{BA2}} \]

\[ u(C_{BA2}) \]

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This is the flight calibration budget
Instrument Calibration – Objectives

• Provision of calibration data needed for data processing chain

• Does the end-to-end flight 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
  – EOL (Hot)
  – Orbital temperature variations
Calibration Topics

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

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

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

Geometric Calibration
- Pointing Direction (LoS)
- Spatial Sampling
- Co-Registration
- Image Quality (MTF)
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 within requirements 😊
Thermal IR Calibration Facility

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

Initial Trials with STM completed April 2012

TV and calibration of S3A instrument March-May 2015

S3B Calibration Oct 2016 – Feb 2017

S3C 2019

S3D 2020…
TIR calibration - Blackbody Source

**Precision RIRs**
Calibrated to ITS90
< 0.01K

**Radiometric Accuracy**
< 0.05K

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

**Sources previously used for all ATSR instruments**

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**Standards**

- ATSR
- ATSR-2
- AATSR
- S3 SLSTR
IR Calibration Test Summary

• Calibration at ‘Nominal’ BOL conditions
  – Centre of Nadir/Oblique views
  – On-Board BBs at nominal settings (250K, 300K)
  – Test over full dynamic range (5K intervals)
  – Test over full swath (reduced number of scene temperatures)

• Calibration at ‘Hot’ EOL conditions
  – Centre of Nadir/Oblique views
  – On-Board BBs at nominal settings (250K, 300K)
  – Test over part dynamic range (10K intervals)

• Tests with different on-board BB temperatures
  – Test performed at ‘Nominal’ BOL conditions
  – Currently at ‘low’, ’medium’, ’high’ power settings
  – +Y and –Y BBs will be switched
  – Test over part dynamic range (10K intervals)

• Orbital simulation tests
Both instruments have comparable NEDT performance and well inside mission requirements.
IR Calibration - Counts Vs. Temps

70us integration time shown only

Min temperature achieved is 224K

Saturation of S7 > 300K (additional step at 305K to confirm)
TIR Calibration - Measured vs Actual BT

Nadir

Oblique
Non-Linearity of S8 and S9 consistent with expected behaviour of PC MCT detectors.

S3A and S3B show very similar behaviour.
Creation of NL Table

Measured Counts and BB Radiances normalised to signal corresponding to 65535 counts

\[ y = \frac{L_{\text{actual}}(DN) - L(0)}{L(DN_{\text{ref}}) - L(0)} \quad \text{- from thermometers} \]

\[ x = \frac{DN_{\text{meas}}}{DN_{\text{ref}}} \quad \text{- from SLSTR} \]

Polynomial function fitted to data to generate coefficients for NL function

\[ NL = \sum_{i=2}^{n} \frac{a_i}{a_1} x^{i-1} \]

Digital counts are linearized using

\[ DN = \frac{DN}{1.0 + NL(x)} \]
Measured - Actual BT SLSTR-B

Nadir

Oblique
Measured - Actual BT

SLSTR-A

Nadir

Oblique
Why the differences?

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

Measurements by PTB confirm 2015 investigation

Hence modification to stop coatings

Temperature gradients in flight BBs
Thermal modelling shows asymmetry of baseplate temperatures
Analysis of BB radiances in progress
Post launch – we can ‘check’ BB signals by comparing the signals when the BBs are at the same temperatures. This is achieved by switching the heated BB and allowing their temperatures to cross-over.

Test is performed during ground calibration as a baseline
Comparison DN vs BB Temps

1\textsuperscript{st} Cross Over (RAD06)

2\textsuperscript{nd} Cross Over (RAD08)
### S3B BB Counts at Cross-Over

#### BB X-Over 1 - Temp = 283.529K

<table>
<thead>
<tr>
<th></th>
<th>+YBB</th>
<th>-YBB</th>
<th>ΔDN</th>
<th>ΔT</th>
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<tbody>
<tr>
<td>S7 Nadir</td>
<td>23501</td>
<td>23554</td>
<td>53</td>
<td>0.082</td>
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<tr>
<td>S8 Nadir</td>
<td>26397</td>
<td>26394</td>
<td>-3</td>
<td>0.055</td>
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<td>S9 Nadir</td>
<td>24735</td>
<td>24778</td>
<td>43</td>
<td>0.101</td>
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<tr>
<td>S7 Oblique</td>
<td>23524</td>
<td>23584</td>
<td>60</td>
<td>0.002</td>
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<tr>
<td>S8 Oblique</td>
<td>26560</td>
<td>26591</td>
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<tr>
<td>S9 Oblique</td>
<td>24872</td>
<td>24896</td>
<td>24</td>
<td>0.002</td>
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#### BB X-Over 2 Temp = 285.690K

<table>
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<tr>
<td>S7 Nadir</td>
<td>25077</td>
<td>25070</td>
<td>-7</td>
<td>-0.010</td>
</tr>
<tr>
<td>S8 Nadir</td>
<td>27516</td>
<td>27511</td>
<td>-5</td>
<td>-0.011</td>
</tr>
<tr>
<td>S9 Nadir</td>
<td>25706</td>
<td>25723</td>
<td>17</td>
<td>0.038</td>
</tr>
<tr>
<td>S7 Oblique</td>
<td>25114</td>
<td>25079</td>
<td>-35</td>
<td>-0.050</td>
</tr>
<tr>
<td>S8 Oblique</td>
<td>27722</td>
<td>27700</td>
<td>-22</td>
<td>-0.046</td>
</tr>
<tr>
<td>S9 Oblique</td>
<td>25854</td>
<td>25831</td>
<td>-23</td>
<td>-0.054</td>
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SLSTR-A – Post Launch

Part 1

Part 2
### S3A BB Counts Comparison at X-Over

#### Post Launch – 29 Mar-2016

**BB X-Over 1 - Temp = 289.1392K**

<table>
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<tr>
<td>S7 Nadir</td>
<td>24658</td>
<td>24745</td>
<td>87</td>
<td>0.108</td>
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<td>S8 Nadir</td>
<td>29764</td>
<td>29777</td>
<td>13</td>
<td>0.026</td>
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<td>S9 Nadir</td>
<td>27087</td>
<td>27093</td>
<td>6</td>
<td>0.017</td>
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<tr>
<td>S7 Oblique</td>
<td>24585</td>
<td>24685</td>
<td>100</td>
<td>0.128</td>
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<td>S8 Oblique</td>
<td>30162</td>
<td>30171</td>
<td>8</td>
<td>0.017</td>
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<tr>
<td>S9 Oblique</td>
<td>27363</td>
<td>27364</td>
<td>1</td>
<td>0.004</td>
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**BB X-Over 2 Temp = 290.5619K**

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<td>S7 Nadir</td>
<td>25904</td>
<td>25896</td>
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<td>S8 Nadir</td>
<td>30454</td>
<td>30443</td>
<td>-11</td>
<td>-0.022</td>
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<tr>
<td>S9 Nadir</td>
<td>27490</td>
<td>27481</td>
<td>-9</td>
<td>-0.024</td>
</tr>
<tr>
<td>S7 Oblique</td>
<td>25821</td>
<td>25794</td>
<td>-27</td>
<td>-0.031</td>
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<tr>
<td>S8 Oblique</td>
<td>30849</td>
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<td>S9 Oblique</td>
<td>27762</td>
<td>27742</td>
<td>-20</td>
<td>-0.052</td>
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#### Pre Launch – 29 Mar-2016

**BB X-Over 1 - Temp = 280.85K**

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<tr>
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<td>18868</td>
<td>18898</td>
<td>31</td>
<td>0.053</td>
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<td>S8 Nadir</td>
<td>25543</td>
<td>25531</td>
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<td>-0.025</td>
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<tr>
<td>S9 Nadir</td>
<td>22593</td>
<td>22581</td>
<td>-12</td>
<td>-0.036</td>
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<tr>
<td>S7 Oblique</td>
<td>18819</td>
<td>18857</td>
<td>37</td>
<td>0.065</td>
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<td>S8 Oblique</td>
<td>25830</td>
<td>25809</td>
<td>-21</td>
<td>-0.043</td>
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<tr>
<td>S9 Oblique</td>
<td>22797</td>
<td>22777</td>
<td>-20</td>
<td>-0.059</td>
</tr>
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**BB X-Over 2 Temp = 285.65K**

<table>
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<th>ΔDN</th>
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<td>S8 Nadir</td>
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<td>S9 Nadir</td>
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<tr>
<td>S7 Oblique</td>
<td>21942</td>
<td>21937</td>
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<td>-0.007</td>
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<tr>
<td>S8 Oblique</td>
<td>28280</td>
<td>28257</td>
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<td>-0.047</td>
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<tr>
<td>S9 Oblique</td>
<td>24527</td>
<td>24509</td>
<td>-18</td>
<td>-0.049</td>
</tr>
</tbody>
</table>

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On-Orbit Monitoring

• Routine monitoring of SLSTR performance is performed by Sentinel-3 Mission Performance Centre
  – Analysis of parameters critical for on-orbit calibration

• Analysis of SLSTR data are performed using.
  • Level-0 data are provided via the MPC FTP server.
  • Level-1 assessment is made via IPF products made available on the MPC server.

• Routine monitoring plots for L0 data are available at:
  http://gws-access.ceda.ac.uk/public/slstr_cpa/phase_E1/SLSTR_Calibration.html
  with username RAL_monitoring and password Sentinel3_RAL.
TIR Radiometric Noise Performance

All channels within specification
BB Temperatures

Heated BB temperature showed increase towards perihelion – Tbb ~ 304K – just below S7 saturation threshold (305K).

May need to reduce heater power to avoid Tbb = 305K

Small drift of PRT#1 (centre of BB) observed
IR gains show increase as detector temperatures warm-up between outgassing cycles.

Calibration should compensate but may see variations in calibration at extremes of scene temperature range due to non-linearity errors.
IR Channel Offsets

IR offsets show small variation due to detector and optics temperature variations.

Offset variations will determine minimum BTs (see later slides on S8 minimum temperature).

Note each detector and odd/even pixels have different offset values.
Nadir/Oblique View Comparisons

S7 shows change between gains of Nadir and Oblique views ~ 0.1%

S8/S9 show small differences <0.01%
SLSTR-A – IASI-A Comparisons

Time Difference 5 min
|IASI sza|<20deg|no_signal
filtered

Tomazic et al Eumetsat Conference 2016
SLSTR-A - IASI-A Comparisons
2K Binned averages

Cold BB at 262K

Where is the ’stray light’?

Note calibration Budget

Tomazic et al Eumetsat Conference 2016
Conclusions

• Pre-Launch Calibration allows us to validate the end-to-end instrument flight calibration systems against known reference targets.
  – Not possible after launch
  – Provides a reference dataset against which the processing algorithms can be verified.

• Papers on calibration results are being prepared

• L1 products contain basic uncertainty estimates
  – Noise derived from BB sources
  – Estimates of calibration uncertainties from pre-launch characterisation
  – Improvements are foreseen…

• Traceability chain needs to be documented in-order for SLSTR to become a reference sensor.
Credits: SLSTR Core team

- 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 contactor.
Additional Slides
References

Calibration Plan

David L. Smith, Tim J. Nightingale, Hugh Mortimer, Kevin Middleton, Ruben Edeson, Caroline V. Cox, Chris T. Mutlow, Brian J. Maddison, Peter Coppo
[doi:10.1117/1.JRS.8.084980]

Description of SLSTR design

Line-Of-Sight Model and Verification

- **Inputs to LoS Model**
  - Direction cosines of detectors relative to nominal beam
  - Scan cone angles
  - Scan rotation angles
  - Encoder characterisation
  - Scan inclination angles

- **Required Uncertainty**
  - Total uncertainty wrt optical cube, < 0.05° (180”)
  - Period <30s, Precision <7”
  - Period < 1 orbit, Precision <15”

- **Line-Of-Sight model in L1 processor is being modified to account for alignment differences in the two scanners compared to ideal pointing**
S3B - Geometric calibration: LoS Measurements vs Model

Solid = model, squares = measurements, x = JOP cone model

Updated processor model gives excellent agreement with measurements 😊
IFOV Measurements

Flight Direction

S3 – 0.870µm  
S6 – 2.25µm  
S7 – 3.74µm

A-Stripe  
B-Stripe

All corresponding channels are optically co-registered
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

- 6 lamps, one (lamp 3) has a variable aperture. 0%=open, 100%=closed. Percentage is not proportional to open area.

- Lamp settings controlled and data recorded using labview interface on a PC

- Three spectrometers mounted on the sphere to monitor source output and traceability to NPL calibration
  - 2 SWIR
  - 1 for VIS-NIR
An exercise was initiated 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.

Measurements performed at RAL in December during SLSTR calibration campaign. Data being processed.

Measurements for OLCI performed in April
Comparisons – RAL vs NPL measurements

VIS-NIR (S1-S3)
Ocean Optics

Diff <1%

SWIR (S4-S5)
Hamamatsu

Diff <3%

Diff <3%

Diff ~43%

Diff ~7%

SWIR (S4-S5)
Ocean Optics

Diff ~13%

Diff ~2.5%

Diff ~11%

Diff ~2%

Good agreement at S1-S3, S5. Discrepancies at S4, S6
Radiometric Response in Earth View

Response Nadir View

Response Oblique View

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SLSTR-B VISCAL Reflectance Factors

Predicted

Measured

Nadir

Oblique

Note – Separate values for each detector + view
Differences have been observed between different methods of evaluating VISCAL reflectance factors in SWIR channels.

- Detector-Detector differences
- Image stripes
- Differences in absolute factors
  – Especially S6

BOL on-orbit measurement of VISCAL signals appear to be more in-line with vicarious calibration + destriping correction.

S1 and S5 Results show good consistency with different methods!
We performed a set of measurements where the source illuminated the diffused and measured the signal response for different scanner positions.

Results determined the range of pixels to use on-orbit.

Showed a significant non-uniformity in the measured responses.
- For SWIR channels different for each detector
- Greater than expected variation in diffuser BRDF

Why?
To investigate cause of non-uniformity we performed some additional measurements at centre of earth view.

We illuminate the earth view with a 50mm diameter source (i.e. underfilling the pupil) and measure the instrument response as a function of scanner position (along scan direction).

Results show all VIS channels appear to fill main aperture uniformly.

Differences seen in SWIR channel A and B stripes. Less uniform response.
Pupil Uniformity – Along Track

We then repeated the measurements, this time moving source in vertical direction (along track direction)

Results show all VIS channels appear to fill main aperture uniformly.

Noticeable differences seen in each SWIR detector.

Conclusion:
Main telescope aperture is not the primary pupil for the SWIR channels

Provides root cause for variations in measured instrument response and Rcal