Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR)

Mireya Etxaluze (STFC RAL Space)

RAL Space Radiometry Group
Dave Smith
Mireya Etxaluze, Ed Polehampton, Caroline Cox, Tim Nightingale, Dan Peters
**Sentinel-3**

- **ESA** is developing a family of Earth observation satellites called **Sentinels** for the **European Union Copernicus** programme.
- **Sentinel-3** will support ocean forecasting systems, as well as environmental and climate change monitoring.
- It consists of the following instruments:
  - **Sea and Land Surface Temperature Radiometer (SLSTR)**
  - **Ocean and Land Colour Instrument (OLCI)**
  - **Radar Altimeter (SRAL)**
  - **Microwave Radiometer (MWR)**
Credits: SLSTR Core team

- **ThalesAlenia**: Sentinel-3 prime contractor
- **Leonardo**: SLSTR instrument prime contractor
  - Focal Plane Assembly (FPA)
  - Front End electronics (FEE)
  - Cryocooler (CCS)
- **JOP**: Opto-mechanical enclosure
- **RAL Space**:
  - Systems design consultancy
  - Ground calibration
  - In-orbit commissioning
  - SLSTR Expert Support Laboratory (part of the **Sentinel-3 Mission Performance Centre**)
Where does SLSTR fit in?

SLSTR follows a series of successful sensors, aiming for continuous and consistent monitoring of sea surface temperatures.

- **1991-2000 ATSR-1**
- **1995-2008 ATSR-2**
- **2002-2012 AATSR**
- **2016 – Sentinel 3A**

Launched
16-Feb-2016 😊
<table>
<thead>
<tr>
<th>Band</th>
<th>λ centre (µm)</th>
<th>Width (µm)</th>
<th>Res. (km)</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0.555</td>
<td>0.02</td>
<td>0.5</td>
<td>Cloud screening, vegetation monitoring, aerosol</td>
</tr>
<tr>
<td>S2</td>
<td>0.659</td>
<td>0.02</td>
<td>0.5</td>
<td>NDVI, vegetation monitoring, aerosol</td>
</tr>
<tr>
<td>S3</td>
<td>0.865</td>
<td>0.02</td>
<td>0.5</td>
<td>NDVI, cloud flagging, Pixel co-registration</td>
</tr>
<tr>
<td>S4</td>
<td>1.375</td>
<td>0.015</td>
<td>0.5</td>
<td>Cirrus detection over land</td>
</tr>
<tr>
<td>S5</td>
<td>1.615</td>
<td>0.06</td>
<td>0.5</td>
<td>Cloud clearing, ice, snow, vegetation monitoring</td>
</tr>
<tr>
<td>S6</td>
<td>2.255</td>
<td>0.05</td>
<td>0.5</td>
<td>Vegetation state and cloud clearing</td>
</tr>
<tr>
<td>S7</td>
<td>3.740</td>
<td>0.38</td>
<td>1.0</td>
<td>SST, LST, Active fire</td>
</tr>
<tr>
<td>S8</td>
<td>10.85</td>
<td>0.9</td>
<td>1.0</td>
<td>SST, LST, Active fire</td>
</tr>
<tr>
<td>S9</td>
<td>12.00</td>
<td>1.0</td>
<td>1.0</td>
<td>SST, LST</td>
</tr>
<tr>
<td>F1</td>
<td>3.740</td>
<td>0.38</td>
<td>1.0</td>
<td>Active fire</td>
</tr>
<tr>
<td>F2</td>
<td>10.85</td>
<td>0.9</td>
<td>1.0</td>
<td>Active fire</td>
</tr>
</tbody>
</table>
As for (A)ATSR series, the conical scanning concept is adopted.

Two separate scans (instead of one for AATSR) have been implemented to increase the swath width:
- A nadir view (1400km)
- An inclined oblique view (740km)

Internal calibration sources are viewed once in each cycle of two scans (0.6 seconds).

Two atmospheric path views are fundamental to characterise the atmosphere (aerosols, water vapour).

\[ \theta = 23.5 \, \text{deg} \]
\[ \beta = 47 \, \text{deg} \]
Nadir and oblique views
Nadir and oblique views
SLSTR Scanning Geometry

Oblique

Nadir

SLSTR (Sea Land and Surface Temperature Radiometer)
Sentinel-3 SLSTR First Image over Egypt 03/03/2016 + Last AATSR image over Egypt 07/04/2012
Sentinel-3 SLSTR First Image over Egypt 03/03/2016
+
Last AATSR image over Egypt 07/04/2012
On-ground Calibration

In order to make reliable maps, careful pre-launch and in-orbit calibration is required!

- Visible channel signals with known reference lamps
- Thermal channel signals with thermally controlled external blackbodies
- Detector positions and shapes with respect to the line of sight
In-orbit calibration

RAL space participates on the commissioning phase:

- Internal calibration source performance and stability
- Scanner stability
- Geometric calibration
- Characterisation of detector gains and stability
- Dynamic range
- Verification of Level-1 images
- Flagging (clouds, saturation etc)

One orbit of data from 3.7µm channel showing the entire scan cycle
Geometric calibration

Quasi-Cartesian grid centred on satellite ground track and aligned to the geoid.

Each pixel is then allocated a longitude and latitude based on the satellite ground track via a 16 km “tie-point” grid.

Geo-location works fine for the sea surface, but for land, there can be view angle related shifts…
The VISCAL signal was constant until the instrument was cool down and the SWIR and the TIR channels were switched on, on March 21.

Oscillations are due to the build up of ice on the FPA.

It is reduced after each decontamination.
In the nadir view, Level-1 data present a positional offset changing from 2 pixels (at the beginning of the swath) to 1 pixel (at the end of the swath) in the **across-track direction**.

In the **along-track direction**, the offset changes from +2 pixels (at the beginning of the swath) to -1 pixel (at the end of the swath).
VIS/SWIR Inter-band coregistration
Offsets were measured by correlation array
TIR Inter-band coregistration

Before correction

After 250m positional offset correction

Inter-band misalignment is due to a time offset in the read outs
SWIR Channel ‘Striping’

- SLSTR uses several detectors per channel

- Early images were very striped due to different detectors having different radiometric responses, and water vapor contamination

Image from the Sahara desert (2.25µm channel)
SWIR Channel ‘Striping’

- SLSTR uses several detectors per channel

- Early images were very striped due to different detectors having different radiometric responses, and water vapor contamination

Image from the Sahara desert (2.25µm channel)
SWIR Channel ‘Striping’

- SLSTR uses several detectors per channel

- Early images were very striped due to different detectors having different radiometric responses, and water vapor contamination

© 2017  RAL Space

Image from the Sahara desert (2.25µm channel)
Verification of radiometric calibration

General comparison with MODIS-A, MERIS, OLCI, and AATSR over deserts reveal that:

- Bands S1, S2 and S3 are 3% higher than the predictions
- SWIR bands largely overestimated (measured radiances are lower than expected)
- About 10% for 1610nm, and ~40% for 2200nm

![Graph showing measured vs predicted radiances for different wavelengths and sensors.](image-url)
Inter-band calibration over sunglint

• First goal is to use sun-glint to compare relative calibrations of VIS/SWIR channels

• Using VIS and the SWIR channels, we can derive the 3.7µm radiances over sun-glint and provide a calibration reference for the fire channel F1.
  • Needed for BTs > 305K where S7 saturates

• Transfer the absolute calibration of one reference spectral band to other spectral bands, from the visible to the NIR wavelengths.

• Radiative transfer modelling of sun-glint over ocean.
### Modeling sunglint
based in ORAC (Oxford-RAL Aerosols and Clouds)

The model accounts for:

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>White-cap contribution to the reflectance</td>
<td>( \rho_{wc}(wcfrac) )</td>
</tr>
<tr>
<td>Total underlight contribution: (Fresnel’s Law, surface transmission and underlight reflectance)</td>
<td>( \rho_{ul}(R_{wb}) )</td>
</tr>
<tr>
<td>Water body reflectance: (Chl concentration, CDOM absorption, back scattering)</td>
<td>( R_{wb} )</td>
</tr>
<tr>
<td>Glint reflectance contribution</td>
<td>( \rho_{gl}(R_{wr}) )</td>
</tr>
<tr>
<td>Reflectance from wind-roughened surface (Cox &amp; Munk 1956)</td>
<td>( R_{wr} )</td>
</tr>
</tbody>
</table>

The surface reflectance:  
\[
\rho_{sr} = \rho_{wc} + (1+wcfrac) \times (\rho_{gl} + \rho_{ul})
\]
## Rayleigh scattering

<table>
<thead>
<tr>
<th>Scattering by the atmosphere ($\tau$, Pressure, angles)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar attenuation</td>
<td>$T_{\text{sol}}$</td>
</tr>
<tr>
<td>Forward scattered solar signal</td>
<td>$R_{\text{sol}}$</td>
</tr>
<tr>
<td>Attenuation of reflected signal</td>
<td>$T_{\text{sat}}$</td>
</tr>
<tr>
<td>Forward scattered reflected signal</td>
<td>$R_{\text{sat}}$</td>
</tr>
<tr>
<td>Direct scattering back to satellite</td>
<td>$R'_{\text{sat}}$</td>
</tr>
</tbody>
</table>

Optical depth: $\tau = (0.008569/\lambda^4)*(1.0 + 0.0113/\lambda^2 + 0.00013/\lambda^4)$

Total transmission: $T = (T_{\text{sol}}+R_{\text{sol}}) *(T_{\text{sat}}+R_{\text{sat}})$

The full surface reflectance: $\rho = \rho_{\text{sr}} * T + R'_{\text{sat}}$
Atmospheric effects

| The transmittance of the atmosphere |  
|-----------------------------------|--
| Optical depth due to H₂O, O₃, CO₂ | SLSTR Level-1 auxiliary data files |
| Optical depth due to Aerosols     | AERONET |

Transmittance: \( \exp\left( -\left( \tau_{\text{H}_2\text{O}} + \tau_{\text{O}_3} + \tau_{\text{CO}_2} + \tau_{\text{aer}} \right) / \cos(\theta) \right) \)

Total surface reflectance: \( \rho_{\text{tot}} = \rho \times T_{\text{gs}} \times T_{\text{go}} \)
AATSR vs. model – South Pacific 04/01/2010

Nadir 0.56 µm
Relative diff. = -1.23%

Nadir 0.66 µm
Relative diff. = 3.09%

Nadir 0.862 µm
Relative diff. = 1.37%

Nadir 1.593 µm
Relative diff. = -2.11%
MODIS vs. model – South Pacific 01/04/2017
Wavelength (nm) | rel.Dif (%)  
---|---  
553.9 | 0.4  
645.8 | 3.1  
856.9 | 2.4  
1628.1 | -11.3  
2114.0 | -39.7
SLSTR vs. model – South Pacific 01/04/2017

Good agreement with the absolute calibration measured on Deserts

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>rel. Dif (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>553.9</td>
<td>0.4</td>
</tr>
<tr>
<td>645.8</td>
<td>3.1</td>
</tr>
<tr>
<td>856.9</td>
<td>2.4</td>
</tr>
<tr>
<td>1628.1</td>
<td>-11.3</td>
</tr>
<tr>
<td>2114.0</td>
<td>-39.7</td>
</tr>
</tbody>
</table>
Current status of the mission

• Level-1 data from Sentinel-3A already available since November
  – e.g. from the Copernicus Online Data Archive  https://coda.eumetsat.int/

• Some issues are still under investigation:
  – Nadir/Oblique geolocation correction is ongoing
  – Inter-band coregistration has been solved but the corrections have not
    been implemented on the Level-1 data from coda.eumetsat.int
  – SWIR calibration error being investigated
  – Transfer the absolute calibration over the 3.7µm radiances over sun-glint
    and provide a calibration reference for the fire channel F1.

• Level-2 maps of sea and land surface temperatures to be released in summer
  2017

• Sentinel-3B SLSTR ground calibration just completed - due for launch towards
  the end of 2017

• Sentinel-3C and Sentinel-3D currently being developed and will be integrated/
  tested over the next 5 years, ready to replace A & B at the end of their life