Activities and plans for Cal/Val of Sentinel Ocean Colour Radiometry
Sentinel Ocean Colour Radiometry requirements

- Cal/val aims to fulfill the mission requirements
- Cal/val planning ensures traceability to the mission requirements [S3 Mission Requirements Traceability Document, 2011; S2 Mission Requirements Document, 2007]
Sentinel-3 cal/val and Mission Performance Framework

- Sentinel-3 OLCI cal/val activities
  - based on joint ESA and EUMETSAT Cal/Val Plan
- Sentinel-3 Mission Performance Framework
  - Quality Working Groups (OLCI-SYN QWG)
  - Mission Performance Centre
  - Sentinel-3 Validation Team
  - Mission Performance activities in-house

**Sentinel-3 OLCI cal/val tasks**
- Radiometric calibration
  - Monitoring of dark offsets
  - Quantifying of aging of solar diffusers
  - Monitoring of instrument response and degradation modelling
- Radiometry validation
  - Verification with Level-1B and Level-3 products
- Spectral calibration
  - Erbium doped diffuser
  - Campaigns: Fraunhofer line and O2 absorption band calibration
  - Correction for the smile effect
- Geometric calibration and validation
  - L1 product quality verification
  - System vicarious calibration
    - NIR and VIS band system vicarious calibration
  - Validation with in situ measurements
    - Acquisition of in situ measurements, measurement archiving
    - Tracability of in situ measurement quality
    - Extraction of OLCI data over validation sites, extract archiving
    - Generation of matchups and trend results
  - Validation with Level-3 products
    - Evaluation of algorithm performance over time and space
    - Evaluation of consistency with other missions
    - Monitoring of the processing chain and implementation
  - L2 product quality verification
OLCI in-flight calibration concept

<table>
<thead>
<tr>
<th>#</th>
<th>calibration type</th>
<th>measurements</th>
<th>frequency</th>
<th>conditions</th>
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</thead>
<tbody>
<tr>
<td>S01</td>
<td>Radiometric calibration</td>
<td>Dark Shutter calibration</td>
<td>About every 2 weeks</td>
<td>South Pole Nominal band set</td>
</tr>
<tr>
<td>S02</td>
<td>Spectral calibration with diffuser</td>
<td>Diffuser 1</td>
<td>About every 3 months</td>
<td>South Pole Erbium band set</td>
</tr>
<tr>
<td>S03</td>
<td>Spectral calibration with diffuser</td>
<td>Diffuser 1</td>
<td>Same as S02</td>
<td>South Pole Erbium band set</td>
</tr>
<tr>
<td>S04</td>
<td>Diffuser 1 ageing</td>
<td>Diffuser 1</td>
<td>About every 3 months</td>
<td>South Pole Nominal band set</td>
</tr>
<tr>
<td>S05</td>
<td>Diffuser 1 ageing</td>
<td>Diffuser 2</td>
<td>Same as S04</td>
<td>South Pole Nominal band set</td>
</tr>
<tr>
<td>S06</td>
<td>Orbital stability</td>
<td>Dark Shutter calibrations operated over an orbit</td>
<td>Specific calibration campaigns</td>
<td>Nominal band set</td>
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<tr>
<td>S07</td>
<td>Spectral calibration using solar Fraunhofer lines</td>
<td>Dark Shutter calibration</td>
<td>Specific calibration campaigns</td>
<td>South Pole Fraunh. band set</td>
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<tr>
<td>S08</td>
<td>Radiometric calibration for observation of atmospheric absorption lines</td>
<td>Diffuser 1</td>
<td>Same as S02</td>
<td>South Pole Atm. absorption band set</td>
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<tr>
<td>S09</td>
<td>Observation of atmospheric absorption lines</td>
<td>Diffuser 1</td>
<td>Same as S02</td>
<td>Atm. absorption band set</td>
</tr>
</tbody>
</table>
S3A OLCI spectral calibration

• OLCI is fully compliant with spectral requirements
  • spectral misregistration $\ll 1.4$nm (OL-DE-020)
  • pre-flight SRF confirmed on-orbit $< 0.4$nm $\ll 1$nm (OL-IQ-100)

• OLCI spectral calibrations on orbit
  • OLCI is programmable and can observe up to the highest spectral sampling of 1.25nm
  • Erbium-doped diffuser, Diffuser 3
  • Fraunhofer lines, Diffuser 1
  • atmospheric absorption lines (O$_2$A), Earth targets

<table>
<thead>
<tr>
<th>#</th>
<th>OLCI nominal spectral bands</th>
<th>$\lambda$ center</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aerosol, in-water property</td>
<td>400</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>Yellow substance/detrital pigments</td>
<td>412.5</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Chlorophyll absorption max</td>
<td>442.5</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Chlorophyll and other pigments</td>
<td>490</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Suspended sediments, red tide</td>
<td>510</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Chlorophyll absorption min</td>
<td>560</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Suspended sediment</td>
<td>620</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>Chlorophyll absorption &amp; fluorescence</td>
<td>665</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>Fluorescence retrieval</td>
<td>673.75</td>
<td>7.5</td>
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<tr>
<td>10</td>
<td>Chlorophyll fluorescence peak</td>
<td>681.25</td>
<td>7.5</td>
</tr>
<tr>
<td>11</td>
<td>Chlorophyll fluorescence ref., atm. corr.</td>
<td>708.75</td>
<td>10</td>
</tr>
<tr>
<td>12</td>
<td>Vegetation, clouds</td>
<td>753.75</td>
<td>7.5</td>
</tr>
<tr>
<td>13</td>
<td>$O_2$ R-branch absorption</td>
<td>761.25</td>
<td>2.5</td>
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<tr>
<td>14</td>
<td>Atmospheric parameters</td>
<td>764.375</td>
<td>3.75</td>
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<tr>
<td>15</td>
<td>Cloud top pressure</td>
<td>767.5</td>
<td>2.5</td>
</tr>
<tr>
<td>16</td>
<td>$O_2$ P-branch absorption</td>
<td>778.75</td>
<td>15</td>
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<td>17</td>
<td>Atmospheric correction</td>
<td>865</td>
<td>20</td>
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<tr>
<td>18</td>
<td>Vegetation, water vapour reference</td>
<td>885</td>
<td>10</td>
</tr>
<tr>
<td>19</td>
<td>Water vapour, land</td>
<td>900</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>Atmospheric/aerosol correction</td>
<td>940</td>
<td>20</td>
</tr>
<tr>
<td>21</td>
<td>Atmospheric/aerosol correction</td>
<td>1020</td>
<td>40</td>
</tr>
</tbody>
</table>


OLCI on-orbit spectral information

• Sentinel-3 OLCI-A spectral response functions (SRF), Sentinel 3 CalVal Team, S3-TN-ESA-OL-660, 2016
• centre wavelength, bandwidth, solar irradiance, RSF x200
• three SRF definitions available (section 7):
  o 21 bands x 5 cameras x 740 CCD columns
  o 21 bands x 5 cameras x 3 CCD columns (start, centre, end)
  o 21 bands average

OLCI Smile correction is accomplished at L2 processing
**S3A OLCI geometric calibration**

- **OLCI is fully compliant with geolocation requirements**
  - Accuracy << 0.5 SSD rms with GCPs (SY-OB-210)
- **Operational performance monitoring: periodic assessment using Ground Control Points from Landsat land cover**
  - Initial analysis 12.10-17.10.2016
    - AC: -0.15 ± 0.06 pix; AL: -0.05 ± 0.06 pix
  - Latest analysis 29.04-03.05.2017
    - AC: -0.25 ± 0.07 pix; AL: -0.16 ± 0.08 pix (robust statistics)

**Location of used GCP and associated along track differences**

- **Along track**
- **Across track**
S3A OLCI radiometric response evolution

OLCI relative radiometric evolution since launch

OLCI revised relative radiometric evolution since launch using the new solar diffuser BRDF model derived from yaw manoeuvres

- OLCI solar diffuser assessment on-orbit performed with a sequence of S3A yaw manoeuvres
  - To reproduce in a single day the annual range of variations in solar geometry on the diffuser
    - S3A Mission Advisory Group recommendation (S3MAG-M4-A10, 2014)
    - S3 OLCI Cal/Val task (OLCI-L1B-CV-280), S3 Cal/Val Plan (S3-PL-ESA-SY-0265, 2014)
    - S3A IOC/CR technical meeting recommendation (S3-MN-ESA-OL-752, 2016)
  - Sequence of yaw manoeuvres executed 07 Dec 2016

Solar diffuser pre-launch BRDF model residuals

±0.5%

±0.9%
S3A OLCI absolute radiometric calibration

- **OLCI radiometric limitations**
  - Absolute and inter-band radiometric calibration are not fully compliant: 2% absolute and 1% inter-band uncertainty for bands < 900nm (OL-IQ-040, -050)

- **Ocean Colour System Vicarious Calibration OC–SVC**
  - Modified strategy is applied to mitigate low matchup numbers early in the mission
  - NIR – Franz et al., 2007, and unconstrained all-NIR fit
  - VIS – MOBY, BOUSSOLE and oligotrophic sites

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**L1B TOA biases: S3A OLCI**

**L2 water reflectance biases**

No OC-SVC applied

Band 490nm OLCI vs AERONET-OC

**L3 oligotrophic water reflectance biases**

No OC-SVC applied

Band 490nm OLCI ratios with MODIS VIIRS
Development of operational Copernicus SVC capabilities

- Development of Copernicus OC–SVC is required
  - for Sentinel-3 and Sentinel-2 missions
  - for decades of upcoming ocean colour operations A/B/C/D [S3 MRTD’11; S3 Cal/Val Plan’14]
  - based on international cooperation and harmonization
- ESA FRM4SOC OC–SVC workshop, Feb 2017
  - need for MOBY-like development, while supporting BOUSSOLE
- EUMETSAT Copernicus OC–SVC studies, Oct 2016 –
  - Step 1: Scientific, Technical and Operational Requirements (pre-phase A)
  - Step 2: Preliminary Design, Project Plan and Costing (phase-A)
  - Step 3: Technical Definition, Specifications, Detailed Design (phase B)
- Step 1: OC–SVC Scientific, Technical and Operational Requirements
  - Deliverables: requirements document and review process
  - Development of a complete OC-SVC “System” measurement uncertainty budget
  - OC-SVC uncertainty budget is the justification for the requirements
  - Review process: two review meetings by the international Review Expert Team and the community
Validation: Sentinel-3 Validation Team – Ocean Colour

- Sentinel-3 Validation Team (S3VT) – international group of expert users
- S3VT provides independent validation evidence on the quality of OLCI products
- S3VT is based on a rolling announcement of opportunity, ESA AO call is continuously open

for more information on S3VT-OC
marc.bouvet@esa.int
ewa.kwiatkowska@eumetsat.int
**Sentinel-3 Validation Team meeting Feb 2017**

- Detailed evaluation of OLCI products
- Recommendations towards product improvements for OLCI L2 public release
- Recommendations towards improved ocean colour user services

**OLCI Chl-a [NN]  OLCI Chl-a  VIIRS Chl-a**

**AERONET –OC Thornton C-Power**

**Baltic Sea FerryScope**

**NOAA STAR OCView with OLCI capabilities**

**Chl from Norwegian Sea cruise**

**Lucinda Jetty Coastal Observatory DALEC, N=15**

**Chl Finish coast**

**Chl Bio-Argo validations**
To establish and maintain SI traceability of FRMs for satellite ocean colour

To consolidate and further develop FRM protocols

To federate the community validating satellite ocean colour radiometry

Web: https://frm4soc.org
Contact: riho.vendt@to.ee

<table>
<thead>
<tr>
<th>Ref</th>
<th>Event</th>
<th>Dates</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>WKP-1</td>
<td>Workshop on Vicarious Adjustment</td>
<td>21 – 23 February 2017</td>
<td>ESRIN, Italy</td>
</tr>
<tr>
<td>LCE-1</td>
<td>SI-traceable Laboratory inter-comparison experiment for FRM OCR and reference irradiance/radiance calibration targets, Verification of reference irradiance and radiance sources</td>
<td>3 – 7 April 2017</td>
<td>NPL, UK</td>
</tr>
<tr>
<td>LCE-2</td>
<td>SI-traceable Laboratory inter-comparison experiment for FRM OCR and reference irradiance/radiance calibration targets, Verification of FRM OCR</td>
<td>08 – 13 May 2017</td>
<td>TO, Estonia</td>
</tr>
<tr>
<td>FICE AMT</td>
<td>Field Inter-Comparison Experiment in the Atlantic Meridional Transect (AMT)</td>
<td>August-September 2017</td>
<td>AMT</td>
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<tr>
<td>FICE AAOT</td>
<td>Field Inter-Comparison Experiment in the Acqua Alta Oceanographic Tower (AAOT)</td>
<td>July 2018</td>
<td>AAOT</td>
</tr>
<tr>
<td>WKP-2</td>
<td>Final Workshop</td>
<td>August 2018</td>
<td>NPL, UK</td>
</tr>
</tbody>
</table>
Next FRM4SOC event

Satellite validation international workshop
Validating Copernicus Sentinel data using Fiducial Reference Measurements

20–21 June 2017, Plymouth, UK

The workshop will focus on the performance of Sentinel -1, -2 & -3 at retrieving ocean colour, sea surface temperature and upper ocean dynamics, in the open ocean and coastal environments and will identify potential strategies for the validation of Sentinel missions in the future.

Sessions include:
- Fiducial Reference Measurement methods and protocols
- Ocean colour validation
- Sea surface temperature validation
- Validation of upper ocean dynamics

The workshop should be beneficial to anyone with an interest in the validation of satellite data.

Registration deadline: 31 May 2017

Limited space available

www.amt4sentinelfrm.org

Keep up-to-date with workshop activities: @amt4sentinelfrm
Operational validation tools and activities

MERMAID Level 2 match-ups:
Time series, scatter plots and statistics

Inter-sensor comparisons at Level 3

Inter-sensor time series and scatter plots
Operational validation tools and activities

Running Level 3 inter-comparisons with contemporaneous global missions and climatologies (L3 binning for validation and monitoring)

Level 2 in situ matchups with FRMs

Cal/Val website

EUMETSAT
• **Ocean colour scientific justification for S3A and S3B Commissioning tandem configuration**
  - Assuring stability, accuracy, and homogeneity of OLCI missions [MRTD, 2011; GCOS 2016]
  - Joint instrument calibration and characterisation
  - Overlapping coverage in support of sensor inter-comparisons and product validations

• **Planned activities**
  - Inter-satellite comparisons over target surfaces using the vicarious methods will benefit of
    - minimized ocean geophysical space and time variability
    - minimized atmospheric space and time variability
    - identical observation and solar geometries
  - Inter-satellite comparisons of calibration and characterization will benefit of
    - direct inter-comparisons of instrument responses, including diffuser and straylight
    - absolute and relative comparisons between the in-flight OLCI-A and the more pristine OLCI-B units
Conclusions

- Sentinel-3A OLCI instrument is in excellent shape
- Ongoing Cal/Val activities to understand and model instrument behaviour and validate L1 products
- Ongoing Cal/Val activities to validate and improve L2 products