Sentinel-3 Calibration and Validation Plan
# Sentinel-3 Calibration and Validation Plan

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1 Introduction

1.1 Scope and Purpose

This document sets out an overall Sentinel-3 strategy and plan for the calibration and validation of all satellite instruments and operational products. It uses a requirements based approach to ensure by traceability to the mission requirements that all parameters relevant for the instrument calibration and operational product validation have been adequately covered. The mission requirements cover the end-to-end Earth observation system including high-level requirements, mission operations, data product development and processing, data distribution and data archiving. The Mission Requirements Traceability Document (MRTD) (AD 4) elaborates the requirements set out in the Mission Requirements Document (MRD) (AD 3) for the Sentinel-3 Mission based on User requirements and mission objectives. The Sentinel-3 MRTD provides the guidelines for the technical implementation of the Sentinel-3 mission requirements within the Sentinel-3 System Requirements Document (SRD) (AD 1) which forms the basis for the Satellite and System related developments. Due to its elaborated level of detail, the MRTD will also be used as source for the traceability of the calibration and validation requirements.

The approach proposed is to identify from the MRTD requirements the relevant error sources and associated related activities needed to ensure that products and services are adequately calibrated and validated.

In order to ensure a consistent approach and a smooth transition from the Commissioning to the Routine Operations phase, the document is written as a joint document between ESA Satellite Project, and ESA and EUMETSAT mission performance monitoring groups. This shall however not impact the clear distribution of responsibilities. The ESA Satellite Project under the supervision of the ESA Satellite Project Manager is in charge for the instrument calibration and product validation as needed for the initial operation of the GMES services, while the ESA and EUMETSAT Mission performance monitoring group under the supervision of Mission Management is responsible for the validation of all products needed for the full operation of the GMES services within the GMES initial operations (GIO) framework. The In-Orbit Commissioning Review (IOCR) will review the achievement of the initial operation capability and marks the handover from Satellite Project to Mission Management. The full operation capability will then be established in a dedicated review during the Routine Operations phase.

This high-level plan is based extensive input document sets provided by the Sentinel-3 space segment industry consortium as well as document from the industrial PDGS consortium. These document sets are the basis for high-level Cal/Val strategy documents issued by the agencies. The space segment industry document set can be grouped in several classes including a DRL-Numbers (S3 Document Requirement Description S3-LI-ESA-SY-0005):

- System calibration and validations plans separated for the optical and topography payload, describing the end-to-end Cal/Val procedures including the underline end-to-end performance budgets (DRL-No SY-5)
- Instrument Characterization and Calibration Plans to define on-ground and in-orbit activities (IN-6)
- Instrument Performance and Calibration Analysis documents to describe test and calibration procedures and expected performances (IN-11)
- Instrument Calibration and Characterization Database Specifications (IN-12)
This high-level Cal/Val plan is a collection of task definitions to conduct a successful calibration and validation of the Sentinel-3 mission. The implementation of the identified Cal/Val tasks will be detailed in a separate Implementation Plan that will take into account the potential constraints linked to the organisation and budget environment.

1.2 Document Structure

After presenting the major elements of the Sentinel-3 mission in Chapter 3 the overall approach for calibration and validation is explained in Chapter 4. Programmatic aspects, responsibilities and mission phase schedules are discussed in Chapter 5. Finally in Chapter 6 follows a relatively formal definition of what shall be done to calibrate and validate Sentinel-3 tracing from mission requirements to parameter tests. It includes all elements of instrument calibration and product validation up to Level 2. Activities for each mission phase will be summarized.

The document is closed with a discussion of the international context for all Sentinel-3 Cal/Val activities in Chapter 7.

At a later stage of the project a specific implementation plan is intended to present the actual tasks and activities that will be performed to address the requirements set out in the second part (i.e. how the Cal/Val work shall be done). This separate document will catalogue and describe cruise and aircraft campaign plans, details of test sites and in situ data sources that will be used for the formal task defined in Chapter 6. As of this version, that chapter is not available. Details for this part will be filled after extensive consultation with the user communities.
# 1.3 Acronyms and Abbreviations

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<td>AATSR</td>
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<tr>
<td>ADF</td>
<td>Auxiliary Data File</td>
</tr>
<tr>
<td>AO</td>
<td>Announcement of Opportunity</td>
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<td>ATBD</td>
<td>Algorithm Theoretical Basis Document</td>
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<td>BB</td>
<td>Black Body</td>
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<td>BOUSSOLE</td>
<td>BOUée pour l’acquisition de Séries Optiques à Long terme</td>
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<td>Bidirectional Reflectance Distribution Function</td>
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<td>BRF</td>
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<tr>
<td>CCD</td>
<td>Charge-Coupled Device</td>
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<td>NTC</td>
<td>Non Time Critical</td>
</tr>
<tr>
<td>OCD</td>
<td>Operational Concept Document</td>
</tr>
<tr>
<td>OLCI</td>
<td>Ocean and land Colour Instrument</td>
</tr>
<tr>
<td>OLTC</td>
<td>Off-Line Tracking Command</td>
</tr>
<tr>
<td>OME</td>
<td>Opto-Mechanical Enclosure</td>
</tr>
<tr>
<td>PDGS</td>
<td>Payload Data Ground Segment</td>
</tr>
<tr>
<td>PRF</td>
<td>Pulse Repetition Frequency</td>
</tr>
<tr>
<td>QC</td>
<td>Quality Control</td>
</tr>
<tr>
<td>QWG</td>
<td>Quality Working Group</td>
</tr>
<tr>
<td>RR</td>
<td>Reduced Resolution</td>
</tr>
<tr>
<td>SZA</td>
<td>Solar Zenith Angle</td>
</tr>
<tr>
<td>SISTeR</td>
<td>Scanning Infrared Sea Surface Temperature Radiometer</td>
</tr>
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</table>
2 Applicable and Reference Documents

In brackets the ID of the S3 project document requirements list S3-LI-ESA-SY-0004 (where applicable)

2.1 Applicable Documents

<table>
<thead>
<tr>
<th>Title</th>
<th>Ref</th>
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</thead>
<tbody>
<tr>
<td>AD 1 - ESA GMES S3 System Requirements Document</td>
<td>S3-RS-ESA-SY-0010, Issue 4.0</td>
</tr>
<tr>
<td>AD 2 – Sentinel-3 Commissioning Phase Plan</td>
<td>S3-RP-ESA-SY-0248 draft, 29/11/2011</td>
</tr>
<tr>
<td>AD 6 – Sentinel-3 PDGS Commissioning Plan</td>
<td>Ref available at GS CDR</td>
</tr>
<tr>
<td>AD 7 – Sentinel-3 PDGS Ramp-up Plan</td>
<td>GMES-S3GS-EOPG-PL-12-0008</td>
</tr>
<tr>
<td>AD 8 – Sentinel-3 Calibration and Validation Implementation Plan</td>
<td>S3-PL-ESA-SY-0380, Issue 1.3,</td>
</tr>
<tr>
<td>AD 9 – Sentinel-3 Scientific Validation Team Implementation Plan</td>
<td>EOP-SM/2641/CD-cd, draft Issue 1</td>
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2.2 Reference Documents

a.) Optical Payload

<table>
<thead>
<tr>
<th>Title (Project Documents)</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD 2 – In Flight Satellite Verification Plan (SY-11)</td>
<td>S3-PL-TAF-SY-1780 Issue 2, 10/10/2011</td>
</tr>
<tr>
<td>RD 3 – MERIS calibration plan</td>
<td>PO-PC-AER-ME-0005 issue 5</td>
</tr>
<tr>
<td>RD 4 – Geometric calibration model for OLC</td>
<td>S3-MO-TAF-0944/2009 Issue 3, 09/06/2010</td>
</tr>
<tr>
<td>RD 5 – Geometric calibration model for SLST</td>
<td>S3-MO-TAF-0944/2009 issue 3, 09/06/2010</td>
</tr>
<tr>
<td>RD 6 – OLCI Performance and Verification Plan (IN-5)</td>
<td>S3-PL-TAF-OL-0740 issue 2, 05/10/2010</td>
</tr>
<tr>
<td>RD 7 – OLCI Calibration and Characterisation Plan (IN-6)</td>
<td>S3-PL-TAF-OL-0342, issue 4, 13/06/2011</td>
</tr>
<tr>
<td>Title (Science Papers)</td>
<td>Issue Cite</td>
</tr>
<tr>
<td>------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>RD 9 – SLSTR Pre-Launch Calibration Plan</td>
<td>S3-PL-RAL-SL-009 issue 2, 12/01/2011</td>
</tr>
<tr>
<td>RD 11 – SLSTR OME Characterisation and Calibration Plan (IN-6)</td>
<td>S3-PL-JOP-SL-00001 issue 3, 24/08/2009</td>
</tr>
<tr>
<td>RD 12 – Optical GPP Test Data Set DIL-22 Definition</td>
<td>S3-TN-ACR-SY-0023 issue 1, 22/07/2011</td>
</tr>
<tr>
<td>RD 14 – TN on O-SPS Analysis Function</td>
<td>S3-MO-TAF-00918/2009 Issue 2.02, 29/07/2010</td>
</tr>
<tr>
<td>RD 15 – Algorithm Theoretical Basis Documents – Level 2 products</td>
<td>ESA/ESRIN S3-L2-SD-03 series</td>
</tr>
<tr>
<td>Reference</td>
<td>Date</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>“Absolute calibration of VEGETATION derived from an interband method based on sunglint over ocean sites”</td>
<td>10, 2004</td>
</tr>
<tr>
<td>RD 49 - AATSR Validation Implementation Plan and AATSR Validation Principles and Definitions</td>
<td>PO-PL-GAD-AT-005 <a href="http://www.leos.le.ac.uk/aatsr/howgood/validation/documentation.html">http://www.leos.le.ac.uk/aatsr/howgood/validation/documentation.html</a></td>
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### b.) Topography Payload

<table>
<thead>
<tr>
<th>Title (Project Documents)</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD 58 – STM System Calibration and Products Validation Plan (SY-5)</td>
<td>S3-PL-CLS-SY-0048 issue 3, 12/02/2011</td>
</tr>
<tr>
<td>RD 59 – SRAL Instrument Calibration and Characterisation Plan</td>
<td>S3-PL-TAF-RA-0336 issue 5, 10/12/2010</td>
</tr>
<tr>
<td>RD 61 – SRAL Verification Plan (IN-5)</td>
<td>S3-PL-TAF-RA-0700 Issue 3 23/09/2010</td>
</tr>
<tr>
<td>RD 62 – MWR Instrument Verification Plan (IN-5)</td>
<td>S3-RP-ECE-MR-0064 issue 1, 06/10/2008</td>
</tr>
<tr>
<td>RD 63 - MWR Characterization and Calibration Plan (IN-6)</td>
<td>S3-PL-ECE-MR-0049</td>
</tr>
<tr>
<td>RD 64 – MWR TN on antenna temperature calibration</td>
<td>S3-TN-ECE-MR-0030 issue 1, 22/01/2008</td>
</tr>
<tr>
<td>RD 65 – STM Level 2 Algorithm Definition, Accuracy and Specifications (SD-3)</td>
<td>S3PAD-RS-CLS-SD03-0017 issue 4, 31/03/2010</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Title (Science Papers)</th>
<th>Ref</th>
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</table>
contamination in coastal areas, Advances in Space Research «Satellite Altimeter Calibration and Deformation Monitoring using GNSS ».

RD 68 - Cancet, M., Bijac, S., Chimot, J. Bonnefond, P., Jeansou, E., Laurain, O., Lyard, F., Bronner, E., Féménias, P., Regional in situ validation of satellite altimeters: calibration and cross-calibration results at the Corsican sites,


Marine Geodesy, Vol. 34, 393-406


RD 77 - RA-2 Sigma Absolute Calibration data set analysis Final Report, Nazzareno Pierdicca, Christian Bignami, Maurizio Fasceotti, Massimo Mazzetta, Giuseppe Castaldo, Dept. Electronic Engineering – Sapienza University of Rome, Italy Ref TPD/P-RP/7, Issue/Rev.: 2.0, Date: 16/04/2008


RD 85 - Cazenave A., K. Dominh, L. Soudarin, F. Ponchaut, C. Le Provost, Sea level changes from TOPEX/POSEIDON altimetry and tide gauges, and vertical crustal motions from DORIS.  

RD 86 - M. Roca et al. “RA-2 Level 1b Processor Verification”  

RD 87 - C. S. Ruf, “Detection of calibration drifts in spaceborne microwave radiometers using a vicarious cold reference”  

RD 88 - Smith, W., Scharroo, R, “Pulse-to-pulse correlation in CryoSat SAR echoes from ocean surfaces: implications for optimal pseudo-LRM waveform averaging”  
Proc. of “20 Years of progress in radar altimetry Symposium”, 2012.

RD 89 - Cryosat Plus for Ocean (CP4O) ESA Science Study  
3 Mission Overview

In response to S-3 mission requirements AD 3 and Copernicus (GMES) data product requirements (AD 3, AD 4), S-3 has been designed to monitor the global environment through measurements that will also be used to constrain and drive global-local numerical prediction models in support of GMES user needs. The aim of the S-3 mission is:

To provide continuity of Envisat type measurement capability in Europe to determine sea, ice and land surface topography, temperature, ocean and land surface radiance/reflectance, and atmospheric measurements with high accuracy, timely delivery and in a sustained operational manner for GMES users.

3.1 Mission Objectives

The specific objectives for the Sentinel-3 mission are defined in the Mission Requirements Document MRD (AD 3) and have been adopted in a traceable format in the Mission Requirements Traceability Document (MRTD) (AD 4):

<table>
<thead>
<tr>
<th>Sentinel-3 Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentinel-3 shall provide continuity of medium resolution Envisat-type land measurement capability in Europe to determine land-surface temperature and land-surface colour with a consistent quality, a very high level of availability (&gt;95%), high accuracy and reliability and in a sustained operational manner for GMES users.</td>
</tr>
<tr>
<td>Sentinel-3 shall provide, in a NRT operational and timely manner, L1b visible, shortwave and thermal infrared radiances and L2 topography products for use by GMES Services with a consistent quality, a very high level of availability (&gt;95%), high accuracy and reliability and in a sustained operational manner for GMES users.</td>
</tr>
<tr>
<td>Sentinel-3 shall provide, in an operational and timely manner, a generalised suite of high-level primary geophysical products with a consistent quality, a very high level of availability (&gt;95%), high accuracy and reliability and in a sustained operational manner for GMES users. Products shall include as priority: Global coverage Sea Surface Topography (SSH) for ocean and coastal areas, Enhanced resolution SSH products in the Coastal Zones and sea ice regions, Global coverage Sea-Surface (SST) and sea ice surface temperature (IST), Global coverage Ocean Colour and Water Quality products, Global coverage Ocean Surface Wind Speed measurements, Global coverage Significant Wave Height measurement, Global coverage atmospheric aerosol consistent over land and ocean, Global coverage Vegetation products, Global coverage Land Ice/Snow Surface Temperature products, Ice products (e.g., ice surface topography, extent, concentration)</td>
</tr>
<tr>
<td>Sentinel-3 shall provide continuity of medium resolution SPOT Vegetation P-like products by providing similar products over land and ocean with a consistent quality, a very high level of availability (&gt;95%), high accuracy and reliability and in a sustained operational manner for GMES users.</td>
</tr>
<tr>
<td>Sentinel-3 shall provide in an operational and timely manner, a generalised suite of high-level secondary geophysical products with a consistent quality, a very high level of availability (&gt;95%), high accuracy and reliability and in a sustained operational manner for GMES users.</td>
</tr>
</tbody>
</table>
reliability and in a sustained operational manner for GMES users. Products shall include as priority:
Global coverage Fire monitoring products (FRP, burned area, risk maps etc),
Inland water (lakes and rivers) surface height data.

Table 1 – Primary Mission Objectives

3.2 Sentinel-3 Constellation

In order to satisfy the large coverage and high revisit requirements, the Sentinel-3 mission is
designed as a constellation of two identical satellites, Sentinel-3A and Sentinel-3B.

Each satellite will operate in a reference orbit with a repeat cycle of 27 days for the overall duration
of the mission. The Sentinel-3A orbit characteristics are summarised in the following table.

<table>
<thead>
<tr>
<th>Type</th>
<th>Near-Polar Sun-Synchronous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean local Solar Time at ascending node</td>
<td>22:00 h</td>
</tr>
<tr>
<td>Repeat Cycle</td>
<td>27 d</td>
</tr>
<tr>
<td>Cycle Length</td>
<td>385 orbits</td>
</tr>
<tr>
<td>Orbits per day</td>
<td>14.259</td>
</tr>
<tr>
<td>Semi-Major axis</td>
<td>7177.92654 km</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.001148 deg</td>
</tr>
<tr>
<td>Inclination</td>
<td>98.645589 deg</td>
</tr>
<tr>
<td>Argument of Perigee</td>
<td>90 deg</td>
</tr>
</tbody>
</table>

Table 2 - Sentinel-3 Orbit Characteristics

The current baseline configuration of the 2-S/C Sentinel-3 constellation foresees a 180-deg in-
plane separation between the two S/C’s.

This configuration guarantees that after each orbit the track of the 2nd S/C falls in the middle of
the gap left by the track of the first, thus optimising the coverage performances for instruments
measuring in the visible.

After a complete repeat cycle the combined tracks of the two S/C’s provide an optimised grid for
altimetry NTC purposes.

Figure 1 - Ground tracks after 27 days of the first Sentinel-3 S/C and of the second S/C in the baseline configuration
(180-deg spacing)
3.3 Sentinel-3 Instrument Characteristics and Modes

The satellite embarks the following instruments:

- The Ocean and Land Colour Instrument (OLCI), a spectrometer imaging in push-broom mode with an across-track electronic scan, building on the ENVISAT MERIS instrument design.
- The Sea and Land Surface Temperature Radiometer (SLSTR), a conical imaging radiometer with a dual view (near-nadir and inclined) capability building on a design heritage from the AATSR of Envisat.
- The SAR Radar Altimeter (SRAL) instrument, a dual-frequency altimeter, derived from the Alcatel Alenia Space line of products such as SIRAL of CryoSat, and Poseidon-3 of Jason-2, providing Low Resolution Sea surface measurements in the continuity of the RA-2 ones of Envisat, and sea-ice, land-ice and inland water monitoring in Nadir SAR mode.
- A Microwave Radiometer (MWR), which supports the SRAL to achieve the overall altimeter mission performance by providing the wet atmosphere correction.
- A GNSS receiver, suitable for the Precise Orbit Determination (POD) processed on ground to achieve the overall altimeter mission performance. Real time navigation and dating information from this equipment will provide spacecraft navigation and dating functions as well as the control of the Radar Altimeter open-loop tracking function.
- A DORIS instrument as a Customer Furnished Item, which constitutes a complementary POD data provider for the Ground Segment as well as a potential (TBC) backup to the GNSS Assembly for the specific commanding of the SRAL Open Loop tracking mode.
- A Laser retro-reflector (LRR).

3.3.1 Ocean and Land Colour Instrument

![OLCI instrument major components (left) and calibration wheel (right)](image)

The OLCI instrument baseline is a follow-up of the MERIS instrument on-board Envisat with additional spectral channels, different camera arrangements and simplified on-board processing.
OLCI is a push-broom instrument with 5 camera modules sharing the field-of-view as follows:

- The five cameras field of view are arranged in a fan-shaped configuration in the vertical plane perpendicular to the platform velocity,
- Each camera has an individual field of view of 14.2 degrees with a 0.6 degree overlap with its neighbours,
- The whole field-of-view is shifted across-track by 12.58 degrees away from the Sun to minimise the Sun glint impact.

OLCI measures top of atmosphere (TOA) radiances at 21 wavelengths. However, the instrument principle – an imaging spectrometer – and design allows the redefinition of these bands, in both location and width, thanks to the programmable acquisition.

<table>
<thead>
<tr>
<th>Band</th>
<th>λ centre (\text{nm})</th>
<th>Width (\text{Nm})</th>
<th>(L_{\text{min}}) W/(\text{m}^2\cdot\text{s} \cdot \mu\text{m})</th>
<th>(L_{\text{ref}}) W/(\text{m}^2\cdot\text{s} \cdot \mu\text{m})</th>
<th>(L_{\text{sat}}) W/(\text{m}^2\cdot\text{s} \cdot \mu\text{m})</th>
<th>SNR@(L_{\text{ref}})</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oa1</td>
<td>400</td>
<td>15</td>
<td>21.60</td>
<td>62.95</td>
<td>413.5</td>
<td>2188</td>
<td>Aerosol correction, improved water constituent retrieval</td>
</tr>
<tr>
<td>Oa2</td>
<td>412.5</td>
<td>10</td>
<td>25.93</td>
<td>74.14</td>
<td>501.3</td>
<td>2061</td>
<td>Yellow substance and detrital pigments (Turbidity).</td>
</tr>
<tr>
<td>Oa3</td>
<td>442.5</td>
<td>10</td>
<td>23.96</td>
<td>65.61</td>
<td>466.1</td>
<td>1811</td>
<td>Chl absorption max., Biogeochemistry, Vegetation</td>
</tr>
<tr>
<td>Oa4</td>
<td>442</td>
<td>10</td>
<td>19.78</td>
<td>51.21</td>
<td>483.3</td>
<td>1541</td>
<td>High Chl, Other pigments</td>
</tr>
<tr>
<td>Oa5</td>
<td>510</td>
<td>10</td>
<td>17.45</td>
<td>44.39</td>
<td>449.6</td>
<td>1488</td>
<td>Chl, Sediment, Turbidity, Red tide.</td>
</tr>
<tr>
<td>Oa6</td>
<td>560</td>
<td>10</td>
<td>12.73</td>
<td>31.49</td>
<td>524.5</td>
<td>1280</td>
<td>Chlorophyll reference (Chl minimum)</td>
</tr>
<tr>
<td>Oa7</td>
<td>620</td>
<td>10</td>
<td>8.86</td>
<td>21.14</td>
<td>397.9</td>
<td>997</td>
<td>Sediment Loading</td>
</tr>
<tr>
<td>Oa8</td>
<td>665</td>
<td>10</td>
<td>7.12</td>
<td>16.38</td>
<td>364.9</td>
<td>883</td>
<td>Chl (2nd Chl abs. max.), Sediment, Yellow Substance / Vegetation</td>
</tr>
<tr>
<td>Oa9</td>
<td>673.75</td>
<td>7.5</td>
<td>6.87</td>
<td>15.70</td>
<td>443.1</td>
<td>707</td>
<td>For improved Fluorescence retrieval and to better account for Smile together with the b. 665 and 680nm</td>
</tr>
<tr>
<td>Oa10</td>
<td>681.25</td>
<td>7.5</td>
<td>6.65</td>
<td>15.11</td>
<td>350.3</td>
<td>745</td>
<td>Chl fluorescence peak, red edge</td>
</tr>
<tr>
<td>Oa11</td>
<td>708.75</td>
<td>10</td>
<td>5.66</td>
<td>12.73</td>
<td>332.4</td>
<td>785</td>
<td>Chl fluorescence baseline, red edge transition.</td>
</tr>
<tr>
<td>Oa12</td>
<td>753.75</td>
<td>7.5</td>
<td>4.70</td>
<td>10.33</td>
<td>377.7</td>
<td>605</td>
<td>O2 absorption /Clouds, vegetation</td>
</tr>
<tr>
<td>Oa13</td>
<td>761.25</td>
<td>2.5</td>
<td>2.53</td>
<td>6.09</td>
<td>369.5</td>
<td>232</td>
<td>O2 absorption band/Aerosol corr.</td>
</tr>
<tr>
<td>Oa14</td>
<td>764.375</td>
<td>3.75</td>
<td>3.00</td>
<td>7.13</td>
<td>373.4</td>
<td>305</td>
<td>Atmospheric correction</td>
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<tr>
<td>Oa15</td>
<td>767.5</td>
<td>2.5</td>
<td>3.27</td>
<td>7.58</td>
<td>250.0</td>
<td>330</td>
<td>O2A used for cloud top pressure, fluorescence over land.</td>
</tr>
<tr>
<td>Oa17</td>
<td>865</td>
<td>20</td>
<td>2.88</td>
<td>6.17</td>
<td>229.5</td>
<td>666</td>
<td>Atmos. Corr. / Aerosol corr., Clouds, Pixel co-registration</td>
</tr>
<tr>
<td>Oa18</td>
<td>885</td>
<td>10</td>
<td>2.80</td>
<td>6.00</td>
<td>281.0</td>
<td>395</td>
<td>Water vapour absorption ref. band. Common reference band with SLST instrument. Vegetation monitoring.</td>
</tr>
<tr>
<td>Oa19</td>
<td>900</td>
<td>10</td>
<td>2.05</td>
<td>4.73</td>
<td>237.6</td>
<td>308</td>
<td>Water vapour absorption / Vegetation monitoring (max. reflectance)</td>
</tr>
<tr>
<td>Oa20</td>
<td>940</td>
<td>20</td>
<td>0.94</td>
<td>2.39</td>
<td>171.7</td>
<td>203</td>
<td>Water vapour absorption, Atmos. / Aerosol corr.</td>
</tr>
<tr>
<td>Oa21</td>
<td>1020</td>
<td>40</td>
<td>1.81</td>
<td>3.86</td>
<td>163.7</td>
<td>152</td>
<td>Atmos. / Aerosol corr.</td>
</tr>
</tbody>
</table>

**Table 3 – Band characteristics of the Sentinel-3 OLCI Instrument**
OLCI Earth Observation data acquisition will be carried out during daytime with a specific time window which is triggered by the Sun Zenith Angle at Sub-Satellite Point. For Earth Observation the SZA must be lower than 80 degrees. At angles higher than 80 deg over the southern hemisphere, specific and periodic calibration can be performed.

The sampling period of the OLCI detectors (CCD) runs at 44 ms, what corresponds to a mean along-track distance of about 300 m. Instrument across-track spatial sampling is about 300 m at Sub-satellite Point. This “native” acquisition resolution is referred to as the Full Resolution (FR).

For the calibration of OLCI is equipped with a calibration assembly, which consists of a mechanism, including a motorized wheel where three diffusers are fixed and that leaves the camera FOV free access to the Earth in imaging mode. Calibrations will happen periodically at the ecliptic South Pole, where the sunlight can enter the Baffle and reach the exposed diffuser in the calibration mechanism.

The OLCI calibration mechanism is equipped with on-board calibration hardware based on Sun diffusers. There are 3 Sun diffusers: 2 “white” diffusers dedicated to radiometric calibration, and one including spectral reflectance features dedicated to spectral calibration:

- **Radiometric calibration**, using the nominal “white” diffuser and including dark signal calibration (with shutter on) on a regular basis, typically every 2 to 4 weeks. The second radiometric “white” diffuser is used the same way but much less frequently, typically every 3 months), allowing monitoring of their relative evolution.

- **Spectral calibration** using successively the nominal “white” diffuser and the spectral one, with specific band sets focussed, at the highest possible spectral resolution, on the spectral features of the spectral diffuser. Comparison of their respective response in almost identical illumination conditions allows accurately locating the spectral diffuser features onto the CCD and hence deriving spectral calibration information. These modes shall be operated with a typical time period of 3 months.

The OLCI calibration is undertaken in the region of the orbit between the observation phase and the eclipse period. Each calibration sequence begins with a dark current evaluation for which the wheel of the mechanism can place a shutter in front of the cameras.

- **Dark calibration**. It is performed before the ecliptic south pole, since the orientation with respect to the sun appears a bit more favourable, before the Earth panel is illuminated by the sun. This sequence lasts 45 seconds which allows the acquisition of 1000 measurement frames. This number of measurements is required in order to reduce the noise and accurately derive the signal produced under dark conditions after averaging, performed on-ground.

With the different diffusers, the operations of the shutter 9 different calibration sequences have been implemented in the OLCI Electronic Unit and can be directly commanded from ground.
3.3.2 Sea and Land Surfaces Temperatures Radiometer

The aim of the Sentinel-3 SLSTR instrument is to maintain continuity with the Envisat (A)ATSR series of instruments (e.g., Edwards et al, 1990; Llewellyn-Jones et al, 1984) that provide a reference SST data set for other satellite missions (Donlon et al, 2010, Donlon et al, 2009). Wherever possible, the SLSTR design is based on the reuse of AATSR concepts using existing and qualified technologies. Following Envisat AATSR heritage, the SLSTR instrument is a conical scanning imaging radiometer employing the along-track-scanning dual view technique (Edwards et al, 1990) to provide robust atmospheric correction over a dual-view swath. Key technical details and a full instrument description can be found in Coppo et al (2010). The instrument includes channels in the visible (VIS), thermal (TIR) and short wave (SWIR) infrared spectrum as described in Table 4. The main improvements over the heritage (A)ATSR instruments include wider swath coverage, more spectral bands, and a spatial resolution of 0.5 km for visible and SWIR bands. Both the SLSTR and OLCI instruments require a clear view to the sun for calibration purposes and accommodating both instruments on the same platform resulted in the SLSTR oblique view pointing backwards. This configuration is different to the Envisat AATSR configuration.
### Table 4 - Sea and Land Surface Temperature (SLST) instrument channel specification.

To maintain continuity, the complete suite of AATSR and ATSR-2 spectral channels (0.55, 0.66, 0.85, 1.6, 3.7, 10.8 and 12 µm) are included in the SLSTR design. Additional channels at 1.378 µm and 2.25 µm have been included to enhance thin cirrus cloud detection (e.g., Gao et al, 1993). The design also includes the capability to measure active wild fires (e.g., Wooster et al 2005) although this capability is secondary to the primary SST retrieval capability. This is achieved by extending the dynamic range of the 3.7 µm channel and including dedicated detectors at 10.8 µm that are capable of detecting fires up to 500K (F1) and 400K (F2) without saturation.

#### Figure 4 - An overview of the Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) instrument highlighting principal components of the instrument design (left). Photograph of the Sentinel-3 SLSTR Structural Test Model (STM) (right).

The SLSTR uses two independent scan chains each including a separate scan mirror (scanning at a constant velocity of 200 rpm), an off-axis paraboloid mirror, and a fold mirror to focus measured...
radiance into the instrument detector assembly. Each scan will measure 2 along-track pixels of 1 km (and 8 pixels at 500 m resolution) simultaneously. This configuration increases the swath width in both views, as well as providing 500 metre resolution in the reflectance channels. Each scan mirror is mounted at an oblique angle to its axis of rotation, and directs radiation into a telescope assembly the optical axis of which is aligned parallel to the rotation axis. As the scan mirror rotates, the line of sight traces out a cone whose intersection with the Earth traces out the measurement swath of the instrument. The scan cone will intersect the Earth view, two calibration black bodies, and a Visible Calibration (VISCAL) Unit, so that the line of sight will encounter each of these once during a complete rotation. An innovative recombination “flip” mirror alternately relays each of the scanned optical beams into a common field plane at the entrance of the detector assembly where there is a cold baffle.

Figure 5 - Outline sketch of the Sentinel-3 SLSTR instrument viewing geometry highlighting the asymmetric nadir swath with respect to the nadir point.

While more complex than the single scan system employed by the ATSR instrument, this configuration increases the instrument oblique view swath to ~750 km (centred at the SLSTR nadir point) and the nadir swath to ~1400 km (offset in a westerly direction). The nadir swath is asymmetrical with respect to the nadir point to provide identical and contemporaneous coverage with OLCI ocean/land colour measurements.

Radiation incident along the line of sight enters the focal plane assembly, where it is split into frequency bands corresponding to the different channels. Radiation in each channel is focussed onto a small array of detector elements that correspond to pixels.
Figure 6 - SRAL instrument characteristics and modes

The S-3 SRAL instrument is a fully redundant dual-frequency (Ku and C-band) nadir-looking radar altimeter that employs SAR altimetry technologies inherited from the CryoSat and Jason altimeter missions. The SAR altimeter approach increases measurement accuracy and along track resolution when compared to conventional altimetry products. SRAL will acquire topography data over all types of surfaces covered by the Sentinel-3 mission (sea, coastal areas, sea ice, ice sheets, ice margins, inland waters). SRAL will provide measurements with a high spatial resolution (~300 m along-track) over coastal regions (up to 300 km offshore), sea-ice and inland areas. The SRAL design includes the following sub-systems:

- A dual-frequency (Ku/C band) near nadir pointing antenna of 1.2 m diameter with a focal length 0.43 m mounted on the Earth pointing face of the satellite.

- A Radio Frequency Unit (RFU) comprised of Solid State Power Amplifiers in Ku and C bands, diplexers used to route signals in the transmit or receive chains, a signal demodulation and “deramp” system, and gain controlled amplifiers to slave the echo level.

- A Digital Processing Unit (DPU) that manages all communication interfaces between the satellite platform (telemetry and telecommands), a chirp generator, full sequencing of the instrument, received signal sampling and all elements of the required for tracking.

Two radar modes are provided by the SRAL design to facilitate autonomous operations. Low Resolution Mode (LRM) is the primary mode when observing level surfaces with homogeneous and smooth topography including open-ocean and smooth ice-sheet plateaux. In this mode, SRAL operates as a conventional pulse limited altimeter with regular Tx/Rx sequences at a Pulse Repetition Frequency (PRF) of 1920 Hz. The SAR Mode (SAR) is to generate high-resolution (~300 m) along-track measurements to maximize information retrieval over more variable terrain areas.
surfaces sea/ice and sea/land transitions in coastal areas or over inland water areas that are challenging for conventional pulse limited altimeter systems.

For both LRM and SAR modes, the tracking function may be a closed loop or an open loop function. “Closed loop” means that the range tracking parameters are computed by the tracking algorithm, while in “Open loop” means that these parameters are computed directly from altitude values read from a one-dimensional OLTC file stored in the instrument coupled with the position/velocity coordinates of the navigation bulletin sent every second to the platform by the GPS receiver.

The geophysical error estimates leading to the altimeter range measurement requirement is summarized in Table 5, indicating the best knowledge from recent altimetry missions such as Envisat and Jason-2. These requirements shall be applicable to the S-3 STM mission for the Phase E2.

<table>
<thead>
<tr>
<th></th>
<th>NRT (&lt; 3hrs)</th>
<th></th>
<th>IGDR (1-3 days)</th>
<th></th>
<th>GDR (&lt;1 mo)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threshold</td>
<td>Goal</td>
<td>Threshold</td>
<td>Goal</td>
<td>Threshold</td>
<td>Goal</td>
</tr>
<tr>
<td>Range Noise</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Sea state bias</td>
<td>5.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Ionosphere</td>
<td>3.0</td>
<td>2.0</td>
<td>1.4</td>
<td>1.0</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Dry troposphere</td>
<td>3.0</td>
<td>2.0</td>
<td>1.4</td>
<td>1.0</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Wet troposphere</td>
<td>4.0</td>
<td>3.0</td>
<td>2.0</td>
<td>1.4</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>RSS Range Error</td>
<td><strong>8.3</strong></td>
<td><strong>6.0</strong></td>
<td><strong>5.0</strong></td>
<td><strong>3.5</strong></td>
<td><strong>4.1</strong></td>
<td><strong>2.9</strong></td>
</tr>
<tr>
<td>Radial Orbit Error</td>
<td>10.0</td>
<td>8.0</td>
<td>4.0</td>
<td>3.0</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>RSS SSH Error</td>
<td><strong>13.0</strong></td>
<td><strong>10.0</strong></td>
<td><strong>6.5</strong></td>
<td><strong>4.6</strong></td>
<td><strong>5.1</strong></td>
<td><strong>3.5</strong></td>
</tr>
</tbody>
</table>

Table 5 - Major error terms for altimeter Height Estimation *(Table to be updated as necessary)*

### 3.3.4 Microwave Radiometer

MWR radiometer is a dual frequency, single polarization and fully redounded radiometer. The centre frequencies of each channel are 23.8 GHz and 36.5 GHz, with a channel bandwidth of 200 MHz.

MWR is a Noise Injection Radiometer (NIR). The noise injection operation consists of adding noise to the antenna branch in order to equal the temperature of the internal load noise temperature. This balanced condition takes places at a common plane for all involved temperatures, which has been defined at the output of the Dicke switch. The Dicke load produces a precisely known noise power equivalent to its physical temperature and signal balancing is performed by injecting noise pulses from a noise diode of variable length into the measurement path. The amount of injected noise allows the retrieval of the brightness temperature.

There are three main operational states: observation, monitoring, and calibration.

During observation, the radiometer is looking through the main antenna towards the Earth and, in case of a brightness temperature lower than the reference temperature, the noise injection pulse is used to retrieve this brightness temperature.
During in-orbit calibration, the MWR uses well characterised cold space noise measured using the Sky Feed Assembly (SFA) and the Dicke load. Fixed amounts (50% and 100%) of noise are injected on top of the cold space signal to calibrate the power of the noise diode and the receiver gain. In addition, periodic short SFA views are made between calibration measurements using the standard NIR operation to monitor the stability of the instrument. To avoid possible electromagnetic interference from SRAL, the MWR design includes a blanking signal to synchronise its measurement cycle to SRAL and optimise the measurement integration time. The anticipated radiometric sensitivity of the MWR is <0.4 K with a stability <0.6 K, and absolute accuracy <3 K over a brightness temperature range of 150-313 K.

![Overview of the Microwave Radiometer](image)

**Figure 7 – Overview of the Microwave Radiometer**

### 3.4 Product Description

As result of the GS prototype developments a set of baseline products at level 1 and 2 are defined which will be produced by the IPF and mandatory Cal/Val analysis and results are required. Note that some products in this list are considered internal and will not be part of the nominal dissemination scheme (i.e. Synergy L1c product). Also the grouping of products is done by geophysical parameters and does not precisely correspond to the product packing defined by the PDGS. The actually PDGS product grouping can be found in AD 5. A specific Product Class ID is introduced to assign associated Cal/Val Tasks (see Figure 8). PDGS Product Nomenclature are added where applicable.
<table>
<thead>
<tr>
<th>Product class (ID) [PDGS Product Nomenclature]</th>
<th>Parameter</th>
<th>Parameter Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLCI Level 1 in RR and FR (OLCI-L1B) [OL_1_EFR] [OL_1_ERR]</td>
<td>Top of Atmosphere radiances</td>
<td>Radiance in [W m² sr-1 μm-1] of 21 OLCI bands with time stamps, flags, geo-location, meteo annotation data set</td>
</tr>
<tr>
<td>OLCI Level 2 in RR and FR (OLCI-L2WLR) [OL_2_WRR] [OL_2_WFR]</td>
<td>Water leaving reflectance (R)</td>
<td>Surface directional reflectance, dimensionless, corrected for atmosphere and Sun specular reflection, at all OLCI channels except those dedicated to atmosphere absorption measurements, and associated error estimates.</td>
</tr>
<tr>
<td>Ocean Colour Products (OLCI-L2OC) [OL_2_WRR] [OL_2_WFR]</td>
<td>Algal pigment concentration 1 (Chl-1)</td>
<td>Chlorophyll-a concentration in Case 1 waters and associated error estimates, in mg.m⁻³</td>
</tr>
<tr>
<td></td>
<td>Algal pigment concentration 2 (Chl-2)</td>
<td>Chlorophyll-a concentration in Case 2 waters and associated error estimates, in mg.m⁻³</td>
</tr>
<tr>
<td></td>
<td>Total Suspended Matter concentration (TSM)</td>
<td>Total suspended matter concentration, and associated error estimates, in g.m⁻³</td>
</tr>
<tr>
<td></td>
<td>Diffuse Attenuation coefficient (Kd)</td>
<td>Diffuse attenuation coefficient for downwelling irradiance, and associated error estimates, in m⁻¹ at 490 nm.</td>
</tr>
<tr>
<td></td>
<td>CDM absorption coefficient (CDOM)</td>
<td>Absorption of Coloured Detrital and Dissolved Material, and associated error estimates, expressed in m⁻¹ at 443 nm.</td>
</tr>
<tr>
<td>Atmosphere Product (OLCI-ATM) [OL_2_WRR] [OL_2_WFR]</td>
<td>Photosynthetically Active Radiation (PAR)</td>
<td>Quantum energy flux from the Sun in the spectral range 400-700 nm and associated error estimates; in Einstein/m²/day.</td>
</tr>
<tr>
<td></td>
<td>Aerosol optical depth over water (AOD-W)</td>
<td>Aerosol load, expressed in optical depth at a given wavelength (865 nm), and associated error estimates.</td>
</tr>
<tr>
<td></td>
<td>Aerosol Angstrom Exponent over water (AAE-W)</td>
<td>Spectral dependency of the aerosol optical depth, between 779 and 865 nm, and associated error estimates.</td>
</tr>
<tr>
<td></td>
<td>Integrated Water vapour column (IWV)</td>
<td>Total amount of water vapour integrated over an atmosphere column, and associated error estimates, kg.m⁻².</td>
</tr>
<tr>
<td>Level 2 Land Products (OLCI-L2LA) [OL_2_LRR] [OL_2_LFR]</td>
<td>OLCI Global Vegetation Index</td>
<td>Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) in the plant canopy.</td>
</tr>
<tr>
<td></td>
<td>red and NIR rectified reflectances</td>
<td>by-product of FAPAR estimate, defined as “virtual” reflectance at 681nm and 685nm largely decontaminated from atmospheric and angular effects, and good proxy to Top of Canopy reflectance</td>
</tr>
<tr>
<td></td>
<td>OLCI Terrestrial Chlorophyll Index</td>
<td>Estimates of the Chlorophyll content in terrestrial vegetation, aims at monitoring vegetation condition and health.</td>
</tr>
<tr>
<td></td>
<td>Integrated Water vapour column</td>
<td>same as in OLCI_L2_WFR but estimated over land surfaces</td>
</tr>
</tbody>
</table>

Table 6: Baseline Product for OLCI, all products will be delivered in full- and reduced resolution
<table>
<thead>
<tr>
<th>Product (ID)</th>
<th>Parameter</th>
<th>Parameter Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLSTR Level 1B (SLSTR-L1B) [SL_1_RBT]</td>
<td>Top of Atmosphere radiances&lt;br&gt;Top of Atmosphere brightness temperatures</td>
<td>Radiance in [W m⁻² sr⁻¹ μm⁻¹] of band S1-S3. Brightness Temperatures for S4-S9 in [K]. All values in dual view with time stamps, flags, geo-location and meteo annotation data set</td>
</tr>
<tr>
<td>Level 2 SST (SLSTR-SST) [SL_2_WST]</td>
<td>Sea Surface skin Temperature (SST)</td>
<td>Stand-alone product conforming to the GHRSTT L2P specification, containing a composite “best SST” field, error estimates and contextual auxiliary data fields, SST in [K] and various other units. Note: intermediate SST estimates (D2/D3/N2/N3 SSTsking products) are produced but not distributed</td>
</tr>
<tr>
<td>Level 2 LST (SLSTR-LST) [SL_2_LST]</td>
<td>Land Surface Temperature (LST)</td>
<td>Single view, two channel land surface temperature in [K], associated error estimates, exception flags, and contextual information&lt;br&gt;Ancillary data: NDVI, GlobCover classification, Fractional vegetation cover</td>
</tr>
</tbody>
</table>

Table 7 - Baseline Product for SLSTR

<table>
<thead>
<tr>
<th>Product</th>
<th>Parameter</th>
<th>Parameter Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1 (SYN-L1C)</td>
<td>Top of Atmosphere radiances&lt;br&gt;Top of Atmosphere brightness temperatures</td>
<td>Combined OLCI and SLSTR spectral channels in acquisition geometry with necessary co-registration data.</td>
</tr>
<tr>
<td>Level 2 (SYN-L2C) + Aerosol Parameter [SY_2_SYN]</td>
<td>Surface Reflectance</td>
<td>Fully atmosphere-corrected Surface Reflectance and associated error estimates. Synergistically retrieved from OLCI channels and SLSTR channels (both nadir and oblique views), except for gaseous absorption channels</td>
</tr>
<tr>
<td></td>
<td>Aerosol Optical Depth over land (AOD-L)</td>
<td>Aerosol load, expressed in optical depth at a given wavelength (550 nm), and associated error estimates</td>
</tr>
<tr>
<td></td>
<td>Aerosol Angström Exponent over land (AAE-L)</td>
<td>Spectral dependency of the Aerosol Optical Depth derived from 40 aerosol models computed with OPAC package and associated error estimates</td>
</tr>
<tr>
<td>Vegetation (SYN-VGT) [SY_2_VGP/VG1/V10]</td>
<td>VGT P-Product (VGT-P) &lt;br&gt;VGT S1-Product (VGT-S1) &lt;br&gt;VGT S10-Product (VGT-S10)</td>
<td>TOA Radiances and vegetation indices composites for 1 and 10 days</td>
</tr>
</tbody>
</table>

Table 8: Baseline Product for synergy Product
<table>
<thead>
<tr>
<th>Product (ID)</th>
<th>Parameter</th>
<th>Parameter Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1b (SRAL-L1B) [SR_1_SRA] [SR_1_CAL]</td>
<td>Radar echoes, single waveform ( \sigma_0 ) values in LRM Mode</td>
<td>20Hz data in Ku- and C-band, instrument and geophys. corrections applied</td>
</tr>
<tr>
<td>Level 1b (SRAL-L1B) [SR_1_SRA] [SR_1_CAL]</td>
<td>Radar echoes, single bursts ( \sigma_0 ) values in SAR Mode</td>
<td>Note: Calibration Measurements (SR_1_CAL) are distributed as a separate product</td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Elevation values (R)</td>
<td>all parameters except backscatter coeff and Wind Speed are provided for LRM and SAR mode in one product</td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Backscatter coefficient</td>
<td></td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Sea Surface Height anomaly (SSHA)</td>
<td></td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Signification Wave Height (SWH)</td>
<td></td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Wind speed (WS) LRM Mode only</td>
<td></td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Sea ice freeboard</td>
<td>Height of sea ice floes above sea surface</td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Sea ice sea surface height</td>
<td>Height of the sea surface in sea-ice areas with respect to a reference datum</td>
</tr>
<tr>
<td>Level 2 Marine Ocean and Sea Ice Areas (SRAL-L2MA) [SR_2_WAT]</td>
<td>Sea ice surface height anomaly</td>
<td>Variations of the Sea Ice Surface Height with respect to a mean sea surface (m)</td>
</tr>
<tr>
<td>Level 2 Land (SRAL-L2LA) [SR_2_LAN]</td>
<td>Elevation values (R)</td>
<td>as baseline acquisitions over land is always in SAR-Mode</td>
</tr>
<tr>
<td>Level 2 Land (SRAL-L2LA) [SR_2_LAN]</td>
<td>Surface height</td>
<td>No specific land algorithms are used for the land product</td>
</tr>
<tr>
<td>Level 2 Land (SRAL-L2LA) [SR_2_LAN]</td>
<td></td>
<td>Note: Surface Height must be computed by the user</td>
</tr>
</tbody>
</table>

Table 9 - Baseline Product for SRAL

<table>
<thead>
<tr>
<th>Product (ID)</th>
<th>Parameter</th>
<th>Parameter Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1b MWR (MWR-BT) [MW_1_MWR] [MW_1_CAL]</td>
<td>Brightness temperatures calibration parameters</td>
<td>geo-located, radiometrically and geometrically corrected brightness temperature measurements (at each of the antenna frequencies)</td>
</tr>
<tr>
<td>GNSS Level 1 (GNSS-L1)</td>
<td>Navigation Solution GNSS measurements</td>
<td>in RINEX format C1,P1,P2,L1,L2 codes</td>
</tr>
<tr>
<td>Orbit Parameter (POD)</td>
<td>Orbit Solutions from GNSS/DORIS/SLR</td>
<td>different latencies</td>
</tr>
</tbody>
</table>

Table 10 - Baseline Product for MWR and POD Payload
4 Calibration and Validation Approach

4.1 Introduction

The payload and the mission objectives of Sentinel-3 have a strong heritage from Envisat, and to a lesser extent from CryoSat and VEGETATION on Spot-5. In the frame of the Envisat mission extensive Cal/Val activities have been defined and executed, and have evolved along the mission, for calibration and validation of L1 and L2 products. In order to ensure continuity of product contents and quality from Envisat, the Sentinel-3 Cal/Val strategy should fully exploit this heritage where applicable. Sentinel-3 is however an operational mission, with main objectives to achieve an operational environment monitoring (both over Land and Ocean). This imposes three main objectives on Cal/Val activities:

a) to provide a comprehensive initial assessment of product validity and quality at the end of commissioning activities;

b) to monitor the stability and the quality of the products throughout the operational phase of the mission;

c) to continuously improve the quality of the products throughout the operational phase of the mission following the evolving user requirements.

This Plan defines the scope of activities that will calibrate the on-board instruments and validate the data products generated operationally and disseminated by the PDGS centres.

4.2 Traceability from Mission Requirements Baseline

The Sentinel-3 Mission Requirements Traceability Document (MRTD) AD 4 defines numbered mission requirements that must each be validated and are reproduced in Table 11 to facilitate their use in the calibration/validation planning. MRTD requirements are the starting point for all Sentinel-3 Cal/Val activities. Figure 8 shows the methodology that has been used to trace MRTD requirements to specific Cal/Val tasks.
Figure 8 - Schematic overview of the approach used to derive specific S3 Cal/Val tasks that link S3 Mission Requirements (MRTD) to products and major error terms.

S3 data products are first linked to a primary MRTD requirement together with other related requirements that are considered relevant: this provides direct traceability to top-level Mission Requirements (the MRTD has been developed specifically for this purpose). A product Error source analysis is then performed to identify the main sources of error for each product. For each major error source an associated Cal/Val Task is identified: each major error source thus has a corresponding Cal/Val task with a traceable identifier to a specific MRTD requirement. Cal/Val tasks descriptions are then presented in a common format and include details required by Cal/Val planning and implementation teams (e.g. methodology, requirements for specific tools, data requirements to perform the analysis).

At the heart of this approach is the derivation of a comprehensive product error tree for each product. Figure 9 shows a top-level breakdown of error sources highlighting the different generic source of contributions to total product error. This breakdown provides a framework to manage how Cal/Val tasks are assigned and executed under different programmatic arrangements.
Figure 9 - Top level breakdown of error sources highlighting the different generic source contributions to total product error.

Instrument Errors (I) refer to those errors associated with instrument hardware and their calibration parameters (e.g., SLSTR VISCAL calibration errors). Satellite<>Instrument coupling errors (C) refer to errors associated with interactions between the platform and the instrument (e.g., pointing errors due to instrument misalignment). Satellite errors (S) refer to that class of errors associated with satellite operations (e.g., orbit maintenance). Processing Errors (P) refer to those errors associated with data processing (e.g., errors due to incorrect configuration of processors, retrieval algorithm errors).

Validation errors (V) refer to those errors arising within the validation process (e.g., in situ data errors, representivity errors, validation protocols). Note that these errors do not affect the validity of the products themselves, but contribute to an overall validation assessment error estimate. The principle approach used to address validation errors is to pursue several independent approaches/analyses to the same issue and compare /synthesize their results.

A complete identification of all possible error terms is a major challenge. Instead, our approach is to identify initially the major sources of error. The objective is to provide an initial “target” that will be used to identify the requirements for data, tools, schedule, and reporting lines/mechanisms, develop specific modelling work, studies, in situ campaigns and on-orbit Task-activities. Collectively these will form the core framework of S3 Cal/Val to provide an assessment of the error component variability, its spatial and temporal scale of fluctuation with sufficient detail to declare and maintain an “Operational” Mission status. It is expected that the number of error sources may increase with Mission experience.

4.3 Numbered Mission requirements from MRTD.

The classification for the column on “applicable” is defined as follows:

A or empty = applicable
N/A = Not applicable for the Cal/Val plan
N/A (Design) = covered by design

Generic requirements about availability of instrument acquisitions (I-Avail) or product generation and dissemination (P-Avail) are considered in this Cal/Val plan as prerequisite criteria (i.e. Chapter 4.4.2) but do not lead necessarily to a specific Cal/Val task definition.
<table>
<thead>
<tr>
<th>MR-ID</th>
<th>Type</th>
<th>Description</th>
<th>related products</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3-MR-10</td>
<td>Service availability</td>
<td>Sentinel-3 products with specified temporal and spatial coverage, fully compliant with specified product quality metrics, and delivered according to specified timeliness requirements, shall be available to the end user with &gt;95% operational availability, measured over any 12 month period with no systematic geographical gaps.</td>
<td>all</td>
<td>A</td>
</tr>
<tr>
<td>S3-MR-20</td>
<td>Service availability</td>
<td>The Sentinel-3 system shall be designed for a duration of 15-20 years.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-30</td>
<td>Service availability</td>
<td>Access to EO data and services shall be ensured before the Sentinel era relying on the set of EO missions capable already contributing to the GMES Services.</td>
<td>P-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-40</td>
<td>Service availability</td>
<td>A facility to provide direct broadcast of Sentinel-3 optical mission data to local ground stations in the line-of-sight of Sentinel-3 shall be considered. Direct broadcast capability shall not drive the mission design.</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>S3-MR-50</td>
<td>Service continuity</td>
<td>Sentinel-3 shall commence operations in a timely manner (target 2013) in order to ensure continuity of Envisat MERIS, AATSR and RA-2 measurement data sets and minimise potential gaps in EO service to GMES.</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>S3-MR-60</td>
<td>Service continuity</td>
<td>Sentinel-3 shall provide continuity of SPOT/vegetation-like instrument capability (with a spatial sampling of ≤1000 m (0.3 km goal) to minimise potential gaps in service to GMES.</td>
<td>SYN-VGT</td>
<td></td>
</tr>
<tr>
<td>S3-MR-70</td>
<td>Service continuity</td>
<td>Sentinel-3 shall provide continuity CryoSat high-resolution along track marine and land ice surface measurements used to derive sea-ice thickness and ice sheet topography.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-80</td>
<td>Service continuity</td>
<td>Sentinel-3 shall provide continuity to radiance (L1b) and geophysical (L2) products based on existing Envisat MERIS, AATSR and RA-2 sensors and enhance them to cover the user information needs expressed by GMES users in the domains of: Ocean Monitoring, Land Monitoring, Atmospheric Monitoring, Emergency Response and Security.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-90</td>
<td>Service continuity</td>
<td>Sentinel-3 shall provide continuity to services based on existing SPOT Vegetation P-like product line to cover the user information needs expressed by GMES services in the domains of: Land Monitoring, Emergency Response and Security.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-100</td>
<td>Performance</td>
<td>Sentinel-3 shall include a dual frequency (nominal frequency of ~13.5 GHz (Ku Band)) nadir pointing altimeter instrument based on the heritage of Envisat RA-2 and CryoSat-2 SIRAL.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-110</td>
<td>Spectral sampling</td>
<td>The Sentinel-3 altimeter system shall include a passive microwave radiometer (MWR) for correction of range delay errors due to tropospheric water vapour. The MWR shall measure the amount of water vapour and liquid water content in the atmosphere, within a field of view centred immediately beneath the spacecraft track making measurements simultaneous and coincident with the altimeter footprint.</td>
<td>MWR-BT</td>
<td></td>
</tr>
<tr>
<td>S3-MR-120</td>
<td>Performance</td>
<td>Sentinel-3 shall provide Visible and Short-Wave Infrared radiance measurements over the ocean (ocean colour) to at least the quality of MERIS on Envisat with improved spectral capability.</td>
<td>OLI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-130</td>
<td>Performance</td>
<td>Sentinel-3 shall provide Visible and Short-Wave Infrared Short-Wave Infrared, and Thermal Infrared radiance measurements to at least the quality of AATSR on Envisat with improved coverage and spectral capability.</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>Requirement</td>
<td>Description</td>
<td>Observations</td>
<td></td>
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<tr>
<td>S3-MR-140</td>
<td>Performance</td>
<td>Sentinel-3 shall provide Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances over land surfaces equivalent to Envisat MERIS, AATSR and similar to SPOT Vegetation, together with those from their combination.</td>
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<tr>
<td>S3-MR-150</td>
<td>Performance</td>
<td>Sentinel-3 shall provide ocean surface topography measurements (SSH, Hs, and surface wind speed) exceeding the level of quality of the Envisat RA-2 altimeter system.</td>
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<tr>
<td>S3-MR-160</td>
<td>Performance</td>
<td>An along track delay-Doppler SAR capability (similar to CryoSat-2 SIRAL) shall be included in the Sentinel-3 altimeter measurement system to provide improved resolution in the coastal zone and sea ice regions.</td>
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<tr>
<td>S3-MR-170</td>
<td>Performance</td>
<td>Sentinel-3 shall provide VIS and TIR measurements suitable for pre-fire early warning (satellite vegetation indices), active fire detection (Fire Radiative Power); and post-fire monitoring (Burned area mapping) to at least the quality of AATSR on Envisat.</td>
<td></td>
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<tr>
<td>S3-MR-180</td>
<td>Performance</td>
<td>Sentinel-3 shall provide measurements of River and Lake Heights (RLH) for large rivers, their tributaries and lakes to at least the quality of the RA-2 on Envisat.</td>
<td></td>
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<tr>
<td>S3-MR-190</td>
<td>Performance</td>
<td>Sentinel-3 TIR measurements shall be acquired continuously around the satellite orbit (i.e. during day and night time).</td>
<td></td>
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<tr>
<td>S3-MR-200</td>
<td>Performance</td>
<td>Sentinel-3 VIS measurements shall be available for the part of the orbit that covers solar illuminated earth surfaces and acquired only during the sun illuminated part of the orbit (when the Solar Zenith Angle (SZA) &lt; 80°).</td>
<td></td>
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</tr>
<tr>
<td>S3-MR-210</td>
<td>Signal to noise</td>
<td>The Sentinel-3 topography instrument shall have a noise level better than 3 cm (1-sigma) for a 1 second average.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-220</td>
<td>Absolute accuracy</td>
<td>The Sentinel-3 topography instrument range accuracy shall allow the recovery of meso-scale circulation signals. As a starting point, the absolute range determination accuracy shall be 0.1 – 1 m.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-230</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter shall be capable of operating in a low resolution mode (LRM) over the open ocean and a high resolution mode (HRM) (~300 m along track resolution) over sea ice and in coastal zones.</td>
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<tr>
<td>S3-MR-240</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter instrument shall acquire data over sea, inland water and ice surfaces.</td>
<td></td>
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<tr>
<td>S3-MR-250</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter shall be capable of providing measurements of sea ice thickness.</td>
<td></td>
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<tr>
<td>S3-MR-260</td>
<td>Spectral sampling</td>
<td>The Sentinel-3 MWR system shall have a minimum of two passive channels operating in Ka- and Q-band. An option to use a 3-frequency MWR will depend on the accommodation of a larger antenna.</td>
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<tr>
<td>S3-MR-270</td>
<td>Performance</td>
<td>The Sentinel-3 MWR shall be capable of providing a wet tropospheric delay correction for the altimeter with an accuracy of 2 cm (goal 1 cm) rms.</td>
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<tr>
<td>S3-MR-280</td>
<td>Performance</td>
<td>Sentinel-3 shall include a precise 3-d positioning instrument to reduce orbit errors to an accuracy goal of 2 cm residual orbit accuracy after offline processing (2-3 cm threshold) required to reach altimeter accuracy targets.</td>
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<td></td>
</tr>
<tr>
<td>S3-MR-290</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter threshold absolute accuracy for $s^\circ$ shall be better than 1 dB, with a resolution of better than 0.1 dB.</td>
<td>SRAL-L2MA</td>
<td></td>
</tr>
<tr>
<td>S3-MR-300</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter drift in $s^\circ$ shall be characterised with an accuracy of better than 0.2 dB with a goal of 0.1 dB over a period of 1 year.</td>
<td>SRAL-L2MA</td>
<td></td>
</tr>
<tr>
<td>S3-MR-310</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter tracker bias shall be minimised by tuning performance of the tracking algorithm. Tracking bias over the ocean is proportional to the Hs, and shall not be higher than a goal of 0.25 cm (1 cm threshold).</td>
<td>SRAL-L2MA</td>
<td></td>
</tr>
<tr>
<td>S3-MR-320</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter derived Hs threshold accuracy shall be 20 cm or 4 % of Hs for 1 second averages over a range of 1 - 20 m. A goal of 5 cm or 1 % (whichever is smaller) is expected after STC/NTC data processing (retracking).</td>
<td>SRAL-L2MA</td>
<td></td>
</tr>
<tr>
<td>S3-MR-330</td>
<td>Performance</td>
<td>The Sentinel-3 altimeter derived wind-speed accuracy shall be better than 2 m s$^{-1}$ for 1 sec. averages over a range of 3 and 20 m s$^{-1}$. A goal of 1.5 m s$^{-1}$ accuracy is expected from improved ground processing.</td>
<td>SRAL-L2MA</td>
<td></td>
</tr>
<tr>
<td>S3-MR-340</td>
<td>Performance</td>
<td>Sentinel-3 shall participate in rigorous inter-satellite calibration and external calibration activities to correct for calibration biases, and maintain long-term uniform performance over the satellite operational lifetime.</td>
<td>all</td>
<td></td>
</tr>
<tr>
<td>S3-MR-350</td>
<td>Performance</td>
<td>The Sentinel-3 near infrared and thermal infrared channels shall be optimised for SST retrieval.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-360</td>
<td>Performance</td>
<td>Building on Envisat/AATSR heritage, Sentinel-3 shall provide an along-track view (bi-angular observation) for VIS/nearer and TIR channels to make the atmospheric correction for SST products robust to changes in aerosol and water vapour loading and to allow aerosol corrections/retrievals over land surfaces.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-370</td>
<td>Performance</td>
<td>The Sentinel-3 SLST instrument on board calibration system shall follow the principles used by Envisat AATSR (i.e. two reference black body cavities and a visible channel calibration system).</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-380</td>
<td>Performance</td>
<td>The Sentinel-3 SLST instrument shall make simultaneous and co-incident measurements with ocean colour measurements.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-390</td>
<td>Performance</td>
<td>The Sentinel-3 SLST instrument shall have stringent sub-pixel co-registration with OLC measurements.</td>
<td>SYN-L1C</td>
<td></td>
</tr>
<tr>
<td>S3-MR-400</td>
<td>Performance</td>
<td>Sentinel-3 shall provide SST measurement capability to at least the quality of AATSR on Envisat: SST shall be accurate to $&lt; 0.3 \text{ K} @ 1 \text{ km spatial resolution}$ and with improved swath coverage.</td>
<td>SLSTR-SST</td>
<td></td>
</tr>
<tr>
<td>S3-MR-410</td>
<td>Performance</td>
<td>Space time coverage requirements for the Sentinel-3 SLST instrument shall take second priority with respect to absolute accuracy requirements.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-420</td>
<td>Performance</td>
<td>Sentinel-3 shall be able to measure Land Surface Temperature (LST) to an accuracy of $&lt; 1 \text{ K}$ with a resolution of 1 km at nadir. This capability shall not reduce the quality of the SST retrievals.</td>
<td>SLSTR-LST</td>
<td></td>
</tr>
<tr>
<td>S3-MR-430</td>
<td>Performance</td>
<td>Sentinel-3 shall be able to measure Ice Surface Temperature (IST) to an accuracy of $10 %$ with a resolution of $&lt; 5 \text{ km}$ (1 km goal) at nadir. This capability shall not reduce the quality of the SST retrievals.</td>
<td>SLSTR-LST</td>
<td></td>
</tr>
<tr>
<td>S3-MR-440</td>
<td>Performance</td>
<td>Sentinel-3 shall be capable of measuring Lake water Surface Temperature (LWST). This capability shall not drive the mission design.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-450</td>
<td>Performance</td>
<td>Sentinel-3 shall be capable of measuring Fire Radiative Power and fire burned area using infrared measurements over land. This capability shall not drive the mission design.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-460</td>
<td>Performance</td>
<td>The Sentinel-3 OLC instrument shall be optimised for measurement of water quality and ocean colour parameters including open ocean (case-1) and coastal shelf (case-2) waters, inland seas and lakes.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-470</td>
<td>Performance</td>
<td>The Sentinel-3 OLC instrument shall include a precise internal calibration system to maintain instrument calibration and stability.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-480</td>
<td>Performance</td>
<td>The Sentinel-3 OLC instrument shall improve over Envisat MERIS by mitigating the impact of sun-glint over the ocean.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-490</td>
<td>Geographic Coverage</td>
<td>Sentinel-3 topography measurements shall be acquired globally in low resolution mode (to support measurements of RLH and production of altimeter DEM). High resolution mode data shall be acquired in the coastal zone, sea ice regions and other selected areas required by GMES users.</td>
<td>SRAL-L2MA, SRAL-L2LA</td>
<td></td>
</tr>
<tr>
<td>S3-MR-500</td>
<td>Geographic Coverage</td>
<td>Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have complete global coverage including oceanic, coastal waters and inland seas, and ice infested waters.</td>
<td>SLSTR-L1B I-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-510</td>
<td>Geographic Coverage</td>
<td>Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have complete global coverage over all land surfaces including lakes, rivers, islands and ice sheets.</td>
<td>SLSTR-L1B I-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-520</td>
<td>Geographic Coverage</td>
<td>Sentinel-3 Ice Surface Temperature (IST) products shall have complete global coverage over ice covered surfaces including oceanic, coastal waters and inland seas.</td>
<td>SLSTR-L1B I-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-530</td>
<td>Geographic Coverage</td>
<td>Sentinel-3 LST and inland Lake Water Surface Temperature (LWST) products shall have complete global coverage over land covered surfaces.</td>
<td>SLSTR-L1B I-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-540</td>
<td>Geographic Coverage</td>
<td>Sentinel-3 SST and, ocean colour products shall have complete global coverage over oceanic, coastal waters, rivers and their tributaries, and inland seas.</td>
<td>SLSTR-SST I-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-550</td>
<td>Geographic Coverage</td>
<td>Sentinel-3 Fire monitoring products shall have complete global coverage over all land surfaces.</td>
<td>SLSTR-L1B I-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-560</td>
<td>Geometrical Coverage</td>
<td>Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have complete global coverage every 1 to 3 days over oceanic and coastal waters.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-570</td>
<td>Geometrical Coverage</td>
<td>Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances over land and ice surfaces shall have complete global coverage in 1 (goal) to 2 days.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-580</td>
<td>Geometrical Coverage</td>
<td>Sentinel-3 land products shall have complete global coverage in ≤2 days at the equator.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-590</td>
<td>Geometrical Coverage</td>
<td>Sentinel-3 SST and ocean colour products shall have complete global coverage every 2-3 days at the equator.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-600</td>
<td>Geometrical Coverage</td>
<td>Sentinel-3 topography products shall provide global ocean coverage every 3-10 days optimised with complementary altimeter missions to deliver maps of SSH at 25-50 km resolution.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-610</td>
<td>Performance</td>
<td>The Sentinel-3 mission shall launch a second satellite as soon as possible following the launch of the first satellite.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-620</td>
<td>Instantaneous coverage</td>
<td>Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have co-located and simultaneous coverage.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-630</td>
<td>Instantaneous coverage</td>
<td>Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances shall have a wide swath width &gt;1000 km.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-640</td>
<td>Instantaneous coverage</td>
<td>Sun glint conditions for the Sentinel-3 visible channels shall be mitigated to the largest extent possible by choice of instrument pointing and final orbit configuration.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-650</td>
<td>Instantaneous coverage</td>
<td>Sentinel-3 topography measurements shall be acquired within the swath of optical measurements to facilitate synergy application.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-660</td>
<td>Number of satellites</td>
<td>The use of multiple satellites and/or merging of several missions is required to achieve an effective revisit time of 1 day over land and coastal regions required by GMES users.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-670</td>
<td>Orbit</td>
<td>The Sentinel-3 orbit shall be optimised with respect to other planned altimeter-bearing missions. The aim is to measure coherent mesoscale ocean structures with a track separation at the equator of ~80 - 150 km.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-680</td>
<td>Orbit</td>
<td>Sentinel-3 shall use a high inclination orbit for optimal coverage of ice and snow parameters in high-latitudes, coverage of the European shelf Seas and merging with complementary altimeter missions.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-690</td>
<td>Orbit</td>
<td>The Sentinel-3 orbit shall be a polar sun-synchronous orbit with a descending node equatorial crossing time similar to Envisat. The final choice of orbit shall consider the Solar Zenith Angle for ocean colour measurements, the impact of sun glint, diurnal surface ocean thermal stratification, morning haze and cloud-cover on optical measurements.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-700</td>
<td>Orbit</td>
<td>The Sentinel-3 threshold performance for NRT orbit determination shall be 10-20 cm, with a goal of 2 cm rms. residual orbit accuracy after offline processing.</td>
<td>GNSS-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-710</td>
<td>Orbit</td>
<td>High accuracy orbit data shall be delivered for use by the altimeter system in ≤2 days (goal) and &lt;5 days (threshold).</td>
<td>POD P-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-720</td>
<td>Spatial resolution</td>
<td>Sentinel-3 topography measurements over the open ocean shall have an along track sample characteristics as follows:</td>
<td>N/A (Design)</td>
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<tr>
<td></td>
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<td>NRT/STC</td>
<td>NT</td>
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<td>&lt;10 km (open ocean)</td>
<td>1 km (open ocean)</td>
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<td>≤300 m (over sea ice and in the coastal zone)</td>
<td>≤300 m (over sea ice and in the coastal zone)</td>
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<tr>
<td>S3-MR-730</td>
<td>Spatial resolution</td>
<td>Sentinel-3 altimeter measurements shall provide sufficient along-track resolution over inland rivers, their tributaries and, lakes although this shall not be a mission driver.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-740</td>
<td>Spatial resolution</td>
<td>Sentinel-3 surface topography measurements shall have enhanced along-track resolution (&lt;300 m) surface topography measurements over relatively flat ice surfaces and in ice-covered and ice free coastal waters.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-750</td>
<td>Spatial resolution</td>
<td>Sentinel-3 SST, IST and LST measurements shall have a spatial resolution of ≤1000 m at nadir.</td>
<td>N/A (Design)</td>
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<tr>
<td>Issue</td>
<td>Spatial resolution</td>
<td>Timeliness</td>
<td></td>
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<tr>
<td>S3-MR-760</td>
<td>Sentinel-3 visible measurements shall have a spatial resolution of ≤1.2 km over the global ocean and ≤0.3-0.5 km in the coastal regions at nadir.</td>
<td>N/A (Design)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-770</td>
<td>Sentinel-3 land colour measurements shall have a spatial resolution of ≤0.3-0.5 km (threshold) at nadir globally.</td>
<td>N/A (Design)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-780</td>
<td>Sentinel-3 shall provide SPOT vegetation-type land products at a spatial resolution of ≤ 1000 m (0.3 km goal) at nadir.</td>
<td>N/A (Design)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-790</td>
<td>Sentinel-3 fire monitoring measurements shall have a spatial resolution of ≤ 1 km at nadir.</td>
<td>N/A (Design)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-800</td>
<td>The observing time of Sentinel-3 ocean and land surface temperature measurements shall be ~10:00 LTAN to be consistent with the Envisat AATSR, to minimise the impact of diurnal thermal stratification of the upper ocean layers, the impact of afternoon cloud cover, morning haze and sun glint over the ocean.</td>
<td>N/A (Design)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-810</td>
<td>The LTAN observing time of Sentinel-3 ocean colour measurements shall be optimised to maximise the solar elevation and minimise the impact of cloud development, morning haze and sun glint over the ocean.</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-820</td>
<td>The observing time of Sentinel-3 land colour measurements shall be optimised to minimise the impact of morning haze and cloud cover.</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-830</td>
<td>Sentinel-3 Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances (L1b products) and altimeter L2 (IGDR type) products shall be available to users in NRT.</td>
<td>P-Avail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-840</td>
<td>Sentinel-3 products for GMES Services shall be made available according to the timeliness requirements described in AD 4</td>
<td>P-Avail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-850</td>
<td>Sentinel-3 OLC instrument Visible, Near Infrared, radiances shall include as a minimum the band spectral characteristics set out in AD 4 taking into account optional bands as follows: A channel at 1.02 microns to improve the existing MERIS atmospheric and aerosol correction capabilities, Additional channels in the O2A spectral region for improved cloud top pressure (height) and water vapour retrieval. Other bands may be considered for fluorescence measurement (e.g. 673nm) and to improve land and ocean geophysical retrievals, provided the instrument complexity is not increased.</td>
<td>OLCI-L1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-860</td>
<td>Sentinel-3 SLST instrument Visible, Near Infrared, radiances shall include as a minimum the band spectral characteristics set out in AD 4</td>
<td>SLSTR-L1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-870</td>
<td>Sentinel-3 SLST and OLC shall use at least one common band for instrument pixel co-registration in overlapping swath regions.</td>
<td>SYN-L1C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-880</td>
<td>Sentinel-3 active fire detection and characterisation capability requires a channel at ~3.7 µm and one other at 11 or 12 µm providing continuity to Envisat AATSR measurements.</td>
<td>SLSTR-L1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-890</td>
<td>For continuity of the SST and ocean colour data sets generated by Sentinel-3, all channels shall have as similar a spectral shape as practicable to those on Envisat MERIS and AATSR.</td>
<td>OLCI-L1B, SLSTR-L1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-900</td>
<td>The spectral shape of Sentinel-3 channels shall be known before flight to 5% of their peak response at any wavelength.</td>
<td>OLCI-L1B, SLSTR-L1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3-MR-910</td>
<td>Spectral sampling</td>
<td>The peak out of band response for each of the channels shall be characterised.</td>
<td>OLCI-L1B SLSTR-L1B</td>
<td></td>
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<tr>
<td>---</td>
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<td></td>
</tr>
<tr>
<td>S3-MR-920</td>
<td>Spectral sampling</td>
<td>Following Envisat MERIS, the OLC instrument shall have the capability to change its band position, band width and gain throughout its lifetime.</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>S3-MR-930</td>
<td>Spectral sampling</td>
<td>The desired spectral resolution for the OLC instrument shall be at least 1.25 nm (MERIS baseline).</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>S3-MR-940</td>
<td>Dynamic range</td>
<td>Sentinel-3 TIR channels shall have a dynamic range optimised for SST retrieval but also allow the retrieval of IST, LWST, LST and cloud top temperature (at least equivalent to Envisat AATSR instruments).</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-950</td>
<td>Dynamic range</td>
<td>Sentinel-3 VIS channels shall have a dynamic range at least equivalent to Envisat MERIS and AATSR instruments.</td>
<td>SLSTR-L1B OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-960</td>
<td>Radiometric Saturation</td>
<td>Sentinel-3 channels used for snow, cloud and fire monitoring shall not saturate for these targets although this is not a driving requirement. The saturation limit over fire is 750 K (goal).</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-970</td>
<td>Radiometric Saturation</td>
<td>Sentinel-3 OLC instrument VIS measurements shall be optimised to measure the ocean colour over the open-ocean and coastal zones but shall not (as a goal requirement) saturate over bright targets such as clouds and land surfaces, throughout its spectral range.</td>
<td>OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-980</td>
<td>Radiometric stability</td>
<td>Sentinel-3 SST measurements shall have a long-term radiometric stability goal of 0.1 K/decade (±0.2 K/decade threshold) for a 5 x 5° latitude longitude area.</td>
<td>SLSTR-SST</td>
<td></td>
</tr>
<tr>
<td>S3-MR-990</td>
<td>Radiometric accuracy</td>
<td>Sentinel-3 infrared channels shall have a radiometric accuracy goal of 0.1 K over a range of 270-320 K traceable to international reference standards.</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1000</td>
<td>Relative radiometric accuracy</td>
<td>Sentinel-3 infrared channels shall have a relative radiometric accuracy of &lt;0.08 K (threshold) with a goal of 0.05 K over a range of 210-350 K expressed as NEAT traceable to international reference standards.</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1010</td>
<td>Absolute radiometric accuracy</td>
<td>Sentinel-3 VIS reflectance’s at TOA shall have an absolute radiometric accuracy goal of &lt;2 % with reference to the sun for the 400-900 nm waveband and &lt;5% with reference to the sun for wavebands &gt; 900 nm traceable to international reference standards.</td>
<td>OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1020</td>
<td>Relative radiometric accuracy</td>
<td>Sentinel-3 OLC instrument VIS reflectance’s at TOA shall have a relative radiometric accuracy threshold of 0.2 % (goal) traceable to international reference standards.</td>
<td>OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1030</td>
<td>Signal to noise</td>
<td>Sentinel-3 OLC instrument VIS channels shall have a high signal to noise specification building on and improving on MERIS heritage.</td>
<td>OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1040</td>
<td>Polarization</td>
<td>Sentinel-3 OLC instrument VIS channels shall have a known polarisation error less than 1 %.</td>
<td>OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1050</td>
<td>Polarization</td>
<td>For the SLST instrument, the difference in responsivity between any two orthogonal polarisations shall not be more than 4% for the TIR channels.</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1060</td>
<td>Polarization</td>
<td>For the SLST instrument VIS and SWIR channels, the responsivity variation with plane of polarisation shall be known to better than 7% with a goal of 5%.</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1070</td>
<td>Characterisation</td>
<td>For the SLST instrument, the responsivity variation with plane of polarisation shall be known to better than 0.5% for all channels.</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1080</td>
<td>Geo-location accuracy</td>
<td>Sentinel-3 shall be designed to ensure geo-location accuracy better than 1.0 rms. of the spatial resolution of the sensor for optical measurements over land and coastal zones and without the need for any Ground Control Points.</td>
<td>OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1090</td>
<td>Geo-location accuracy</td>
<td>Improved geo-location accuracy is possible when using ground control points and Sentinel-3 shall be designed to ensure a geo-location accuracy of better than 0.5 rms. of the spatial resolution of the optical sensor when using ground control points.</td>
<td>OLCI-L1B, SLSTR-L1B, SYN-L1C</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1100</td>
<td>Inter-channel co-registration</td>
<td>The inter-channel spatial co-registration for Sentinel-3 visible measurements shall be &lt; 0.5 of the spatial resolution of the sensor over the full spectral range (goal of 0.3 of the spatial resolution of the sensor).</td>
<td>OLCI-L1B, SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1110</td>
<td>Inter-channel co-registration</td>
<td>The inter-channel spatial co-registration for Sentinel-3 SWIR and TIR measurements shall be sufficient to allow these channels to be co-registered with visible channels at higher spatial resolution data.</td>
<td>SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1120</td>
<td>Inter-channel temporal co-registration</td>
<td>The co-registration between Sentinel-3 optical images acquired at different times (e.g. from different spacecraft) shall be accurate to 1.0 rms. of the spatial resolution of the sensor.</td>
<td>OLCI-L1B, SLSTR-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1130</td>
<td>Inter-channel co-registration</td>
<td>Sentinel-3 OLC channels 442, 490, and 510 nm shall be closely co-registered to avoid errors in blue/green chlorophyll retrieval algorithms.</td>
<td>N/A (Design)</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1140</td>
<td>Inter-channel co-registration</td>
<td>Sentinel-3 OLC channels 620 and 665 shall be co-located and have as little difference as possible in the atmospheric paths to minimise errors in the atmospheric correction procedures.</td>
<td>OLCI-L1B</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1150</td>
<td>Geo-location accuracy</td>
<td>Sentinel-3 shall be designed to ensure sufficient geo-location accuracy of topography measurements in the coastal and ice zones and for inland water (river and lake) monitoring applications.</td>
<td>SRAL-L1</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1160</td>
<td>Calibration</td>
<td>The Sentinel-3 instrument payload shall be characterised and calibrated prior to launch as required to meet the instrument performance requirements specified for each instrument.</td>
<td>all</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1170</td>
<td>Validation</td>
<td>Sentinel-3 measurements on-orbit shall be validated to demonstrate conformance to GMES user requirements. Operational long-term validation and verification of all data products throughout the mission lifetime is required to monitor product uncertainty estimates.</td>
<td>P-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1180</td>
<td>Service Data Products</td>
<td>Sentinel-3 shall provide data products required by GMES services. A non-exhaustive list of high-priority products from Sentinel-3 is provided in Chapter 4</td>
<td>all, P-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1190</td>
<td>Service Data Products</td>
<td>All Sentinel-3 measurements and products shall include product uncertainty estimates.</td>
<td>all, P-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1200</td>
<td>Service Data Products</td>
<td>Sentinel-3 shall provide River and Lake Hydrology (RLH) (e.g. lake area, lake height differences from reference height, lake volume change) and River and Lake Altimetry (RLA, containing individual re-tracked radar echo waveforms) products shall be delivered to the hydrological services in a timely and operational manner.</td>
<td>SRAL-L2LA</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1210</td>
<td>Service Data Products</td>
<td>Sentinel-3 shall provide global coverage atmospheric aerosol products that minimise differences between retrieval algorithms over land and over ocean surfaces. Products shall make full use of S3 optical channels and dual view capability.</td>
<td>SYN-L2C SLSTR-LST</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1220</td>
<td>Service Data Products</td>
<td>Sentinel-3 shall provide data products in acceptable formats used by operational NOP and NWP systems (e.g., netCDF, L2P, BUFR).</td>
<td>P-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1230</td>
<td>Service Data Products</td>
<td>Sentinel-3 data Level-0 products shall be archived adhering to good data stewardship principles for use in long term climate monitoring studies.</td>
<td>P-Avail</td>
<td></td>
</tr>
<tr>
<td>S3-MR-1240</td>
<td>Service Data Products</td>
<td>Access to Sentinel-3 L1b altimeter high resolution echo waveform data shall be provided to users on request to allow necessary regional development of RLH, and coastal altimetry products including better validation and uncertainty estimation.</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

**Table 11** - All Sentinel-3 mission requirements
4.4 Planning

The high-level planning of Cal/Val activities entails all mission phases where calibration and validation activities have to be considered:

- the pre-launch phases where the Cal/Val activities will be prepared;
- the Space Segment Commissioning phase (Phase E1) (AD 2, AD 6, AD 7) where all instruments operation aspects will be verified and all in-orbit calibration and validation activities will be initiated to support the Sentinel-3 GMES services initial operations (GIO). Results from Phase C/D instrument characterisation campaigns will be essential for these activities;
- the Routine Operations phase (Phase E2) where full operational status will be achieved and calibration and validation activities will continue.

The actual detailed planning will be documented in specific Cal/Val implementation plans:

- implemented Cal/Val activities by the space segment for Phase E1 (AD 8)
- implemented Cal/Val activities by the Mission Performance Center (MPC)
- planned campaign activities by the Sentinel-3 Validation Team (S3VT) (AD 9)

Progress for each phase will be assessed through formal reviews and workshops, supported by the various Cal/Val teams. The mandatory milestone during which a detailed status on the Cal/Val activities has to be given is the In Orbit Commissioning Review (IOCR) scheduled 5 months after CP start. This review should be complemented by other reviews and workshops as follows:

- a Cal/Val preparation workshop: to assess the status of external validation campaigns (ships, in-situ networks, etc.) (CP Start–3m);
- a Cal/Val rehearsal workshop: to verify all anticipated Cal/Val procedures (CP Start -1m) in sync with overall GS rehearsal activities;
- the In Orbit Commissioning Review to review satellite, instrument performances and the flight operations center and declare their readiness for operations (more detailed objectives are described in Chapter 4.4.2)
- the 1st Validation workshop: to provide a status on the quality of all products, a detailed one for all L1 products and a preliminary one for all L2 products (CP Start +5-6m, which could coincide with the IOCR);
- dedicated L2 products validation reviews: to authorize the data dissemination to all users of any set of L2 products for full operation capability (when needed, and as soon as possible after the end of the Commissioning phase);
- regular Cal/Val workshops during Routine Operations phase: to re-assess the quality of all products, and discuss any possible improvements to the algorithms and processing parameters (1 per year throughout the mission lifetime – TBC).

The different Cal/Val phases and associated milestones are illustrated in the following Gantt diagram:
4.4.1 Cal/Val Preparation activities

The Cal/Val plan preparation activities will start in Phase C/D and will last until launch. It is expected that Cal/Val preparation will largely benefit from technical activities that will have already started or completed in phases C and D with a focus on comprehensive instrument characterisation and definition of calibration strategies. Details on these can be found in the individual instrument documents (“IN-6/IN-11”, RD 4 - RD 10 and RD 59 - RD 63).

In order to assess the maturity and readiness of all Commissioning phase Cal/Val related activities a Cal/Val rehearsal shall be conducted before the launch. Priority shall be given to checking that appropriate data transfer procedures, including the use of central storage facilities and databases are satisfactorily working to support the Cal/Val activities during the Commissioning phase, and complete testing of all specific software tools foreseen to be used by the Cal/Val teams.

The Cal/Val preparation activities shall therefore, as a minimum, cover the following tasks:

- establishing Cal/Val teams;
- supporting discussions and tests concerning the corrective maintenance activities of the following processors:
  - instrument simulators (SPS),
  - prototype processors (L1 GPP processors and L2 PAD processors),
  - operational processors (IPFs);
- supporting discussions addressing potential evolutions of instruments’ data processors (see list above);
- completing the planning of Cal/Val activities, including:
  - the detailed definition of interfaces expected to support the Cal/Val activities (e.g. interfaces to all processing and support centres like CNES, EUMETSAT, etc.,
  - the detailed plan of in-situ campaigns;
- producing all Cal/Val procedures;
- specifying and having technical resources developed, such as:
o computer infrastructures dedicated to Cal/Val activities,
o needed SW tools,
o Cal/Val databases for storing in-situ campaign data,
o automated product subset extractions,
o data screening and quality assurance protocols,
o 3rd party RS data (i.e. Envisat, Jason,..).

* And concerning the Cal/Val rehearsal:
  o Identification of its scope,
  o Coordination of its activities.

And the Cal/Val rehearsal shall at list cover the following tasks:

* support any activity addressing the verification of all systems and tools that will be used for the Cal/Val activities, such as:
  o PDGS processing,
  o dissemination of data to Cal/Val teams,
  o exercising the Quality Control (QC) tools,
  o generation of and access to all internal and external pre-launch ADFs;
* test read and write access to all Cal/Val database;
* verify data quality monitoring procedures for Commissioning phase;
* generate mission timeline data, instrument mode switching procedures;
* verify all Cal/Val procedures, including the procedures expected to report between the different teams and agencies.

### 4.4.2 Assumptions for the Satellite in-orbit Verification Phase

The first activities after launch will include the gradual switch-on of all instruments, checks on health status of platform, AOCS and payload (AD2). This Satellite in-orbit Verification Phase (SIOV) starts after transition of the satellite to NORMAL mode by the FOS at the end of the Launch and early Orbit Phase (LEOP). The SIOV terminates with the satellite in its operational orbit and functionally verified. The outgassing of the optical instruments is complete or on-going and the cool-down to operational temperatures has started.

At the end of the SIOV, the instruments are switched on, functional tests are performed and verification in orbit of all the elements of the mission is established.

As condition for any initiation of Cal/Val activities the satellite platform has to be checked during this phase. The success criteria are:

* All satellite services are available and nominal. This includes power, thermal control, data handling, tele-command and telemetry, on-board recording, telecommunication, etc.
* Nominal orbit is reached and nominal attitude control is achieved (yaw steering)
* Packet format and datation has been checked
4.4.3 Assumptions on Ground Segment status

In order to process all instrument data streams for Cal/Val purposes the most important objective for the ground segment is to:

- Confirm readiness of the PDGS system for initial data processing capabilities (i.e. all Level 1 and partial Level 2 data product availability) required to serve Phase E1 Cal/Val activities.

This relates to the preparation activities described in Chapter 4.4.1 which must be successfully completed before commissioning. In addition the following PDGS elements should be functional or completed:

- All prototype processors have been successfully cross-validated with the operational IPF system thus confirming no software related processing errors or remaining errors in product specifications.
- Cal/Val rehearsals are successfully completed
- All necessary auxiliary data sets are validated and are available to process instrument data during commissioning.
- Mission planning and management tools are operational (this includes calibration acquisitions schedules, orbit control and monitoring)
- Details of PDGS Commissioning procedures have been established including detailed planning and contingencies plans.
- Operation procedures are established by FOS and/or PDGS for specific needs expressed in the Cal/Val plan, such as calibration sequences, extract requests, routine incorporation of calibration changes/updates in the ground segment
- Access to all instrument characterization data (SCDDB) is ensured for all instruments and any Cal/Val task.
- Rapid information generation and exchange for all of Cal/Val analyses is ensured. This includes information on data processing recipes, statistical results and presenting on adequate information channels (i.e. websites, bulletins) to all Cal/Val team members.
- Coordinate with Mission management dedicated collection and processing of specific payload data products for given geographical locations and times to ensure that instruments are collecting data at the right place and right time coincident with in situ campaign activities as required

The overall commissioning of the PDGS including the “ramp up” of operational functions and data dissemination up to and following IOCR is described in a specific “PDGS commissioning document” (AD 6/AD 7).

4.4.4 Cal/Val activities during Commissioning Phase

The nominal duration of the Commissioning phase will be 5 months for Sentinel-3A and be reduced to 3 months for the following satellites.
The IOCR marks the end of the Space Segment commissioning phase. Its objectives, detailed in the Sentinel-3 Space Segment Commissioning plan (AD2), are here following summarised:

- Ensure the satellite and its subsystems has reached the required performance stability fulfilling the success criteria specified for entering into the operational phase,
- Confirmation that all the instruments are in their operational modes and calibrated,
- Confirmation that the conditions for mission handover from the Project team to the Mission Management team have been achieved, i.e.
  - that the EUMETSAT FOS GS is fully operational and capable of routine monitoring and control of the satellite,
  - that the PDGS is able to support data production and distribution as required for the GIO Phase

The primary goal of the Cal/Val activities to be performed during the Commissioning phase will be to have all Level 1 products fully assessed and validated. It is understood that a full scientific validation of all Level 2 products will not realistically be available at this time, it is expected that at least a preliminary quality assessment of all L2 products shall be given at the IOCR.

The objectives of the Cal/Val activities during the Commissioning phase will therefore be to:

- calibrate all instruments;
- tune all L1 processing parameters;
- verify all L1 processing functions (ie. geolocation, datation etc.);
- verification and preliminary validation of all L1 products;
- provide a preliminary quality assessment of all other L2 products, including synergy products.

Industry teams had already provided a first iteration to propose Cal/Val activities describing for each instrument the details of the calibration and validation approaches (RD 1 / RD 58); these constituted an important source of information for the preparation of the Commissioning Cal/Val plans but will be superseded by the final implementation plans (see Chapter 4.4) currently under preparation.

4.4.5 Cal/Val activities during Routine Operations

It is acknowledged that the duration of the Space Segment Commissioning phase and the available resources will not permit to have sufficient time to scientifically validate all L2 products. It is therefore envisaged to pursue the validation of remaining L2 products during the first phase of the Routine Operations. This should lead to declaring the Sentinel-3 fully operational only few months after the end of the Space Segment Commissioning phase (Phase E1).

These validation activities will continue to exploit dedicated in-situ measurement campaigns and all Commissioning phase results. Further fine-tuning of processing parameters might also still be necessary during the Routine Operations phase.

Also, for all L2 products uncertainty estimate should be made available and routinely produced during the extended validation phase.
This validation phase will be concluded with dedicated validation workshop(s) where the readiness of data dissemination to all users for each L2 product will be finally assessed.

Following the Validation of all L2 products, the following activities shall be pursued during the Routine Operations phase for each instrument/product:

- Continuous monitoring and revision of instrument on-board calibration and characterization;
- Further science algorithms and data product improvement developments;
- Periodic full mission reprocessing incorporating new instrument knowledge and algorithm advancements and improve mission operational and scientific output and continuity.
5 Responsibilities and Resources

5.1 Responsibilities

In general all established Cal/Val teams can be classified as:

- The ESA (and associated contractors) / EUMETSAT teams (Project)
- The teams outside ESA and EUMETSAT

For the following chapters team structures and objectives are described separately for Phase E1 and E2. However there will be a natural transition of team structures from E1 to E2 as key members and functions will sustain.

Figure 11 sketches a generic workflow of Cal/Val activities.

![Generic structure for Cal/Val workflow](image)

The responsibilities between the 3 Sentinel-3 Cal/Val specific phases will be split as follows:

- the **Cal/Val preparation activities** to take place before launch will be conducted and organised by the relevant parties;
- the Space Segment **Commissioning phase**, including all its Cal/Val activities, will be led by the Sentinel-3 ESA satellite project with the support of other ESA and EUMETSAT teams for the validation activities;
- the **Routine Operations phase**, including all its Cal/Val activities, will be under the responsibility of the Sentinel-3 Mission Management.

The selection process for team members is not finalized yet. A direct selection of specific “mandatory” experts will be complemented by an Cal/Val Announcement to commission the Sentinel-3 Validation Team (S3-VT) to extend the core teams with external expertise.

The teams will include all necessary expertise for calibration and validation; these shall allow fulfilling the following tasks:
• **Calibration tasks:**
  - full in-flight calibration and (re)characterisation of all instruments;
  - comprehensive verification of Level 1 data processors (tuning of all relevant processing parameters, regeneration of all L1 auxiliary products);
  - prepare and advise on necessary Level 1 processor updates;
  - routine calibration monitoring and assessment after the end of the Commissioning Phase;

• **Validation tasks:**
  - In Commissioning Phase Level 2 algorithm verification for all L2 “baseline” products (tuning of all relevant processing parameters, regeneration of all L2 auxiliary products);
  - Level 2 algorithm validation starting during Commissioning Phase and continued in Phase E2;
  - Quantifying error estimates for L1 and L2 products;
  - Long term monitoring for consistency and constant quality of geophysical products;
  - Advise on re-processing campaigns.

### 5.1.1 Cal/Val teams during Preparation activities

For pre-launch activities a specific “technical instrument calibration team” can be defined comprising ESA staff and industry experts only.

### 5.1.2 Cal/Val teams during Commissioning Phase

The Cal/Val teams during the Commissioning phase will be grouped as follows (AD 2):

- Optical Cal/Val E1-CP Team including sub-teams for OLCI and SLSTR
- Topo Cal/Val E1-CP Team including sub-teams for SRAL,MWR and POD

These teams shall all be constituted of a selection of experts coming from:

- ESA staff members that were part of the project team;
- ESA and EUMETSAT staff members that were part of the PDGS development team;
- data product specialists selected from the L1/2 ATBD author teams (the “ESL” Envisat approach);
- specialists from the Industry Support Team (for calibration and characterisation tasks);
- scientists representing the GMES core user facilities.

These teams will all report to the Commissioning Phase Management Team.

In addition, the Industry Support Team with selected specialists from the satellite prime contractor and payload subcontractors will support the Cal/Val activities during the Commissioning phase. (AD 2)
Also for precise orbit determination technical support will be necessary from GNSS/DORIS instrument engineers and FOS orbit specialists until the specific POD service provided by the PDGS is fully validated.

The optical E1-CP team might as well be complemented by experts that will concentrate on the new synergy L1c product, with a focus on the specific issues like geometrical co-registration and validation of geophysical parameters at Level 2c.

As Sentinel-3 is defined to serve operational services expert user feedback from the GMES core services should be included in validation activities. As experience from other operational mission have demonstrated (i.e. METOP) the use of robust and mature data assimilation centres ingesting Sentinel-3 data streams already in a Commissioning Phase can provide valuable product quality feedback.

### 5.1.3 Cal/Val teams during Routine Operations

EUMETSAT and ESA will be in charge of the routine quality control, the calibration analysis and the validation analysis in continuous manner during the Routine Operations.

Details on sharing of responsibilities, contractual frameworks and objectives are under discussion. This includes also details on control and update mechanism for product algorithms.

On system level the following framework elements for Phase E2 Cal/Val are considered:

- A contractual framework for a Mission Performance Center (MPC) at ESRIN
- The Marine Processing Center at Eumetsat considering the heritage from existing elements like OSI-SAF and others.
- A set of technical and scientific boards to advise Mission Management how to ensure consistent product quality throughout the mission lifetime.
- An independent Validation Team S3-VT which will be identified with a specific Announcement of Opportunity Call.

The S3-VT will include subgroups dedicated to data products:

- S3-VT Altimetry team
- S3-VT Ocean colour team
- S3-VT Sea and Sea Ice Surface Temperatures team
- S3-VT Land parameters team

It is expected that teams defined for Phase E1 will be transferred to the Phase E2 under a new management structure to be defined between ESA and Eumetsat. The S3-VT established in Phase E1 will continue their support to both agencies with in-situ measurements and product analysis. The S3-VT may be extended with further expertise i.e OSI-SAF members, GMES services experts etc. All these possible groups are referred as “S3 Validation Teams” in this document.

The Processing Centres will be equipped with tools and team that provide regular monitoring of the data quality. When a problem or anomaly is detected, a specific mission operation board will decide in a quick manner on the solution to solve the problem (it can be a fix or patch in the processor, a change in the ADF, a change in the Instrument Table Parameter). The detail organisation of this board is not described in this document.
5.2 Supporting Resources and Services

Specific tools and resources which are considered mandatory for each Cal/Val task are described in Chapter 6 within the corresponding Cal/Val task description. Also, a complete compilation of resources is listed in Annex 1.

5.2.1 Instrument Performance Simulators

One central resource will be the different System Performance Simulators (SPS) which allow an end-to-end performance analysis for each instrument up to Level 2 products. As one essential element, ground processor prototypes (GPP) have been developed for L1 and L2 production chains. For pre-launch the SPS/GPP tools will be used:

- to generate representative data sets and the corresponding level 0-2 test data.
- to assess the performance of ground processing limited to the ones that have no or weak heritage from Envisat (e.g. OLCI straylight correction, L1c-coregistration, SRAL SAR Mode).
- to verify that processing has no negative impact on instrument performance (e.g., SNR, spectral calibration)
- to provide the appropriate test data sets to tune/optimize ground processing algorithms for potential design changes or in cases of inferior instrument performances.
- to provide the appropriate test data sets to tune/optimize algorithms for geophysical Level-2 products.

The prototype processors will be cross-validated with the operational Payload Data Ground Segment (PDGS) systems. The generation of appropriate test data sets is with the S3 project responsibility.

The SPS/GPP tools will then be used during the Space Segment commissioning phase for the first part of the Validation phase. The L0 data produced by the Satellite will be injected into the GPP/SPS chain and the generated products will be compared with the corresponding operational products produced by the PDGS.

A draft TDS description for the optical GPP can be found in RD 12.

5.2.2 Cal/Val data storage and distribution

Several data streams have to be coordinated and made available to all relevant Cal/Val entities: Instrument status and calibration data, SPS/GPP Test Data Sets, in-situ data from validation campaigns and vicarious calibration sources, external auxiliary data (i.e. meteo, forecast model data and potential 3rd party RS data products). Basic requirements for such databases include:

- easy access with proper documentation of data sources, formats and quality
- appropriate management and scheduling of data streams (i.e. ensure availability of campaign data during Commissioning Phase)
6 Cal/Val Tasks definition

Following the approach set out in Chapter 4, for each product (linked to an MRTD requirement) an error analysis is then performed to identify the main sources of errors and an associated Cal/Val Task(s) has been defined.

By this approach each task shall cover all associated error sources. Each Cal/Val task is assigned a unique identifier and task descriptions are presented in a common format and include details required by Cal/Val planning and implementation teams. (see Figure 8).

Error terms and validation activities are described in this chapter for each instrument and each processing level. In addition, tasks are labelled with a classification scheme to classify the level of importance that may be used to prioritise S3 Cal/Val activities according to the following criteria:

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1-LOW</td>
<td>Minimum impact on E1 activities with no impact on IOCR</td>
</tr>
<tr>
<td>E1-MED</td>
<td>Some impact on E1 activities that may potentially impact IOCR</td>
</tr>
<tr>
<td>E1-HIGH</td>
<td>Major impact on E1 activities that will have a negative impact on IOCR</td>
</tr>
<tr>
<td>E1-CRIT</td>
<td>Critical impact on E1 activities that will halt all progress towards IOCR</td>
</tr>
<tr>
<td>E2-LOW</td>
<td>Minimum impact on Mission status: requires further non-critical work.</td>
</tr>
<tr>
<td>E2-MED</td>
<td>Medium impact on Mission status: requires immediate attention</td>
</tr>
<tr>
<td>E2-HIGH</td>
<td>High impact on Mission status: activities shall be initiated immediately to resolve issues.</td>
</tr>
<tr>
<td>E2-CRIT</td>
<td>Mission is severely impacted.</td>
</tr>
</tbody>
</table>

Table 12 – Classification of Cal/Val Tasks for the level of importance

All Cal/Val tasks are presented in this section for each of the processing chains: OLCI, SLSTR, SYN, SRAL, MWR and POD; and are described using the following structure:

**Task Description**: provides a very brief and high-level description of the task;

**Task Aim and Objectives**: provides the ultimate aim of the task, and the list of measurable objectives;

**Parameters for analysis**: identifies the list of parameters that are being analysed (e.g. “chlorophyll” for the OLCI L2 Ocean Colour Validation, or “dark offset measurements data” for the OLCI L1 radiometric calibration task);

**Methodology**: describes in some details the underlying scientific background, and the different steps required to accomplish the task;

**Input/output data needs**: lists the set of input data required for the tasks, identified through their PDGS product types when products are needed as input data, and including their timeliness (NRT/STC/NTC) when appropriate; lists as well the output data produced by the task;

**Required tools**: identifies the set of tools required for accomplishing the task;

**Anticipated results**: describes the expected task results which might consist of:

- update a specific Auxiliary Data File,
• recommendations to change some on-board settings (e.g. some IPTs),
• recommendations to change some on-ground settings (e.g. algorithms, product size, format
definition, etc.)
• report (i.e. for the Cal/Val tasks just meant to be monitoring the quality of the end-
products, or comparing the S-3 products with other sources);

**Task schedule:** identifies:

• the list of tasks that have to be accomplished before this task starts; in other words the pre-
requisites to start the task,
• the level of importance of the task (e.g. E1-HIGH), and the underlying reason for the
proposed level,
• the possible repetition and frequency of the task (e.g. one off during the commissioning, or
every 2 weeks during the mission’s lifetime).

Also, it is understood that a report shall be produced whenever a task is performed, and that this
report shall be forwarded to the Cal/Val management body. This reporting will therefore, for
clarity, not be mentioned in any of the tasks descriptions.
6.1 OLCI

The OLCI imaging spectrometer is calibrated in-flight using three diffuser panels and a shutter plate placed on a calibration wheel and respectively inserted in the instrument field of view to perform radiometric calibration, to trace degradation of the diffusers themselves, and to perform spectral calibration, all supported by contemporary dark calibrations. Traceability to international standards is ensured through pre-launch characterization of the diffuser plates.

Post-launch, essential activities are planned to systematically monitor and model OLCI absolute response and degradation of its radiometry and characterization in order to assure long-term stability. The OLCI radiometric model needs then to be independently validated by vicarious means, including sensors inter-comparisons.

In L1B processing spectral and geometric models are taken into account. Those models are initiated from pre-launch characterisation (e.g., FPA stability, Line of Sight), and need update during the first months of satellite life and through routine operations using measurements from spectral calibrations and campaigns or over Ground Control Points (GCP).

For ocean colour, the final performance is met by the system, and not only by the instrument itself (RD 27). Mission requirements surpass instrument specifications. All parts of the system have to be analysed in concert and considered as individual contributions to the total performance. Level-1 and Level-2 calibration and validation tasks described below are therefore intertwined and have common elements.

6.1.1 Constraints and Assumptions

In addition to the general statements from Chapter 4.4.2 and 4.4.3 for the Cal/Val task definitions in this chapter the following constraints and assumptions apply for OLCI:

- OLCI instrument SIOV tests have been successful and concluded (classified E1-CRIT)
- OLCI outgassing has been performed in SIOV (classified E1-HIGH)
- Microband and band settings to nominal band set
- Gain settings verified
- Offset Control Loop set
- All operation modes and corresponding Earth /calibration target views checked

Access to all L1b data streams shortly after the end of SIOV is mandatory (classified E1-CRIT).

Full L2 operational products validation is not expected to be reached at IOCR, the final validation is targeted during E2 (classified E1-MED).
6.1.2 *Instrument Error Analysis*

*Figure 12* – Preliminary OLCI Error Analysis
### 6.1.3 Task Definitions for OLCI Level 1b Products

<table>
<thead>
<tr>
<th>MRTD key requirement</th>
<th>S3 Products ID</th>
<th>Major Error Source</th>
<th>Cal/Val Tasks</th>
<th>Responds./Schedule</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S3-MR-1010: Absolute radiometric accuracy:</strong></td>
<td>OLCI-L1B</td>
<td>Diffuser - - charac. error - model error - alignment error</td>
<td>Preparation for on-orbit Level-1b activities</td>
<td>E1: after SIOV</td>
<td></td>
</tr>
<tr>
<td>Sentinel-3 VIS reflectance’s at TOA shall have an absolute radiometric accuracy goal of &lt;2% with reference to the sun for the 400-900 nm waveband and &lt;5% with reference to the sun for wavebands &gt; 900 nm traceable to international reference standards.</td>
<td></td>
<td></td>
<td>(OLCI-L1B-CV-100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S3-OB-1 : Primary)</td>
<td></td>
<td></td>
<td>Radiometric Calibration</td>
<td>E2: ongoing</td>
<td></td>
</tr>
<tr>
<td>(S3-MR-80: Service continuity)</td>
<td></td>
<td></td>
<td>(OLCI-L1B-CV-200)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S3-MR-120: Performance)</td>
<td></td>
<td></td>
<td>Radiometry Validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S3-MR-1020: Rel. radiometric)</td>
<td></td>
<td></td>
<td>(OLCI-L1B-CV-300)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S3-MR-120: Performance:</strong></td>
<td>OLCI-L1B</td>
<td>Pre-launch characterisation error - Diffuser BRDF model and temporal degradation Camera-to-camera characterization Temporal spectral evolution Geometric error Methods error</td>
<td>Preparation for on-orbit Level-1b activities</td>
<td>E1: after SIOV</td>
<td></td>
</tr>
<tr>
<td>Sentinel-3 shall provide Visible and Short-Wave Infrared radiance measurements over the ocean (ocean colour) to at least the quality of MERIS on Envisat with improved spectral capability.</td>
<td></td>
<td></td>
<td>(OLCI-L1B-CV-100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S3-OB-1 : Primary)</td>
<td></td>
<td></td>
<td>Radiometric Calibration</td>
<td>E2: ongoing</td>
<td></td>
</tr>
<tr>
<td>(S3-MR-80: Service continuity)</td>
<td></td>
<td></td>
<td>(OLCI-L1B-CV-200)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S3-MR-120: Performance)</td>
<td></td>
<td></td>
<td>Radiometry Validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S3-MR-1080: Geo-location accuracy:</strong></td>
<td>OLCI-L1B</td>
<td>AOCs contributors Platform/structure contributors OLCI contributors</td>
<td>Geometric Calibration</td>
<td>E1: after SIOV</td>
<td></td>
</tr>
<tr>
<td>Sentinel-3 shall be designed to ensure geo-location accuracy better than 1.0 rms. of the spatial resolution of the sensor for optical measurements over land and coastal zones and without the need for any Ground Control Points.</td>
<td></td>
<td></td>
<td>(OLCI-L1B-CV-600)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(S3-OB-1 : Primary)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(S3-MR-80: Service continuity)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>(S3-MR-120: Performance)</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>(S3-MR-1090: Geolocation)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(S3-MR-1100: Interchannel coreg.)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(S3-MR-1120: Interchannel coreg.)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(S3-MR-1130: Interchannel coreg.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(S3-MR-1140: Interchannel coreg.)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
6.1.3.1 Preparation for in orbit Cal/Val activities (OLCI-L1B-CV-100)

Task Description

This task is applicable for all further Level-1B Cal/Val tasks.

Task aim and objectives

- Consolidation of an initial list of sites for Level-1B radiometry verification
- Automating execution of individual verification/validation analyses on new incoming OLCI data and on the mission-long time series, including data processing recipes, result web presentation and documentation (Level-0 to Level-3 processing followed by global and regional temporal trending, anomaly analyses, and mission inter-comparisons; Level-1B images after possible Rayleigh correction and coastline overlaying)
- Level-1B product format verification with inspection of mask and flag values, radiance range checks (Subtask OLCI-L1B-CV-110)
- Creation of a database of ground control points (GCP) for geometric calibration
- Initial geometric modeling from on-ground characterizations, an initial kernel for the GCP database, preparation for validation of the geo-location requirements
- Implementation of GCP extraction tools, GCP visualization tools, and geolocation modeling tool
- Consolidated list of diagnostic sites for Level-1B geometric verification
- Cal/Val rehearsal testing should address processing of radiometric calibration sequences and ADF generation, ingestion of new ADFs into the PDGS for use in Level-1 processing, processing of radiometric calibration sequences to populate the long-term trend database and exercising of the modelling tools
- Preparation for data processing, including verification of the Level-1B processing, simulated L1 products, testing extraction tools, preliminary validation of the products
- Prelaunch studies using MERIS to improve characterization and calibration of OLCI, including establishing a goal on OLCI temporal stability; reducing dependence of the...
diffuser BRDF model on the solar azimuth angle and narrowing uncertainties on subsequent radiometric calibrations; better characterizing and correcting for straylight, smile, and discontinuities at camera interfaces; linking MERIS/OLCI and OLCI 3A/3B time series

- Prelaunch studies using MERIS to reduce absolute and relative uncertainties of the vicarious calibration verification techniques, development of absolute mission inter-calibration methods at Level-1B radiances, and a common vicarious calibration strategy between OLCI and SLSTR
- Preparation to run routinely and quickly Cal/Val tasks that are data and processing demanding, such as reprocessings of subsets of global mission archives
- Establishment of on-line and off-line data extraction tools, including off-line extraction of any lat/lon coverage of mission historical data
- Establishing a methodology for quantifying uncertainty budgets per pixel and deriving pre-launch and in-orbit estimates
- Assuring capabilities for Level 3 processing during Phase E1 and regular full mission reprocessings for Phase E2

6.1.3.1.1 Verification L1b product contents (OLCI-L1B-CV-110)

Task description
This task is designed to verify the contents of L1b product contents and confirm that they conform to specification.

Task aim and objectives
This task shall for a variety of typical targets (ocean, land, ice, clouds):

- Verify the visual consistency of all OLCI L1B image data
- Verify the coding of all flags and parameters
- Verify that all data are present in the L1b product and conform to specification

Parameters for analysis
- OLCI L1b radiances, flags

Methodology
OLCI L1b products will be systematically checked and verified against product specifications for a number of randomly chosen orbits.

Input/Output data needs
- OLCI L1b products

Required tools
- S3 Toolbox or any netCDF analysis SW

Anticipated results
Verification of OLCI L1b products
Task Schedule

This task starts as soon as OLCI L1b data are available

6.1.3.2 Radiometric Calibration (OLCI-L1B-CV-200)

Task Description

The task covers the on-board radiometric calibration measurements, their processing by the PDGS, and off-line analysis of the Level-1B radiometric calibration products. The task produces instantaneous dark offsets and radiometric gains for every calibration event. If needed, it also results in the update of OLCI overall dark offsets and gain coefficients at a reference time used in the instrument temporal evolution equation as well as the equation parameters of the gain temporal degradation which all are stored in the calibration Auxiliary Data File (ADF). This is classified as: E1-CRIT and E2-CRIT.

The radiometric on-board calibration is performed by setting the instrument in the calibration mode and by viewing the sun illuminated white diffuser. The calibration sequence starts with a dark current measurements performed at closed shutter over the sun port. Calibrations occur at the orbital South Pole. The diffuser BRDF - and its underlying diffuser model - is OLCI’s radiometric primary standard traceable to International System of Units.

Radiometric calibration depends on the radiometric and spectral models, which are a part of the ground processor and may have to be updated with time. Exposure to space environment implies also ageing of its components, including diffuser plates and optics. Whereas the aging of the instrument (and its inherent instrumental response) is accounted for in the gain coefficients computation, the ageing of the diffuser plate reflectance impacts the estimation of the radiance at instrument entrance. Hence, it is necessary to monitor and quantify this ageing independently, through a second reference diffuser plate, used much less frequently. The derived ageing coefficient is expressed as a time and wavelength dependent factor affecting the originally characterised BRDF.

Task Aim and Objectives

The OLCI Radiometric Calibration task has the following 5 objectives:

• produce the instantaneous radiometric calibration - gain and offset - of the instrument
• monitor the dark current measurements
• quantify the ageing of the nominal diffuser and gain coefficients
• derive the temporal radiometric degradation of the instrument
• warn when new calibration measurements diverge from the operational model

The task aim is to generate and update the Auxiliary Data File (ADF), which contains OLCI calibration information used operationally by the PDGS OLCI Level-1b processor. The task is fundamental to meeting OLCI absolute radiometric accuracy goal of 2% (and 5% for bands > 900 nm). Moreover, the task is critical to ensuring strict instrument temporal stability for operational services and climate monitoring.

Parameters for analysis

The task uses:
• on-board calibration measurements obtained from using the nominal and reference solar diffusers,
• dark current measurements,
• CCD temperatures, NAVATT packets and computed smear, straylight, non-linearity,
• characterisation and models data (SCCDB), auxiliary data, including platform and instrument data, processing control parameters

These measurements are systematically processed by the PDGS to instantaneous OLCI Level-1 radiometric calibration products (OL_1_RAC). The sequence of radiometric calibration measurements is set at fixed solar azimuth angles at the orbital South Pole in order to limit the range of potential diffuser response variability w.r.t. its on-ground BRDF characterization.

The following expert off-line analyses adjust models of solar diffuser and instrument radiometric degradations.

The analyses produce OLCI reference gain, offset and degradation model parameters for the calibration ADF.

**Methodology**

Details of methodologies and activities are described in RD 1.

The activity shall start before launch and will continue over the mission lifetime. In addition, a spare or witness sample of the FM white diffusers shall be routinely spectro-radiometrically characterised on ground to establish the FM diffuser degradation between the last characterization and the launch. The outcome of these measurements can help to assess on-ground and in-flight performance degradation of the flight diffusers.

OLCI radiometric calibration task can be de-composed into four steps:
• on-board radiometric measurements,
• routine radiometric calibration processing,
• expert off-line analyses of radiometric calibration data,
• update of the calibration parameters ADF−, if required.

The first step, routine on-board radiometric calibrations, always includes dark current measurements, followed by sunlight illuminated diffusers measurements. During the calibration sequence the calibration wheel is rotated to insert the shutter into the instrument field of view for dark calibration and then to insert the sun exposed white diffusers for radiometric calibration. The calibrations are performed at the orbital South Pole.

• The nominal diffuser will be deployed every 15 days at fixed sun azimuth angles (about every 200 orbits)
• The reference diffuser will be deployed every 3 months at fixed sun azimuth (about every 1200 orbits)
• It is recommended that all diffuser measurements are acquired at a fixed set of sun azimuth angles to obtain annual repeatability of measurements at the same geometry

The reference diffuser calibration is used to develop the diffuser ageing model by comparisons against nominal diffuser measurements. The diffuser ageing calibration is performed on two consecutive orbits. On the first orbit, the nominal diffuser sequence is accomplished, while on the
second orbit the reference diffuser is deployed. Initially, three diffuser acquisitions will be needed to derive the ageing model.

The second step is automated processing of calibration data to obtain instantaneous OLCI radiometric calibration products, which define instantaneous radiometric gain and dark offset. This processing is incorporated as a part of the PDGS operational processing.

In the third step, the calibration data are investigated off-line in concert with other instrument characterization and models evidence to derive or revise instrument degradation model and update reference calibration coefficients.

- This step shall be performed systematically and comprehensively throughout the mission lifetime. It shall ensure continuous monitoring of instrument radiometric degradation, periodic updating of the degradation model, as well as an instant response to sudden degradation if it occurs, and rapid validation of updated models and revised modelling methods.
- OLCI radiometric modelling is required to meet the 2% absolute accuracy goal for bands ≤ 900 nm, and 5% for bands > 900 nm.
- Strict radiometric long-term stability needs to be assured for operational OLCI marine and land services.

The step requires consolidation of radiometric calibration and diffuser aging modelling. The diffuser aging should assume degradation of both diffusers which is proportional to their respective exposures to space environment. The off-line analyses may also address other pertinent issues to improve OLCI calibration such as spectral modelling, dark calibration and instrument characterization, including diffuser BRDFs, straylight, non-linearity. The step is important because temporal stability requirements are particularly high for ocean colour services. The ocean signal is low compared to the instrument TOA measurements and a small 1% drift in calibration will correspond to a large 10% drift in user products for which the requirements state 5% absolute uncertainty and 0.5% stability over a decade (AD4, RD53).

In the fourth step, the OLCI calibration ADF is updated when the results of on-board calibrations deviate from the existing degradation model meaningfully, and injected in the PDGS to support the operational production of OLCI Level-1b products.

**Input/Output Data needs**

**Input data are:**

- OLCI calibration ADF
- all accumulated OLCI L1 calibration products (OL_1_RAC), which cover dark offset and instantaneous gain coefficients
- BRDF models for both nominal and reference diffusers
- instrument spectral models and parameters
- straylight modelling, smear, non-linearity, exact calibration geometry
- If the need arises, further in-depth instrument calibration analyses may investigate OLCI dark offset tables, characterization and models data, programmation data, platform and instrument data.

**Output data are:**

- instantaneous dark offsets and gain coefficients in the OL_1_RAC files
• updated version of the instrument calibration ADF, if required
• specifically, instrument degradation model and diffuser ageing model

Required Tools
• Mission planning tools to schedule on-board radiometric calibrations
• Tool providing the range of OLCI solar azimuth angles year-round with respect to the white diffusers at the orbital South Pole. The tool shall allow selecting a set of the most prevalent angles that will enable to keep about the nominal frequency of OLCI calibrations
• Automated processing of calibration measurements to obtain instantaneous gains
• Routine and expert monitoring tools that allow to display specific parameters, such as dark offset trending, offset control loop dependence, diffuser ageing, instantaneous gain evolution, and the degradation model
• Expert tools that enable instrument response analyses and modelling. The tools use calibration measurements from both diffusers. The tools model dark offset variability, diffuser ageing, and instrument degradation. The tools will automatically warn when new calibration measurements diverge from the operational model

Anticipated results
• updates to the instantaneous gain parameter and updates to the instrument radiometric degradation model
• degradation model uncertainties
• monitoring and updates to the nominal diffuser ageing model
• updates to the calibration ADF used in OLCI Level-1b processing, if warranted
• diffuser ageing monitoring reports
• instrument temporal degradation reports, including monthly comparisons between the radiometric degradation model and the actual calibration measurements and quantitative change assessments
• warning when new calibration measurements diverge from the operational degradation model

Task schedule
The schedule of activities to be performed for each sub-task after launch is given in the dedicated sub-sections below.

6.1.3.2.1 In-flight verification of instrument characterization (OLCI-L1B-CV-210)

Task description
Changes since pre-launch characterization shall be verified in E1 for the following parameters:
• dark offset level and along-orbit evolution
from Earth Observation mode acquisitions at the nominal band set during the instrument functional checks while OLCI is still in the shutter position (repeated measurements along several
orbits obtaining 1000 frames 15 times along the orbit and, if possible, with OCL ON and OFF for standard mode and reference, plus additional acquisitions at calibration sequence windows in the orbital south pole, if feasible)

- verification and detection of defective CCD cells

from dark offset and radiometric response measurements during dark offset acquisitions when OLCI is still in the shutter position.

During E1, other radiometric calibration and general instrument characterization parameters referred to in RD 1 will be analysed, including straylight, non-linearity, geometric accuracy, spectral characterization, instrument to platform alignment, scheduling of calibration events, temperature correction coefficients to provide

- update of performance budget estimates based on in-flight data assessment,
- update of performance models based on in-flight data assessment.

6.1.3.2.2 **Deriving first in-flight radiometric calibration parameters (OLCI-L1B-CV-220)**

The first calibration sequence in E1 using the nominal diffuser shall be acquired as soon as possible after instrument switch-on, and processed immediately, in order to:

- verify the on-board calibration sequence
- verify the calibration processing
- verify the calibration ADF generation process
- consolidate radiometric calibration from updated spectral model, if required;
- construct the preliminary in-flight calibration ADF

The following Commissioning radiometric calibrations shall

- compute the first calibration coefficients from in-flight measurements
- initiate trend monitoring and modeling for diffusers and optics, if needed apply more frequent on-board reference calibrations
- allow as early as possible Earth observation data processing to Level-1B
- estimate radiometric drift at the end of E1, assess the need for operational updates
- release 1st operational ADF

6.1.3.2.3 **Monitoring of the Dark Offsets (OLCI-L1B-CV-230)**

Dark offsets are measured within each calibration sequence. They are systematically accumulated throughout the mission lifetime, both in the Commissioning and Routine Operations phases.

Off-line monitoring will evaluate all available dark offset measurements that are acquired using the nominal band set. Long term stability will be monitored. Results will be cross-checked with along-orbit and orbital south pole observations in shutter position obtained during post-launch OLCI functional checks to verify short time trend consistency. When the stability is questioned, a contingency action shall be initiated, including a possible update to the calibration ADF.

Dedicated dark calibration campaigns to evaluate the orbital stability can be scheduled during the mission, particularly when instrument degradation is suspected.
Dark offset stability shall be reported monthly along with reporting on the instrument radiometric degradation.

6.1.3.2.4 **Quantifying ageing of nominal diffuser (OLCI-L1B-CV-240)**

**Task Description**

OLCI radiometric calibration using the reference diffuser will be performed every 3 months (about every 1200 orbits) throughout the mission lifetime, both in the Commissioning and Routine Operations phases. The calibration is accomplished by deploying nominal diffuser and reference diffuser with the nominal band set on two consecutive orbits. First post-launch reference shall be acquired as soon as possible after the instrument switch-on. Instantaneous gains will be processed on-line.

Off-line analyses and modelling shall quantify ageing of the solar diffusers. The modelling can start after the third acquisition but should not be exploited until a significant correlation is achieved. In the Commissioning phase, only 2 acquisitions will occur at the foreseen rate that will prevent any modelling. The rate at which initial ageing sequences are acquired may be increased depending on the recommendation of the instrument team.

After the Commissioning phase, status of nominal diffuser ageing shall be reported every half a year.

6.1.3.2.5 **Monitoring of instrument response and degradation modelling (OLCI-L1B-CV-250)**

OLCI radiometric calibration using the nominal diffuser will be performed every 15 days (about every 200 orbits) throughout the mission lifetime, both in the Commissioning and Routine Operations phases. First post-launch calibration shall be acquired as soon as possible after the instrument switch-on. Instantaneous gains will be processed on-line. In the Commissioning, consolidated radiometric calibration shall be produced from the updated spectral model and degradation trend monitoring and the modelling shall be initiated.

Off-line analyses and modelling shall derive the time trend in OLCI response degradation. The calibration model shall be continuously investigated and revised when new instrument characterization knowledge and new calibration measurements are acquired. In the Routine Operations, a new model cannot be put into operations without comprehensive verifications as indicated in the subsequent sections.

Frequency of model revisions will depend on the stability of OLCI degradation and how well the derived models predict it. OLCI will need more frequent model updates early in the mission. OLCI radiometric degradation model and the instantaneous calibration measurements shall be reported monthly. An automated warning shall be provided when new calibration measurements diverge from the operational degradation model.

6.1.3.2.6 **Updating of calibration ADF (OLCI-L1B-CV-260)**

The characterization and calibration ADF shall be updated upon availability of higher quality data from OLCI dark offset monitoring and radiometric degradation monitoring and modelling. A new calibration ADF cannot be released to operational processing by PDGS until comprehensive
validation exercises are accomplished. A number of iterations to validate test ADFs may be required before optimizing on the best degradation model.

It is expected that the consolidated radiometric calibration shall be completed by the end of Commissioning phase and the validated calibration ADF is released. In the Routine operations phase, the calibration ADF may be updated on a yearly basis, depending on the measured instrument temporal evolution.

6.1.3.2.7 Radiometric Calibrations for sun azimuth angle dependency (OLCI-L1B-CV-270)

Task Aim and Objectives
Considering the experience with MERIS, the diffuser BRDF model depends on the solar azimuth angle, which causes cyclic trends in instrument radiometric calibration measurements over time. The dependence can be potentially modelled or the uncertainties can be reduced by performing on-board calibrations at a set of fixed sun azimuth angles. A set of such angles shall be investigated. The angles should be the same year-to-year and as common as possible in the OLCI diffuser viewing geometry so that the degradation trends can be built along these fixed azimuths.

Required Tools:
Development of a tool providing the range of OLCI solar azimuth angles year-round with respect to the white diffusers at orbital south pole. The tool shall allow to select the most prevalent angles that will enable to keep about the nominal frequency of OLCI calibrations.

6.1.3.2.8 Yaw maneuvers for Solar Diffuser on-orbit recharacterization (OLCI-L1B-CV-280)

Task Aim and Objectives
Solar Diffusers (SD) are the main OLCI calibration sources and the SD BRDF is characterized with high precision pre-launch as the SD calibration is very important for the OLCI product accuracy. However, the experience with MERIS demonstrated that SD calibration measurements on orbit still include residual trends linked to measurement geometries. The yaw maneuvers aim to address relative characterization of the on-board SD, re-assessing pre-launch values for BRDF, sun baffle and diffuser alignment, baffle straylight contribution by comparing with in-flight measurements. The goal of this task is to re-characterize and validate the solar diffuser BRDF on orbit by using multiple observations at several spacecraft yaw angles. The benefit of the on-orbit BRDF characterization is that the diffuser observations are performed over the complete range of illumination angles that are used in the nominal SD calibrations and over all operational instruments bands/spectral settings. This approach has been successfully applied to SNPP VIIRS and to Terra and Aqua MODISes and the derived SD BRDFs are used in operations (McIntire et al. 2012, Xiong et al. 2003).

This is classified as E1-LOW and E2-MED. The task is not included in the satellite project cal/val implementation plan. An assessment is needed whether such an activity can be integrated in the current mission planning for Phase E1 or E2.
Task description

OLCI BRDF characterisation on ground is performed with high accuracy (<0.5%) and traceable to international standards. Also SLSTR and OLCI BRDF measurement benches are compared to allow inter-comparison between both instruments.

OLCI BRDF check in flight are performed using standard orbital South Pole instrument calibration sequences but through a series of small yaw manoeuvres defined to represent the various solar azimuth angles encountered through the year on the SD. The spacecraft flight in any given orbit provides a range of elevation angles. The series of yaw manoeuvres can be accomplished on consecutive orbit South Pole crossings throughout a single day, or potentially over two days. Only the BRDF of the nominal diffuser shall be characterized to limit aging of the reference diffuser, under the assumption that the reference and nominal diffuser BRDFs are similar.

Analyses will compare pre-launch and on-orbit SD BRDF results and an updated BRDF model will be developed. The task has impact on the characterisation and models data, instrument radiometric calibrations and the degradation modelling.

6.1.3.3 Radiometry Validation (OLCI-L1B-CV-300)

This task includes the following sub tasks:

- Radiometric Verification at Level 1b (OLCI-L1B-CV-310)
- Radiometric Validation with Level 3 products (OLCI-L1B-CV-320)

6.1.3.3.1 Radiometry Verification at Level-1B (OLCI-L1B-CV-310)

Task description

The task will use vicarious techniques at Level-1B radiances to:

- verify OLCI absolute calibration. This is classified as: E1-HIGH and E2-HIGH.
- verify OLCI temporal degradation model. This is classified as: E1-HIGH and E2-HIGH.

The methods which compose this task and operate at Level-1B radiances have uncertainty budgets which are too high in comparison with the absolute radiometric accuracy requirement for OLCI of 2% and they are therefore qualified as verification.

There are a number of potential methods available across the community. Some of them may be less feasible for OLCI operational Cal/Val. Cal/Val experts shall therefore decide on individual priorities for implementation.

Task methodologies shall be implemented in two modes:

- on-line verifications of newly acquired and processed OLCI data
- off-line evaluations of OLCI characterization and calibration modelling

The following should be further investigated:

- reducing absolute and relative uncertainties of the vicarious techniques, including reducing uncertainties in derived temporal trends
- developing absolute mission inter-calibration methods at Level-1B radiances
### Task Aim and Objectives

The task goal is to

- verify whether OLCI meets its 2% absolute radiometric calibration requirement
- verify OLCI temporal stability and consistency with other contemporaneous missions
- verify the modelling strategy developed for OLCI absolute calibration and temporal degradation following acquisition of new on-board calibration measurements and new instrument knowledge

### Parameters for analysis

The vicarious techniques require at Level-1B

- data extracts over specific static global sites
- data extracts over dynamic surfaces, such as clouds

For static sites, coverage extracts are typically screened for clouds, averaged and formatted with some descriptive information added (for example, METRIC and SADE). For dynamic surfaces, the surfaces are identified in Level-1B products and further statistically processed.

In the on-line mode

- static sites are systematically extracted and processed from newly acquired data at NRT timeliness according to the list of ground sites
- dynamic surfaces may be difficult to process on-line, the feasibility of on-line NRT timeliness shall be established before implementing.

In the off-line mode

- both static sites and dynamic surfaces are extracted off-line
- extractions are typically from data reprocessed from Level-0 and across mission-long time series
- new concepts in Level-1B vicarious techniques are tested, involving additional new sites and new vicarious calibration strategies

### Methodology

Level-1B-based vicarious techniques encompass diverse methodologies that address calibration, characterization and degradation monitoring of optical instruments. The methods listed below have uncertainties 3 to 5% absolute and 1 to 5% inter-band relative, which is beyond OLCI requirements of 2% absolute and 1% inter-band relative. However, mean statistics from these methods can be used in OLCI verification and in inter-comparisons with other missions, including Sentinel-3 SLSTR and between OLCI Sentinel-3A and 3B. In a special circumstance when OLCI’s on-board calibration capabilities become severely degraded, these methods could also be extended to generate calibration corrections.

Principles and methodologies of Level-1B vicarious techniques for the purposes of operational missions have been developed within the Global Space-based Inter-Calibration System (GSICS) and are aimed to be applied in near real-time. Complementary and similar methods have been established as best practise by the CEOS Working Group on Cal/Val (WGCV) IVOS subgroup.
Following CEOS QA4EO guidelines, and GSICS and IVOS recommendations, the methodologies should be documented and should provide a clear decomposition of their uncertainties.

In the framework of GSICS and CEOS WGCV IVOS, the methodologies identified are:

- **Deserts**: temporal stability and inter-comparison (estimated uncertainty of 2 to 4%) and absolute (5%) (RD 28)
- **Rayleigh**: absolute or pseudo absolute (estimated uncertainty of 2 to 4%) (RD 29)
- **Snow**: relative (RD 30)
- **Glitter**: inter-band (estimated uncertainty of 1 to 2%) (RD 31)
- **Deep Convective Clouds**: absolute (estimated uncertainty of 3 to 5%), inter-band (1 to 2%) (RD 32)
- **Temporal and angular matching**: relative (estimated uncertainty 2-3%) (RD 33)
- **LANDNET**: absolute, transfer from a high resolution sensor that is well characterised through in situ measurements to a medium resolution sensor, like OLCI, over invariant sites equipped with surface and atmospheric measurements

**Remarks:**

- Not all of these methods merit E1-HIGH and E2-HIGH priorities for OLCI. Some of them may be less feasible in an operational OLCI Cal/Val setting. Cal/Val experts shall decide on individual priorities for these methodologies and on the most effective operational strategy.
- Initial expert recommendation is to use the Rayleigh scattering method to verify absolute calibration of OLCI blue to red bands and to monitor OLCI spatial and temporal stability (RD 57). A modified Rayleigh method is also recommended to become a vicarious calibration approach for early in the mission, see Chapter 6.1.4.2.2 (OLCI-L2-CV-220).
- The recommendation should be followed given in task description to investigate possibilities for reducing absolute and relative uncertainties of these methodologies and to develop new approaches, which can also be measurement specific.

**Input/Output Data needs**

- On-line access to all mission data; at least all Level-0 data, all RR higher levels, and selected core sites FR higher levels

Easy access to all OLCI EO data is required to support the verification and validation activities. It is therefore desired that all OLCI Level-0 and Level-1B data reside on-line for instantaneous access. If this requirement is presently difficult to meet, at least mission-long Level-0 data shall be stored on-line and quick Level-1B and higher-level processing capabilities. All RR higher level data shall be stored on-line. Individual vicarious techniques shall define FR static site needs that shall also be stored on-line.

On-line access to data is critical. As new static sites are added to verifications and off-line evaluations are ordered, an instantaneous access to mission-long data will be vital. Dynamic surfaces, such as clouds, have no fixed locations and off-line evaluations will again need direct access to data. When vicarious techniques are used to verify new radiometric degradation models, rapid test reprocessing of specific orbit arcs from Level-0 using the new models is required.

- Preliminary list of specific static sites
The list of static sites for vicarious techniques is discussed at GSICS and CEOS WGCV IVOS level. The site network, together with the methodologies, constitutes an international standard reference to which the calibration results should be traced. Thus, the site selection is considered to be of high importance to the Sentinel-3 Cal/Val plan. The list also allows inter-comparisons with other instruments and is similar to the list used for SLSTR vicarious calibration, which supports the common OLCI and SLSTR strategy.

Currently identified potential sites are listed below; however the final list may be different. A list of priority sites may be defined in Phase E1.

**Desert sites** (the entire site must be imaged for verification analyses)

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Lat center (°)</th>
<th>Long center(°)</th>
<th>lat-min</th>
<th>lat_max</th>
<th>long_min</th>
<th>long_max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arabia1</td>
<td>18.88</td>
<td>46.76</td>
<td>18.38</td>
<td>19.38</td>
<td>46.26</td>
<td>47.26</td>
</tr>
<tr>
<td>Arabia2</td>
<td>20.13</td>
<td>50.96</td>
<td>19.63</td>
<td>20.63</td>
<td>50.46</td>
<td>51.46</td>
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<tr>
<td>Arabia3</td>
<td>28.92</td>
<td>43.73</td>
<td>28.42</td>
<td>29.42</td>
<td>43.23</td>
<td>44.23</td>
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<td>Sudan1</td>
<td>21.74</td>
<td>28.22</td>
<td>21.24</td>
<td>22.24</td>
<td>27.72</td>
<td>28.72</td>
</tr>
<tr>
<td>Niger3</td>
<td>21.57</td>
<td>7.96</td>
<td>21.07</td>
<td>22.07</td>
<td>7.46</td>
<td>8.46</td>
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<td>Egypt1</td>
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<td>26.1</td>
<td>26.62</td>
<td>27.62</td>
<td>25.6</td>
<td>26.6</td>
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<tr>
<td>Libya1</td>
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<td>13.35</td>
<td>23.92</td>
<td>24.92</td>
<td>12.85</td>
<td>13.85</td>
</tr>
<tr>
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<td>25.55</td>
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<td>20.98</td>
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<td>28.05</td>
<td>29.05</td>
<td>22.89</td>
<td>23.89</td>
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<tr>
<td>Algeria1</td>
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<td>23.3</td>
<td>24.3</td>
<td>-0.9</td>
<td>0.1</td>
</tr>
<tr>
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<td>25.59</td>
<td>26.59</td>
<td>-1.88</td>
<td>-0.88</td>
</tr>
<tr>
<td>Algeria3</td>
<td>30.32</td>
<td>7.66</td>
<td>29.82</td>
<td>30.82</td>
<td>7.16</td>
<td>8.16</td>
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<tr>
<td>Algeria4</td>
<td>30.04</td>
<td>5.59</td>
<td>29.54</td>
<td>30.54</td>
<td>5.09</td>
<td>6.09</td>
</tr>
<tr>
<td>Algeria5</td>
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<td>2.23</td>
<td>30.52</td>
<td>31.52</td>
<td>1.73</td>
<td>2.73</td>
</tr>
<tr>
<td>Mali1</td>
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<td>18.62</td>
<td>19.62</td>
<td>-5.35</td>
<td>-4.35</td>
</tr>
<tr>
<td>Mauritania1</td>
<td>19.4</td>
<td>-9.3</td>
<td>18.9</td>
<td>19.9</td>
<td>-9.8</td>
<td>-8.8</td>
</tr>
</tbody>
</table>

**Rayleigh and Glitter sites** (significant part of the site must be imaged)

<table>
<thead>
<tr>
<th>n°</th>
<th>Name</th>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Recommended Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>PacSE</td>
<td>South-East of Pacific</td>
<td>-44.9</td>
<td>-20.7</td>
<td>-130.2</td>
</tr>
<tr>
<td>1</td>
<td>PacNW</td>
<td>North-West of Pacific</td>
<td>10</td>
<td>22.7</td>
<td>139.5</td>
</tr>
<tr>
<td>2</td>
<td>PacN</td>
<td>North of Pacific</td>
<td>15</td>
<td>23.5</td>
<td>179.4</td>
</tr>
<tr>
<td>3</td>
<td>AtlN</td>
<td>North of Atlantic</td>
<td>17</td>
<td>27</td>
<td>-62.5</td>
</tr>
<tr>
<td>4</td>
<td>AtlS</td>
<td>South of Atlantic</td>
<td>-19.9</td>
<td>-9.9</td>
<td>-32.3</td>
</tr>
<tr>
<td>5</td>
<td>IndS</td>
<td>South of Indian</td>
<td>-29.9</td>
<td>-21.2</td>
<td>89.5</td>
</tr>
</tbody>
</table>

**Snow sites**

<table>
<thead>
<tr>
<th>Name</th>
<th>centre</th>
<th>NE corner</th>
<th>NW corner</th>
<th>SW corner</th>
<th>SE corner</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOME C</td>
<td>123.83</td>
<td>-74.63</td>
<td>108.32</td>
<td>-73.49</td>
<td>126.47</td>
</tr>
<tr>
<td>DomeC1</td>
<td>120.265</td>
<td>-78.593</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>DomeC2</td>
<td>113.736</td>
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<td>TBD</td>
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<td>TBD</td>
</tr>
<tr>
<td>DomeC3</td>
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<td>-75.102</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>DomeC4</td>
<td>128.715</td>
<td>-77.383</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
The sites for Deep Convective Clouds method have no fixed locations. 10 to 20 dynamic areas around the tropics can be expected.

Temporal and angular matching methodologies use sites such as salt lake UYUNI in Bolivia.

**LANDNET sites**

<table>
<thead>
<tr>
<th>Name</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuz Golu</td>
<td>33.33</td>
<td>38.83</td>
<td>TUBITAK UZAY</td>
</tr>
<tr>
<td>Railroad Valley Playa</td>
<td>-115.69</td>
<td>38.5</td>
<td>NASA/GSFC</td>
</tr>
<tr>
<td>Negev</td>
<td>35.01</td>
<td>30.11</td>
<td>Ben Gurion University</td>
</tr>
<tr>
<td>La Crau</td>
<td>4.86</td>
<td>43.56</td>
<td>CNES</td>
</tr>
<tr>
<td>Ivanpah Playa</td>
<td>-115.40</td>
<td>35.57</td>
<td>NASA/GSFC</td>
</tr>
<tr>
<td>Frenchman Flat</td>
<td>-115.93</td>
<td>36.81</td>
<td>NASA/JPL</td>
</tr>
<tr>
<td>Dunhuang</td>
<td>94.34</td>
<td>40.13</td>
<td>NSMC/CMA</td>
</tr>
<tr>
<td>DOME-C</td>
<td>123</td>
<td>-74.5</td>
<td>University of Washington</td>
</tr>
</tbody>
</table>

- Data from other missions

Depending on the individual methodology requirements, respective data from stable and contemporary missions can be needed as well as data from heritage instruments. The list of missions may include SLSTR, MERIS, MODIS, VIIRS, and Proba V. These data requirements, including specific static site subsets, shall be established by the Cal/Val experts concerned. The selected data shall then reside on-line within the Cal/Val facility.

**Required Tools**

- Data visualization and analysis tools. These tools shall be required for OLCI Level-1B data and data from other missions used by the verification techniques.

- Data extraction tools

Extraction tools for vicarious techniques can be separated into the three tools providing three main functionalities:

The first functionality is a simple data extraction, along and across swath around the test site at Level-1B radiances. The input for the extraction is the test site description (lat and lon limits). The output of the extraction is a complete Level-1B file limited in coverage to the extraction area. This is a generic extraction tool that can operate both on-line during the operational processing as well as off-line on all mission-long time-series.

The second functionality consists of post-processing of the extracted data to prepare them for the vicarious calibration analysis. The post-processing depends on the vicarious calibration method. Typically, the post-processing includes cloud screening, macro pixel averaging and reformatting. Thresholds and precise parameters depend on the methodologies. An example of the tool that was used for MERIS was METRIC.

The third functionality is used for on-line extractions and it consists of automated storage of simple and/or post-processed extracts in a database and pushing the extracts to respective Cal/Val teams.
• Search and access to mission data

Instantaneous search and access to all OLCI EO data is required to support off-line extractions across mission-long archives over any verification sites. A tool is thus needed that searches and retrieves locations of OLCI files that cover a given lat/lon range and time span. It is desired that all respective OLCI data reside on-line for instantaneous access and it is linked with a capability to quickly reprocess subsets of these data using test calibration ADFs.

• Recalibration tool and approach

The Level-1B-based vicarious techniques need to be configured to efficiently verify the calibration ADF, which may be accomplished over a number of iterations with test ADFs in order to optimize on the best calibration and degradation model. This requires the time-series of extracts to be reprocessed with the test calibration ADFs for which two options are currently perceived and described below. The suitable methodology needs to be agreed and implemented before the launch.

Processing from Level-0 products. At Level-0 no geographic extracts are possible, thus respective orbits arcs defined by acquisition start and stop times will need to be processed. The disadvantage is that Level-0 to 1 processing is potentially slow compared to the specific activities which may limit the Cal/Val effectiveness.

Processing from Level-1B with recalibration applied on top of operational Level-1B radiances. This recalibration methodology would be efficient but still needs to be developed. The method is associated with a certain error because, for example, the stray light correction will be applied only on the operational calibrated radiances. However, the error will be small (expected in a fraction of a percent over the mission) and significantly lower than the accuracy of the Level-1B-based verification techniques.

• Extract database

A database needs to be developed to hold the extracts over the core Level-1B-based vicarious calibration sites. Depending on the recalibration strategy described in the previous point, the database may also have to retain corresponding Level-0 files. However, the Level-0 files will not have to be physically stored in the database when the Cal/Val infrastructure supports instant search and access to the mission-long data archives that reside on-line. The database has to be repopulated after each full mission reprocessing.

• Verification analysis tools

The vicarious techniques employ their own specific set of tools to perform radiometry verifications. The types of tools therefore will depend on the actual methodologies selected for OLCI. Examples are MUSCLE processing tool developed for SADE data repository for desert, Rayleigh, snow, glitter, and cloud methods, and DIMITRI tools developed for temporal and angular matching.

• Hardware and software for data reprocessing of test data subsets for Cal/Val

Cal/Val data processing infrastructure is needed, both computers and automated procedures to realize data extraction, processing, and distribution (RD 53). The approach is dependent on the selected recalibration strategy and shall use test calibration ADFs for the processing each time a test update of the ADF is issued. The infrastructure shall rapidly access and reprocess core extracts in the database and access, extract and reprocess throughout the mission any newly selected sites. The reprocessed data extracts shall be delivered for verification in the expedited and automated manner.
Anticipated results

The task results will:

• Verify and monitor absolute accuracy of the radiometric model
• Verify and monitor OLCI radiometric stability through time
• Support mission inter-comparisons, including within Sentinel-3

The following shall be reported:

• on a monthly basis syntheses of the results shall be provided
• verification and validation results shall be continuously posted on the OLCI project web pages

Task schedule

The task shall be executed throughout the mission in the Commissioning and Routine Operation phases.

The PDGS related timeliness on the tasks is

• in the on-line mode, the specific core global sites are systematically extracted at the Level-1B on-line in the NRT as new OLCI data come in and are processed. The extracts shall be automatically stored in the database and distributed to verification analysis tools and respective recipients who will perform the analyses so that accuracy assessments are available as early as possible.

• in the off-line mode, off-line extractions from OLCI mission-long time series are requested from new sites at Level-1B or after off-line test site reprocessing is requested from any site selection. The extracts are then distributed to verification analysis tools and respective recipients who perform the analyses.

In the Commissioning phase E1:

• vicarious verifications shall start with on-line mode extractions for the core sites immediately after launch as soon as a quality controlled calibration ADF is available to the PDGS and the first Level-1B products are processed
• off-line processing and verifications of recalibrated data over the core sites shall be accomplished to optimise the calibration ADF and achieve the best calibration at the end of the Commissioning phase
• vicarious techniques shall provide the first ratio and trend plots and statistics for inspection at 3-months from launch and shall update the results for the Commissioning phase review

In the Routine Operations phase E2:

• on-line extractions at the core sites shall run continuously and be combined with on-going vicarious verifications
• off-line extractions and verifications will be requested throughout mission Routine Operations to investigate new sites or surfaces and to verify revised degradation models
• off-line recalibration processing and verifications on the core and new site extracts will be routinely accomplished to investigate incremental changes to the calibration ADF
• vicarious techniques shall provide ratio and trend plots and statistics for inspection at regular intervals of 2 months
6.1.3.3.2 Radiometric Validation with Level 3 products (OLCI-L1B-CV-320)

Tasks description

As OLCI continuously changes on orbit, its calibration and characterization will become the main challenge. The task will use Level-3 radiances over ocean surfaces to

- verify OLCI absolute calibration. This is classified as: E1-HIGH and E2-HIGH.
- validate OLCI temporal degradation model. This is classified as: E1-HIGH and E2-HIGH.

The task uses water-leaving radiances because they enable detection of potential absolute biases and calibration drifts which are as small as a fraction of percent at TOA radiances. The water-leaving radiances are directly related to Level-1B TOA radiances. The intermediate atmosphere contributes about 90% of the signal but is accurately modelled over open ocean and, particularly, in oligotrophic waters (RD 36). The removal of the atmosphere makes the water-leaving radiances an order of magnitude more sensitive to the instrument absolute calibration and radiometric degradation. Level-3 products average out remaining noise and provide comprehensive and vast statistics for the validation (RD 53).

Task methodologies shall be implemented in two modes:

- on-line monitoring of newly acquired and processed OLCI data
- off-line validations of OLCI characterization and calibration modelling

The off-line mode will enable systematic evaluations of OLCI modelling efforts. The calibration ADF will require thorough optimization before it is implemented in the PDGS operational processing and/or used in full mission reprocessings. Many iterations may be required which will loop over:

- expert analyses of calibration and characterization data to model OLCI calibration and degradation and create test ADFs when new on-board calibration measurements are acquired or new instrument knowledge emerges
- off-line test reprocessings of validation data subsets from Level-0 using the test ADFs
- radiometry validations at marine Level-3 products

Task Aim and Objectives

The task goal is to systematically monitor and adjust calibration of the instrument which is constantly changing on-orbit. The task aims to achieve the accuracy, long term stability, and multi-mission consistency that are required by operational and climate-related services. The purpose is to

- enable prompt detection of instrument degradation and rigorous quality assurance
- warn when there is a sudden degradation problem
- verify whether OLCI meets its 2% absolute radiometric calibration requirement in comparison with other contemporaneous missions
- validate OLCI long-term radiometric stability, consistency with other missions, and continuity to previous missions, such as MERIS and SeaWiFS
- enable rapid prototyping and transfer of instrument calibration ideas to operations
- repeatedly test OLCI absolute radiometric calibration and temporal degradation modelling to optimize on best strategies and options and to select the most stable models that give best results in verifications
The importance of the task is amplified by OLCI marine-domain applications which have absolute and temporal stability requirements that surpass instrument specifications. These requirements warrant implementing calibration verification methods that reach beyond Level-1B radiances and focus on Level-3 marine radiances where the sensitivity to calibration is magnified.

**Parameters for analysis**

- global deep-ocean and oligotrophic water-leaving reflectances at Level-3

Level-3 data are derived using standard binning procedures from Level-2 products and typically at 9km resolution and at daily, 4-day and monthly coverage (RD 34). For Level-2 processing, the use of ultimate meteorological and other ancillary files is needed, thus the NTC timeliness is assumed with a preference for 2 to 5-day delay maximum from the time of data acquisition. OLCI reduced resolution observations, RR, can be used to generate the Level-3 data. Deep-ocean and oligotrophic water coverage are extracted from the global Level-3 files based on provided Level-3 bin masks.

In the on-line mode

- when all daily global Level-2 files are available at NTC, the files are further processed on-line into 1-day global Level-3 files. For the validation, dailies will be only investigated in the Commissioning phase

- after respective sequences of Level-3 daily files become available, the daily Level-3s are combined on-line into 4-day and monthly Level-3 products. Each 4-day Level-3 counting sequence must start with the first day of the calendar year.

In the off-line mode

- typically, mission-long Level-3 global time series will be repeatedly processed off-line from Level-0 to Level-3 and will continue increasing in length and volume as mission progresses

- the evaluations can use a temporal subset of 4-day Level-3 products per every 32-day period of the mission (RD 27, RD 53). This will result in temporal mission subsampling down to about 1/8th of the mission

**Methodology**

The task to verify and optimize OLCI absolute calibration is based on inter-comparisons of OLCI Level-3 water-leaving reflectances with coincident Level-3 reflectances from other stable and contemporaneous missions. The absolute verification is primarily suitable for the marine branch and when processing chains from different ocean colour missions are equivalent and the vicarious adjustment is considered, such as for MERIS and OLCI and for OLCI on Sentinel-3A and 3B. The inter-comparisons will be accomplished in global deep-ocean and in oligotrophic waters. Further regional subsets can be investigated within the deep-ocean coverage. The verification methods include inter-comparisons and ratios.

The methods are explained in RD 36. Task actions are the following:

- matching corresponding Level-3 bins between the missions which are associated with the same temporal and spatial coverage
- selecting matched Level-3 bins according to deep-ocean and oligotrophic water masks
- selecting matched Level-3 bins according to deep-ocean region definitions
- calculating mean water-leaving reflectances and mean mission ratios at equivalent spectral bands for all individual deep-ocean, oligotrophic and regional mission pairs
• providing cumulative statistics, mean reflectances, histograms, mean ratios, standard
deviations
• if a timeseries is used, plotting temporal trends, mean reflectances from both missions, and
mean ratios
• automated result posting on the OLCI project web pages, side-by-side the previous or
similar relevant results
• automated notification, if a sudden degradation is detected

The task to validate and optimize OLCI temporal degradation model is based on evaluations of the
stability of Level-3 oligotrophic water-leaving reflectances. The task is equally valid for OLCI
marine, land and synergy branches. From experience with MERIS, individual bands degrade in
concert and the blue range of the spectrum degrades the most while the near-infrared the least.
Marine products are thus ideal for trend detection because any potential atmospheric
uncertainties vary in the opposite spectral order and because of the magnified radiometric
sensitivity when the atmosphere is removed. Validation methods include:

• temporal trends
• temporal anomalies
• trend inter-comparisons

Many actions associated with these methods overlap with the actions accomplished for absolute
calibration verifications. The methods are explained in RD 36. The trend inter-comparison
method is the same if a time-series is used, where the other contemporaneous mission is treated as
a baseline for temporal stability of oligotrophic waters. On the other hand, the two methods of
temporal trends and anomalies do not rely on another mission baseline but on the long-term
stability of oligotrophic waters themselves.

The sequence of actions for temporal trends:
• selecting Level-3 bins according to oligotrophic water masks
• calculating mean reflectances and standard deviations for each point in the time-series
• plotting mean values across the time-series (in the Commissioning phase and first years of
Routine Operations, mean values should be plotted along values from another
contemporaneous mission and alongside other mission climatology)
• if over a year of data are available, additionally plotting mean reflectance annual cycles to
show whether they are consistent between the years
• automated result posting on the OLCI Cal/Val web pages, side-by-side the previous or
similar relevant results
• automated warning when there is a trend or discontinuity

The sequence of actions for temporal anomalies:
• selecting Level-3 bins according to oligotrophic water masks
• calculating mean reflectances and standard deviations for each point in the time-series
• extracting mean reflectance annual cycles from the time-series (in the Commissioning
phase and the first years of Routine Operations, mean annual cycles can be defined from
other stable missions, such as SeaWiFS)
• plotting mission-long temporal trends after subtracting the mean annual cycle from the time-series, over-plotting standard deviations and the linear fit into the trend with its uncertainties
• automated result posting on the OLCI project web pages, side-by-side the previous or similar relevant results
• automated warning when there is a drift or a discontinuity

The methods will extract instrument sudden degradation problems as well as slow trends in data. For example, MERIS bias due to turning off the offset control loop, which controls dark current limits, was only discovered owing to Level-3 temporal anomalies. The bias constituted a fraction of percent of Level-1B TOA radiances and could not be discerned with other methods.

Recommendation for test data reprocessings in the Cal/Val facility (or in Mission Performance Monitoring Facility) is the following: a mission-long timeseries of 4-day global files per every 32-day period in the mission shall be reprocessed from Level-0 to Level-3 within 1-2 days, assuming a 10-year old mission (RD 53).

Input/Output Data needs
• all OLCI data products or at least all Level-0 data, all RR higher levels including Level-3, and selected regional deep-ocean sites FR higher levels

This requirement restates the need for easy access to all OLCI EO data in support of the calibration, verification and validation activities and for on-line archiving of the data listed above at minimum. This task has the sensitivity to detect OLCI calibration and degradation drifts at the level required by marine applications but at the same time it necessitates instantaneous access to vast OLCI datasets. While on-line mode analyses use in-coming data at hand, the prototyping of calibration and degradation models and their validations and optimizations are performed off-line and need access to mission-long time-series. The off-line mode relies on repeated reprocessings of subsampled time-series with test calibration ADFs to Level-3 products. On-line access to relevant mission files within the Cal/Val facility is therefore a prerequisite.

• Definitions of areas of interest for L3 validation (see Figure 13)
• Regional deep-ocean subset definitions (Table 14)
• Data from other missions

Figure 13 – Defined ocean regions for OC validation tasks: oligotrophic waters chl-a < 0.1mg/m³ (right), regions with depths > 1000m (left)
Table 14 – Deep water regions identified for OC validation with L3 data series

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<tr>
<th>Region ID</th>
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<th>Maximum Latitude</th>
<th>Minimum Longitude</th>
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Both on-line and off-line modes as well as absolute calibration verifications and degradation validations will require access to corresponding Level-3 products from other stable, contemporary and historical missions. The list of missions may include MERIS, SeaWiFS, MODIS, and VIIRS. There is a particular need for missions which span the gap between MERIS and OLCI. The selected data shall reside on-line within the Cal/Val facility.

- Output data are Level-3 products, daily, 4-day and monthly, and plots and statistics displayed on the OLCI Cal/Val web pages

**Required Tools**

- Recalibration tool and approach

The task needs to be configured to efficiently qualify successive versions of the calibration ADF throughout the mission before they are implemented in the operational PDGS processing. Each qualification may be accomplished over a number of iterations with test ADFs in order to optimize on the best calibration and degradation models at each instance. This requires the subsampled mission-long time-series to be reprocessed with the test calibration ADFs to Level-3 products. The OLCI recalibration with new ADFs may be accomplished using the two options below and the suitable methodology needs to be agreed and implemented before the launch:

Processing from Level-0 products. Processing from Level-0 to Level-1B, -2 and -3 is the most desirable approach and the most accurate. The disadvantage is that Level-1 processing is slow which may prohibit the task effectiveness or disable its major premise as a major Cal/Val tool.

Processing from Level-1B with recalibration applied on top of operational Level-1B radiances. This recalibration methodology would be efficient but still needs to be developed. The method would be associated with a certain error because, for example, the stray light correction would be applied
only on the operational calibrated radiances. The error is expected to be small in a fraction of a percent but may become significant over the mission.

- Level-3 binning tools

The task will use Level-3 marine derived products, primarily water-leaving reflectances. Level-3 data will be processed using standard binning procedures from Level-2 products and typically at 9km resolution and at daily, 4-day and monthly coverage (RD 34). For Level-2 processing, the use of ultimate meteorological and other ancillary files is needed, thus the NTC timeliness is assumed with a preference for 2 to 5-day delay maximum from the time of data acquisition. Level-3 products from other missions may have to be brought to the required spatial and temporal resolution, if they are different.

- Tools for mission inter-comparisons
- Tools for OLCI degradation temporal trending
- Tools for OLCI degradation anomaly trending
- Tools for result posting on the OLCI Cal/Val web pages
- Tools for automating the full sequence of on-line mode Level-3 processing, inter-comparison/trending, and result posting on the OLCI project web pages
- Tools for automating the full sequence of off-line mode data reprocessing, inter-comparison/trending, and result posting on the OLCI project web pages
- Hardware and software for data reprocessings

The task relies on PDGS hardware and software infrastructure and procedures to repeatedly process, verify/validate and post results. It is recommended that the PDGS processing capabilities allow recurring reprocessings of mission-long RR timeseries of 4-day global files, per every 32-day period in the mission, to Level-3 within 1 to 2 days maximum. The tentative requirements assume preferred recalibration processing starting from Level-0 products.

Tentative requirements for the PDGS Cal/Val infrastructure (RD 53):

1) permanent on-line storage from 100 to 150 TB per year of data (on-line: all Level-0 data, all RR higher levels including Level-3, and selected sites FR higher levels, as well as data from other missions used in the validations)

2) Cal/Val system built in the operational environment or on an exact mirror of the operational environment

3) processing capacity scaled to reprocess 5 to 15% of the global mission data from Level-0 to Level-1, -2, and -3 in 1 calendar day (RD26)

**Anticipated results**

The task will:

- Detect instrument degradation problems and issue a warning
- Verify and monitor absolute accuracy of the radiometric model
- Validate and monitor OLCI radiometric stability through time
- Enable systematic evaluations of OLCI calibration modelling and optimization efforts
- Assure only best calibration models are implemented in operational processing and/or used in full mission reprocessings
• Support mission inter-comparisons and continuity, including within Sentinel-3

The following shall be reported:

• on a monthly basis syntheses of on-line monitoring shall be provided showing marine product inter-comparisons and marine product stability
• results of off-line validations shall be provided when undertaken
• verification and validation results shall be continuously posted on the OLCI project web pages

**Tasks schedule**

The task shall be executed throughout the mission in the Commissioning and Routine Operation phases.

The PDGS related timeliness on the tasks is

• in the on-line mode, Level-3 daily, 4-day, and monthly products shall be automatically processed at NTC. The data shall then be submitted to mission inter-comparison and degradation trending tools, and the verification/validation results shall be posted on OLCI Cal/Val web pages. The desired NTC timeliness is a delay of 2 to 5 days maximum from the data acquisition, instead of the NTC limit of one month.
• in the off-line mode, off-line global time-series recalibration and processing from Level-0 to Level-3, verification/validation, and result posting are expected to be accomplished within 1 to 2 days

In the Commissioning phase E1:

• absolute calibration verifications shall start in the on-line mode immediately after launch as soon as a quality controlled calibration ADF is available to the PDGS and the first Level-1B products are processed
• degradation trend validations shall be initiated
• the task shall provide ratio and trend plots and statistics weekly for inspection and continuously on the OLCI project web pages
• off-line verifications/validations will be requested to optimize and consolidate radiometric calibration

In the Routine Operation phase E2:

• the task shall run in a continuous manner in the on-line mode
• the task shall provide trend plots and statistics that will be inspected monthly and continuously updated on the OLCI project web pages
• off-line verifications/validations will be run throughout the mission pending new instrument characterization knowledge and accumulation of on-board calibration measurements. The continuous revisions will aim at the goal of 0.1% radiometric stability knowledge within the mission (RD26).
6.1.3.4 Spectral Calibration (OLCI-L1B-CV-400)

Task Description

The task will characterize and monitor OLCI spectral evolution throughout the instrument lifetime and will model spectral variations across each camera field of view.

The spectral calibration is accomplished using the on board erbium doped diffuser, and is complemented by taking advantage of some specific narrow spectral features, such Fraunhofer lines and the O2 absorption bands. This task will also develop correction for the smile effect and limit discontinuities at camera interfaces.

Task Aim and Objectives

The objective of the task is to

- verify OLCI absolute spectral calibration with respect to pre-launch characterisation
- monitor throughout the mission OLCI spectral characterization and update the spectral model, if required, with details of its time dependency
- warn when spectral measurements show a shift
- implement spectral smile correction in the Level-2 instrument data processing

Updates in the spectral model need to be incorporated into the calibration ADF. This leads to the re-evaluation of instrument radiometric response and degradation modelling which may also have to be updated in the calibration ADF and thoroughly validated.

The task aims to limit OLCI product uncertainties that are due to shifts in absolute central wavelengths in rows of the camera CCD arrays. The task also aims to reduce trends across the field of view of OLCI cameras and camera-to-camera discontinuities that have detrimental impact on consistency of Level-2 products. For example, in MERIS residual camera-to-camera discontinuities may approach 0.5% at Level-1B radiances. Many spectral calibration methods should be used and compared in order to derive the most robust spectral model.

Parameters for analysis

The task uses:

- on-board spectral calibration measurements from the erbium diffuser
- corresponding dark current and radiometric measurements
- Fraunhofer line measurements via white diffuser illuminated by the sun
- O2 absorption line measurements via Earth view port
- potential other spectral feature calibrations, such as proposed calcium absorption spectral line
- some methods require radiative transfer simulations and training of regression models

These measurements are systematically processed by the PDGS to Level-0 and Level-1 instantaneous OLCI spectral calibration products.

The following expert off-line analyses use additional

- instrument characterization and model data
• calibration ADF

The analyses produce OLCI spectral model parameters for the comparison with pre-launch characterization and with data in the calibration ADF. The parameters characterizing the OLCI spectral model (wavelengths of each pixel of each camera) will be updated through this task, as they evolve through time.

Methodology
The methodologies are described in details in RD1 and REF, and an overview is given in the subsections below.

Anticipated results
According to the results, the spectral model of the instrument may change in-flight from the pre-launch measurements and throughout the mission. This will result in updates to the OLCI calibration ADF, and the on-board band settings as well. Updates in the spectral model necessitate the re-evaluation of instrument radiometric response and degradation modelling which may also have to be updated in the calibration ADF. The updated ADF cannot be implemented in the PDGS operational processing without prior detailed validation.

The expected results include

• report on the verification of the pre-launch characterisation
• monitoring reports, including long-term trend plots and statistics
• spectral model parameters
• warnings when there is a discrepancy between the operational spectral model and new observations
• updated and validated calibration ADF
• correct for the smile effect

Further details the different sub-tasks are given below.

6.1.3.4.1 Spectral calibration using the Erbium doped diffuser (OLCI-L1b-CV-410)

This task is classified as: E1-CRIT and E2-CRIT.

Methodology
The spectral calibration using the on-board Erbium doped diffuser plate (RD 40) is performed in two steps. First, the instrument is configured to have adjacent bands – at the highest spectral resolution – centred on the selected spectral features, and the pixels are calibrated using the radiometric “white” calibration diffuser. At the same channel setting, on the following orbit the erbium doped diffuser is deployed and the measurements from the spectral features are acquired. Processing on ground determines the position on the detector array of the peak of the erbium absorption features. The position of absolute central wavelengths of CCD cells is achieved through
shape matching of the erbium observations referenced against the white diffuser observations and uses correlation with the reference spectrum of the erbium diffuser.

**Task Schedule**

In the Commissioning phase the first spectral calibration acquisitions shall take place as soon as possible after switch-on of the instrument. It shall be followed by a spectral calibration campaign using other spectral features and ranges (Fraunhofer lines and O2 absorption bands). Following the results of the analysis, the model will be updated. The timing of the spectral calibrations is important because the instrument spectral model is used in radiometric calibrations. In the Routine Operations phase, spectral calibrations using the on board spectral diffuser shall take place every 3 months, and shall be complemented by spectral calibration campaigns twice a year (see RD 1).

It is expected that the first spectral model shall be completed by the end of Commissioning phase together with the first radiometric calibration model. The spectral model may be updated on a yearly basis throughout the Routine operations phase, depending on its temporal evolution. Long-time monitoring starts when at least three erbium doped diffuser spectral calibrations are available.

**Input/Output data needs**

The activities will be carried out using the following input data:

- on-board erbium-doped diffuser raw measurements processed to Level-0 spectral calibration products generated through the PDGS
- OLCI calibration ADF
- Output is Level-1 OLCI calibration product containing wavelength characterization from spectral calibration.

**Required tools**

- spectral calibration analysis and modelling tool (determination of the absolute central wavelength and response curve of any cell in each of the camera CCDs)
- monitoring tools that allow to display and monitor specific parameters and compare against pre-launch characterization and the data in the calibration ADF.
- automated Level-1 processing of calibration measurements to obtain instantaneous spectral calibration results

**6.1.3.4.2 Spectral calibration using Fraunhofer lines (OLCI-L1b-CV-420)**

This task is classified as: E1-CRIT and E2-CRIT.

**Methodology**

Because of their well-defined wavelengths, Fraunhofer lines are used to characterize the wavelengths of measured spectra in the visible and near infrared (RD 40). A number of strong Fraunhofer lines, which can be detected with the OLCI instrument, need to be selected before launch. During calibration campaigns, OLCI bands are re-defined to cover the selected Fraunhofer lines with the highest possible spectral resolution (1.25 nm for OLCI) and the observations are acquired off the radiometric white diffuser. Fraunhofer observations are typically taken over three
successive orbits. The methodology for data analysis is similar to the one used in the erbium-doped diffuser calibration and also employs shape matching against a reference spectrum. The Fraunhofer line observations cannot be however referenced against the white diffuser to eliminate the instrument response. A reference (relative) spectrum is thus implemented covering each selected Fraunhofer line across its observed bandwidth plus a margin to accommodate for potential spectral shifts. For every spatial pixel, the result is the central wavelength of given CCD rows one for each observed Fraunhofer line.

**Task Schedule**

In the Commissioning phase, one Fraunhofer calibration will take place shortly after the on-board spectral calibration and no later than one month after the instrument switch-on. The calibration will be particularly critical if the erbium calibration shows meaningful changes in OLCI spectral response from pre-launch characterizations.

In the Routine Operations phase, Fraunhofer line calibration campaigns shall closely follow on-board spectral calibrations using the Erbium diffuser. The frequency of Fraunhofer campaigns shall be every 6 months to once a year and the frequency needs to be determined in the Commissioning phase.

**Figure 14** – MERIS Instruments swath for a specific spectral campaign in 2008, OLCI requirements for multiple orbit spectral campaigns will be reduced.

**Input/Output data needs**

The activities will be carried out using the following input data:

- instruments spectral configuration shall be reconfigured to Fraunhofer configuration (Fraunhofer absorption band matching), where the specific band configurations need to be established prior to launch but will likely be similar to MERIS (393, 485, 588, 655, 855 and 867 nm)

- re-definition of the bands shall be managed though an update of an Instrument Parameter Table (IPT, previously called on Envisat CTI for Configuration Table Interface) uploaded to the instrument, but generated at least one month before the campaign.
• Level-0 OLCI products as generated by the PDGS and covering the Fraunhofer line measurements off the white diffuser without the spectral relaxation
• Output is Level-1 OLCI calibration product containing wavelength characterization from spectral calibration.

Required tools
• tool allowing spectral matching technique for Fraunhofer calibration. Similar tools have been used for MERIS spectral calibration and could possibly be re-used.
• radiative transfer tools should be used for the exploitation of spectral campaign data. MOMO has been used for the Fraunhofer spectral calibration for MERIS.
• Monitoring tools will allow to display and monitor specific parameters.
• Mission planning tools shall be used to plan the campaign and the calibration.

6.1.3.4.3 Spectral calibration using O2 absorption bands (OLCI-L1b-CV-430)
This task is classified as: E1-CRIT and E2-CRIT.

Methodology
Two methods were used for MERIS (RD 40). Similar methods will be used for OLCI. During O2 calibration campaigns, OLCI bands are configured to cover the selected O2 absorption bands and the neighbouring reference bands with the highest possible spectral resolution (1.25 nm for OLCI).

a.) the pressure homogenisation algorithm

The methodology is based on the determination of the surface pressure from the oxygen A band. In this spectral range (759 to 770 nm), the solar radiation measured at the top of the atmosphere depends mainly on the oxygen absorption and therefore on the surface elevation. The oxygen absorption can be measured from space from a two-band ratio R, between the reflectances measured in the oxygen A-band and the reflectances in a close non-absorbing band. When the scattering cannot be neglected, there exists a pressure level defined as the apparent pressure, $P_{\text{app}}$, where outgoing photons originate preferentially. The ratio R is well correlated with air mass, and may be directly converted into the actual surface pressure using a polynomial regression. Surface pressure is computed for each narrow oxygen channel and a given spectral shift $\Delta \lambda$ and the optimal spectral shift is found that minimizes pressure dispersion.

b.) a artificial neural network (ANN) algorithm based on the spectral variation of the extinction coefficient

The ANN learns the variability of the radiance extinction gradient that is simulated from radiative transfer calculations for different surface pressures, aerosol optical thickness and surface albedos. The response from a number of narrow channels is simulated at a step of 0.01 nm around the absorption bands. The ANN uses normalized spectra and the airmass factor, and matches them with the learned spectral shift in the narrow channels.

Task Schedule
In the Commissioning phase, O2 spectral calibration campaign may follow the Fraunhofer campaign one month after the instrument switch-on.
In the Routine Operations phase, O2 spectral calibration campaigns shall follow Fraunhofer campaigns and have the same schedule of activities. The O2 spectral campaign will cover 1 to 3 orbits (TBC) and different ground targets, including bright targets. Ideally, 3 orbits covering Middle East, Africa, Atlantic Ocean should be included.

**Input/Output data needs**

The activities will be carried out using the following input data:

- instruments spectral configuration shall be reconfigured to O2 configuration to match the O2 absorption bands as close as possible and the configuration shall be established prior to launch but likely similar to MERIS
- re-definition of the bands shall be managed through an update of an Instrument Parameter Table
- Level-0 OLCI products as generated by the PDGS covering the O2 measurements made during the campaign without the spectral relaxation

Output is Level-1 OLCI calibration product containing wavelength characterization from spectral calibration.

**Required tools**

- Tools for computing oxygen absorption, surface pressure and for optimizing the spectral shift that minimizes pressure dispersion
- Radiative transfer tools
- ANN tools and ANN training and testing
- Monitoring tools will allow to display and monitor specific parameters
- Mission planning tools shall be used to plan the campaign and the calibration

6.1.3.4.4 **Correction for the smile effect (OLCI-L1b-CV-440)**

This task is classified as: E1-CRIT and E2-CRIT.

**Methodology**

Spectral variations across the field of view (FOV) of OLCI cameras, the smile effect, are modelled from the results of the spectral calibrations and corrected at Level-2 processing. The model defines the spectral dispersion law of each CCD at the centre of the camera FOV and represents it as a polynomial based on the detector row (spectral dimension). The variation across the camera FOV is modelled as a polynomial of the CCD detector column (spatial dimension). The wavelength dependence in the CCD detector bandwidths is represented by a third polynomial. This set of 3 polynomials constitutes the spectral model of a camera. The smile correction converts each camera and each pixel in-band reflectance to the nominal wavelength reflectance using a first order Taylor expansion. In-band and nominal irradiances are used for radiance to reflectance conversion.

Subsequent changes to the spectral model and the smile correction should be verified via image quality methodologies before being implemented in the operational PDGS processing.
Task Schedule

Spectral models of OLCI cameras need to be developed before launch using OLCI pre-launch spectral characterization. The smile correction is also implemented pre-launch as a part of the Level-2 processing.

In the Commissioning phase, spectral models of the cameras may be adjusted depending on the results of erbium diffuser calibrations and spectral campaigns.

In the Routine Operations phase, camera spectral models shall be adjusted respectively and their temporal evolution shall also be modelled if it varies over the mission lifetime. The modelling method as well as the smile correction may be further investigated and modified. The changes need to be verified before put into the operational PDGS processing.

Input/Output data needs

There are the following data needs:

- results of the spectral calibrations, Level-1 OLCI products as generated by the PDGS
- configuration of the smile correction

Required tools

- Tools for reading OLCI spectral calibration data and creating a spectral model for each camera
- Tools for smile correction in Level-2 processing

6.1.3.5 Geometric Calibration /Validation (OLCI-L1B-CV-500)

6.1.3.5.1 Validation/Calibration at ground control points (OLCI-L1b-CV-510)

Task Description

This task will accomplish automated geometric correlation with ground control points (GCP) to validate the accuracy of geometric calibration and to derive errors, if found. This task is classified as E1-CRIT and E2-HIGH.

Task Aim and Objectives

The objective is to validate OLCI geometric performance and to calibrate the geometric model if a problem is found. The geometric model is composed of the Instrument Pixel Pointing Vectors Model (IPPVM) for each OLCI camera and of the Geometric Calibration Model defined by thermo-elastic (TEM) quaternions for each OLCI camera.

Parameters for Analysis

The main parameters that will be investigated in this task are

- Absolute OLCI L1b geolocation accuracy over specific calibration orbits in terms of residuals computed by using GCPs
- TEM quaternions dependency with respect to the satellite position along the orbit (OOP)
- TEM quaternion dependency with respect to the day of the year (DOY)
• IPPVM performance

Methodology
This task will analyse absolute geolocation accuracy for OLCI L1b products. The method is based on automated matching and correlation of OLCI images with maps at GCPs. The task will require the following actions:

• set of GCPs will be used to evaluate the relative accuracy (GCP database will be built in phase C/D)
• geometric calibration scenes for GCP database can be located where a correlation pattern is easy to find and offers high contrast, such as small bright islands and coastline hooks
• OLCI L1B input products shall be automatically filtered according to GCP distribution and available clear sky conditions;
• Selected OLCI scenes will be automatically correlated with the reference GCPs, yielding individual along-track and across-track offsets, stratified according to match quality, orbital position, camera and pixel, and spectral band;
• The retrieved GCPs will be filtered to remove outliers
• for individual correlation analyses, GCPs shall be well represented in OLCI images covering all 5 cameras
• correction on the pointing information will be done by fitting residual errors to a across/along track polynomial model. The chosen approach is to use a Fourier series for the TEM quaternions and a polynomial low for the IPPVM
• results shall be given per camera

Ideally the geometric calibration and verification should be done for images spread along the orbit, such that the deformation effect due to temperature variation along the orbit or platform attitude and orbital accuracy changes can be identified (even though such variation for OLCI should be very small or inexistent). For example, one scene can be in high north latitude, one or more in middle latitude, and one in high south latitude. For MERIS, Senegal and Italy were used. However to obtain the best fitting of the geometric deformation models in function of the satellite position along the orbit (OOP) it is recommended to process GCPs well distributed along the full orbit. Since the TEM quaternions may also vary in function of the season, this operation shall be repeated regularly in order to verify the dependency of the deformation model with respect to the day of the year.

Figure 15 show examples of features that could be useful for GCP.

Input/Output data needs

• OLCI L1b products
• GCP Database
• Most updated IPPVM and TEMs quaternions in the SCCDB
• All geometry parameters for analysis shall be required.

Required tools
A data visualisation and analysis tool is needed allowing the following operations:
• extract OLCI scenes over GCP sites by matching GCPs with OLCI product pixels
• use cloud detection flags in extracting OLCI products
• correlate the coastline with OLCI scenes
• extract deformation vectors and fit residual errors to a cross- and along-track polynomial model
• investigate for all bands to establish inter-band co-registration
• provide information to update and optimise the geometric model, if needed automate the entire process

Figure 15 – Example of RS imagettes with ground features useful for control point definitions

Anticipated Results
The results shall allow:
• validation of detailed absolute, relative and inter-band geometric accuracy
• determination of error sources
• revision of the geometric model and update of the pointing vector
• potential update of Auxiliary Data File (ADF) and information on the satellite orbit and attitude

Pointing information is expected to be updated infrequently, once or twice per mission.

**Task schedule**

The PDGS-related timeliness on the task is as follows:

- GCP database will be built pre-launch
- GCP extraction and matching shall be accomplished automatically during NRT off-line QC

In the Commissioning phase E1:

- the task shall be performed just after launch. For one calibration update 14 days of data acquisition are required. It is expected to have an update every 3 weeks.
- complete geometric accuracy shall be defined by the end of the Commissioning phase

In the Routine Operations phase E2:

- the task will be a regular activity at a frequency TBD, for example 15 days of one month may be selected once per season
- the task will mainly verify the accuracy of the geometric correction
- according to the results, OLCI’s geometric model may be reviewed and updated

6.1.3.5.2 **Validation with external RS data (OLCI-L1b-CV-520)**

**Task Description**

This task will accomplish detailed geometric correlation and matching by comparison with external RS data from other missions to validate the accuracy of geometric calibration and to correct for errors, if needed. This task is classified as E1-MED and E2-HIGH.

**Task Aim and Objectives**

The objective is to validate OLCI geometric performance and to calibrate the geometric model if a problem is found.

**Parameters for Analysis**

The main parameters that will be investigated in this task are

- instrument reference: viewing geometry, camera parameters, spectral band co-registration
- satellite orientation: attitude, ephemeris, orbit accuracy
- OLCI imaging of ground control points (GCP) in common with the reference mission at Level-1B FR
- GCP imaging from another high spatial resolution mission at Level-1B where the images are well characterised, geometrically calibrated and orthogeolocated, for example Landsat 7 was used for MERIS, Sentinel-2 can be used for OLCI
Methodology

This task will analyse absolute and relative geometric accuracy as well as the accuracy of the inter-band co-registration. The method is based on matching and correlation of OLCI and external reference scenes and will require the following actions:

- set of GCPs in common with the reference mission will be used to evaluate the relative accuracy (GCP database will be built in phase C/D)
- GCPs shall come from well characterised and geometrically calibrated and orthogeolocated images from other missions. Ideally, these should be higher resolution missions, for example Landsat 7 was used for MERIS and Sentinel-2 can be used for OLCI.
- geometric calibration test sites for GCP database can be located where a correlation pattern is easy to find. High contrast facilitates the processing, such as in small bright islands and coast hooks, but high mountains can be problematic.
- for individual correlation analyses, GCPs and the matching reference sites shall be well represented in images, covering all 5 cameras
- correction on the pointing information will be done by fitting residual errors to a across/along track polynomial model
- results shall be given by camera

Ideally the geometric calibration and verification should be done for images spread along the orbit, such that the deformation effect due to temperature variation along the orbit or platform attitude and orbital accuracy changes can be identified

Input/Output data needs

- OLCI Level-1b products
- GCP site database
- All Parameters for Analysis shall be required.

Required tools

The following tools shall be used:

- extract OLCI scenes over reference GCP sites in an automatic manner by matching GCPs with OLCI product pixels
- use cloud detection flags in extracting OLCI products
- employ dedicated display tool to show the GCPs in individual images
- remap OLCI extracts and reference GCP images to the same projection and same ground pixel size, apply a projection and rescaling tool
- match OLCI’s and reference GCP sites
- extract deformation vectors and fit residual errors to a cross- and along-track polynomial model
- investigate for all bands to establish inter-band co-registration
- display image deformation vectors
- provide all the information to update and optimise the geometric model, if needed
Anticipated Results

The results shall allow:

• validation of detailed absolute, relative and inter-band geometric accuracy
• determination of error sources through disparity analysis
• revision of the geometric model and update of the pointing vector
• potential update of Auxiliary Data File (ADF) and information on the satellite orbit and attitude

Additionally:

• it is not envisaged to perform a geometric correlation over reference GCP sites for each image
• pointing information is expected to be updated infrequently (once or twice per mission)

Task schedule

The PDGS-related timeliness on the task is as follows:

• reference GCP site database will be built pre-launch
• timeliness on the task shall be establishes pre-launch, the task will not be frequent, for example executed once a year
• extraction of GCP scenes, including cloud screening, shall be done in NRT off-line
• the following matching, remapping, correlation, visualization, and correction analyses shall be accomplished off-line

In the Commissioning phase E1:

• the task shall be performed just after launch
• complete geometric accuracy shall be defined by the end of the Commissioning phase

In the Routine Operations phase E2:

• the task will be a regular activity at a frequency TBD, for example once a year
• the task will mainly verify the accuracy of the geometric correction
• according to the results, OLCI’s geometric model may be reviewed and updated

6.1.3.5.3 Geometric Verification (OLCI-L1b-CV-530)

Task Description

The tasks will verify OLCI geometric accuracy by regular evaluations of the geometric calibration through visual inspection. This is classified as E1-MED and E2-HIGH

Task Aim and Objectives

The objective is to routinely verify OLCI geometric performance.

Parameters for Analysis

The main parameters that will be investigated in this task are
• a small list of diagnostic sites
• OLCI extractions for the sites composed of Level-1B and/or Level 2 FR scenes, including individual band images and RGB quicklooks, with the coastline overlaid, converted to image format, and posted on-line for visual inspection

Methodology
This task will analyse absolute and relative geometric accuracy as well as the accuracy of the inter-band co-registration.

The method is based on coastline overlay onto Level-1B and/or Level 2 scenes for visual inspection and will require the following actions:
• pre-launch selection of a small and targeted list of diagnostic sites (Level-1B FR extractions for site lat/lon coordinates, across and along OLCI track
• possible correction of the Level-1B extracts for Rayleigh scattering (TBC)
• overlaying of the individual band extracts with coastline
• creating extract RGB quicklooks with coastline overlaid
• converting the extracts to image format
• posting for visual inspection on OLCI Cal/Val web site
• routine and automated operation during off-line QC
• visual inspection weekly in the Commissioning phase and then continually during the Routine Operations but less frequently, e.g. monthly

Input/Output data needs
• All Parameters for Analysis shall be required
• Level-1B FR sites shall be automatically extracted at NRT for given, always constant, sets of latitude and longitude coordinates with the following post-processing also automated

Required tools
Tools working in an automated manner during off-line QC shall be needed:
• perform lat/lon-based site extractions at Level-1B across and along OLCI track at FR and RR
• overplot coastline on individual band images
• create RGB quicklooks and overplot coastline
• convert to image format
• post per-band images and RGB quicklooks on the OLCI Cal/Val web site
• automate the complete process for off-line QC

Anticipated Results
The task shall allow the routine verification of OLCI geometric accuracy, absolute, relative and inter-band, by inspecting the agreement between the computed location of coastlines and the land outline in OLCI images
Task schedule

The PDGS-related timeliness on the tasks is

- extraction of diagnostic site data and production of Level-1B RGB band images and quicklooks with coastline overlaid is done daily in NRT during off-line QC
- visual verification of the accuracy of the geometric correction is off-line

In the Commissioning phase E1:

- visual checks on diagnostic sites will be conducted weekly

In the Routine Operations phase E2:

- this will be a regular activity and a part of the routine quality control
- visual checks on diagnostic sites will be conducted monthly

6.1.3.5.4 Geometric Verification RR versus FR (OLCI-L1b-CV-540)

Task Description

This task will evaluate reduced- versus full resolution geometric accuracy. This is classified as E1-HIGH and E2-MED.

Parameters for Analysis

The main parameters that will be investigated in this task are

- a small list of diagnostic sites, the same as for FR verifications in OLCI-L1B-CV-530
- OLCI extractions for the sites composed of Level-1B FR and matching RR scenes, including individual band images and RGB quicklooks, with the coastline overlaid, converted to image format, and posted on-line for visual inspection

Methodology

- extraction and on-line posting of RR per-band images and RGB quicklooks alongside FR following the same methodology as with FR
- extractions requested once in the Commissioning phase and on occasion in the Routine Operations in parallel with the corresponding FR site extractions

Input/Output data needs and Required tools

the same parameters and tools as used in FR verifications

Task schedule

In the Commissioning phase E1:

- evaluation of RR versus FR geometric accuracy will be accomplished once during the Commissioning phase

In the Routine Operations phase E2:

- RR versus FR analysis will be conducted if there are relevant processing chain changes
6.1.3.6 Image Quality Check (OLCI-L1B-CV-600)

Task Description
The task will consist of the verification of some parameters related to image quality. They are linked to radiometric + spectral + geometric features. Therefore the task can be split in the following sub-tasks:

- **Modular Transfer Function assessment (OLCI-L1B-CV-610)** The MTF values using natural targets (bridges, beaches, and pier) and bi-resolution method if feasible (using Sentinel-2 if the time and geometry is coincident). This is classified as E1-MED and E2-MED

- **Signal to Noise ratio estimate (OLCI-L1B-CV-620)**. The methodology for SNR estimate is still to be defined (uniform target and statistical method). This is classified as E1-MED and E2-MED

- **Straylight assessment (OLCI-L1B-CV-630)**. This is basically a prelaunch activity classified as critical. In-flight methodology still has to be developed. This is classified as E1-LOW and E2-MED

- **Non Linearity assessment (OLCI-L1B-CV-640)**. This is principally a prelaunch activity classified as critical. In-flight methodology has to still be developed. This is classified as E1-LOW and E2-HIGH

- **The radiometric differences at camera interfaces following the methodology developed by Bouvet et al. (RD 35)**. Inter-camera analysis (OLCI-L1B-CV-650). This is classified as E1-LOW and E2-HIGH

- **Frame to frame noise assessment (OLCI-L1B-CV-660)**. Asses the “horizontal stripping” by visual inspection of L1/L2 products. This is classified as E1-MED and E2-MED

- **Detector radiometric equalization (OLCI-L1B-CV-670)**. This is classified as E1-HIGH and E2-HIGH

- **Verification of cross-track artefacts using marine L2/L3 products (OLCI-L1B-CV-680)**. This is classified as E1-HIGH and E2-HIGH

6.1.3.6.1 Modulation Transfer Function Assessment (OLCI-L1B-CV-610)

**Task Description**
Assessment of the Modulation Transfer Function of the instrument by the analysis of Earth targets. This is classified as E1-LOW and E2-MED. This activity is not included in the satellite project Cal/Val implementation plan.

**Task Aim and Objectives**
To verify in flight that the OLCI complies with its spatial resolution requirement (S3-MR-760) and assess the image contrast for selected features.

During pre-launch characterisation, the MTF is characterised for 5 points within the FoV of each camera and for 5 wavelengths spanning the whole spectral range. The MTF is measured for more than 30 spatial frequencies between 0 and Nyquist frequency and the measurement accuracy is better than 0.03. Verification in-flight requires statistical methodologies (on sufficient amount of level 1 and level 2 observations) and a parallel assessment of straylight.
Parameters for analysis
- OLCI TOA radiance

Methodology
The MTF assessment methods are:
- Analysis of natural target images where the spatial extent of the contrasting element (e.g. bridges, beaches, and pier) is assumed to be known;
- bi-resolution method if feasible (using Sentinel-2 if the time and geometry is coincident).

Further details TBD.

Input/output data needs:
- extracted L1B OLCI images at pre-defined Earth locations;
- co-located high resolution Sentinel-2 L1B images

Required tools:
Generic tool for image processing and image display should be used. It should be complemented by specific and ad-hoc tool for MTF calculation, statistic calculation;

Anticipated results:
Report on MTF performance;

Task schedule:
Pre-requisites: initial radiometric calibration achieved, after initial assessment in Phase E1, it is anticipated that the spatial resolution of OLCI is a very stable parameter and needs to be checked a few times along the mission.

6.1.3.6.2  Signal to Noise Ratio assessment (OLCI-L1B-CV-620)

Task Description
Assessment of the SNR of the instrument by analysis of Earth targets. This classified as E1-MED and E2-MED

Task Aim and Objectives
Verify in flight that the OLCI complies with its SNR requirements (S3-MR-1030);

Parameters for analysis
- OLCI TOA radiance

Methodology
The methodology is still to be defined, potentially, uniform targets and statistical methods;
Input/output data needs

Extracted OLCI L1B images according to criteria TBD. SNR verification is based on uniform targets, primarily Lambertian surfaces. SNR site requirements are therefore strongly close to those of radiometric calibration sites;

Required tools

Generic tool for image processing and image display should be used. It should be complemented by specific and ad-hoc tool for statistic calculation;

Task schedule

Pre-requisites: Radiometric calibration,
SNR should be monitored continuously as the ageing of electronic components can degrade it along the mission. Frequency TBD.

6.1.3.6.3 Straylight assessment (OLCI-L1B-CV-630)

Task Description

Assessment of stray light in the instrument by analysis of Earth targets. This task is defined as E1-MED and E2-HIGH.

Task Aim and Objectives

From MERIS experience, stray light has a strong impact on radiometric accuracy, by redistributing energy in the across-track and in the spectral dimension. For OLCI, critical on-ground characterisation and modelling efforts are undertaken: OLCI stray light correction is making use of 2D kernels in spectral and spatial dimensions. Those kernels have been obtained by correlating an ASAP ray-tracing model to the camera test results. The performance of L1b stray light correction is verified within the Optical System Performance Simulator demonstrating good results. Verification in-flight requires statistical methodologies (on sufficient amount of level 1 and level 2 data) and a parallel assessment of the MTF.

In any case, it is important to assess in-flight the stray light itself, and the effectiveness of the stray light correction.

Parameters for analysis

- OLCI Level 1b data

Methodology

Attempt to characterise straylight can be done using natural targets (cloud with sharp shape over dark surface). Straylight in the instrument will need to be separated from straylight in the atmosphere due to photon scattering off bright targets, clouds or land. This task will not be described in the first version of the Cal/Val plan as the method is not yet completely mature.

The current straylight implementation scheme is a trade-off between run-time and performance. The related parameters need to be evaluated during the commissioning phase and Phase E when Level 2 data is fully available.
Input/output data needs
OLCI L1B images according to criteria TBD, processed on-line with stray light correction, and off-line without stray light correction.

Required tools
TBD

Anticipated results
report on OLCI straylight and straylight correction assessment;

Task schedule:
Pre-requisites: radiometric calibration; spectral calibration.
Repetition TBD.

6.1.3.6.4 Non-linearity assessment (OLCI-L1B-CV-640)

Task Description: Assessment of the non-linearity in the instrument by analysis of Earth targets. This is classified as E1-LOW and E2-MED. This activity is not included in the satellite project Cal/Val implementation plan.

Task Aim and Objectives: To evaluate OLCI non-linearity correction.

Parameters for analysis: OLCI Level 1b data

Methodology: TBD;

Input/output data needs: Earth targets at high and low radiance magnitude spanning the instrument dynamic range.

Required tools: TBD

Anticipated results: TBD;

Task schedule:
Priority TBD,
pre-requisites TBD,
repetition TBD.

6.1.3.6.5 Inter-camera analysis (OLCI-L1B-CV-650)

Task Description: Analysis of the radiometric differences at the camera-to-camera interfaces. This is classified as E1-LOW and E2-MED. This activity is not included in the satellite project Cal/Val implementation plan.

Task Aim and Objectives: the fields of view of the 5 OLCI camera modules overlap on a few pixels. Analysis of the radiometric differences between those overlap pixels may contribute to the in-depth understanding of the OLCI radiometric behaviour.
Parameters for analysis: OLCI Level 1b data

Methodology: The radiometric differences at camera interfaces following the methodology developed by Bouvet et al. on observations over Antarctica (RD 35);

Input/output data needs: Radiometric and spectral differences at camera interfaces use uniform targets. Ideally DOME-C images.

Required tools: TBD;

Anticipated results: TBD

Task schedule
Pre-requisites: radiometric calibration
Repetition and frequency TBD.

6.1.3.6.6 Frame-to-frame noise assessment (OLCI-L1B-CV-660)

Task Description: provides frame to frame systematic noise (horizontal stripping) by visual inspection of L1/L2 products. This is classified as E1-MEDIUM and E2-MEDIUM

Task Aim and Objectives: verify the absence of horizontal striping in OLCI products

Parameters for analysis: OLCI TOA radiance; OLCI L2 Water-leaving radiance

Methodology: Visual inspection

Input/output data needs: OLCI L1B and L2 products extracted according to criteria TBD;

Required tools: image extraction and display tools TBD;

Anticipated results: striping assessment;

Task schedule:
pre-requisites: radiometric calibration
Repetition TBD.

6.1.3.6.7 Detector radiometric equalization (OLCI-L1b-CV-670)

Task Description
Equalization for pixel-to-pixel radiometric non-uniformity. This task is classified as E1-HIGH and E2-HIGH.

Task Aim and Objectives
The objective is to remove pixel-to-pixel (per detector) systematic radiometric noise in individual OLCI cameras. The Dome Concordia test site in Antarctica is used for the radiometric analysis.

Parameters for analysis
- OLCI Level-1B extracts containing full swath covered over Dome Concordia within at least ± 250km radius.
Methodology
This task will extract statistically significant pixel-to-pixel radiometric variability in Level-1B radiances per band and camera.

The statistics are collected over all suitable coverage swaths of the Dome-Concordia site and time-dependent.

Detailed description of the methodology is presented in RD34.

Input/Output data needs
- Level-1B FR extracts over Dome Concordia

Required tools
- off-line Level-1B extractions
- Level-1B reading and statistical analysis tools

Anticipated Results
Pixel-by-pixel equalization LUT for inclusion in the calibration ADF.

Task schedule
The PDGS-related timeliness
- Level-1B extractions are performed at NRT off-line
- data analyses are accomplished off-line

In the Commissioning phase
- pixel-by-pixel equalization will be initiated and the first LUT will be generated

In the Routine Operations phase
- the task will routinely update the equalization LUT (which is time dependent) in by-monthly intervals

6.1.3.6.8 Verification of cross-track artefacts using marine products (OLCI-L1b-CV-680)

Task Description
This task will use a system approach to verify the magnitude of OLCI cross-track trends associated with spectral, radiometric and other characterization that cause camera-to-camera discontinuities and trends within camera fields of view. This task is classified as E1-HIGH and E2-HIGH.

Task Aim and Objectives
Evaluate the magnitude of OLCI camera-to-camera discontinuities and trends within camera fields of view.

Parameters for analysis
Water-leaving reflectances from global deep-water Level-2 coverage and monthly Level-3 products.
Methodology

The task uses water-leaving radiances that are directly related to Level-1B TOA radiances and carry through TOA radiance artefacts, including discontinuities at camera interfaces and trends across camera FOV. The removal of the atmosphere makes water-leaving radiances an order of magnitude more sensitive to these artefacts.

The artefacts will be evaluated and monitored using Level-2 to Level-3 comparisons of water-leaving reflectances over deep waters (RD 36). The sequence of actions includes the following:

- screening of global deep-water Level-2 pixels (must be after complete BRDF correction)
- screening of Level-3 bins (deep ocean only and at least 3 different scenes in each bin)
- matching of Level 2 pixels with overlapping Level-3 bins
- ordering of the pixel and bin pairs according to their pixel numbers across track
- computing mean water-leaving reflectance statistics and ratios for each cross-track pixel number
- evaluating and plotting the cross-track trends, primarily the ratios, across camera fields of view and camera-to-camera

Typically, Level-2 to Level-3 comparisons are performed once per season throughout the mission.

Input/Output data needs

Level-2 to Level-3 comparisons require

- Level-2 global deep-water daily marine products from a number of consecutive days
- corresponding Level-3 global deep-water coverage, a monthly centred on the Level-2 dates

Required tools

- Level-3 binning tools

The task will use Level-3 marine derived products, primarily water-leaving reflectances. Level-3 data will be processed using standard binning procedures from Level-2 products and typically at 9km resolution and at monthly coverage. Level-3 bin statistics must include a number of pixels and a number of scenes contributing to each bin and a sum of squares of individual product values.

- Level-2 pixel and Level-3 bin screening and matching tools
- Statistics computation, result plotting and Cal/Val web posting

Anticipated Results

Input on residual instrument artefacts. Input to instrument characterization studies concerning smile effect, straylight, BRDF, pointing accuracy.

Task schedule

The PDGS-related timeliness

- The task shall be executed off-line

In the Commissioning phase

- Verify the magnitude of OLCI cross-track trends at the end of the phase
In the Routine Operations phase

- Routine checks once per season throughout the mission

### 6.1.4 Task Definitions for OLCI Level 2 Products

OLCI Level-2 activities are separated between marine and land domains. The sources of uncertainties contributing to Level-2 product uncertainty are numerous. The main source of uncertainty is Level-1B, addressed in the previous section. The LUT generation, ancillary data, and Level-2 algorithms themselves, including the atmospheric correction, are important contributors. Validation of LUTs will be done prelaunch and LUT QC is a routine activity during operational phase E2. Routine QC activities are not specifically discussed hereafter.

For ocean colour, the applicable requirements of 5% uncertainty on water-leaving radiances cannot be achieved by the instrument itself. The final performance is achieved by the system, which is composed of the instrument itself as well as science algorithms and calibration and validation processes. Therefore, this chapter first focuses on calibrating the system through ocean colour vicarious adjustment. Only then validation of ocean products is presented. Validation of two essential sets of products is described: water-leaving reflectances and water constituent concentrations.

OLCI land product activities concentrate fully on validation and concern the following products: OLCI terrestrial chlorophyll index and the OLCI Global Vegetation Index together with the corresponding rectified surface reflectances.

At this stage, validation of the aerosol products is considered only necessary as a means to validate the atmospheric correction process (NB: there are no official atmospheric products from OLCI. Aerosol product is considered as By-Product).

<table>
<thead>
<tr>
<th>MRD key requirement (further associated req.)</th>
<th>S3 Prod. ID</th>
<th>Major Error Source</th>
<th>Cal/Val Tasks</th>
<th>Respons. Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3-OB-1 Primary.</td>
<td>OLCI-L2WL R, OLCI-L2OC</td>
<td>Uncertainties at L1B, Uncertainties in the LUT table generation, Uncertainties due to vicarious calibration, Uncertainties due to the preprocessing (cloud masking/classification), Uncertainties due to L2 algorithms, Uncertainties due to ancillary data, Uncertainties due to the processor implementation</td>
<td>Preparation for L2 Cal/Val (OLCI-L2WLR-CV-100), Ocean Colour Vicarious Calibration (OLCI-L2WLR-CV-200), Ocean Colour Validation with in-situ measurements (OLCI-L2WLR-CV-300), Ocean Colour Validation with Level 3 products (OLCI-L2WLR-CV-400), Ocean Colour Processing Quality Validation (OLCI-L2WLR-CV-500)</td>
<td></td>
</tr>
<tr>
<td>S3-OB-2: Primary</td>
<td>OLCI-L2LA</td>
<td>Uncertainties at L1B, Uncertainties in the LUT table generation, Uncertainties due to the preprocessing (cloud masking/classification)</td>
<td>Land Products Validation (OLCI-L2LA-CV100)</td>
<td></td>
</tr>
</tbody>
</table>

Sentinel-3 shall provide continuity of an Envisat-type ocean measurement capability for GMES services with a consistent quality, a very high level of availability (>95%), high accuracy and reliability and in a sustained operational manner for GMES users, including: Ocean, inland sea and coastal zone colour meas, to at least the level of quality of MERIS

(S3-MR-460: performance) (S3-MR-480: Performance) (S3-MR-1170: validation) (S3-MR-1190: Service Data Products)

(S3-MR-1170: validation) (S3-MR-1190: Service Data Products)
Table 15 – OLCI L2 Cal/Val Tasks definition

6.1.4.1 Preparation for Level-2 Cal/Val (OLCI-L2-CV-100)

Task Description
This task is applicable for all further Level-2 Cal/Val tasks.

Task aim and objectives

- Verification of atmospheric LUTs and Level-2 processing parameterization
- Preparation for systematic testing and development of science algorithms, processors, and products
- Establishment of on-line and off-line data extraction tools, including off-line extraction of any lat/lon coverage of mission historical data
- Assuring off-line Cal/Val activities are executed on a mirror of the operational environment
- Preparation to run routinely and quickly Cal/Val tasks that are data and processing demanding, such as reprocessing of subsets of global mission archives
- Assuring off-line Cal/Val activities are executed on a mirror of the operational environment
- Data extraction, screening, matching against in situ measurements as well as ingestion of other RS data sources
- Development of ocean colour vicarious calibration strategy for early in the mission (as 2 to 3 years of matchups may be required to achieve vicarious gain convergence)
- Peer review on ocean colour vicarious calibration protocols, including oceanic and atmospheric properties at the site, site characterization, field instrument calibration, measurement traceability, methodology for deriving vicarious gains and its reproducibility, FR versus RR vicarious gain verification
- Development of a common ocean colour vicarious calibration strategy for all S3 missions
- Implementation and verification of automated OLCI extraction and processing for ocean colour vicarious calibration (this includes verification of exact reproducibility of TOA to water-leaving radiance and water-leaving radiance to TOA processing, and of exact result reproducibility on the operational platform with the operational IPF)
- Ocean colour vicarious calibration rehearsal before launch
- Level-2 and Level-3 product visualisation with mask and flag overlay

6.1.4.2 Ocean Colour System Vicarious Calibration (OLCI-L2WLR-CV-200)

Task Description
System vicarious calibration is critical for ocean colour. The required accuracy on water-leaving reflectance retrievals is 5% in the blue-green spectral range (ADF 4). It was set up to enable discrimination of ten classes of chlorophyll concentration between each of the three orders of magnitude, 0.03, 0.3, 3 and 30 mg/m³, using a band ratio algorithm (Antoine and Morel 1999). However, the ocean signal is fairly dark in the visible spectrum. It comprises about 5 to 15% of the signal measured by a sensor on the top-of-the-atmosphere (TOA) over the open ocean in the blue and green range. The large contribution from the atmosphere means that the instrument needs to
be calibrated to better than 0.5% (RD 27). As instruments themselves cannot reach such accuracies prior to launch and on-orbit, vicarious calibration was proposed by Howard R. Gordon in 1998 (Gordon, 1998) as a strategy for achieving the required accuracy by the system.

**Task Aim and Objectives**

The objective is to vicariously calibrate the system to meet uncertainty requirements on derived Level-2 products, particularly water-leaving reflectances – 5% uncertainty in the blue-green spectral range, and chlorophyll-a concentrations – 30% uncertainty.

The requirement for 5% uncertainty on water-leaving reflectances translates to less than 0.5% uncertainties at OLCI TOA radiances after the vicarious calibration (RD 27).

The stability of the gain extraction is aimed to be at mean 0.1% uncertainty at standard errors about the mean.

The task is crucial. For example, for MERIS, in the Level 2 ocean branch, the vicarious adjustment process adjusts the TOA radiances by 1 to 2% in the blue and green bands. This enables MERIS relative per cent errors on water-leaving reflectances to be constrained within 5% in these wavelengths in case-1 waters (except for band 443, where RPD is -6.5%).

**Parameters for analysis**

Level-1B extracts shall be analysed over the vicarious calibration sites. Extracts shall be automatically generated at NTC, typically of the size of 100x100 km centred on the lat/lon of the vicarious calibration site. Systematic extractions shall be stored in the validation database.

Visible band calibration also uses in situ measurements from the vicarious calibration source, such as buoy. In situ data shall be automatically acquired, ideally, in an expedited manner, particularly in the OLCI Commissioning phase.

**Overall methodology**

Vicarious calibration is a calibration of the system. It is accomplished to meet the overall performance requirements put on the system. For this reason the complete system needs to be vicariously calibrated in the exact state as it is implemented in the operational processing. This includes the same atmospheric correction used for forward operational processing and inverse vicarious calibration, the same ancillary data and processing parameters. Forward and inverse atmospheric correction should aim to be reproducible with, ideally, machine accuracy. In practical terms, the vicarious calibration should ideally be a parallel module in the operational processing, it should share most code and parameterization with the forward processor, and should be executed in the operational environment or on an exact mirror of it.

The vicarious calibration methodology has been adopted for MERIS (RD 40) and has been described in literature, including detailed protocols (RD 46).

**Required tools**

- Automated data extractions over vicarious calibration sites at Level-0, -1B, and -2 and storage in a dedicated database
- Acquisition of vicarious calibration in-situ measurements for visible band calibration from external providers, measurement screening and a corresponding database including a full
record of metadata, measurement protocols followed, measurement uncertainties, data quality, and links to corresponding OLCI extracts at Level-0, Level-1B, and Level-2

- Tools for Level-1B visual inspection and screening
- Tools for gain derivation following existing protocols (taking into account potential buoy drifts)

**Anticipated results**

- derivation of OLCI vicarious calibration gains for ocean colour processing
- goal for the gain uncertainty is 0.1% on standard errors about the mean
- calibration of instrument/algorithm system to uncertainty better than 0.5%
- accuracy on water-leaving reflectance retrievals is 5% in the blue-green spectral range

On a monthly basis, the following shall be reported:

- vicarious calibration gain time series and the overall gains per band up to date

**Task Schedule**

The timeliness on the task is the following:

- extraction of OLCI Level-0 and Level-1B subsets over the vicarious calibration sites. The desired delay is a few days from the data acquisition.
- visible calibration also depends on the speed of analysis and delivery of the in situ measurements – expedited delivery is recommended for the Commissioning phase
- derivation of vicarious gains is off-line

In the Commissioning phase:

- vicarious calibration shall be initiated. It is understood that 2 to 3 years of matchups may be required to achieve gain convergence (RD 27) thus only a preliminary vicarious calibration can be expected by the end of the Commissioning phase.

In the Routine Operations phase:

- vicarious calibration shall continue as a routine procedure throughout the mission. The goal is 0.1% uncertainty on standard errors about the mean for the gain extraction (RD 27).

**6.1.4.2.1 Vicarious calibration of the NIR bands (OLCI-L2-CV-210)**

OLCI NIR bands are vicariously calibrated for ocean colour applications. This is classified as: E1-CRIT and E2-CRIT.

**Parameters for analysis**

- Level 0 and Level-1B extracts over specific NIR vicarious calibration sites

Extract size is 100x100 km centred on the lat/lon of the vicarious calibration site.

Extracts shall be automatically generated over OLCI’s lifespan. Systematic extractions shall be stored in the vicarious calibration database.
Methodology

Level-0/1B extractions: Vicarious calibration of the NIR bands is performed over locations characterized by clear oligotrophic waters, which are most homogenous ocean waters on Earth, and by stable aerosol conditions that are representative of non-coastal maritime atmospheres. Typically, two oligotrophic sites are selected, South Pacific Gyre and South Indian Ocean, although the final definition of the site strategy shall be decided before launch.

Extract visual inspection and screening: 100x100 km extracts are visually inspected and limited to 15 x 15 pixels centred on the calibration target, which are further screened for clouds, sun glint, straylight, and viewing and solar geometry. If all 15 x 15 pixels pass, the further processing follows.

Prediction of TOA instrument response: TOA instrument response for the extract pixels is predicted using adapted operational processing chain including TOA contributions from the pre-processing, e.g. smile, and the values for atmospheric gases and Rayleigh. Only aerosol contribution is modelled, where a number of techniques has been proposed in the past. MERIS method assumed two most stable NIR bands and used aerosol spectral shape for the other NIR bands. NASA method assumed a maritime aerosol model at a given constant Angstrom and an aerosol depth from just a single NIR band. Potential other methods can be proposed and the decision needs to be made before the instrument launch.

Derivation of vicarious gains: The instantaneous NIR gains are computed per band by comparing the predicted TOA instrument response with the actual values for the 15 x 15 pixels. The final single vicarious NIR gain per band is obtained by spatial and temporal, throughout the mission, averages computed using the mean of the semi-interquartile range (MSIQR), which is defined as the simple average of the data within the 25th to 75th percentiles) to minimize the effects of spurious outliers.

6.1.4.2.2 Vicarious adjustment of the visible bands (OLCI-L2-CV-220)

OLCI visible bands are vicariously calibrated for ocean colour applications. This is classified as: E1-CRIT and E2-CRIT.

Parameters for analysis

- Level-0/1B extracts over specific visible vicarious calibration sites

Extract size is 100x100 km centred on the lat/lon of the vicarious calibration site.

Extracts shall be automatically generated over OLCI’s lifespan. Systematic extractions shall be stored in the vicarious calibration database.

Methodology

Level-0/1B extractions: Vicarious calibration of the visible bands is performed over locations characterized by clear homogeneous waters and stable maritime aerosol conditions which are equipped with high precision and accuracy in-water radiometric instrumentation. MOBY is a hyperspectral SI-calibrated buoy which has been used as a sole vicarious calibration target for generations of ocean colour missions (RD 38). MERIS full-mission reprocessing in 2011 used MOBY and BOUSSOLE for vicarious calibration. There is a need for the vicarious calibration source to match the spectral range of OLCI. The final definition of the VIS vicarious calibration strategy shall be decided before launch. The recommendation for early in the mission is to apply in-situ radiometric profiling floats which will become operational by the Sentinel-3 launch (RD 57)
The data from the floats is proposed to be used in combination with the modified Rayleigh scattering method after the NIR vicarious calibration is performed.

**Extract visual inspection and screening:** 100x100 km extracts are visually inspected and limited to 5 x 5 pixels centred on the calibration target, which are further screened for clouds, sun glint, straylight, chlorophyll concentration and aerosol optical thickness limits and spatial homogeneity, as well as viewing and solar geometry. If all 5 x 5 pixels pass, the further processing follows.

**Screening of in situ data:** Measurements from the field instrument are screened for instrument malfunction, significant buoy tilt, for exceeding variability’s in radiance extrapolation from the buoy arms, and for differences in measured surface irradiances from a clear-sky irradiance model. In situ measurement must be within a short time span from the satellite overpass.

**Prediction of TOA instrument response:** TOA instrument response for the extract pixels is predicted using largely the operational processing chain with the TOA contributions from the pre-processing, including smile, and from the atmosphere, including gases, Rayleigh and aerosols, where the aerosols are extracted assuming the NIR vicarious calibration given in the previous step. The water-leaving radiance part is added from the field instrument measurements.

**Derivation of vicarious gains:** The instantaneous visible gains are computed per band by comparing the predicted TOA instrument response with the actual values for the 5 x 5 pixels. The final gain for the scene is computed as the MSIQR over the distribution of the 25 pixel gains. The MSIQR provides a final level of statistical outlier rejection to minimize effects such as sub-pixel scale clouds or undetected straylight in the individual gains. The final single vicarious visible gain per band is obtained by aggregating gains obtained throughout the mission via the MSIQR.

### 6.1.4.3 Ocean Colour Validation with in situ measurements (OLCI-L2WLR-CV-300)

**Task Description**

This task encompasses activities associated with acquisition, quality assurance and archiving of in situ measurements and OLCI product validation. It must be pointed that in situ data are used for product validation as well as for algorithm validation and development. The long-term validation plan shall conceive support for

- existing and new stationary platforms and long-term measurement networks (including a new one in oligotrophic waters)
- evolution and maintenance of in situ measurement archives
- consolidation and update of measurement protocols
- uniform ocean colour validation protocols
- standardization of in situ measurement uncertainty budgets and traceability of measurement processing
- measurements across European marine biogeochemical provinces in support of robust validation and bio-optical algorithm development
- in situ data policy aligned across Agencies
- field instrument calibration and inter-calibration round robins
• recurrent field campaigns, and campaign coordination with global partners
• development of in situ instrumentation and new instrument concepts
• prioritization of field variables collected by providers and increasing standardization of core field variable lists

**Task Aim and Objectives**
• uncertainty estimates on core marine products based on matchups with in situ measurements
• algorithm performance evaluation over spatial domains and time series
• assessment of impact of processor or algorithm changes
• verification of vicarious calibration

**Parameters for analysis**
• water-leaving reflectances
• chlorophyll concentration, case-1 and case-2 algorithm
• diffuse attenuation coefficient
• other water constituents: total suspended matter and CDOM
• photosynthetically active radiation
• integrated water vapour column
• measurement geometry, i.e. solar and viewing angles

6.1.4.3.1 **Acquisition of in situ measurements (OLCI-L2WLR-CV-310)**

**Methodology**
This is classified as: E1-HIGH and E2-CRIT. In situ validation measurements for the task come from
• stationary platforms, such as BOUSSOLE and AERONET-OC
• field campaigns
• in-situ radiometric profiling floats

Acquisition of in situ data from those sources shall be secured. Expedited data availability may be requested in the Commissioning phase or during particular validation events.

Data shall be acquired as automatically as possible, especially from stationary platforms. The data shall be formatted, pre-processed, preliminarily screened, and made ready for the archive.

6.1.4.3.2 **Traceability of in situ measurement quality (OLCI-L2WLR-CV-320)**

**Methodology**
This is classified as: E1-HIGH and E2-HIGH. The task needs to ensure that in situ measurements are accompanied by a detailed breakdown of:
• uncertainty budgets on instrument calibration
The information must be detailed because deviations from standards and protocols can cause significant problems in the interpretation of differences between in-situ and OLCI data. The systems shall be consistent with the QA4EO guidelines (http://qa4eo.org/).

6.1.4.3.3 In situ measurement archiving (OLCI-L2WLR-CV-330)

Methodology
This is classified as: E1-HIGH and E2-CRIT. This task maintains and further develops a comprehensive archive of in situ measurements. The database shall archive the measurements accompanied by their metadata, uncertainty budgets and protocols quality (OLCI-L2WLR-CV-320), as well as measurement quality ranking.

6.1.4.3.4 Extractions of OLCI data over validation targets (OLCI-L2WLR-CV-340)

Methodology
This is classified as: E1-CRIT and E2-CRIT. This task shall be implemented in two modes:

- on-line extraction at NTC over permanent validation sites for newly acquired and processed OLCI Level-2 data, extracts at Level-0, Level-1B and Level-2 in OLCI data format
- off-line extractions across OLCI mission-long archives over any validations sites at Level-2 or Level-1B or Level-0

Systematic lat/lon extractions are required for all optical products (OC, SST, LST, land Validation). The requirements are the same: the tools shall be able to extract systematically a portion of the data – across and along swath extraction – with the basic information (lat/lon/flag...etc...). In a standard configuration, the extraction tool should be able to format the extracted data into the standard OLCI product format that could be further processed by IPF or analysed and displayed as a standard OLCI file. Additionally, the extraction tool should be able to perform filtering based on cloud or quality flags according to the application. It shall also be able to perform some basic operations (averaging, macro pixel, etc.) depending on the application. Extractions shall follow agreed protocols, including data screening where cloudy extracts are excluded.

6.1.4.3.5 OLCI data from validation sites archiving (OLCI-L2WLR-CV-350)

Methodology
This is classified as: E1-HIGH and E2-HIGH. This task shall perform:

- archiving of Level-0, Level-1B and Level-2 OLCI extracts from newly acquired and processed OLCI data over a standard set of permanent validation sites
• retrospective archiving of Level-0, Level-1B and Level-2 OLCI extracts for other sites and field campaigns in the in situ measurement archive
• reprocessing of extract archives when new processors become operational

6.1.4.3.6 **Generation of matchups and validation results (OLCI-L2WLR-CV-360)**

**Methodology**

This is classified as: E1-HIGH and E2-CRIT. This task generates matchups, scatter plots, histograms, statistics based on pairs of in situ measurements in the archives and corresponding OLCI extracts. Matchups are generated for:

- operational Level-2 OLCI data, routine update at bi-monthly intervals
- reprocessed OLCI extracts from Level-1B, when scheduled
- reprocessed OLCI extracts from Level-0, when scheduled

The matchup strategy shall apply ocean colour validation protocols (RD 16). The results can be given as in situ versus OLCI data as well as in situ versus OLCI (e.g. ratios) against other parameters, such as reflectance levels or viewing and solar geometries.

6.1.4.3.7 **Generation of side-by-side in situ and OLCI trends (OLCI-L2WLR-CV-370)**

**Methodology**

This is classified as: E1-HIGH and E2-CRIT. For stationary sites this task generates time series of OLCI product temporal evolution, i.e. trends compared with corresponding time series of in situ measurements. Additional histograms and statistics are provided. The time series are generated for:

- operational Level-2 OLCI data, routine update at bi-monthly intervals
- reprocessed OLCI extracts from Level-1B, when scheduled
- reprocessed OLCI extracts from Level-0, when scheduled

The OLCI screening strategy shall follow agreed ocean colour validation protocols.

6.1.4.3.8 **Verification of instrument calibration and development of products and science algorithms (OLCI-L2WLR-CV-380)**

**Methodology**

This is classified as: E1-MED and E2-HIGH. This task reprocesses OLCI extracts from Level-1B or from Level-0 in an off-line fashion that allows in situ matchups to be used for iterative verification of instrument absolute and temporal calibration, as well as for development, validation and optimization of products and algorithms. OLCI site locations depend on a calibration issue, a product or a science algorithm under investigation. Nevertheless, reprocessing of OLCI archive corresponding to the entire contents of the in situ database may be routinely required. The validations use:
matchups ((OLCI-L2WLR-CV-360)
side-by-side in situ and OLCI trend analysis (OLCI-L2WLR-CV-370)

**Input/Output data needs (all OLCI-L2WLR-CV-310 to -380)**

The input data are

- OLCI Level-2 marine products
- OLCI Level-0 and Level-1B products are needed to reprocess Level-2 marine products for product and algorithm testing, tuning and comparison.
- in-situ data with accompanying measurement metadata, uncertainty budgets, protocols, and quality ranking

Stationary platforms include permanent moorings in case 1 waters equipped with optical buoys, such as MOBY and BOUSSOLE. Stationary platforms in coastal zones offer above water and atmospheric observations and continuous measurement time series, such as AERONET Ocean Colour (AERONET-OC). AERONET-OC has been extensively used for validation of MODIS, SeaWiFS and MERIS data. It is recognised by CEOS as “Reference Test Site” for ocean colour consistent with QA4EO. The network provides several benefits:

- traceable (with defined uncertainties quantified, when appropriate, through reference standards);
- globally distributed (ideally representing the wide range of geophysical conditions that remote sensing products are expected to observe);
- continuous (time-series of quality assured data are fundamental for assessing remote sensing products from successive space missions);
- cross-site consistent (uncertainties should be likely the same for all measurement sites and measurement conditions);
- accessible (availability, through suitable data policy, is a key element for any Cal/Val program).

Campaign measurements provide complementary in situ data across variable marine biogeochemical provinces and in open ocean that are not measured by fixed platforms. There are few points per campaign but of high quality. The campaigns should collect multiple field variables, contributing to validation of water leaving radiances, chlorophyll, suspended particulate matter, CDOM concentrations as well as inherent optical properties (absorption and volume scattering function), atmospheric properties, and SST.

Output data are validation results, plots and statistics.

**Required tools**

- Tools to acquire in situ data from stationary platforms, semi- or fully automatic ([OLCI-L2WLR-CV-310](#))
- Tools to perform the initial in situ data formatting, pre-processing and screening ([OLCI-L2WLR-CV-310](#))
- Tools to support acquisition of in situ data from other sources, e.g. reformatting ([OLCI-L2WLR-CV-310](#))
- Tools to support archiving of in situ data and accompanying metadata, uncertainties, protocols ([OLCI-L2WLR-CV-320](#))
• In situ archive (OLCI-L2WLR-CV-330)

The archive shall support comparisons between in-situ measurements and satellite data, examples are MERMAID and NOMAD / SeaBASS. MERMAID holds in situ measurements alongside matching MERIS extracts. It provides text files of in situ data, matched with concurrent MERIS Level-2 extracts (including flags, auxiliary information and the intermediate outputs of the processing). The extraction interface allows users to select matchups according to their own requirements for site, parameters, flags and statistical screening, and to produce validation statistics and plots (hermes.acri.fr/mermaid/). On the other hand, NOMAD holds in situ measurements only. On-line tools allow on-the-fly matchups with multi-mission ocean colour and SST data following user specifications.

The database supports validation and also future algorithm development.

The database should be linked to the processing environment. Any changes in the products, algorithms or auxiliary files shall be followed by the reprocessing of the OLCI extracts collected to date and by validation to make a quantitative assessment of the improvements. This is linked to tasks OLCI-L2WLR-CV-360, -370, and 380.

• Extraction tool (see OLCI-L2LRF-CV-340)

• Search and access to mission data

Instantaneous search and access to all OLCI EO data is required to support off-line extractions across mission-long archives over any validations sites at Level-2, Level-1B and Level-0. A tool is thus needed that searches and retrieves locations of OLCI files that cover a given lat/lon range and time span. It is desired that all respective OLCI data reside on-line for instantaneous access and a capability is provided to quickly reprocess these data using test calibration ADFs or revised Level-2 algorithms.

Hardware, software and automated procedures for data reprocessing

The task relies on PDGS hardware and software infrastructure for Cal/Val and automated procedures to repeatedly process OLCI extracts, validate and post results.

Anticipated results

Every two months, the following shall be reported:

validation results up to date

• validation report shall provide error bar on the products

• recommendations on the algorithm performance over spatial domains and time-series

• optimization of calibration, processor or algorithm changes

verification of vicarious calibration

Task schedule

The tools preparation and adaptation to OLCI shall start in phase C/D.

The timeliness on the task is the following:

• extraction of OLCI data over stationary validation sites will be at NTC

• all other validation activities are performed off-line, although some of them should be automated as much as possible
In the Commissioning phase E1:

- the matchup database shall be populated from day 1
- validation with in situ measurements will be initiated but no complete Level-2 validation is expected
- expedited delivery of validation measurements can be recommended
- at least one dedicated campaign should be planned

In the Routine Operations phase E2:

- validation with in situ measurements shall continue as a routine procedure throughout the mission
- the population of the matchup database shall continue regularly
- campaigns should take place every 2 to 3 years

6.1.4.4 Ocean Colour Validation with Level-3 products (OLCI-L2WLR-CV-400)

Task Description

The task provides a standard mechanism for evaluating derived product consistency and stability at global, regional and local scales and at daily, monthly, seasonal and mission-long time spans. The task enables to quantify relative impacts of algorithm and product implementation as well as subsequent revisions and development. The task concerns all OLCI ocean colour products and it is implemented using Level-3 data. The task is complementary to radiometry validation with L3 products (OLCI-L1B-CV-300) and it uses similar methodology and tools. This is classified as E1-LOW and E2-CRIT

Task methodologies shall be implemented in two modes:

- on-line monitoring of newly acquired and processed OLCI data
- off-line validations of OLCI algorithm and product revisions and development

The off-line mode will enable systematic evaluations of OLCI science algorithm and data product revisions when on-line monitoring finds initial problems. It will also facilitate day-2 algorithm and product revisions and development. The algorithms and products will require comprehensive large scale testing across global and long-term temporal domains before they are qualified for operational processing and/or a full mission reprocessing. Many iterations may be required which will loop over:

- science algorithms and data product revisions / development
- reprocessing of validation time series from Level-1B (see: Parameters for analysis)
- validations at Level-3 marine products (see Chapter 6.1.3.5.2)

Task Aim and Objectives

The task goal is to

- continuously monitor the processing chain and implementation, enable instant detection of problems and rigorous quality control
• issue a warning if a problem is detected
• assess OLCI consistency with other missions
• evaluate algorithm performance over spatial and temporal domains, their LUTs and parameterization
• assess impacts of processor or algorithm changes on temporal and spatial stability of derived products
• repeatedly test proposed science algorithm and product revisions, enable rapid prototyping and transfer of development to operations

Parameters for analysis

• The task requires global, regional and local OLCI core products at Level-3

Level-3 data are derived using standard binning procedures from global Level-2 products and typically at 9km resolution and at daily, 4-day and monthly coverage (RD 34). For Level-2 processing, the use of ultimate meteorological and other ancillary files is needed, thus the NTC timeliness is assumed with a preference for 2 to 5-day delay maximum from the time of data acquisition. OLCI reduced resolution observations, RR, can be used to generate the Level-3 data. Various oceanic coversages are extracted from the global Level-3 files based on provided Level-3 bin masks.

In on-line mode

• when all daily global Level-2 files are available at NTC, the files are further processed on-line into 1-day global Level-3 files.
• after respective sets of Level-3 daily files become available, the daily Level-3s are combined on-line into 4-day and monthly Level-3 products. The 4-day Level-3 counting sequence must start with the first day of the year.

In off-line mode

• mission-long Level-3 global time series will be repeatedly processed off-line from Level-1B to Level-3. The evaluations can use a temporal subset of 4-day Level-3 products per every 32-day period of the mission (RD 26). This will result in temporal mission subsampling down to about 1/8th of the mission
• depending on the algorithm or product revisions, shorter time series may be sufficient, for example across two seasons

Methodology

The task will be based on standard mapped image (SMI) figures, temporal trends, and sensor inter-comparisons. Some of the methods are explained in RD 36.

1) SMI figures

SMI figures can be derived from any time-span Level-3 products and from global or regional ocean colour coverage by these products. The Level-3 SMI products are image representations of binned data products on a two-dimensional array in an Equidistant Cylindrical (also known as Platte Carre) projection of the globe (RD 37). Each SMI product represents data binned over the period covered by the parent Level-3 binned product. The arithmetic mean is used in each case to obtain the values for the SMI grid points. SMI products are further converted to standard figures for visual inspection.

2) Temporal trends
Temporal trends can be derived from daily, 4-day, monthly and seasonal Level-3 products as well as from any spatial subset of global ocean colour coverage by these products. The methodology is as follows:

- for each Level-3 product in the time series, select bins according to desired coverage masks, e.g. deep-ocean, oligotrophic, mesotrophic, eutrophic waters, regional zones
- calculate mean values and standard deviations for the products within the desired coverage
- plot mean values across the time series (in the Commissioning phase and first years of Routine Operations, mean values should be plotted along values from another contemporaneous mission and alongside other mission climatology)
- if over a year of data are available, additionally plot annual cycles to show whether they are consistent between the years
- automatically post results on the OLCI Cal/Val web pages, side-by-side with the previous or similar relevant results

3) Sensor inter-comparisons

Sensor inter-comparisons apply to any time-span Level-3 products as well as to any spatial subset of global ocean colour coverage by these products. Respective product trends are compared between concurrent missions for the exact same temporal and spatial coverages. The methodology is as follows:

- match corresponding Level-3 bins between the missions for each point in the time series
- for each Level-3 product in the time series, select bins according to desired coverage masks, e.g. deep-ocean, oligotrophic, mesotrophic, eutrophic waters, regional zones
- calculate mean values and standard deviations for the corresponding products between the missions within the desired coverage
- plot the mean values across the time series side-by-side for both missions
- provide cumulative statistics, histograms
- plot mean ratios of values across the time series
- automatically post results on the OLCI Cal/Val web pages, side-by-side with the previous or similar relevant results

**Input/Output data needs**

- On-line access to all OLCI data; at least all Level-0 data, all RR higher levels including Level-3, and selected sites FR higher levels

This requirement restates the same need from tasks OLCI-L1B-CV-300 and OLCI-L1B-CV-400, which necessitates easy access to all OLCI EO data in support of the verification and validation activities. For this task, fast turn-around on algorithm and product validation will be vital when on-line monitoring finds initial problems and as day-2 algorithms and products are revised and further developed.

Here, on-line access to Level-1B data is needed because off-line validations will require instantaneous access to global mission-long subsampled time series to repeatedly process it to Level-3 products. On-line access to mission standard Level-3 files is also needed.

It is recommended that a mission-long time series of 4-day global files per every 32-day period in the mission shall be reprocessed from Level-0 to Level-3 within 1 to 2 days, assuming a 10-year old mission (RD 27).
• Global coverage subsets with water types including deep water regions (> 1000m in depth), oligotrophic, mesotrophic and eutrophic regions (see Table 14 and Figure 13). These sites could be augmented by additional Case-2 water sites like the Baltic, North Sea and Chesapeake Bay.

• Data from other OC missions

Both on-line and off-line modes will require access to corresponding Level-3 products from other stable and contemporary missions and to other mission Level-3 climatologies. The list of missions may include MERIS, MODIS, and VIIRS. The selected data shall reside on-line within the Cal/Val facility.

Required tools

• Level-3 binning tools

The task will use Level-3 marine derived products processed using standard binning procedures typically at 9km resolution and at daily, 4-day and monthly coverage (RD33). Level-3 bin statistics must include a number of pixels and a number of scenes contributing to each bin and a sum of squares of individual product values. For Level-2 processing, the use of ultimate meteorological and other ancillary files is needed, thus the NTC timeliness is assumed with a preference for 2 to 5-day delay maximum from the time of data acquisition. Level-3 products from other missions may have to be brought to the required spatial and temporal resolution, if they are different.

• Tools for producing standard mapped image (SMI) figures

• Tools to assess temporal trends and anomalies

• Tools for sensor inter-comparisons

• Tools for result posting on the OLCI Cal/Val web pages

• Tools for automating the full sequence of data processing, inter-comparison/trending, and result posting on the web pages

• Hardware and software for data reprocessing

The task relies on PDGS hardware and software infrastructure and procedures to repeatedly process, verify/validate and post results. It is recommended that the PDGS processing capabilities allow recurring reprocessing of mission-long RR time series of 4-day global files, per every 32-day period in the mission, to Level-3 within 1 to 2 days maximum. The tentative requirements assume preferred recalibration processing starting from Level-0 products. Tentative requirements (RD 53):

• permanent on-line storage from 100 to 150 TB per year of data (on-line: all L0 data – RR and FR, all RR higher levels including Level-3, and selected sites FR higher levels, as well as data from other contemporaneous missions used in the validations)

• Cal/Val system built in the operational environment or on a exact mirror of it

• processing capacity scaled to reprocess 5 to 15% of the global mission data from Level-0 data to be processed to Level-1, -2, and -3 in 1 day
6.1.4.4.1 Monitoring of the processing chain and implementation (OLCI-L2WLR-CV-410)

The task will continuously monitor the processing chain and implementation. The task will enable instant detection of problems, when they occur, and rigorous quality control. This is classified as: E1-HIGH and E2-CRIT.

The task is implemented in the on-line mode on newly acquired and processed OLCI data at NTC. The task is based on SMI figures, temporal trends, and sensor inter-comparisons.

The task will use global ocean for SMI figures, and deep water, oligotrophic, mesotrophic, eutrophic, Hawaii and SPG subsets for temporal trends and sensor inter-comparisons.

In the Commissioning phase E1:

- start with the first calibrated OLCI data. Visual inspection of SMI figures and temporal trend and sensor inter-comparison plots will occur weekly. An automated warning will be issued if a problem is detected. Level-3 time series will be reprocessed using the final calibration of the Commissioning phase.

In the Routine Operations phase E2:

- visual inspection will occur monthly. Automated warning on a trend or discontinuity will be implemented.

6.1.4.4.2 Assess OLCI consistency with other missions (OLCI-L2WLR-CV-420)

The task will inter-compares spatial and temporal consistency of OLCI with other missions and continuity to other mission time series. This is classified as: E1-HIGH and E2-CRIT.

The task will be a part of the on-line mode from OLCI-L2WLR-CV-410 as well as it will be executed in the off-line mode to test algorithm / product revisions.

The task is based on sensor inter-comparisons and will use deep water, oligotrophic, mesotrophic, eutrophic, Hawaii and SPG subsets.

In the Commissioning phase E1:

- start with the first calibrated OLCI data. Visual inspection of plots will occur weekly. An automated warning will be issued if a problem is detected. Level-3 time series will be reprocessed using the final calibration of the Commissioning phase.

In the Routine Operations phase E2:

- visual inspection will occur monthly. Automated warning on a trend or discontinuity will be implemented.

6.1.4.4.3 Algorithm performance over spatial and temporal domains (OLCI-L2WLR-CV-430)

The task will evaluate algorithm performance over spatial and temporal domains and the performance of processing LUTs and algorithm parameterization. This is classified as: E1-HIGH and E2-CRIT.

The task will be a part of the on-line mode from OLCI-L2WLR-CV-410 as well as it will be executed in the off-line mode.
The task is based on temporal trends and it will be accomplished in all global and regional ocean subsets.

In the Commissioning phase E1:

- start with the first calibrated OLCI data. Visual inspection of plots will occur weekly. An automated warning will be issued if a problem is detected. Level-3 time series will be reprocessed using the final calibration of the Commissioning phase.

In the Routine Operations phase E2:

- visual inspection will occur monthly. Automated warning on a trend or discontinuity will be implemented.

6.1.4.4.4 **Repeatedly test impact of processor or algorithm changes (OLCI-L2WLR-CV-440)**

The task will assess impacts of processor or algorithm changes on temporal and spatial stability of derived products. It will enable to repeatedly test proposed revisions, support rapid prototyping and transfer of development to operations. This is classified as: E1-HIGH and E2-CRIT.

The task will be executed in the off-line mode when algorithm or product revisions are investigated. Algorithm or product changes cannot be implemented in the operational processing without this comprehensive evaluation.

The task is based on SMI figures, temporal trends, and sensor inter-comparisons. Temporal trends and sensor inter-comparisons will be accomplished in the types of waters most affected by the algorithm/product changes as well as, always, in global deep-ocean and oligotrophic waters for the sanity check.

In the Commissioning phase E1:

- start with the first calibrated OLCI data if initial product problems are discovered.

In the Routine Operations phase E2:

- visual inspection when results are available

6.1.4.5 **Ocean Colour Processing Quality Validation (OLCI-L2WLR-CV-500)**

6.1.4.5.1 **Cloud masking verification (OLCI-L2WLR-CV-510)**

**Task Description**

Cloud masking verification. This task is classified as: E1-HIGH and E2-HIGH.

**Task Aim and Objectives**

- verify the cloud masking accuracy as it impacts the final product quality
- limit cloud masking uncertainties as they lead to large products uncertainties

**Parameters for analysis**

- pixel classification (land/sea and cloud)
- Level-2 pixel flags
Methodology
The cloud masking quality shall be assessed by using a large number of images:

- image inspect visualisation
- supervised pixel classification

Required tools

- Database of images
- classification tools (identifying various classes like land, sea, cloud, semi-transparent clouds, sun glint...etc)
- database of pixel classification results, statistic tools, image processing tool.

Anticipated results

- Auxiliary file tuning
- Algorithm tuning

Task schedule
The tools preparation and adaptation to OLCI shall start in phase C/D.

- During the Commissioning phase E1 high effort shall be dedicated to this task to fine tune the auxiliary files and algorithm.
- During Routine Operations phase E2 classification verification is a low level task, but high effort shall be planned for assessing the quality for each reprocessing configuration

6.1.4.5.2 Level-2 Flags verification (OLCI-L2WLR-CV-520)

Task Description
This task shall verify all flags over ocean surfaces. It is classified as: E1-MED and E2-HIGH.

Task Aim and Objectives

- verify pixel flags as they impacts the final product quality
- limit flag uncertainties as they lead to large products uncertainties

Parameters for analysis

- pixel classification (land/sea and cloud)
- Level 2 pixel flags

Methodology
The flag quality shall be assessed by using a large number of images with manual visual inspection and methods for supervised pixel classification

Required tools

- Database of OLCI L2 images
• classification tools (identifying various classes like land, sea, cloud, semi-transparent clouds, sun glint...etc)
• database of pixel classification results, statistic tools, image processing tool

**Anticipated results**
• Auxiliary file tuning
• Algorithm tuning

**Task schedule**
The tools preparation and adaptation to OLCI shall start in phase C/D.
During the Commissioning phase E1 high effort shall be dedicated to this task to fine tune the auxiliary files and algorithm.
During Routine Operations phase E2 classification verification is a low level task, but high effort shall be planned for assessing the quality for each reprocessing configuration

6.1.4.5.3 **Validation of aerosol product over ocean (OLCI-L2WLR-CV-530)**

**Task Description**
Validation of aerosol products over ocean. This task is classified as: E1-HIGH and E2-HIGH.

**Task Aim and Objectives**
• validate aerosol optical thickness (AOT)
• validate aerosol models (Angstrom)
• verify the atmospheric correction
• verify vicarious calibration in the NIR

**Parameters for analysis**
• AOT at 865nm
• Angstrom exponent

**Methodology**
• matchups with AERONET measurements over coastal and island stations
• concurrent AOT and Angstrom time series for AERONET sites, OLCI product and AERONET measurements
• Level-3 time series of AOT and Angstrom OLCI products over SPG and SIO gyres, oligotrophic waters and selected regional sites
• mission inter-comparisons
• visual inspection of Level-2 products

**Required tools**
• Level-2 extractions over AERONET sites
• AOT and Angstrom matchups, including implementation of data screening protocols
• scatter plots and statistics
• concurrent AOT and Angstrom time series
• Level-3 binning, site selections, time-series plotting and mission inter-comparisons
• Level-2 visualization

Anticipated results
• Feedback to atmospheric correction
• Feedback to aerosol models
• Feedback to vicarious calibration in the NIR

Task schedule
The tools preparation and adaptation to OLCI shall start in phase C/D.
During the Commissioning phase E1, Aerosols shall be validated as soon as initial calibrated Level-2 products are released
During Routine Operations phase E2, Aerosol product validation shall continue throughout the mission and may lead to change in aerosol models and atmospheric correction

6.1.4.6 OLCI Land Products Validation (OLCI-L2LRF-CV-300)

Task Description
The OLCI terrestrial chlorophyll index (OTCI) is designed to monitor vegetation condition remotely by estimating chlorophyll content using reflectance in the red edge region of the spectra (RD 15). The OTCI makes use of the shift in the ‘red edge’ part of the spectrum where absorption drops dramatically.
The OGVI is the algorithm used to retrieve information of absorbed photosynthetical radiation by the vegetated terrestrial surfaces from an analysis of the Top Of Atmosphere (TOA) data acquired by OLCI. It is the green Fraction of Absorbed Photosynthetically Active Radiation (FAPAR).
The overall validation strategy is similar for both parameters.

Task Aim and Objectives
The objective of this task is to validate the OLCI land products and to associate the products with an error bar.

Parameters for analysis
The parameters to be validated are:
• OTCI – OLCI Terrestrial Chlorophyll Index which is the continuation of MERIS TCI and the associated rectified channels.
• OGVI – OLCI Global Vegetation Index which is the continuation of MERIS GVI.

Methodology
Validation of OLCI land parameters will be performed by:
• Comparison with in-situ data (OLCI-L2LRF-CV-310) (classified E1-HIGH and E2-CRIT)
• Comparison with other sensors (classified E1-HIGH and E2-CRIT) and parameter monitoring, statistical analysis
• Level 3 products analysis (classified E1-MED and E2-HIGH)

6.1.4.7 Land Product Validation with in-situ measurements (OLCI-L2LRF-CV-310)

Task Description
This task encompasses activities associated with acquisition, quality assurance and archiving of in situ measurements and OLCI product validation. It must be pointed that in situ data are used for product validation as well as for algorithm validation and development. The long-term validation plan shall conceive support for:

• Acquisition of in-situ measurements,
• evolution and maintenance of in situ measurement archives,
• consolidation and update of measurement protocols,
• standardization of in situ measurement uncertainty budgets and traceability of measurement processing,
• field instrument calibration and inter-calibration round robins,
• recurrent field campaigns, and campaign coordination with global partners,
• development of in situ instrumentation and new instrument concepts,
• prioritization of field variables collected by providers and increasing standardization of core field variable lists.

Task Aim and Objectives
• uncertainty estimates on core Land products based on matchups with in situ measurements
• algorithm performance evaluation over spatial domains and time series
• assessment of impact of processor or algorithm changes

Parameters for analysis
• OLCI Terrestrial Chlorophyll Index - OTCI
• Rectified channels
• OLCI Global Vegetation Index – FAPAR

Methodology
• Permanent measurements if possible,
• field campaigns

Acquisition of in situ data from those sources shall be secured. Expedited data availability may be requested in the Commissioning phase or during particular validation events.
Data shall be acquired as automatically as possible, especially from stationary platforms, formatted, preliminarily screened, and inserted into the archive.

The OLCI terrestrial chlorophyll index (OTCI) is designed to monitor vegetation condition remotely by estimating chlorophyll content using reflectance in the red edge region of the spectra. The OTCI makes use of the shift in the ‘red edge’ part of the spectrum where absorption drops dramatically. The remotely sensed signal over a vegetation canopy is a function of the interaction of the radiation and the canopy structure, the proportion of leaves and canopy that are in direct sunlight and the amount of background that is in view of the sensor. The signal will vary according to the size, orientation and spacing of the target and the sun-sensor geometry. Therefore, to understand the performance of OTCI and its utility in the provision of scientifically robust measures of canopy chlorophyll content and concentration there is a need to validate the index across a range of vegetation types and environmental conditions.

The measurements and campaign protocols for OLCI validation is described in RD 42.

Recommendations are given for the Elementary Sampling Units for each vegetation type, the vegetation type and status, the Leave Area Index data sampling, the chlorophyll concentration sampling, the Error Propagation calculation.

For the OGVI, as for the OCTI, the validation will consist in comparison against ground-based estimation and similar FAPAR products from various sensors.

Coordinated campaigns for OGVI and OCTI should be prepared in order to minimise the costs. In the same manner, the definition for the sites extractions (“super sites”) should be common to OGVI and OCTI as far as possible.

Nadine Gobron from JRC reported on the assessment of uncertainties of the operational MERIS FAPAR products, also called MERIS Global Vegetation Index (RD 43). OLCI FAPAR – OGVI – will be similar to MGVI. The validation will address the same issues. This publication references the difficulties related to the in-situ measurements “like the needed vertical and horizontal fluxes separately against the direct and diffuse radiation, measured with the appropriate sampling step and at a spatial resolution compatible with the remote sensing products, for the same ambient conditions as those prevailing during the acquisition of the remote sensing data” (RD 43).

6.1.4.7.1 Traceability of in situ measurement quality (OLCI-L2LRF-CV-320)

Methodology

The task needs to ensure that in situ measurements are accompanied by a detailed breakdown of:

- uncertainty budgets on instrument calibration
- uncertainty budgets on measurement platform
- measurement protocols followed and corresponding uncertainties, including environmental uncertainties at the site
- measurement processing methodologies and associated uncertainties

The information must be detailed because deviations from standards and protocols can cause significant problems in the interpretation of differences between in-situ and OLCI data. The systems shall be consistent with the QA4EO guidelines (http://qa4eo.org/).
6.1.4.7.2 In situ measurement archiving (OLCI-L2LRF-CV-330)

Methodology
This task maintains and further develops a comprehensive archive of in situ measurements. The database shall archive the measurements accompanied by their metadata, uncertainty budgets and protocols quality, as well as measurement quality ranking.

6.1.4.7.3 Extractions of OLCI data (OLCI-L2LRF-CV-340)

Methodology
This task shall be implemented in two modes:

- on-line extraction at NTC over permanent validation sites for newly acquired and processed OLCI Level-2 data
- off-line extractions across OLCI mission-long archives over any validations sites at Level-2 or Level-1B or Level-0

Systematic lat/lon extractions are required for all optical products (OC, SST, LST, land Validation). The requirements are the same: the tools shall be able to extract systematically a portion of the data – across and along swath extraction – with the basic information (lat/lon/flag...etc...). It should be able to perform filtering based on cloud or quality flag according to the application. It shall be to perform some basic operation (averaging, macro pixel, etc) depending on the application. Extractions shall follow established protocols, including data screening where cloudy extracts are excluded.

6.1.4.7.4 OLCI extract archiving (OLCI-L2LRF-CV-350)

Methodology
This task shall perform:

- archiving of Level-0, Level-1B and Level-2 OLCI extracts from newly acquired and processed OLCI data over a standard set of permanent validation sites
- retrospective archiving of Level-0, Level-1B and Level-2 OLCI extracts for other sites and field campaigns in the in situ measurement archive
- reprocessing of extract archives when new processors become operational

6.1.4.7.5 Generation of matchups and validation results (OLCI-L2LRF-CV-360)

Methodology
This task generates matchups, scatter plots, histograms, statistics based on pairs of in situ measurements in the archives and corresponding OLCI extracts. Matchups are generated for:

- operational Level-2 OLCI data, routine update at bi-monthly intervals
- reprocessed OLCI extracts from Level-1B, when scheduled
reprocessed OLCI extracts from Level-0, when scheduled

The matchup strategy shall apply ocean colour validation protocols, including OLCI data screening and averaging standards.

6.1.4.7.6 Development of calibration, product and science algorithms (OLCI-L2LRF-CV-370)

Methodology

This task reprocesses OLCI extracts from Level-1B or from Level-0 in a off-line fashion that allows iterative development, verification and optimization of instrument calibration, and product and algorithm efforts. OLCI site locations depend on a calibration issue, a product or a science algorithm under investigation. Nevertheless, reprocessing of OLCI archive corresponding to the entire contents of the in situ database may also be ordered. The validations use:

- matchups (OLCI-L2LRF-CV-360)

Input/Output data needs (all OLCI-L2LRF-CV-310 to -370)

The input data are

- OLCI Level-2 Land products
- OLCI Level-0 and Level-1B products are needed to reprocess Level-2 Land products for product and algorithm testing, tuning and comparison.
- in-situ data with accompanying measurement metadata, uncertainty budgets, protocols, and quality ranking

Campaign measurements provide complementary in situ data across various type of vegetation. Data from in-situ radiometers or airborne radiometers will be used. Today, AISA-Eagle sensor or CASI sensors are the potential sensors to be used for the airborne campaign. The sensors shall be able to simulate the OLCI spectral bands.

Output data are validation results, plots and statistics.

Required tools

- Tools to acquire in situ data
- Tools to perform the initial formatting, pre-processing and screening
- Tools to support acquisition of in situ data from other sources, e.g. reformatting
- Tools to support archiving of in situ data and accompanying metadata, uncertainties, protocols
- Extraction tool
- In situ archive

The archive shall support comparisons between in-situ measurements and satellite data, examples are MERMAID for ocean colour. (see Chapter 6.1.4.3)
The database supports validation and also future algorithm development. The database should be linked to the processing environment. Any changes in the products, algorithms or auxiliary files shall be followed by the reprocessing of the OLCI extracts collected to date and by validation to make a quantitative assessment of the improvements.

**Anticipated results**

Every two months, the following shall be reported:

- validation results up to date
- validation report shall provide error bar on the products
- recommendations on the algorithm performance over spatial domains and time series
- optimization of processor or algorithm changes
- verification of vicarious calibration

**Task schedule**

The tools preparation and adaptation to OLCI shall start in phase C/D. The timeliness on the task is the following:

- extraction of OLCI data over stationary validation sites will be at NTC (if applicable)
- all other validation activities are performed off-line, although some of them should be automated as much as possible

In the Commissioning phase E1:

- the matchup database shall be populated
- validation with in situ measurements will be initiated but no complete Level-2 validation is expected
- expedited delivery of validation measurements can be recommended
- at least one dedicated campaign should be planned

In the Routine Operations phase E2:

- validation with in situ measurements shall continue as a routine procedure throughout the mission
- the population of the matchup database shall continue regularly
- campaigns should take place every 2 to 3 years

6.1.4.7.7 **Land Products Validation with external RS data (OLCI-L2LRF-CV-380)**

**Task Description**

The in-situ measurements should be complemented by a regular and routine activity of validation or verification based on the analysis of Level 2 data, Level 3 data from other missions as well as analysing temporal trend and general statistics. High resolution sensor, Sentinel-2 in particular, could be used also for verification.
Task Aim and Objectives

The task goal is to

- continuously monitor the processing chain and implementation, enable instant detection of problems and rigorous quality control
- assess OLCI consistency with other missions
- evaluate algorithm performance over spatial and temporal domains, their LUTs and parameterization
- assess impacts of processor or algorithm changes on temporal and spatial stability of derived products
- repeatedly test proposed science algorithm and product revisions, enable rapid prototyping and transfer of development to operations

Methodology

For satellite comparison, particular attention should be taken when comparing different algorithms that are not necessarily addressing the same FAPAR parameter. Table 16 below gives an overview of the different FAPAR retrieved by Satellite

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Input data</th>
<th>Output product</th>
<th>Retrieval Method</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>JRC-FAPAR</td>
<td>Top of Atmosphere (TOA) BRFs in blue, red and near-infrared bands</td>
<td>Instantaneous green FAPAR based on direct incoming radiation</td>
<td>Optimization Formulate based on Radiative Transfer Models</td>
<td>Gobron et al. (2000, 2006, 2008)</td>
</tr>
<tr>
<td>NASA MODIS LAI/FPAR</td>
<td>Surface reflectance in 7 spectral bands and land cover map</td>
<td>FAPAR with direct and diffuse incoming radiation</td>
<td>Inversion of 3D Model versus land cover type with backup solution based on NDVI relationship</td>
<td>Knyazikhin et al. (1998a)</td>
</tr>
<tr>
<td>NASA MISR LAI/FPAR</td>
<td>Surface products BHR, DHR &amp; BRF in blue, green, red and near-infrared bands + CART</td>
<td>FAPAR with direct and diffuse incoming radiation</td>
<td>Inversion of 3D Model versus land cover type with backup solution based on NDVI relationship</td>
<td>Knyazikhin et al. (1998a)</td>
</tr>
<tr>
<td>GLOBCARBON</td>
<td>Surface reflectance red, near infrared, and shortwave infrared</td>
<td>Instantaneous (Black leaves) FAPAR</td>
<td>Parametric relation with LAI as function as Land cover type</td>
<td>Plummer et al. (2006)</td>
</tr>
<tr>
<td>CYCLOPES</td>
<td>Surface reflectance in the blue, red, NIR and SWIR bands</td>
<td>FAPAR at 10:00 solar local time</td>
<td>Neural network</td>
<td>Baret et al (2007)</td>
</tr>
<tr>
<td>JRC-TIP</td>
<td>Broadband Surface albedo in visible and near-infrared bands</td>
<td>FAPAR &amp; Green FAPAR for direct &amp; diffuse incoming radiation</td>
<td>Inversion of two-stream model using the Adjoint and Hessian codes of a cost function</td>
<td>Pinty et al. (2007)</td>
</tr>
</tbody>
</table>

Table 16 – Comparison of different FAPAR retrieval methods

The validation of the OLCI land products will be conducted in the context of the CEOS Land Product validation Subgroup (see chapter on International Context). LPV promoted the development of a validation method based on a comparison with in situ test site. The method is called OLIVE - OnLine Interactive Validation Exercise, (RD 44). OLIVE provides in situ and high
resolution reference maps for the validation of LAI, fAPAR and albedo products. It is a validation against Direct sites that can be considered as a benchmark of EO land products. With the increasing number and importance of satellite data sets in the context of international conventions, OLIVE offers the mechanisms to provide products that have been independently validated to internationally accepted standards. The validation protocols have been agreed at CEOS level. The source code and reference data are made available to users. Validation reports are public. The access is done via the Cal/Val portal (http://calvalportal.ceos.org/). Quick description of OLIVE can be found at: http://www.ceos.org/images/wgcv/wgcv29/OLIVE-PARaMETER_Baret.pdf

**Input/Output data needs**

The task will be carried out mainly from the OLCI L2 and L3 land product data.

The list of selected sites will be determined at a later stage.

The sites list should cover a wide range of vegetation types and environmental conditions.

The inter-comparison exercise will be carried out with similar sensor flying contemporarily with OLCI. One can mention MODIS, VIIRS, Sentinel-2. Comparison with Sentinel-2 will be of particular interest due to the high spatial resolution of Sentinel-2.

For the OTCI, RAPIDEYE satellite provides the right channels in the red edge domain that can be used to apply the OTCI and MTCI algorithm. RAPIDEYE can serve as a transfer function from MERIS MTCI and OLCI OTCI (if RAPIDEYE is still in operation at S3 launch time).

In addition, as for Sentinel-2 the high spatial resolution of RAPIDEYE will be of particular interest to validate the S3 OTCI.

**Required tools**

The main tools needed for this task are:

- Extraction tool that allow the extraction of OGVI and OCTI over selected area.
- Basic image processing tool, allowing averaging, statistic computation, transect.
- Monitoring tool, that would plot the long term trend and the statistic information over the selected sites.
- Level 3 generation tools (see RD 45).
- Comparison tools.
- OLIVE (RD 44).

**Anticipated results**

The result will a validation report providing error bar to the products.

The uncertainties information will be updated following the results of this task.

**Reporting requirements**

- Report the early assessment to IOCR
- Validation Report at Validation Workshops
- Regular reports to ESA / EUM teams and Mission Management
Task schedule

The validation of the OLCI land product shall start as soon as calibrated L1B data are available. The details on the places (Test Site), temporal frequencies and full equipments for the campaign will be discussed and decided at a later stage.

In anticipation, one can say that a campaign shall take place during the Commissioning phase after the “first stabilisation” of the Level 1 data. In order to do this, in-situ measurements, Airborne data and ancillary information are needed. Ideally, the in-situ measurement should consists of sampling of biophysical variables, taking ground spectral measurements using radiometer and measuring aerosol (for proper atmospheric correction). Ideally, during the Commissioning phase or shortly after, we would need measurements during spring, summer and autumn in order to capture most of the land variability.

Then regular campaign should take place every two years – TBC -

First assessment of the OLCI Land Products is expected at the end of the Commissioning phase. The validation is continuous task that shall last during the complete mission life time.

6.1.4.8 Land Products Processing Quality Validation (OLCI-L2LRF-CV-400)

6.1.4.8.1 Cloud masking verification (OLCI-L2LRF-CV-410)

Task Description

Cloud masking verification. This task is classified as: E1-HIGH and E2-HIGH. This task is similar to OLCI-L2WLR-CV-510 and can be conducted in a coordinated manner.

Task Aim and Objectives

- verify the cloud masking accuracy as it impacts the final product quality
- limit cloud masking uncertainties as they lead to large products uncertainties

Parameters for analysis

- pixel classification (land/sea and cloud)
- flags

Methodology

The cloud masking quality shall be assessed by using a large number of images:

- image inspect visualisation
- supervised pixel classification

Required tools

- Database of images
- classification tools (identifying various classes like land, sea, cloud, semi-transparent clouds, sun glint...etc)
- database of pixel classification results, statistic tools, image processing tool.
**Anticipated results**
- Auxiliary file tuning
- Algorithm tuning

**Task schedule**
The tools preparation and adaptation to OLCI shall start in phase C/D.

During the Commissioning phase E1 high effort shall be dedicated to this task to fine tune the auxiliary files and algorithm.

During Routine Operations phase E2 classification verification is a low level task, but high effort shall be planned for assessing the quality for each reprocessing configuration.

6.1.4.8.2 **Surface classification flag verification (OLCI-L2LRF-CV-420)**

**Task Description**
Flag verification. This task is classified as: E1-HIGH and E2-HIGH.

This task is similar to OLCI-L2WLR-CV-520 and can be conducted in a coordinated manner.

**Task Aim and Objectives**
- verify pixel flags as they impacts the final product quality
- limit flag uncertainties as they lead to large products uncertainties

**Parameters for analysis**
- pixel classification (land/sea and cloud)
- flags

**Methodology**
The flag quality shall be assessed by using a large number of images:
- image inspect visualisation
- supervised pixel classification

**Required tools**
- Database of images
- classification tools (identifying various classes like land, sea, cloud, semi-transparent clouds, sun glint...etc)
- database of pixel classification results, statistic tools, image processing tool

**Anticipated results**
- Auxiliary file tuning
- Algorithm tuning
**Task schedule**

The tools preparation and adaptation to OLCI shall start in phase C/D.

During the Commissioning phase E1 high effort shall be dedicated to this task to fine tune the auxiliary files and algorithm.

During Routine Operations phase E2 classification verification is a low level task, but high effort shall be planned for assessing the quality for each reprocessing configuration.

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### 6.2 SLSTR

#### 6.2.1 Constrains and assumptions

For the Cal/Val task definitions in this chapter the following constrains and assumptions apply for SLSTR:

- SLSTR instrument SIOV tests have been successful and concluded (classified E1-CRIT)
- SLSTR outgassing has been performed in SIOV and the FPA is cooled to operating temperature. (classified E1-CRIT)
- Instrument Gain and offset settings are according to pre-launch characterisation
- views for calibration black bodies and VISCAL have been derived during SIOV
- All operation modes checked

Access to L1b data streams shortly after the end of SIOV is mandatory (classified E1-CRIT)

Full L2 operational products validation is not expected to be reached at IOCR, with on-going validation and periodic reviews throughout during E2 (classified E2-MED). L2 products should be made available to the calibration validation teams during phase E1 if available (classified E2-CRIT). Note that without access to L2 products (SSTskin and LST in particular) any validation analysis will be challenging.

#### 6.2.2 Instrument Error Analysis

A top-level product uncertainty analysis has been performed for SLSTR L1 and L2 baseline products. This is presented in Figure 16 that traces the main sources of uncertainty. An additional category dedicated to uncertainties arising within the validation process (V type uncertainties) itself (e.g. uncertainties arising from the in situ data used as a validation data source, uncertainties due to the validation methodology employed) has been included to recognise the fact that no measurement is free of error (often in situ data contemporaneous with satellite measurements is incorrectly used as a reference “truth”).
6.2.3 **Task Definitions for SLSTR Level 1b Products**

For the majority of channels, SLSTR is a self-calibrating instrument. The on-board calibration system involves the use of two highly stable blackbody (BB) reference targets (for the thermal channels) maintained at different temperatures above and below the range of earth targets (but optimised for SST retrievals), and a diffusely reflecting target (VISCAL) that is illuminated once per orbit (for the VIS-SWIR channels). Traceability to international standards is maintained through the on-ground characterisation on-board calibration sources and pre-launch calibration.

Notably, the F-1 and F-2 Fire channels are not self-calibrating as the upper dynamic range of these channels exceeds that of the on-board blackbodies. F1 and F2 will require vicarious adjustments using reference radiance sources on ground.

The validation process for geolocation is similar to OLCI with the use of SPS and GPP. Due to scanning mechanism the pre-launch characterisation of scanner and mirror performance is essential.
### MRTD key requirement
(further associated req.)

<table>
<thead>
<tr>
<th>S3 Prod. ID</th>
<th>Major Uncertainty Source</th>
<th>Cal/Val Tasks</th>
<th>Respons. Schedule</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3-MR-990: Radiometric accuracy:</td>
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<tr>
<td>Sentinel-3 infrared channels shall have a radiometric accuracy goal of 0.1 K over a range of 270-320 K traceable to international reference standards.</td>
<td>Scan pixel map Calibration of TIR channels Calibration of F1/F2 Signal noise Radiometric bias Signal dynamic range Digitisation Blackbody performance ADF and processor optimisation Pre-flight calibration</td>
<td>Prep. for L1 Validation (SLSTR-L1B-CV-100) TIR Channel Calibration &amp; Performance (SLSTR-L1B-CV-200)</td>
<td>E1: Data required immediately after instrument switch on to characterise and configure SLSTR in flight E2: on-going performance monitoring and vicarious calibration of F1/F2</td>
<td></td>
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</tbody>
</table>

| S3-MR-1010: Absolute Radiometric Accuracy: | | | | |
| Sentinel-3 VIS reflectance’s at TOA shall have an absolute radiometric accuracy goal of <2% with reference to the sun for the 400-900 nm waveband and <5% with reference to the sun for wavebands > 900 nm traceable to international reference standards. | Dynamic Range Radiometric noise VISCAL illumination VISCAL processing parameters Radiometric bias | Preparation (SLSTR-L1B-CV-100) VIS/SWIR Channel Calibration & Performance (SLSTR-L1B-CV-300) | E1: Data required immediately after instrument switch on to characterise and configure SLSTR in flight E2: on-going performance monitoring |
6.2.3.1 Preparation for in orbit Cal/Val activities (SLSTR-L1B-CV-100)

Task Description

This task is applicable for all further Cal/Val task on VIS, SWIR and TIR channels. It is specifically required to ensure that all tools, data flows and methods are tested and prepared prior to Phase-E activities.

Task aim and objectives

- Consolidation and preparation of Scientific Validation Team (S3VT) including solicitation of inputs from external scientific community (at least 18 months in advance of launch)
- Preparation of meaningful test data sets for SLSTR products.
- Define fire channel calibration, verification and validation methodology based on pre-launch studies.
- Familiarisation with SLSTR simulator system and products.
- Consolidate interfaces (communication and data access, results feedback etc) to all relevant Calibration and validation teams (internal and external (S3VT))
- Consolidation of all target ground sites for Level-1B radiometry verification, geolocation testing and diagnostic studies.
- Establish and test on-line and off-line L1b data extraction tools, including off-line extraction of any lat/lon coverage of mission historical data required
- Creation of an extensible validation match up database (building on community best practice) to store satellite image data and in situ measurements with on-line access and query capability.
- Validation protocols are agreed and clearly documented in publically accessible documents.
- Confirm that adequate in situ infrastructure (e.g. SST drifters, ARGO floats, ship-borne and Land radiometers, Land Surface Temperature, ice surface temperature, lake surface temperature etc.) are available and access to data has been established and tested.
• Creation of a database of ground control points (GCP) for geometric calibration (shared with OLCI)
• Initial geometric modelling from on-ground characterizations, an initial kernel for the GCP database, preparation for validation of the geo-location requirements (shared with OLCI)
• Implementation of GCP extraction tools, GCP visualization tools, and geolocation modeling tool (shared with OLCI)
• Pre-launch study to establish a methodology to quantify uncertainty budgets and deriving pre-launch estimates for all errors.
• Prelaunch studies using AATSR/MERIS to reduce absolute and relative uncertainties of vicarious calibration verification techniques, development of absolute mission inter-calibration methods at Level-1B radiances, and a common vicarious calibration strategy between OLCI and SLSTR (shared with OLCI).

Anticipated results
This task will ensure that the SLSTR cal/val teams and validation community have all available tools to conduct their work, have clear reporting lines, established and tested data flows, agreed analysis methodologies and have successfully completed a rehearsal.

Task Schedule
This task starts 2 years prior to launch.

6.2.3.1.1 Verification L1b product contents (SLSTR-L1B-CV-110)

Task description
This task is designed to verify the contents of L1b product contents and confirm that they conform to specification.

Task aim and objectives
This task shall for a variety of typical targets (ocean, land, ice, clouds):
• Verify the visual consistency of all SLSTR L1B image data
• Verify the coding of all flags and parameters
• Verify that all data are present in the L1b product and conform to specification

Parameters for analysis
• SLSTR L1b radiances, flags

Methodology
SLSTR L1b products will be systematically checked and verified against product specifications for a number of randomly chosen orbits.

Input/Output data needs
• SLSTR L1b products

Required tools
• S3 Toolbox or any netCDF analysis SW
Anticipated results
Verification of SLSTR L1b products

Task Schedule
This task starts as soon as SLSTR L1b data are available.

6.2.3.2 TIR Calibration and Performance (SLSTR-L1B-CV-200)

Task Description
The aim of this task is to verify the configuration and performance the thermal Infrared (TIR) radiometric calibration of SLSTR L1B and monitor the performance of the TIR calibration over time within Phase E1.

Task Aim and Objectives
The aims of this task is to verify and monitor the SLSTR TIR channel radiometric calibration during Phase E1 and ensure this performance during Phase E2:

The following objectives have been established for specific sub-tasks:

- SIOV optimization of pixels in scan cycle pixel map (earth views, blackbody calibration views, clearance of baffles) (SLSTR-L1B-CV-210)
- Verification and monitoring of channel performance: dynamic range and radiometric noise. (SLSTR-L1B-CV-220)
- Verification and monitoring of SLSTR thermal environment. (SLSTR-L1B-CV-230)
- Verification of blackbody performance: Black body Thermometry Self-consistency (SLSTR-L1B-CV-240)
- Verification of blackbody performance: Thermal gradients and stability (SLSTR-L1B-CV-250)
- L1b processing optimization and maintaining of radiometric calibration processing parameters (calibration period, weighting functions) and monitoring of radiometric gain and offset value stability for all channels. (SLSTR-L1B-CV-260)
- Vicarious calibration of SLSTR Fire Channels: Vicarious cross calibration of F1/2 against S7/8 channels and calibration using sun glint (SLSTR-L1B-CV-270)
- Radiometric bias characterisation: Inter-satellite comparisons (SLSTR-L1B-CV-280)

Input/Output data needs
Sustained access to full orbit of data is required to fulfil all monitoring aspects of this task. Some tasks can be performed with several days of data.

Task Schedule
This task shall start at the end of SIOV and FPA cool down when SLSTR instrument science data are available.
6.2.3.2.1 Optimization of pixels in scan cycle pixel map (SLSTR-L1B-CV-210)

Task Description
The launch environment may have affected the beam clearances to the earth views and calibration targets. Pixels with clear views of the calibration sources and earth views will be identified using in flight instrument source packets during SIOV. This task will verify and confirm that the pixel target table, verified during ground tests, and SIOV is correct and updated if required.

Aim and Objectives
The aim of this task is to verify and update the pixel target table using in flight data.

The objectives for this task are:

• To access in flight ISP as soon as possible.
• To analyse ISP data to verify the target pixel map for each channel [S7, S8, S9, F1, F2] the SLSTR instrument.
• To adjust the Pixel target map for each channel [S7, S8, S9, F1, F2] compared to pre-flight data if required.
• To confirm that the Pixel target maps are correct.

Task Parameters for analysis

• Detector counts
• Scan pixel target map

Methodology
To locate the edges of SLSTR clear view lines to target scenes, it is necessary to have sufficient contrast between the view and the instrument’s optics enclosure. For the on-board blackbodies the best contrast is seen in the thermal infrared channels.

Distinguishing the clear pixels for the calibration targets is straightforward because of the stability of the signal from the targets. The limits of the clear view are simply the points where the signal begins to fall off. The edges of the nadir and along-track swaths are not so clear-cut because the signal remains variable, even when the instrument structure fills part of the beam. Furthermore, in the infrared, the signal from the optics enclosure will be similar in magnitude to the earth scene radiances. However, good contrast can be obtained using the visible channels over bright targets (e.g. land, cloud) and it is possible to detect where the signals fall off. It is important to verify that data are not influenced by the SLSTR baffles that will have large thermal excursions around the orbit.

• ISP data will be unpacked and detector counts extracted.
• Counts for each channel will be plotted as a function of pixel number.
• Signals will be analyzed to confirm that the scan pixel target map is correct and not influenced by SLSTR baffles.
• Anomalies shall be identified and used to optimize the scan pixel target map.

Input/Output data needs
Input data:
At least 14 (TBC) orbits of data are required for this task in order to provide sufficient target contrast between earth targets and SLSTR baffles.

Output data:

Plots of scan pixel number as a function of detector counts as a function of scan pixel number for [F7, F8, F9, F1, F2]

Required tools

- Tool to read ISP and extract detector counts.
- Tool to read scan pixel target map.
- Tools to analyses data (e.g. IDL/Matlab).

Anticipated results

- Plots of scan pixel number vs detector counts.
- Identification of anomalies in scan target pixel map.
- Update of scan pixel target map as required.
- Verification of pixel target maps.

![Figure 17: Example of detector count and Pixel number over AATSR +BB and –BB for the 11um channel (Credit: RAL)](image)

Task Schedule

This task shall start at the end of SIOV when SLSTR instrument data are available.

This task shall end within the Phase E1.

6.2.3.2.2 Verification and monitoring of channel performance: dynamic range and noise characteristics (SLSTR-L1B-CV-220)

Task description

This task will analyse SLSTR L1b and ISP (if required) to characterise and quantify IR channel performance in terms of dynamic range and noise characteristics.

Task aim and objectives

- To conform that SLSTR IR radiance measurements are within the specified dynamic range.
- To confirm and monitor the noise characteristics of SLSTR IR radiance measurements.
Parameters for analysis

- Calibrated radiance data from all IR channels.

Methodology

L1b data will be analysed over a variety of targets to verify that the dynamic range is within expected limits. Specific target sites can be derived for this purpose to fully automate the procedure. Alternatively manual data analysis will be required.

In-flight, the radiometric noise is monitored using the two on-board blackbodies signals following the approach described in (RD 48). IR noise characteristics (NEdT) will be established by analysing blackbody target views. The analysis shall include time series analysis of noise characteristics around the orbit. During these analyses the temperature and temperature stability of the FPA and detectors will be monitored to verify that they conform to requirements throughout the analysis. The thermal characteristics of the blackbody targets shall also analysed.

Checks on correlations to scan drive motor and cryo-cooler parameters (for ATSR-2 noise performance derived from the on-board blackbodies can be subtly affected by scan mirror rotation instability and cryo-cooler drive). The analysis shall include a stability analysis of all parameters across Phase E1. The analysis shall be continued across Phase E2. A transition plan for these activities to Phase E2 shall be established for this purpose.

Input/Output data needs

Input:

- Regular access is required to SLSTR L1b data.
- Access to ISP and calibrated thermometry from FPA and BB units.

Required tools

The following tools are required:

- Tools to read and manipulate SLSTR L1b data (e.g., IDL/Matlab or dedicated code)

Anticipated results

- Confirmation that calibrated IR radiance data are within specified dynamic range.
- Characterisation of in-flight NEdT for IR radiance data.
- Report of E1 results at IOCR and regular reports for E2 thereafter.

Task Schedule

This task shall start at the end of SIOV when SLSTR instrument data are available. This task shall operate throughout Phase E1 and E2.

6.2.3.2.3 Verification and monitoring of SLSTR thermal stability (SLSTR-L1B-CV-230)

Task description

This task is designed to monitor and characterise the SLSTR thermal environment throughout Phase E1. Knowledge of SLSTR thermal stability is required to investigate instrument anomalies.
Task aim and objectives
- Measured temperatures will be analysed for conformance to specified limits and stability criteria.
- At the end of Phase E1 a report of thermal stability shall be provided

Parameters for analysis
The temperatures of the following subsystems (TBC) will be monitored routinely:
- Blackbodies (see also Task SLSTR-L1B-CV-240)
- Cryo-Cooler
- FPA temperatures
- Dome Temperatures
- Aperture stop (parabolic mirror temperature)
- OME optics temperature (Flip Mirror, Fold Mirror, Scan Mirror).
- OME enclosure
- Radiators
- FEE
- TAEO and BBEU
- CDE
- CPE
- Mechanisms

Methodology
All available temperature sensors shall be monitored in flight to characterise the thermal stability of the SLSTR instrument.

Time Series plots of instrument temperature sensors shall analysed for out of bound conditions and significant excursions. Ideally an automated system is required to routinely perform this analysis and report anomalies for further investigation.

Methodology established in this task can be used in Phase E2 to monitor thermometry performance/degradation and stability. A transition plan for these activities to Phase E2 shall be established for this purpose.

Input/Output data needs
Input:
Regular access (at least daily if not all data) is required to SLSTR calibrated thermometry data.

Required tools
The following tools are required:
- Tools to read SLSTR ISP and generate calibrated thermometry data for all thermometers on board
• Tools to analyse thermometry data for out of specification values and anomalies. The tool should perform such analyses automatically and report anomalies appropriately.

**Anticipated results**

Clear reporting lines are required to ensure anomalies are promptly reported.

- Accurate knowledge of the SLSTR thermal environment
- Validation that all sub-systems are within thermal specification and stability
- Early warning of potential problems.
- Regular access to instrument thermometry data.
- Report of E1 results at IOCR and regular reports for E2 thereafter.

**Task Schedule**

This task shall start at the end of SIOV when SLSTR instrument data are available.

This task runs across both Phase E1 and E2.

6.2.3.2.4 **Verification of blackbody performance (SLSTR-L1B-CV-240)**

**Task description**

This task will characterise and validate the performance of both in-flight infrared calibration blackbody cavities.

**Task aim and objectives**

The aim of this task is to validate the in-flight performance of the IR calibration blackbody cavities. The following objectives apply:

- Analyse and quantify the characteristics and stability of all blackbody thermometry.
- Analyse and quantify the characteristics and stability of thermal gradients within each blackbody.
- Perform blackbody crossover tests.
- Provide a report of findings at IOCR.
- Provide regular result reports throughout Phase E1.

**Parameters for analysis**

- Validation of blackbody thermometry (PRT and thermistors)
- Detector signals form ISP and calibrated radiances from L1b
- Validation of the thermal homogeneity of blackbody cavities
- Validation of relative performance of blackbody

**Methodology**

All blackbody PRT and thermistors will be analysed for conformance to accuracy and stability requirements. The analysis shall include multiple orbits to validate thermometry stability.

The thermal homogeneity of each blackbody as derived from thermometry (relative to the cavity mean value) will be analysed for conformance to accuracy and stability requirements. The analysis shall include multiple orbits to validate the stability of blackbody homogeneity.
Based on these analyses, an optimal choice of thermometers for use in the calibration of SLSTR shall be defined. This analysis will be used as an independent validation of similar activities during the SIOV phase.

Blackbody crossing temperate cycles shall be scheduled to verify the relative performance of each blackbody and compare to pre-flight characterisation measurements. Each blackbody is thermally cycled using heaters or allowed to cool from the nominal hot state as appropriate and radiometric measurements collected throughout the cycle. This requires dedicated commanding of the instrument. At the point where each blackbody temperature is identical, detector signal measurements should be identical. Any deviation implies an error in the thermometry of the blackbody or a change in the cavity emissivity (caused by damage, contamination). This approach does not yield an absolute error measure (this can only be established during pre-launch characterisation) but allows the relative performance of the calibration blackbodies to be assessed in flight. When performed at regular (TBC) intervals, crossing temperature cycles provide a powerful measure of the quality of calibration. Black body crossing temperature analyses at different crossover temperatures should be performed regularly throughout the instrument lifetime (at least annually as for AATSR). It should be noted that crossing temperature analysis will require SLSTR to cease normal science data acquisition.

**Input/Output data needs**

**Inputs:**
- SLSTR L0
- SLSTR inflight BB measurements
- HKTM/L0 data

**Required tools**

The following tools are required:
- Tools to read and manipulate SLSTR Lo data (e.g., IDL/Matlab or dedicated code)

**Anticipated results**

- Report on the validation (compliance, characteristics and stability) of blackbody thermometry (PRT and thermistors), thermal homogeneity of blackbody cavities and relative performance of blackbody for IOCR.
- Monitoring of blackbody thermometry (PRT and thermistors), thermal homogeneity of blackbody cavities and relative performance of blackbody across the mission timeline.

**Task Schedule**

This task shall start at the end of SIOV when SLSTR instrument data are available.

This task runs across both Phase E1 and E2.
6.2.3.2.5 Calibration and validation of SLSTR Fire Channels (SLSTR-L1B-CV-250)

Task description
This task is dedicated to the calibration and validation of F1/2 channels and monitoring its performance.

Task aim and objectives
The temperature of SLSTR calibration blackbodies does not allow a calibration of the fire channels across their full dynamic range. Extrapolating radiance errors from the blackbody calibration to higher the radiances of the Plank function will magnify the total error. The aim of this task is to calibrate and adjust if required the F1 and F2 in flight calibration.

Parameters for analysis
- F1 and F2 calibration parameters

Methodology
The SLSTR F1 and F2 channels will be calibrated and characterized prior to flight. The two-point blackbody calibration (as used by S7-S9) will be used to correct any first order measurement offset or drift in the instrument gain.

Vicarious cross calibration of F1/2 against S7/8 Channels: To achieve cross-calibration, both the F1/S7 and F2/S8 channels must simultaneously measure a signal which falls within the dynamic range of both channels. However in referencing the fire channel to a single scene temperature in the spectral channel will only give a single point calibration. This means that the calibration will correct for offset but not for any change in gain. The use of vicarious calibration scenes, such as that offered by sun glint, would provide a common source that could be used to perform a cross calibration. Using this technique it is possible to achieve reasonable accuracies. Provided that the overlap range is between 290K and 320K the radiometric accuracy requirement should be achievable.

Use of sun-glint. The sun glint radiance is high and spectrally flat and is thus a suitable target for the cross channel calibration. Simulated sun glint temperature maps for SLSTR have been developed and in smooth-sea (low wind/wave) conditions provide a useful calibration target. Additional effort is required to account for atmospheric effects and surface surface roughness before the sun glint calibration method can be used as an absolute calibration method although such a target is suitable as a relative cross-channel calibration method. Further work is required to develop this calibration approach.

Input/Output data needs
- SLSTR Lo
- SLSTR L1b

Required tools
- A tool to predict optimal geometries for sun-glint locations and the environmental conditions at the sea surface (roughness) and in the atmosphere.
- Data processing and visualisation tools (e.g. IDL/MATLAB etc).
Anticipated results

- Validation of fire channel calibration.

Task Schedule

This task shall start at the end of SIOV when SLSTR instrument data are available. This task runs across both Phase E1 and E2.

6.2.3.2.6 L1b processing optimization (SLSTR-L1B-CV-260)

Task description

This task is dedicated to validating and maintaining radiometric calibration processing parameters and monitoring of radiometric gain and offset value stability for all channels.

Task aim and objectives

The aim of this task is to optimise the processing parameters used for SLSTR infrared calibration and monitors the evolution of the calibration parameters.

Parameters for analysis

- Radiometric calibration gain
- Radiometric calibration offset

Methodology

The stability of the infrared calibration gain and offset parameters derived from blackbody calibration a measurement is related to the noise characteristics of the calibration data. Some averaging over several calibration cycles may be required to optimise the calibration gain and offset values within the L1b processor. This is in turn related to the number of scan cycles over which blackbody signals are averaged to obtain a representative calibration measurement and the weighting of blackbody thermometers. This task will monitor the characteristics of the SLSTR IR calibration gain and offset.

Input/Output data needs

TBW

Required tools

TBW

Anticipated results

- Optimised calibration of SLSTR IR calibration parameters

Task Schedule

This task shall start at the end of SIOV.
6.2.3.2.7 Radiometric bias characterisation: Inter-satellite comparisons (SLSTR-L1B-CV-270)

Task Description

The inter-comparison of level 1 products with other EO data is a key component of the commissioning and routine operations phase of Sentinel-3. These can be used for calibration validation, performance monitoring, and in some cases extended to generate inter-calibration corrections, which can be applied in either real-time or re-analysis processing. EUMETSAT plan to conduct these activities on an ongoing basis following principles and methodologies developed within the Global Space-based Inter-Calibration System (GSICS).

The infrared channels of SLSTR will be compared with the Infrared Atmospheric Sounding Interferometer (IASI), which is a stable, well characterised instrument, adopted as a community inter-calibration reference by GSICS. The methodology for this inter-comparison is currently immature but being developed through a study at EUMETSAT. The solar-band channels of SLSTR and OLCI will be compared to other LEO instruments, for example MODIS, VIIRS, GOME-2, or SCIAMACHY, where available, using a combination of invariant targets and direct ray-matching methods, currently under development in GSICS. They will also be compared with corresponding channels of geostationary imagers, and may prove to be valuable inter-calibration reference instruments. Inter-comparisons between S3A and S3B are essential. Double differencing methods with NWP data, using multiple sensor data, should also be used, as demonstrated in the EUMETSAT NWP-SAF activities.

Inter-comparisons of level products with other satellite data is necessary, such as with MODIS, AVHRR and VIIRS as available. These inter-comparisons can be done at the radiance level and by comparing brightness temperatures. A brightness temperature tool should be provided within the MPM. The system will allow the products to be re-processed through to higher levels from L0 to L1 to L2, although as no geo-location information is provided with the Lo files, these will need to be complete files and not sub-sets. Verification and quality control of uncertainty estimates (theoretical error for the single SST products) to within expected ranges should be performed. Methodologies to inter-calibrate and bridge the gap between AATSR and SLSTR should be developed using a combination of Metop-A and Metop-B AVHRR and IASI data. This task is classified as E1-CRIT and E2-CRIT.

Input/Output data needs

Input data:
- SLSTR L1b data from TIR channels (S3A and B)
- Level 1b TIR data from other polar-orbiting satellite missions where available (e.g. AATSR, IASI, MODIS, SCIAMACHY, VIIRS, GOME-2, AVHRR).
- Level 1b TIR data from other geostationary satellite missions e.g. SEVIRI.

Output data:
- Global inter-comparisons via web-page and reports.
- Correction datasets.

Required tools

Tools should be developed based on the principles and methodologies developed within GSICS.
Anticipated results

GSICS bias monitoring and corrections should be produced in near-real time, and for reprocessed products. Plots showing the inter-comparison results should be displayed on a web-page and made available through the reporting structure. Derived corrections should be made available within datasets.

Task Schedule

The task should start in the commissioning phase, and continue throughout phase E2. Some activities will be needed pre-launch to prepare for tools and to refine and finalise the methodologies.

6.2.3.3 Visible/SWIR Calibration and Performance (SLSTR-L1B-CV-300)

Task Description

This task is dedicated to verification and validation and monitoring of SLSTR VIS/SWIR performance

Task aim and objectives

In Phase E1:

- Optimization of pixels in scan cycle pixel map (earth views, VISCAL views)
- First light test of VISCAL before cool-down to look at quasi-invariant sites (systematic extractions).

In Phase E2:

- Periodic check of selected calibration target pixels in scan cycle.
- Monitor the stability of VISCAL and dark signals.
- Determination of long-term stability.

Long-term activities (starting in Phase E1):

- Radiometric Bias Characterisation: Calibration Using In-Situ Reference, satellite inter-comparisons and aerosol/Rayleigh scattering measurements using stable desert, ice and cloud e.g. Arctic stratus and tropical cumulo-nimbus.
- In situ radiometric measurements over the CEOS landnet targets supported by coordinated radiometer inter-comparisons (e.g. QA4EO-WGCV-IVO-CLP-008).
- Optimization and maintenance of VISCAL ADF processing parameters (thresholds, duration, position on orbit).
- Verification and monitoring of Signal Channel Performance: dynamic range, digitisation check, radiometric noise.
- Cross-calibration and band matching with OLCI at least once per year.
- Absolute calibration of 1.3µm channel using simultaneous nadir overpasses, and the 1.6µm and 2.2µm channels.
6.2.3.4 Stray-light monitoring (SLSTR-L1B-CV-310)

Task aim and objectives

- Monitor scan dependent variations in brightness temperature and SST.
- Monitor stray-light over gas-flares and fires where brightness temperature is greater than 350K.

6.2.3.5 Geometric Calibration and Verification (SLSTR-L1B-CV-400)

Task aim and objectives

- SLSTR Initial geolocation calibration
- SLSTR geolocation validation
- SLSTR geolocation validation
- Monitoring of SLSTR geolocation
- Verification of land-flagging, cloud-clearing, and uncertainty estimates.

In principle, this task will share tools and the approach of OLCI (OLCI-L1B-CV-500)

6.2.3.6 Cloud-mask verification and adjustment (SLSTR-L1B-CV-500)

Task Description

The purpose of this task is to check and verify the threshold-based cloud-mask in the level-1b dataset, and make adjustments to the auxiliary data sets where necessary. In addition, assuming a Bayesian Cloud Detection scheme is implemented, probabilities (flags or parameters) of cloud cover for different surfaces (i.e. open ocean, sea-ice, land) should be verified and compared with the threshold cloud scheme. As a third part to the task, the SSES and quality level fields within the L2P should be investigated for utilising the Bayesian cloud probabilities.

Aim and objectives

- Verification of level 1b threshold-based cloud mask. Since the cloud detection scheme is based on AATSR, adjustments should be made to adapt to the SLSTR wider swath and analysis and adaptations made for the additional channel tests. Adjustments on the thresholds and coefficients in the cloud detection auxiliary datasets should be performed.
- Verification and comparison of Bayesian probabilities (if supplied) with threshold-based cloud detection tests. Auxiliary LUTs supplied as part of the Bayesian Cloud Detection should be adjusted and tuned in the commissioning period.
- Analysis of recommended threshold probabilities for NWP and climate purposes if Bayesian Cloud Detection used.
- Investigation and recommendation of use of L2P SSES and quality level information as a way of recording and utilising the Bayesian Cloud Detection probabilities. This aspect is closely linked to task "6.2.4.1.9 Initial characterisation and validation of Sensor Specific Error Statistics".
Task Parameters for analysis

The following parameters will be analysed:

- L1b cloud flags and Bayesian cloud probabilities.

Methodology

- Analysis ‘by eye’ of selected scenes, and comparison to model fields and image data. Intercomparison of the threshold and Bayesian cloud schemes when both available.

- Comparison of threshold based cloud mask with Bayesian probabilities, and the recommended threshold values for NWP and climate purposes. Conversion of probabilities to a cloud-clear mask based on the recommended probabilities for direct comparison with the threshold mask.

- Analysis of proportion of perfect classifications, hit rate, false alarm rate and true skill score as described in RD 55.

Input/Output data needs

Input data requirements:

- SLSTR L1b and L2P data products
- Model data containing cloud fraction and total cloud cover.

Output data requirements:

- Update of L2P SSES based on recommendations of use of Bayesian Cloud Detection.

Required tools

Level 1b and L2P reader tools.

Anticipated results

At the end of phase E1 a report shall be provided on the verification and validation of both cloud masks where used, including recommendations of thresholds and coefficients for the cloud detection auxiliary dataset, thresholds probabilities for NWP and climate purpose for the Bayesian method, and recommendations into the use of L2P SSES for communicating the use of Bayesian Cloud probabilities. Throughout E2, continual update of results as plots, statistics and assessments shall be produced.

Task schedule

This task shall start as soon as SLSTR-L1b data is available. The verification and comparison of cloud detection methods, and the update of the auxiliary LUT for both cloud detection schemes, shall be completed in phase E1. The tasks to recommend probability thresholds, and to investigate and recommend the use of L2P SSES and quality level information, shall begin in phase E1 and continue through phase E2, with further assessments of the LUT when needed.
6.2.4 Task Definitions for SLSTR Level 2 Products

<table>
<thead>
<tr>
<th>MRTD key requirement (further associated req.)</th>
<th>S3 Product ID</th>
<th>Major Uncertainty Source</th>
<th>→ Cal/Val Tasks</th>
<th>Respons. Schedule</th>
<th>Status</th>
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<tbody>
<tr>
<td><strong>S3-MR-400: Performance:</strong> Sentinel-3 shall provide SST measurement capability to at least the quality of AATSR on Envisat. SST shall be accurate to &lt; 0.3 K @ 1 km spatial resolution and with improved swath coverage. (S3-OB-1: Primary - Continuity) (S3-OB-2: Primary - L1b) (S3-MR-80: Service continuity) (S3-MR-350: Performance) (S3-MR-540: Geographic coverage) (S3-MR-590: Geometric coverage) (S3-MR-750: Spatial resolution) (S3-MR-940: Dynamic range) (S3-MR-980: Radiometric stability) (S3-MR-1170: Validation) (S3-MR-1180: Service Data Products) (S3-MR-1190: Service data products)</td>
<td>SLSTR-SST</td>
<td>Product format Bias Geolocation uncertainty Mask uncertainty Cloud flag uncertainty Retrieval uncertainty Processor uncertainty Ice uncertainty Calibration uncertainty</td>
<td>Product Validation (SLSTR-SST-CV-100)</td>
<td>E1: after SIOV E2: ongoing</td>
<td></td>
</tr>
<tr>
<td><strong>S3-MR-420: Performance:</strong> Sentinel-3 shall be able to measure Land Surface Temperature (LST) to an accuracy of &lt; 1 K with a resolution of 1 km at nadir. This capability shall not reduce the quality of the SST retrievals. (S3-OB-1: Primary - Continuity) (S3-OB-2: Primary - L1b) (S3-MR-80: Service continuity) (S3-MR-530: Geographic coverage) (S3-MR-750: Spatial resolution) (S3-MR-940: Dynamic range) (S3-MR-1170: Validation) (S3-MR-1180: Service Data Products) (S3-MR-1190: Service data products)</td>
<td>SLSTR-LST</td>
<td>Product format Bias error Geolocation uncertainty Mask error Cloud flag uncertainty Retrieval uncertainty Processor uncertainty</td>
<td>Product Validation (SLSTR-LST-CV-100)</td>
<td>E1: after SIOV E2: ongoing</td>
<td></td>
</tr>
</tbody>
</table>

Table 18 – SLSTR L2 Cal/Val Task definitions
6.2.4.1 SST product validation (SLSTR-SST-CV-100)

Task Description

The purpose of this activity is to validate the SLSTR SSTskin product SLSTR-SST using a variety of reference data. This includes activities to validate the SSTs using in situ data from the drifting and moored buoy networks, along with ship-board radiometer data, and performing inter-comparisons using level 4 SST analyses. These activities can begin in phase E1 and continue in phase E2. There are also a number of essential tasks needed in phase E1 to tune the SST retrieval, and provide uncertainty estimates from initial comparisons with drifting buoys. The monitoring of volcanic aerosol and desert dust is also necessary to allow the optimum weighting of “best SST” algorithm to be chosen, according to the pixel-level aerosol conditions.

Aim and Objectives

The aim of this task is to demonstrate that the SLSTR-SST product complies with mission requirements S3-MR-400 and S3-MR-980.

The following Objectives are defined:

In Phase E1

- Preparations for SLSTR on-orbit SST Product Cal/Val (Subtask SLSTR-SST-CV-110).
- Adjustment of offset coefficients to improve the inter-algorithm consistency and recomputation of SST retrieval coefficients (Subtask SLSTR-SST-CV-115) (E1-CRIT).
- SST Bias Characterisation: Inter-satellite comparisons (Subtask SLSTR-SST-CV-120) (E1-HIGH).
- SST Bias Characterisation: with in-situ measurements (Subtask (SLSTR-SST-CV-130) (E1-CRIT).
- SST bias Characterisation: inter-algorithm comparisons (Subtask SLSTR-SST-CV-135) (E1-CRIT).
- Monitoring of volcanic aerosol conditions, and exercise to determine when to switch to N3R (Subtask SLSTR-SST-CV-140) (E1-CRIT).
- Monitoring of desert dust conditions, and exercise to determine when to switch algorithms (Subtask SLSTR-SST-CV-150) (E1-CRIT).
- Inter-comparisons with operational SST analyses (Data driven and model outputs) (Subtask SLSTR-SST-CV-155) (E1-HIGH).
- Initial characterisation and validation of SST errors (SSES) (Subtask SLSTR-SST-CV-160) (E1-CRIT).
- Execution of dedicated in situ validation campaigns (E1-CRIT).
- Collection of in situ ground truth data over ocean sites and from the GTS (E1-CRIT).

In Phase E2

- Monitoring SST Bias Characterisation: Near Real Time (NRT and NTC) SST measurement validation (Subtask SLSTR-SST-CV-130) (E2-CRIT)
- Monitoring SST Bias Characterisation: On-going Inter-satellite comparisons (Subtask SLSTR-SST-CV-120) (E2-HIGH)
Monitoring SST Bias Characterisation: Inter-algorithm comparisons (Subtask SLSTR-SST-CV-135) (E2-CRIT)

On-going collection of in situ ground truth data over ocean sites and GTS (E2-CRIT)

On-going monitoring, characterisation and validation of SST errors (SSES) (Subtask SLSTR-SST-CV-160) (E2-CRIT)

On-going monitoring of volcanic aerosol conditions for the determination of use of N3R (Subtask SLSTR-SST-CV-140) (E2-CRIT)

On-going monitoring of desert dust conditions for algorithm order determination (Subtask SLSTR-SST-CV-150) (E2-CRIT)

HR-DDS activities (E2-HIGH)

Task Parameters for analysis

The following parameters will be analysed:

- L2P SSTskin measurement
- D2/D3/N2/N3/N3R SSTskin measurements
- Differences between SLSTR SSTskin measurements and [drifting buoy, Moored buoy, Argo, ship-board radiometer, L4 SSTanalysis, satellite (AATSR, IASI, AVHRR, VIIRS, AMSR2, SEVIRI, SLSTR SST algorithms and S3A/B, where available)]

Methodology

- Inter-comparisons between in situ data and retrieved SSTskin measurements shall form the basis of the validation.
- Uncertainties in both satellite and in situ data shall be defined in all related analyses as an uncertainty table.
- SSTdepth measurements derived from the global drifting buoy array and ARGO array shall form the operational in situ validation data set, including the use and separate identification of high stability SST sensors on buoys. These will be complemented by NWP surface wind speed estimates to assess the state of thermal stratification in the upper ocean that may lead to errors in the validation process: in thermally stratified ocean conditions the buoy SST may be measuring water that is significantly cooler at depth compared to the satellite measurement in the top 10um of the ocean.
- Ship-borne radiometers, traceable to SI standards, shall be used as regional reference data sets to confirm the global operational validation statistics. It is highly desirable that at least 10 regular-repeat measurement lines are established covering all climatological atmospheric regimes for this purpose.
- SSTdepth measurements will be converted to a pseudo-skin SST measurement for direct comparison with SLSTR SSTskin measurements, using either a model or empirical correction method.
- All in situ measurements shall report the depth of measurement.
- SSTdepth measurements derived from the operational network of moored buoys shall complement the drifting buoy array. Moored buoys from the tropical moored buoy arrays should be identified and used separately to the coastal moored buoys.
• SSTdepth measurements derived from the Argo profiling floats when at the Surface (<7m depth) shall complement the drifting buoy array. Effort is required to establish the exact depth of Argo surface layer temperature measurements on a case-by-case basis (at least by operator).
• SSTskin measurements form in situ ship mounted radiometers in regional deployments shall complement the drifter data as they provide independent and SI standards-traceable measurements of SSTskin (i.e. exactly the same quantity measured by SLSTR). They also provide a method of “bridging the gap” between AATSR and SLSTR.
• Global inter-comparisons with other satellite SST data will be used to check for consistency of SLSTR SSTskin measurements.
• Global inter-comparisons with L4 SST analyses will be used to check the consistency of SLSTR SSTskin measurements on a daily basis.
• Near real time validation and on-line activities shall run continuously for the entire mission duration.
• Offline and delayed mode validation activities shall run continuously for the entire mission duration.
• Inter-algorithm comparisons between SLSTR SSTskin measurements from the single algorithm SST internal products will be used to check for consistency of the SLSTR SSTskin measurements.

Input/Output data needs

Input data requirements:
• Continuous access to SLSTR-SST products in NRT.
• Operational L4 SST analysis (e.g. Met Office OSTIA product).
• Quality controlled in situ drifting buoy data in NRT.
• Quality controlled moored buoy data (from coastal and tropical moored buoy arrays).
• Quality controlled Argo data.
• Quality controlled SI-standards traceable ship-mounted radiometer data.
• Near contemporaneous satellite SST data which could include IASI, AVHRR, SEVIRI, VIIRS, AMSR2, MODIS where available.
• Updated buoy black-lists SST data, analyses, and auxiliary data when available.
• Observation minus analysis and Observation minus background statistics from ocean model data assimilation systems.

Output data:
• SLSTR Matchup Dataset containing satellite imagette data (from SLSTR and other near contemporaneous satellite SST), metadata and near-contemporaneous (matchup within +/- 50km and +/- 2 hours) in situ data. Daily, weekly, monthly, global and regional time-series of bias ($\Delta$SST (SLSTR minus in situ SST)), standard deviation, number of matchups for all comparisons.
• Global maps of bias, standard deviations per pixel for all in situ types.
• Gridded into 5-degree boxes and mapped: biases; standard deviations (including multi-way
and uncertainty estimations) for all in situ types on a monthly basis.

• Other analyses delivered by regular hard copy report and via web interface.

• During Phase E1, there may be limited scope to perform this task due to SLSTR-SST data availability and it is expected that only test cases shall be used over specific infrastructure. However, the Matchup Dataset should begin to be populated as soon as SLSTR Level 2 data is available using all available in situ sources.

**Required tools**

The following tools are required to perform this task.

• Analysis tool to extract SLSTR data over in situ locations (and for n by n boxes) and perform matchups between in situ and SLSTR (a matchup engine service, or local IDL, Matlab tools).

• A dedicated multi parameter Matchup database with analysis and visualization functions (MDB, relational database or related computer data files) containing globally distributed matchup data (satellite data and matched in situ SST data, supporting surface wind and other auxiliary meteorological data). The ESA Felyx project [http://hrdds.ifremer.fr/](http://hrdds.ifremer.fr/) provides the basic starting point for this tool.

Tools are required in Phase E1 and Phase E2 activities and could be shared.

**Anticipated results**

• Separate analyses and statistical reports for D3, D2, N3, N2, N3R and L2P.

• Daily, weekly, monthly, global and regional time-series of bias, standard deviation, number of matchups for all comparisons.

• Global maps of bias, standard deviations per pixel for all in situ types.

• Gridded into 5-degree boxes and mapped: biases; standard deviations (including multi-way and uncertainty estimations) for all in situ types.

• Bias plotted versus latitude, satellite zenith angle, wind-speed.

• Histograms of bias and standard deviations (with respect to in situ; compared to other S3 single SST products; other satellite data and SST analyses).

• All separate analyses for day and night; per quality level; varying collocation with graded match-up criteria.

• Global maps of uncertainties.

• Comparisons of theoretical uncertainty versus Single Sensor Error Statistics (SSES): check distribution of errors globally and against water vapour, wind speed.

• Full statistical analysis: global, plus regional (e.g. OSI-SAF/MyOcean mask), including the use of robust statistics.

• Bias versus standard deviation of SST in an n by n grid box.

• Global maps of differences with L4 analyses such as OSTIA and HadISST.

• Hovmoller diagrams of bias against time and latitude.

• Scatterplots and correlations between two collocated observation types e.g. satellite and radiometers.
• Satellite inter-comparison analyses and links with existing systems, for example, such as those available from the GHRSSST HR-DDS and NESDIS Squam web-pages.

Task Schedule
This task shall start as soon as SLSTR-SST data are available. This task shall run for the duration of the mission, ideally across Phase E1 and E2. The collocation of SLSTR SST data with in situ data to provide a MD should begin as soon as level 2 SLSTR SST data is available. The collocations should be updated daily with in situ data daily, and continually with SLSTR data. As some in situ data is provided in a delayed manner to the GTS, and ship-board radiometer data may be added later, there should be scope for collocations to be re-extracted for past data. Some analyses (including time-series, histograms, difference maps per pixel, OSTIA) should be performed daily and displayed on a web-page, whilst other can be provided weekly or monthly as they depend on the collection of a large amount of data (gridded maps, HadISST, uncertainty analyses).

6.2.4.1.1 Preparations for SLSTR on-orbit SST Product Cal/Val (SLSTR-SST-CV-110)

Task Description
This task is designed to prepare the necessary tools and activities prior to SLSTR E1 SLSTR_SST product validation activities. At the end of this task all tools, teams and systems shall have been prepared, tested and validated. This task is defined as E1-CRIT.

Aim and Objectives
The aim of this task is to prepare all required teams, tools, systems and activities required to validate SLSTR_SST products.

The following objectives have been established for this task:

• Matchup Dataset (MDB) creation, test and verification.
• Matchup engine test and verification.
• Inter-comparison of validation radiometers and other reference in situ data completed.
• Operational in situ data access, data flow and QC test and verification, and the use of black-lists.
• Global data extraction and extraction of child products for satellite data, in situ data, and collocated matchups. The ability to sub-set data to perform separate retrieval tests and validation should be possible, alongside the requirement to be able to reprocess from Level 0 through to level 2. The collocation method should be flexible, and models such as skin to sub-skin models should be able to be used in conjunction with the tool to adjust the SSTs to be able to compare similar geophysical quantities.
• Comparison tool for operational SST analyses.
• Satellite inter-algorithm comparison tool test and verification, including against a reference sensor.
• SLSTR inter-algorithm comparison tool and verification, including against a reference algorithm.
• Volcanic aerosol conditions monitoring tool, and a tool/operator to allow the switch to volcanic aerosol conditions for specific latitude bands.
• Desert dust monitoring tool. A method to re-order the algorithms and update the flags should be possible based on the result of the desert monitoring tool.
• SSES derivation and assignment tool.
• SLSTR product test and analysis tools (range checks, cloud check, mask check, flag check, range check, etc) test and verification, Geolocation test data and tools test and verification including use of GPP.
• Operational extraction of sub-scenes for Cal/Val test and verification.
• Statistical and visualisation tool to analyse extracted SLSTR and in situ collocations. This should include analyses required for all SST validation tasks.

Task Parameters for analysis
• None

Methodology
• Methodology is described for each sub-task in following sections
• Reports are generated according to sub-task requirements

Input/Output data needs
Input data requirements:
• Input data requirements are described for each sub-task in following sections
Output data requirements:
• Output data requirements are described for each sub-task in following sections

Required tools
• Required tools are described for each sub-task in following sections

Anticipated results
• Results are described for each sub-task in following sections

Task Schedule
This task shall start at the end of SIOV when SLSTR instrument data are available and have been processed to provide SLSTR_SST products.
This task shall end within the E1 Phase.

6.2.4.1.2 Adjustment of offset coefficients to improve the inter-algorithm consistency and re-computation of SST retrieval coefficients (SLSTR-SST-CV-115)

Task Description
This task is designed improve inter-algorithm consistency using the approach from the AATSR Reprocessing for Climate (ARC) project as described in (RD 19). The task is necessary to remove inter-algorithm biases per total column water vapour band, and to match the retrievals to a
reference algorithm. In addition, re-computation of the pre-launch SST retrieval coefficients should take place in E1 if necessary. This task is defined as E1-CRIT.

**Aim and Objectives**

The aim of this task is to adjust the offset coefficients for all elements of the algorithm LUT.

The following objectives have been established for this task:

- Re-compute the pre-launch SST retrieval coefficients in phase E1 if necessary.
- Adjust the offset coefficient in each total column water vapour band to match results from a reference algorithm.
- Determine method of choice of reference algorithm and channels.
- Update coefficient LUTs.

**Task Parameters for analysis**

- D2/D3/N2/N3/N3R SSTskin measurements
- SLSTR L1b data

**Methodology**

- Follow method described in [RD 18].

**Input/Output data needs**

Input data requirements:

- all parameters for analysis

Output data requirements:

- Updated coefficient LUT

**Required tools**

- Tool to analyse algorithms with regard to a reference algorithm, which may or may not be based on the channels used for the single SST products, and determine the offset coefficient adjustments for each total column water vapour band.
- Tools to evaluate the retrieval coefficients, for example, based on the AATSR for Climate approach adopted at the University of Edinburgh [RD 18].

**Anticipated results**

- Update the algorithm LUT to implement the offset adjustment, and overall retrieval coefficient derivations.

**Task Schedule**

This task shall take place in the Commissioning phase and be complete by the end of phase E1. There should be the possibility of re-evaluating the exercise in phase E2.
6.2.4.1.3 SST Bias Characterisation: Inter-satellite comparisons (SLSTR-SST-CV-120)

Task Description
This task will perform regular extractions of SLSTR-SST products and compare these to near contemporaneous satellite data with similar spectral characteristics and viewing geometry. The outputs of this task allow an assessment of the SST product accuracy, spatial homogeneity and cloud clearing. In addition to inter-comparisons using extracted data around targets, global comparisons and time-series will also be performed. This task is defined as E1-HIGH and E2-HIGH.

Aim and Objectives
The aim of this task is to perform regular inter-comparisons between SLSTR-SST products with other satellite data SST products.

The following objectives are defined:

- Inter-comparisons with other satellite data products for targets sites.
- Inter-comparisons with other satellite data for global time-series and maps.

Task Parameters for analysis

- L2P SSTskin measurement
- D2/D3/N2/N3/N3R SSTskin measurements
- Differences between SLSTR SSTskin measurements and AATSR, IASI, AVHRR, VIIRS, AMSR2, SEVIRI, satellite SST data and between S3A and B as available.

Methodology

- SLSTR-SST and SLSTR_L1B child products shall be extracted for the target sites listed in Table 26. The target sites have been reviewed and endorsed by the International GHRSST Science Team (Table 28). A map of the site locations is given in Figure 18.
- Satellite SST product and L1B data from other satellite instruments (including AATSR, SEVIRI, AVHRR, IASI and other GHRSST products as available) are extracted over target sites (including around an n by n box) listed in Table 28.
- Access to global SLSTR and other satellite data for collocations, comparisons, anomaly difference maps and time-series.
- Satellite products are ingested into the inter-comparison tool.
- The inter-comparison tool shall provide reports of SST bias, variability and other statistical measures for each target site. The tool shall provide the ability and flexibility to do global difference anomaly maps and time-series for inter-comparisons with specified other satellite SST data (not necessary all that are available).
- Inter-comparison results (spatial and numeric time series at each site) shall be available for users at an open web portal, and the global anomaly difference maps and time-series.
Table 19 – GHRSSST defined SST site categories

The purpose of the HRDDS sites is to provide a provide a manageable data set for all SST EO data sets (for example AATSR, MODIS, AMSRE, TMI, AVHRR, and other GHRSSST data as available) that are distributed in a manner that provides adequate sampling of atmospheric variability that impacts the SST retrieval process. In addition sites over the marginal ice zone and over semi-permanent in situ infrastructure are provided. In all, 255 sites are provided. In some cases at primary sites, data from the in situ observing system is also available from the HRDDS, for example at the TRITON buoy sites; where possible the name of the sites includes the World Meteorological Organisation (WMO) identification number of the relevant mooring or installation, thus further easing the acquisition of ancillary data by the user.

Table 19 – GHRSSST defined SST site categories

<table>
<thead>
<tr>
<th>Site Type</th>
<th>No. Sites</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>63</td>
<td>Primary sites are positioned at the location of operational in situ observing systems, or established non-operation long time series in situ observing systems. These sites are mostly in the tropical or northern Atlantic and Pacific.</td>
</tr>
<tr>
<td>Secondary</td>
<td>77</td>
<td>Secondary sites are located over areas of abnormal atmospheric or oceanic conditions, or over oceanographically representative areas. They are globally distributed.</td>
</tr>
<tr>
<td>Partner</td>
<td>21</td>
<td>Partner sites are generated at the request of third parties. For example, sites have been added for the Russian State Hydrometeorological University, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Met Office and others.</td>
</tr>
<tr>
<td>GlobColour</td>
<td>17</td>
<td>GlobColour sites have been added to match the initial set of DDS sites to the ESA GlobColour project. The provide a link between the two projects.</td>
</tr>
<tr>
<td>Polar</td>
<td>45</td>
<td>Polar sites where added at the request of EUMETSAT, in order to validate SST from the MetOp-A satellite.</td>
</tr>
<tr>
<td>Coastal</td>
<td>32</td>
<td>Coastal waters, enclosed seas and lakes. Sites are only classified in this group if they do not fall into any other classification</td>
</tr>
</tbody>
</table>

Figure 18 - Location of GHRSSST HRDDS Sites A table with coordinates of reference site can be found in Annex 1 – Chapter 8.2

Input/Output data needs

Input data:

- All SLSTR L2b (D3, D2, N3, N2, N3R) and L2P full orbit products.
- All SST products from participating satellite instruments (e.g. AVHRR, AATSR, IASI, SEVIRI, MODIS, TMI, VIIRS, AMSR2, as available)
- L4 SST analyses
- In situ data (moored and drifting buoys)
• NWP fields (surface Wind)

Output data:
• Target site data granules via download from inter-comparison tool.
• Daily statistical reports, maps and time series at each target site and globally showing bias, variability and other estimators.
• Global inter-comparisons, anomaly time-series, maps and reports.

**Required tools**
• Operational child product extraction of other satellite data sets.
• Inter-comparison and analysis tool.
• Inter-comparison web site for visualisation.
• Global data analysis, comparison and visualisation tools.

**Anticipated results**
• Image data that can be used to QC SLSTR_L2P data on a daily basis
• Daily statistical reports
• Anomaly reports in NRT if problems are detected

**Task Schedule**
This task shall start in Phase E1.
This Task shall be continued throughout E2, and updated daily.

6.2.4.1.4 **SST Bias Characterisation: Comparisons with in-situ measurements (SLSTR-SST-CV-130)**

**Task Description**
This task will compare SLSTR-SST measurements with near contemporaneous in situ SST measurements to validate the SST retrieval algorithm and monitor its performance. The task involves the collocation of SLSTR-SSTs with in situ data from drifting and moored buoys, Argo, and ship-board radiometers, with the flexibility to collocate observations with AVHRR and SEVIRI SSTs at a later date. Extraction of the in situ data and collocation of the satellite and in situ data should be performed continually, with the ability to add more in situ data, especially within the previous month as it becomes available either from the GTS or offline. The ability to add further auxiliary and meteorological data to the dataset should be possible, including quality control information of the in situ data (black-lists, uncertainties, flags). The possibility to use varying locations of extractions should be possible due to the mobile nature of drifting buoys and Argo profilers, and allow extractions of a specified region (n by n) around a target. The priorities for this task are listed in Aim and Objectives.
Aim and Objectives

The aim of this task is to validate the SLSTR-SST SSTskin retrieval algorithm and L2P products using in situ reference data.

The following Objectives are defined:

- Validation using in situ ship mounted radiometers.[E2-CRIT]
- Validation using in situ drifting buoy measurements, including higher accuracy drifting buoy data (HRSST). [E1-CRIT, E2-CRIT]
- Validation using Argo drifting float data in the surface layer.[E2-CRIT]
- Validation using moored buoy measurements (using coastal [E2-MED] and the tropical moored buoy array separately [E1-HIGH, E2-CRIT]).

Task Parameters for analysis

- L2P SSTskin measurement
- D2/D3/N2/N3/N3R SSTskin measurements
- L2P SSES and theoretical uncertainty

Methodology

The measurement protocols are defined in the AATSR Validation Measurement Protocol (VMP), which is part 2 of the AATSR Validation Implementation Plan. Validation principles and definitions are defined in the AATSR Validation Principles and Definitions (RD 49 and ref. therein)

The operational data set that shall be used for validation of SLSTR is the drifting buoy array providing SSTdepth measurements adjusted and/or filtered to account for thermal stratification of the surface ocean during the day.

The reference data set to be used for SLSTR validation shall be independent SI-traceable measurements form ship mounted infra-red radiometer systems deployed on a number of regular transit likes that span the variability of atmospheric states.

Additional reference data shall be derived from maintained global moorings (as part of the tropical moored array) and from Argo floats. Both data sets need to be adjusted for the impact of diurnal stratification (diurnal thermocline).

Comparison to ship mounted radiometers

Ship mounted IR radiometers provide accurate (~0.1K) SSTskin measurements and those used for SLSTR validation shall be traceable to SI standards following agreed protocols (e.g. CEOS/NPL in situ radiometer inter-comparison exercises). Ship-mounted radiometers measure exactly the same physical parameter (the SSTskin temperature) as SLSTR and provide independent validation data. Sufficient deployments are required to span the atmospheric conditions under which the SLSTR retrieval algorithm is valid. Deployments shall target at least: Tropical, mid latitude and high latitude regions.

Independent ship-mounted radiometer are essential reference data to link SLSTR to the long term (A)ATSR data set.

The collection of ship-mounted radiometer measurements shall start during Phase E1, and continue throughout Phase E2.
**Comparison with in situ drifting buoy networks**

In situ drifting buoys provide an operational in situ data source for SST validation activities and are maintained by the Data Buoy Cooperation Panel (DBCP). Drifting buoys measure the SST at depth (SSTdepth) that is typically between 0.1 -1 m depending on the buoy design, sea state and surface wind speed. SST measurements from drifting buoys are accurate to ~0.2K and are not traceable to SI standards (although efforts are being made to address this issue). For SLSTR validation, SSTdepth measurements must be adjusted to provide a measure of the SSTskin that is free of thermal skin effect and diurnal stratification. Diurnal stratification of the upper ocean occurs in conditions of low wind speed and high solar radiation leading to a warming of the upper few metres of the ocean. Diurnal warming can reach magnitudes of >4 K (RD 50, RD 51). Adjustment of SSTdepth to SSTskin is typically made using a model based approach (RD 20) providing sufficient forcing data is available or by filtering the validation data set for low wind speed (< 6m/s) day-time data and applying an offset of 0.17K (RD 17). The latter approach is considerably easier to implement and is found to be robust.

Moored buoys provide SSTdepth measurements at a variety of depths typically ranging from 0.25 and deeper in the tropical Atlantic, Pacific and Indian Oceans. Additional moored bouys are maintained in shelf regions. Sensors are recalibrated on a regular (typically 6 months or longer) basis. SSTdepth measurements must be adjusted to provide estimates of the SSTskin in the same manner as drifting buoys before they are used in SLSTR validation analyses.

SST measurements from ships are not generally used for satellite SST validation activities as they are often of poor quality. Significant biases due to warming of ships pumped water supplies are often found. Nevertheless, if well maintained and installed correctly, some ship SST measurements are of a suitable quality for SST validation work.

Strict and severe quality control of the input data should take place before any matchup analysis.

The bias and standard deviation calculated from the comparison to the reference dataset are derived from a database of match-up coincidences produced within predefined spatial and temporal limits; the current GHRSST match-up limits are ±25 km, and ±6 hours. These figures shall be treated as extreme values and all effort should be made by validation teams to provide contemporaneous matchup data. Methods of multi-sensor match-up processing e.g. (RD 24, RD 51), should be used to understand global and regional biases and uncertainties.

Validation activities can be listed as NRT (3-hours), online (1-day), offline (1-month), and delayed (re-processed). The level-2 validation activities are described separately according to the different time-scales, with the accuracy indicated.

Global validation activities are broad-scale such as drifting buoys, other satellite data and SST analyses. Measurements from the tropical moored buoy arrays and observations from ship-board radiometers provide higher accuracy measurements. Argo and higher accuracy drifting buoy data do have global distributions, but the quantity of sensors is much less than drifting buoys.

**Comparison with Argo**

Argo near surface profile measurements shall be used for the validation of the satellite SSTs. Argo profiling floats measure the temperature and salinity between the surface and depth (around 2000m) every 10 days with the transmission of the data by satellite. In order to be of use for satellite SST validation, un-pumped data should be used where the profilers continue to record the temperature up to the surface rather than stopping at 5dB. Argo data provides highly accurate measurements over global scales. Care must be taken to ensure that the depth of SST
measurement is accurately known and appropriate adjustments made to correct for SSTdepth and SSTskin differences as for drifting buoys.

**Summary of tasks, prioritised by scale or accuracy**

- Large-scale drifting buoy comparisons. The drifting buoys have a global accuracy of around 0.2K. Accurate adjustment for SSTskin and SSTdepth is required.
- Comparisons with Argo. Accurate adjustment for SSTskin and SSTdepth is required.
- Comparisons with coastal moored buoys and TAO/PIRATA/Indian Ocean moored buoy arrays (global accuracy of ~0.12K (RD 22). Accurate adjustment for SSTskin and SSTdepth is required.
- Information on uncertainties and quality flags on in situ, EO, and auxiliary data should be able to be updated, before the offline validation begins. For example, the utilisation of the Meteo-France buoy blacklist should be incorporated.
- Comparisons with radiometers on ships of opportunity (e.g. ISAR (RD 18) and SISTeR (RD 23).
- Further GTS extractions and comparisons of drifting buoys and HRSST (HRSST accuracy 0.05K, see https://www.ghrsst.org/ghrsst-science/science-team-groups/stval-wg/dbcp-ghrsst-pilot-project/). Accurate adjustment for SSTskin and SSTdepth is required.
- Comparisons with Argo (most data is available within 24-hours from the GTS, but delayed mode scientifically quality controlled data is also available). Accurate adjustment for SSTskin and SSTdepth is required.
- Comparisons with GTMBA (accuracy 0.12K) and any updated coastal moored buoy information. Accurate adjustment for SSTskin and SSTdepth is required.

**Delayed mode activities (longer than 1 month for in situ to arrive):**

- Update all comparisons with new in situ data.
- Updated auxiliary data (e.g. ERA-interim, OSI-SAF sea-ice products).
- Updated quality control and black-lists should be used and matchup data reprocessed (or method to update flag in current extractions available).
- Repeat all validation analyses with updated satellite, in situ, and auxiliary data.
- Validation of theoretical uncertainties.

**Input/Output data needs**

- Input data:
  - D3, D2, N3, N2, N3R and L2P SST products.
  - Access to all in situ data, updated when available.
- Output data:
  - Quality control data and buoy black-lists.
  - Analyses and statistics through visualisation and web interfaces.

**Required tools**

- Tools to perform multi-way comparisons (e.g. in situ and two plus satellite sources) both at Level-2 level (e.g. SST-CCI, (RD 24, RD 25) and level-2/3/4 (RD 54) should be developed, to gain information on standard deviations of differences and uncertainties.
• Evaluation of processor upgrades, new coefficients and new algorithms should be able to be tested on extractions, allowing multiple streams for Cal/Val.

• Application of skin to sub-skin SST models to allow a true validation comparisons in cases when comparing SSTs at different depths (e.g. drifting buoys and satellite skin) and in different atmospheric conditions is mandatory including the use of diurnal variations models.

• Web visualisation tools for time-series, maps, and statistical reports for target sites (and nxn boxes) and globally).

• Tools to be able to sub-set and select random data for different purposes (e.g. validation, retrieval developments).

Anticipated results

• Knowledge of product error characterisation on global and regional scales (per algorithm).

• Analyses of global, regional biases and validation.

• Full statistical analysis for each algorithm using each in situ source.

Task Schedule

This task shall start in Phase E1.

This Task shall be continued throughout E2, and be updated on a daily basis for near-real time data. Recently acquired older in situ data, and updated other auxiliary data will be imported and the collocation, extraction and analysis repeated.

6.2.4.1.5 SST Bias Characterisation: Inter-algorithm comparisons (SLSTR-SST-CV-135)

Task Description

This task will perform regular and continual comparisons between the SLSTR single SST products (D3, D2, N3, N2, N3R). The outputs of this task allow immediate identification of algorithm issues, and to analyse closely impacts such as dust, clouds, and inter-algorithm behaviours. This task is defined as E1-CRIT and E2-CRIT.

Aim and Objectives

The aim of this task is to perform regular and continual inter-comparisons between SLSTR single SST products (D3, D2, N3, N2, N3R).

Task Parameters for analysis

• L2P SSTskin measurement

• D2/D3/N2/N3/N3R SSTskin measurements

Methodology

• Comparisons will be made globally and for target sites between the single SLSTR SST retrievals.

• Single SLSTR SST products will be extracted over target sites (including around an n by n box).

• Access to global data for collocations, comparisons and time-series.
• Satellite products are ingested into an inter-algorithm comparison tool.
• The inter-algorithm comparison tool shall provide reports of SST bias, variability and other statistical measures for each target site, and globally.
• Inter-algorithm comparison results (e.g. spatial and numeric time series) at each site and globally shall be available for users at an open web portal.
• Analysis should be performed in NRT, offline, and for reprocessing activities.

**Input/Output data needs**

**Input data:**
- All single SLSTR SST L2 (D3, D2, N3, N2, N3R) and L2P full orbit products.
- Target site data granules via download from inter-algorithm comparison tool.

**Output data:**
- Global time-series and histograms of differences.
- Daily statistical reports and time series at each target site showing bias, variability and other estimators.

**Required tools**
- Inter-algorithm comparison and analysis tool.
- Inter-algorithm comparison web site for visualisation.

**Anticipated results**
- Time-series and histograms updated daily.
- Daily statistical reports.
- Anomaly reports in NRT if problems are detected.

**Task Schedule**
This task shall start in Phase E1.
This Task shall be continued throughout E2.

6.2.4.1.6 Monitoring of volcanic aerosol conditions, and exercise to determine when to switch to N3R (SLSTR-SST-CV-140).

**Task Description**
This task will perform regular and continual monitoring of the SLSTR single SST products (D3, D2, N3, N2, N3R) and L2P to identify when stratospheric loadings of volcanic ash may be impacting the quality of the SST retrievals. In principle, the dual-view capability of SLSTR is robust to such effects. However the larger single-view swath of SLSTR at nadir will not be robust in these atmospheric conditions. When volcanic ash is detected, then the algorithm order priority will change as described in (RD 15). These changes will be implemented throughout relevant latitude bands, with the ability to be continually updated. This task is defined as E1-CRIT and E2-CRIT.
Aim and Objectives

The aim of this task is to perform regular and continual monitoring of volcanic ash conditions impacting the SLSTR SST products (D3, D2, N3, N2, N3R, L2P).

Task Parameters for analysis

- L2P SSTskin measurement
- D2/D3/N2/N3/N3R SSTskin measurements
- SLSTR L1b data
- Others e.g. external satellite aerosol data tbc

Methodology

- A pre-launch activity to identify which level of volcanic ash loadings are necessary to cause the algorithm order priority to be switched is needed.
- The method of identifying the volcanic ash loadings should be confirmed with a pre-launch activity. The use of SLSTR channels S8 and S9 could be considered e.g. using method such as the “reverse-absorption” technique (RD 26), for which an activity is still necessary to determine the detection thresholds.
- The method developed pre-launch should be applied per orbit and continually from the commissioning phase, to monitor and identify cases of significant volcanic aerosol loadings.
- The volcanic ash monitoring tool shall provide reports of volcanic ash loadings and when they have exceeded a threshold level (in order for the algorithms to be switched in the case of “volcanic aerosol conditions”) for each target site, and globally.
- Provision to switch to “volcanic aerosol condition” for a specified range of latitudes (to be updated weekly after an eruption), and following the recommendations and re-ordering of algorithm priorities as described in (RD 15).
- Analysis should be performed in NRT, online, offline, and for reprocessing activities when deemed appropriate.

Input/Output data needs

Input data:

- All single SLSTR SST L2 (D3, D2, N3, N2, N3R) and L2P full orbit products.
- Aerosol data tbc.
- Daily reports of analyses and identification when volcanic aerosol conditions occur.

Required tools

- Volcanic aerosol analysis and monitoring tool.
- Volcanic aerosol web site for visualisation.
- Tool/operator to allow switch to volcanic aerosol conditions for specific latitude bands, to be updated on a weekly basis following an eruption.

Anticipated results

- Monitoring analyses updated daily.
- Anomaly reports in NRT if problems are detected.
• Switch to volcanic aerosol conditions for specific latitude bands when necessary.
• Update ordering of algorithms for volcanic ash conditions and flag accordingly.

**Task Schedule**

This task shall start in Phase E1.

This Task shall be continued throughout E2 on a continual daily basis.

**6.2.4.1.7 Monitoring of desert dust conditions, and exercise to determine when to switch algorithms (SLSTR-SST-CV-150).**

**Task Description**

This task will perform regular and continual monitoring of the SLSTR single SST products (D3, D2, N3, N2, N3R) and L2P to identify when desert dust may be impacting the quality of the SST retrievals. In principle, the dual-view capability of SLSTR is robust to such effects. However the larger single-view swath of SLSTR at nadir will not be robust in these atmospheric conditions. When desert dust is detected, then the algorithm order priority will change as described in (RD 15). These changes will be implemented for particular pixel locations, as identified by relevant flags or annotation datasets, with the ability to be continually updated. In addition L2P_flags in the L2P SST will be used to identify desert dust conditions. This task is defined as E1-CRIT and E2-CRIT.

**Aim and Objectives**

The aim of this task is to perform regular and continual monitoring of desert dust conditions impacting the SLSTR SST products (D3, D2, N3, N2, N3R, L2P), implementation recommendations of the ARC project, and as described in RD 21.

**Task Parameters for analysis**

• L2P SSTskin measurement
• D2/D3/N2/N3/NR3 SSTskin measurements
• SLSTR L1b data

**Methodology**

• A pre-launch activity to evaluate and update if necessary the method for an infra-red desert dust index as used for the ATSR’s and as described in (RD 21).
• The method developed pre-launch should be applied continually from the commissioning phase, to monitor and identify cases of desert dust at an observational level.
• The desert dust monitoring tool shall provide reports of desert dust and when they have exceeded a threshold level (in order for the algorithms to be re-ordered following RD 15) for each target site, and globally.
• Provision to re-order algorithm priorities as described in (RD 15)
• Provision to add a flag to QC-flags to identify that a pixel is affected by desert dust.
• Activity should be performed in NRT, offline, and for reprocessing activities.
Input/Output data needs

Input data:
  • All single SLSTR SST L2 full orbit products, and L1b data.
  • Other data tbc.

Output data:
  • Updated QC flags in L2P SST to identify when observations affected by desert dust.
  • Daily reports of analyses and identification including maps when desert dust occurs.

Required tools
  • Desert dust analysis and monitoring tool.
  • Desert dust web site for visualisation.
  • Tool/operator to allow re-ordering of algorithms for observations affected by desert dust, and updating QC_flags in L2P SST to reflect this.

Anticipated results
  • Monitoring analyses updated daily.
  • Anomaly reports in NRT if problems are detected.
  • Switch to desert dust conditions for specific pixels when necessary, and update QC_flags.

Task Schedule
This task shall start in Phase E1.
This Task shall be continued throughout E2 on a continual basis.

6.2.4.1.8 Inter-comparisons with operational SST analyses (SLSTR-SST-CV-155).

Task Description
This task will perform regular and continual monitoring of the SLSTR single SST products (D3, D2, N3, N2, N3R) and L2P with operational SST analyses. Daily and monthly level 4 analyses will be compared with SLSTR-SST data, and difference anomaly maps and statistics displayed on a web-page. This task is defined as E2-HIGH.

Aim and Objectives
To produce global anomaly maps, time-series and statistics of differences between SLSTR-SST and operational SST analyses. In addition level 4 climate SST analyses should be used to perform monthly comparisons. To give a real time indication of any global or regional issues in the data.

Task Parameters for analysis
  • L2P SSTskin measurement.
  • D2/D3/N2/N3/NR3 SSTskin measurements
  • Operational SST analyses.
Methodology

The SST analyses are provided in a gridded format with full data coverage, in contrast to the SLSTR swath data limited by cloud coverage. Therefore an activity to collocate the data should take place based on reducing the larger SST analysis grid to the SLSTR near-coincident observation and computing and storing averaged SST difference anomalies, relevant to the time validity of the level 4 analysis (e.g. daily or monthly). Time of day should be considered, for example only using night-time data to reduce the effects of diurnal variations in SST. The SST analyses report a foundation SST measurement, therefore the SST analysis data needs to be converted to a skin SST measurement to enable direct comparisons with the SLSTR data. This conversion can either be performed using Donlon et al, 2002 (but only for wind-speeds over 6m/s) or with the use of a skin effect model such as Fairall et al, 1996. Quality flags in both the SST analyses and SLSTR-SST data should be used to ensure only the best quality data is compared.

Input/Output data needs

Input data:

- All single SLSTR SST L2 full orbit products.
- Operational SST and L4 analyses such as OSTIA or HadISST.

Output data:

- Global maps of anomaly differences, time-series and statistical reports.

Required tools

- Extraction and reading tools for SST operational analyses.
- Satellite inter-comparison tool.

Anticipated results

- Monitoring analyses of anomaly differences updated daily, and displayed on a web-page.
- Anomaly reports in NRT if problems are detected.

Task Schedule

This task shall start in Phase E1. The activity should be performed in online, offline and for reprocessing activities.

This Task shall be continued throughout E2, on a daily basis for the inter-comparisons with operational SST analyses. Comparisons with climate level 4 SST analyses should be performed on a monthly basis.

6.2.4.1.9 Initial characterisation and validation of Sensor Specific Error Statistics (SLSTR-SST-CV-160).

Task Description

This task involves the derivation of the Sensor specific error statistic (SSES) bias and standard deviation values derived from drifting buoy comparisons in line with recommendations from GHRSSST-STVAL. This task is defined as E1-CRIT and E2-CRIT. Within the L2P SST file, the SSES
bias and standard deviation fields are filled from information from a LUT based on the quality level.

**Aim and Objectives**

The task should take place in the Commissioning phase to derive the SSES as input to the error LUT. A pre-launch activity is necessary to confirm methodologies and recommendations from AATSR SSES, however, final methodologies cannot be confirmed until at least E1 when characteristics of the data become apparent and an SSES scheme particular to these characteristics can be developed. Therefore, the derivation of the SSES should continue into phase E2 with 6-monthly updates thereafter as recommended by GHRSST. Evaluation of the theoretical uncertainty should also be performed, along with an assessment of the contribution to the overall retrieval uncertainty from cloud contamination in the channel brightness temperatures.

**Task Parameters for analysis**

- L2P SSTskin measurement.
- D2/D3/N2/N3/NR3 SSTskin measurements
- Global drifting buoy SST data.

**Methodology**

- Pre-launch activity to confirm methodology and implement tools to derive SSES based on AATSR and GHRSST recommendations.
- Collocation of global SLSTR SSTs (using all algorithm types) with drifting buoy SSTs.
- Follow the methodology used for AATSR and recommended by GHRSST to derive the SSES bias and standard deviations for each algorithm separately (D3, D2, N3, N2, N3R).
- Initial SSES should be derived by the end of phase E1, with six-monthly updates in phase E2.
- Refinements to retrieval error as function of number of adjacent pixels containing cloud.
- Monitoring and validation of SSES compared to theoretical uncertainty and standard deviations of errors determined from multi-way comparisons, should be performed in NRT, online, offline, and for reprocessing activities.
- The contribution to the overall retrieval uncertainty from cloud contamination in the channel brightness temperatures should be determined empirically through comparisons of SLSTR SST with in-situ buoy observations for different levels of cloud cover in neighbouring pixels. This should be done by comparing the root-mean-square deviation of the SST difference for clear-sky and cases with differing numbers of adjacent cloudy pixels. This method gives an estimate of the uncertainty contribution as a function of cloud cover in adjacent pixels, performed separately for each retrieval type.

**Input/Output data needs**

Input data:

- All single SLSTR SST L2 (D3, D2, N3, N2, N3R) and L2P full orbit products.
- Global drifting buoy SST data obtained from the GTS.
Output data:
- SSES bias and standard deviation for each quality level as input to SSES auxiliary file LUT.

**Required tools**
- Operational access to global matchups of SLSTR SST and in situ data for all algorithm types.
- Tools for compare and analyse uncertainties contained within the products (SSES, theoretical uncertainty) and those derived from other methods (e.g. multi-way comparisons).

**Anticipated results**
- Matchup database of SLSTR SSTs (for all algorithms) for target sites and all drifting buoy locations globally.
- Analyses of collocations and matchups following GHRsst guidelines.
- Report of initial characterisation in the Commissioning phase (by the end of phase E1).
- Implementation into LUT of initial characterisation by the end of phase E1.
- Six-monthly updates of SSES values for error LUT.
- Implementation on a six monthly basis or as recommended by GHRsst of updated error LUT.

**Task Schedule**
This task shall start in Phase E1 with the initial determination of the SSES method based on the characteristics of the data. This Task shall be continued throughout E2, with six monthly updates of the SSES bias and standard deviation based on recommendations from GHRsst-STVAL.

**6.2.4.2 LST product validation (SLSTR-LST-CV-200)**

**Task Description**
The land surface temperature product shall be validated and the long term performance shall be monitored

**Methodology**
In Phase E1
- Preparation for validation activities, including finalisation of protocols (Subtask SLSTR-LST-CV-210)
- Optimization of LST processing parameters
- LST Bias Characterisation: Inter-satellite comparisons
- LST Bias Characterisation: Comparisons with in-situ measurements
- Execution of dedicated in situ validation campaigns
- Initial characterisation and validation of LST error
In Phase E2

- Collection of in situ ground truth data over land sites
- Monitoring LST Bias Characterisation: Satellite inter-comparison of LST measurements
- Monitoring and maintenance of the LST geolocation
- Characterisation and validation of LST error following established protocols.

6.2.4.2.1 Preparations for LST Product Cal/Val (SLSTR-LST-CV-210)

**Task aim and objectives**

The objective is the validation of the land Surface Temperature. The quality of the final product depends largely on the quality of the AUXILIARY files used in input (Biomes, vegetation information, meteofiles) and on the quality of the pixel classification, including the cloud masking. Activities will be dedicated to the quality control of the AUX files.

**Parameters for analysis**

The analysed parameters will be:

- The LST
- The cloud masking
- The land/sea/lake mask
- The Biomes, fractional vegetation cover, water vapour

**Methodology**

- Matchup Database (MDB) test and verification
- Matchup engine test and verification
- Inter-comparison of validation radiometers and other reference in situ data completed
- Operational in situ data access, data flow and QC test and verification
- Satellite inter-comparison system test and verification
- SLSTR-LST product read and visualisation tools test and verification
- SLSTR-LST product test and analysis tools (range checks, cloud check, mask check, flag check, range check, etc) test and verification
- Geolocation test data and tools test and verification
- Operational extraction of sub-scenes for Cal/Val test and verification

The LST derived from SLSTR is the continuation of the LST provided by AATSR (with different swath/coverage and hopefully improved auxiliary data). Nevertheless, the validation activities will be the continuation of existing activities.
Similar to the other products, a four-phase approach is to be taken for LST validation:

- Comparison of satellite-retrieved LST with in situ measurements.
- Radiometric-based validation which consists of calculating the ground LST from TOA brightness temperatures simulated using surface emissivity and temperature data plus atmospheric profile data in a radiative transfer model.
- Inter-comparisons with similar LST products from other sources such as AATSR, AVHRR, MODIS, and SEVIRI.
- Time series analysis to quantify trends and to identify potential instrument drift.

In order to follow this approach, there will be a need:

- To provide validation measurements across a wider range of land surface biomes, so as to better represent the heterogeneity of landscapes,
- To support the implementation of new long-term in situ validation sites and carefully directed in situ field campaigns.
- To understand the role of atmospheric factors, such as clouds and aerosols, on the quality of the data.
- To improve understanding of the influence of temporal changes, such as vegetation phenology, soil moisture and snow, on land surface emissivity,
- To provide users with realistic uncertainty budgets. This allows the quality of the data to be included in climate analyses and data assimilation.
- The in-situ test sites still need to be defined, selected and assessed for suitability, both in terms of logistics and usefulness. A suitable site should be able to provide continual measurements, produce new insights into the accuracy of LST retrievals.
- The continuation of existing validation activities over a range of atmospheric conditions, and land surface emissivity changes is also essential for understanding long term trends in the accuracy, and to characterise instrument drift.
- In addition, the validation plan requests an increase in well-defined campaigns, like those such as SEN2FLEX and SEN3EXP.
- The data from continuous in-situ site measurements or well targeted campaigns shall be quality controlled and stored in a core validation database. This will amalgamate existing / developing databases, such as the UoL (University Of Leceister – currently in charge of AATSR LST validation) matchup database and the SEN4LST database, providing a single source for all LST users to access.
- During the campaign or continuous in-situ measurements, ancillary data such as emissivity, soil moisture and cloud base height, to be collected in addition to radiometric measurements. For homogeneous sites a single radiometer may be sufficient, providing the homogeneity of the landscape stretches beyond the limits of a satellite pixel. For heterogeneous sites each endmember need to be measured at the time of a satellite overpass. In areas of high topography or in landscapes of heterogeneous structure shadow effects to be modelled to enable a more accurate comparison with satellite retrieved LST.
- The In situ radiometers need to be re-calibrated and inter-compared at regular intervals to correct for potential instrument drift. See chapter on QA4EO.
- A core validation database should be developed and maintained in order to be able to support future coefficient and algorithm development. Once updated, it will be necessary
to reprocess all of the validation match-ups collected to date, to make a qualitative assessment of the improvement of the updated coefficients / algorithms. The quality of the data depends on the quality of the auxiliary data used for the processing (biomes map, water vapour...etc..) and also on the cloud masking. A particular attention will be paid to the quality control of the input auxiliary data. In addition, the effect of aerosol should be also quantified and possibly corrected.

- Inter-institutional coordination between those responsible for maintaining in situ sites and collecting data, and those responsible for developing the matchup database, analysing the validation data, and improving the algorithms is requested.

**Input/Output Data needs**

The LST, L1B over selected sites will be needed.

The sites will be determined at later stage.

The selection, characterisation and assessment of test sites need to be carefully done. As example, one can mention the sites that were used by AATSR validation program or Severi validation program:

The LSA-SAF sites: Evora, Portugal; Gobabeb, Namibia; Dahra, Senegal

The ARM sites: SGP, Oklahoma, USA; Niamey, Niger.

Others: Valencia, Spain – University of Valencia; Cardington, UK – UK Met Office, Australian sites.

**Required Tools**

- Extraction tools
- Level 3 tools
- Matchup database
- Satellite inter-comparison tools
- SLSTR-LST product read and visualisation tools test and verification
- SLSTR-LST product test and analysis tools (range checks, cloud check, mask check, flag check, range check, etc) test and verification

**Anticipated results**

The results of the LST validation activity will be:

- Matchup database population and maintenance
- Tuning of AUXILIARY files
- Tuning of LST coefficients
- Validation reports providing products error bars
Reporting requirements

- Statistics of the LST validation activities shall be updated on a daily basis.
- Validation statistics shall be made available via Sentinel-3 Cal/Val web site
- Reports to QWG
- Reports to Mission Management
- Reports to Mission Scientists

Task Schedule

This task shall start as soon as SLSTR-LST data are available
This task shall run for the duration of the mission, across Phase E1 and E2.

6.2.4.2.2 Characterisation and validation of LST products (SLSTR-LST-CV-220)

Task aim and objectives

The objective is the full validation of the land Surface Temperature products and the characterisation of the errors. The task consists in the continuation of previous task, with dedicated effort on the validation and characterisation of the auxiliary files (biomes, vegetation fraction, meteofiles, geolocation) and on the quality of the pixel classification, including the cloud masking. During this task, the protocols defined in previous activities will be applied in order to fully characterise the final products. During this task, continuous acquisition of Fiducial reference measurements and the management of Match-Up data base will be ensured.

Parameters for analysis

The analysed parameters will be:

- The LST
- The cloud masking
- The land/sea/lake mask
- The Biomes, fractional vegetation cover, water vapour

Methodology

- Continuation of previous tasks.
- Application of the LST protocols (the protocols and other LST documentation are available in the (A)ATSR Land Surface Temperature Portal: http://lst.nilu.no). The general approach can be classify in different categories:
- Category A: Comparison of satellite LST with in situ measurements. This is the traditional and most straightforward approach to validating LST. It involves a direct comparison of satellite-derived LST with collocated and simultaneously acquired LST from ground-based radiometers.
• Category B: Radiance-based validation. This technique uses top-of-atmosphere (TOA) brightness temperatures (BTs) in conjunction with a radiative transfer model to simulate ground LST using data of surface emissivity and a atmospheric profiles of air temperature and water vapour content.

• Category C: Inter-comparison with similar LST products. A wide variety of airborne and spaceborne instruments collects thermal infrared data and many provide operational LST products. An inter-comparison of LST products from different satellite instruments can be very valuable for determining LST.

• Category D: Time series analysis. Analysing time series of satellite data over a temporally stable target site allows for the identification of potential calibration drift or other issues of the instrument that manifest themselves over time. Furthermore, problems associated with cloud contamination for example may be identified from artefacts evident in the time series. Care must be taken in distinguishing between instrument-related issues such as calibration drift and real geophysical changes of the target site or the atmosphere.

**Input/Output Data needs**

The LST products and L1B over selected sites will be needed. The sites will be determined at later stage. The selection, characterisation and assessment of test sites need to be carefully done. As example, one can mention the sites that were used by AATSR validation program or Severi validation program:

The LSA-SAF sites: Evora, Portugal; Gobabeb, Namibia; Dahra, Senegal

The ARM sites: SGP, Oklahoma, USA; Niamey, Niger.

Others: Valencia, Spain – University of Valencia; Cardington, UK – UK Met Office, Australian sites.

Lake Tahoe, used in the AATSR and MODIS program.

**Required Tools**

• Extraction tools
• Level 3 tools
• Matchup database
• Satellite inter-comparison tools
• SLSTR-LST product read and visualisation tools test and verification
• SLSTR-LST product test and analysis tools (range checks, cloud check, mask check, flag check, range check, etc) test and verification

**Anticipated results**

The results of the LST validation activity will be:

• Matchup database population and maintenance
• Tuning of AUXILIARY files
• Tuning of LST coefficients
• Validation reports providing products error bars

**Reporting requirements**

• Statistics of the LST validation activities shall be updated on a daily basis.
• Validation statistics shall be made available via Sentinel-3 Cal/Val web site
• Reports to QWG
• Reports to Mission Management
• Reports to Mission Scientists

**Task Schedule**

This task shall start as soon as SLSTR-LST data are available. This task shall run for the duration of the mission, across Phase E1 and E2.

### 6.3 SYN

The focus for the synergy product is the quality of the co-registration process. The radiometric information from OLCI/SLSTR L1b products is not changed at L1c thus a consistency check for the proper L1b input is sufficient. Further, it is assumed that for geo-location, a geometric modelling is also taken into account in the L1b processing. The geometric model are composed of the Instrument Pixel Pointing Vectors Model (for each camera for OLCI, for each view for SLSTR), and the Geometric Calibration Model (attitudes biases and orbital harmonics for OLCI and SLSTR). On Level 2 the atmospheric correction scheme validation is essential.

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(S3-MR-1110: CoReg SWIR/TIR)
Table 20 – Synergy L1/L2 Cal/Val Task definitions

### 6.3.1 Constraints and Assumptions

TBW

### 6.3.2 Instrument Error Analysis

TBW

### 6.3.3 Task Definitions for SYN Level 1c Products

#### 6.3.3.1 Product Consistency with Level 1b data (SYN-L1C-CV-100)

**Task description**

This activity shall check the format and content of the L1c product. In particular the radiometry calibration has to be consistent with the L1b processing. Pixel gridding in L1c shall correspond to a non-regridded (L1a step) image grids from L1b OLCI and SLSTR channels.

**Task Aim and Objectives**

TBW

**Parameters for analysis**

TBW

**Input/Output data needs**

TBW
Required tools
TBW

Methodology
TBW

Anticipated results
TBW

Reporting requirements
TBW

Task Schedule

6.3.3.2 Inter-channel co-registration analysis (SYN-L1C-CV-200)

Task description
For the synergy product the co-registration uncertainty needs to be analysed and compared with the requirements.

Task Aim and Objectives
The SYN L1C product is based on OLCI L1B and SLSTR L1B which have reversed to the original geometry (L1A). Therefore the radiometry, absolute geolocation and spectral calibration have been validated in the previous validation tasks applicable for OLCI and SLSTR (chapter 6.2 and 6.3). Based on GCP and image correlation, the task shall evaluate the performance of the collocation process. This is classified as E1-High and E1-High

Parameters for analysis
The input data are the L1C and the tie-point data collection.

Methodology
For the synergy product the co-registration uncertainty needs to be analysed and compared with the requirements. In the processor tie points are defined by geographic coordinates on the Earth were OLCI and SLSTR images reference channels can be matched by correlation by Level 1c process. This tie points database is contained in the SCCDB. However there is also another possibility consisting in defining a regular grid of tie points along and across track in the L1c product.

The principle is to perform during phase E1 the verification of the l1c coregistration performance by using both the strategies. However in both case not all the tie points shall be used for the coregistration, in fact this data base will be split in two parts:

- A calibration tie points data base
- A validation tie points data base

The calibration tie point database is used to perform the L1c matching process to match SLSTR images over OLCI images by correlation. The validation tie points data base is used to assess the
performance and to validate the requirements on the 2 reference bands (same OLCI and SLSTR spectral band). If needed, the process can be completed by manual operations.

The outcomes of this processing will trigger at least one of the following actions:

- One or both strategy permit to achieve the L1c accuracy, so no action is taken
- In case both the strategies fail so the parameters of the regular grid are modified until the L1c accuracy is achieved

In case both the strategies fail the fixed database of tie points spread over the Earth is modified. One possible solution is to take as reference the database of GCPs used for the L1b absolute geolocation verification.

**Input/Output data needs**

Database of ground control points

**Required tools**

For this phase, the tools here below have to be available:

- An S3 image extraction tool
- A GCPs data bases
- An image correlation tool
- An image visualization tool
- The geometric specific tools which has to be developed in Phase C/D.

**Anticipated results**

- the co-registration uncertainty of the synergy product

**Reporting requirements**

The reports are:

- compliance reports,
- Complete geometric calibration models for an entire year.
- Every year (TBC), a compliance reports and/or calibration model parameters update.

**Task Schedule**

Phase C/D:

- to develop and to valid Image quality tools
- to define E1/E operational detail schedule of geometric calibration/validation from CAL/VAL
6.3.4 Task Definitions for SYN Level 2 Products

6.3.4.1 Surface Reflectance Algorithm Validation (SYN-L2C-CV100)

Task Description

By making use of all the OLCI and SLSTR channels, and taking profit of the angular capabilities of SLSTR, the Sentinel-3 SYNERGY branch will generate a surface directional reflectance products in all the OLCI and SLSTR bands (except the absorption bands) and the associated information on Aerosol – Aerosol Optical Depth at 550 nm, Angstrom coefficient, Aerosol model index number.

The algorithm is describe in the ATBD (RD 15)

The ATBD reports also a validation strategy – see chapter 4.11 accuracy assessment. The validation is mainly based on the validation of the aerosol properties (main difficulties in the atmospheric correction). This is done by using coincident data with the AERONET network equipped by sun photometer. The sites cover a range of surface types and sources of aerosol, and include examples of cloudy and clear scenes.

This task is classified as E1-MED and E2-CRIT.

Task Aim and Objectives

The objective is to validate the surface reflectance and therefore to validate the aerosol retrieval. Error bar associated to the products will be validated and potentially the methodology will be updated.

Parameters for analysis

This task will address the validation of the Surface reflectance in all the OCLI and SLSTR channels.

By making use of all the OLCI and SLSTR channels, and taking profit of the angular capabilities of SLSTR, the Sentinel-3 SYNERGY branch will generate a surface directional reflectance products in all the OLCI and SLSTR bands (except the absorption bands) and the associated information on Aerosol – Aerosol Optical Depth at 550 nm, Angstrom coefficient, Aerosol model index number.

The aerosol effects are the main source of error in the retrieval of the surface reflectance. The aerosol properties are retrieved from the L2C atmospheric correction processing. Therefore a particular attention will be given to the validation of the aerosol properties retrieval.

Methodology

The validation is mainly based on the validation of the aerosol properties (main difficulties in the atmospheric correction). This is done by using coincident data with the AERONET network equipped by sun photometer. The sites cover a range of surface types and sources of aerosol, and include examples of cloudy and clear scenes.

The analysis using Aeronet network will provide a large number of coincident points allowing statistical analysis. However, this approach should be completed by measurements coming from ad-hoc campaigns. The number of match-up will be probably less, but of better quality and fit for the purpose of the validation of the surface reflectance. The campaigns should involve the direct measurement of surface reflectance and the measurements of atmospheric parameters.

Coordinated campaigns for SYN, OGVI and OCTI should be prepared in order to minimise the costs. In the same manner, the definition for the sites extractions (“super sites” ??) should be common to SYN, OGVI and OCTI as far as possible.
- **Validation of aerosol products over land:**

The main source for the validation of the aerosol products (AOT and Angstrom exponent) over land is AERONET. These data should be collected and matched with S-3 / OLCI acquisitions.

**Input/Output data needs**

The input data will be the L2C SYN products. A list of sites should be automatically extracted. The sites cover a range of surface types and sources of aerosol, and include examples of cloudy and clear scenes. The full list of sites is still to be defined; in anticipation, below is reported the list of 68 sites that was used to validate and test the algorithm. The sites cover a range of surface types and sources of aerosol, and include examples of cloudy and clear scenes.

![Figure 19 - Location of sites used selected for aerosol retrieval validation](image)

<table>
<thead>
<tr>
<th>Site name</th>
<th>lat</th>
<th>long</th>
<th>Cover type</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abracos_Hill</td>
<td>-10.8°N</td>
<td>-62.4°E</td>
<td>Forest</td>
<td>8</td>
</tr>
<tr>
<td>Beijing</td>
<td>40.0°N</td>
<td>116.4°E</td>
<td>Urban</td>
<td>6</td>
</tr>
<tr>
<td>Cart_Site</td>
<td>36.6°N</td>
<td>-97.5°E</td>
<td>Grassland</td>
<td>7</td>
</tr>
<tr>
<td>Lille</td>
<td>50.6°N</td>
<td>3.1°E</td>
<td>Urban</td>
<td>4</td>
</tr>
<tr>
<td>Mongu</td>
<td>-15.3°N</td>
<td>3.1°E</td>
<td>Semi-arid</td>
<td>8</td>
</tr>
<tr>
<td>Ouagadougou</td>
<td>12.2°N</td>
<td>1.4°E</td>
<td>Semi-arid</td>
<td>23</td>
</tr>
<tr>
<td>Tinga_Tingana</td>
<td>-29.0°N</td>
<td>140.0°E</td>
<td>Semi-arid</td>
<td>6</td>
</tr>
<tr>
<td>Tomsk</td>
<td>56.5°N</td>
<td>85.1°E</td>
<td>Forest</td>
<td>4</td>
</tr>
<tr>
<td>Barcelona</td>
<td>41.39°N</td>
<td>2.12°E</td>
<td>Coastal</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 21 - List of sites used selected for aerosol retrieval validation**

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**Required tools**
Extraction tools, monitoring tool and image processing tools are requested to perform this task.

**Anticipated results**
The results will be a validation report providing error bar associated to the L2C SYN products. The uncertainties associated to every pixel will be validated and potentially updated.

**Reporting requirements**
Reporting include:
- Early assessment report to IOCR
- Full Validation Report at Validation Review(s)
- Regular reports to MPC / EUM teams
- Regular reports to QWG
- Regular reports to Mission Manager/Validation Scientist

**Task Schedule**
The task should start once the L1B of OLCI and SLSTR would have been calibrated and once the L1C would have been validated. An early assessment of the product will require a statistically representative distribution of the AERONET data in space and time. Preliminary assessment should be available at the end of the Commissioning phase. Then, the validation activities will be a continuous process through the mission life providing update on the parameter uncertainties.

---

**6.3.4.2 Vegetation Product Validation (SYN-VGT-CV100)**

**Task Description**
The aim of this product is the continuity with SPOT VGT mission. Therefore this task will consist mainly in the comparison with SPOT VGT or/and PROBA V. This activity is classified as E1-MED and E2-CRIT.

**Task Aim and Objectives**
The objective of this task is to assess the quality to the product derived from the SYNERGY branch simulating the SPOT VGT products.

**Parameters for analysis**
The parameters that will be validated are the Top Of Atmosphere radiance and the bottom of atmosphere reflectance provided as the continuity of SPOT VGT.

**Methodology**
The S-3 VGT products are products mimicking the currently produced Spot/VGT products. Comparisons shall be carried out to investigate/verify that the S-3 VGT like products provide continuity to the data stream from Spot /VGT1, Spot/VGT 2 and Proba-V. Comparisons shall be
carried out in particular at L1, L2 and L3 level. Operations of Spot/VGT 2 are planned until end 2013. The Proba-V mission should be launched in 2013 and ensure continuity of Spot/VGT data stream. Proba-V and VEGETATION are thus the obvious candidates for direct comparisons of: TOA radiances and NDVI. Assuming availability of the previously mentioned missions at the time of the S-3 operations, direct comparisons over fixed terrestrial sites of S-3 VGT like TOA radiances versus the VEGETATION and Proba-V. Vicarious calibration tool and methodologies can be used for further assessment of the radiometric capacity after the SYN VGT L2 processing. SADE, DIMITRI, D. Smith or SNO type of methodologies can be used.

The task is presented as a global validation of the final product. The comparison with SPOT VGT and/or PROBA V will be the main task. However, prior to that task, subtasks aiming at the verification of the spectral interpolation, binning process and atmospheric correction process will conducted. They are not detailed in the current version of the document; they are embedded in the overall validation of the final product.

**Input/Output data needs**

The input data are the L2C VGT products. They will be compared with SPOT VGT (if flying at that time) and/or with PROBA V.

**Required tools**

The required tools should include basic image processing tool (statistic, transec, histogram...etc...), monitoring tool and comparison tool.

**Anticipated results**

The result will be a validation report assessing the accuracy of the SYN VGT product and comparison with SPOT VGT or Proba V data.

**Reporting requirements**

Reporting include:

- Early assessment report to IOCR
- Full Validation Report at Validation Review(s)
- Regular reports to MPC / EUM teams
- Regular reports to QWG
- Regular reports to Mission Manager/Validation Scientist

**Task Schedule**

The task shall start once the OCLI and SLSTR L1B products are calibrated and the L1C product is validated. Early assessment should take place during the Commissioning phase. The validation during phase E2 is a continuous process.
6.4 SRAL

The Calibration and Validation of the Sentinel-3 STM products is a significant challenge due to the stringent mission measurement requirements and their safeguarding all over the mission lifetime.

Altimetry is unique in that the altimeter system should be considered as a whole system. Essential for accurate range estimates is the complement by a microwave radiometer sensor for deriving the wet troposphere correction, and a tracking system (GNSS, DORIS, LRR) for performing an adequate precise orbit determination (POD). In other words, the final STM product quality depends not only on the characterisation and calibration of the SRAL sensor but also on the performance MWR, the Precise Orbit Determination payload as well as platform stability and COG specification. The altimeter system has thus to be considered as gathering all the contributions from several sensors. For this reason, the error budget of the altimeter system also includes error estimates of the wet tropospheric correction and radial orbit.

The MWR sensor as well as the tracking system sensors is presented in the subsequent chapters.

The Sentinel-3 SRAL calibration and validation approach is based on a similar methodology as developed for the ERS-2 and Envisat altimeters.

6.4.1 Constraints and Assumptions

For the Cal/Val task definitions in this chapter the following constraints and assumptions apply for SRAL:

- SRAL instrument as well as MWR, GPS and DORIS instruments SIOV tests have been successful and concluded (classified E1-CRIT)
- Initial transmit and receive gains settings have been confirmed

Access to L1b and L2 data streams shortly after the end of SIOV is mandatory (classified E1-CRIT)

A preliminary L2 products validation is expected to be reached at IOCR, the final validation is targeted during E2 (classified E1-MED)

6.4.2 Instrument Error Analysis

As an outcome of the Phase E1, the S-3 SRAL error budget table shall be updated with the error estimates of the different terms (See Table 5). The S-3 STM error budget table shall be reviewed and updated at least on yearly basis during Phase E2.

The error budget can be grouped following the classification outlined in Figure 9. A summary view is provided in Figure 20.
Figure 20 – SRAL Error Analysis
### 6.4.3 Task definitions for SRAL Products

<table>
<thead>
<tr>
<th>MRTD key requirement (further associated req.)</th>
<th>S3 Products ID</th>
<th>Cal/Val Tasks</th>
<th>Respons. Schedule</th>
<th>Status</th>
</tr>
</thead>
</table>
| **S3-MR-150**  
Sentinel-3 shall provide ocean surface topography measurements (SHH, SWH, and surface wind speed) exceeding the level of quality of the Envisat RA-2 altimeter system.  
(S3-MR-180: River&Lake Obs)  
(S3-MR-220: Meso-scale obs.)  
(S3-MR-1200: RLIH service)  
(S3-MR-280: POD) | SRAL-L1B  
SRAL-L2MA  
SRAL-L2LA | Cross-Calibration with other altimetry missions  
(SRAL-L2MA/LA-CV-140)  
Range-Calibration with in-situ measurements  
(SRAL-L2MA/LA-CV-150)  
Product Validation  
(SRAL-L2MA-CV-200)  
Validation vs in-situ measurements  
(SRAL-L2MA/LA-CV-220)  
Validation vs other altimetry missions  
(SRAL-L2MA-CV-210)  
Global Mission Assessment (SRAL-L2MA/LA-CV-240) | | |
| **S3-MR-210**  
The Sentinel-3 topography instrument shall have a noise level better than 3 cm (1-sigma) for a 1 second average.  
(S3-MR-310: Tracker bias) | SRAL-L1B  
SRAL-L2MA | Internal Calibration Sequence Validation  
(SRAL-L1B-CV-110)  
Tracking Mode Validation  
(SRAL-L1B-CV-120) | | |
| **S3-MR-290**  
The Sentinel-3 altimeter threshold absolute accuracy for $o^\circ$ shall be better than 1 dB, with a resolution of better than 0.1 dB  
(S3-MR-300: $o^\circ$drift) | SRAL-L2MA | External Calibration with Transponder  
(SRAL-L2MA-CV-130) | | |
| **S3-MR-320**  
The Sentinel-3 altimeter derived SWH threshold accuracy shall be 20 cm or 4 % of SWH for 1 second averages over a range of 1 - 20 m.  
A goal of 5 cm or 1 % (whichever is smaller) is expected after STC/NTC data processing (retracking). | SRAL-L2MA | Cross-Calibration with other altimetry missions  
(SRAL-L2MA-CV-140)  
Range-Calibration with in-situ measurements  
(SRAL-L2MA/LA-CV-150) | | |
| **S3-MR-330**  
The Sentinel-3 altimeter derived wind-speed accuracy shall be better than 2 m s$^{-1}$ for 1 sec averages over a range of 3 and 20 m s$^{-1}$.  
A goal of 1.5 m s$^{-1}$ accuracy is expected from improved ground processing. | SRAL-L2MA | Cross-Calibration with other altimetry missions  
(SRAL-L2MA-CV-140)  
Wind, wave product validation vs models  
(SRAL-L2MA-CV-230) | | |
| **S3-MR-160**  
An along track delay-Doppler SAR capability (similar to CryoSat-2 SRAL) shall be included in the Sentinel-3 altimeter measurement system to provide improved resolution in the coastal zone and sea ice regions.  
(S3-MR-180: River&Lake Obs)  
(S3-MR-220: Meso-scale obs.)  
(S3-MR-230: Mode switch) | SRAL-L1B  
SRAL-L2LA | Internal Calibration Sequence Validation (SRAL-L1-SAR-CV110) | | |
| **S3-MR-250**  
The Sentinel-3 altimeter shall be capable of providing measurements of sea ice thickness | SRAL-L2MA | sea-ice freeboard validation with CryoSat  
(SRAL-L2MA-CV250) | | |

*Table 22 – SRAL Cal/Val Task definitions*
6.4.3.1 Preparation for in orbit Cal/Val activities (SRAL-L2MA-CV-000)

Task Description
To prepare all in-flight cal/val activities for SRAL

Task Aim and Objectives
- consolidate work package descriptions and commitment for TAS and CNES in Phase E1
- ensure needed data streams for all partners
- provide transponder system for range calibration

Task schedule
Activity is initiated in Phase C/D

6.4.3.2 Instrument Calibration (SRAL-L2MA-CV-100)

Task Description
This task refers to the calibration of the altimeter payload during the Phase E1 and E2. It covers the payload calibration as well as the inter-satellite and external calibrations.

Task Aim and Objectives
The calibration includes several sub-tasks:
- Inter Calibration Sequence Validation (SRAL-L1B-CV-110) (Classified as E1-CRIT and E2-CRIT)
- Tracker Validation (SRAL-L1B-CV-120) (Classified as E1-CRIT and E2-CRIT)
- External Transponder Calibration (SRAL-L2MA-CV-130) (Classified as E1-CRIT and E2-HIGH)
- Cross-Calibration with other altimetry missions (SRAL-L2MA-CV-140) (Classified as E1-HIGH and E2-CRIT)
- Calibration with in-situ data (SRAL-L2MA-CV-150) (Classified as E1-HIGH and E2-CRIT)

6.4.3.2.1 Internal Calibration Seq. Validation (SRAL-L1B-CV-110)

Task Description
During the Commissioning Phase, an assessment and characterisation of the in-flight characterisation of the SRAL sensor versus the on-ground characterisation is performed; to ensure the SRAL sensor characterisation is maintained after launch.

The first calibration mode (CAL1) gives the measurement of the instrument Point Target Response (PTR) by feeding the signal from the emission channel back to the receiver channel and allows the computation of the SRAL internal path delay and power corrections.

The second mode (CAL2) gives the transfer function of the altimeter receiving chain by processing received thermal noise with no transmitted signal being present (RD 86).
**Task Aim and Objectives**

To verify the health of the SRAL internal calibrations, to characterise their performance, and to optimise their parameters and planning.

**Parameters for analysis**

The two internal SRAL calibrations CAL1 and CAL2 are assessed and compared to the ground characterisation.

Monitored parameters are: the shapes and phase stability of point target response (PTR), the shape and stability of the low pass filter (LPF), the values of CNG attenuators.

**Methodology**

The SRAL internal calibration modes are nominally fully characterized before launch during the ground acceptance test. During phase E1, a number of scenarios are played in order functionally validate the possible configurations of the calibration parameters and assess their in-orbit performances. The objective is to guarantee the good instrumental operating, to characterize the various features of the calibration responses and assess the calibration performances versus the initial specifications.

A comparison between measurements before and after launch is performed to quantify possible drifts on the main features due to the launch. The assessment of the internal calibrations is complemented by the Level 2 data analysis.

Then, for the whole life of the mission, the two calibration modes (in the same configurations) are activated several times a day (by macro-commands) with a double objective:

- To continuously characterize the shapes and positions of the Point Target Response and Low Pass Filters in order to daily introduce updated corrections in the altimeter processing chains that generate the level 2 products. The main corrections using calibration results are the following: correction of the waveforms by the low pass filter before to be retracted, computation of the total power of the PTR in order to correct the sigma0 estimation, computation of the difference of internal paths between the emission and reference channels in order to correct the range estimation.

- To ensure an unceasing monitoring of the instrument, allowing to follow the electronics ageing and to check the good health of the equipment.

The characterisation and long term monitoring of the S-3 SRAL internal calibration shall be supported by cross-comparison with specific concomitant SRAL temperatures from House-Keeping Telemetry (HKTM).

**Input/Output data needs**

- Ground characterisation of the SRAL instrument
- “SR_1_CAL____” Calibration parameters for LRM and SAR mode (resolution 20Hz)
- LTM (Long Term Monitoring) files, containing the CAL1 and CAL2 signals resulted from the calibration modes and used as auxiliary files in the L1B Processing chain
- HKTM information from EDDS FOS system
**Required tools**

Specific tools are needed for the above to support characterisation & performance assessment of the internal calibrations, visualization, comparison, HKTM reading tool and long term monitoring of calibration parameters.

**Anticipated results**

Recommendations are delivered to the PDGS for the mission planning of the SRAL internal Calibrations as well as possible corrections or fine-tuning of the ground processing.

At the end of Phase E1, a full validation of the long term monitoring calibration files (CAL1 & CAL2) will be performed prior to the reprocessing of the Commissioning Phase data.

The full characterisation of the CAL1 path delay is the basis for the long term monitoring of the SRAL instrument for the mission lifetime.

**Reporting requirements**

Regular reporting relative to the internal calibrations performance and planning shall be performed to the S-3 STM Cal/Val team and Management.

**Task Schedule**

An in-depth assessment of the CAL1 and CAL2 calibration is performed during Phase E1.

Long-term monitoring is performed for the mission lifetime, throughout Phase E2.

### 6.4.3.2.2 Tracking Mode Validation (SRAL-L1B-CV-120)

**Task Description**

Several new functionalities have been implemented within the SRAL instrument, which requires full validation. In particular, the SAR and LRM acquisition modes and the open-loop (OL) or closed-loop (CL) tracker available S-3 SRAL will request an extensive validation and inter-comparison phase in order to ensure that performances are at least equivalent with respect to the reference mission on one hand (measurements availability over ocean and quality of these measurements) and to increase data coverage and data availability on coastal zones (water/land transitions) and on continental water areas (lakes) on the second hand.

An important activity will be the Validation of the Open Loop tracking principle, (dedicated to the measurement of inland waters height, coastal waters height and ice margins), including validation of the on-board one-dimensional DEM topography dataset (Open-loop tracking command (OLTC) Table).

The ability of SRAL to switch from closed-loop (CL) to open-loop (OL) tracking needs an analysis, to clearly identify the performances of each mode over ocean but, most important to cover sea/land transitions for improved range estimates in coastal areas. However OL measurements will be not be possible over all surfaces as the on-board OLTC memory is limited. Thus a trade-off for the regions to be covered with CL and OL might be necessary (Figure 21). This trade-off will require specific scientific analysis for inland water- and land targets. In Phase E1 this trade-off will not be completed.
Figure 21: OLCT table memory segmentation structure indicating the regions where a DEM value is present. There is no global coverage possible

Task Aim and Objectives

Tracking modes will be validated during Phase E1 and continuously monitored during Phase E2. The objectives are to check the operability and the performances of each tracker modes versus the mission objectives.

Parameters for analysis

In closed and open loop tracking modes, the range tracking performances have to be checked by analyzing the position of the waveform earliest detectable part in the window according to tracking mode, to the over-flown surface, to the SRAL mode (LRM or SAR). Data coverage and data availability on coastal zones (water/land transitions) and on continental water areas (lakes) for all of the modes should also be assessed.

Various other operating parameters will be also evaluated, such as the correction terms generated by the tracking loops (AGC, coarse and fine altitude corrections...)

Methodology

The tracking capability will be assessed as part of the global statistical evaluation of OLTC table information (also available in CL mode) over all surface types as well as on the cross-comparison of the S-3 STM performances versus a reference Altimeter mission. The DEM coded in the OLTC may need adjustments depending on the OL mode performance results

The tracking performance will also have to be checked and analysed while measurement mode transitions and also while switching between tracking modes within a given measurement mode. In particular, loss of data have to be checked against the System Requirements which is of a maximum of 2 km along the satellite track for a measurement mode transition and of 1km along the satellite track while switching between tracking modes within a given measurement mode.

Concerning the gain tracking, independence between Ku and C gain loops in case of closed loop range tracking mode should be checked by comparing the Ku and C bands AGC values over areas affected by rain cells.
Input/Output data needs

- STM SRAL L1 products
- Mission Planning information
- SRAL mode mask
- OLTC Table

Required tools

Tools have to be developed, consisting in simple algorithms to help detecting if the waveform is available and to estimate the position of the earliest detectable part. Then statistic tools have to be used on the estimated parameters.

Anticipated results

Assessment of OL performance, indications for potential OLTC updates, verifying OLTC updates in follow-on cycles during Phase E1.

Reporting requirements

Regular reporting shall be performed.

Task Schedule

This task shall be initiated in Phase E1, as soon as Level 1 products will be available. The tracking capability shall be monitored over the mission lifetime, throughout Phase E2.

6.4.3.2.3 External Transponder Calibration (SRAL-L2MA-CV-130)

Task Description

The External calibration is used to calibrate the overall altimeter measurement in a single site and perform long-term stability monitoring of the altimetry system, with the most accurate methods. Several equipments are thus set up at this site in order to limit as much as possible the differences between the altimeter measurement and the in-situ measurements.

Such sites have been used for ESA missions (Venice experiment for ERS-1, Mediterranean Sea absolute calibration for EnviSat), and non-ESA missions (Lampedusa and Harvest experiments for TOPEX/Poseidon, Senetosa experiment for Jason-1). For Sentinel-3 a transponder site in Crete will be established.

Transponder calibration also have limitations: the number of samples are limited to direct transponder overflights and there might be local, regional errors which impact the accuracy of the comparisons (for instance regional in-situ calibration of altimeter observations are often corrupted by local geoid effects and orbit errors). Even if these dedicated sites are specifically equipped to reach a good local accuracy, the transponder calibration should be complemented by using a large number of in-situ tide gauge measurements. (see task SRAL-L2MA-CV-150)

Task Aim and Objectives

The on-ground transponder technique will calibrate and monitor the on-board instrument Range and Sigma0 stability (RD 66, RD 68).
The selection of the Crete transponder site will also allow a multi-mission analysis as the transponder can be used for Sentinel-3a/3b and Jason-CS.

Parameters for analysis

- S-3 STM altimeter Range, Sigma0 (LRM, SAR modes)
- Altimeter Range and Sigma0 from coexisting missions

Methodology

The absolute calibration of altimetry missions is a crucial concern to insure the required long-term stability of the sea surface height, as well as backscatter and wind speed estimates.

Dedicated transponders serve as an alternative and independent technique for altimeter’s calibration. A microwave transponder receives, amplifies and retransmits, with minimal distortion, the satellite’s radar altimeter pulse which is emitted and recorded again on-board the satellite. Consequently, a transponder deployed accurately beneath a satellite's pass mirrors the radar echo, thus, providing us a well-defined point of reflection. The measure of the pulse's two-way travel-time yields the range between satellite and transponder. The range is also corrected for propagation delay (dry, wet troposphere ionospheric corrections) and solid earth and ocean tides are taken into account.

Input/Output data needs

- SRAL Level 0 NRT products
- Altimeter Level 0 data from coexisting mission in case of multi-mission site

Required tools

- Fully characterised, calibrated and operational Range and Sigma0 transponders
- Specific tool for transponder echo processing

Anticipated results

- Absolute Range and Sigma0 calibration measurements (LRM, SAR modes)
- Potentially multi-mission absolute cross-calibration Range and Sigma0 biases

Reporting requirements

Regular reporting shall be performed to the S-3 STM Cal/Val team and Management.

Task Schedule

Depending on the S-3 orbit and on the possible deployment of the Range and Sigma0 transponders, a number of transponder over-passes will be identified for the Phase E1 and the task shall be regularly performed throughout Phase E2.
6.4.3.2.4 Cross-Calibration with other altimetry missions (SRAL-L2MA-CV-140)

Task Description
This task covers the inter-calibration of the Sentinel-3 STM mission versus any other altimeter mission, for the determination of the relative differences (e.g. bias, slope, and noise).

Task Aim and Objectives
The objective of this task is to determine the relative biases of the Sentinel-3 STM mission versus other altimeter missions and perform the necessary adjustments to guarantee required data quality and continuity. More specifically, this task shall look at the estimation of cross-calibration results to ensure the data continuity of the S-3 STM mission with the Envisat Altimeter one (i.e. back to 8 April 2012).

This task is nominally performed over Open Ocean and shall be performed for the two SRAL LRM and SAR modes. The cross-calibration exercise will assess the respective performances of the two SRAL operating modes.

The Cross-calibration of LRM mode measurements shall be nominally performed versus reference and operational altimeter missions, with similar instrumental characteristics and flying at the time of the S-3 launch and allowing the bridge with the Envisat mission (i.e. Jason-2)

The CryoSat mission shall be considered as the reference mission for the SAR mode.

Any other altimeter and/or microwave radiometer satellites flying at the time of Sentinel-3 launch (HY-2, SARAL/Altika, Jason-3, etc) shall be envisaged for the cross-comparison.

Parameters for analysis
- Altimeter range, Sea Surface Height (SSH)
- Sea Level Anomaly (SLA)
- Rivers & Lakes water level
- Significant Wave Height (SWH)
- Wind Speed (WS), Sigma0,
- Wet Tropospheric Correction (dH)

Methodology
Except for innovative missions or very dedicated objectives, altimeter missions are to be considered in a multi-mission context. It is true if one considers the importance of combining several altimeter missions to provide modellers and applications with the best sampling by altimeter observations. It is also the case for missions that ensure continuity, at least to some extent, with respect to another.

Apart from these mission objectives, it is also essential, in a statistical point of view, to compare altimeter measurement to other concurrent altimeter measurements. Thus a great part of the quality assessment of altimeter missions is built on comparisons with other missions. In a statistical point of view, this method is the most reliable due to high number of comparison points (as compared to in-situ comparisons for instance). Furthermore this method not only allows comparing the synthetic measurement (SSH) but also cross-calibrating several measurement components or ancillary data.
Investigations addressing the characterization of long-term changes from multiple altimeter missions must consider the cross-calibration question, and are expected to contribute significantly to this aspect of Cal/Val.

Comparisons to mean sea surfaces (with now improved precision) shall be used to relate the missions. The ability of dual-satellite crossover methods to precisely cross-calibrate two different altimeters has been well established. It shall thus be used between Sentinel-3 and the reference mission(s).

The following methods are envisaged:

- Cross-calibration of the SRAL main geophysical parameters against a reference flying mission (e.g. Jason-2, CryoSat, HY-2, Altika), range, significant wave height and wind speed (sigma0) over ocean surfaces.
- Cross-calibration of the SRAL main altimeter range against operational missions (e.g. CryoSat, Jason, AltiKa) over Rivers & Lakes water surfaces (optional).
- Global comparison at cross-overs and along the collinear tracks of millions of globally distributed data (significant error reduction), including cross-calibration of LRM and SAR resolution tracking modes.

Both the crossover method and the repeat track method have their own advantages. The advantage of the repeat track method, applicable only to satellites on the same orbit but providing many more data points for comparison, is its higher accuracy.

The output of these methods is the estimate of a bias plus its formal error. Drifts will be estimated on the long term during the Phase E2.

The essential goals of this activity are also to detect any instrumental or algorithmic problem in the Sentinel-3 measurement system. To this end, the Sentinel-3 parameters will be continuously compared against analogous parameters from other altimetric missions. This activity will also better enable oceanographic studies using combined data sets through the improvement of models and algorithms.

**Input/Output data needs**

- S-3 SRAL Level 2 NTC data products
- Precise orbit
- Envisat, CryoSat, Jason-2, HY-2, other missions L2 GDR products

The harmonisation of the Envisat altimetry data products to the S-3 STM reference (e.g. algorithm, model, corrections) shall be envisage prior to the S-3 launch to ease the cross-calibration exercise.

**Required tools**

- Cross-over and Collinear Track tools
- Special processing has to be set up to homogenize references, parameters and models as much as possible, before cross-calibration is performed
- Quality Assessment tool for data set comparison
- Multi-mission data-base for cross-calibration and cross-validation
Anticipated results

- Cross-comparisons results (bias and associated error, geographically correlated error) on range, SSH, SLA, SWH, Sigma0 and Wind Speed for the two LRM and SAR modes.
- Cross-Calibration results with respect to Envisat mission (Range, SWH, Sigma0, Wind Speed)

Reporting requirements

Regular reporting will be performed to the S-3 STM Cal/Val team and Management done during Phase E1.

A final report will be delivered at the end of Phase E1.

Regular reporting shall be performed through Phase E2.

Task Schedule

The cross-calibration starts with the availability of the S-3 SRAL Level 2 products. Beyond the validation task to be performed, this ensures thorough data product verification via intensive use of these products by the Cal/Val team. First inter-calibration results shall be delivered by end of Phase E1 with recommendations for adjustments/corrections of the ground processing and/or on-board calibration.

This task shall be undertaken throughout the Sentinel-3 mission life to mostly look at the long-term stability aspects, and will benefit from other altimeters flying at the same time.

6.4.3.2.5 Range Calibration with in-situ data (SRAL-L2MA-CV-150)

Task Description

In situ-calibration of the overall altimeter measurement system will be performed using distributed in situ networks (tide gauges and ARGO floats) and dedicated calibration sites. The principal objective of this task is to use observations from tide gauges or other sensors, from dedicated and equipped calibration sites, directly on (or near) Sentinel-3 ground tracks to calibrate the sea-surface height and ancillary measurements made by the satellite as it passes (nearly) overhead.

The establishment of a permanent and fully equipped S-3 STM calibration and validation site shall be envisaged for the duration of the GMES Sentinels mission series to ensure sustainable Cal/Val and long term monitoring of the S-3 mission performances (Recommendation from S-3 Cal/Val workshop in March 2012).

Task Aim and Objectives

The objectives for the in-situ calibration task are:

- The use of independent measurements to calibrate the S-3 SRAL altimeter.
- The detection of potential anomalies (jumps or drifts) in altimeter sea level measurements, not detectable by comparison with other altimeter missions.
- The S-3 SRAL altimeter range and range bias stability long-term monitoring versus in-situ measurements.
- The detection of potential anomalies in in-situ data and estimate their quality.
• The inter-calibration of the S-3 STM mission versus Envisat to ensure the data continuity between the two missions.

**Parameters for analysis**

- S-3 SRAL altimeter range(LRM, SAR modes)

**Methodology**

*Dedicated Calibration Sites*

In the traditional “overhead” concept of altimeter calibration, direct comparisons of the sea level and ancillary measurements derived independently from the satellite and in situ data are used to develop a time series of absolute calibration estimates for the satellite sensors (altimeter and radiometer) and the overall measurement system.

Dedicated verification sites (e.g. Corsica site, RD 68) offer the advantage of direct over flight geometry, and a survey tie to the geocenter. The direct over flight geometry reduces errors introduced by decorrelation of Sea Surface Height (SSH) and environmental parameters as the cross-track distance to the ground track increases. It is not today insured that Sentinel-3 will pass exactly over dedicated verification sites but the improvements in the processing techniques allow now performing altimeter calibration even far from the dedicated calibration site via a regional in situ calibration method (RD 69). The tie to the geocenter enables the computation of an absolute bias in the measurement system, and also accommodates the separation of vertical land motion at the experiment site from potential instabilities in the altimeter range system. In addition, dedicated verification sites typically feature several collocated sensors to help discriminate between different sources of error. The instrument suite may include water vapor radiometers, meteorological sensors, GPS, Doris, and SLR, and buoys in addition to tide gauges.

In situ calibration of radar altimeter is operated at the vertical or near a dedicated Cal/Val site. A direct comparison of altimetric data with in situ data is operated. This configuration leads to handle the differences compared with the altimetric measurements system at a global scale: the Geographically Correlated Errors at regional (orbit, sea state bias, atmospheric corrections…) and local scales (geodetic systematic errors, land contamination for the instruments, e.g. the radiometer). It should be interesting to share in situ Cal/Val experiments already conducted at various sites on other missions (Corsica, Harvest, Gavdos, Vanuatu, Kerguelen, lakes and rivers…). The reason is that local conditions are different for several observations site. So that geophysical conditions and a common protocol for computing the SSH bias, could permit to increase statistically the sea surface bias estimation.

*Distributed Tide-Gauge Calibration*

The relative range calibration consists in monitoring the long-term altimeter bias. The objective is to estimate temporal drifts of altimeters with long term monitoring of satellite altimetry systems and to correct them by the means of tide gauges data network. The main objective of this activity is to perform the Sentinel-3 SRAL range monitoring using a global tide gauge network.

The usefulness of tide gauge data networks for calibrating satellite altimetry systems was demonstrated by several authors (RD 83, RD 84, RD 85). Their proposition was to use tide gauge data as an independent system to monitor drifts and bias of altimeter system over time.

The main interest of tide gauges for altimetry is to provide independent measurements of sea surface height variations. The basic idea of the method is that differences between tide gauges and...
altimetry should not have any drift or bias over long time scales. Selecting tide gauge stations where the differences between altimetry heights and tide gauge sea levels are small is essential to get good variance estimates.

Although active research work might be still needed, this approach can today be included in the operational assessment and long-term monitoring to be set up for the Sentinel-3 STM Phase E1 and E2.

**Distributed ARGO Calibration**

Argo T/S profiles constitute a complementary dataset to tide gauges measurements. Indeed, although the temporal sampling is worse (one profile every ten days for one float and one hourly measure for tide gauges), the spatial coverage of the Argo network is much larger since the global open ocean is almost completely sampled. Anyway, it is important to keep in mind that several results obtained through this activity are made robust thanks to the use of multiple types of in-situ data (T/S profiles and tide gauges). These cross-comparison with several types of in-situ datasets increase the quality of calibration and validation of altimeter measurements.

Contrary to tide gauges measurements, which are (almost) directly comparable with altimetry, T/S profiles only provide steric height above a reference level (chosen as 900 meters) which is called the Dynamic Height Anomaly (DHA). As altimetry provides the height of the total water column, a specific method is used to discuss the same physical content and compare the two types of data.

**Input/Output data needs**

- Level 2 NTC products
- Tide gauges time series
- ARGO float time series
- Mobile laser tracking station
- Ground MWR
- Weather station
- GPS, GPS buoys
- Moorings

**Required tools**

- Quality Assessment tool for cross-comparison

**Anticipated results**

A determination of the S-3 STM range calibration versus in-situ measurements shall be delivered by end of Phase E1. Information on the range bias and stability will be performed on the long term during Phase E2.

**Reporting requirements**

Regular reporting shall be performed during Phase E1

The reporting done in Phase E2 shall be disseminated to the user community
Task Schedule

This task shall be initiated during Phase E1 as soon as Level 2 products are available and will be carried all over the S-3 STM mission lifetime.

6.4.3.2.6 Cross-calibration of LRM and SAR modes (SRAL-L2MA-CV160)

Task Description

During the Commissioning Phase, the LRM and SAR mode need to be cross-calibrated and performances of both modes need to be compared on all observed surfaces. During Phase E1 the SRAL altimeter command sequence will include specific LRM/SAR mode acquisitions to allow a analysis of both modes in this early mission phase. For a complete validation users will expect to receive no or only minimal biases in estimates of sea level, wind speed and significant wave height between the two operating modes. In addition, when the two modes are inter-calibrated, the comparison with LRM mode altimeters (Jason-2, AltiKa, Hy-2A) and SAR mode altimeters (CryoSat) will be facilitated. A dedicated cross-calibration will also raise confidence in the SAR mode after having had many years of LRM mode operations.

Task Aim and Objectives

To cross-calibrate the range estimates and provide a preliminary analysis of potential LRM/SAR instrument biases and there effect on wind speed and significant wave height estimates, to identify the differences in terms of precision and special resolution, to establish confidence in the quality of SAR mode operations over ocean surfaces which have been demonstrated with promising results from CryoSat-2 measurements (RD 89).

Parameters for analysis

Noise level of the elementary measurements (20-Hz) and spatial resolution of features to be detected as well as all ocean parameters, wind speed, wave height, and sea level will be analysed, in terms of bias between the different operating modes (LRM and SAR).

Methodology

In order to facilitate the cross-calibration of the different operating modes of SRAL (LRM and SAR), it is necessary to collect global measurements with the smallest temporal and regional separation possible. 2 approaches are possible for this:

1. Operating the altimeter in specific LRM and SAR mode cycles. In addition during the SAR cycle analyse the simultaneous reconstructed LRM waveform (pseudo LRM) and conduct the analysis for all orbits. Time separation for equivalent LRM/SAR observations of a specific surface point is 27 days (for LRM) or zero (for PLRM).

2. Define a command sequence to switch between SAR and LRM mode alternatively on ascending and descending orbit and limit the analysis to cross-over points. Time separation is in the order of several days.

For method 1 it is assumed that PLRM waveform are equivalent to LRM echoes but with a higher noise level due to lower number of individual echoes available to build the PLRM waveform. As the measurements are quasi-simultaneous any geophysical biases due to time decorrelation are eliminated (i.e. identical wind and wave conditions over open ocean). However as the altimeter is not switching the operation modes certain instruments effects, which might differ for SAR and
LRM mode, cannot be discovered with PRLM data alone. Also the higher noise levels (RD 88) might limit the comparison for wind and wave effects. This method has been demonstrated in the Jason-2 calibration phase.

The mode scenario for method 1 foresees the following sequence:

- one full cycle in LRM, serving as a reference LRM data set for all subsequence acquisitions and analyses. To detect instrument effects a certain region of interest could be defined where SRAL is switched from LRM to SAR mode. This approach has been successfully demonstrated with CryoSat.

- Cycle 2 and onward are done in the Sentinel-3 baseline SAR mode. SAR acquisitions to be compared with LRM data from previous cycle and PLRM echoes.

For method 2 the inter-comparison strategy is addressed and achieved by operating SRAL during two consecutive cycles alternatively in LRM and SAR mode on ascending and descending tracks. That is to say that during repeat cycle 2 (TBD) of the commissioning phase E1 SRAL will be operating in LRM mode on ascending tracks and in SAR mode on descending tracks; during repeat cycle 3 (TBD) SRAL will be operating in SAR mode on ascending tracks and LRM mode on descending tracks. As for method 1 during cycle 1 (TBD) the altimeter will be operating in LRM mode only (to improve the OLTC table), while during cycle 4 (TBD) the altimeter will be operating in the way it is intended to operate after commissioning (LRM and SAR mode in different regions).

During the two cycles with “interleaved mode operations” we will thus gain two inter-comparison opportunities:

- During each cycle, SRAL will achieve a limited global coverage of all ocean and landmasses in both modes. Even building simple histograms of the measurements would already be very instructive in finding LRM/SAR differences. By alternating ascending and descending operations during two cycles, possible dependencies on the direction of flight can be eliminated. Additionally, for example in coastal areas, the expected gain of the SAR operation over LRM can be studied because every track will be sampled in both modes during two cycles.

- During each cycle one can construct crossovers between LRM and SAR mode measurements (of sea level, wave height and wind speed). Even though limited, the cross-over analysis is expected to build up a significant statistics of the differences between the two measurement modes. Due to the temporal decorrelation of wind and wave conditions at the cross-over points it might however be difficult to separate instrument- from geophysical effects, at the required centimeter level.

**Input/Output data needs**

- Ground characterisation of the SRAL instrument
- SRAL mode mask
- Mission planning information
- SRAL L1a, L1b, L2 STC and NTC products both in SAR (containing PLRM) and LRM mode.

**Required tools**

Cross-calibration can be performed using existing tools to analyse:
Global statistics (per pass, daily, per cycle) of wind speed, wave height and sea level
Crossover generators and analysis tools
Collinear track analysis tools

**Anticipated results**

Among the anticipated results are the following:

- Estimates of biases between LRM and SAR mode measurements of range as well as wind speed (backscatter), wave height.
- Possible linear on non-linear differences between the two modes, as evidenced from SAR/PRLM comparison or crossover analyses.
- Comparisons of performance of the different modes in coastal areas, in terms of noise and resolution.
- Global comparisons of noise in the elementary measurements; comparisons of the measurement spectra.

**Reporting requirements**

First reporting is expected during or by the end of the commissioning phase E1.

**Task Schedule**

All operations and in-depth analyses are to be performed during Phase E1.

**6.4.3.3 Product Validation (SRAL-L2MA-CV-200)**

**Task Description**

This task refers to the validation of SRAL Level 2 products during the Phase E1 and E2 acquired over all surface types. The validation is performed via a series of processes specific to the Altimetry system, aimed at assessing, by independent means, the quality of the data products derived from the system inputs.

In the current version this task focuses on validation activities for ocean surface but will be extend for other surfaces type at a later stage. Of particular importance is the heritage from CryoSat for sea ice freeboard estimates where a draft validation task is described in Chapter 6.4.3.3.5 (SRAL-L2MA-CV-250)

**Task Aim and Objectives**

The parameters to be validated are mainly level2: Range, SSH, SWH, Wind Speed, orbit and geophysical corrections. The parameters are validated independently or as a whole via end-to-end validation processes.

This task includes the following sub-tasks:

- Validation vs other altimetry missions (SRAL-L2MA-CV-210) (Classified as E1-HIGH and E2-CRIT) & (SRAL-L2LA-CV-210) (Classified as E1-HIGH and E2-CRIT)
• Validation vs in-situ measurements (SRAL-L2MA-CV-220) (Classified as E1-MED and E2-CRIT) & (SRAL-L2LA-CV-220) (Classified as E1-LOW and E2-HIGH)
• Wind, wave product validation vs models (SRAL-L2MA-CV-230) (Classified as E1-HIGH and E2-HIGH)
• Global mission assessment (SRAL-L2MA-CV-240) (Classified as E1-CRIT and E2-CRIT) & (SRAL-L2LA-CV-240) (Classified as E1-CRIT and E2-CRIT)
• Sea ice freeboard validation with Cryosat data (SRAL-L2MA-CV-250)

6.4.3.3.1 Validation vs other altimetry missions (SRAL-L2MA-CV-210) (SRAL-L2LA-CV-210)

Task description

The product validation aims at demonstrating that the product is of geophysical relevance. This task is based on checks of the S3 STM Level 2 product quality and accuracy versus spaceborne measurements.

In addition classical cross-calibration activities shall be done over non-ocean surfaces types, i.e. coastal areas, rivers & lakes, land, continental ice with a specific assessment of the fitness-for-purpose and quality assessment of the data to the area of interest. However, details for a specific cross-over analysis for non-ocean surfaces is still TDB.

Task Aim and Objectives

This task aims at validating the altimeter parameters accuracy and stability over Phase E1 and Phase E2 and its consistency versus other altimeter missions.

Parameters for analysis

• Altimeter range
• Sea Surface Height (SSH)
• Sea Level Anomaly (SLA)
• Significant Wave Height (SWH)
• Wind Speed
• Geophysical corrections
• Surface height
• Wet Tropospheric Correction (dH)

Methodology

A great part of the validation and quality assessment of altimeter missions is built on comparisons with other missions. In a statistical point of view, this method is the most reliable due to high number of comparison points (as compared to in-situ comparisons for instance). Furthermore this method not only allows comparing the synthetic measurement (SSH) but also cross-comparing several measurement components or ancillary data.
The validation exercise versus altimeter missions will ensure the validity and consistency of the Sentinel-3 satellite series as well as the consistency of the Sentinel-3 missions with other flying altimeter missions or past ones, this being furthermore a strong prerequisite for the generation of multi-sensor L3 data products.

The validation exercise versus altimeter missions will also assess the validity and quality of the Sentinel-3 STM mission data over non open ocean areas (e.g, coastal areas, rivers & lakes, continental ice, dry land).

**Input/Output data needs**
- S-3 SRAL NTC Level 2 products
- Level 2 NTC products from altimeter missions

**Required tools**
- Crossover calculation and analysis
- Along-track Sea Level Anomalies
- Comparison to Mean Sea Surfaces
- Statistical and visualization tools

**Anticipated results**
A determination of the error estimates (e.g. biases, drift, geographically correlated error, spectral content, S-3 STM quality assessment, continuity and coherence assessment between missions) shall be delivered by end of Phase E1 and consolidated over the mission lifetime. Information on stability of the different geophysical parameters will be performed on the long term during Phase E2.

**Reporting requirements**
Regular reporting shall be performed during Phase E1.

The reporting done in Phase E2 shall be disseminated to the user community

**Task Schedule**
This task shall be initiated during Phase E1 as soon as Level 2 products are available and will be carried all over the S-3 STM mission lifetime.

6.4.3.3.2 **Range Validation vs in-situ measurements (SRAL-L2MA-CV-220)**

**Task Description**
This task corresponds to performance checks of the S-3 STM L2 product versus in-situ measurements over ocean surfaces. An extension of this activity for land and inland water targets is TBD.
Task Aim and Objectives
This task aims at demonstrating that the product is of geophysical relevance; by validating the altimeter range accuracy and stability over the Phase E1 and Phase E2 versus in-situ measurements like tide gauges and ARGO buoys.

Parameters for analysis
- Altimeter range
- Sea Surface Height
- Sea Level Anomaly

Methodology
Validation versus in-situ measurements consists in the comparison between observations from space and in-situ measurements. This method is extensively used in altimetry nearly for all missions, since using an independent source of data (independent from altimetry in general) represents an essential method for quality and performances assessment. Valuable results are obtained when comparing altimeter measurements with respect to a global tide gauge network and ARGO buoys. The method is now operationally used for most of the operational altimeters.

The permanent tide gauge network provides an estimation of range drift, which is complementary to the relative range bias obtained from cross-calibration, based on altimetry alone. The permanent tide gauges network is also necessary to cross-calibrate non overlapping missions.

The validation exercise of the S-3 STM altimeter range may also benefit of existing Cal/Val results from dedicated Cal/Val site located by some lakes (RD 69).

Input/Output data needs
- Level 2 NTC products
- Tide gauges time series
- ARGO float time series
- Ground MWR
- Weather station
- GPS, GPS buoys
- Moorings
- Wet Tropospheric Correction (dH) derived from MWR and models
- Gauge measurements from rivers and lakes for land product validation

Required tools
- Quality Assessment tool for cross-comparison with external in-situ data

Anticipated results
A preliminary determination of the error estimates shall be delivered by end of Phase E1. Information on the range bias and stability will be performed on the long term during Phase E2.
Reporting requirements
Regular reporting shall be performed during Phase E1 and Phase E2.

Task Schedule
This task shall be initiated during Phase E1 as soon as Level 2 products are available and will be carried all over the S-3 STM mission lifetime.

6.4.3.3.3 Wind, wave product validation vs models (SRAL-L2MA-CV-230)

Task Description
This task corresponds to the comparison of the S-3 STM Significant Wave Height (SWH) and Wind Speed (WS) parameters versus the ECMWF model and in-situ measurements.

Task Aim and Objectives
The aim of this task is to assess and monitor the quality of the above products versus the ECMWF model and in-situ data. This task is nominally done on the NRT products to ensure a good quality of the satellites data in input to any assimilation model. An OFL activity is also performed to assess the overall quality and consistency of the SWH and WS data set over the mission lifetime. (see RD 70, RD 71, RD 72, RD 73)

Parameters for analysis
- Significant Wave Height
- Wind Speed
- Sigma0

Methodology
The validation and monitoring of the different parameters is nominally based on the data processed in near real time (NRT). Radar backscatter coefficient (s°), surface wind speed and Ku- and C-Band SWH products from the SRAL instrument are among the parameters to be monitored and validated against the ECMWF model products and, for wind and wave products, against the in-situ buoy and platform observations. The later is available through the Global Telecommunication System (GTS).

When possible, a combination of all of the observation sources (multiple-collocation) is also used for validation.

It must be stressed that the number of in-situ observing stations is very limited (few-several 10’s) and most of them are located in the Northern Hemisphere (NH) around the North American and European coasts. The exceptions are few buoys in the Tropics, mainly around Hawaii, and off the South African coasts in the Southern Hemisphere (SH). Therefore, any validation against in-situ data mainly reflects the quality of the products in the NH.

Input/Output data needs
- S-3 SRAL Level 2 data products (NRT & STC)
• ECMWF model analysis
• ECMWF WAM model first guess
• In-situ wave measurements
• In-situ wind measurements

**Required tools**

• Quality Assessment tool for cross-comparison

**Anticipated results**

A determination of the error estimates (e.g. biases, drift) shall be delivered by end of Phase E1 and consolidated over the mission lifetime. Information on stability of the different geophysical parameters will be performed on the long term during Phase E2.

**Reporting requirements**

Regular reporting shall be performed during Phase E1.

The reporting done in Phase E2 shall be disseminated to the user community.

**Task Schedule**

This task shall be initiated as soon as Level 2 products are available.

6.4.3.3.4 **Global mission assessment (SRAL-L2MA-CV-240) (SRAL-L2LA-CV-240)**

**Task Description**

This task refers to overall quality and performance assessment of the S-3 STM measurement system in LRM and SAR mode, using intrinsic verification and relying on a global statistical evaluation approach. The performance assessment shall be done for the two SRAL instrument modes (LRM and SAR). Long term monitoring shall be implemented during Phase E2 and will extend the described calibration and limited validation activities in Phase E1.

**Task Aim and Objectives**

The aim of this task is to assess and monitor the performances of the S-3 STM data products versus the initial mission accuracy and mission objectives. The task will aim at establishing the global error budget of the L2 products and breakdown of the budget for each error component. This shall be nominally done for the two LRM and SAR modes of the SRAL instrument, with respect to the different surface types (e.g. LRM over open ocean, SAR over ocean, coastal zones and inland waters, LRM over ice surfaces).

The Global Statistical evaluation gathers all the procedures that are used operationally in the quality and performance assessment of altimeter measurements, using intrinsic verification. In fact the great number of altimeter measurements allows efficient statistical methods. These methods include computation of all statistical characteristics of altimeter measurements and of all the components entering the computation of the geophysical parameters, spectral analysis of the parameters, visualisations of any kind of parameters, etc.
The global statistical evaluation tools provide a great number of the Quality Assessment (QA) / Quality Control (QC) results during the Phase E1, but also for long term monitoring (Phase E2). Among this large number of statistical tools, two algorithms particularly used for altimeter data shall be considered, i.e. crossover analysis and repeat track analysis.

The key strategy of the quality and performance assessment of altimeter measurements is to maintain the comparisons all along the mission lifetime, from the methodologies described previously in chapter 6.4.3.2 and 6.4.3.3 This allows to precisely monitoring the overall system behaviour, from instrument performance to algorithm and products quality. The long term monitoring is obviously a crucial QA/QC activity during Phase E2. These activities are thus intrinsically part of the mission establishment, and directly associated to the mission operations.

Parameters for analysis

- All meaningful S-3 STM parameters (Range, SLA, SWH, WS, Sigma0, dH, BT, etc.)

Methodology

Cal/Val comparisons shall be performed over different data periods (e.g. a portion of a track, a track, one cycle, several cycles, several years) to achieve the goals of systematic quality assessment of Sentinel-3 data and of long-term monitoring of altimeter parameters and geophysical corrections. In addition, these analyses will provide a way to assess algorithm improvements throughout the Sentinel-3 mission.

The data coverage will be characterized and the missing measurements before and after data editing will be analysed. This will allow the estimation of altimeter tracking capabilities over all surface types and geographical coverage of all geophysical corrections.

In terms of data analysis, generate various plots of all the measurement system parameters (along-track and 2-d map representations), along with histograms and scatter diagrams to support detection of anomalous data will be generated.

Along-track wave number spectra (globally or geographically averaged) will be computed for all measurement parameters (e.g. geophysical corrections, sea surface height).

The measurement system precision will use analysis of sea-surface height differences at global crossover points.

Both sea-state bias (parametric and non-parametric models) and time tag bias will be estimated at crossovers.

Repeat track analysis will also be used to estimate the measurement system precision. Repeat-track data (between two successive cycles and relative to a collinear mean) will also serve to measure the influence of alternative correction terms and models. Low-frequency sea-level-anomaly signals (drift, seasonal signals) will be geographically analysed, and global sea-level trends will be deduced from cycle-averaged time series of sea-surface height.

Analyses of sea level anomaly wave number spectra will provide an estimation of instrumental noise. It shall be emphasized that Sentinel-3A will use a new repeat ground track;

SLA will so be computed using a mean sea surface (MSS) instead of an altimeter mean profile. This will slightly impact the accuracy of the monitoring but the recent MSS (TBD) will reduce this impact.
Input/Output data needs

- S-3 SRAL Level 2 data over target surfaces
- S-3 SRAL Level 1B data over target surfaces

Required tools

The Sentinel-3 Cal/Val tools shall support the following capabilities:

- Data editing, missing measurements determination
- Crossover calculation and analysis
- Collinear-track analysis
- Along-track sea-level anomaly calculation and analysis
- Calculation of geophysical corrections and/or sea-surface height, sea-level anomalies, and wave-number spectra
- Representation of statistical output and visualization

Anticipated results

An estimation of the S-3 STM error budget shall be presented at the end of Phase E1, providing a first error estimates achieved within the 5 months of the Commissioning Phase.

The S-3 STM error budget table shall be regularly revisited and consolidated during Phase E2.

Reporting requirements

Regular reporting to the Cal/Val team and end users during Phase E2.

Task Schedule

This task shall be initiated as soon as SRAL Level 1B and Level 2 are available.

6.4.3.3.5 Sea ice freeboard validation with CryoSat data (SRAL-L2MA-CV-250)

Task Description

This task shall assess the quality of the sea ice freeboard measurements from SRAL by comparing with CryoSat data and in-situ measurements. Also different sea-ice retracker models (present and future) shall be analysed. This task is classified as E1-LOW and E2-MED.

Task aim and Objectives

This task shall build up regional statistics for freeboard measurements from both satellites for areas with sufficient geographical and time overlap.

Input/Output data needs

Level 2 data products from S3 SRAL and CryoSat SIRAL in SAR-Mode
6.5 MWR

The objective of the MWR Calibration is to provide a wet tropospheric correction with an error better than 1 cm rms. The MWR onboard Sentinel-3 will also ensure the data continuity with the Envisat MWR mission.

The Sentinel-3 MWR calibration and validation approach is based on a similar methodology as developed for the ERS and Envisat microwave radiometers.

The calibration/validation exercise is making use of systematic comparisons between brightness temperatures, tropospheric wet delays and total atmospheric water content derived from the Sentinel-3 MWR measurements and:

- pre-launch characterization data
- radiative transfer calculations based on coincident meteorological fields from ECMWF,
- simultaneous satellite observations
- simultaneous in-situ observations

6.5.1 Constraints and Assumptions

Similar to SRAL the SIOV should conclude with

- Gain (and offset ?) settings optimised
- All operation modes checked

6.5.2 Instrument Error Analysis

TBW

6.5.3 Task Definitions for MWR

The MWR Level 2 information is embedded in the SRAL Level 2 products. As a result of this, the validation tasks are assigned to product SRAL-L2, in addition to the MWR-L1B product.

<table>
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<tr>
<th>MKTD key requirement (further associated req.)</th>
<th>S3 Products ID</th>
<th>Major Error Source</th>
<th>→ Cal/Val Tasks</th>
<th>Respons. Schedule</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3-MR-270 The Sentinel-3 MWR shall be capable of providing a wet tropospheric delay correction for the altimeter with an accuracy of 2 cm (goal 1 cm) rms. (S3-MR-110): FOV, sampling</td>
<td>MWR-BT</td>
<td>Calibration Errors Antenna Side Lobes RFI</td>
<td>Preparation of in-orbit Cal/Val activities (MWR-BT-CV-100) Radiometric Calibration Verification (MWR-BT-CV-200) Vicarious Calibration (MWR-BT-CV-300)</td>
<td>E1 before SIOV E1 after SIOV E2 ongoing</td>
<td></td>
</tr>
</tbody>
</table>
6.5.3.1 Preparation of in orbit Cal/Val activities (MWR-BT-CV-100)

Task Description

Preparation activities cover the complete assessment of the pre-launch instrument characterization such as temperature characterization, antenna pattern characterization, side lobe corrections which have to assessed at SIOV (see Chapter 4.4.2)

Task Aim and Objectives

Results from the instrument characterization need to be checked and verified

Parameters for analysis

- Functionality of operation modes
- Physical temperatures of thermistors
- Noise injection temperature
- Gain and linearity
- Antenna Beam Efficiency and Side Lobes measurements
- Efficiency of the blanking signals

Methodology

After the launch of the satellite and the switch-on of the radiometer the main instrument parameters will be verified. The stability of these parameters will be monitored over a given number of days in orbit.

6.5.3.2 Verification of Radiometric Calibration (MWR-BT-CV-200)

Task Description

This task shall cover all activities to verify and monitor the parameters of the MWR in-flight calibration.

Task Aim and Objectives

This tasks shall verify the observation sequence consisting of earth pointing, monitoring and calibration cycles.
The task includes the following sub-tasks:

- Verification on the on-board calibration scheme
- Verification of the 23.8 GHz brightness temperature calibration measurements
- Verification of the 36.5 GHz brightness temperature calibration measurements
- Verification on the on-board calibration timeline

**Methodology**

After the switch-on of the radiometer and the first functional tests the instrument will be operated in its nominal mode. The stability of the brightness temperature measurements when pointed to the calibration loads will be observed over a given number of days in orbit. Task is closely related to MWR-BT-CV-200

For the calibration timeline the instrument will be programmed to perform the internal calibration and monitoring in given time intervals. Depending on the instrument stability the timeline to perform these tasks shall be optimized. This activity can be grouped in two observation periods: A phase for extended sky view measurement to determine the instrument stability followed by a nominal operations phase to validate the internal calibration cycles.

The S-3 MWR validation shall also rely on long-term survey activities:

- Survey of the sensor principal internal parameters such as the different radiometric counts, the gain and residual term.
- Analysis of the brightness temperatures measured over specific areas with dry atmosphere and stable annual cycle. The favorite sites are the Sahara for the hot brightness temperatures and the Antarctic plateau for the cold ones. Over these regions, the idea is that any natural variation shall affect the two sensor channels in a similar way, allowing easily in this way to point out any drift on one particular channel. The cold ocean water locations will also be used, following Ruf’s method developed for Topex/TMR.
- In-depth analysis of the raw data in case of anomaly detection.

**Task Schedule**

Phase E1-HIGH – Revisit regularly in Phase E2

**6.5.3.3 Vicarious Calibration (MWR-BT-CV-300)**

**Task Description**

This task covers the monitoring of the calibration of the Sentinel-3 MWR built on a systematic comparison of MWR Brightness Temperatures versus simulated ones by a radiative transfer model over coincident meteorological fields from ECMWF and by comparison with Envisat radiometer measurements. Therefore it breaks down in two tasks:

- Vicarious calibration using NWP fields from ECMWF as a reference (MWR-BT-CV-310)
- Comparison with other spaceborne radiometers (MWR-BT-CV-320)
6.5.3.3.1 Vicarious Calibration with ECMWF data (MWR-BT-CV-310)

Task Description
This task covers the monitoring of the calibration of the Sentinel-3 MWR built on a systematic comparison of MWR Brightness Temperatures versus simulated ones by a radiative transfer model over coincident meteorological fields from ECMWF. This task is defined as E1-HIGH, E2- HIGH

Task Aim and Objectives
The aim of this task is to properly calibrate and ensure continuity in quality and performance of the MWR derived brightness temperatures.

Parameters for analysis
- Sentinel-3 MWR Brightness Temperatures

Methodology
The Sentinel-3 MWR calibration exercise is built on a systematic comparison between Sentinel-3 MWR Brightness Temperatures over ocean and simulations by a radiative transfer model over coincident meteorological fields from ECMWF. The MWR calibration is in the end a relative calibration versus a reference, which shall be considered as the most up-to-date at the time of the Commissioning Phase.

Following a verification phase of the MWR sensor functioning and its thermal stabilization, the Sentinel-3 Phase E1 focuses on the calibration of the MWR Brightness Temperatures instrumental parameters for each channel. This is done by comparison with coincident simulated brightness temperature from ECMWF meteorological fields. Coincidence criteria (time difference, conditions) shall be similar to those applied for previous radiometers of the same class.

Input/Output data needs
- S-3 MWR Level 1B products
ECMWF analysis fields (2D surface: SST, wind, 3D profiles: T, P, Wv, Wc) with periodicity TBD

Required tools
- Atmospheric Radiative Transfer Model
- Quality Assessment tool for comparison (e.g. scatter plots)

Anticipated results
- Statistics of the radiometric stability of the MWR along the mission.
- MWR Brightness Temperatures calibration corrections (bias, slope)
- Time series of S-3 MWR /analysis collocation statistics, stratified by TBD

Note that monitoring the MWR-A and MWR-B against the same reference will allow spotting easily instrument - vs. model changes.

Task Schedule
The calibration of the Sentinel-3 MWR will depend on the time needed for the thermal stabilization of the MWR sensor. A first set of calibration results will be nominally delivered by end of Phase E1.
The vicarious calibration of the S-3 MWR shall be repeated on a regular basis during the S-3 mission lifetime and also after each major update of the ECMWF model.

Dependencies: MWR-BT-CV-200

6.5.3.3.2 Comparison with other missions (MWR-BT-CV-320)

Task Description
This task covers the performance monitoring of the Sentinel-3 MWR built on a systematic comparison of MWR Brightness Temperatures with other suitable space missions. This task is defined as E1-MOD, E2-LOW

Task Aim and Objectives
The aim of this task is to verify the stability of the S-3 MWR instrument behavior by comparison with similar measurements.

Parameters for analysis
- Sentinel-3 MWR Brightness Temperatures
- Suitable co-located satellite measurements Jason, AltiKa

Methodology
- The comparison of the Sentinel-3 MWR Brightness Temperatures is performed with MWR measurements (e.g. Jason JMR or AltiKa) when available, where one channel is exactly the same as for Sentinel-3 (23.8 GHz). These comparisons will be done either over stable targets (Antarctic plateau for AltiKa mission, Greenland even if less stable than the Antarctic plateau but nevertheless useful for Jason mission, and hot areas) or at crossover points. As the calibration of those radiometers is not as good as that of S-3 (absence of cold space view), the comparison is mostly an indicator of stability.

Input data needs
- S-3 MWR Level 1B data products
- Jason /AltiKa radiometer Level 1B data products

Output
Time series of co-located brightness temperature measurements, trend plots

Required tools
- Quality Assessment tool for comparison (e.g. scatter plots)

Anticipated results
Assessment of the stability of the MWR performance

Task Schedule
The calibration of the S-3 MWR shall be repeated on a regular basis during the S-3 mission lifetime
6.5.3.4 Validation of MWR correction with model and in-situ data (SRAL-L2MA-CV-600)

Task Description
The validation of the MWR radiometer correction is performed by comparison of the MWR Level 2 parameters with external observation and model data. According to the representativeness of the external reference for the wet tropospheric path delay, this task breaks down into the following sub-tasks:

• Comparison of MWR water vapour and liquid water content with values derived from radiosonde measurements (SRAL-L2MA-CV-610)
• Comparison of MWR water vapour and liquid water content with values derived from ECMWF fields
• Comparison of MWR wet tropospheric path delay with ground-based GPS measurement measurements

As both radiosonde and GPS measurements require a long period of accumulation to obtain meaningful statistics, a rapid initial assessment versus ECMWF fields, for water vapor content, wet tropospheric correction and cloud liquid water content supports phase E1.

Task Aim and Objectives
This task aims at validating the Level 2 MWR parameters such as wet tropospheric altimeter path delay, water vapor and liquid water content.

Methodology
The Sentinel-3 MWR validation activity consists in two steps:

1. comparison of the MWR Level 2 parameters which are actually by-products of the main MWR mission, with corresponding observation or model data;
2. comparison of the MWR wet tropospheric path delay with path delay estimates derived from the same observation and model data, as well as directly comparable measurements.

As a conclusion the assessment of the wet tropospheric path delay accuracy contributes to the topography mission error budget.

Anticipated results
An error estimate (bias, slope) of the MWR Level 2 parameters shall be delivered by end of Phase E1.

The error estimate of the MWR wet tropospheric correction is then regularly performed during Phase E2 to establish the Sentinel-3 Altimetry system overall error budget and its validity over the S-3 STM mission lifetime.
6.5.3.5 Comparison of MWR L2 products with radiosonde measurements (SRAL-L2MA-CV-610)

Task Description
The validation of the MWR radiometer correction is performed by comparison of the MWR Level 2 parameters with radiosonde observations.

Task Aim and Objectives: see above

Parameters for analysis
- MWR wet tropospheric altimeter path delay
- MWR water vapor

Methodology
The most reliable method is the statistic comparison with in-situ measurements, i.e. with measurements performed by radiosoundings for water vapor. This is not applicable to the cloud liquid water content for which no routine measurement is performed. Therefore only clear sky soundings well collocated with MWR products shall be retained.

The statistic comparison with in-situ data requires more than one-year time to accumulate enough collocated data. It is therefore considered as a long-term survey activity.

The Phase E2 MWR validation will focus on a thorough long-term stability monitoring of the MWR measurements, being of utmost importance for the Mean Sea Level (MSL) trend and climatological studies.

Input/Output data needs
- S-3 MWR wet tropospheric altimeter path delay and water vapour extracted at radiosonde locations
- Radiosonde measurements Space and time collocation criteria: TBD

Required tools
Quality Assessment tool for cross-comparison data set and error estimates
Tool implementing the algorithm to compute path delay from water vapour vertical distribution

Anticipated results
An error estimate (bias, slope) of the MWR Level 2 parameters shall be delivered by end of Phase E1.

The error estimate of the MWR wet tropospheric correction is then regularly performed during Phase E2 to establish the Sentinel-3 Altimetry system overall error budget and its validity over the S-3 STM mission lifetime.

Task Schedule
The validation starts following the MWR calibration and lasts for the mission lifetime.
Priority: E1-High, E2-High
6.6 Orbit Determination Payload (GNSS/DORIS)

The Precise Orbit Determination (POD) verification and validation activities shall cover the full range of orbit products from the ones generated by the Sentinel-3 FOS (predicted and restituted) to the NRT and off-line orbit products (NRT, MOE and POE orbits) nominally generated by CNES and the GMES POD Service in support to the Sentinel-3 PDGS. These activities will rely on a cooperative analysis from an assigned POD expert team, the established POD processing centres (FOS, CNES, GMES POD Service) and possibly on further external scientists working on satellite orbit modelling.

<table>
<thead>
<tr>
<th>MRTD key requirement (further associated req.)</th>
<th>S3 Products ID</th>
<th>Major Source</th>
<th>Error</th>
<th>Cal/Val Tasks</th>
<th>Schedule</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>S3-MR-700 The Sentinel-3 threshold performance for NRT orbit determination shall be 10-20 cm, with a goal of 2 cm rms. residual orbit accuracy after offline processing.</td>
<td>S3-MR-710</td>
<td>POD</td>
<td>Verification Tests (GNSS-L2-CV-100)</td>
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<td>Data residuals analysis (POD-CV-110)</td>
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<td>Validation with overlapping data sets (POD-CV-120)</td>
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<td>E1 after SIOV</td>
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<td></td>
<td>altimeter Cross-over analysis (POD-CV-130)</td>
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<td>E2 ongoing</td>
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<td>DORIS/GNSS orbit comparison (POD-CV-300)</td>
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<td>Long-term orbit cross-validation (POD-CV-400)</td>
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<tr>
<td>S3-MR-710 High accuracy orbit data shall be delivered for use by the altimeter system in ≤2 days (goal) and &lt;5 days (threshold).</td>
<td>S3-MR-710</td>
<td>POD</td>
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<td>E1 after SIOV</td>
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<td>E2 ongoing</td>
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Table 24 – MWR Cal/Val Tasks definition
Validation activities can be distinguished by *operational verification* and additional *expert verification*. The operational activities are to ensure that the orbits included on the STC and NTC meet mission accuracy requirements. The *expert verification* focuses on a more detailed understanding of the nature of the orbit error, and of its impact on the end users. It includes long term monitoring of the orbit quality, especially to enable the early detection of potential drifts.

### 6.6.1 Constraints and Assumptions

The SIOV should be concluded with:
- All DORIS operation modes checked
- All GNSS receiver operation modes checked
- Interfaces to POD center functional and verified

### 6.6.2 Instrument Error Analysis

**TBW**

### 6.6.3 Task Definitions for POD Products

The orbit error is caused by imperfect knowledge of the spacecraft position in the radial direction. It is actually the largest error on altimetry measurements of sea surface topography. It depends on the quality of the satellite tracking system.

For T/P and Jason-1, precise orbit determination is achieved via three distinct tracking systems (DORIS, Laser, GPS) providing almost global coverage of satellite orbits. Envisat orbits (thanks to DORIS) are likely to (almost) reach a similar accuracy. The radial orbit error obtained is thus accurate to about 2 cm, compared to 5-10 cm accuracy for the most recent GEOSAT, GEOSAT Follow On and ERS-1/2 orbits available. Orbit errors are long-wavelength errors (about 40 000 km) that can be reduced by analysing the altimeter data. Global crossover minimization can thus be used to estimate the orbit error without removing too much of the large-scale oceanic signal.

More generally using inverse techniques, the orbit error signal could be obtained through a global adjustment taking into account not only the spatial but also the temporal characteristics of the orbit error and oceanic signal.

The following activities shall be done:
- Determination of the size the radial orbit error via crossover analyses
- Verification of the interpolation of the orbit files and the referencing of the orbit
- Estimation of time tag errors by minimization of crossover height differences
- Long wavelength orbit error estimation by global minimization of crossover differences

### 6.6.3.1 Preparation for in orbit Cal/Val activities (POD-CV-100)

**TBW**
6.6.3.2 Verification Tests (POD-CV-200)

Task Description
Several orbit verification test procedures are possible due to the redundant Sentinel-3 POD payload. The nature of the tests will depend on the orbit product under consideration. For the STC orbit ephemeris, which is produced using DORIS or GPS data, cross comparison between one solution and the other will be used for external tests. For the NTC orbit ephemeris, which uses the three data sets from GPS, DORIS and LRR together to compute the orbit. The parameters that should be monitored define the necessary sub-tasks:

- Data residual analysis (POD-CV-110)
- Validation with overlapping data sets (POD-CV-120)
- Altimeter Cross-over analysis (POD-CV-130)

6.6.3.2.1 Data residuals analysis (POD-CV-210)

Task Description
Residuals for a current orbit solution shall be analysed

Task Aim and Objectives
- Analysis of the statistical distribution of the residuals
- Analysis of the temporal distribution of the residuals (spectral analysis)
- to be conducted after each orbit determination step (STC and NTC)
- Decomposition of the residuals into time and range biases and analysis of the fluctuations and trends in these biases as part of the STC and NTC final quality verification. The meaning of this test is limited because a cut-off criteria is applied to these biases during data editing
  - Analysis of high elevation SLR residuals

Selected high elevation laser tracking passes provide an accurate measure of the spacecraft range when it is close to the zenith and thus is a good estimate of the spacecraft altitude. Part of the NTC final quality verification

6.6.3.2.2 Validation with overlapping data sets (POD-CV-220)

Task Description
Orbits computed for the same time period using different data sets are compared.

These tests provide a good evaluation of the orbit quality. Overlaps with reduced dynamics orbits which contain data in common do not provide any information because the orbit very closely follows the data

Methodology
This test can be used in different ways
- overlap between successive orbits (comparison over the few hours in common)
overlap between a 7-day arc and a shorter arc (in this case all the data of the short arc is common to both orbits)

• overlap between orbits computed over the same time period by splitting the data into two independent subsets

**Task Schedule**
Part of the NTC operational verification process

### 6.6.3.2.3 Altimeter Cross-over analysis (POD-CV-230)

**Task Description**
Residuals of the altimeter measurements at cross-over points are computed. The residual signal due to tide model errors and ocean variability is so high that this test does not provide a good estimate of orbit error. However, it is useful to evaluate the relative quality of different orbits.

**Task Schedule**
Part of the NTC final quality verification. Validates the STC after delivery

### 6.6.3.3 DORIS/GNSS orbit comparison (POD-CV-300)

**Task Description**
DORIS and GNSS are used independently to produce Sentinel-3 orbits which are then compared together to evaluate systematic errors. SLR residuals are computed for both of these orbits to evaluate the consistency of the 3 data types. Systematic biases between data types due to incoherent reference systems might overwhelm these tests.

**Task Schedule**
Part of the NTC production process. Validates the STC after delivery

### 6.6.3.4 Long-term orbit cross-validation (POD-CV-400)

**Task Description**
Orbits computed by different groups using different configuration and/or different software are compared; when long series are available, the main focus is put on geographically correlated radial differences and on the North/South shift between different solutions; special care is taken in observing the stability of these characteristic signatures over time.

**Methodology**
Potential contributors of the expert verification activities are UT/CSR, NASA GSFC, CNES, ESOC, DELFT, EUMETSAT operational department.
**Input/Output data needs**

- S-3 NRT and OFL S-3 orbit products
- Other S-3 orbit solutions
- SLR data

**Anticipated results**

A determination of the orbit error (across-track, along-track, radial orbit accuracy, 3D accuracy, SLR residuals, dead-band analysis) shall be delivered by the end of the Phase E1.

**Reporting requirements**

Regular reporting to the Cal/Val team shall be performed during Phase E1. The reporting done in Phase E2 shall be made available to the user community.

**Task Schedule**

These tasks shall be initiated as soon as orbital information will be available on ground.
7 International context

Any potential opportunity for participation in international Cal/Val activities shall be outlined in this chapter.

7.1 QA4EO

QA4EO has been endorsed by CEOS as a contribution to facilitate the GEO vision for a Global Earth Observation System of Systems (GEOSS). The aim of GEOSS is to deliver comprehensive and timely knowledge / information products worldwide to meet the needs of its nine “societal benefit areas”. This can only be achieved through the synergistic use of data derived from a variety of sources (satellite, airborne and in situ) and the coordination of the resources and efforts of the GEO members.

To accomplish this vision, starting from a system of disparate systems that were built for a multitude of applications, requires the establishment of an internationally coordinated operational framework to facilitate interoperability and harmonisation. The success of this framework, in terms of data, is dependent upon the successful implementation of two key principles: 1. Accessibility / Availability and 2. Suitability / Reliability. Success also requires effective communication of these principles to all stakeholders.

To implement these principles in a harmonised manner, CEOS (the space arm of GEO), through discussion with calibration and validation experts from around the world, established QA4EO to facilitate interoperability of GEO systems. QA4EO is based on the adoption of guiding principles, which are implemented through a set of key operational guidelines derived from best practices, for implementation by the GEO community. Although these guidelines were originally developed to meet the needs of the space community, they have been written with the aid of national metrology institutes of the UK and the USA and, where appropriate, are based on best practices of the wider non-EO community. They should therefore be readily adoptable by all GEO communities as a top-level framework that can subsequently be translated and implemented to serve each specialist need.

Reference: http://qa4eo.org/background.html

QA4EO is particularly relevant for the Cal/Val application. One of the major QA4EO principle is to provide a measurement with a quality indicator be based on a quantifiable assessment of evidence to demonstrate the level of traceability to internationally agreed (where possible SI) reference standards. This is a key principle for a Cal/Val program.

This Cal/Val plan tries to be consistent with the QA4EO approach.

QA4EO provides some key guidelines applicable for any Cal/Val program. Among others, one can report:

- A guide to establish a Quality Indicator on a satellite sensor derived data product
- A guide to “reference standards” in support of Quality Assurance requirements of QA4EO
- A guide to content of a documentary procedure to meet the Quality Assurance requirements of CEOS
- A guide to comparisons – organisation, operation and analysis to establish measurement equivalence to underpin the Quality Assurance requirements of QA4EO
- A guide to establishing validated models, algorithms and software to underpin the Quality Assurance requirements of QA4EO
• A guide to expression of uncertainty of measurements
• A guide to establishing quantitative evidence of traceability to underpin the Quality Assurance requirements of QA4EO

It also provide few procedures or best practise applicable for this Cal/Val program. One can mention:
• Protocol for the CEOS WGCV Comparison of techniques/instruments used for surface IR radiance/brightness temperature measurements
• A procedure for establishing a “land-based” reference standard test-site
• A best practise guide to land “test-site” characterisation
• Guidelines for the identification and set-up of new systems complying with requirements for satellite ocean colour applications
• Methodologies that should be applied to determine immersion factors for both radiance and irradiance underwater sensors
• Absolute Calibration using Rayleigh Scattering
• Protocol for the CEOS WGCV pilot Comparison of techniques/instruments used for vicarious calibration of land surface imaging through a ground reference standard test site.

This best practises referred in the QA4EO website are complemented by other procedures discussed and agreed at CEOS level.

QA4EO give an international framework for the Cal/Val activities. This framework facilitate the communication and the comparison of various methods and results, and facilitate the interpretation of the Cal/Val results. Therefore it makes easier and safer the utilisation of the data in the context of GMES where the multi-sensor approach is the basis of the various application.

7.2 Envisat-SENTINEL-3 continuity

One of the major requirements for the Sentinel-3 mission is to ensure the continuity with Envisat mission, see AD-3.

The continuity between both missions shall be addressed at product level, but also at Cal/Val level. Main procedures used for Envisat shall be used as far as possible and adapted for Sentinel-3. The experience gained in the Envisat Cal/Val activities shall be brought forward for Sentinel-3.

As Envisat went out of operations in April 2012, continuous “in situ” validation will contribute to understanding of intra-sensor differences and may be used as a “transfer standard” (for example MOBY/BOUSSOLE or ISAR/SiSTeR). Therefore it is absolutely mandatory to maintain the in situ infrastructures. The in situ data traceable to SI, would ensure a continuity between both missions.

Methodologies to inter-calibrate and bridge the gap between AATSR and SLSTR should be implemented using Metop (A and B) IASI and AVHRR data, in collaboration with GSICS. Methodologies to ensure MERIS and OLCI consistency and continuity should be developed using in situ measurements as well as available satellite data, including MODIS, VIIRS, SPOT and other missions.
7.3 International cooperation

A written in the chapter 7.1, QA4EO is the international framework in which one the Cal/Val activities will be performed. QA4EO is support by technical international groups that define procedures and standards used in Cal/Val. Sentinel-3 Cal/Val entities (ESA-MPC/EUMETSAT, Cal/Val scientist, S3CVT) will be an important contribution to these groups and in return, the Cal/Val plan and its application will have to follow as far as possible the recommendations and the technical advices provided by the international community. That would also allow a better comparison and therefore integration with other missions, which is a key element in the GMES space program.

The following groups shall be mentioned:

**CEOS Working Group Cal/Val**

- **Infra Red Visible Sensors IVOS** (http://ceoswgcv-ivos.org/), dealing with the radiometric, geometric calibration and image quality issues. IVOS promotes international and national collaboration in the calibration and validation of all IVOS and, thus, to assist in the improved application of data from satellite sensors, addresses all sensors (ground based, airborne, and satellite) for which there is a direct link to the calibration and validation of satellite sensors, identifies and agree on calibration and validation requirements and standard specifications for IVOS, identifies test sites and encourage continuing observations and inter-comparison of data from these sites. Standard test sites, vicarious calibration best practises are discussed and established within IVOS. IVOS also addresses the ocean colour and Surface Temperature problematic. IVOS harmonises its approach with more thematic and specific groups like LPV, GHRSSST, IOCCG and GSICS.

- **Land Product validation LPV** (http://lpvs.gsfc.nasa.gov/), dealing with the validation of the Land parameters. LPV subgroup activities are divided up into 8 focus areas related to product families; biophysical, surface radiation/albedo, fire/burn scar detection, land cover mapping, land surface temperature/emissivity, soil moisture, snow and phenology. LPV develops CEOS-endorsed community consensus “best practice” protocols for land product validation, data collection, analysis and accuracy reporting, identifies and supports global core sites for both systematic and episodic measurements of land surface properties via tower measurements, field campaigns, use of ground and near-surface sensors (with IVOS and WGISS), contributes to satellite land product inter-comparison activities, develops procedures for validation data exchange and management.

**GHRSSST** (https://www.ghrsst.org/)

The aim of the GHRSSST is to provide the best quality sea surface temperature data for applications in short, medium and decadal/climate time scales in the most cost effective and efficient manner through international collaboration and scientific innovation. The Global Ocean Data Assimilation Experiment (GODAE) is an international collaboration for ocean forecasting activities which, in 2002, initiated a GODAE High Resolution SST Pilot Project GHRSSST-PP to address an emerging need for accurate high resolution sea surface temperature (SST) products. Sentinel-3, through the GMES services, will be an important contributor of GHRSSST. GHRSSST also tackle issues related to Cal/Val as satellite inter-comparison and integration are key features of GHRSSST activities.
IOCCG (http://www.ioccg.org/about_ioccg.html)

The International Ocean-Colour Coordinating Group (IOCCG) was established in 1996 following a resolution endorsed by the Committee on Earth Observation Satellites (CEOS). The group is made up of an international Committee of experts comprising representatives from both the provider (Space Agencies) and user communities (scientists, managers). The objectives of the IOCCG are to develop consensus and synthesis at the world scale in the subject area of satellite ocean colour radiometry (OCR). Specialised scientific working groups are established to investigate various aspects of ocean-colour technology and its applications, and their findings are published in the highly-acclaimed IOCCG Report Series. Continuity of ocean colour radiance datasets is addressed through the CEOS OCR-Virtual Constellation. The IOCCG also has a strong interest in capacity building, and conducts and sponsors advanced training courses on applications of ocean-colour data in various countries around the world. One of the main objective of IOCCG is to optimize quality of data for calibration and validation.

The Ocean Surface Topography Science Team (OSTST).
http://www.aviso.oceanobs.com/en/courses/sci-teams/index.html,
http://sealevel.jpl.nasa.gov/science/ostscienceteam/

The OSTST supports basic research and investigations associated with Jason-2/OSTM as well as other satellite altimetry missions, including TOPEX/Poseidon (TP), Jason-1 (J-1), Envisat and the upcoming Jason-3 mission. The goals of the OSTST are: to provide the scientific underpinning for production of the best possible satellite-derived ocean surface topography data sets, to demonstrate the Earth science and applications arising from analyses of the ocean surface topography data and to evaluate operational use of ocean and continental surface topography data. The OSTST is closely cooperating with the coastal altimetry community (http://www.coastalaltimetry.org/), that is the international community of scientists working on development and applications of altimetry in the coastal zone. Concerted plenary meetings are held on a yearly basis.

GSICS (http://gsics.wmo.int/)

GSICS is an international collaborative effort initiated in 2005 by WMO and the CGMS to monitor, improve and harmonise the quality of observations from operational weather and environmental satellites of the Global Observing System (GOS). GSICS aims at ensuring consistent accuracy among space-based observations worldwide for climate monitoring, weather forecasting, and environmental applications. This is achieved through a comprehensive calibration strategy which involves monitoring instrument performances, operational inter-calibration of satellite instruments, tying the measurements to absolute references and standards, and recalibration of archived data. GSICS delivers calibration corrections needed for accurately integrating data from multiple observing systems into products, applications and services. GSICS contributes to the integration of satellite data within the Global Earth Observation System of Systems (GEOSS) of the Group on Earth Observations (GEO). GSICS approaches shall be harmonised as far as possible with the CEOS-IVOS approaches. Sentinel-3 Cal/Val program will apply both GSICS and CEOS-IVOS methodologies.

The Sentinel-3 Cal/Val program and its represents (ESA-MPC, EUMETSAT, S3CVT) shall participate and contribute to the groups mentioned above. It would insure the feedback and
experience of Sentinel-3 into this groups and in return it would insure the feedback and experience
from this groups into the Sentinel-3 Cal/Val program. It would also facilitate the data Cal/Val
results interpretation, the data inter-comparison and therefore the multi-missions application.

7.4 International In-situ instruments intercomparison

The community has agreed that quality indicators need to be based on a quantifiable assessment
of evidence to demonstrate the level of traceability to internationally agreed (where possible SI)
reference standards. This documented evidence should include a description of the processes
involved together with an uncertainty budget. The most effective means of demonstrating traceability and establishing an overall uncertainty budget is to perform a formal comparison against a reference standard which, by virtue of its position in the traceability chain hierarchy, has
an uncertainty significantly smaller than that being declared / required by the process under test.
Such a comparison may in general terms be called a “calibration” and is clearly an essential
component of any activity to establish a true uncertainty budget for a measurement and any
consequential products but from an interoperability perspective can sometimes be considered a
secondary activity.

Regular inter-comparison exercises shall take place regularly – every 4 years. They are an
important component of the Cal/Val program. In the optical domain, 3 types of activities shall
cover the Sentinel-3 ranges with specifics needs:

- Ocean Colour In-situ radiometric instrument inter-comparison,
- Infra-red radiometer inter-comparison,
- Land radiances measurements in the Visible wavelengths inter-comparison.

7.4.1 Ocean Colour radiometric instrument inter-comparisons

The validation program should include regular inter-comparison exercises: Objective of the
activity is a comparison of state-of-art in situ radiometric measurement and processing methods thorough laboratory/field experiments.

Inter-comparison of data products from simultaneous measurements performed with independent
systems and methods is a viable approach to assess the consistency of data and additionally to
investigate uncertainties. It is essential to evaluate the performance of independent measurement
methods and also the ability of individuals to properly implement them (see Reference inter-
comparison 1 below).

The activity should include three phases: 1. laboratory inter-calibration of radiometers; 2. field
inter-comparison of methods with inter-calibrated radiometers; 3. evaluation and discussion of
results.

All radiometers utilized in the field experiment should be calibrated with respect to standards
(NPL or NIST). The field inter-comparison comprises the simultaneous deployment of multiple
identical above-water systems, multiple identical in-water mooring systems, and additional
reference systems. This will provide materials for comparing results from: i. identical systems and
measurement methods; ii. identical systems and different measurement methods; and iii. different
systems and different measurement methods.
Results shall be summarized and discussed in an open workshop. The report(s) shall be used by the Sentinel-3 OLCI Cal/Val plan, allowing the comparison with in-situ data to be fully traceable to a standard reference.

As example, one can mention that such activity took place at JRC in July 2010. Description and results can be found in Reference inter-comparison 1 given below.

Ideally such experiment should take place every 4 years. It should be an international effort, involving cost sharing between agencies.

Reference inter-comparison 1. :
G. Zibordi, et al, 2012, In situ determination of the remote sensing reflectance: an inter-comparison,

7.4.2 Infra Red Radiometer Intercomparison
A comparison of terrestrial based infrared (IR) radiometric instrumentation used to support calibration and validation of satellite borne sensors with emphasis on sea/water surface temperature should be done at regular interval. The objectives of the comparison exercise are to establish the “degree of equivalence” between terrestrially based IR Cal/Val measurements made in support of satellite observations of the Earth’s surface temperature and to establish their traceability to SI units through the participation of National Metrology Institutes (NMIs).

The comparison exercise should consist of two stages: first stage in laboratory where the instruments are calibrated to a reference transfer radiometer and a second stage that involve contemporaneous measurements on sea.

All participants shall develop uncertainty budgets for all measurements reported.

Such activities took place to support the (A)ATSR validation program. 3 inter-comparison campaigns took place at MIAMI. Results and references can be found in Reference inter-comparison 2. given hereafter.

Reference inter-comparison 2. :

7.4.3 Land radiances measurements in the Visible wavelengths inter-comparison
The overall objective of the inter-comparison is to establish knowledge of the degrees of equivalence between ground based vicarious calibration teams and their ability to evaluate/establish traceability to SI for in-flight sensors measuring land spectral radiance.

The vicarious calibration technique known as the reflectance-based method depends on measurements of the surface reflectance of a test site at the time of sensor overpass. Therefore; scene acquisition time, view nadir, solar geometry should be known for the satellite. Ground data collection is performed in situ using spectro-radiometers to obtain radiance and reflectance values at the time of satellite acquisition. Atmospheric characterization of the site is also required, that
includes the measurement of the aerosol optical properties, column ozone, and precipitable column water vapour content. From these measurements top of the atmosphere radiance at the sensor within its spectral bands are computed using a Radiative Transfer Code (RTC). Sensor DN values and at-sensor-radiance is then used to calculate radiometric calibration parameters as offset and bias.

The inter-comparison exercise should include:

- The evaluation of differences in field instrument primary calibrations using Reference standards used and traceability (based on “Laboratory” information) and On-site calibrations/validations,
- The evaluation of differences in methods for characterising and assigning “radiometric value” to a site, for multiple view angles,
- A formal traceability of the site reference site based on an evaluation of all comparison results.
- A multi-sensor (satellite and aircraft) comparison linked to the ground calibration derived from the multi-team comparison.

Such inter-comparison exercises took place at the Tuz Gulu site in 2009 and 2010. Reports of the campaign can be found Reference inter-comparison 3. given below.

Reference inter-comparison 3.:

Irina Behnert, National Physical Laboratory, Results of Tuz Gölü comparison: Surface based measurements, CEOS WGCV IVOS workshop, 18th October 2010, Ispra.

http://calvalportal.ceos.org/cvp/web/guest/ivos/ispra/day1
8  **Annex 1: Available Resources**

The following tables provide an overview of existing resources developed by other missions and projects which could serve the Sentinel-3 Cal/Val planning. The tables do not imply any priorities or recommendations. The actual exploited resources for S3 will be reported in Chapter 5 and Chapter 6.

### 8.1 Analysis Software Tools and in-situ Data Archives for validation purposes

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEAM</td>
<td>ESA Tool for analysis of optical imagery</td>
<td><a href="http://www.brockmann-consult.de/cms/web/beam/">http://www.brockmann-consult.de/cms/web/beam/</a></td>
</tr>
<tr>
<td>BRAT</td>
<td>ESA Tool for analysis of altimeter data</td>
<td><a href="http://earth.eo.esa.int/brat/html/data/toolbox_en.html">http://earth.eo.esa.int/brat/html/data/toolbox_en.html</a></td>
</tr>
<tr>
<td>Geocal</td>
<td>ESA Tool for geolocation analysis for optical instruments</td>
<td>Under development</td>
</tr>
<tr>
<td>Sentinel-3 Toolbox</td>
<td>ESA Tool for the analysis of OLCI/SLSTR imagery</td>
<td>Under development</td>
</tr>
<tr>
<td>Lo converter</td>
<td>ESA Tool to convert binary S3 ISP data to netCDF</td>
<td>available</td>
</tr>
<tr>
<td>netCDF Tools</td>
<td>various tools and API for netCDF Data processing</td>
<td><a href="http://www.unidata.ucar.edu/software/netcdf/index.html">http://www.unidata.ucar.edu/software/netcdf/index.html</a></td>
</tr>
<tr>
<td>SST-CCI</td>
<td>SST Analysis Tool</td>
<td>Tomazic et al, 2011; O’Carroll et al, 2012 etc</td>
</tr>
</tbody>
</table>

**Table 25 – Existing Analysis Software Tools**

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERMAID</td>
<td>DB of MERIS imagery and in-situ optical measurements</td>
<td><a href="http://hermes.acri.fr/mermaid/home/home.php">http://hermes.acri.fr/mermaid/home/home.php</a></td>
</tr>
<tr>
<td>Globcolour</td>
<td>DB of ocean colour in-situ data on specific diagnosis sites (data from 1997 – today)</td>
<td><a href="http://www.globcolour.info">http://www.globcolour.info</a></td>
</tr>
<tr>
<td>SeaBASS</td>
<td>DB of ocean colour in-situ data</td>
<td><a href="http://seabass.gsfc.nasa.gov/">http://seabass.gsfc.nasa.gov/</a></td>
</tr>
<tr>
<td>Medspiration</td>
<td>SST L2P data archive (until 2009)</td>
<td><a href="http://www.medspiration.org/">http://www.medspiration.org/</a></td>
</tr>
<tr>
<td>SADE</td>
<td>DB of optical measurements (?)</td>
<td>CNES</td>
</tr>
<tr>
<td>DIMITRI</td>
<td>in-situ project for desert and snow sites</td>
<td>Marc Bouvet</td>
</tr>
<tr>
<td>AVISO</td>
<td>High level altimetry data products</td>
<td><a href="http://www.aviso.oceanobs.com">http://www.aviso.oceanobs.com</a></td>
</tr>
<tr>
<td>ARGO</td>
<td>DB of global measurements from ocean floaters</td>
<td><a href="http://wo.jcommops.org/cgi-bin/WebObjects/Argo">http://wo.jcommops.org/cgi-bin/WebObjects/Argo</a></td>
</tr>
</tbody>
</table>

**Table 26 – Existing databases and resources for validation**
8.2 In-situ measurement sites

To be completed.

<table>
<thead>
<tr>
<th>Site</th>
<th>Description</th>
<th>Status</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESA Campaign DB</td>
<td>DB of specific ESA campaign activities</td>
<td></td>
<td><a href="http://earth.esa.int/campaigns/">http://earth.esa.int/campaigns/</a></td>
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<tr>
<td>Boussole Buoy</td>
<td>stationary buoy in the Mediterranean for-time-series of optical properties</td>
<td>active</td>
<td><a href="http://www.obs-vlfr.fr/Boussole/">http://www.obs-vlfr.fr/Boussole/</a></td>
</tr>
<tr>
<td>TAO</td>
<td>ocean buoy array in the Pacific</td>
<td>active</td>
<td><a href="http://tao.noaa.gov/">http://tao.noaa.gov/</a></td>
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<tr>
<td>PSMSL</td>
<td>Global Tide Gauge Network</td>
<td>active</td>
<td><a href="http://www.psmsl.org/">http://www.psmsl.org/</a></td>
</tr>
<tr>
<td>AERONET</td>
<td>network global aerosol measurements</td>
<td>active</td>
<td><a href="http://aeronet.gsfc.nasa.gov/">http://aeronet.gsfc.nasa.gov/</a></td>
</tr>
<tr>
<td>AERONET OC</td>
<td>Ocean Colour in-situ network</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>NDBC</td>
<td>NOAA National Data Buoy Center</td>
<td>active</td>
<td><a href="http://www.ndbc.noaa.gov/">http://www.ndbc.noaa.gov/</a></td>
</tr>
<tr>
<td>NCAVEO</td>
<td>UK Network for in-situ data</td>
<td>?</td>
<td><a href="http://www.ncaveo.ac.uk/">http://www.ncaveo.ac.uk/</a></td>
</tr>
<tr>
<td>Venice Tower</td>
<td>long time series of optical measurements</td>
<td>active</td>
<td>Giuseppe Ziboldi -JRC</td>
</tr>
<tr>
<td>Ship tracks</td>
<td>regular ocean colour measurements with ferry and cargo ships</td>
<td></td>
<td>Ramses Trios, Norway (Kai Sorensen)</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Simbada (D. Ramon)</td>
</tr>
<tr>
<td>Portugal Water</td>
<td>hyperspectral radiometer site</td>
<td>?</td>
<td>John Icely–Sagremarisco, Algarve</td>
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<tr>
<td>ClimZoo</td>
<td>Site for Level-3 analysis</td>
<td>?</td>
<td>?</td>
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<tr>
<td>LSA-SAF Sites</td>
<td>Evora, Portugal; Gobabeb, Namibia; Dahra, Senegal</td>
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<td></td>
</tr>
<tr>
<td>Valencia</td>
<td>LST calib site</td>
<td></td>
<td>University of Valencia</td>
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<tr>
<td>MTCSI/MGVI</td>
<td>specific validation sites for MTCSI/MGVI</td>
<td>?</td>
<td>?</td>
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Table 27 – Potential in-situ measurements sites

Table 28 - Target reference sites for SLSTR-SST validation work, (based on the GHRSST High Resolution Diagnostic Data Set (HR-DDS) definitions)
<table>
<thead>
<tr>
<th>Site</th>
<th>Long Name</th>
<th>Long</th>
<th>Lat.</th>
<th>Site</th>
<th>Long Name</th>
<th>Long</th>
<th>Lat.</th>
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<td>GHRST_Madeira</td>
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<td>ghr002</td>
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<td>ghr036</td>
<td>GHRST_Central_Southern_Ocean</td>
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Annex 2: Definitions and Terminology

The CEOS Framework on Calibration and Validation defines agreed definitions and guidelines for Cal/Val procedures of remote sensing data. Some basic definitions relevant for the Sentinel-3 payload are referred here (RD 13)

9.1.1 Definitions

Uncertainty/Accuracy: non-negative parameter characterising the dispersion of the quantity values that are being attributed to a measurement (quantity), based on the information used. Usually it includes both random and systematic errors that have not been recognised and or corrected for. Where possible this should be derived from an experiment an estimate based on other information, e.g., experience.

Accuracy: Closeness of agreement between a quantity value obtained by measurement and the true value of the measurand

![Accuracy and Precision Diagram](image)

Figure 22: Accuracy and Precision

Quality Indicator: a means of providing “a user” of a product (which is the result of a process) sufficient information to assess its suitability for a particular application. This “information” should be based on a quantitative assessment of its traceability to an agreed reference standard (ideally SI).

Characterization: Measurement, potentially completed by an analytical modelling, of certain parameters over a range of conditions, to provide information for in-flight calibration and ground processing initialization, and predict in-orbit performance

Calibration: a process of quantitatively defining the system response to a known, controlled signal input. Hence the calibration process aims at determination of the sensor model parameters precisely. This is the working definition used by the Working Group on Calibration and Validation (WGCV) of the international Committee on Earth Observation Satellites (CEOS).

Validation: a process of assessing, by independent means, the quality of the data products derived from the system inputs. Thus validation is subsequent to calibration and requires different procedures even though the two operation (“Cal/Val”) are linked. The validation process aims to check the quality of the data. According to the accuracy results obtained in the validation process,
the calibration procedure might be repeated. On the other hand, the validation process can be applied for the methods as well.

Vicarious calibration refers to techniques that make use of natural or artificial sites on the surface of the Earth for the post-launch calibration of sensors. These targets are imaged in near-coincident fashion by the sensor to be calibrated and by one or more well-calibrated sensors from satellite or aircraft platforms or on the ground.

9.1.2 Error Types

The errors affecting each measurement from instruments can be categorized by their spatial and temporal variability.

Random error: a component of the total error which, in the course of a number of measurements, varies in an unpredictable way. It is not possible to correct for random error. They can be described with a certain statistical distribution function (i.e. Gaussian, white/pink noise etc.)

Long term drift errors: An error associated with the ageing of components. It corresponds to slowly varying behaviour and is sometimes difficult to separate from geophysical trends.

Harmonic errors: an error term corresponding to cyclic changes. It may be linked to the orbital period, to seasonal fluctuations, to the solar cycle etc.

Bias: a residual offset error which usually appears after launch and expresses the difference between actual values once the satellite is operational and the pre-launch definition it is a stable and constant value through the satellite time life

The uncertainty of measurement shall be estimated according to the ISO Guide to the Expression of Uncertainty in Measurement (QA4EO-QAEQ-DQK-006). All validation institutes should provide a full breakdown of their measurement uncertainties following the example template provided in Table 29 taken from QA4EO-WGCV-IVO-CLP-008 for an intercomparison exercise over Tuz Golu.

Type A uncertainties are based on a statistical analysis of the measurements. E.g. experimental standard deviation of the mean from n independent, multiple, random measurements.

Type B uncertainties are based on a priori knowledge – E.g. quoted uncertainty from the supplier.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type A Uncertainty / %</th>
<th>Type B Uncertainty in Value/(Appropriate Units)</th>
<th>Uncertainty in radiance/reflectance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeatability of measurement</td>
<td>( u_{\text{repeat}} )</td>
<td>( u_{\text{repeat}} )</td>
<td></td>
</tr>
<tr>
<td>Reproducibility of measurement</td>
<td>( u_{\text{repro}} )</td>
<td>( u_{\text{repro}} )</td>
<td></td>
</tr>
<tr>
<td>Site Variability</td>
<td>( u_{\text{site}} )</td>
<td>( u_{\text{site}} )</td>
<td></td>
</tr>
<tr>
<td>Model Uncertainty</td>
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<td>( u_{\text{Mod}} )</td>
<td></td>
</tr>
<tr>
<td>Primary Calibration</td>
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<td>( u_{\text{prim}} )</td>
<td></td>
</tr>
<tr>
<td>Drift Since Calibration</td>
<td>( u_{\text{drift}} )</td>
<td>( u_{\text{drift}} )</td>
<td></td>
</tr>
<tr>
<td>RMS Total</td>
<td>( u_{\text{total}} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 29 - Example table showing the breakdown of measurement uncertainties (ref QA4EO-WGCV-IVO-CLP-008)

The RMS total refers to the usual expression i.e. square root of the sum of the squares of all the individual uncertainty terms as shown in the example for Type A uncertainties. Some more basic formulas to calculate different error terms are summarized in the Sentinel-3 SRD (AD 1).