Copernicus Cal/Val Solution

D1.1 - Optical Missions Cal/Val requirements

Ref: CCVS.ACR.D1.1

Version: 1.0

Date: 31/05/2021

GA 101004242

Document Reference

	Company
Work Package	1
WP leader	E. Jakobson (U. Tartu)
Deliverable Title	Optical Missions Cal/Val requirements
Delivery Number	D1.1
Delivery Type	Report
Dissemination Level	Public
Version	1.0
Date of issue	31/05/2021
Lead beneficiary	ACRI-ST
Lead authors	L. Bourg (ACRI-ST), B. Pflug (DLR), Martin Bachmann (DLR), M. Neuveu Van Malle (TAS-F), N. Gobron (JRC)
Contributors	
Reviewed by	E. Jakobson (U. TARTU)

Changes Log

Version	Date	Changes
1.0	31/05/2021	Initial Version

This project has received funding from the European Union's Horizon 2020 programme under grant agreement No 101004242.

Table of Content

List of Figures

List of Tables

1 Introduction

1.1 Scope of the document

This document intends to identify the requirements applicable to the calibration and validation (Cal/Val) activities for the optical missions of the Copernicus Space Component. These optical missions can be further classified as Surface Colour and Surface Temperature missions. Missions dedicated to atmosphere composition are addressed in a specific document and as such excluded from the present document, even if based on optical remote sensing techniques.

Copernicus Space Component Surface Colour missions are:

- Sentinel2/MSI
- Sentinel3/OLCI
- Sentinel3/SYN
- CHIME

Copernicus Space Component Surface Temperature missions are:

- Sentinel3/SLSTR
- LSTM

1.2 Reference Documents

This section lists the documents containing Calibration and Validation requirements identified and analysed during this study.

1.2.1 Sentinel2

- [S2-MRD]: GMES Sentinel-2 Mission Requirements Document EOP-SM/1163/MR-dr, i2r0, 30/01/2007
- [S2-CALVALPE] Sentinel-2 Calibration and Validation Plan for the Operational Phase, GMES-GSEG-EOPG-PL-10-0054, issue 1.6, 22/12/2014
- [S2-CVP]: S2-PDGS-MPC-ROCVP i5r0 11/04/2016
- [S2-SRD]: GMES Space Component Sentinel-2 Payload Data Ground Segment System Requirements Document, GMES-GSEG-EOPG-RD-09-0028, version 2.4
- [S2-SSRD]: GMES Sentinel-2 System Requirements Document, S2-RS-ESA-SY-0001 issue 6.0, 11/11/2009

1.2.2 Sentinel3

- [S3-MRD]: Sentinel-3 Mission Requirements Document, EOP-SMO/1151/MD-md, i2r0, 19/02/2007
- [S3-MRTD]: Sentinel-3 Mission Requirements Traceability Document, EOP-SM/2184/CD-cd, i1r0, 07/02/2011
- [OLCI-ATBD]: OLCI Level 0, Level 1b Algorithm Theoretical Basis Document, S3-ACR-TN-007, issue 5.0, 10/12/2014.
- [SLSTR-ATBD]: SLSTR: Algorithm Theoretical Basis Definition Document for Level 1 Observables, S3-TN-RAL-SL-032, issue 7.0, 24/07/2017.

1.2.3 CHIME

- [CHIME-MRD]: Copernicus Hyperspectral Imaging Mission for the Environment - Mission Requirements Document, ESA-EOPSM-CHIM-MRD-3216, i3 r0, 21/01/2021
- [CHIME-SSRD]: CHIME Space Segment Requirements Document, CHIM-RS-ESA-PM-0002, 18/07/2019

1.2.4 LSTM

- [LSTM-MRD]: Copernicus High Spatio-Temporal Land Surface Temperature Mission: Mission Requirement Document, ESA-EOPSM-HSTR-MRD-3276, i2r0, 08/03/2019
- [LSTM-SSRD]: LSTM Space Segment Requirement Document, LSTM-RS-ESA-PM-0002, issue 1.0, 18/07/2019

2 Sentinel Optical Missions

2.1 Surface Colour Missions

2.1.1 Sentinel2/MSI

SENTINEL-2 is a wide-swath, high-spatial resolution, multi-spectral imaging mission, supporting Copernicus services and applications such as land management, agriculture and forestry, disaster control, humanitarian relief operations, risk mapping and security concerns.

SENTINEL-2 mission objectives are to provide:

- systematic global acquisitions of high-spatial resolution, multispectral images allied to a high revisit frequency
- continuity of multi-spectral imagery provided by the SPOT series of satellites and the USGS LANDSAT Thematic Mapper instrument
- observation data for the next generation of operational products, such as land-cover maps, land-change detection maps and geophysical variables.

The high revisit requirement is supported by a constellation of two Sentinel-2 satellites flying in the same orbit but phased at 180°, providing revisit frequency of 5 days at the Equator.

The Sentinel-2 mission systematically acquires data over land and coastal areas in a band of latitude extending from 56° South (Isla Hornos, Cape Horn, South America) to 82.8° North (above Greenland):

- all coastal waters up to 20 km from the shore
- all islands greater than 100 km^2
- all EU islands
- the Mediterranean Sea
- all closed seas (e.g. Caspian Sea).

The mission geographical coverage is depicted in Figure 1.

The SENTINEL-2 Multispectral Instrument (MSI) has a swath width of 290 km, it samples 13 spectral bands with spatial resolution from 10 m to 60 m: four bands at 10 m, six bands at 20 m and three bands at 60 m (see Table 1).

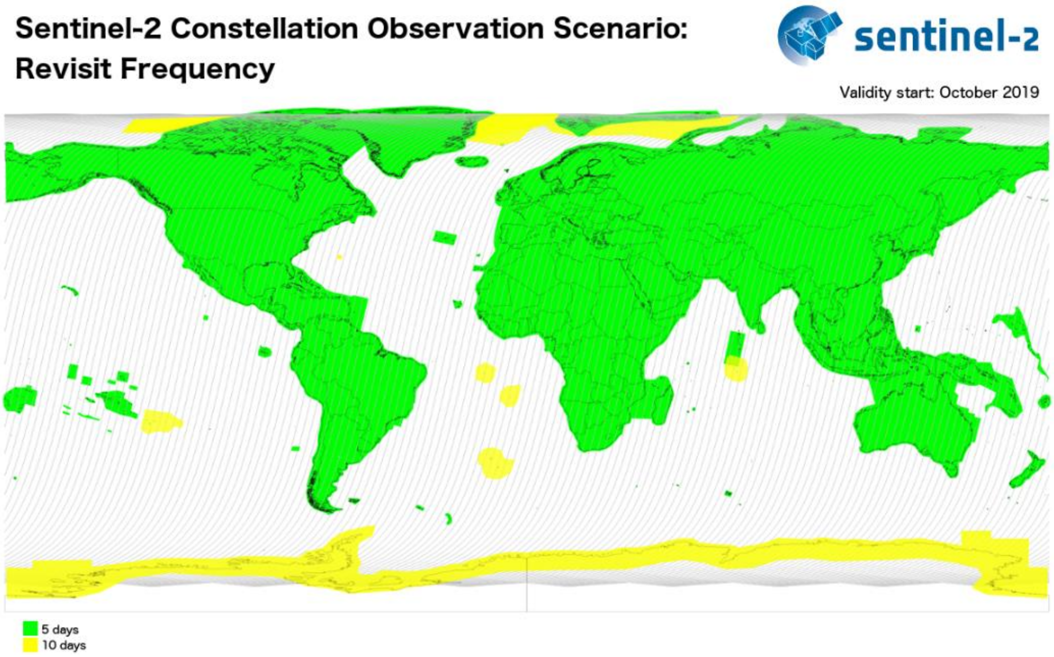

Figure 1 : Sentinel-2 MSI twin satellites acquisition coverage and revisit time.

Table 1: MSI original spectral bands specification from [S2-MRD]. Synthesis of purposes and heritage of the spectral bands of Sentinel-2. Symbol '' denotes bands that have same centre wavelength as LDCM but narrower bandwidth.*

Band #	λcenter (nm)	width Δλ (nm)	Purpose	Heritage
1	443	20	Atmospheric correction (aerosol scattering)	MODIS, ALI, LDCM
2	490	65	Sensitive to vegetation senescing, carotenoid, browning and soil background; atmospheric correction (aerosol scattering)	MERIS, LDCM, Landsat
3	560	35	Green peak, sensitive to total chlorophyll in vegetation.	MERIS, LDCM*, SPOT-5, Landsat
4	665	30	Chlorophyll absorption maximum.	MERIS, LDCM*, Landsat
5	705	15	Position of red edge; consolidation of atmospheric corrections / fluorescence baseline.	MERIS
6	740	15	Position of red edge, atmospheric correction, retrieval of aerosol load.	MERIS
7	775	20	LAI, edge of the NIR plateau	MERIS, ALI
8	842	115	LAI	SPOT-5, Landsat
8a	865	20	NIR plateau, sensitive to total chlorophyll, biomass, LAI and protein; water vapour absorption reference; retrieval of aerosol load and type.	MERIS, ALI, LDCM*
9	940	20	Water vapour absorption, atmospheric correction.	MODIS, MERIS
10	1375	20	Detection of thin cirrus for atmospheric correction.	MODIS, LDCM
11	1610	90	Sensitive to lignin, starch, and forest above ground biomass. Snow/ice/cloud separation.	LDCM, SPOT-5, Landsat
12	2190	180	Assessment of Mediterranean vegetation conditions. Distinction of clay soils for the monitoring of soil erosion. Distinction between live biomass, dead biomass and soil, e.g. for burn scars mapping.	LDCM, Landsat

2.1.2 Sentinel3/OLCI

The main objective of the Sentinel-3/OLCI (Ocean and Land Colour Instrument) mission is to measure ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring, and climate monitoring. The mission definition was driven by the need for continuity of ENVISAT and SPOT surface colour data, with improvements in instrument performance and coverage.

The Sentinel-3 orbit is similar to the orbit of Envisat allowing continuation of the Envisat time series. It uses a high inclination orbit (98.65°) for optimal coverage of ice and snow parameters in high latitudes. The Sentinel-3 orbit is a near-polar, sun-synchronous orbit with a descending node equatorial crossing at 10:00 h Mean Local Solar time. The orbit reference altitude is 814.5 km.

The orbital cycle is 27 days (14+7/27 orbits per day, 385 orbits per cycle). The orbit cycle is the time taken for the satellite to pass over the same geographical point on the ground. The two in-orbit Sentinel-3 satellites enable a short revisit time of less than two days for OLCI and less than one day for SLSTR at the equator based on the instruments' respective swath widths. Sentinel-3B's orbit is identical to Sentinel-3A's orbit but flies ±140° out of phase with Sentinel-3A.

OLCI observes globally the Earth surface, over a 44 min time window on the descending (daytime) path of each orbit, according to illumination conditions on ground: observation starts when the Sun Zenith Angle (SZA) at the sub-satellite point goes below 80° and stops when it again reaches 80° (Figure 2). The OLCI instrument having a field of view of 68.5° that covers a swath width of 1270 km, the mean global coverage revisit time for OLCI land colour observations is 2.2 d at the equator (one operational satellite) or 1.1 d (in constellation) with the values decreasing at higher latitudes, due to orbital convergence.

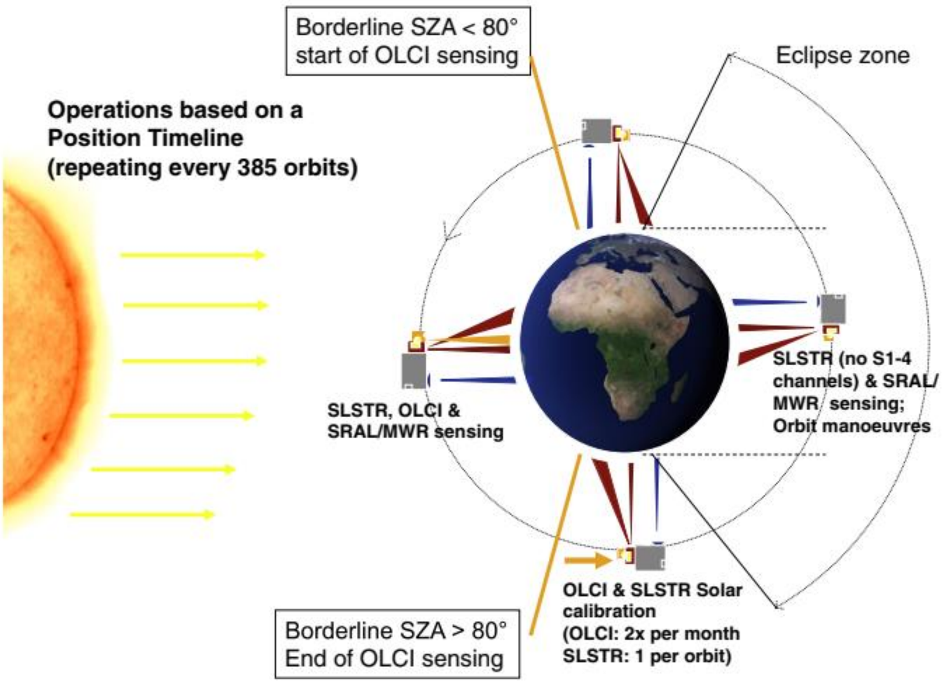

Figure 2: An overview of Sentinel-3 operations and instrument payload acquisitions for each orbit. Blue indicates SRAL, red SLSTR and orange OLCI.

The OLCI instrument is a programmable, medium-spatial resolution, imaging spectrometer operating in the reflective solar spectral range (390 nm to 1040 nm) (Donlon et al., 2012). Its twenty-one spectral bands are programmable by ground command both in width and in position by steps of 1.25 nm (Donlon et al., 2012). The 1270 km field of view is shared between five identical cameras arranged in a fan shape configuration, each camera covering a 14° field of view (see Figure 3).

The image is constructed using the push-broom principle, where a narrow strip of the Earth is imaged into the entrance slit of the spectrometer, defining the across track dimension, while the motion of the satellite provides the along track dimension.

The spectral dimension is achieved by imaging the entrance slit of the spectrometer via a dispersing grating onto a 2-D CCD array. The CCD covers the spectral range with a nominal 1.25 nm spectral sampling interval. The OLCI spectral bands are constructed by first binning one or more CCD spectral samples, in the shift register of the CCD detector, into micro-bands; and further grouping them into bands digitally (spectral relaxation) before transmission to ground. Main spectral and radiometric characteristics of the OLCI bands are listed in Table 2.

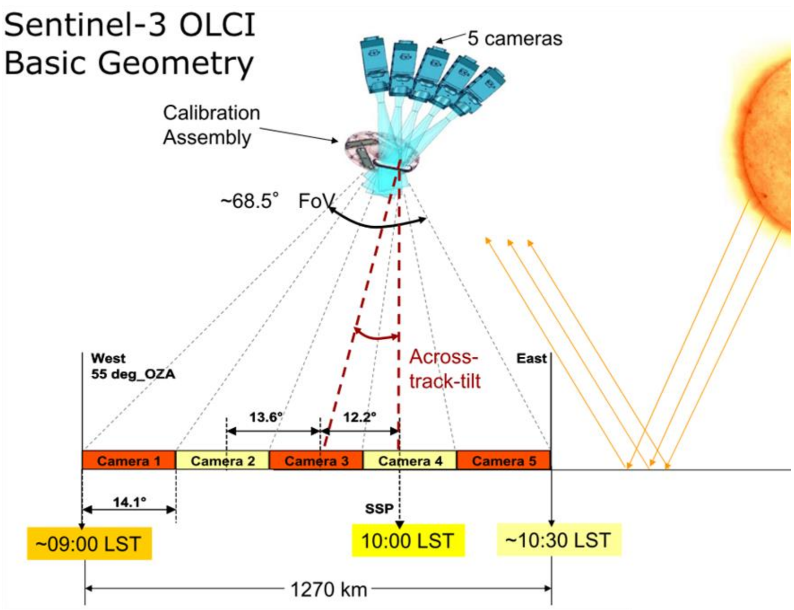

Figure 3: OLCI basic viewing geometry.

Table 2: OLCI bands characteristics, adapted from (Donlon et al., 2012).

Band	λ centre	Width	Lmin	Lref	Lsat	SNR	Function
	nm	nm	W/(m² sr µm)	W/(m² sr µm)	W/(m² sr µm)	@Lref & 1.2km	
Oa1	400	15	21.6	62.95	413.5	2188	Aerosol correction, improved water constituent retrieval.
Oa2	412.5	10	25.93	74.14	501.3	2061	Yellow substance and detrital pigments (Turbidity).
Oa3	442.5	10	23.96	65.61	466.1	1811	Chl absorption maximum, Biogeochemistry, vegetation.
Oa4	442	10	19.78	51.21	483.3	1541	High Chl, other pigments.
Oa5	510	10	17.45	44.39	449.6	1488	Chl, sediment, turbidity, red tide.
Oa6	560	10	12.73	31.49	524.5	1280	Chlorophyll reference (Chl minimum)
Oa7	620	10	8.86	21.14	397.9	997	Sediment loading
Oa8	665	10	7.12	16.38	364.9	883	Chl (2nd Chl abs. max.), sediment, yellow substance/vegetation
Oa9	673.75	7.5	6.87	15.7	443.1	707	For improved fluorescence retrieval
Oa10	681.25	7.5	6.65	15.11	350.3	745	Chl fluorescence peak, red edge.
Oa11	708.75	10	5.66	12.73	332.4	785	Chl fluorescence baseline, red edge transition.
Oa12	753.75	7.5	4.7	10.33	377.7	605	O_2 absorption reference, clouds, vegetation.
Oa13	761.25	2.5	2.53	6.09	369.5	232	O_2 absorption band, fluorescence over land.
Oa14	764.375	3.75	3	7.13	373.4	305	O_2 absorption band, fluorescence over land.
Oa15	767.5	2.5	3.27	7.58	250	330	O_2 absorption band, fluorescence over land.
Oa16	778.75	15	4.22	9.18	277.5	812	Atmos. corr./aerosol corr.
Oa17	865	20	2.88	6.17	229.5	666	Atmos. corr./aerosol corr., clouds, pixel co-registration. Common reference band with SLSTR instrument.
Oa18	885	10	2.8	6	281	395	Water vapour absorption reference band.
Oa19	900	10	2.05	4.73	237.6	308	Water vapour absorption/vegetation monitoring (max. reflectance).
Oa20	940	20	0.94	2.39	171.7	203	Water vapour absorption, atmos./aerosol corr.
Oa21	1020	40	1.81	3.86	163.7	152	Atmos./aerosol corr.

2.1.3 Sentinel3-SYN

The Sentinel 3 SYNERGY mission is based on the synergetic use of the two optical instruments on-board the sentinel-3 platforms: OLCI and SLSTR. The initial objective was to ensure the continuity with the SPOT/VEGETATION mission, as requested by the Copernicus Land Service. This objective has then been extended to the continuity of the PROBA-V mission but also to the production of global land surface reflectances at OLCI/SLSTR wavelengths, together with the aerosol parameters used for atmosphere correction. Later, a new set of global (i.e. Land and Ocean) aerosol parameters has been added to the SYNERGY mission objectives.

The first step of SYNERGY processing chain is then to collocate and co-register OLCI and SLSTR simultaneous acquisitions, project these acquisitions on a reference grid and take benefit of this wider radiometric and angular range to apply an aerosol retrieval algorithm.

SYNERGY products are created from a combination of OLCI and SLSTR Level-1B products (including both nadir and oblique views). The SYNERGY swath is then corresponding to the common area between OLCI and SLSTR swaths, restricted to the daylight part of the SENTINEL-3 orbit (i.e. where the sun zenith angle at satellite ground track is lower than 80°).

As a consequence, the swath widths of SYNERGY L2 products are similar to the OLCI ones (~1270 km). The SLSTR nadir and oblique view areas not covered by OLCI images are filtered out from SYNERGY processing.

Concerning SYNERGY VGT-like products, the swath width is similar to the SYN L2 products, but the latitude range is restricted from 56° S to 75° N, to be consistent with VEGETATION products.

The mean global coverage revisit time is based on the longest revisit time of the two instruments, OLCI and SLSTR. At the equator with two operational satellites, it is less than 2 d.

The spectral channels used by the SYNERGY processor are all the OLCI ones excluding those dedicated to atmospheric absorption (Oa13 to Oa15, Oa19 and Oa20, see Table 2) and the SLSTR VIS/ NIR (S1 to S3) and SWIR (S5 and S6) channels, excluding S4 at 1.37 µm and thermal channels S7 to S9 (Table 3).

2.1.4 CHIME

The Copernicus Hyperspectral Imaging Mission for the Environment (CHIME) is a future imaging spectroscopy mission in the VIS/SWIR spectral domain, at high spatial and spectral resolution. It is intended to add to and to complement the conventional passive optical multispectral remote sensing missions, such as Sentinel-2, by providing a continuous high-resolution spectrum allowing for a better discrimination of target compositions and quantities.

CHIME's main Mission Objective is "To provide routine hyperspectral observations through the Copernicus Programme in support of EU- and related policies for the management of natural resources, assets and benefits. This unique visible-to-shortwave infrared spectroscopy based observational capability will in particular support new and enhanced services for food security, agriculture and raw materials. This includes sustainable agricultural and biodiversity management, soil properties characterisation, sustainable mining practices and environment preservation." (from [CHIME-MRD]).

The mission requirements in terms of geographic coverage – "All land surfaces and inland water bodies between latitudes -56° S and +84° N including islands greater than 100 km^2, coastal zones within 50 km distance from land and open water wherever the depth does not exceed 50 m" – is more or less aligned to that of Sentinel-2/MSI and the revisit time set from 10 d to 12.5 d (10 d is the Sentinel-2 single-satellite achievement). Another requirement is that CHIME shall be capable to provide observations over land surface areas whenever the Sun Zenith Angle is lower than 84°, which has in requirement on the Level-2A atmospheric correction software. Spatial sampling distance shall be between 20 m (Goal) and 30 m (Target), with the Level-1C and Level-2A products being resampled to the Sentinel-2 grid.

In the spectral domain, the wavelengths area between 400 nm and 2500 nm shall be covered contiguously with a spectral sampling interval (SSI) of 10 nm or lower. Other important requirements are that spectral co-registration shall be better than 0.1 SSI, and band center wavelengths shall be known better than 0.5 nm over the mission lifetime. Regarding the radiometric properties, the radiometric accuracy shall be better than 5 % absolute at the reference radiance level, and better than 1 % relatively.

Of interest for the COPERNICUS optical surface missions is that the absolute radiometric inter-calibration coefficients with respect to other Copernicus optical surface imaging satellites and selected international hyper-spectral missions shall be generated and made available to users.

In order to achieve these goals, on-board calibration facilities (incl. solar diffusers, doped calibration sphere) are foreseen, but have to be confirmed. Additional vicarious validation activities are foreseen but are currently not detailed.

For the Core Product, which is Level-2A, the surface reflectance accuracy shall be better than $0.05*\rho + 0.005$ (TBC) for SZA ≤ 60° (TBC) and AOT at 550 nm ≤ 0.6 (TBC) for at least 95% of the Level-2A product. Within the spectral ranges 1330 nm to 1480 nm, 1760 nm to 1950 nm and 2450 nm to 2500 nm, for SZA > 60° or AOT > 0.6 this requirement is on a best-effort basis.

2.2 Surface Temperature Missions

2.2.1 Sentinel3-SLSTR

The Sea and Land Surface Temperature Instrument (SLSTR) on-board Sentinel-3 is a medium spatial resolution scanning radiometer that is designed to provide accurate measurements of surface temperatures. The key features of SLSTR are:

- Thermal infrared (TIR) spectral bands at 3.74 µm, 10.8 µm and 12 µm with detectors that are cooled to 87 K and a spatial sampling distance of 1 km.
- Channels in the Visible (VIS) to Short Wave InfraRed (SWIR) range for improved daytime cloud detection, at a spatial sampling distance of 0.5 km
- A dual view that allows the same terrestrial scene to be viewed through two atmospheric paths: a near nadir view, and an oblique view at 55° zenith angle.

- Two conical scanners to provide a 1400 km wide nadir view and 750 km oblique view.

Thanks to continuous acquisition of the thermal channels, over the day and night parts of the orbit, the coverage is global and the global revisit time at the equator is less than one day with two satellites flying.

The spectral bands and their applications are listed in Table 3. A more detailed description of the SLSTR design and the predicted performance is in Coppo et al. (2010).

Table 3: SLSTR Spectral Bands.

Band	Central Wavelength	Bandwidth	Spatial Resolution at Nadir	Function
S1	0.555 µm	0.020 µm	0.5 km	Chlorophyll, dual-view AOD over land
S2	0.659 µm	0.020 µm	0.5 km	Vegetation Index, dual-view AOD over land, masking of sunglint and clouds for daytime active fire detection
S3	0.870 µm	0.020 µm	0.5 km	Vegetation Index, dual-view AOD over land
S4	1.375 µm	0.015 µm	0.5 km	Thin Cirrus Cloud Detection
S5	1.610 µm	0.060 µm	0.5 km	Clouds, Active Fire (at night as alternative to S6), Ice/cloud discrimination
S6	2.225 µm	0.050 µm	0.5 km	Clouds, Active Fire (at night)
S7	3.700 µm	0.380 µm	1.0 km	Night-time dual-view SST, Active Fire
S8	10.850 µm	0.900 µm	1.0 km	Dual-view SST/LST, Active Fire
S9	12.000 µm	1.000 µm	1.0 km	Dual-view SST/LST
F1	3.700 µm	0.380 µm	1.0 km	Active Fire
F2	12.000 µm	0.900 µm	1.0 km	Active Fire (not currently used)

2.2.2 LSTM

The LSTM (Land Surface Temperature Monitoring) mission objective is to complement Sentinel observation capabilities with high spatio-temporal resolution Thermal Infrared observations over land and coastal regions in support of agriculture management services and a range of additional services ([LSTM-MRD]). The primary objective addresses the monitoring of evapotranspiration through the capture of land surface temperature variability. A complementary objective is to support services benefiting from TIR observations, noticeably soil composition, urban heat islands, coastal zone management and high-temperature events.

The mission requirements in terms of geographic coverage – "systematic observations over land and inland water areas between latitudes -56° S and +84° N including major islands (with a surface greater than 100 km^2), coastal waters covered by Sentinel-2 or within 100 km from the shoreline" – is more or less aligned to that of Sentinel-2/MSI. The revisit time is required "from daily (goal) up to 3 d (threshold)" ([LSTM-MRD]).

Spatial sampling distance shall be between 30 m and 50 m.

Spectral requirements are complex and must distinguish between those related to primary (mandatory) and to complementary (optional) mission objectives. The first category requires a set of channels in the continuity of the SLSTR mission, with some improvements: between 3 and 5 thermal channels (2 for SLSTR), 2 SWIR channels (as for SLSTR) and 5 VISNIR channels (3 for SLSTR). The second category specifies a set of 5 to 20 additional TIR channels, with two levels of priority. These spectral requirements are reported in Table 4 and Table 5 below, adapted from [LSTM-MRD]

Table 4: LSTM TIR spectral bands for primary (left) and secondary (right) mission objectives.

Band	Goal / Threshold	λ centre (µm)	Width (µm)
TIR-1	G	8.6	0.18 (G) / 0.30 (T)
TIR-2	G	8.9	0.18 (G) / 0.30 (T)
TIR-3	T	9.2	0.18 (G) / 0.30 (T)
TIR-4	T	10.9	0.4
TIR-5	T	12.0	0.47

Band	Goal / Threshold	λ centre (µm)	Width (µm)
TIR-S1	G	8.2	0.2 (G)
TIR-S2	G	9.1	0.2 (G)
TIR-S3	G	8.63	0.1 (G)
TIR-S4	G	12.63	0.1 (G)
TIR-S5	T	7.5	0.1 (G) / 0.2 (T)
TIR-S6	T	12.2	0.1 (G) / 0.2 (T)
TIR-S7	G	9	0.1 (G)
TIR-S8	G	9.8	0.1 (G)
TIR-S9	T	10.5	0.1 (G) / 0.2 (T)
TIR-S10	T	10.95	0.1 (G) / 0.2 (T)
TIR-S11	T	12.3	0.1 (G) / 0.2 (T)
TIR-S12	T	9.3	0.1 (G) / 0.2 (T)
TIR-S13	T	9.53	0.1 (G) / 0.2 (T)

Table 5: LSTM VIS/NIR/SWIR spectral bands

Band	λ centre (µm)	Width (µm)
VNIR-0	0.490	0.065
VNIR-1	0.665	0.030
VNIR-2	0.865	0.020
VNIR-3	0.945	0.020
SWIR-1	1.375	0.030
SWIR-2	1.610	0.090

3 Sentinel Optical Core Products

This section lists the Core Products addressed by the present document. Their list has been built for existing missions from the actual PDGS production and for future mission according to their respective Mission Requirements Document, as listed in section 1.2.

3.1 Surface Colour Products

3.1.1 Sentinel2/MSI

S2/MSI product available to users are:

- The Level-1C product, providing orthorectified Top-Of-Atmosphere (TOA) reflectance, with sub-pixel multispectral registration.
- Level-2A product, providing orthorectified Bottom-Of-Atmosphere (BOA) reflectance, with sub-pixel multispectral registration. A Scene Classification map (cloud, cloud shadows, vegetation, soils/deserts, water, snow, etc.) is included in the product.

Orthorectification is the process of geometrically correcting satellite imagery such that the image grid follows a given map projection.

3.1.1.1 Level 1

MSI-L1C products are generated with following radiometric calibration activities applied:

- Dark signal calibration
- Absolute radiometric calibration
- Relative gains calibration (pixels response non uniformity)
- defective pixels interpolation (SWIR detectors re-arrangement parameters generation)
- crosstalk correction

- They provide TOA reflectances for each spectral band resampled with a constant Ground Sampling Distance (GSD) of (10, 20 and 60) m depending on the native resolution of the different spectral bands.
- MSI-L1C products are provided as ortho-images in the Universal Transverse Mercator (UTM) projection. They are 110x110 km^2 granules including a 5 km extension on all sides to ensure an overlap with neighbouring granules. The granules, also called “tiles”, are based on the Military Grid Reference System (MGRS).
- The content of the MSI Level 1C product is summarised in Table 6.

Table 6: Main MSI Level 1C product content

Product Package Structure	
Metadata files	
File name	**Composition**
MTD_MSIL1C.xml	Product Metadata XML fields (General information like acquisition date and time, processing baseline, spacecraft name, product generation time) (Instrument data: lambda0, FWHM, solar_flux, spectral_response, physical_gains) (Geometric information, Auxiliara data and Quality_Indicators_Info)
MTD_TL.xml	Granule Metadata XML fields (Sensing Time, Geocoding, Geometry (SZA, SAA, OZA, OAA), Quality flags)
Measurement Data files	
Native spatial resolution	**Composition**
10 m	B02, B03, B04, B08
20 m	B05, B06, B07, B08A, B11, B12
60 m	B01, B09, B10
Additional files	
File name	**Composition**
FORMAT_CORRECTNESS.xml GENERAL_QUALITY.xml GEOMETRIC_QUALITY.xml SENSOR_QUALITY.xml	Quality Information XML fields
MSK_DEFECT_B??.gml MSK_DETFOO_B??.gml MSK_NODATA_B??.gml MSK_SATURA_B??.gml MSK_TECQUA_B??.gml MSK_CLOUDS_B00.gml	Defective pixels mask per band, Detector footprint mask per band, No data mask per band, Saturated pixel mask per band, Technical quality mask per band. Cloud mask
AUX_ECMWFT	sea_level_pressure, total_ozone
TCI	True Color Image
PVI	Preview Image

3.1.1.1.1 Measurement equation

No Level 1 ATBD could be identified for Sentinel-2/MSI. [S2-CALVALPE] however, provides inputs on the MSI radiometric model, even if not in a fully comprehensive way.

The instrument radiometric equation express the signal measured at the output of the detection chain as follows:

$$V(p,b,l,d) = \Omega(p,b,d) \cdot \int_{\lambda} R(\lambda) \cdot T_{sep}(\lambda) \cdot T_{filter}(b,p,\lambda) \cdot S_{det}\big(p,\lambda,\Omega(p,b,d) \cdot R(\lambda)\big) \cdot d\lambda + \bar{V}(p,l,b,d,0) + N(p,l,b,d,R(\lambda)) \quad \text{(Eq 1)}$$

where:

- p is the considered pixel,
- l is the considered line,
- b is the considered spectral channel,
- d is the considered detector,
- R (λ) is the input spectral radiance (expressed in $W.m^{-2}.sr^{-1}.\mu m^{-1}$),
- Ttel (λ) is the spectral transmission of the telescope,
- Tsep (λ) is the spectral transmission of the spectral separator,
- Tfilter (p,b,λ) is the spectral transmission of the channel b filter located in front of pixel p,
- Ω(p,b,d) is the solid angle under which the pixel p of the band b sees the output pupil,
- Sdet(p,λ,Ω(p,b,d).R(λ)) is the spectral sensitivity of the detector p, for the current input radiance,
- $\overline{\mathrm{V}}(\mathrm{p},\mathrm{l},\mathrm{b},\mathrm{d},0)$ is the measured signal with a input radiance equal to zero,
- N(p,l,b,d, R(λ)) is a function that includes possible alterations of the current measurement (e.g. instrument noise, straylight)

This equation is completed by the expression of the digitisation step, including the application of the electronic gain, providing the corresponding raw counts:

$$X\big(p,l,b,d,R(\lambda)\big) = trunc[G(p,b,d,R(\lambda)) \cdot V(p,l,b,d,R(\lambda))] \quad \text{(Eq 2)}$$

where:

- *trunc(x)* is the truncation function, that produces the integer between 1 and 2^{12}-1 the closest to x.

This acquired digital signal is then submitted to an "equalization step" aiming at at optimizing the efficiency of data compression before transmission t ground:

$$\begin{cases} Z_{VCU} = 0 \; if \; X < C_{VCU} \\ Z_{VCU} = A_1 \cdot (X - C_{VCU}) if \; C_{VCU} < X \leq C_{VCU} + Zs_{VCU} \\ Z_{VCU} = A_2 \cdot (X - C_{VCU} - Zs_{VCU}) if \; X > C_{VCU} + Zs_{VCU} \end{cases} \quad \text{(Eq 3)}$$

And Z_{VCU} is truncated to the closest integer between 1 and 4095.

The equation used to retrieve the radiance R from the instrument counts is not directly derived from (Eq 1) above. The radiometric processing is implemented in 3 steps:

1) the VCU processing (on-board equalization) is inverted

- Dark offset and relative gains are applied,

2) The mean absolute gain is then applied to scale the equalized counts into radiance.

The dark offset is obtained from night-time ocean observations under appropriate conditions (absence of lucent plankton and significant Moon light). It is amended at the time of correction by a short time variation term, including cross-track variation, derived from blind pixels on each side of each detector measured simultaneously to the Earth observations.

The radiometric gain is derived from in-flight observations of a sun-lit diffuser whose bi-directional reflectance distribution function (BRDF) has been characterized on ground. The mean absolute gain and the relative gains are derived from the same measurement data set and non-linearity correction is included in the relative gain term base on ground characterisation data rescaled to the sun-lit diffuser measurement.

A fourth step is foreseen for the correction of the optical and electronic crosstalk, but it is not described and only introduced as a potential contingency.

3.1.1.2 Level 2

MSI-Level-2A surface reflectance products are generated with Sen2Cor processor whose main purpose is to correct Sentinel-2 Level-1C products from the effects of the atmosphere. Level-2A processing is applied independently to single granules of TOA Level-1C orthorectified reflectance products. Note that this independent processing of neighbouring granules can lead to visible steps between adjacent granules.

The content of the MSI Level 2A product is summarised in Table 7. L2A products provide:

- Surface (or BOA) reflectance images which are provided at different spatial resolutions (60 m, 20 m and 10 m);
- Aerosol Optical Thickness (AOT) maps (60 m, 20 m and 10 m);
- Water Vapour (WV) maps (60 m, 20 m and 10 m);
- Scene Classification (SCL) map together with Quality Indicators for cloud and snow probabilities (60 m and 20 m).

The Scene Classification module provides a Scene Classification map divided in 11 classes. This map does not constitute a land cover classification map in strict sense. Its main purpose is to be used internally in Sen2Cor in the atmospheric correction module to distinguish between cloudy pixels, clear pixels and water pixels. Two quality indicators are also provided: a cloud confidence map and a Snow confidence map with values ranging from 0 to 100 %.

The Water Vapour content is retrieved from Level-1C image using a Sentinel-2 adapted APDA (Atmospheric Pre-corrected Differential Absorption) algorithm that uses a ratio between band B8A and band B09.

The Aerosol Optical Thickness (AOT) at 550 nm is estimated using the Dark Dense Vegetation (DDV) pixel method introduced by [12]. AOT estimation fails when there are no DDV pixels in the image. The current fallback solution for that case is to perform the atmospheric correction with a constant, configurable AOT.

Table 7: Main MSI Level 2A product content

Product Package Structure	
Metadata files	
File name	**Composition**
MTD_MSIL2A.xml	Product Metadata XML fields (General information like acquisition date and time, processing baseline, spacecraft name, product generation time) (Instrument data: lambda0, FWHM, solar_flux, spectral_response, physical_gains) (Auxiliara data and Quality_Indicators_Info)
MTD_TL.xml	Granule Metadata XML fields (Sensing Time, Geocoding, Geometry (SZA, SAA, OZA, OAA), Quality flags)
Measurement Data files	
Folder name	**Composition**
R10m	B02, B03, B04, B08, AOT, WVP
R20m	B02, B03, B04, B05, B06, B07, B08A, B11, B12, AOT, WVP, SCL
R60m	B01, B02, B03, B04, B05, B06, B07, B08A, B09, B11, B12, AOT, WVP, SCL
Additional files	

File name	Composition
FORMAT_CORRECTNESS.xml GENERAL_QUALITY.xml GEOMETRIC_QUALITY.xml RADIOMETRIC_QUALITY.xml SENSOR_QUALITY.xml	Quality Information XML fields
MSK_DEFECT_B??.gml MSK_DETFOO_B??.gml MSK_NODATA_B??.gml MSK_SATURA_B??.gml MSK_TECQUA_B??.gml	Defective pixels mask per band, Detector footprint mask per band, No data mask per band, Saturated pixel mask per band, Technical quality mask per band.
MSK_CLDPRB_20m, MSK_CLDPRB_60m	Cloud probability images
MSK_SNWPRB_20m.jp2 MSK_SNWPRB_60m.jp2	Snow probability files
AUX_ECMWFT	sea_level_pressure, total_ozone
TCI_10m, TCI_20m, TCI_60m	True Color Images
PVI	Preview Image

3.1.2 Sentinel3/OLCI

The S3/OLCI products distributed to users are the following (the Core Products are highlighted in **coloured bold** font):

- The **OLCI Level 1b product**, providing ortho-geolocated **Top-Of-Atmosphere (TOA) radiances** re-gridded onto a regular along-track and across-track grid, in two spatial resolutions: 0.3 km (Full Resolution or FR) and 1.2 km (Reduced Resolution or RR). The core parameters, TOA radiances, are annotated with several additional information required by further processing and use: time stamps, geolocation, quality and classification flags, meteorological information, illumination and acquisition angles, spectral information, and references to at-sensor acquisition grid.
- The **OLCI Level 2 Land product**, providing, on the same image grids than Level 1 products, the **OLCI Terrestrial Chlorophyll Index** (OTCI), the **Green Instantaneous Fraction of Absorbed Photosynthetically Active Radiation** (GIFAPAR, formerly referred to as the OLCI Global Vegetation Index – OGVI), and the **Integrated Water Vapour** (IWV). These core Level 2 products are, comparably to Level 1 products, annotated with time stamps, geolocation, quality and classification flags, meteorological information, illumination and acquisition angles, spectral information, and references to at-sensor acquisition grid.

- The **OLCI Level 2 Marine product**, providing, on the same image grids than Level 1 products, **water-leaving directional reflectances**, water AOPs and IOPs products (**Chlorophyll**, **Total Suspended Matter**, **Non-algal Absorption Coefficient**, **Diffuse Attenuation Coefficient**), atmosphere corrections by-products **Aerosol Optical Thickness** & **Aerosol Angstroem Exponent**, **Integrated Water Vapour**, **Photosynthetically Available Radiation.**

3.1.2.1 Level 1

The content of the OLCI Level 1B product is summarised in Table 8 for the Full Resolution product “OL_1_EFR____”. The “OL_1_EFR___” product is composed of a Manifest file, 22 measurement data files and 7 annotation files. The 22 data files are: 21 files containing radiances at each band (one band per file), plus an additional file providing all data related to pixels that have been removed during the re-sampling process.

The Reduced Resolution “OL_1_ERR___” product contains the same files except the one related to removed pixels. Bearing this exclusion in mind, description of Table 8 applies.

The core OLCI Level 1 products are:

- TOA radiance
- Georeferencing data: longitude and latitude at pixels.

Table 8: OLCI Level 1B product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
Oa01_radiance.nc	Oa01_radiance
Oa02_radiance.nc	Oa02_radiance
… continue	… continue
Oa21_radiance.nc	Oa21_radiance
removed_pixels.nc	Oa01_radiance, Oa02_radiance, …, Oa21_radiance Longitude, latitude, altitude, SZA, detector index, quality flags.
Annotation Data files	
File name	**Composition**
time_coordinates.nc	time_stamp
geo_coordinates.nc	longitude, latitude, altitude
qualityFlags.nc	quality_flags
tie_geo_coordinates.nc	longitude, latitude
tie_geometries.nc	SZA, SAA, OZA, OAA
tie_meteo.nc	horizontal_wind, sea_level_pressure, total_ozone, humidity, reference_pressure_level, atmospheric_temperature_profile, total_columnar_water_vapour
instrument_data.nc	lambda0, FWHM, solar_flux, detector_index, frame_offset, relative_spectral_covariance

3.1.2.1.1 Measurement equation

The OLCI radiometric model is defined in [OLCI-ATBD] as follows.

$$X_{b,k,m,t} = NL_{b,m}\begin{bmatrix} A^0_{b,k,m}\cdot\left(L_{b,k,m,t} + SL_{b,k,m,t}(L_{*,*,*,*})\right) + \\ Sm_{b,k,m,t}(L_{*,k,m,*} + SL_{*,k,m,*}(L_{*,*,*,*})) + \\ C_{b,k,m,t} \end{bmatrix} + \varepsilon \quad \text{(Eq 4)}$$

Hence radiance retrieval follows:

$$L_{b,k,m,t} = \frac{1}{A^0_{b,k,m}} \cdot \begin{bmatrix} NL^{-1}_{b,m}\left(X_{b,k,m,t} - \varepsilon\right) - C_{b,k,m,t} \\ -Sm_{b,k,m,t}\left(L_{*,k,m,*} + SL_{*,k,m,*}\left(L_{*,*,*,*}\right)\right) \end{bmatrix} - SL_{*,k,m,*}\left(L_{*,*,*,*}\right) \quad \text{(Eq 5)}$$

where:

- *b*, *k*, *m* and *t* subscripts stand for the spectral band, the spatial pixel, the camera and the acquisition time, respectively (* stands for multiple values up to the entire range of the subscript it replaces),
- $X_{b,k,m,t}$ is the OLCI raw sample,
- $NL_{b,m}$ is a non-linear function representing the non-linear transformations which take place in the CCD, amplifier, and A/D converter; *NL* depends on band and gain settings,
- T_t^{CCD} is the temperature of the OLCI detectors (CCDs) at time t,
- $A^0_{b,k,m}$ is the "absolute radiometric gain" in counts/radiance unit; A^0 depends on band and gain settings; It also includes a long-term time dependency that shall be accounted for but is not reported here to avoid mixing with the short scale time index t
- $L_{b,k,m,t}$ is the spectral radiance distribution in front of OLCI,
- $Sm_{b,k,m,t}$ is the smear signal, due to continuous sensing of light by OLCI, including during transfer from the image to the storage zone of the CCD,
- $C_{b,k,m,t}$ is the dark offset (including an on-board compensation), dependent on time, band and gain settings.
- $SL_{b,k,m}$ represents the stray light contribution to the signal: for a given sample, some stray light contribution is expected from all the other samples in the camera, spread into the sample by specular (ghost image) or scattering processes within the spectrometer, or from adjacent samples in terms of time and of camera, i.e. close but out of the field of view of the camera, spread as well by specular or scattering processes within the ground imager and transmitted through the slit to the spectrometer.
- ε is a random process representative of the noise and measurement errors.

The retrieval of the radiance at instrument input (Eq *5*) is thus done in two steps: (a) the radiometric scaling, providing $\left(L_{b,k,m,t} + SL_{b,k,m}\left(L_{*,*,*,*}\right)\right)$ from $X_{b,k,m,t}$ using knowledge of $NL_{b,m}$, $C_{b,k,m,t}$, $A^0_{b,k,m}$, $Sm_{b,k,m,t}$; and (b) the stray light correction, providing $L_{b,k,m,t}$ by substrating an estimate of $SL_{b,k,m}\left(L_{*,*,*,*}\right)$ determined from $\left(L_{b,k,m,t} + SL_{b,k,m}\left(L_{*,*,*,*}\right)\right)$.

- $NL_{b,m}$ is known from on-ground characterisation,
- $C_{b,k,m,t}$ is regularly derived from on-board calibration measurements with a shutter in front of the instrument,

- $A^0_{b,k,m}$ is regularly derived from on-board calibration measurements of a sun-lit diffuser of known BRDF (bidirectional reflectance distribution function) under known illumination geometry; it is derived using the radiometric model described above (Eq *4*) but starting from the known radiance from the sun-lit diffuser and the measured counts (Eq *6*).

$$A^0_{b,k,m} = \frac{\begin{bmatrix} NL^{-1}_{b,m}\left(X_{b,k,m,t} - \varepsilon\right) - C_{b,k,m,t} \\ -Sm_{b,k,m,t}\left(L^{cal}_{*,k,m,*} + SL_{*,k,m,*}\left(L^{cal}_{*,*,*,*}\right)\right) \end{bmatrix}}{L_{b,k,m,t} + SL_{*,k,m,*}\left(L^{cal}_{*,*,*,*}\right)} \quad \text{(Eq 6)}$$

- $Sm_{b,k,m,t}$ is obtained from the so-called smear band, measuring the signal integrated over the whole spectral range during the charge transfer from the image zone to the storage zone of the CCD.
- $SL_{b,k,m}(L_{*,*,*,*})$ is computed from $\left(L_{b,k,m,t} + SL_{b,k,m}(L_{*,*,*,*})\right)$ by a convolutive process using point spread functions characterised on-ground at set of spatial positions and wavelengths.

All the fundamental terms of the OLCI radiometric calibration are computed using in-flight measurements, either from the Earth observation target (smear, stray light) or from dedicated radiometric calibration observations (gain, dark offset) but also rely on pre-launch ground characterisation items:

- Solar diffuser BRDF, absolute and relative behaviour with illumination geometry
- Instrument spectral response functions (ISRF), used to derive in-band equivalent solar irradiance for the conversion of diffuser reflectance into radiance
- Non-linearity correction tables
- Stray light point-spread functions

It should be noted that both diffuser BRDF and ISRF ground characterisation are completed by dedicated in-flight measurements. The long-term evolution of the solar diffuser reflectance (darkening) is measured using a reference diffuser, used much les frequently, and corrected for.

3.1.2.2 Level 2

3.1.2.2.1 Land Level 2 product

The content of the OLCI Level 2 LAND product is summarised in Table 9.

The core OLCI Level 2 Land products are:

- Green Instantaneous FAPAR (variable name OGVI)
- OLCI Terrestrial Chlorophyll Index (OTCI)

- Integrated Water Vapour

Table 9: OLCI Level 2 LAND product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
ogvi.nc	OGVI, OGVI_err
otci.nc	OTCI, OTCI_err, OTCI_QS
iwv.nc	IWV, IWV_err
Annotation Data files	
File name	**Composition**
rc_ogvi.nc	RC681, RC681_err, RC865, RC865_err
lqsf.nc	LQSF (Land Quality and Sciencce Flags)
time_coordinates.nc	time_stamp
geo_coordinates.nc	longitude, latitude, altitude
tie_geo_coordinates.nc	longitude, latitude
tie_geometries.nc	SZA, SAA, OZA, OAA
tie_meteo.nc	horizontal_wind, sea_level_pressure, total_ozone, humidity, reference_pressure_level, atmospheric_temperature_profile, total_columnar_water_vapour
instrument_data.nc	lambda0, FWHM, solar_flux, detector_index, frame_offset, relative_spectral_covariance

The core OLCI Level 2 Land products are:

- Green Instantaneous FAPAR (variable name OGVI)
- OLCI Terrestrial Chlorophyll Index (OTCI)
- Integrated Water Vapour

3.1.2.2.2 Marine Level 2 product

The content of the OLCI Level 2 MARINE product is summarised in Table 10.

The core OLCI Level 2 Land products are:

- **Water leaving directional reflectances**
- Water AOPs and IOPs products
    - **Chlorophyll concentration** (CHL_OC4ME & CHL_NN),
    - **Total Suspended Matter** (TSM_NN),
    - **Non-algal Absorption Coefficient** (ADG_443_NN),
    - **Diffuse Attenuation Coefficient** (KD490_M07),
- **Instantaneous Photosynthetically Available Radiation** (PAR)
- Water Atmosphere Corrections by-products: **Aerosol Optical Thickness** and **Angstroem Exponent** (T865 and A865)
- **Integrated Water Vapour** (IWV)

Table 10: OLCI Level 2 MARINE product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
OaNN_reflectance.nc	OaNN_ reflectance, OaNN_ reflectance_err for NN (OLCI channels) in {01-12, 16-18, 21}
chl_oc4me.nc	CHL_OC4ME, CHL_OC4ME_err
chl_nn.nc	CHL_NN, CHL_NN_err
tsm_nn.nc	TSM_NN, TSM_NN_err
trsp.nc	KD490_M07, KD490_M07_err
iop_nn.nc	ADG_443_NN, ADG_443_NN_err
par.nc	PAR, PAR_err
w_aer.nc	T865, T865_err, A865, A865_err
iwv.nc	IWV, IWV_err
Annotation Data files	
File name	**Composition**
wqsf.nc	WQSF (Water Quality and Sciencce Flags)
time_coordinates.nc	time_stamp
geo_coordinates.nc	longitude, latitude, altitude
tie_geo_coordinates.nc	longitude, latitude
tie_geometries.nc	SZA, SAA, OZA, OAA
tie_meteo.nc	horizontal_wind, sea_level_pressure, total_ozone, humidity, reference_pressure_level, atmospheric_temperature_profile, total_columnar_water_vapour
instrument_data.nc	lambda0, FWHM, solar_flux, detector_index, frame_offset, relative_spectral_covariance

3.1.3 Sentinel3-SYN

The S3/SYNERGY products distributed to users are the following (the Core Products are highlighted in **coloured bold** font):

- **SY_2_SYN**: **Surface Reflectance** and **Aerosol parameters** over Land
- **SY_2_VGP:** 1 km VEGETATION-Like product (~VGT-P) - **TOA Reflectance**

- **SY_2_VG1:** 1 km VEGETATION-Like product (~VGT-S1), 1 d synthesis **surface reflectance** and **NDVI**
- **SY_2_V10:** 1 km VEGETATION Like product (~VGT-S10) 10 d synthesis **surface reflectance** and **NDVI**
- **SY_2_AOD:** Global Aerosol parameters over land and sea on super pixel resolution (4.5 km x 4.5 km): **Aerosol Optical Thickness** at several wavelengths (442.5, 555, 659, 865, 1610 and 2250) nm, **Aerosol Angstroem Exponent** at 550 nm, AOT of fine mode aerosol at 550 nm, AOT of dust aerosol at 550 nm, Aerosol Absorption Optical Thickness at 550 nm, Aerosol Single Scattering Albedo at several wavelengths (442.5, 555, 659, 865, 1610 and 2250) nm, **Surface Directional Reflectance** (BRF) at several wavelengths (442.5, 555, 659, 865, 1610 and 2250) nm.

3.1.3.1 SYNERGY Level 2 product SY_2_SYN

The content of the Synergy Level 2 Land product is summarised in Table 11.

The core Synergy Level 2 Land products are:

- **Surface Directional Reflectances** over Land for OLCI channels Oa1 to Oa12, Oa16 to Oa18 and Oa21, and SLSTR channels S1, S2, S3, S5 and S6 acquired in both Nadir and Oblique views.
- Aerosol parameters over Land: **Aerosol Optical Thickness** and **Aerosol Angstroem Exponent** at 550 nm

Table 11: SY_2_SYN product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
Syn_Oa*nn*_reflectance.nc	Surface directional reflectance associated with OLCI channel Oa*nn*, *nn* in {01-12, 16-18, 21}
Syn_S*n*N_reflectance.nc	Surface directional reflectance associated with SLSTR channel Sn acquired in nadir view, *n* in {1, 2, 3, 5, 6}
Syn_S*n*O_reflectance.nc	Surface directional reflectance associated with SLSTR channel Sn acquired in oblique view, *n* in {1, 2, 3, 5, 6}
Syn_AOT550.nc	Aerosol Optical thickness at 550 nm

Syn_Angstrom_exp550.nc	Aerosol Angstrom exponent
Syn_SDR_removed_pixel.nc	Surface directional reflectance and aerosol parameters associated with removed pixel
Annotation Data files	
File name	**Composition**
Syn_AMIN.nc	Aerosol index number
flags.nc	Classification and quality Flags associated with OLCI, SLSTR and SYNERGY products
geolocation.nc	High resolution georeferencing data
time.nc	Time stamp annotations
Syn_annot_rem.nc	Annotation parameters associated with removed pixel
tiepoint_olci.nc	Low resolution georeferencing data and Sun and View angles associated with OLCI products
tiepoint_slstr_n.nc	Low resolution georeferencing data and View angles associated with SLSTR nadir view products
tiepoints_slstr_o.nc	Low resolution georeferencing data and View angles associated with SLSTR oblique view products
tiepoints_meteo.nc	ECMWF meteorology data

3.1.3.2 SYNERGY VEGETATION-like Level 2 product SY_2_VGP

The content of the Synergy SY_2_VGP Land product is summarised in Table 12. It contains the the SPOT VGT-P continuity products.

The core SY_2_VGP Land products are:

- **TOA Reflectances** over Land for SPOT-VGT channels B0, B2, B3 and MIR on the OLCI image grid.

Table 12: SY_2_VGP product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
B0.nc	TOA reflectance associated with VGT- B0 channel
B2.nc	TOA reflectance associated with VGT- B2 channel

B3.nc	TOA reflectance associated with VGT- B3 channel
MIR.nc	TOA reflectance associated with VGT- MIR channel
Annotation Data files	
File name	**Composition**
vaa.nc	View Azimuth Angle
vza.nc	View Zenith Angle
saa.nc	Solar Azimuth Angle
sza.nc	Solar Zemith Angle
ag.nc	Aerosol Optical thickness
og.nc	Total Ozone Column
wvg.nc	Total column water vapour
sm.nc	Status flags

3.1.3.3 SYNERGY VEGETATION-like Level 2 product SY_2_VG1 and SY_2_V10

The content of the Synergy SY_2_VG1 and SY_2_V10 Land products is summarised in Table 13. These products contain respectively the Single 'best' value for Surface reflectance at the four VGT channels over 1 d period and the Maximum value composite over a 10 d period at the four VGT channels. Their contents are identical.

The core SY_2_VGP Land products are:

- **Surface Reflectances** over Land for SPOT-VGT channels B0, B2, B3 and MIR on the OLCI image grid.

Table 13: SY_2_VG1 / SY_2_V10 products content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
B0.nc	Surface reflectance associated with VGT- B0 channel
B2.nc	Surface reflectance associated with VGT- B2 channel
B3.nc	Surface reflectance associated with VGT- B3 channel
MIR.nc	Surface reflectance associated with VGT- MIR channel

NDVI.nc	Normalised difference vegetation index
Annotation Data files	
File name	**Composition**
vaa.nc	View Azimuth Angle
vza.nc	View Zenith Angle
saa.nc	Solar Azimuth Angle
sza.nc	Solar Zenith Angle
ag.nc	Aerosol Optical thickness
og.nc	Total Ozone Column
wvg.nc	Total column water vapour
tg.nc	Synthesis Time
sm.nc	Status flags

3.1.3.4 SYNERGY Global AOD Level 2 product SY_2_AOD

The content of the Synergy Global Aerosol Optical Depth products is summarised in Table 14.

The core SY_2_AOD Land products are:

- **Surface Reflectances** over clear sky Land and Water pixels for channels OLCI Oa3, SLSTR S1, S2, S3, S5, and S6 on the OLCI image grid.
- **Aerosol Optical Thickness** at several wavelengths (442.5, 555, 659, 865, 1610 and 2250) nm, **Aerosol Angstroem Exponent** at 550 nm, AOT of fine mode aerosol at 550 nm, AOT of dust aerosol at 550 nm, Aerosol Absorption Optical Thickness at 550 nm, Aerosol Single Scattering Albedo at several wavelengths (442.5, 555, 659, 865, 1610 and 2250) nm.

Table 14: SY_2_AOD product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
NTC_AOD.nc	Surface directional Reflectances, retrieved and derived global aerosol parameter at several spectral bands, contextual parameters (annotations)

Annotation Data files	
File name	**Composition**
None	

3.1.4 CHIME

The Core Data Product of CHIME will be the Level-2A product, with additional Level-1 products for advanced users, and a set of higher-level downstream products in the core domains of "sustainable agriculture and food security" as well as "raw materials".

3.1.4.1 Level 1

Currently two Level 1 Core data Products are foreseen: Level-1B (see Table 15) and Level-1C product (see Table 16).

Table 15: CHIME L1B Product

L1B Product	
L1B Product features:	
	Top-of-Atmosphere (TOA) Radiance in units of [W m^{-2} sr^{-1} μm^{-1}] pixel level information.
	All radiometric and spectral calibration applied.
	Geometric information (e.g., redefined viewing model) is computed and appended, but not applied.

Table 16: CHIME L1C Product

L1C Product	
L1C Product features:	
	Top-of-Atmosphere Reflectance [%] pixel-level information.
	All radiometric and spectral calibration applied.
	Geometrically refined, in ortho-rectified geometry (UTM/WGS84, framed tiles).

3.1.4.2 Level 2

The currently available specification of the L2A Core Data Product is summarized below in Table 17.

Table 17: CHIME L2A Product

L2A Product	
L2A Product features:	
	Bottom-of-Atmosphere (BOA) reflectance [%] pixel-level information.
	Ortho-rectified geometry incl. the usage of a DEM (see also Level-1C).
	Appended pixel classification (side product from the atmospheric correction process) allowing to distinguish opaque clouds, thin clouds, cloud shadows, vegetation, etc.
	Specification according to the CEOS Analysis Ready Data for Land (CARD4L)

3.1.4.3 Higher-level products

The list of the higher-level downstream products is still not finalized; candidates for these high priority products are given in Table 18 below.

Table 18: Candidate CHIME high priority products (higher level)

Product
Sustainable Agriculture and Food Security
Canopy and leaf nitrogen content
Leaf mass and specific leaf area
Canopy water content
Leaf and canopy pigments (Chlorophyll, Carotenoids, Anthocyanins)
Soil organic carbon (SOC) content
Soil textural / structural composition
Quantification of non-photosynthetic vegetation (NPV)
Raw Materials
Composition and abundance of raw materials (minerals): ferric oxide content, clay mineral compositions
Additional Application Products
Inland and coastal waters: phytoplankton, total suspended matter, submerged habitat classification

Biodiversity: physiological (e.g., pigments), morphological (e.g., specific LAI) and functional plant traits, species composition and others
Snow, ice and hydrology: snow grain size, light absorbing impurities and others
Environmental degradation and hazards: oil spill area and volume, large gas leaks and others

3.2 Surface Temperature Products

3.2.1 Sentinel3-SLSTR

3.2.1.1 Level 1

The content of the SLSTR Level 1B product is summarised in Table 19. Table 20 provides a description of the abbreviations used in Table 19.

The core SLSTR Level 1 products are:

- TOA radiance and brightness temperatures
- Georeferencing data: longitude and latitude at pixels.

Table 19: SLSTR Level 1B product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
S*n*_radiance_an.nc	Radiance file for 'a' stripe of S*n* channel, *n* in {1, 2,3, 4, 5, 6} (VIS & SWIR channels), nadir view.
S*n*_radiance_ao.nc	Radiance file for 'a' stripe of S*n* channel, *n* in {1, 2,3, 4, 5, 6} (VIS & SWIR channels), oblique view.
S*n*_radiance_bn.nc	Radiance file for 'a' stripe of S*n* channel, *n* in {4, 5, 6} (SWIR channels), nadir view.
S*n*_radiance_bo.nc	Radiance file for 'a' stripe of S*n* channel, *n* in {4, 5, 6} (SWIR channels), oblique view.
S*n*_BT_in.nc	Brightness Temperature file of S*n* channel, *n* in {7, 8, 9} (TIR channels), nadir view.
S*n*_BT_io.nc	Brightness Temperature file of S*n* channel, *n* in {7, 8, 9} (TIR channels), oblique view.
F*n*_BT_*g*n.nc	Brightness Temperature file of F*n* channel, *n* in {1, 2} (FIRE channels), oblique view; *g* is the grid indicator and can be f for F1 and i for F2.
F*n*_BT_*g*o.nc	Brightness Temperature file of F*n* channel, *n* in {1, 2} (FIRE channels), oblique view; *g* is the grid indicator and can be f for F1 and i for F2.
Annotation Data files	
File name	**Composition**
*Cn*_quality_*gv*.nc	VIS and SWIR channels quality files, *Cn* – the channel – in {S1 to S9, F1, F2}, *g* – the grid – in {a, b, i, f} and v – the view –in {n,o}, as for radiance/BT files described above.
flags_*gv*.nc	Flag files for each grid *g* in {a, b, i, f} and view *v* in {n,o}
indices_*gv*.nc	Files of indices of source instrument coordinates (scan, detector) for each grid *g* in {a, b, i, f} and view *v* in {n,o}
geodetic_*gv*.nc	Files of geodetic coordinates (longitude, latitude, elevation) for each grid *g* in {a, b, i, f} and view *v* in {n,o}
geodetic_tx.nc	Files of geodetic coordinates (longitude, latitude, elevation) at Tie Points
cartesian_*gv*.nc	Files of cartesian coordinates (lang and cross-track) for each grid *g* in {a, b, i, f} and view *v* in {n,o}
cartesian_tx.nc	Files of cartesian coordinates (lang and cross-track) at Tie Points
time_*g*n.nc	Time annotation file for each nadir grid *g* in {a, b, if}
geometry_t*v*.nc	Acquisition geometry file for each view *v* in {n,o}
viscal.nc	Visible calibration coefficients
met_tx.nc	Meteorological parameters at Tie Points

Table 20: band/grid/view abbreviation meaning

Variable	Placeholder	Possible Values
band	<b>	S1 – S9, F1, F2
grid	<g>	'i' – 1 km Thermal InfraRed grid 'f' – 1 km dedicated F1 grid 'a' – 500 m visibile and SWIR "A stripe" grid 'b' – 500 m visible and SWIR "B stripe" grid 'c' – 500 m TDI grid 't' – Tie point grid
view	<v>	'n' – nadir view 'o' – oblique view 'x' – view agnostic

3.2.1.1.1 Measurement equation

There is no synthetic radiometric model equation in [SLSTR-ATBD], however the calibration of instrument counts into radiance (VIS-SWIR channels S1 to S6) or brightness temperatures (TIR channels, S7 to S9, F1 and F2) follows the usual steps for a radiometer:

1. Non-linearity correction,
2. Scaling of NL-corrected counts into radiance (TIR) or reflectance (VIS-SWIR)

$$L_{TIR} = Offset_{TIR} + Slope_{TIR} \cdot NL^{-1}(X) \qquad \text{(Eq 7)}$$

$$R_{VIS-SWIR} = Slope_{VIS-SWIR} \cdot \left(NL^{-1}(X) - X_{BB\_cold}\right) \qquad \text{(Eq 8)}$$

3. Conversion of radiance into brightness temperature (BT, TIR channels) and reflectance into radiance (VIS-SWIR).

$$BT_{TIR} = L2T(L_{TIR}) \qquad \text{(Eq 9)}$$

$$L_{VIS-SWIR} = R_{VIS-SWIR} \cdot \frac{E_0^{channel}}{\pi} \qquad \text{(Eq 10)}$$

The non-linearity correction look-up-tables are obtained from pre-launch characterisation. The coefficients of the linear scaling equation are obtained from in-flight measurements at low and high signal: cold and hot black-bodies for TIR channels, measured at every scan, cold black body and solar diffuser for the VIS-SWIR channels, the latter observed once every orbit. Consequently, TIR calibration coefficients are derived continuously while VIS-SWIR ones are derived once per orbit.

TIR calibration coefficients are determined from the measured black body pixels counts and temperatures (averaged over small time windows, of the order of 10 scans), and the process makes use of a look-up table for the conversion of black body temperature into radiance. The look-up-table is based on the integration of the Planck function over each channel filter profile. As a final step of the conversion of BB temperatures into radiance, a correction of the mean background instrument temperature is applied, based on the measurend fore-optics temperature and black bodies emissivity constants. Once average counts and average radiances are computed for the hot and cold black bodies, the linear coefficients are derived for each channel, view, detector, over the considered calibration period.

VIS-SWIR calibration coefficients are determined from the pixel counts over the visible calibration target (the VISCAL unit) during the period when it is illuminated by the sun at normal incidence, completed by cold black body counts as the zero-light calibration point (dark offset). The slope of the NL-corrected count to reflectance linear law is derived from the averaged VISCAL counts, corrtected by the averaged dark count level, and the known VISCAL reflectance factor R, characterised on-ground.

All the fundamental terms of the SLSTR radiometric calibration are computed using in-flight measurements, from dedicated radiometric calibration observations (black bodies and VISCAL device) but also rely on pre-launch ground characterisation items:

- VISCAL reflectance factor
- Instrument spectral response functions (ISRF), used to derive in-band equivalent solar irradiance (VIS-SWIR channels), and temperature to radiance look-up-tabes (TIR channels)
- Black bodies emmissivity coefficients
- Non-linearity correction tables

3.2.1.2 Level 2

3.2.1.2.1 Level 2 Land product

The content of the SLSTR Level 2 LAND product is summarised in Table 21.

The core SLSTR Level 2 Land products are:

- Land Surface Temperature

Table 21: SLSTR Level 2 Land product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
LST_in.nc	Land Surface Temperature file, contains LST, LST uncertainty, and exception flags., in the 1 km TIR Nadir grid.
Annotation Data files	
File name	**Composition**
LST_ancillary_ds.nc	Ancilary data file with intermediate results as: NDVI, biome index, fractional vegetation cover, TCWV, biome class validation status
flags_in.nc	Flag files for the TIR Nadir view grid
indices_in.nc	Files of indices of source instrument coordinates (scan, detector) for the TIR Nadir view grid
geodetic_in.nc	Files of geodetic coordinates (longitude, latitude, elevation) for the TIR Nadir view grid
geodetic_tx.nc	Files of geodetic coordinates (longitude, latitude, elevation) at Tie Points
cartesian_in.nc	Files of cartesian coordinates (lang and cross-track) for the TIR Nadir view grid
cartesian_tx.nc	Files of cartesian coordinates (lang and cross-track) at Tie Points
time_in.nc	Time annotation file for the TIR Nadir view grid
geometry_tn.nc	Acquisition geometry file for the Nadir view
met_tx.nc	Meteorological parameters at Tie Points

3.2.1.2.2 Level 2 Marine products

There are two SLSTR Level 2 Marine products distributed to users: the **SL_2_WCT**, providing several estimates of the **Sea Surface Temperature** (SST) corresponding to the various retrieval possibilities (selection or combination of channels and views); and the **SL_2_WST** providing a single **Sea Surface Temperature** estimate, from the best-performing SST estimate. For both, the core product is the **Sea Surface Temperature** (highlighted in **coloured bold** font).

Their contents are summarised in Table 22 and Table 23, respectively.

Table 22: SLSTR Level 2 Marine SL_2_WCT product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
N2_SST_in.nc	Single view, two channel (N2) sea surface temperature, in the 1 km TIR Nadir grid.
N3R_SST_in.nc	Single view, three channel aerosol-robust (N3R) sea surface temperature, in the 1 km TIR Nadir grid.
N3_SST_in.nc	single view, three channel (N3) sea surface temperature, in the 1 km TIR Nadir grid.
D2_SST_io.nc	dual view, two channel (D2) sea surface temperature, in the 1 km TIR Nadir grid.
D3_SST_io.nc	dual view, three channel (D3) sea surface temperature, in the 1 km TIR Nadir grid.
Annotation Data files	
File name	**Composition**
flags_in.nc, flags_io.nc	Flag files for the TIR Nadir and Oblique view grids
indices_in.nc, indices_io.nc	Files of indices of source instrument coordinates (scan, detector) for the TIR Nadir and Oblique view grids.
geodetic_in.nc, geodetic_io.nc	Files of geodetic coordinates (longitude, latitude, elevation) for the TIR Nadir and Oblique view grids
cartesian_in.nc, cartesian_io.nc	Files of cartesian coordinates (lang and cross-track) for the TIR Nadir and Oblique view grids
geometry_tn.nc, geometry_to.nc	Acquisition geometry file for the Nadir and Oblique views
time_in.nc	Time annotation file for the TIR Nadir view grid
cartesian_tx.nc	Files of cartesian coordinates (lang and cross-track) at Tie Points
geodetic_tx.nc	Files of geodetic coordinates (longitude, latitude, elevation) at Tie Points
met_tx.nc	meteorological parameters at Tie Points

Table 23: SLSTR Level 2 Marine SL_2_WST product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
L2P.nc	Sea Surface Temperature file, contains SST "best" estimate and accompagnying data.
Annotation Data files	
File name	**Composition**
time_in.nc	Time annotation file for the TIR Nadir view grid

Note: The SL_2_WST L2P SST measurement dataset follows the GHRSST GDS 2.0 [see GHRSST] L2P dataset specification. The dataset contains a single SST field which is composited from the best-performing single-coefficient SST field in any given part of the swath, and a number of supporting data fields which provide a context for the SST field. The L2P SST dataset is generated on a wide 1 km measurement grid.

3.2.1.2.3 Level 2 Fire product

The content of the OLCI Level 2 Fire product is summarised in Table 24.

The core OLCI Level 2 Fire products are:

- Fire Radiative Power

Table 24: SLSTR Level 2 Fire product content

Product Package Structure	
Manifest file	
File name	**Composition**
xfdumanifest.xml	Metadata XML fields
Measurement Data files	
File name	**Composition**
FRP_in.nc	Fire Radiative Power file: contains a list of detected fires with FRP estimates and uncertainties, and accompagnying data, with their coordinates the 1 km TIR Nadir grid.
Annotation Data files	
File name	**Composition**
flags_in.nc, flags_fn.nc	Flag files for the TIR and F1 Nadir view grids
indices_in.nc, indices_fn.nc	Files of indices of source instrument coordinates (scan, detector) for the TIR and F1 Nadir view grids
geodetic_in.nc, geodetic_fn.nc	Files of geodetic coordinates (longitude, latitude, elevation) for the TIR and F1 Nadir view grids
cartesian_in.nc, cartesian_fn.nc	Files of cartesian coordinates (lang and cross-track) for the TIR and F1 Nadir view grids
geometry_tn.nc	Acquisition geometry file for the Nadir view
time_in.nc	Time annotation file for the TIR Nadir view grid
cartesian_tx.nc	Files of cartesian coordinates (lang and cross-track) at Tie Points
geodetic_tx.nc	Files of geodetic coordinates (longitude, latitude, elevation) at Tie Points
met_tx.nc	Meteorological parameters at Tie Points

3.2.2 LSTM

3.2.2.1 Level 1

The current list of foreseen Core Data Products in the LSTM Level-1C product (according to [LSTM-MRD]) is provided in Table 25.

Table 25: LSTM L1C Product

L1B Product
Radiometrically and geometrically calibrated TOA radiance and Brightness Tempeartures at each of the specified spectral band, orthorectified and resampled onto a uniform spatial grid, including required quality flags

3.2.2.2 Level 2

The current list of foreseen Core Data Products in the LSTM Level-2 product (according to [LSTM-MRD]) is provided inTable 26.

Table 26: LSTM L2 Product

L1B Product
Land Surface Temperature
Land Surface Emissivity per TIR spectral band
Bottom of atmosphere surface reflectance per VNIR spectral band
Total column water vapour
Cloud mask

4 Existing requirements

4.1 Mission requirements

4.1.1 Surface Colour Products

4.1.1.1 Sentinel2/MSI

The minimum (Lmin) and maximum (Lmax) radiance levels of Table 27 specify the instrument full dynamic range. The reference (Lref) and maximum (Lmax) radiance levels of Table 27 specify the instrument reduced dynamic range.

Table 28 provides the Fixed Pattern Noise (FPN) values for the instrument. For calculating the FPN, an average line is computed by averaging each column in the image. Then FPN performance is computed by assessing the RMS (root mean square) deviation along sections of fixed size (100 consecutive pixels over a given detector). These values are normalized by the mean value computed over each section.

Table 27: MSI spectral bands characteristics and specified performances

Band number	Spatial Sample Distance (SSD) (m)	Central wavelength (nm)	Bandwidth (nm)	Radiance sensibility range $L_{min} < L_{ref} < L_{max}$ ($W.m^{-2}.sr^{-1}.\mu m^{-1}$)	SNR Specification (at L_{ref})
1	60	443	20	16 < 129 < 588	129
2	10	490	65	11.5 < 128 615.5	154
3	10	560	35	6.5 < 128 < 559	168
4	10	665	30	3.5 < 108 < 484	142
5	2	705	15	2.5 < 74.5 < 449.5	117
6	20	740	15	2 < 68 < 413	89
7	20	783	20	1.5 < 67 < 387	105
8	10	842	115	1 < 103 < 308	174
8a	20	865	20	1 < 52.5 < 308	72
9	60	945	20	0.5 < 9 < 233	114
10	60	1375	30	0.05 < 6 < 45	50
11	20	1610	90	0.5 < 4 < 70	100
12	20	2190	180	0.1 < 1.5 < 24.5	100

Table 28: Fixed Pattern Noise (FPN) for MSI spectral bands

FPN ($W.m^{-2}.sr^{-1}.\mu m^{-1}$)	L_{min}	L_{ref}	L_{max}
B1	0.034	0.258	1.176
B2	0.107	0.256	1.231
B3	0.073	0.256	1.118
B4	0.066	0.216	0.968
B5	0.088	0.149	0.899
B6	0.091	0.136	0.826
B7	0.075	0.133	0.774
B8	0.04	0.206	0.616
B8a	0.114	0.114	0.616
B9	0.027	0.027	0.466
B10	0.002	0.015	0.166
B11	0.007	0.008	0.14
B12	0.003	0.003	0.049

Table 29: Sentinel-2 MSI L1 radiometric image quality requirements

Req. Code	Req. Name	Requirement Description	Parent Req. in [MRD] / [SRD] / [SSRD]
S2-MP-000	Absolute radiometric uncertainty	The absolute radiometric uncertainty shall be better than 5 % (goal 3 %) for the set of bands specified in Table 27 over the reduced dynamic range (goal: full dynamic range). This requirement applies to unpolarized scene.	MR-S2-15 MSI-IQ-030
S2-MP-005	Multi-temporal relative radiometric uncertainty	Assuming a stable and spatially uniform scene, the Level-1B data shall be constant for any given spectral channel to better than 1 % over the reduced dynamic range (goal: full dynamic range) over the satellite in-orbit lifetime.	S2-PDGS-SYS-315 MSI-IQ-040
S2-MP-010	Inter-band relative radiometric uncertainty	Assuming a stable and spatially uniform scene, the Level-1C data shall be constant from one spectral band to any other one to better than 3 % over the reduced dynamic range (goal: full dynamic range) and over the satellite in-orbit lifetime.	MR-S2-16 MSI-IQ-050
S2-MP-015	Cross-unit relative radiometric uncertainty	Assuming a stable and spatially uniform scene, the Level-1B data shall be constant for any given spectral channel, acquired by two MSI instruments on different Sentinel-2 satellites, to better than 3 % over the reduced dynamic range (goal: full dynamic range) over the satellite in-orbit lifetime.	MSI-IQ-045
S2-MP-020	Linearity	The linearity error $\varepsilon_i(L)$ shall be lower than 1 % for any pixel i and at any radiance level L comprised between Lmin and Lmax, as specified in Table 27.	S2-MP-020 MSI-IQ-022
S2-MP-025	Spatial uniformity	Assuming a stable and spatially uniform scene, the Level-1B data shall be constant for any given spectral	MSI-IQ-035

Req. Code	Req. Name	Requirement Description	Parent Req. in [MRD] / [SRD] / [SSRD]
		channel to better than 0.5 % over the reduced dynamic range (goal: full dynamic range) and over the day- time part of the orbit.	
S2-MP-030	Defective pixels	Defective pixels shall be identified and interpolated in the resampled product (Level-1C).	S2-PDGS-SYS-315
S2-MP-035	Signal-to-Noise Ratio (SNR)	The Signal-to-Noise Ratio (SNR) shall be higher than the values specified in Table 27.	MR-S2-17 MSI-IQ-015
S2-MP-040	Fixed Pattern Noise (FPN)	The fixed pattern noise shall be lower than or equal to the values specified in Table 25 over contiguous sections of the focal plane with an across-track length of 100 pixels. This requirement is applicable over the full dynamic range from Lmin to Lmax, as specified in Table 27.	S2-MP-040 MSI-IQ-020
S2-MP-045	Modulation Transfer Function (MTF)	The system modulation transfer function (MTF), at Nyquist frequency, shall be higher than 0.15 and lower than 0.30, in both across-track and along-track, for the spectral bands at 10 m and 20 m SSD, and not higher than 0.45 for the spectral channels at 60 m SSD.	S2-PDGS-SYS-315 MSI-GE-045
S2-MP-050	MTF stability	The MTF stability over the satellite in-orbit lifetime shall be better than 10 % peak-to-peak.	MSI-GE-050
	Polarisation sensitivity	The instrument polarisation sensitivity shall be less than 0.05 (0.03 goal).	MSI-PO-060
	Polarisation sensitivity variation	The variation of the instrument polarisation sensitivity across the field of view shall be less than 0.01.	MSI-PO-065
	Defects	The number of defects in an image shall be less than 0.1% for each spectral channel in each elementary detector unit. If numerical binning of detector elements is used, the percentage of defects shall be defined after binning.	MSI-IQ-090

Table 30: Sentinel-2 L1 geometric requirements in [S2-SSRD]

Absolute pointing	The Multispectral Instrument Line of Sight absolute pointing accuracy shall be better than or equal to 2 km at 3 σ confidence level. This does not apply to extended mode.
Geolocation	The geo-location accuracy of Level 1 b data w.r.t. reference ellipsoid shall be better than 20 m at 2 σ confidence level without the need of any Ground Control Points (GCP).
Geolocation	The geo-location accuracy of Level 1 c data w.r.t reference map shall be better than or equal to 20 m at 2 σ confidence level without the need of any GCP.

Geolocation	The geo-location accuracy of Level 1 c data w.r.t reference map shall be better than or equal to 12.5 m at 2 σ confidence level with the use of GCP.
Co-registration	The spatial co-registration accuracy of both Level 1 c data acquired at different dates over the same geographical area shall be better than or equal to 0.3 SSD at 2 σ confidence level, including compensation for the effects of terrain height variation with a DEM of SRTM-class accuracy and when image-to-image correlation is applied to data from the same spectral band.
Co-registration	The inter-channel spatial co-registration of any two spectral bands shall be better than 0.30 the coarser achieved spatial sampling distance of these two bands at 3 σ confidence level. This requirement shall be met for level 1c data.

Table 31: Sentinel-2 L2A and L2B products requirements in [S2-SSRD]

Parameter	Range	Accuracy Goal
L2A		
Aerosol Optical Thickness, AOT [at 550 nm]	0.05 – 3.0	10 %
Water vapour, WV [g/cm^2]	0.1 – 4 g/cm^2	10 %
Bottom-of-atmosphere reflectance		5 %
L2B (see note below)		
Generic land cover classification, GLCC		85 %
Leaf area index, LAI	1 - 6	10 %
Fraction of Absorbed Photosynthetically Active Radiation, fAPAR	0.1 – 0.95	RMSE=0.05 S/N=21
Leaf Chlorophyll Content, C_{ab} [μg/cm^2]	(0 – 90) μg/cm^2	10 %
Leaf Water Content, C_W [g/cm^2]	(0.0001 - 0.001) g/cm^2	10 %
Leaf Dry Matter Content, C_{dm} [g/cm^2]	(0.0005 – 0.1) g/cm^2	10 %

Note: requirements for L2B products are defined in [S2-SSRD] but the L2B product is not generated by the ground segment.

4.1.1.2 Sentinel3/OLCI

Table 32: Ocean Colour requirements as expressed in [S3-MRD] and [S3-MRTD]

Parameter	Range	Accuracy Case 1 water	Accuracy Case 2 water
Marine Reflectance [at 442 nm]	0.001 – 0.04	5 × 10^{-4}	5 × 10^{-4}

Water leaving radiance Lw (λ) [mW/cm^2/µm/Sr] (atmospherically corrected)	0.0 – 1.0	5 %	5 %
Photosynthetically available radiation, PAR quanta [µmol m^{-2} s^{-1}]	0 – 1400	5 %	5 %
Diffuse attenuation coefficient (turbidity), K [m^{-1}]	0.001 – 0.1	5 %	5 %
Chlorophyll, Chl [mg/m^3]	0.001 – 150	threshold 30 % goal 10 %	threshold 70 % goal 10 %
Total Suspended Matter, TSM [g/m^3]	0.0 – 100	threshold 30 % goal 10 %	threshold 70 % goal 10 %
Coloured Dissolved Organic Material, CDOM (a_{412} [m^{-1}])	0.01 – 2	threshold 50 % goal 10 %	threshold 70 % goal 10 %
Harmful Algae Bloom [mg/m^3] (same req. as Chlorophyll)	0.1 – 100	threshold 30 % goal 20 %	threshold 70 % goal 30 %

Table 33: Land Colour requirements as expressed in [S3-MRD]

Parameter	Range	Accuracy Goal	Accuracy Threshold	Frequency
MERIS Global Vegetation Index **(MGVI)** (or NDVI)	0 - 1	<5 % at 0.3 km	<10 % at 1 km	< (7 – 10) d
MERIS Terrestrial Chlorophyll Index (**MTCI)**	0 - 3	<5 % at 0.3 km	<10 % at 1 km	< (7 – 10) d
Fraction of Absorbed Photosynthetically Active Radiation, **FAPAR** quanta [µmol m^{-2} s^{-1}]	0 - 1	<5 % at 0.3 km	<10 % at 1 km	< (7 – 10) d
Fraction of Vegetation Ground Cover (**FCover**)	0 - 1	<5 % at 0.3 km	< 10 % at 1km	weekly
Leaf Area Index (**LAI**)	0 - 10	<5 % at 0.3 km	< 10 % at 1km	weekly

Notes:

1) MGVI and MTCI are outdated variable names: they are currently referred to as OGVI and OTCI respectively; OGVI is also referred to as GI FAPAR, i.e. Green Instantaneous FAPAR

2) Requirements for MGVI and FAPAR are redundant as MGVI is a FAPAR

Table 34 : OLCI radiometric Requirements from [S3-MRTD]

S3-MR-970	Radiometric Saturation	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.

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.
S3-MR-1020	Relative radiometric accuracy	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.
S3-MR-1030	Signal to noise	Sentinel-3 OLC instrument VIS channels shall have a high signal to noise specification building on and improving on MERIS heritage.
S3-MR-1040	Polarization	Sentinel-3 OLC instrument VIS channels shall have a known polarisation error less than 1 %.

Table 35: OLCI geometric requirements from [S3-MRTD]

Geolocation	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.
Geolocation	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.
Co-registration	The inter-channel spatial co-registration for Sentinel-3 visible measurements shall be < 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).
Co-registration	The co-registration between Sentinel-3 optical images acquired at different times (e.g. from different Sentinel-3 spacecraft) shall be accurate to 1.0 rms. of the spatial resolution of the sensor.

4.1.1.3 Sentinel3/SYN

No quantitative performance requirement specifically addressing any of the SYN products could be identified in either [S3-MRD] or [S3-MRTD]. However, as derived from coregistered OLCI and SLSTR Level 1B data, the following single-instrument requirements apply:

- Radiometric requirements (Table 34 and Table 44)
- Geometric Requirements (Table 35 and Table 45)

Nevertheless, no requirement on Level 2 products is defined.

4.1.1.4 CHIME

In the following, the current Mission Requirements for CHIME related to calibration / validation are outlined. Note that so far, not all Cal/Val requirements are fully specified, and that the foreseen Higher Level Downstream Data products are currently unconfirmed candidates.

Table 36 : CHIME Radiometric Requirements from [CHIME-MRD]

Parameter	Range	Accuracy Goal	Accuracy Threshold	Frequency
Absolute radiometric accuracy at Lref	(400 – 1760) nm and (1950 – 2450) nm Best effort otherwise.	< 2 %	< 5 %	
Relative spatial radiometric accuracy	(400 – 1760) nm and (1950 – 2450) nm Best effort otherwise.	< 1 % (TBC)		
Relative spectral radiometric accuracy	(400 – 1760) nm and (1950 – 2450) nm. Best effort otherwise.	< 0.2 %	< 1 %	
Polarization sensitivity	(400 – 2500) nm	< 1 %	< 5 %	
Noise equivalent delta radiance at Lref	For land observations	See table Table 37 below		
Noise equivalent delta radiance at Lref	For water observations	See table Table 38 below		

Table 37 : CHIME NEdL requirements, land observations

wavelength (nm)	NEdL (W/sr/m2/micron)
400 ≤ λ ≤ 430	0.4
430 ≤ λ ≤ 500	0.4 – (λ-430) 0.12/70
500 ≤ λ ≤600	0.28 – (λ-500) 0.07/100
600 ≤ λ ≤ 830	0.21 – (λ-600) 0.02/230
830 ≤ λ ≤ 890	0.19 – (λ-830) 0.02/60
890 ≤ λ ≤ 940	0.17 – (λ-890) 0.03/50
940 ≤ λ ≤ 1130	0.14 – (λ-940) 0.04/190
1130 ≤ λ ≤ 1280	0.1 – (λ-1130) 0.015/150
1280 ≤ λ ≤1330	0.085 – (λ-1280) 0.015/50
1330 ≤ λ ≤ 1480	best effort
1480 ≤ λ ≤ 1520	0.05 +(λ-1480) 0.015/40
1520 ≤ λ ≤ 1760	0.065 – (λ-1520) 0.015/240
1760 ≤ λ ≤ 1950	best effort
1950 ≤ λ ≤ 2050	0.05 – (λ-1950) 0.015/100
2050 ≤ λ ≤ 2450	0.035 – (λ-2050) 0.007/400
2450 ≤ λ ≤ 2500	best effort

Table 38 : CHIME NEdL requirements, water observations

Wavelength (nm)	Width (nm)	L_{ref_w} (W/sr/m2/micron)	SNR_W after spectral/spatial binning
400	15	62.95	2188
412.5	10	74.14	2061
442.5	10	65.61	1811
490	10	51.21	1541
510	10	44.39	1488
560	10	31.49	1280
753.5	10	10.33	605
778.75	15	9.18	812

Table 39: CHIME Spectral Requirements from [CHIME-MRD]

Parameter	Range	Accuracy Goal	Accuracy Threshold	Frequency
Spectral coverage		(400 – 2500) nm, contiguous		
Spectral Sampling Interval (SSI)		< 10 nm		
Spectral resolution (as FWHM)		< 10 nm		
Spectral co-registration	For all spectral channels	<0.05 SSI	< 0.1 SSI	
Uncertainty in center wavelength knowledge		< 0.5 nm		Over in-orbit lifetime

Table 40: CHIME Spatial Requirements from [CHIME-MRD] and [CHIME-SSRD]

Parameter	Range	Accuracy Goal	Accuracy Threshold	Frequency
Spatial Sampling Distance (SSD)		20 m	30 m	
Along- and across-track SSD	For all spectral channels	Within 5 %		
Along- and across-track MTF	For all spectral channels, at Nyquist frequency	> 0.3 MTF	> 0.2 MTF	
Spatial co-registration	For all spectral channels	< 0.05 SSD	< 0.1 SSD	
Absolute geo-location accuracy (L1B)	At 95 % confidence level	< 1 SSD		
Relative geo-location accuracy w.r.t S2 GRI (L1C and higher)	At 95 % confidence level	< 0.3 SSD		

Table 41: Additional requirements

Parameter	Range	Accuracy Goal	Accuracy Threshold	Frequency
Surface reflectance accuracy (L2A)	(400 – 1320) nm (1490 – 1760) nm (1960 - 2440) nm	Surface reflectance accuracy better than 0.05*ρ +		

	SZA < 60°, AOT < 0.6. Best effort otherwise.	0.005 (TBC) for SZA ≤ 60° (TBC) and AOT at 550 nm ≤ 0.6 (TBC) for at least 95 % of the Level-2A product.		

4.1.2 Surface Temperature Products

4.1.3 Sentinel3/SLSTR

Table 42: Land Temperature Requirements as expressed in [S3-MRD]

Parameter	Range	Accuracy Goal	Accuracy Threshold	Frequency
Fire Radiative Power (**FRP**)	(0 – 650) K	TBD at 1 km	TBD at 1 km	daily
Fire Disturbed Area	0 - 1	< 5 % at 0.3 km	<10 % at 1 km	5 – 10 d
Land Surface Temperature **(LST)**	(210 – 350) K	<1 K at 1 km	At 1 km	daily

Table 43 : Sea Surface Temperature User Product Requirements from [S3-MRD]

Application	Temperature accuracy [K]	Spatial resolution [km]	Revisit Time
Weather prediction	0.2 – 0.5	10 – 50	6 – 24 h
Climate monitoring	0.1	20 – 50	8 d
Ocean forecasting	0.2	1 – 10	6 – 24 h
Coastal/local	0.5	< 0.5	≤1 d

Table 44: Sea and Land Surface Temperature Instrument Performance Requirements from [S3-MRTD]

MR-ID	Type	Description
S3-MR-400	Performance	Sentinel-3 shall provide SST measurement capability to at least the quality of AATSR on ENVISAT: SST shall be accurate to < 0.3 K @ 1 km spatial resolution and with improved swath coverage
S3-MR-420	Performance	Sentinel-3 shall be able to measure Land Surface Temperature (LST) to an accuracy of < 1 K with a resolution of 1 km at nadir. This capability shall not reduce the quality of the SST retrievals.
S3-MR-430	Performance	Sentinel-3 shall be able to measure Ice Surface Temperature (IST) to an accuracy of 10 % with a resolution of < 5 km (1 km goal) at nadir. This capability shall not reduce the quality of the SST retrievals.

MR-ID	Type	Description
S3-MR-940	Dynamic range	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).
S3-MR-950	Dynamic range	Sentinel-3 VIS channels shall have a dynamic range at least equivalent to ENVISAT MERIS and AATSR instruments.
S3-MR-980	Radiometric stability	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° × 5° latitude longitude area.
S3-MR-990	Radiometric accuracy	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.
S3-MR-1000	Relative radiometric accuracy	Sentinel-3 infrared channels shall have a relative radiometric accuracy of <0.08 K (threshold) with a goal of 0.05 K over a range of (210-350) K expressed as NEΔT traceable to international reference standards.
S3-MR-1050	Polarisation	For the SLST instrument, the difference in responsivity between any two orthogonal polarisations shall not be more than 4 % for the TIR channels.
S3-MR-1060	Polarisation	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 %.

Table 45: SLSTR geometric requirements from [S3-MRTD]

Geolocation	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.
Geolocation	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.
Co-registration	The inter-channel spatial co-registration for Sentinel-3 visible measurements shall be < 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).
Co-registration	The co-registration between Sentinel-3 optical images acquired at different times (e.g. from different Sentinel-3 spacecraft) shall be accurate to 1.0 rms. of the spatial resolution of the sensor.

4.1.4 LSTM

Table 46 : LSTM radiometric requirements from [LSTM-MRD]

MR-ID	Type	Description
MR-OBS-060	Performance	The dynamic range at L2 product level (LST) shall be from 270 K to 350 K (threshold) and 200 K to 460 K (goal)
MR-OBS-065	Performance	The accuracy at L2 product level (LST total uncertainty) shall be better than 1 K (goal) and 1.5 K (threshold)
MR-OBS-070	Performance	The accuracy at L2 product level (LSE total uncertainty) shall be better than 2 % at TBD confidence level
MR-OBS-075	Performance	The accuracy at L2 product level (TCWV total uncertainty) shall be better than TBD % at TBD confidence level, for TCWV ranging from TBD to TBD g/cm^2
MR-OBS-085	Performance	The Noise Equivalent Delta Temperature (NEDT) for the TIR bands shall not exceed 0.1 K (RMS value) as goal and 0.15 K as threshold for reference brightness temperature of 300 K over an uniform scene.
MR-OBS-086	Performance	The Noise Equivalent Delta Temperature (NEDT) for the TIR bands shall not exceed 0.15 K (RMS value) as goal and 0.3 K as threshold for the threshold dynamic range of brightness temperature over an uniform scene.
MR-OBS-095	Performance	The dynamic range, reference radiance and RMS value of the Signal to Noise Ratio (SNR) for the VNIR-SWIR band shall be as specified in Table 47
MR-OBS-095	Performance	The Absolute Radiometric Accuracy (ARA) shall be better than 5% for the VNIR-SWIR bands (with 3 % goal fr VNIR bands) over the dynamic range, and better than 0.3 K for the TIR bands over the goal dynamic range or 0.5 K(T)/0.3 K(G) over the threshold dynamic threshold (threshold). Absolute radiometric accuracy shall include the interband crosstalk and straylight contributions. Absolute radiometric calibration shall be traceable to SI standards.

Table 47: Dynamic range and SNR for LST VNIR-SWIR bands

Band	L_{Min} ($W.m^{-2}.sr^{-1}.\mu m^{-1}$)	L_{Max} ($W.m^{-2}.sr^{-1}.\mu m^{-1}$)	L_{Ref} ($W.m^{-2}.sr^{-1}.\mu m^{-1}$)	SNR@L_{Ref}
VNIR-0	11.70	615.48	128.00	162
VNIR-1	3.31	484.13	108.00	142
VNIR-2	0.95	307.80	52.39	100
VNIR-3	0.51	232.91	8.77	114
SWIR-1	0.06	45.00	6.00	100
SWIR-2	0.40	69.78	4.00	133

Table 48: LSTM geometric requirements from [LSTM-SSRD]

Absolute pointing	The LSTM instrument Line of Sight absolute pointing accuracy shall be better than or equal to 2 km at 99.7 % confidence level.

Geolocation	The geo-location accuracy of level-1b and level-1c data w.r.t the reference ellipsoid shall be equal to or better than 1 SSD, in any direction, at 95 % confidence level, without the use of any Ground Control Points (GCP).
Geolocation	The geo-location accuracy of level-1c shall be equal to or better than 0.5 SSD, in any direction, at 95 % confidence, using Ground Control Points (GCP) and on a scene of 100 km x 100 km.
Co-registration	The inter-channel spatial co-registration of any LSTM mission level-1c product shall be less than 0.3 SSD at 99.7 % confidence level.
Co-registration with S2 GRI	The spatial co-registration, at level 1c, between the LSTM mission observations and Sentinel-2 GRI shall be equal to or better than 0.3 SSD at 95 % confidence level and over a scene of 100 km × 100 km.

5 Missing Requirements

5.1 Surface Colour Products

The following CALVAL requirement gaps have been identified.

5.1.1 Sentinel3/OLCI

- No performance requirement addressing OLCI Integrated Water Vapour.
- No performance requirement addressing OLCI Aerosol Optical Thickness (AOT) and Aerosol Angstroem Exponent (AAE) over water, but this may be acceptable as these are so-called “by-products” of the atmosphere correction.

5.1.2 Sentinel3/SYN

- No performance requirement addressing SY_2_SYN Surface Directional Reflectance (SDR).
- No performance requirement addressing SY_2_SYN AOD and AAE.
- No performance requirement addressing SY_2_K TOA Reflectance.
- No performance requirement addressing SY_2_VG1/V10 Surface Directional Reflectance (SDR).