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DOCUMENT

Sentinel-6/Jason-CS Cal/Val Concept (CVC)

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Table of contents:

1 INTRODUCTION

This document provides the Cal/Val Concept (CVC) for the Sentinel-6/Jason-CS Mission (termed 'The Mission' or 'S6') and contains the high-level planning of the post-launch Cal/Val activities required to fully validate the S6-A and S6-B products over their respective mission lifetimes.
In this document we use the term 'calibration' to describe the estimation and correction of measurement system errors, and the term 'validation' to describe the estimation of geophysical parameter retrieval errors.

The document elaborates the concept by providing in §3 the mission overview, description of the system elements including spacecraft, payload and definition of products and required latencies. §4 provides the key objectives of the Cal/Val and the planning needed to meet those objectives in terms of meetings, documentation and a description of the Cal/Val Implementation Plan (CVIP), [RD 3]. §5 gives a detailed list of all the key performance parameters and §6 provides the details of the payload and product Cal/Val elements.

Annexes are provided for the novelties of the mission, Annex 1, the elements of Cal/Val infrastructure that need consideration for the S6 mission Annex 2, high-level work packages of the CVIP in Annex 3 and the template for detailing the CVIP work-packages in Annex 4.

This issue of the document makes two key assumptions of the roles of the MAG and MPWG following launch.

1.1 Scope

This document includes four sections: Section 3 provides an overview of the mission with the objectives, description of the mission and its data products. Section 4 concerns the Cal/Val organisation between the partner Agencies of the mission in order to validate system and end user requirements and associated specifications in terms of performance. It is not in the scope of this document to elaborate on activities that are established through separate EU and US function as a function of the OSTST or ESA sea-level CCI, for example. Section 5 describes how the performance assessment will be achieved through the post launch commissioning and operational phases of the mission throughout which the Cal/Val activities take place. Section 6 presents a high-level overview of the various experiments and analyses that will be conducted by project teams in order to support validation activities.

This document does not elaborate on the detailed implementation of Cal/Val activities covered by the Calibration and Validation Implementation Plan (CVIP), [RD 3] that defines the individual work packages to implement this CVC.

This is the second issue of the document consolidates the outcome of MPWG, Project level review, system CDR and MAG comments. An issue 3 will only be submitted if there needs to be additional special calibration operations that might arise from the spacecraft at the Flight Acceptance Review (FAR) that could impact Cal/Val.

Uncertainties in this document are all stated as 1-σ unless otherwise stated.

1.2 Acronyms and Abbreviations

AIR	Azimuth impulse response
AMR-C	Advanced Microwave Radiometer – Climate quality
AOCS	Attitude and orbit control system
AR	Acceptance Review

ARCS	AMR Radiometer Calibration System
ATBD	Algorithm Theoretical Baseline Document
AVISO	Archiving Validation and Interpretation of Satellite Oceanographic
BoL	Beginning of Life
BT	Brightness Temperature
CAL-1	Impulse response calibration for burst phase/amplitude, internal path delay, etc.
CAL-1-ECHO	Impulse response calibration commanded per radar cycle used.
CAL-1-INST	Poseidon-4 Instrument calibration to obtain the full instrument transfer function to be derived and allow tuning of it.
CAL-2	Heritage functional mode for obtaining
CCI	Climate change initiative
CHR	Commissioning Handover Review
CMEMS	The Copernicus Marine Environment Monitoring Service
CNES	Centre National d'Études Spatiales
CVC	Cal/Val Concept
CVIP	Cal/Val Implementation Plan
DEM	Digital elevation model
DORIS	Doppler Orbitography and Radio-Positioning Integrated by Satellite
ECMWF	European Center for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EIRP	Effective Isotropic Radiated Power
EMB	Electromagnetic Bias
EoL	End of Life
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
ENSO	El Niño/Southern Oscillation
EoL	End of Life
ESA	European Space Agency
EURD	End User Requirements Document
FRM	Fiducial Reference Measurement
GFO	Geosat Follow-on
GIM	Global ionosphere maps
GMSL	Global mean sea level
GNSS	Global Navigation Satellite System
GNSS-POD	European GNSS receiver used for POD
GNSS-RO	US GNSS used for the secondary RO mission
GOCE	Global Ocean Circulation Experiment
GPP	Ground processor prototype
GPS	Ground Positioning System
GRACE	Gravity Recovery and Climate Experiment
G/S	Ground Segment
GTS	Global Telecommunication System
ICD	Interface Control Document
IOAPA	In-orbit Annual Performance Assessment
IOV	In-orbit verification
HK	House-keeping telemetry
HRMR	High Resolution Microwave Radiometer
JMR	Jason Microwave Radiometer
KP	Key point
HR	Unfocussed processing of altimeter interleaved echoes producing multilooked waveforms
LEOP	Launch and early orbit phase
LR	Low Resolution pulse-width limited power echoes derived from open burst interleaved

	data
LRM	Low Resolution Mode. A mode of operation specific to heritage Jason -1, -2 & -3 missions, SIRAL and SRAL of CryoSat and Sentinel-3, respectively.
L0	Annotated ISPs
L1B	Level 1B
L2	Level 2
MPB	Mission Performance Budget
MPWG	Sentinel-6 Mission Performance Working Group
NASA-JPL	National Aeronautics and Space Administration – Jet Propulsion Laboratory
NC	Non Conformance
NCEP	National Centre for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real Time
NRTAVS	Near Real-Time Altimeter Validation System
NTC	Non-Time Critical
OGS	Overall Ground Segment
OLTC	Open Loop Tracking Commands
ORR	Operations Readiness Review
OSTM	Ocean Surface Topography Mission
OSTST	Ocean Surface Topography Science Team.
P4	Poseidon-4
PDF	Probability Density Function
PDR	Preliminary Design Review
POD	Precise Orbit Determination
PODRIX	Precise orbit determination receiver X (instrument)
PRF	Pulse Repetition Frequency
RADS	Radar Altimeter Database System
RDB	Radar Data Base
RFCT	Radio Frequency Compatibility Test
PFAC	Permanent Facility for altimeter Calibration
PDAP	Payload Data Archiving and Processing
POD	Precise Orbit Determination
PPS	Pulse per second – Primary clocking of the satellite.
RADS	Radar Altimeter Database System
RF	Radio Frequency
RIR	Range impulse response
RMDCN	Regional Meteorological Data Communication Network
ROSES	Research Opportunities in Space and Earth Sciences
RSS	Root Sum Squared
SAR	Synthetic Aperture Radar
SatIOV	Satellite IOV
s/c	Space craft
SI	Système international
SIRAL	Synthetic Interferometric Radar Altimeter
SNR	Signal to noise ratio
SRAL	Sentinel-3 Synthetic Aperture Radar Altimeter
SRD	System requirements Document
SCS	Supplemental Calibration System of the AMR-C
SIOV	System In-Orbit Verification
SIOVR	System In-Orbit Verification Review
SLA	Sea level anomaly

SSALTO	Segment Sol multi-missions dALTimetrie, d'orbitographie et de localisation précise
SSB	Sea State Bias
SSH	Sea Surface Height
SIVVRR	System Integration Verification and Validation Readiness Review
SIVVR	System Integration Verification and Validation Review
STC	Short-term critical
STR	Star Tracker
SWH	Significant Wave Height
TBA	To be added
TBC	To be confirmed
TBD	To be determined
TBW	To be written
TEC	Total Electron Content
TED	Thermo-Elastic Distortion
TM/TC	Telemetry and Telecommand
TMR	TOPEX Microwave Radiometer
V&V	Verification and validation
VTEC	Vertical ionospheric total electron content

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2.1 Applicable & Reference Documents

2.1.1 Applicable Documents

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3 MISSION OVERVIEW

Since 1992 four high accuracy radar altimeter missions have provided the capability for the international physical oceanography community to make an important advance in scientific research and operational applications.

The heritage reference missions are TOPEX/Poseidon (T/P, launched in August 1992), Jason-1 (launched in December 2001), OSTM/Jason-2 (launched in June 2008), and Jason-3 (launched in January 2016). These heritage reference missions have supplied the long-term reference data set ±66° latitude supplemented by higher inclination mission data from ERS-1/2, EnviSat. CryoSat-2 and Sentinel-3A/3B.

These missions, both individually and combined, provide an accurate monitoring of Global Mean Sea Level (GMSL) rise that is recognised to be a key indicator of Climate Change. They also provided data allowing essential contributions in other domains such as ocean circulation (including operational models), tides, marine meteorology, geophysics and geodesy. High accuracy radar altimeter missions are unique in providing global and continuous observation of the ocean and of providing a better understanding of short to long-term changes of ocean circulation. The missions are established as essential components of current and future global ocean observation systems. These systems integrate the products derived from Radar altimeter (in addition to other complementary satellite data and their products) and in-situ data into models and require the continuity and permanence of ocean measurements to produce time series over several decades.

The near-real time and short-term capability of the heritage have fed several pilot experiments that demonstrated the growing importance of operational ocean observation products and short-range ocean prediction for a variety of applications (e.g. ship routing, environmental hazards, support to maritime industries).

The mission will provide continuity to the unique accuracy and coverage of the heritage reference missions in support of climate change monitoring, research and forecasting, as well as operational applications related to extreme weather events and operational oceanography. The mission also provides improved design for climate scale monitoring of GMSL. The mission consists of two identical satellites flying in sequence designed to provide near-real-time measurements to operational users of sea surface height, significant wave height, and wind speed to support operational oceanography and climate monitoring. As a secondary objective, the mission will also include Radio Occultation (GNSS-RO) user services which is elaborated further in [RD 2] and not discussed further in this document apart from the potential use of the RO's POD data that can in principle supplement the primary mission.

Each S6 satellite will be launched sequentially into the Jason orbit (±66° latitude) to overlap and continue the services initiated by TOPEX/Poseidon and currently maintained by the Jason reference altimeter series. The mission uses a state of the art satellite platform hosting an improved synthetic aperture radar altimeter (Poseidon-4) and microwave radiometer (AMR-C) to secure operational continuity of the long-term ocean surface topography climate data record until the early 2030's. The S6 missions form an international collaboration with contributions from NASA, NOAA, ESA, EUMETSAT, CNES, and the European Union.

3.1 Mission Objectives

Primary Mission (Ocean Topography)

The main purpose of the mission is to provide continuity of the satellite altimetry data record created using measurements from the heritage reference missions. The S6 mission is planned to continue and extend this series and to comply with the operational needs and services of the Copernicus programme.

The S6 mission will continue the role of the reference mission. To fulfil that continuity, as well as to satisfy the needs of the funding there are a number of high-level objectives. Note that these are not mission requirements, rather they are higher-level objectives which motivate the mission requirements.

1. *Sentinel-6 shall be an operational mission.*

This objective means that the mission will meet the needs of operational services such as weather and ocean weather services. It leads to mission requirements on availability (that is lack of “down-time”), on reliability and on the distribution of data products very shortly after the relevant measurements are taken by the satellite.

2. *Products shall be of sufficient quality for scientific research.*

This objective reflects Jason-CS’s role as the reference mission and is the motivation for requirements related to measurement and product quality, particularly for the products generated after sufficient time has elapsed for the production of high-quality corrections. It also leads to requirements on the calibration and validation of products. The next objective reflects the need for continuity of the data record from the Jason series:

3. *Products shall continue the long-term data series from the heritage reference missions, to quantify and monitor global sea level variability and the rate of global sea level rise.*

This objective leads to requirements on the content of the data products as well as on the continuity of the space-time sampling between missions.

4. *Products shall contribute to marine meteorology by providing Significant Wave Height and Wind Speed observations in near real-time.*

This objective also motivates requirements on the content of the data products and their timeliness.

5. *Products shall maintain their quality closer to the coastline previous heritage reference missions due to the use of SAR altimetry.*

This objective intends to make use of the evolving techniques in radar altimetry to improve the performance of the mission in coastal areas (re-tracking and high resolution wet tropospheric correction), and is reflected in requirements related to high resolution altimetry. In addition to these sources, mission requirements are also framed to respond to the End-User Requirements expressed in [RD 6] and are recorded in the System Requirement Document, [AD 1].

The main operational and scientific observation objectives are outlined below:

Altimeter data provision to operational ocean forecast systems: for example. Copernicus Marine Environment Monitoring Service (CMEMS, for example) provides state-of-the-art information available on the global ocean (worldwide coverage) and on European seas, based on the combination of space and in situ observations, and their assimilation into 4D models (including the time frame) such as: temperature, salinity, currents, sea ice, sea level, wind and biogeochemical parameters. Such operational systems depend heavily on satellite ocean observations and altimetry data are thus core observations for sea level monitoring and forecasting

The monitoring and forecasting of mesoscale ocean signals (typical scales of 30-300 km and 20-90 days) have specific applications in domains like fishery activity, marine safety, monitoring of oil spills, marine fauna surveys, oil drilling, commercial navigation and military defense. Observations of mesoscale activity has developed through near real time applications. This requires joint use of multi-mission altimetric data and models. Dense spatial and temporal sampling is required for such applications and, consequently, the combination of S6 data with other available altimetric data will be mandatory.

Coastal applications have now become essential as they have a strong and direct impact on populations living near the shore. As regional models are also developing, there is also a strong demand for high resolution/high accuracy altimeter data. Of course, the density of the observation sampling is a crucial issue for these applications, but there is also a need for improving the accuracy and the coverage of altimeter data near the coasts.

Global ocean circulation: determination from satellite altimetry is particularly important to describe and characterize the main features of the ocean circulation, i.e. the location of the main currents, their intensity, their transport, and their temporal variability. The global absolute dynamic topography, as determined from altimetry, is also useful to validate and initialize global ocean models and to adjust data assimilation techniques. To depict the large scales of the mean ocean circulation, the orbits of altimetric satellites must be known at least with the same performance as Jason-2 by design.

Climate and large-scale signals: the dynamic and hydro-halo-thermal coupling of the oceans with the atmosphere makes the overall climate system very sensitive to small sea level changes, at time scales for the ocean signals from a few days to a few decades. It was demonstrated that the accuracy of sea level observations must be no worse than that of T/P and Jason-1/2 in order to make further progress in understanding and simulating the El Niño/Southern Oscillation (ENSO) signal. The physical processes of the warm/cold events in the Pacific depend on sea level differences between North and South subtropics on the order of 2-to-4 cm that cannot be observed by less accurate altimetry.

Mean sea level estimations from altimetry: This direct measurement is a key indicator of global climate change. Indeed, several causes can explain the MSL variations observed by altimetry can have several causes, including thermosteric expansion and global mass variations. The current estimate of the GMSL rise is 3.3 mm/yr over the 20-year period of TOPEX/Poseidon, Jason-1, OSTM/Jason-2 and Jason-3. But large variations are observed around this linear trend, due to large-scale ocean signals and interannual variability. Also, strong variations exist in the local estimates of the MSL variation. This shows that continuous attention has to be paid to altimeter data accuracy, for all components of the system: altimeter and radiometer sensors, orbit calculation and geophysical corrections. MSL estimations from altimetry, are an essential climate indicator because a major part of the observed sea level chance is due to the ocean heat content. Collecting ocean heat content data on the long term puts strong requirements in terms of continuity of precise altimetry and on international Agencies to maintain this.

In addition to sea surface height, altimeters provide estimates of significant wave-height and wind speed, which are of both scientific and operational interest in marine meteorology. From a climatological point of view it is very valuable to take advantage of the altimetric coverage of sea-state and wind speed observations is very valuable. Other uses of altimetry include propagation of swell (through models), interactions between sea state and currents, etc. Altimetric data are operationally assimilated in several meteorological models. Merging multi-satellite data sets is key when studying sea-state parameters because this provides improved spatio-temporal sampling for sea-state parameters.

The cloud/rain water vapour content measured by microwave radiometers on-board altimetric satellites are dedicated to the correction of altimeter data, but are also used to monitor atmospheric characteristics in the troposphere and can be used to constrain operational weather models. In the same way, studies of the ionosphere and upper atmosphere can take advantage of the ionospheric electron content measured by use of the dual-frequency C- and Ku-band altimeters and of the atmospheric drag estimated during precise orbit determination. These global data give interesting information on the solar and geomagnetic characteristics of the thermosphere. Rain and ocean/atmosphere gas fluxes at the sea surface are other parameters that can be derived from the analysis of the dual-frequency radar altimeter measurements.

Altimetric sea state and sea level data are also used to adjust, validate and improve models simulating dramatic and sudden events such as hurricane intensification, storm surge, or tsunamis. As an example, altimetry has been advantageously used to investigate the interactions between upper ocean thermal structure and the intensification of hurricanes. Results of such studies are used to produce forecasts based on the combination of altimetry, sea surface temperature and ocean models (where no terrestrial sensors may not operate during a hurricane)..

Because of the importance of understanding the hydrological cycle and of managing the Earth's water resources, inland waters are crucial, especially to monitor the space-time variations of rivers, lakes, reservoirs and flooded regions.

Although the orbital inclination of the reference orbit is low makes it less suitable for observation of polar regions, the S6 missions are also considered as part of the global altimetric infrastructure for observing sea ice (for example, Caspian Sea during winter) and potentially some land-ice fields such as the Juneau Ice Cap in Alaska, for example.

3.2 Mission Description

The S6 satellite system is designed to provide measurements of global sea level change and variability. The mission consists of two identical satellites flying in sequence (with an expected ~5 year launch separation) designed to provide near-real-time measurements to operational users of sea surface height, significant wave height, and wind speed to support operational oceanography and climate monitoring. Each satellite will be launched sequentially into the reference orbit to overlap and continue the long-term data record. The launch of the A and B satellites are currently planned for 2020 and 2025, respectively and the nominal design lifetime of each satellite is 7 years. The mission uses a state of the art satellite platform hosting an improved synthetic aperture radar altimeter (Poseidon-4) and microwave radiometer (AMR-C) to secure operational continuity of the long-term ocean surface topography climate data record until the early 2030's.

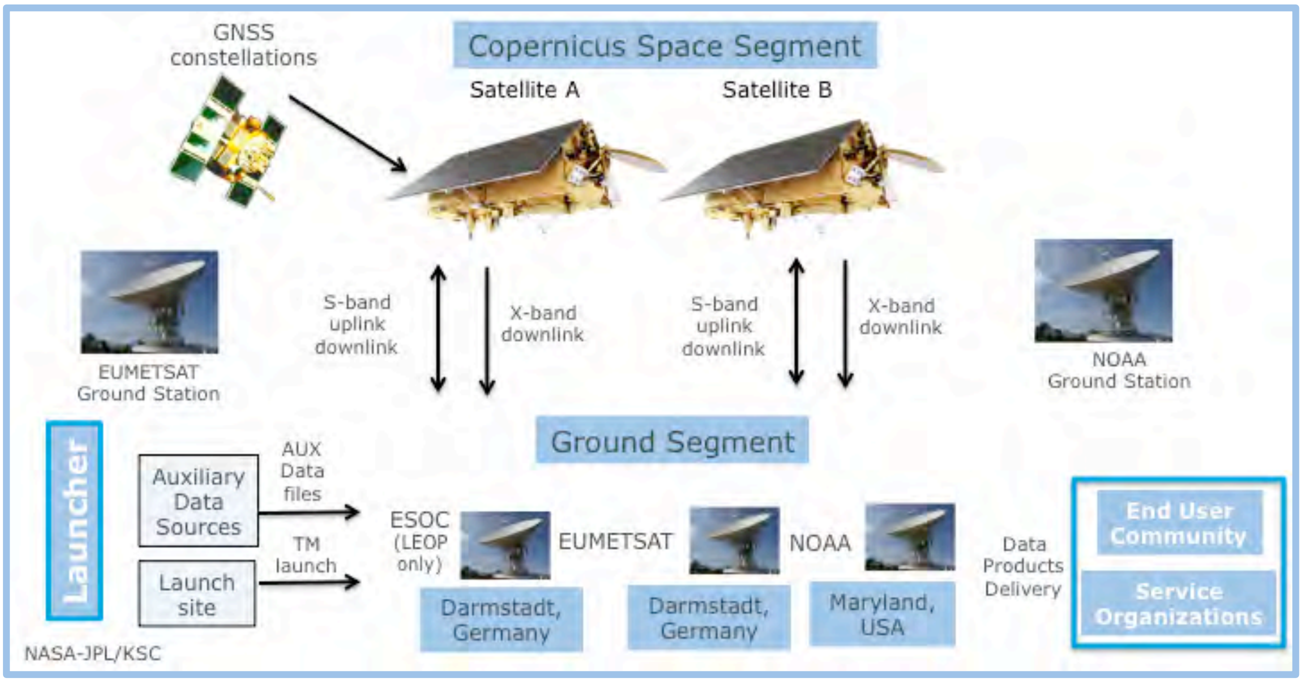

Figure 3-1 Sentinel-6 Jason-CS System overview.

As with all satellite systems the S6 mission level requirements are broken down from end user requirements (the EURD,[RD 6]) to the system requirements (SRD, [AD 1]). The overall breakdown is provided in Figure 3-2

This document elaborates the calibration and validation of product performance requirements established in the applicable SRD.

Cal/Val also relies on inputs coming from lower level requirements such as the Satellite System Requirements Document (SSRD, [RD 9]) and the US Instruments Performance Requirements (US-PRD, [RD 11]).

The SSRD establishes the instrument level requirements for the Radar Altimeter, DORIS and GNSS-POD for which the instrument level calibration is established on-ground and then in orbit during Satellite IOV. These then feed to the SRD.
The AMR-C performance requirements feed directly to the SRD performance requirements.

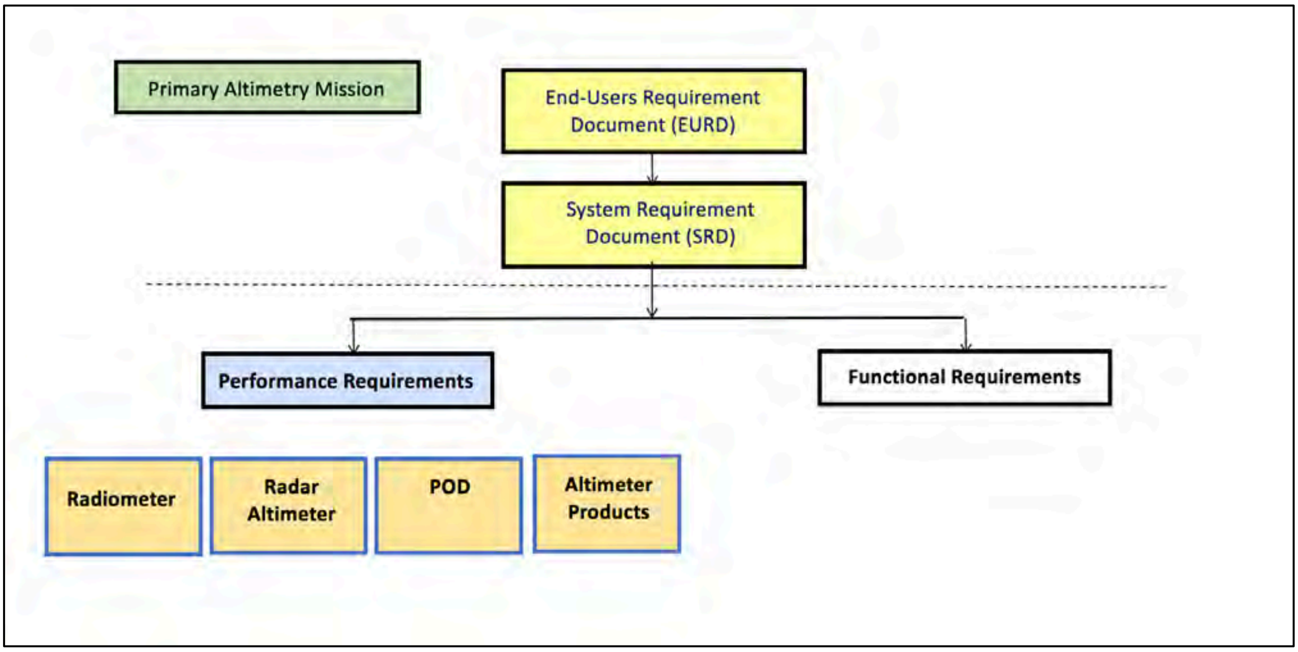

Figure 3-2 Flow down of altimetry mission requirements

3.2.1 Spacecraft

The satellites are specified, designed and tested to fulfil the SSRD [RD 9] that flow down from the System Requirement Document. An image of the satellite is provided in Fig. 3-3 and its estimated properties are provided in Figure 3-4. The payload is described in the next section.

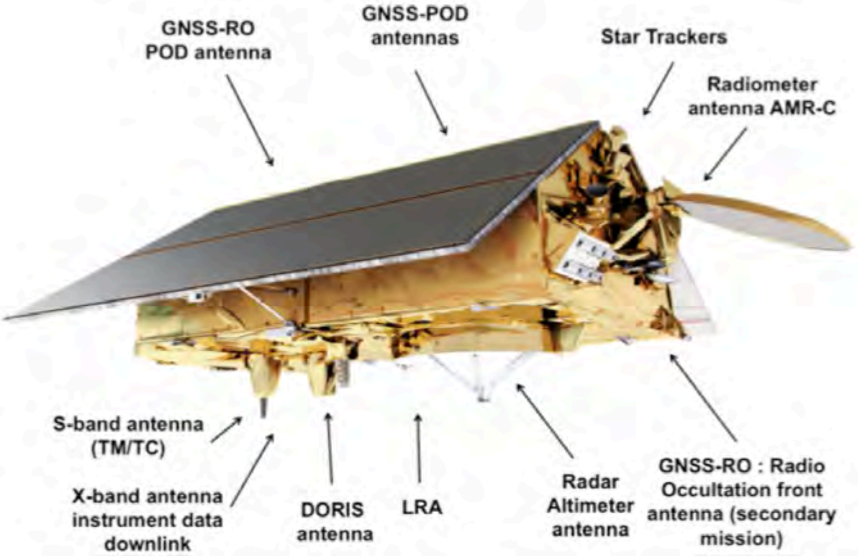

Figure 3-3 Sentinel-6/Jason-CS spacecraft showing all the key external payload elements.

Orbit	LEO non sun-synchronous • Repeat cycle: 10 days • Mean altitude: 1336 km; Inclination: 66°
Lifetime	6 months commissioning 5 year operational mission
Mass	1440 Kg (including fuel)
Satellite Dimensions	Flight configuration 5.13 m x 4.17 m x 2.35 m Stowed configuration 5.13 m x 2.47 m x 2.35 m
Power	891W average consumption
RF Links	- X-band data downlink: 150 Mbps at 8.090 GHz - S-band TTC link: 32 kbps uplink,1 Mbps downlink
Data	Volume: order of magnitude 1200 Gbit/day; On-board storage: 496Gbits (BoL)
Instruments	• SAR Radar Altimeter: Poseidon-4 • AMR-C Climate-quality microwave radiometer (NASA/JPL contribution) • Precise Orbit Determination: GNSS POD Receiver; DORIS • Laser Retroreflector Array (NASA/JPL contribution) • TriG Receiver for Radio Occultation (NASA/JPL contribution)
Flight Operations	Mission control for LEOP from ESOC. IOV, Commissioning and routine operations from EUMETSAT. Two operational ground stations, at Fairbanks and Kiruna (TBC)
Launch Vehicle	Falcon-9 procured by NASA-JPL/KSC. (selected in October 2017)

Figure 3-4 Sentinel-6 Data Sheet

3.2.2 Payload

Radar Altimeter: The primary payload of the S6 satellites is the Poseidon-4 Radar Altimeter developed by ESA. The instrument is designed with state-of-the-art digital technology that improves on precision and stability over heritage reference missions. For science operations the Poseidon-4 altimeter will operate with a continuous open burst of "interleaved" continuous high pulse-rate mode (termed HR) that allows for both pulse-width limited Low Resolution (LR) with a slightly better performance than the Jason-3 equivalent and high resolution (HR) SAR processing with a much improved performance. This dual functionality was developed as a recommendation of the OSTST, [RD 42]. The concept is achieved by using a Pulse Repetition Frequency (PRF) some ~4 times that of Jason-3 and 0.5 times that of the SAR of the Sentinel-3 radar (SRAL). Due to constraints during the development phase to keep data volume below limits such that NRT products are available within the required 3 hours. Hence, a function is added to the design that reduces the data volume by a factor 2 and is termed Range Migration Compensation (RMC). There are several impacts of this function that have been addressed in the development of prototype Level 1 and Level 2 products (see Annex 1 for an initial list). There are continuing activities to understand the finer details of performance between this new operation versus Jason-3 in order to perform adequate cross-calibration. In addition, the mode of operation has to be demonstrated not only to meet the system requirements but also to demonstrate

acceptable performance for all geophysical surface phenomena (large geoid slope, for example). This is a key element of the Cal/Val.
The instrument also generates echoes that can be processed by exploiting the full scatter phase history with fully focussed algorithms, [RD 43], though this is not baseline. The instrument features a full set of calibration modes allowing the calibration of level 1b products for path delay, azimuth & range impulse responses, echo power and transfer filter.

Advanced Microwave Radiometer – Climate Quality (AMR-C): Developed by NASA-JPL, the primary purpose of the AMR-C is to provide data necessary to generate a correction for the delay (slowing) of the Poseidon-4 pulses and backscatter attenuation due to the total integrated water vapour content of the troposphere. The AMR-C is an evolution of the AMR developed for Jason-2 and Jason-3, which itself was based on the TMR[1] and JMR[2] embarked on the TOPEX/Poseidon and Jason-1 missions respectively. The AMR-C provides retrievals of Brightness Temperature at 18.7, 23.8 and 34 GHz calibrated by means of an on-board Supplemental Calibration System (SCS) that uses a rotating secondary reflector to view a warm calibration on-instrument target and cold sky every 5-10 days. In addition, a periodic cold sky calibration is planned that involves a pitch manoeuvre of 80°. Due to the nature of the platform design, it should be possible to perform such a calibration manoeuvre as often as 10 days[3], though this could be relaxed once the system is characterised. This calibration approach in addition to other sources of external calibration will improve overall long-term stability of the radiometer measurements of tropospheric delays and attenuation. These calibration measurements are then used by ground software, namely the AMR Radiometer Calibration System (ARCS), to generate calibration coefficients for the overall AMR-C science data processing. Higher frequency channels are designed into the AMR-C system as an experiment to improve retrievals over coast areas.

DORIS:
For this sub-system the DORIS Navigator is used within the NRT processing. The instrument also provides the ultra stable oscillator (USO) that provides the clock for the Poseidon-4 precise retrievals and positional information allowing improved altimeter surface tracking and improving coastal and inland water retrievals. The DORIS system also provides satellite tracking data that are used in the POD processing.

GNSS-POD:
Developed by RUAG under ESA funding and provided by ESA for the S6 satellites, the 16 channels instrument includes the ability to track both GPS and Galileo constellations. The GNSS-POD provides the internal PPS to all the equipment on board including the payload. The instrument provides tracking data that are used in the POD processing.

LRA:
The Laser Retro-reflector Array, from NASA-JPL, is used with global satellite laser ranging stations to provide independent tracking measurements for the POD processing or POD validation. It consists of 9 quartz corner cubes arrayed as a truncated cone with one cube embedded in the centre and the remaining eight other cubes distributed azimuthally around the cone.

Star-Trackers:
Used within the on-board Attitude and Orbit Control System (AOCS), the instrument attitude

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[1] TOPEX Microwave Radiometer.
[2] Jason Microwave Radiometer.
[3] The Jason-3 is placed in a calibration manoevre each ~30 days due to platform design.

information (quaternions) key to the Poseidon-4 SAR retrievals that are sensitive to platform 'mis-pointing' from the nominal local normal yaw steered. These data (quaternions) also provide key attitude information for POD processing. For long term stability which of the three star trackers is used in the AOCS at any given time is needed as is the temperature of the head.

3.3 Product level Definition

The definition of products is provided in [RD 22] and [RD 23] and listed below:

- ***Level 0 products*** are computer-readable data directly representing the output of the on-board instrument in its native data structure and in engineering units (e.g. clock cycle counts), after extraction from the downlinked data stream. Data are chronologically ordered and any overlapping (duplicate) data have been removed. Quality flags related to the reception and decoding process may be appended.
- ***Level 1A products*** are time-ordered unpacked Level-0 packets, geolocated and converted from engineering to SI units. Individual waveforms are calibrated for instrument effects, but not corrected for geophysical effects.
- ***Level 1B products*** are fully calibrated and geo-located data containing averaged (for LR pulse-width limited processing) or multi-looked waveforms (in the case of HR unfocussed SAR processed waveforms).
- ***Level 2 products*** maintain the same time structure and sampling as the level 1 products from which they are derived, but also contain a ~1Hz sampled sub-structure. The measurement data are converted into geophysical quantities, and combined with auxiliary input data from other sources to yield geophysical parameters (for example, sea surface height, wave height etc.). The auxiliary data parameters and geo-location data are appended to the product.

3.4 Data Product Latency

The mission products definitions are mainly derived from the Sentinel-3 and Jason-3 products definitions. In terms of Cal/Val of the mission and cross calibration with Jason-3, it is thus mandatory that the data products are processed with the same auxiliary models, apart from those that are mission specific, such as SSB.

Concerning the primary mission, three operational data services associated to different levels of product latency and targeting different applications are provided (see 5.2 regarding differences in performances at the different latency):

Near Real-Time	NRT	Made available within 3 hours after data sensing to the end-users via the distribution dissemination channels. NRT using on-board navigator for the orbit
Short Time Critical	STC	Made available within 36 hours from data sensing after consolidation of some auxiliary data (e.g. preliminary determined orbit data) to end-users
Non Time Critical	NTC	Made available to the end users by EUMETSAT within typically 60 days from data sensing. These products are not delivered but archived. Consequently, NTC products will be retrieved by the users from the EUMETSAT data retrieval service.

Near Real Time Altimetry Service (ALT-NRT)

The objective of the ALT-NRT service is to make available ALT Level 2 products to the end-users in within 3 hours of acquisition. The ALT-NRT Level 2 products provide information on the sea-state like Significant Wave Height (SWH), Wind Speed and Sea Surface Height (SSH) derived from the observations.

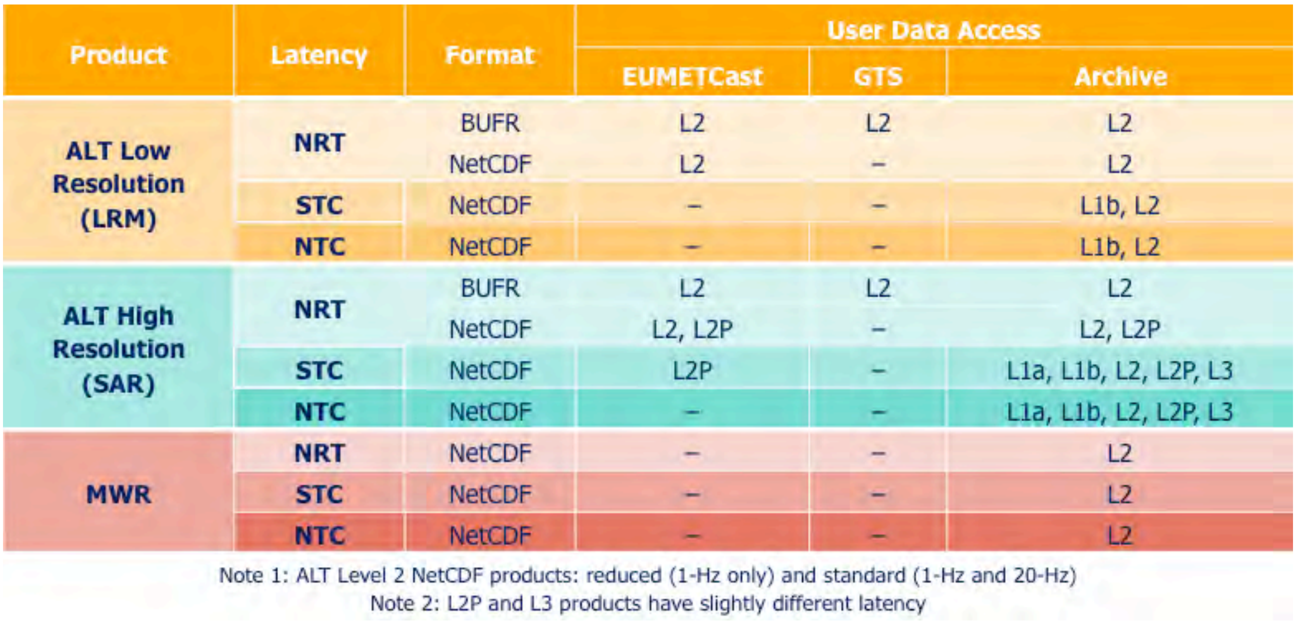
Short Time Critical Altimetry Service (ALT-STC)

The ALT-STC service aims to make ALT-STC Level 1 and Level 2 products available to the end-users within 36 hours after data acquisition. The ALT-STC Level 2 products also provide information on the sea-state, such as Significant Wave Height (SWH), Wind Speed and Sea Surface Height (SSH) derived from the observations, using improved ancillary data (e.g., orbit altitude, meterological models, etc).

Non Time Critical Altimetry Service (ALT-NTC)

This service will make Level 2 products available to the end-users within 60 days after data acquisition. The ALT-NTC Level 2 products also provide information on the sea-state, such as Significant Wave Height (SWH), Wind Speed and Sea Surface Height (SSH) derived from the sensed data, using improved ancillary data (e.g., primarily orbit altitude).

A list of the operational science products is provided below..



Product	Latency	Format	User Data Access		
			EUMETCast	GTS	Archive
ALT Low Resolution (LRM)	NRT	BUFR	L2	L2	L2
		NetCDF	L2	–	L2
	STC	NetCDF	–	–	L1b, L2
	NTC	NetCDF	–	–	L1b, L2
ALT High Resolution (SAR)	NRT	BUFR	L2	L2	L2
		NetCDF	L2, L2P	–	L2, L2P
	STC	NetCDF	L2P	–	L1a, L1b, L2, L2P, L3
	NTC	NetCDF	–	–	L1a, L1b, L2, L2P, L3
MWR	NRT	NetCDF	–	–	L2
	STC	NetCDF	–	–	L2
	NTC	NetCDF	–	–	L2

Note 1: ALT Level 2 NetCDF products: reduced (1-Hz only) and standard (1-Hz and 20-Hz)

Note 2: L2P and L3 products have slightly different latency

Figure 3-5 Operational Science Products available to users

3.4.1 Calibration Products

3.4.1.1 Radar Altimeter

The following calibration products are available ([RD 22][RD 24])

- Range Impulse Response (RIR)
- Internal path delay calibration
- Instrument gain calibration
- Azimuth Impulse Response (AIR)
- Instrument Transfer filter

Calibration parameters applied to level 1A and level 1B products are appended within the product.

3.4.1.2 Radiometer

AMR-C Calibrations are listed in the ICD, [RD 12].

3.4.2 Supplementary Products/Reports

The ground segment generates reports concerning monitoring, product quality, etc.
Performance reports are delivered from the partners to EUMETSAT as system coordinators as described in respective ICDs, [RD 12], [RD 13], [RD 14] and [RD 15].
In addition product validation reports are provided by the system with NASA-JPL and CNES.
Ad hoc reports may be generated depending on issues raised post launch. For example, drift monitoring may need special attention.

4 CAL/VAL OBJECTIVES AND PLANNING

4.1 Cal/Val Objectives and Requirements

During the assessment and the verification phase of the mission (the first 6-12 months after launch), the majority of ground-processing algorithms and all critical output quantities and associated errors will be calibrated and validated (though some elements such as instrument drift require a much longer period that could extend over the mission lifetime). This will be done through statistical analysis and by comparison with external measurements from in-situ equipment or other satellite missions. The calibration/verification outputs will be compared with the mission requirements and the expected error budget specifications.

The parameters to be verified include altimeter range, associated corrections, orbit, wind speed (derived from σ^0 which also requires validation) and SWH. In addition to the biases, the calibration process will provide an estimation of the individual drifts of each componsent of the measurement system components alone. Instrument calibrations will be monitored at least once each cycle throughout the life of the mission to determine if the measurement system is meeting its requirements.

The NTC products will be validated on a cycle-by-cycle basis by EUMETSAT[4], CNES and NASA-JPL prior to dissemination to users.

In this document we use the term ‘calibration’ to describe the estimation of system errors, and the term ‘validation’ to describe the estimation of geophysical parameter retrieval errors.

Calibration covers aspects of the measurement system which need to be addressed in the generation of all Level 1b data products. Since Level 1b algorithms and associated products take care of the conversion from the instruments’ measurement quantities (engineering units) into standard physical (SI) units, they may be addressed by many techniques. Examples of internal calibration compensation cover internal path delay in computing the apparent echo range, phase or power measurement impacted by the instrument design, or compensating for gain and linearity in generating brightness temperature as measured by a microwave radiometer. Following calibration of the measurement system a residual error is present in the data.

Validation, on the other hand, is a term used in the context of the conversion of these instrument measurements into the geophysical quantities in the Level 2 data products. Validation results in the characterisation of the uncertainty in the extraction of the key geophysical parameters (SSH, SWH and wind speed) from the calibrated altimeter echoes (which are termed retrieval errors) and in the various correction parameters which will be applied to the Level 1b data.

Calibration parameters are applied during the generation of the Level 1b data products. Pre-launch estimates will be available (and initially used) but improved estimates need to be established in-orbit. Furthermore, the uncertainty associated with these calibration parameters will be characterised in-orbit.

In contrast, validation, in general, is exclusively about the characterisation of uncertainty in the Level 2 geophysical parameters. Commonly, this is achieved by suitable analysis of the Level 2 data themselves, often in combination with in-situ measurements and comparison from data generated by other satellite observations (such as during tailing formation with Jason-3, or with Sentinel-3A and -3B, for example). In designing such methods, care needs to be taken with the spatial and temporal scales and correlation of the uncertainties.

Elaborating a bit further, the objectives of calibration and validation are:

- To establish the values of parameters needed in the generation of Level 1b and Level 2 products;
- To establish the values of any relative offsets (biases) between the equivalent measurements made by the mission and the previous reference missions;
- To determine system drift is within the mission requirements;

.

- To characterise the uncertainties in the measurements provided in the mission data products (and used to derive the in-orbit error budget to close out mission level requirements).

4.2 Cal/Val Organisation and Responsibilities

Determination of the uncertainties in the instruments and in the Level 2 geophysical products is a continuing process that involves participation of both the project and science teams. The principal objectives of joint verification are to:

1) assess the performance of the measurement system (altimeter, radiometer, and orbit-determination subsystems) and products;
2) when necessary, i.e if a non-conformance or marginal performance is observed) improve ground and on-board processing.

To succeed in these objectives, the general approach is to pool the talents and resources of the project and science teams. During the first months of the mission, intensive verification will be performed to verify the integrity of the system and to implement system adjustments where necessary before authorising the nominal operational phase. However, the verification effort will continue afterwards on a routine and permanent basis.

Organisation between the 5 partners (ESA/NASA/CNES/NOAA/EUMETSAT)
At the system level, EUMETSAT will coordinate, with the agreed support of other partners, the mission assessment and verification phases, as defined in the mission project plan and perform evaluation and calibration activities to verify the mission performance achieved in-orbit. Regular reporting of Cal/Val activities and results will be organised via the MPWG (or similar body set-up post launch (for example teleconferences of the MPWG or dedicated in-orbit assessment meetings, see section 4.2.3).
EUMETSAT will start processing near real time data using the latest agreed version of the near real time processing system within the Payload Data Archiving and Processing (PDAP) system. Products will first be made available to all partners, via ICDs to allow for analysis, and reporting, as defined in the CVIP, [RD 3].

4.2.1 Cal/Val Implementation Plan (CVIP)

The Cal/Val Implementation Plan, [RD 3], is a document that establishes throughout the mission lifetime, a link between Validation activities and performance elements of the SRD (and EURD) that require validatation by means of a set of agreed Work Packages between the Partners. The document elaborates what is needed (input data, tools, etc.) to perform and complete a Work Package and to further demonstrate that the uncertainty of geophysical measures can be derived in order to meet the SRD performance requirements. In some cases Work Packages of Cal/Val appear duplicated and covered by more than one Agency, this is due to each partner having different established methods of validation. For example, this is very typical of how POD performances are assessed by multiple groups). These multi entity methods and results are typically presented at OSTST meetings.
The outcome of all the CVIP work-packages will be presented within dedicated S6 assessment meetings, see §4.2.3. and discussed by the MPWG on a regular basis.

Annex 3 provides the draft list of Work Packages and their distribution between the Agencies. Annex 4 provides the template for which the partners describe each of the Work Packages.

The CVIP will be finalised at the pre-launch SIVVR.

4.2.2 Reporting and Archival Plans

Reporting will be handled at several levels:

1. MPWG: Reporting in the form of presentations of CVIP WP status and any key findings or ad hoc issues on a regular basis when needed. Minutes are produced and provided to the Partner Project Management.
2. MAG[5]: Presentations to the MAG concerning key findings and issues. Presentations and MAG Minutes of Meeting are produced and provided to the Partner Project Management. The MAG reports to the OSTST on an annual basis by presentation. At the time of writing, the role of the MAG post launch is to be established and might be replaced by separate Agency level validation teams.
3. Annual in-orbit Cal/Val assessment reports will be generated by the MPWG in advance of annual assessment meetings to be approved by the project management. The assessments provide a complete performance budget update and the status of performances versus SRD requirements. The report also elaborates on issues that require further investigation and possible resolution.
4. High level Cal/Val presentations of performance status and key issues for resolution to management via advice from validation teams and the OSTST.
5. End of nominal mission lifetime assessment report to provide the status of close-out for all performance requirements and health, in terms of performance of the mission.

4.2.3 Meeting Plan

The following plan is envisioned to prepare the detailed Cal/Val planning followed by the implementation of the activities required to assess and report on the status and eventual close-out.

Meeting	Frequency	Location	Activities
MPWG Telecon	When needed		Nominally bi-weekly
MPWG face to face meetings	4/year	Partner premises	Detailed planning, analysis and reporting
SIVVR	Once	EUMETSAT	Approval of the Cal/Val planning by the partners
Product quality workshop	As needed during Commissioning then 1-2 times per year (with IOAPA)	EUMETSAT	Assess product performance against requirements and pre-launch MPB. Provide quality assessment go-ahead for management to approve release of NRT/STC and NTC products
SIOVR	Once	EUMETSAT	Assessment of Cal/Val status and product quality
AR/CHR	Once	EUMETSAT	Preparation of individual performance assessments
			Consolidation of performance assessments

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[5] The status of the MAG following launch TBD.

			Comparison with pre-launch MPB
			Act on elements requiring changes to the CVC/CVIP due to in-orbit Non Conformance (NC), for example
			Preparation of presentation input to review
In-orbit Annual Performance Assessment (IOAPA)[6]	1/year	EUMETSAT	
			Preparation of individual performance assessments
			Consolidation of performance assessments
			Assessment of product quality
			Comparison with pre-launch MPB
			In-orbit assessment results of performance requirements
			Act on elements requiring changes to the CVC/CVIP due to in-orbit NCs, for example
MAG or post-launch advisory body	2/year	Partner premises	Report plans, status and key findings
OSTST	1/year	Varies	Report status and key findings

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[6] This is similar to the REVEX reviews.

4.3 Post-Launch Verification and Validation Phases

Whilst pre-launch verification/validation, calibration and characterisation of satellite and payload is finalised for the Flight Acceptance Review and that of the operational processors for the Operational Readiness Review (ORR), the focus of this document follows the post launch V&V. Figure 4-1 shows the various operational phases following the launch of the satellites. Post-launch Verification & Validation (V&V) activities formally take place after the LEOP phase, with some exceptions like the In-Orbit RF (see below) that could start earlier and some Telecommand and Telemetry checks prior to the handover of operations from ESA to EUMETSAT.

- **Satellite In-Orbit Verification (Satellite IOV)** activities for the satellites including payload; Part of which is the in-Orbit RF test campaign, [RD 4]
- **System In-Orbit Validation (SIOV),** to demonstrate that the system is ready for acceptance and for hand-over to the Operations Department, by showing that all System requirements are met and that all operations can be conducted with the satellite in orbit.
- **Commissioning** where the products are verified and validated and for which uncertainties can be derived for the key geophysical parameters included in the Level 2 product.

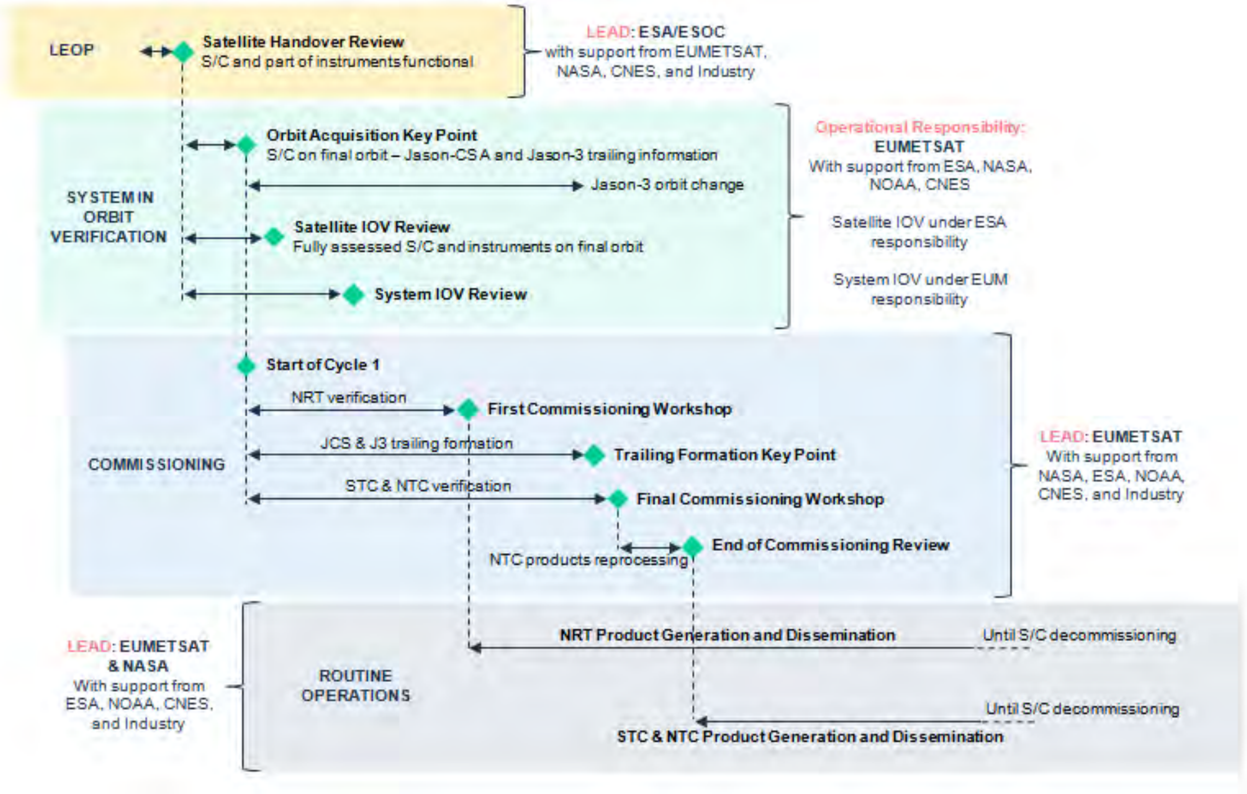

Figure 4-1 Post Launch operational phases, the time line is not to scale but covers the Phase E1 that commences after Flight Acceptance Review (FAR) at the launch campaign into the LEOP, through system IOV, Commissioning, Phase E operations and Phase F satellite decommissioning.

Satellite In-Orbit Verification (SatIOV)

The Satellite In-Orbit Verification (**SatIOV**), [RD 4], is a precursor of the system In-Orbit Validation activities. It will be planned by ESA with TC/TM being conducted by EUMETSAT. The objective of Satellite IOV is to confirm the correct functioning and performances of the platform and instruments before system In-Orbit Verification activities formally start (see SIOV concerning overlap).

In-Orbit RF Test Campaign

The In-Orbit RF test campaign is part of the Satellite In-Orbit verification and is a specific campaign that can impact planning of some early Cal/Val activities.

The overall objectives of RF tests are the verification of compliance with Sentinel-6 space-to-ground transmission requirements (EIRP, frequency accuracy / stability, modulation / spectral properties and probability of bit / frame error) and the confirmation of the ground-to-space reception requirements (receiver sensitivity, ability to command versus input power flux density) and the assessment of S-band transponder[7] properties (telemetry and ranging modulation index and transponder coherence ratio). In-orbit link budgets will be compiled.

This activity complements the Radio Frequency Compatibility Test (RFCT) campaign executed before the launch.

System tests will also be performed post-launch for the link in Ku-Band between the Altimeter instrument and the on-ground transponders.

System In-Orbit Verification (SIOV)

The System In-Orbit Verification overlaps with Satellite IOV activities and after the tuning of the on-board and on-ground databases as needed, remaining System V&V activities will proceed up to the Acceptance Review (AR) and Commissioning Review (CHR-A) at the end of each satellite Commissioning phase.

System In-Orbit Verification will perform the characterisation of elements that could not be tested in a fully realistic way before the launch. Two examples are the validation of flight dynamics (e.g., manoeuvre performances) and the validation of the product accuracy.

The preliminary characterisation of the system, using real data from the satellite(s) as input, will start in parallel to Satellite In-Orbit Verification activities. Of relevance for flight dynamics validation are potential drift stop manoeuvres that may be done soon after the launch. For the mission data chains, a preliminary functional validation of mission data ingestion and processing and of dissemination of generated products can be done. It will be checked that the processing load and timeliness is within expected bounds.

Commissioning Phase

This phase starts after the LEOP, overlaps with the SIOV Phase, and ends when the data and processing algorithms are satisfactorily calibrated and validated for the NRT Products and Offline Products. The nominal duration of this phase is 5 months for the NRT and STC services and up to 12 months for the NTC service.

Product Cal/Val

A key objective for post-launch activities, and the purpose of this document, is the full characterisation of mission performances (i.e. the quality of the generated mission products) at Level 1 and Level 2 (i.e., establish geophysical parameter retrieval uncertainties) and the assessment of compliance with the specified mission and system requirements.

Cal/Val coordination is performed by EUMETSAT with the support of the partners, under the Mission Performance Working Group (MPWG) and with the support of the Mission Advisory Group (MAG) .

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[7] The S-band transponder is used for the S-band up-down link verification rather than a transponder used for the purpose of Radar altimeter calibration.

4.3.1 Sentinel-6A Phasing versus Jason-3

When the orbit of Sentinel-6A reaches the nominal of the Jason-3 satellite it will follow Jason-3 by a few minutes (between 1 and 10 minutes according to requirement, though advised by the MAG to be of the order of 30 seconds, [RD 44], which in principle can be achieved). This Jason-3 and Sentinel-6A phasing, named the "trailing formation flight phase" will have a duration of 6 months to about a year[8] and the final duration will be determined by means of the a decision made collectively by all Partners based on inputs from the MPWG. It is presumed[9] that Jason-3 will be still operational at the time of Sentinel-6A commissioning, that to some it is deemed cruicial. This overlap will gives provides a unique opportunity to carefully cross-calibrate the two systems, at the engineering and geophysical levels, considering that they are both observing the same environment. This is the case for the altimeters (Poseidon-3 versus Poseidon-4), the radiometers (AMR-C on-board Sentinel-6A versus AMR on-board Jason-3), and the geophysical corrections (Sentinel-6A versus Jason-3). After the phase it is envisioned that the Jason-3 will be shifted to an interleaved track, similar to Jason-2; this phase is called the "interleaved phase".

The management of the Jason-3 orbit is not covered by the responsibility of the Sentinel-6 partnership. However, the criteria for transitioning the operational Jason-3 reference mission responsibilities to operational Sentinel-6A are:

- The S6A behaviour and instruments performances are nominal (this is demonstrated at the end of Commissioning and annual assessment reviews);
- The key products performances of Sentinel-6A are at least equal to Jason-3 and agreed by all partners (it may not be possible to close out subtleties of drift between the two missions at this stage);
- The Sentinel-6A production timeline is in line with mission requirements;
- All ground processing centres behaviours are nominal with expected quality of products;

The operational deactivation of Jason-3 is not a function of the Sentinel-6 mission responsibilities and is handled by Jason-3 partners and the OSTST, for example. Nevertheless, coordination is expected between the Sentinel 6 and Jason-3 teams.

4.3.2 Sentinel-6A Phasing versus Sentinel-6B

It is expected that a 6-month overlap is required between the S6A and S6B satellites in order to cross-calibrate the two systems based on the same design. This is described in some detail in [RD 44].

4.3.3 Operational Phase

Regular "cycle-by-cycle" validation of geophysical parameters to enable the goal of "1 mm altimetry" and to continuously check the integrity of the system will continue for the life of the mission. "Cycle-by-cycle" validation implies over-flights of verification sites (point measurements), tide gauge comparisons (distributed measurements), and global analysis, etc.

As with Jason-3, continuous monitoring of the instrumental characteristics will be performed in order to detect as soon as possible any drift (or unexpected behaviour) of the altimeter or radiometer, and in order to be able to process the data by considering the most recent instrumental characteristics (by means of the most recent instrument calibration, for example). "Cycle-by-cycle" instrumental validation reports will be produced during the whole of the mission lifetime.

The NTC products will be validated on a cycle-by-cycle basis prior to dissemination to users. This validation will be performed first by EUMETSAT, and then followed by NASA-JPL and CNES. NTC products will be disseminated upon the concurrence of EUMETSAT, NASA-JPL CNES and ESA (TBC) validation teams.

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[8] [SRD] R-S-01090, [AD 1].

[9] Contingency cases were Jason-3 is not available will be defined in due course.

5 SENTINEL-6/JASON-CS PERFORMANCE ASSESSMENT

5.1 Introduction

Important Cal/Val objectives are the certification of the actual performance with respect to the error budget specifications, and the delivery of comprehensive performance estimation to the end-users. In this respect, achievement over any goals can also be addressed.

So far, the performance assessment of altimetry missions has been summarized by a “classical” error budget, that is to say a table with all satellite-related sources of errors along with the corresponding Root-Sum-Square (RSS).

The next section of this chapter will give an overview of the classical mission performance assessment with the global table and RSS.

5.2 Performance Assessment

5.2.1 Introduction

This section summarises the performance requirements specified in the Jason-CS System Requirements Document, [AD 1] that contribute to the overall sea level error budget. The table below lists the values and the identification number of the SRD requirement for each measurement, each latency, and for both low and high-resolution altimetry. In some case the term ‘goal’ is used though this is not binding on design.

	LR			**HR**		
	NRT req	**STC req**	**NTC req/goal**	**NRT req**	**STC req**	**NTC req/goal**
Ku-band range noise (a)	1.5 R-S-00570	1.5 R-S-00430	1.5/1.0 R-S-00270	0.8 R-S-00970	0.8 R-S-00840	0.8/0.5 R-S-00690
C-band range noise (a)	5.7 R-S-00580	5.7 R-S-00440	5.7 R-S-00280			
Ionosphere (b)	0.5 R-S-00590	0.5 R-S-00450	0.5/0.3 R-S-00290	0.5 R-S-00980	0.5 R-S-00850	0.5/0.3 R-S-00700
Sea state bias	2.0 R-S-00600	2.0 R-S-00460	2.0/1.0 R-S-00300	2.0 R-S-00990	2.0 R-S-00860	2.0/1.0 R-S-00710
Dry troposphere	0.8 R-S-00610	0.7 R-S-00470	0.7/0.5 R-S-00310	0.8 R-S-01000	0.7 R-S-00870	0.7/0.5 R-S-00720
Wet troposphere	1.2 R-S-00620	1.2 R-S-00480	1.0/0.8 R-S-00320	1.2 R-S-01010	1.2 R-S-00880	1.0/0.8 R-S-00730
Altimeter range RSS	2.93 R-S-00560	2.90 R-S-00420	2.83/1.73 R-S-00260	2.64 R-S-00960	2.61 R-S-00830	2.53/1.49 R-S-00680
RMS orbit	5.0 R-S-00630	2.0 R-S-00490	1.5/1.0 R-S-00330	5.0 R-S-01020	2.0 R-S-00890	1.5/1.0 R-S-00740
Total RSS sea surf. height	5.79 R-S-00640	3.53 R-S-00500	3.20/1.99 R-S-00340	5.65 R-S-01030	3.29 R-S-00900	2.94/1.80 R-S-00750
Significant wave height (d)	15 cm + 5% R-S-00650	15 cm + 5% R-S-00510	15/10 cm + 5% R-S-00350	15 cm + 5% R-S-01040	15 cm + 5% R-S-00910	15/10 cm + 5% R-S-00760
Wind speed	1.5 m/s R-S-00660	1.5 m/s R-S-00520	1.5/1.0 m/s R-S-00360	1.5 m/s R-S-01050	1.5 m/s R-S-00920	1.5/1.0 m/s R-S-00770

σ^0 (c)	0.3 dB R-S-00670	0.3 dB R-S-00530	0.3 dB R-S-00370	0.3 dB R-S-01060	0.3 dB R-S-00930	0.3 dB R-S-00780

a. After ground processing, averaged over 1 second, for 2 meter wave height.
b. Derived from Ku- and C-band range difference, averaged over 200 km.
c. After cross-calibration with other altimeter missions
d. for the range of 0.5 to 8 m SWH.

Table 5-1 Performance Requirement Budget

5.2.2 Individual Measurement Accuracy

This section provides some insights and details on the 'classical' error budget and requirements given in Table 5-1 with the origin and estimation process for each error contribution. The main figures are generally given as simple scalars that are not dependent on sea state, location, time, or correlation scales.

5.2.3 Range Noise

The following values have been adopted in the Jason-CS System Requirements Document [JCS-SRD-v3] concerning the noise of the Ku-band and C-band range measurements as a function of significant wave height.

SWH (m)		LR Ku-band	LR C-band	HR Ku-band
1		1.2 cm	4.5 cm	0.7 cm
2		1.5 cm	5.7 cm	0.8 cm
5		2.4 cm	9.1 cm	1.3 cm
8		3.2 cm	12.0 cm	2.0 cm
JCS-SRD-v3 Req.	**NRT**	R-S-00570	R-S-00580	R-S-00970
	STC	R-S-00430	R-S-00440	R-S-00840
	NTC	R-S-00270	R-S-00280	R-S-00690

Table 5-2 Range Requirements Budget

Random noise is traditionally the metric used to assess the instrument performance, thus it is generally accepted as being of fundamental importance. However instrumental white noise is sometimes confused with high-frequency signals (red noise from 0.5 Hz and higher frequencies) observed on actual 1 Hz altimeter products (reduced in altimteric Ku-band SAR and Ka-band due to footprint size). 1 Hz processing whilst reducing noise integrates high-frequency changes of altimeter parameters as well as the response of data processing algorithms to high-frequency signals or inconsistent or erroneous data (e.g. sigma-blooms or rain cells, apparent mispointing, or other artefacts, for example), but also side-effects from along-track smoothing due to the tracking or re-tracking algorithms used.

Prior to launch, estimates of instrument white noise will be obtained from theoretical design considerations and numerical laboratory tests. However, it is also important to understand the white noise characteristics once the altimeter is in the operational space environment. This understanding will be gained by examining the spectral density derived from Fourier analysis (white noise plateau) on 20-Hz data; or by performing polynomial fits directly to small batches of altimeter data (residual of the 20-Hz to 1-Hz compression).

As for previous missions, the white noise assessment for altimeter will be performed on a combination of the system noises from the Ku- and C-band channels (which provide the two frequencies necessary for correcting the ionospheric path delay). This is expected to yield open ocean performance similar to that of Jason-1&2 with 7.6 cm for 20 Hz data, which is equivalent to 1.7 cm on 1 Hz along-track averages with 2-m SWH and 11-dB σ^{0}. In practice, due to the correlated and non-Gaussian signals observed on high frequencies, the coloured (1-Hz) noise can be higher.

This “1 Hz equivalent” white noise is naturally dependent on the SWH parameter, and the specification and goals on this dependency are shown in the previous tables.

5.2.4 Sea-Surface Height

The classical and global error budget is assessed on the SSH (sea surface height), which is a common and directly usable measurement for users. The SSH is given as a height above the reference ellipsoid (WGS-84) through the difference of the altimeter range (corrected from atmospheric and sea-state effects) and the satellite altitude provided by the Precise Orbit Determination (POD) system.

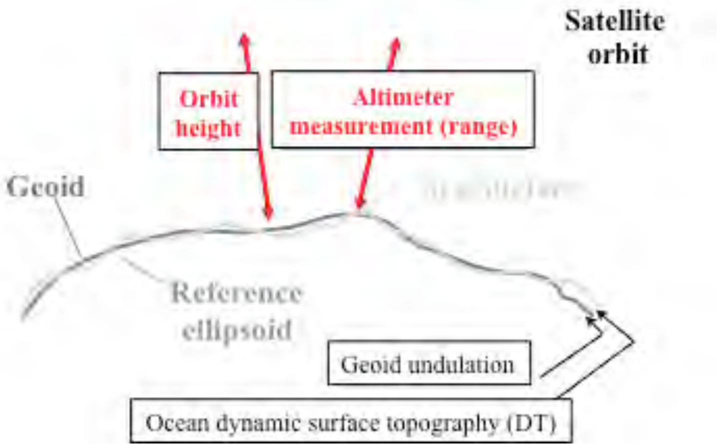

Figure 5-1

The group velocity of the altimeter radar pulses is slowed by the presence of free electrons in the Earth’s ionospheric layer. As the Total Electron Content (TEC) is highly variable in time and in space, accurate measurement of the resulting delay requires fine sampling coincident with the radar measurements. The ionospheric dispersion is linear, and thus the delay can be computed by combining the dual-frequency measurements of the radar altimeter.

Assuming that the ionosphere correction error is the direct result of the range measurement noise on each band, the typical accuracy of the resulting correction is 0.5 cm or better. The analysis of the random part of the ionosphere correction difference between Jason and T/P confirmed this figure, at least for the global and non-systematic effects.

Alternatively, external ancillary data in the form of TEC (Total Electron Content) grids computed from GPS-based observations and an ionosphere model provide a model of the ionosphere delay. However, the accuracy of such an external ionosphere correction does not match the classical dual frequency approach.

The troposphere also delays the radar-altimeter signals. The dry air mass of the atmosphere implies a delay of 0.23 cm per mbar. The ECMWF atmospheric pressure products used to derive this dry-troposphere correction have an RMS uncertainty of about 3 mbar, implying an RMS uncertainty of 0.7 cm for the correction itself (Ponte et al, [RD 16]). The pressure fields provided by weather centres have now reached a higher level of accuracy.

Errors in the dry-troposphere correction can be partially characterized using differences of various model pressure outputs (i.e. NCEP, ARPEGE, ECMWF); however, it should be kept in mind that the competing models assimilate many of the same meteorological observations. In situ measurements of pressure may provide a more accurate, though spatially limited, portrayal of the errors.

The water vapour content within the troposphere is another cause of altimetric path delay. The radiometer on-board will measure brightness temperatures used to retrieve the wet-tropospheric correction with an uncertainty better than 1.2 cm for a single 1 Hz measurement. The long-term calibration of the radiometer will be carried out using on-Earth brightness temperature references as well as dedicated cold-sky calibration pitch manoeuvres and the on-board SCS. The cold-sky manoeuvre, developed for the Jason-3 mission, points the radiometer boresight away from the Earth toward cold space, presenting a stable known 2.7 K signal to the instrument. These manoeuvres for Sentinel-6 can take place as often as every ~10 days if needed. However, as noted, the Sentinel-6/Jason-CS radiometers also provide a calibration mechanism, the SCS, that improves the performance by means of a on-board hot calibration target and by means of a mirror can also observe deep space, this calibration is expected every ~5 to 10 days. The AMR path delay retrievals will also be validated using comparisons with ground-based radiometers, and radiosonde soundings, as well as other space-based radiometers (for example, SSM/I). The troposphere affects the radar signal at various time-space scales, from high frequency—in the vicinity of atmospheric fronts and near the coasts—to low frequency and large scales.

The electromagnetic bias (EMB) and skewness biases affect the accuracy of altimeter measurements and Level-2 re-tracker (in the form of bias) and are dependent on SWH. The EMB results from the fact that the radar senses an average sea surface lower than the true average sea surface, due to amplification from wave troughs. This bias can be expressed as a percentage of SWH, with the percentage being a complex function of the sea-surface slope and elevation statistical distribution. Associated errors on the EMB estimate for past missions give an error of 1 cm to 2 cm for the typical SWH of 2 m, but this error can reach more critical values in the high-latitude regions that experience consistently high SWH.

Based on the performances of the altimetric system and associated media corrections, the range of the satellite above the sea surface will be measured with an standard uncertainty of 3 cm RMS at 1 Hz sampling for typical sea state conditions of 2 m SWH and 11 dB sigma naught. Expected off-line improvements in the processing are expected to decrease the overall range error to the RMS level of 2.25 cm.

An on-going effort by international POD experts to improve surface force modelling, and reference system characterization, combined with the benefits of comprehensive tracking systems such as DORIS, satellite laser ranging, and GPS, and improved gravity models from recent gravity missions, have led to improved POD performance in terms of accuracy and consistency. The resulting RMS accuracy for the baseline precision T/P orbits is estimated to be 1.5 cm for the radial component and even better, of the order of 1 cm, on Jason-1/2/3. S6 is expected to have a similar performance Particular emphasis will be placed on the reduction of geographically correlated errors. Optimal combinations of DORIS and GPS data should also support this objective. Consequently, a goal of 1 cm RMS uncertainty on the radial component of the orbit has been set. In practice, the satellite laser ranging data are typically reserved as an external independent metric to validate the POD solutions.

The sea-surface height measurement obtained by combining the range derived from the altimeter and the altitude of the satellite derived from POD will be provided. During the verification phase and throughout mission life, this sea-surface height measurement and its constituents will be calibrated and verified to ensure the accuracies are in compliance with the error budget. The global Cal/Val activity will rely on dedicated multi-satellite cross-comparisons and statistical analysis, on various comparisons with global tide-gauge network and transponders. Local estimation of absolute calibration, SSH bias and relative cross-mission bias will be performed with high-precision calibration sites.

The NRT products, mainly used for near-real time applications in marine operational oceanography and meteorology, require also a consistent validation activity, especially during the verification phase. The quality of this product will be a slightly lower than NTC mainly due to the lower orbit determination accuracy and the use of "predicted" media correction (e.g. dry troposphere delay, dynamic atmospheric corrections). However, it will be in accordance with the requirements for the relevant near-real time applications.

5.2.5 Bias and drift

The TOPEX/Poseidon Jason series have collected over 25 years of high quality altimetric data, not only on individual measurements or random noise, and on the ocean variability, but also in terms of stability through the missions' lifespan. These data have been used to monitor the global mean sea level (MSL) trend of 3.3 mm/year with an uncertainty of about 0.5 mm/year (analysing the uncertainty of each altimetry correction made for calculating the GMSL, as well as a comparison with tide gauges).
Being able to support 1 mm/year MSL trend estimation is a critical objective. It is therefore an important challenge to connect Sentinel-6/Jason-CS with previous altimeter series with care and consistency, but also to ensure that the end-to-end biases and drifts are well controlled and minimised. The lower uncertainty in the trend estimate will allow one to measure changes in the trend and the Sentinel-6 will be the first to have a requirement on the GMSL trend uncertainty. The consequence is the need for stability and/or precise drift analysis and correction on all potential sources of error (altimeter, radiometer, orbit, media corrections).
The planned trailing formation of Jason-3 and S6A during the Verification Phase will be very valuable to perform the first coherency checks and to minimize geographically correlated errors.
This objective will be pursued during the rest of the mission by global and regional MSL trend analysis, and comparison with global tide gauge networks and transponders. In addition, local aspects of the MSL trends may be precisely assessed through in situ calibration experiments.

The drift on the range measurements as specified in the SRD, [AD 1] are presented in the Table 5-3 below.

Measurement	Drift Requirement (1 σ)	JCS-SRD-v3 Req. ID
Global mean sea level	1 mm/yr	R-S-01960
Altimeter range	0.7 mm/yr	R-S-01970
Orbit error	0.1 mm/yr	R-S-01980
Microwave radiometer	0.7 mm/yr	R-S-01990
SSB (from backscatter coefficient)	0.1 mm/yr	R-S-02000
Geophysical corrections	0.1 mm/yr	R-S-02010
Regionally averaged sea level	5 mm/yr	R-S-02020
Backscatter coefficient	0.1 dB/yr	R-S-02030

Table 5-3 Drift Requirements Budget

5.2.5.1 Retrieval of global mean sea level

In order to derive global mean sea level change from Poseidon-4 measurements, requirements on drifts in the several contributions to the sea level anomaly have been specified.

The critical steps in setting these requirements on drift error in the global mean sea level are the following:

The uncertainty in the determination of global mean sea level drift shall be less than 1 mm/year. This is around one third of the established value of global mean sea level rise over the altimeter era.

This drift is allocated to the altimeter range (0.7 mm/year) and the radiometer wet tropospheric correction (0.7 mm/year), which is the largest allocations for the system drift error budget contributors to the altimetric system drift. Smaller drifts are allocated to orbit error (as a result of unmodelled or imperfectly modelled reference frame or gravity field variations), sea state bias (due to drifts in backscatter), and additional environmental corrections (0.1 mm/year each).

The RSS of these contributions amounts to a global mean drift error of 1 mm/year.

5.2.5.2 Retrieval of regional mean sea level

In addition to global mean sea level, regional sea level has become an important climate variable. Therefore, a requirement was introduced to support the retrieval of regional sea level trends to better than 5 mm/year. This value is justified as follows:

With “regionally averaged sea level” we mean the average of all sea level measurements within one repeat cycle and within an ocean area of approximately 40000 km^2 (approximately 2^o by 2^o).

The requirement is to ensure that none of the elements contributing to the regional drift will exceed 5 mm/year.

Assuming the correction for all recognised significant systematic effects and given that for NTC products, the combined standard uncertainty (precision) of the 1-second along-track averaged sea surface height measurements shall be less than 3.2 cm during the whole operational period, there is an implicit local/regional drift requirement of about 3.5 cm over a 7 year mission lifetime.

5.2.5.3 Retrieval of wind speed

In order to avoid a significant drift in wind speed retrievals, a limit needed to be set on the drift in backscatter coefficient. A requirement was set at 0.1 dB/year for drift error in the backscatter coefficient, which would correspond to approximately 0.4 m/s/year in retrieved wind speed. Given the already existing requirement of no more than a 0.3 dB error in backscatter, and a mission duration of seven years, this would effectively already be met halfway through the mission, even without further monitoring of the drift. However, this requirement ensures that the drift in the backscatter is carefully monitored and compensated in the NTC products.

5.2.5.4 Retrieval of significant wave height

No requirements are set on any drift in significant wave height since the stability of the transfer function of the Poseidon-4 is assured[10]. Nevertheless, it is believed that the digital architecture of the Poseidon-4 altimeter on S6 ensures that no distortions of the waveforms occur over time, and hence negligible drifts on significant wave height retrievals are expected. A point to note is that whilst the thermal noise remains the same, the drift in the P4 high power amplifier will drift and requires compensation and monitoring.

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[10] The TOPEX radar suffered from drift in the transfer function resulting in an associated drift in SWH.

5.2.6 Level 2 Wind/Wave Estimates

The requirement on the standard uncertainty of significant-wave-height measurements is also specified as in Table 5-1 Performance Requirement Budget.

The absolute accuracy of σ° will be better than 0.7 dB (for a sigma naught varying between 7 dB and 16 dB). The sigma0 drift over 1 year will be measured with an accuracy of 0.2 dB to 0.1 dB as a goal. The derived wind speed accuracy will be better than 1.5 m/s for 1 Hz averages (for a range between 3 m/s and 20 m/s).

Verifying significant wave height and wind speed (from σ°) to 1.5 m/s is also an objective of the Cal/Val. The necessary comparisons will be performed extensively during the verification phase, based on cross-comparisons with in-situ measurements, model outputs and other satellite measurements and will continue on a regular basis afterwards.

6 PAYLOAD AND PRODUCT CAL/VAL IMPLEMENTATION

The full description of Cal/Val Implementation is provided in [CVIP], [RD 3], and described here at the high level in terms of the payload and Cal/Val of the products.

6.1 Internal Sensor Calibration

6.1.1 Poseidon-4

There are a number of sources of the error in echo delay timing. There are errors in the clock that measures the timing, errors in the path length of the radio-frequency (RF) sections of the instrument and errors that arise due to distortions in the shape of the echo. The first two of these are expected to be small. Clock errors in altimetry typically arise from drifts in the oscillators used to generate the clock pulses that time the echo flight. Sentinel-6 uses the DORIS and GNSS-POD instruments for orbit reconstruction, which makes the comparison of the on-board timing of the echo with an absolute GNSS time (average GPS time) a relatively simple matter. Time-of-flight errors from this source are expected to be negligible. The absolute length of the RF sections is well-determined pre-launch, and its variation is expected to be negligible.

On the other hand, variations in shape of the echo will lead directly to variations in echo timing because the timing of the echo is determined from its shape. Because the precision demanded of the measurement is very high, and in particular very much higher than the instrument resolution, very subtle variations in echo shape can give rise to apparent changes in measured time-of-flight. In detail, there are many instrument sources of such an error. Two in particular are important.

Firstly, all radar echoes are distorted by a uniform random phase per scattering element, this effect is termed ‘speckle’. This fluctuation arises because the echoes are the incoherent summation of many small, randomly phased echoes from small scattering regions of the surface. Consequently, the echo power of an individual echo is exponentially distributed. The main purpose of multi-looking is to reduce this fluctuation through summing statistically independent ‘looks’ at any given surface location. Nonetheless a fluctuation remains. This fluctuation is minimised by instrument design; it is nonetheless the largest single source of error in a point measurement. Since the Poseidon-4 design is such that low resolution (LR) echoes telemetered are the accumulation of waveforms at ~9 kHz (i.e., above the de-correlation PRF of ~3 kHz a special attention is needed when comparing with LR waveforms from Jason-3 that are formed on-board from decorrelated waveforms, [RD 38]. For high resolution SAR waveforms processed on-ground the, speckle errors decorrelate from observation to observation; they are un-correlated errors in this sense.

Unlike heritage altimeters delivering, in theory, LR aliased waveforms, (Jensen, [RD 40] and Smith & Scharroo, [RD 39]), the Poseidon-4 waveform sampling provides 395/320 ~1.23 oversampling for the on-board LR waveforms compared with Jason-3. The impact, if any will occur at very low SWH since the full bandwidth of the instrument contains a signal in the frequency domain and subject to aliasing. This will need a special consideration.

In previous altimetry missions a second source of signal distortion arises from the intermediate- frequency (IF) sections of the instrument. These contain signal filters that precede the digitisation of the signals. The response of these filters may vary with temperature and with age, giving rise to timing errors that may occur at orbital frequencies or longer-term drifts. In the design of the Poseidon-4 altimeter the IF section of the instrument is replaced by digital components that are less affected by aging and temperature variations. The associated CAL-2 mode is still available for monitoring and to confirm this assumption.

6.1.1.1 Tracking modes

The performance of the open and closed loop tracking is carried out in the early phase of the mission (addressed by specific verification in the CVIP). The relative performance is also established early during the mission versus those of Jason-3 and Sentinel 3A and B. From this an operational scenario is derived and once the capacity for open loop resources is established during Commissioning, then secondary objectives for inland water will allow the partners to establish the performances in this case.

6.1.1.2 On-board Range Migration Compensation (RMC) and on-ground reversal

One of the on-board functions of the radar is that of Range Migration Compensation (RMC) that has been developed in order to reduce data volume and allow simultaneous LR and HR data, [RD 42]. This functionality requires dedicated verification activities. The high-level functionality is provided in Figure 6-1and the impact on single SAR processed waveforms is provided in Figure 6-2. The relative performances of the RMC versus RAW-SAR over nominal and sloping regions is described in [RD 41].
The operation mode mask will need to be developed based on the agreed understanding of relative SAR-RAW vs RMC performances. The current non-operational mode mask is used purely for sizing the system based on a set of assumptions at the time of generation.

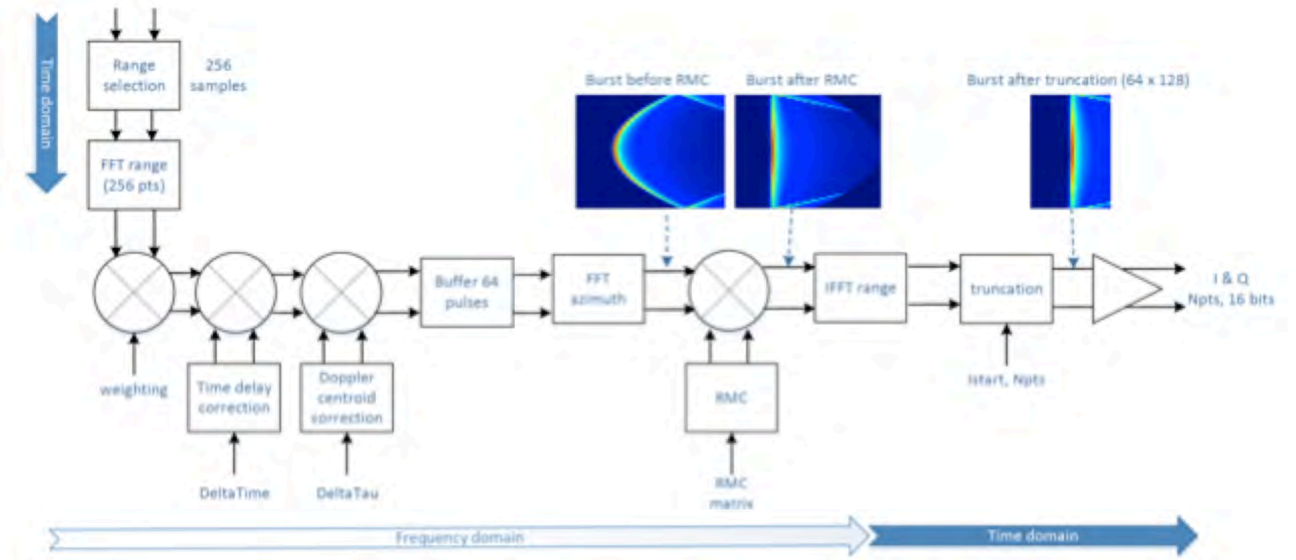


Figure 6-1 Poseïdon-4 on-board RMC high level functionality

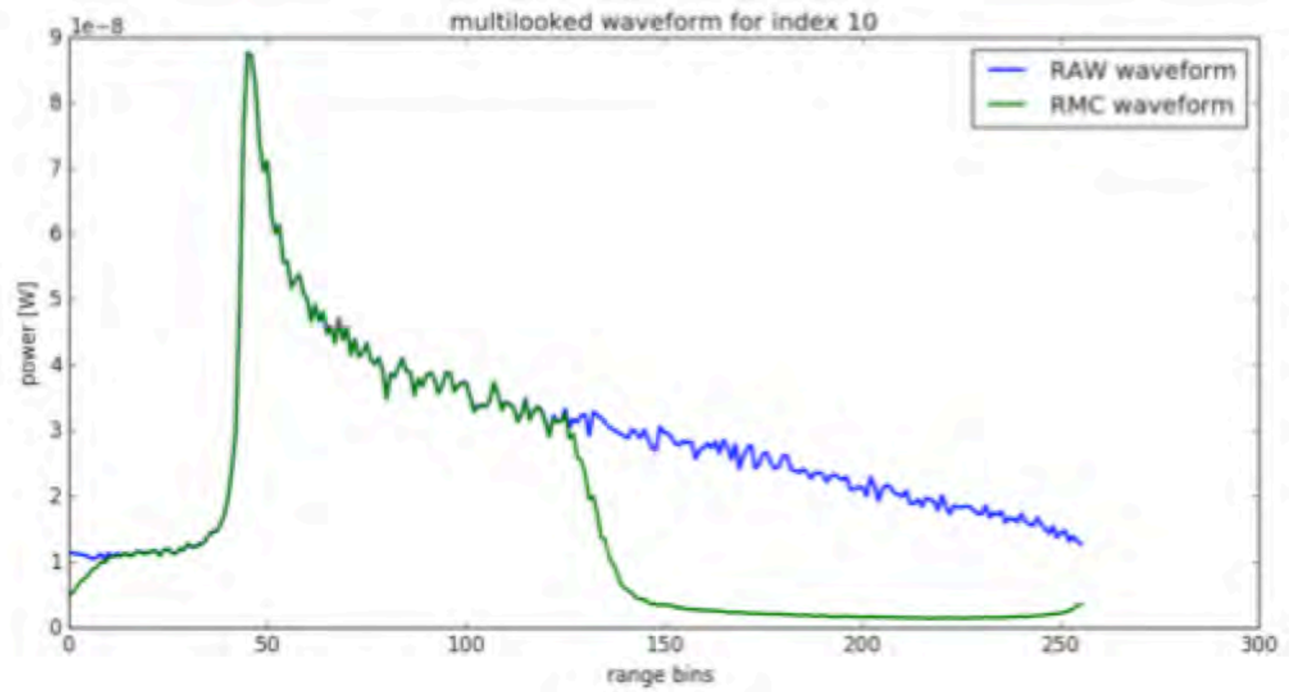


Figure 6-2 Comparison of RAW HR waveform and corresponding reconstructed RMC HR waveform

6.1.1.3 Internal Calibrations

To reduce the contributions of signal distortions and aging effects and to allow regular monitoring of instrument functions and parameters calibration is performed at the beginning and throughout mission lifetime.

The following four internal calibration modes and settings will be available:
- CAL-pulse (currently at 1 Hz)
- CAL-1 SAR
- CAL-1 LRM
- CAL-1 RMC
- CAL-1 INSTR

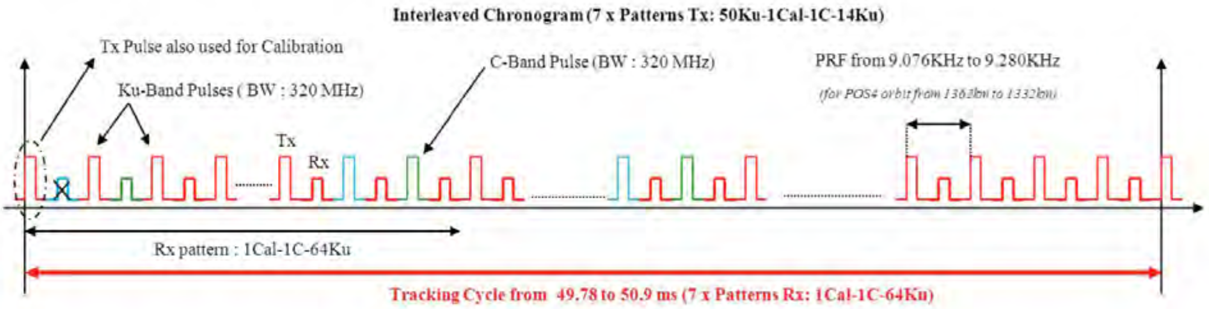


Figure 6-3 Tracking radar cycle chronogram of the interleave mode showing the CAL-pulse at the beginning of each burst

The CAL-pulse is a pulse at the beginning of each burst, 7 bursts per radar cycle (see Fig. 6-3) allowing continuous monitoring and calibration of internal path delay and Poseidon-4 gain.

The principle of the CAL-1 mode is to perform measurements by looping back the Tx chain directly to the Rx chain through a dedicated path in the duplexer in order to monitor parameters which may evolve with regard to thermal environment and aging on this internal path, and to provide a reference of most of the measurement path. Therefore, the CAL-1 path encompasses as much as possible of the Tx and Rx paths.

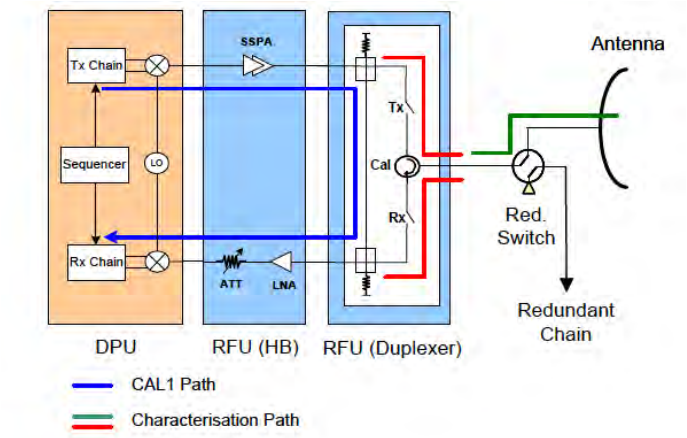


Figure 6-4 Calibration and characterization paths

CAL-1 INSTR is a dedicated mode to measure the internal instrument transfer function.

A CAL2 mode retrieving the spectrum of the range window is implemented for monitoring purpose only and it is not considered necessary for calibration, because of the to the mostly digital design of the Poseidon-4 altimeter that differs from the previous Poseidon design.

The Internal Calibration modes will be functionally assessed during the Satellite IOV. Performances will be validated during the Commissioning and Cal/Val phases.

6.1.1.4 External Calibrations

The external elements of the radar include the antenna and waveguides that are characterised on ground. In orbit external calibration by means of range and σ^0 transponders are required as are calibrations from stable distributed surfaces such as Salar de Uyuni in Bolivia that only be observed during the orbit drigting phase (during satellite IOV) or in a later geodetic type phase after nominal operations are completed on the S6A or S6B satellites..

6.1.1.5 Altimeter measurements

Parameters such as estimated range, SWH, backscatter coefficient, mispointing angle, and waveforms are analysed. These studies will include noise-level estimates using Fourier Transform analysis as well as computation of along-track statistics (mean and standard deviation) over the ocean and other surfaces. Histograms and dispersion diagrams will also be computed for these parameters.

6.1.1.6 Roll and Pitch Altimeter Calibration Manoeuvres

A key issue for the altimetric estimation is the precise pointing of the antenna at nadir. Even if the retracking algorithm can cope with mispointing angles up to 0.7°, it is very important to calibrate the pointing of the platform that optimises the radar return. The procedure involved roll and pitching the satellite typically up to 0.4°. This is performed early on during Commissioning.

Advanced Microwave Radiometer-C

The AMR-C radiometer provides a single polarization, radiometric brightness temperature measurement at three frequencies (18.7, 23.8, and 34.0 GHz) in a nadir beam co-aligned with the altimeter to provide “wet” tropospheric path delay (PD) corrections for nadir altimeter range measurements. Therefore, it is critical to meeting science requirements. The wet PD is highly variable in space and time as shown in the map below (Fig 6-5). A High Resolution Microwave Radiometer (HRMR) will be included as an experiment on the Sentinel-6 mission. The HRMR is aimed towards demonstrating the use of high frequency channels (90, 130, and 168 GHz) for extending the wet path delay measurements into coastal zones, with a performance goal of 1.0 cm accuracy within 5-50 km of coasts. There are no mission measurement objectives or performance requirements dependent on or linked to the HRMR. Therefore, only the AMR-C data are used to meet science requirements and for producing the science data products.

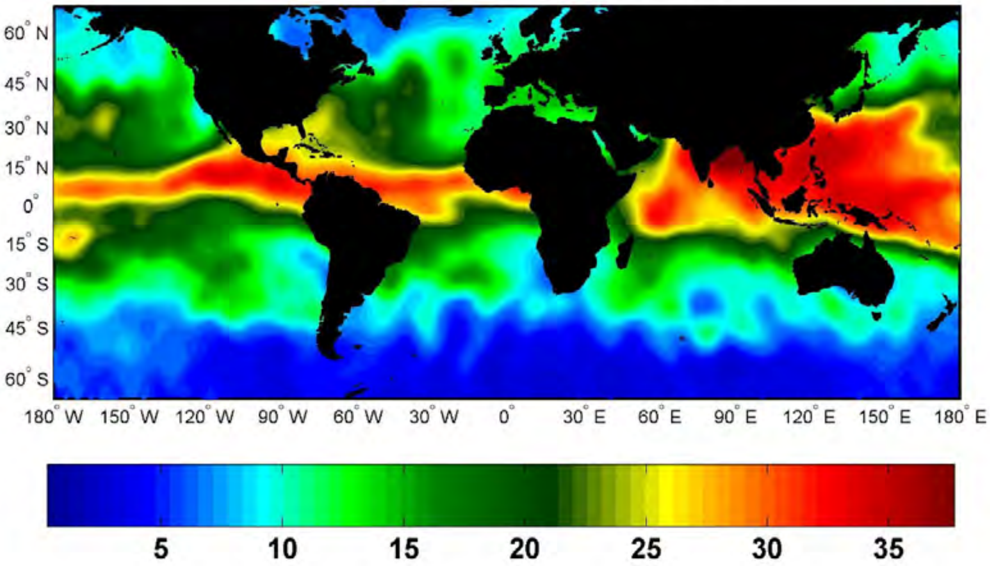


Figure 6-5 10-day mean of wet tropospheric path delay (units in cm)

The requirements can be broken down into two main performance categories. The first is the accuracy of a single along track measurement reported at 1Hz, which is 0.8 cm for the NTC science data products, and 1.2 cm for the STC and NRT products. The second is the stability of the radiometer measurement over time, which is +/- 0.7 mm (standard uncertainty) averaged over any one-year period.

A key development for the Sentinel-6 mission is the AMR-C is equipped with an on-board supplemental calibration system (SCS) that enhances the stability performance of the wet tropospheric correction. The SCS uses a rotating secondary reflector to view a warm calibration target (on-board) and view cold sky every 5-10 days.

The Autonomous Radiometer Calibration System (ARCS) is implemented at JPL. The ARCS system will ingest the AMR telemetry data and provide diagnostics that allow a user to quickly assess whether the calibration has changed and adjust the Level 1B calibration coefficients by the proper amount to recalibrate the instrument prior to L2 data production.

The ARCS system uses a variety of external reference sources with which the user can detect radiometer gain and offset changes. For Jason-2, these reference sources were on-Earth brightness temperature references with validation checks against independent estimates of path delay and wind speed. But, the performance of ARCS is limited to the stability of the natural on-Earth reference targets that it forces the AMR calibration to agree with. The ARCS system uses a so-called vicarious cold reference (Ruf, 2000,[RD 17]), which is a statistical lower bound on ocean surface brightness temperature. The cold reference has a statistical uncertainty, when sampled every 10 days, ranging from 0.3° to 0.5° K between the three channels. The 23.8 GHz channel has the larger uncertainty due to the increased sensitivity to water vapour in this band. For the hot reference, pseudo-blackbody regions in the Amazon rain forest are used. The Amazon hot reference has an uncertainty of about 1.5-2K when sampled every 10 days. To reduce this uncertainty on the AMR long term calibration and mitigate against potential climate signals leaking into the long-term record, a dedicated cold sky calibration manoeuvre is being performed for Jason-3, and is planned for Sentinel-6/Jason-CS.

As a back up to the SCS, a cold sky calibration manoeuvre is available by means of a pitch of the satellite such that the AMR-C main beam points at homogenous cold space. The system can support this type of additional calibration as frequency as every ~10 days. The sky is a very stable calibration source with a known brightness temperature of about 2.7° K. When the spacecraft is pitched, the sidelobes and backlobes of the antenna pattern that normally see cold space will now see the Earth. This means that the calibrated antenna temperature will always be higher than 2.7° K due to the emission from the Earth in the sidelobes. In principal, the Earth contribution can be removed from the cold sky antenna temperature using an estimate for the Earth scene brightness temperature and the fractional power received from the Earth. But, this adds an uncertainty as these quantities are not known exactly.

The manoeuvre is planned to occur every ~10 to ~30 days and will be ingested into the ARCS system. The cold sky measurement provides a 1-point stable calibration reference that will be used to track the system stability and improve the long-term calibration when combined with the on-Earth references for the warm-end calibration. When the cold sky manoeuvre is performed every ~10 to ~30 days, the uncertainty on the brightness temperature drift estimates falls below 0.1°K/yr with about 8 months of data, whereas it takes 2 years of observations with the vicarious cold reference for the uncertainty to fall to this level and 5 years with the Amazon hot reference. The PD drift uncertainty falls below 1mm/yr in under 2 years if the cold sky reference is used, whereas it takes about 3 years to achieve this uncertainty if the vicarious cold reference and the Amazon reference are used. In the case where it is known a priori whether the calibration change is a gain or offset change, then the PD drift uncertainty falls below 1mm/yr within one year.

The AMR-C team at JPL will monitor and ensure the integrity of the products on an on-going basis. Post-launch calibration will take place for AMR-C brightness temperatures and path-delay retrieval algorithms using ground truth as well as comparisons with data from other spaceborne radiometers and global models. Elements (the lower three channels) of the AMR-C and AMR are assumed to be the same allowing direct comparison between these elements during the formation flying phase under the condition that the time lag between the two satellites is be short enough in order to observe the same atmospheric conditions, which is nominally planned during the tandem phase.

6.1.2 DORIS

The Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) receiver measures the Doppler shift to terrestrial beacons broadcasting on two frequencies. This information is used to compute over fixed measurement intervals the average range rate of the Jason-CS satellite with respect to the beacon(s). The information is used to determine the satellite's 3D position in real time from an on-board orbit determination system called DIODE (Determination Immediate d' Orbite par DORIS Embarque). The range-rate measurements are also essential elements of the POD activity. The measurements will be thoroughly evaluated as part of the POD verification activity.

6.1.3 Laser Retroreflector Array

The laser retroreflector array (LRA) is a nadir-oriented array that draws its heritage from the Jason missions. Serving as a target for ground-based laser ranging systems, the array supports collection of precise range information for verification of POD, or direct use in POD. The array is entirely passive, and as such, there are no operation or calibration modes. The high elevation data will be used as part of the POD verification activity, in order to verify the ephemeris quality in the radial component.

6.1.4 GNSS POD receiver (GPS and Galileo)

The GNSS POD Receiver will provide data that will be used to enable the system-level Precise Orbit Determination (POD) requirements to be met.

The GNSS POD receiver is multi-constellation (GPS & Galileo) multi-frequency (L1/E1, L2 and L5/E5a) and is a direct continuation of RUAG Space's GPSR-G2 legacy GPS-receivers for Precise Orbit determination (POD), which are used on many European missions such as the Sentinel 1,2,3 A and B units..
The GNSS POD receivers provides the raw code and carrier phase data which are converted on ground first to L1a after conversion to engineering units then to the Rinex formatted L1b data after corrections of known biases through the calibration database. The Level 1b data are then further processed to POD products

6.2 Precise Orbit Determination Verification

The POD verification activity will rely on cooperative investigation among project POD teams (CNES and JPL, for example) and facilities (Copernicus POD facility, for example). Section to be further elaborated to establish POD responsibility and support, etc.

6.3 Global Altimeter Data Analysis

The partner agencies will analyse global products with statistical analyses. The project teams will exchange and jointly interpret selected Cal/Val results from the fully validated off-line science products before concurring on release of the data to the user community. Entities such as the OSTST will also take part in of some studies of the global altimeter data via national AO calls (for example, ROSES).

6.3.1 Sentinel-6 Global Analysis

Global analysis includes maps of differences of the key geophysical retrieval parameters such as SSH, σ^0 and wind speed between missions (such as S6A-J3, S6A-S3A/B, S6A-S6B etc) per cycle. In addition, spectral SLA are generated to show consistency between the missions.

6.3.1.1 CNES

CNES is expected to follow the model of the SSALTO/CalVal activities implemented for TOPEX/Poseidon, Jason-1 OSTM/Jason-2, and Jason-3. Cal/Val comparisons will be performed over different data periods (for example. a portion of a track, a track, one cycle, several cycles, several years) to achieve the goals of systematic quality assessment of data products and in addition, these analyses will provide a way to assess algorithm improvements throughout the Jason-3 mission.

The CalVal tools developed by SSALTO (and AVISO) have been extensively used for T/P, ERS-1 and ERS-2, Envisat and GFO and SARAL, Jason-1, OSTM/Jason-2, and Jason-3. These tools will be exploited for Sentinel-6 and support the following capabilities: 1) data editing, missing measurements determination; 2) crossover calculation and analysis; 3) along-track sea level anomaly calculation and analysis; 4) calculation of geophysical corrections and/or sea-surface height, sea-level anomalies, and wave-number spectra; 5) representation of statistical output and visualization.

Using these tools, SSALTO Cal/Val will compute and compile information on various Cal/Val quantities. For example, 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, SSALTO/CalVal will 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. Along-track wave number spectra (globally or geographically averaged) will be computed for sea surface height.

Analysis of sea-surface height differences at global crossover points will be used by SSALTO Cal/Val to estimate the measurement system uncertainty. Crossover comparisons with Jason-3 will also be performed. The sensitivity of the crossover differences to different corrections and algorithms will be quantified (e.g. variance explained by each correction). The long wavelength orbit error will be estimated by global minimization of crossover differences. 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 uncertainty. 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.

6.3.1.2 ESA

ESA will mainly perform activities related to the satellite and EU payload verification by means of the satellite IOV activity that takes place after LEOP. ESA with its industrial contractors will take care of functional verification of the satellite and carry out dedicated activities relating to the Poseidon-4 such as characterizing and establishing the in-orbit performance of the radar by means of performing specific sets of internal and external calibration. In addition to the analysis performed by industry that will report on the SIOV activities, the project will make use of analysis tools and Level 1 and 2 Ground Processor Prototype (GPP) for verification only. In addition, global analysis is performed via programmes such as the Climate Change Initiative (CCI) and its sea-level Essential Climate Variable (ECV).

6.3.1.3 EUMETSAT

The Cal/Val activities at EUMETSAT to be elaborated in the CVIP are expected to include the following tasks:

- monitoring the quality of the near real time products using NRTAVS (Near Real-Time Altimeter Validation System);
- assessing the quality of the altimeter measurements, detecting biases, and validating the geophysical corrections using the Radar Altimeter Database System (RADS);
- contributing to the advancement of the quality of the overall mission, assisting the various missions centers in solving key problems during the Commission phase and thereafter;
- reporting the results to the user community and promoting further advancement of the quality of the data products.

6.3.1.4 NASA

NASA-JPL will cover the key elements of the AMR-C product validation. In addition, a parallel Cal/Val effort will be undertaken at NASA/JPL, where several levels of operational altimeter product verification are envisioned. A global near real time (NRT) CalVal function, based on the comprehensive Near Real-Time Altimeter Validation System (NRTAVS) system developed for NOAA, will operate at JPL on NRT product families at JPL. This highly automated procedure is triggered by the release of near real time products and will produce comprehensive, running web-based summaries of individual correction terms, as well as wind, wave and sea-surface height. The summaries include geographic images, statistical profiles of pass parameters and data flags, as well as estimates of the radial orbit error. JPL's stackfile will also be used to generate global statistical analyses of the STC and NTC products, following similar approaches used for Jason-1/2/3. The latter will be used to form differences (across all corrections/fields) with the Jason-3 data during the formation flight phase).

6.3.1.5 NOAA

The Cal/Val activities at NOAA to be elaborated in the CVIP is expected to include the following tasks:

- monitoring the quality of the near real time products using NRTAVS (Near Real-Time Altimeter Validation System);
- assessing the quality of the altimeter measurements, detecting biases, and validating the geophysical corrections using the Radar Altimeter Database System (RADS);
- contributing to the advancement of the quality of the overall mission, assisting the various missions centers in solving key problems during the commission phase and thereafter;
- reporting the results to the user community and promoting further advancement of the quality of the data products.

6.3.2 Cross Calibration with other missions

The objective of the altimeter cross-calibration is to compare the performance of the Sentinel-6A and 6B against that of other in-orbit altimeter missions. At the time of the Sentinel 6A launch, it is possible that Sentinel-3A -3B and Jason-3 will still be in-orbit.

Concerning Sentinel-6A and Jason-3 a ~1 year cross validation is anticipated with both satellites sampling the ocean only by ~30 seconds apart, [RD 44], and along the same ground track allowing very accurate comparisons. Cross-calibration between satellites will be useful for comparing relative performances with the two differing measurement systems to estimate possible biases and drifts between the two systems. In this case the repeat-track analysis will provide full geographical coverage, and with high precision since geophysical variability is expected to be close to zero. This method will allow comparison of all geophysical and environmental corrections and corrected sea surface height. It will also lead to an estimate of relative bias and drift, along with a characterization of the specific contributions of all underlying parameters.

The project teams will also perform spectral and regional analysis of differences in order to estimate long and short wavelength errors and geographical biases between the two altimeters.

Various other types of comparisons will be performed during the verification phase, e.g., comparison of geographical coverage, measurement densities, statistics of edited measurements using the same criteria, estimation of time-tag bias and sea-state bias. The results of the cross calibration will contribute to the goals of estimating bias and drift and assessing the data quality and error budget by the end of the verification phase.

In addition, cross-calibration with the Sentinel-3A -3B (and later -3C and -3D) satellites will allow for comparison of global maps of elevation, SWH and wind speed.

There will be a formation flying phase of the Sentinel-6A and 6B satellites to cover a period of ~6 months.

Other altimeter missions may be in orbit during the operational period of the Sentinel-6 satellites.

6.4 In-Situ Techniques for Evaluating the Overall Measurement System

In situ validation of the overall measurement system will be performed using dedicated verification sites, as well as distributed tide gauges. The principal objective of these programs is to use observations from tide gauges and other sensors directly on (or near) Sentinel-6 ground tracks to calibrate the sea-surface height and ancillary measurements made by the satellite as it passes (nearly) overhead. A roadmap of standardising calibration facilities is provided in [RD 18] with experience of the establishment of a calibration system provided in [RD 19].

6.4.1 Dedicated calibration sites

The Sentinel-6 satellites will pass over dedicated verification sites every 10 days as they trace out their repeat ground track. 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 offer the advantage of direct overflight geometry, and a survey tie to the geocenter. The direct overflight geometry reduces errors introduced by decorrelation of SSH and environmental parameters as the cross-track distance to the ground track increases. The tie to the geocenter enables the computation of an absolute bias in the altimetric 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 vapour 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 of a dedicated Cal/Val site. A direct comparison of altimetric data with in situ data is performed. This configuration leads to the differences compared with the altimetric measurements system at a global scale: the Geographically Correlated Errors at regional (orbit, sea state bias, atmospheric corrections, etc.) and local scales (geodetic systematic errors, land contamination for the instruments, e.g. the radiometer). It is intended to share in situ CalVal experiments already conducted at various sites (Corsica, Harvest, Bass Strait, Gavdos and Crete for ocean but also instrumented sites for lakes and rivers like Issyk Kul lake and Amazon basin). 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.

6.4.2 Ku-Band Passive and Active Transponders

Active

Active transponders have been established for pulse-width limited (and thus lower SNR) altimeter missions as an external calibration source. With the definition, implementation and deployment of the Crete transponder, [RD 7] and [RD 8], with in-situ reference systems (DORIS ground station, GNSS reference points, radiometer for wet tropospheric correction, etc.). Transponders allow verification of σ^0, range, datation, geometry amongst other parameters. Transponders are mandatory for Cal/Val of altimeter missions, cross calibration of missions and providing a translation to Fiducial Reference Measurements (FRM) for Altimetry ([RD 18] and [RD 19]) systems. Transponders need regular calibrations to avoid aliasing drifts into the altimetric system, [RD 20].

At this time only one range transponder facility is at the disposal of the Cal/Val team, CDN1 in Crete, assuming continued EC Copernicus funding under the next Multi-Financial Framework (MFF 2021-27). As to whether full redundancy is need is for discussion at the mission level but also with the funding Agencies as is the potential for siting transponders in different geographical regions.

Active transponders require accurate positioning (with FRM standard uncertainty) information with GPS (and Galileo) and ideally a with a separate redundant positioning system (DORIS beacon). A microwave radiometer is needed to derive the wet tropospheric delay during transponder calibrations in addition to the GNSS-derived delays.

There is no normalised backscatter coefficient (σ^0) transponder in current operation. A σ^0 transponder was developed for the ESA EnviSat RA-2. This transponder is being refurbished by ESA and would be ready for Sentinel-3 σ^0 calibrations in 2019 (as well as for Sentinel-6)..However, the design is unlikely to function with high PRF instruments since the design involved re-generating and transmitting a chirp. Further discussion is needed to decide on the need for planning of such a system.

Passive

With the establishment of Fully Focussed processing, [RD 43], and improved signal to noise ratio it is possible corner reflectors provide the necessary radar cross section (RCS) for validating σ^0, range and verifying datation. Corner reflectors do not hold the disadvantage of potential internal drift of delay in active transponders though SNR may turn out to be marginal.

6.4.3 Distributed Tide-Gauge Comparison

While the information from the dedicated calibration sites proved invaluable for detecting biases in the satellite measurement systems, the most reliable external information on the stability of the sea-surface height measurement was afforded by the global tide-gauge network. Cooperating tide gauges in this network are rarely found along the satellite's ground track; moreover, only a few are directly collocated with GPS or DORIS to provide information on vertical land motion. When determining the stability of the altimeter measurement system; however, these limitations can be overcome by combining calibration time series from the many distributed tide gauges into a single ensemble result (see Mitchum, 1998, [RD 28] and [RD 29]). The resulting drift estimate provides information that is complementary to the calibration estimates from the dedicated sites.

The comparison with the tide gauge network allows to (Valladeau et al., 2012, [RD 30]):

1. detect any potential drifts or jumps in the altimeter mean sea level;
1. estimate the potential improvements of the altimeter SSH provided by new altimeter standards;
2. detect the potential anomalies of the computed in-situ datasets.

6.4.4 Argo network and GRACE and GRACE Follow-On

Temperature and salinity profiles (such as Argo), combined with gravity measurements, provide independent estimates of sea surface height variations. Indeed, methods have been developed to compare the steric part of the altimeter data to the in-situ data heights.

Moreover, the accuracy on the absolute trend of sea level differences between altimeter and in-situ Argo T/S data has been improved by adding the mass contribution to the sea level (GRACE measurements) to the Argo steric contribution so that similar physical contents are compared.

For example, over the 2004-2012 period, absolute MSL drifts referenced to Argo and GRACE data indicated that the Envisat MSL drift is greater than the one of Jason-1 (2.0 vs 0.6 mm/yr).

The GRACE mission has ended but a GRACE Follow-On mission has been launched (2018), which should allow for continued comparisons with Argo and Sentinel-6. Satellite laser ranging to LAGEOS and satellite-to-satellite tracking of other missions (e.g. SWARM) may also allow for some monitoring of the long-wavelength gravity field during the gap between GRACE and GRACE-FO.

6.5 Altimeter Correction Terms: External Verification

6.5.1 Water Vapour Delay

The on-orbit calibration of the AMR-C will be performed through a combination of nationally funded activities (for example, via OSTST) and the Sentinel-6 JPL project.

6.5.1.1 ARCS system

The AMR-C brightness temperatures (BT) will be calibrated to on-Earth brightness temperature references and to the cosmic microwave background during the cold sky manoeuvres. During the initial Cal/Val period, dependencies of the calibration on instrument temperature will be removed by sampling the BT references as a function of the AMR-C thermistor measurements and reducing the slope to zero. After that, the ARCS system will be used during the mission to facilitate the long-term calibration and provide the ARCS user with the comparisons and necessary information to both monitor and correct the long-term calibration.

One of the main advantages of the cold sky calibration is detection of radiometer drift. Because the sky temperature is 2.7K and stable to better than 0.1 K, a gain or offset drift would be readily detectable, but not distinguishable. Another brightness temperature reference at a warmer TB is be required to separate the drift component due to gain and that due to offset. To monitor the PD to 1 mm/yr translates to monitoring the brightness temperature to about 0.1 K/yr. The current approach with Jason-2 and -3 uses both the vicarious cold reference and Amazon hot reference to separate gain drifts from offset drifts as well other information such as comparisons of retrieved wind speed with the altimeter and path delay with the model. With the cold sky manoeuvre, the approach is to use the cold sky reference and the vicarious cold reference to estimate gain and offset drifts. This would replace the Amazon reference, which has a large uncertainty (~2° K), with the cold sky reference which is stable to better than 0.1 °K. This will offer an improvement in radiometer long term calibration. An additional advantage is that the cold sky reference is independent of any other sensors or climate signals and absolutely stable on climate time scales (e.g. $>10^6$ years). It should be noted that one important assumption here is that the on-Earth references themselves have no long term drift component. Even with the cold sky manoeuvre, the long term calibration of the AMR is still be susceptible to drift in the on-Earth references since the vicarious reference is used in the calibration. This points to the advantage of the concept proposed for Sentinel-6, which would have two on-board stable calibration targets by means of the SCS. The targets proposed have flown on all imaging radiometer systems and have exhibited no documented long term drifts over 20+ years.

The path delays will be validated using globally distributed radiosonde soundings and the ECMWF model. It is expected that OSTST investigators will provide additional validation.

6.5.1.2 Comparison to model and other radiometers

The wet tropospheric correction based on the AMR-C measurements will also be compared with the ECMWF model. AMR-C retrievals will also be cross-calibrated with the Jason-3 AMR during the validation phase.

6.5.2 Ionosphere Delay

Jason-3 data will be valuable to cross-calibrate the Sentinel-6 ionosphere correction during the formation flying validation phase. Nearly direct comparisons between the ionospheric delay inferred from the two altimeters will be conducted during the formation flight phase. The implication of “nearly direct” is that the time difference is short enough to support the assumption that the two altimeters measure the same ionospheric medium. However, this comparison, even with a time difference of a few minutes, might lead to some differences due to scintillations. This calibration technique will provide a useful verification of the Sentinel-6 ionospheric correction after only a few repeat cycles.

An external source of comparison will be the JPL GPS-based global ionospheric maps (GIM) correction that will be present in both OSTM/Jason-2 and Jason-3 data products. GIM use dual-frequency (L-band) GPS measurements from over 100 ground receiver locations to produce a global map of vertical ionospheric total electron content (VTEC) with an accuracy of 1.5 - 2 cm at the Ku-band frequency of the POS-3B channel. The GIM provide a measure of integrated column density up to GPS altitudes (20,000 km), with a horizontal resolution of 2–5 degrees in latitude and longitude. Analyses of both performances and stability of this ionosphere correction compared to the dual-frequency approach have shown that it represents a good alternative. In terms of calibration of Sentinel-6, and cross-calibration between Sentinel-6 and Jason-3, it could provide a good means to link the ionosphere corrections from the two missions.

6.5.3 Sea surface effects

The sea state bias correction (SSB) is still an important source of error in the sea surface height error budget. Unfortunately, theoretical models do not provide enough accuracy for an operational correction, since all the interactions between the sea surface and the electromagnetic wavelength are very complex and difficult to model.

Therefore, the operational SSB correction is estimated empirically by fitting data to a relationship between SSB, SWH and wind speed (U), both measured by the altimeter (see Gaspar and Florens, 1998, [RD 31], Gaspar et al, 2002 [RD 32] and Labroue et al, 2004 [RD 33]). It is based on the altimeter sea height measurements and assuming that all of the sea height residual (not corrected for SSB) is the result of sea-state bias. The SSB correction will have to be computed for the Sentinel-6 mission using these latest techniques.

The SSB obtained for Sentinel-6 will be extensively compared to the SSB models of other altimetric missions (Jason-3, OSTM/Jason-2, SARAL or others) derived with the same technique. This assessment will help to improve our knowledge of the sea state and electromagnetic bias. The trailing formation flight phase when Sentinel-6 and Jason-3 are very close to each other will be of great interest for the SSB validation and comparison, since both altimeters measure the same sea state. The SSB solution that will be used during the first Sentinel-6 cycles will be the Jason-2/3 SSB solution which is the best a-priori solution considering that retracking algorithms on both missions are the same.

Various tests of use of additional information from operational wave model (WaveWatch3, [RD 36]) to improve the SSB modeling have been performed in the past (Tran et al, 2006 [RD 34] and Vandemark et al., 2002 [RD 35]). These works could be applied to the Jason-2 and Jason-3 data in the future but additional validation is required before operational implementation.

6.6 Wind/Wave Measurements

Wind speed and significant wave height measurements will be validated through comparisons with in-situ data (e.g., from buoys), other satellite data and model output.

Sentinel-6 fast-delivery NRT wind/wave products and wind/wave measurements in STC/NTC products will be validated against Numerical Wave Prediction (NWP) models from both ECMWF and Météo France.

For the first Sentinel-6 cycles, a Collard wind solution will be implemented and evaluated (as for Jason-3, see [RD 37]). The comparison between both missions will be very instructive for the wind and waves contributions insofar as the measurements are close enough. In particular, a comparison will be done between sigma-naught coefficients for both missions allowing us to re-compute the wind solution or to estimate biases induced by the possible discrepancies between both sigma-naught histograms.

In the same time, comparison with collocated data from buoys and other altimeter missions will allow the validation of both Sentinel-6 fast-delivery (NRT) and off-line (STC/NTC) wind/wave products.

Annex 1 Novelties of the mission with respect to Cal/Val

Main element	Sub-Element	Description	Comment
Mission	GMSL drift	For the first time a drift requirement on the GMSL is applied at EURD and SRD. This is a major undertaking for a mission and requires detailed Cal/Val planning at system and sub-system. It involves calibrating the drift of Brightness Temperature of the AMR-C that translate to a drift on the wet tropospheric correction of surface range retrieval from the Radar and the calibration of the Radar range.	
		Mode-Mask: Although the use of mode-masks is not new (CryoSat-2 and the original LRM/SAR Sentinel-3 mask), the S6 mode mask is unique to this mission as a function of the radar design with SAR-RAW, SAR-RMC and LRM sub-modes. In particular how the mask is designed to cover global ocean, coastal and specific regions of cal-val interest, for example, transponder and tide gauge passes may benefit from both SAR-RAW and RMC data at least until the end of the over-lap phase of J3 and S6A. Depending on the optimisation, this may free up SAR-RAW or RMC for inland water bodies.	Following analysis of RMC performances a pre-launch operational mask can be derived, though will need input from the early phases of Commissioning to be tuned.
		The S6 OLTC will be fully uncompressed and updated compared to J3 which is compressed into 1 Mb of on-board store. Hence, the OLTC will need to be derived from latest models and at the full uncompressed rate. The current OLTC used for testing and based on pre-launch J3 (i.e., uncompressed version based on the compressed J3 model) and therefore insufficient.	The OLTC can be developed before launch and up-linked before launch –Most likely a new model will be uplinked once the operational orbit is achieved TBC.

		The AOCS of Sentinel-6 is different from Jason-3. Impacts could be related POD, thermal behaviour and calibration, etc.	The details are elaborated in CVIP
Payload	Radar Altimeter, (Poseïdon-4)		
		Simultaneous LR/HR:	
		PRF	
		RMC	
		Sampling: Due to the nature of the radar design the waveform sampling for on-board generated LR data is ~1.23 times that of Jason-3 which has some impacts (see processing)	
		Drift: Enhanced internal calibration of the radar is performed by including calibration pulse each second. External calibration is achieved by means of transponder range measurements.	
		Although used in conventional SAR imagers, the Poseidon-4 functions by use of matched filter rather than the full de-ramp method. This function is new to spaceborne radar altimeters during the period of the reference ocean mission and requires careful verification.	The on-ground testing of the radar reduces the risk of this design to negligible and an extensive in-orbit verification in the satellite IOV is planned.
	Microwave Radiometer (AMR-C)		
		Supplementary Calibration System (SCS) is a new element and will require effort in the early months to establish its performance and impact on reducing AMR-C BT and product drift	

		Frequency of cold-space manoeuvres: Although established for Jason-3, the frequency for Sentinel-6 could be operationally as often as every 10 days which needs consideration in terms of operations and processing.	
	DORIS	Mini-USO: The new design will need to be monitored to establish drift characteristics and that all other performances are expected in orbit.	
	GNSS-POD	The GNSS-POD is both GPS and GALILEO compatible: GPS L1 C/A ; GPS L1 P(Y) (codeless or semi-codeless); GPS L2 P(Y) (codeless or semi-codeless); GPS L2C; GPS L5; GALILEO E1; GALILEO E5a.	
Ground Processor			
	Altimeter Level 1b	Handling of ambiguity due to PRF < Doppler bandwidth	
		RMC versus RAW SAR is new in altimetry and the impact of waveform truncation needs some consideration.	
		Difference in chronogramme between missions and how to handle cross-calibration.	
		~1.23 oversampled LR waveforms have reduced aliasing compared with Jason-3 at very low SWH. Impacts TBD.	
		Etc,	
	Altimeter Level 2	Oversampling and impact on re-tracking of RMC waveforms.	

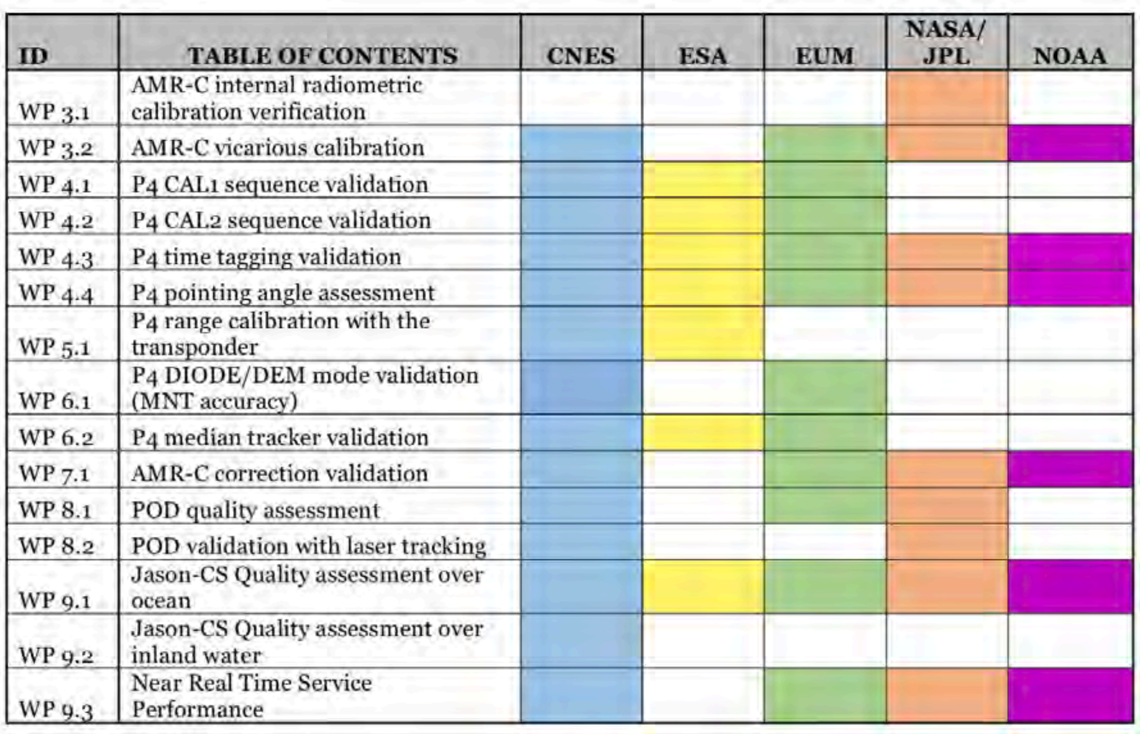
		Evolving product versus J3 and S3	
		Etc	

Annex 2 Novelties of the Cal/Val Infrastructure

Main element	Sub-Element	Description	Impact
Transponder sites	Normalised Backscatter coefficient, σ°	Transponders need to be equipped to allow external calibration of σ°. There are no existing high PRF σ° transponders in operation.	Medium. Future development is being covered for the long-term including Sentinel-6. It is possible the use of corner reflectors and using fully focussed processing a valuable redundancy will be achieved. This will be known in time for Sentinel-6A launch.
	Polarisation	The polarisation of the Poseidon-4 is the same as the Jason-3 and Sentinel-3 and te CDN1 transponder is circularly polarised .	No impact. Power levels to be checked w.r.t Sentinel-3.
	Wet tropospheric Correction	Upward looking off-the shelf Microwave Radiometer needed at transponder sites	Minor: TBC – one being procured for Crete and ready for installation in 2019
	Number of sites:	For the reference mission only one dedicated transponder site is available at the time of writing. A discussion is needed as to whether one is sufficient and whether another in a different location will benefit long-term Cal/Val. Same design should be used as that of Crete CDN1)	Major if > 1 needed since there ia cost attached and a major risk to Cal/Val
Tide-Gauge stations		The current set of Tide-Gauge stations is hemispherically biased and this needs consideration for the long-term Cal/Val	TBD
		Tide gauges are of different design	NOAA/ESRL has managed to install standardized, automated global monitoring (weather, atmospheric chemistry) stations all over the world (see

			https://www.esrl.noaa.gov/gmd/dv/site/?active=1) It seems that a (sparse) global network of standardized, highly precise TG would be an equally valuable effort, and could mitigate current problems such as the inability of the research community to access the SA Navy's TG data, the extreme paucity of stations in some parts of the world, and quality issues. Especially in the coming era of "1 mm altimetry", it seems that this is a reference whose time has come.
Wave Buoys		Wave-buoys allow wave height to be assessed and provide information of swell	None.

Annex 3 Cal/Val Implementation Draft Work Packages and Distribution.



ID	TABLE OF CONTENTS	CNES	ESA	EUM	NASA/ JPL	NOAA
WP 3.1	AMR-C internal radiometric calibration verification				🟧	
WP 3.2	AMR-C vicarious calibration	🟦		🟩	🟧	🟪
WP 4.1	P4 CAL1 sequence validation	🟦	🟨	🟩		
WP 4.2	P4 CAL2 sequence validation	🟦	🟨	🟩		
WP 4.3	P4 time tagging validation	🟦	🟨	🟩	🟧	🟪
WP 4.4	P4 pointing angle assessment	🟦	🟨	🟩	🟧	🟪
WP 5.1	P4 range calibration with the transponder	🟦	🟨			
WP 6.1	P4 DIODE/DEM mode validation (MNT accuracy)	🟦		🟩		
WP 6.2	P4 median tracker validation	🟦	🟨	🟩		
WP 7.1	AMR-C correction validation	🟦		🟩	🟧	🟪
WP 8.1	POD quality assessment	🟦		🟩	🟧	
WP 8.2	POD validation with laser tracking	🟦			🟧	
WP 9.1	Jason-CS Quality assessment over ocean	🟦	🟨	🟩	🟧	🟪
WP 9.2	Jason-CS Quality assessment over inland water	🟦				
WP 9.3	Near Real Time Service Performance	🟦		🟩	🟧	🟪

Annex 4 Cal/Val Implementation WP Template

WP X.Y [Work-Package Title]

Table X-Y: WP X.X [Work-Package Title]

Responsible agency	CNES, ESA, EUMETSAT, NASA-JPL or NOAA
Objective	High level description of the activity objective
SRD Requirements covered by this activity	
Requirement ID	**Description**
	Requirement(s) from SRD, [AD 1]
Pre-condition to start	For example LEOP and instrument switch-on and functional check-out
Expected Phase and Duration	Sat IOV, Sys IOV, commissioning, operations.
Required input data	List of input data types based on ICDs
Parameters to be analysed	List of parameter, for example, SWH uncertainty.
Expected output	List of the data generated. Specific plots.
Tools	Naming of the tool or tool set.
Schedule	Planning of events and the need for specific operations (manoeuvre, calibrations, etc.)

Detailed activity

- A detailed explanation of the activities along with planning, procedures (at least high level) and the description of how the requirements are closed out.
- Specific references to the work package

Rehearsal activity (if any)

- What is the pre-launch rehearsal activity, the schedule, required input data and any reporting .