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Jason continuity of services: continuing the Jason altimeter data records as Copernicus Sentinel-6

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Abstract

The Sentinel-6 mission is proposed as a multi-partner programme to continue the Jason satellite altimeter data services beyond the Jason-2 and Jason-3 missions. The Sentinel-6 mission programme consists of two identical satellites flying in sequence to prolong the climate data record of sea level accumulated by the TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3 missions from 2020 to beyond 2030. The Sentinel-6 mission intends to maintain these services in a fully operational manner. A key feature is the simultaneous pulse-limited and synthetic aperture radar processing allowing direct and continuous comparisons of the sea surface height measurements based on these processing methods and providing backward compatibility. The Sentinel-6 mission will also include Radio Occultation user services.

1 Introduction

The Sentinel-6 mission is proposed as a multi-partner program to continue the Jason altimeter data services beyond Jason-2, currently fully operational, and Jason-3, currently pre-operational. The Jason Continuity of Service (Jason-CS) programme constitutes EUMETSAT's contribution to the Copernicus Sentinel-6 mission to be developed and implemented through a partnership between the EU, ESA, EUMETSAT, NASA, and NOAA. From 2020 to beyond 2030, the Sentinel-6 mission will uniquely extend the climate record of sea level measurements accumulated since 1992 by TOPEX/Poseidon (e.g. Fu et al., 1994), Jason-1 (e.g. Ménard and Fu, 2001), Jason-2 (e.g. Lambin et al., 2010), and Jason-3. A prime mission objective is to continue this long global sea level time series with an error on sea level trend of less than 1 $\mathrm{mm\,yr^{-1}}$. The Sentinel-6 mission will also be an essential observing system for operational oceanography and seasonal forecasts in Europe and beyond. It will provide measurements of sea surface height, significant wave height, and wind speed without degradation in precision and accuracy compared to the currently flying Jason-2 mission. As such, like its predecessors, the proposed mission will provide key user measurement services for sea level rise monitoring, operational oceanography, and marine meteorology. These services will be aligned with those of the Sentinel-3 missions (e.g. Donlon et al., 2012), which will be operational in the same era, see Fig. 1.

In addition to the altimeter data service, Sentinel-6 will also include a radio occultation instrument (GNSS-RO) as a secondary payload, taking advantage of the non sun-synchronous orbit of Sentinel-6. The GNSS-RO measurements will provide information on atmospheric pressure, temperature and water vapour as well as ionospheric data. The radio occultation data service primarily addresses the needs of meteorological and climate users.

The Sentinel-6 mission programme consists of two identical satellites (Jason-CS A and Jason-CS B) with each a nominal lifetime of 5.5 years and a planned overlap of at least 6 months. The satellites will be launched sequentially into the "Jason orbit" to take over the services of Jason-3 when this scheduled mission becomes of age. Currently, the launches of Jason-CS A and B are planned for 2020 and 2026, respectively.

2 Programmatic set-up

Figure 2 outlines the multi-partner programme and agreement set-up underlying the Sentinel-6 missions. The European contribution will be implemented through the combination of the ESA GMES Segment 3 programme (GSC-3), the optional EUMETSAT Jason-CS programme and the EU Copernicus Programme, for the joint benefits of the meteorological and Copernicus user communities in Europe. In addition, on behalf of the United States, NASA and NOAA are developing a dedicated Jason-CS programme. The following high level sharing of responsibilities is envisaged (which may still be subject to some changes):

- EUMETSAT is the system authority and is responsible for the Sentinel-6 ground segment development and operations preparation. EUMETSAT will also carry out the operations build up and operations of the Sentinel-6 system including both satellites and delivery of data services to Copernicus Service Providers and users on behalf of the EU.

– ESA is responsible for the development of the first Jason-CS satellite and the instruments prototype processors as well as for the procurement of the recurrent satellite on behalf of EUMETSAT and the EU.

– NASA will deliver the US payload instruments for both satellites and will provide ground segment development support, launch services, and contributions to operations.

The three space agencies will share the responsibility for the science team coordination and the calibration/validation activities, with EC being involved in the interactions with the science teams. In addition, agreements will be concluded between EUMETSAT and CNES and between NOAA and NASA for system and science expertise support.

3 Mission objectives

Sentinel-6 will be a truly operational mission in all aspects of its main user services. Hence, full emphasis is put on reduction of downtime to a minimum, on timely distribution of data products, and on high quality and reliability of the measurement data. The mission will also include support to information service providers and major reprocessing activities.

The Sentinel-6 product suite is currently being detailed. The baseline is to provide a product suite that will enable an optimal combination with products from other altimeter missions. This is particularly pursued for combining Sentinel-6 with the Sentinel-3 SRAL missions. Next to the conventional Level 2 products, known as Geophysical Data Records for the Jason missions, the Sentinel-6 product suite will include Level 1 products aimed at the further study of the intrinsic altimeter waveforms and development and innovative processing techniques. Also, the generation of higher level single mission products (Level 2P and Level 3) are supported in order to serve mainly the ocean modelling community.

Sentinel-6 products are to meet high standards, such that they will be of sufficient quality to serve as the high precision reference mission for other altimeter missions. It has been formally required that the mission performance shall not be worse than the known performance of Jason-2. With the current design however the expectation is that the Sentinel-6 mission will outperform Jason-2 on many aspects and will form a reliable state of the art reference for various other altimeter missions in the near future.

The Sentinel-6 products will also maintain their quality closer to the coastline than products from its predecessor Jason missions (e.g. Raney, 1998; Gommenginger et al., 2012; Halimi et al., 2014). This, among other techniques, will be facilitated by replacing the conventional Low Resolution Mode (LRM) altimeter by one that has along-track Synthetic Aperture Radar (SAR) capabilities.

The Sentinel-6 radio occultation products will contribute to operational weather forecasting and to assessments of atmospheric climate trends by providing information that allows to derive atmospheric temperature and water vapour profiles. In addition, ionospheric data is also provided up to 500 km altitude.

4 Mission characteristics

The Sentinel-6 Space Segment consists of two successive Jason-CS satellites (A and B), based on the CryoSat-2 heritage platform, with some tailoring to specific needs of the Sentinel-6 mission. The satellites will embark the following main payload:

- a radar altimeter (Poseidon-4), to measure the range between the satellite and the mean ocean surface, determine significant wave height, and wind speed, and provide the correction for the altimeter range path delay in the ionosphere by using signals at two distinct frequencies (Ku-band and C-band);

- a microwave radiometer (AMR-C), to provide a correction for the wet tropospheric path delay for the altimeter range measurement;

- Precise orbit determination (POD) instruments – namely a Global Navigation Satellite System and Precise Orbit Determination receiver (GNSS-POD), a Doppler Orbitography and Radiopositioning Integrated by Satellite instrument (DORIS), and a Laser

Retroreflector Array (LRA) – to provide with high accuracy and precision a measurement of the orbital position as needed for the conversion of the measurement of altimeter range into a sea level;

– a Radio Occultation instrument (GNSS-RO), to provide (with high vertical resolution) all-weather atmospheric and ionospheric soundings by tracking GNSS satellites.

The latter instrument is added to Sentinel-6 as a secondary mission to provide radio occultation observation services to meteorological users. However, the primary altimeter mission supported by the other instruments takes priority in all design and mission planning.

It is important to remark that the Poseidon-4 radar altimeter has evolved significantly from the Poseidon-3A and -3B instruments on board Jason-2 and -3, respectively. In addition to a conventional pulse-width limited processing, also known as Low Resolution Mode, the Poseidon-4 on board the Jason-CS satellites will also have the facility of simultaneous High Resolution (HR) processing, generally referred to as Synthetic Aperture Radar processing (or SAR mode), as discussed in Sect. 6. This High Resolution processing will provide further service alignment with the SAR mode of the Sentinel-3 SRAL mission.

The Jason-CS satellites will fly in the same orbit as its predecessors, TOPEX/Poseidon and the Jason missions (see Table 1). This is a non-sun-synchronous orbit with nominal altitude of 1336 km and 66° inclination. The orbit period is 112 min and 26 s and the ground track cycle repeats approximately every 9 days and 22 hours. Because of the relatively large ground track spacing of 315 km at the equator, Jason-CS alone will not be able to satisfy the sampling requirements for mesoscale oceanography. Thus, the Sentinel-6 mission is coordinated with other altimeter missions, chiefly the Sentinel-3 mission, to provide together a complementary spatio-temporal sampling of the oceans and serve as a high-precision reference to sea level change studies.

5 Product definition and product services

5.1 Altimeter product definition

The raw data downlinked from the satellite consist of a serial stream of data bits embedded within a framework of transfer frames. This level of data, which may be temporarily archived at the reception station, is not readable by a general-purpose computer and not included in the set of product level definitions. The data is then converted onwards to Level 0 and higher.

Level 0 products are computer-readable data directly representing the output of the on-board instrument in its native data structure and in native units (e.g. clock cycle counts), after extraction from the downlinked data stream. Data are chronologically ordered with any overlapping (duplicate) data removed. Quality flags related to the reception and decoding process may be appended.

Level 1 products generally maintain the same time structure and sampling as the Level 0 products from which they are derived. The instrument measurements are converted into recognised engineering units (e.g. seconds) and calibration data are appended (Level 1a) or applied (Level 1b). Geo-location data are also appended. In case of Sentinel-6 Level 1a products will include all the recorded individual echoes, whereas Level 1b provides the synthesised waveforms. A Level 1b-S product, similar to what is produced for Sentinel-3 is not envisioned, however, software will be provided to derive these from the Level 1a product.

Level 2 products maintain the same time structure and sampling as the Level 1 products from which they are derived. The measurement data are converted into geophysical quantities, and combined with auxiliary input data from other sources (such as geophysical corrections coming from meteorological models) to yield directly useful geophysical parameters, e.g. sea surface height (SSH), significant wave height (SWH), and wind speed. The auxiliary data parameters and geophysical corrections are appended. For altimetry, Level 2 products contain measurements of SWH, wind speed, and SSH, at a high rate of about 20 measurements per second, which are then averaged along-track to form one averaged measurement every approximately 1 s. These products are thus equivalent to the Geophysical Data Records (GDRs) for the Jason missions. The data structures of Level 1 and Level 2 will be similar, making it easy for users to combine the waveform information in the Level 1 products with the geophysical information stored in the Level 2 products.

Level 2P products are enhanced Level 2 products, aimed at harmonisation between missions, e.g. applying the same geophysical corrections across the missions, or applying externally derived biases to the data in case they have not been applied yet in the operational Level 2 products.

Level 3 products contain geophysical parameters that have been spatially and/or temporally resampled or corrected. This may include averaging over multiple measurements.

Level 4 products are described as thematic data, and are generally gridded parameters that have been derived from the analysis of the satellite measurements but are not directly derived from them. These products are elaborated by service providers and users and are not delivered by the Sentinel-6 programme.

5.2 Radio Occultation product definition

For the GNSS-RO, Level 0 products will contain raw data. At Level 1a, phase and amplitude data as well as the satellite orbits of the occultation are provided. The Level 1b products will include the main variables for assimilation, such as the vertical bending angle profile. At Level 2, temperature, water vapour profiles are provided, while Level 3 products will have been spatially and/or temporally resampled and averaged.

5.3 Product services

Based on the synthesis of the operational applications various product services are identified. Tables 2 and 3 match the applications with the appropriate product levels. Since the requirements on the timeliness and quality of the products may vary by application, the Sentinel-6 mission will include operational user product services at three different latencies: Near Real Time (NRT), Short Time Critical (STC), and Non Time Critical (NTC). Details about the various product services are given below and in Table 4. These latencies map onto the various applications for which the services are set-up. The latencies also effectively govern the quality of the auxiliary data used in their generation, with better quality data available after a longer elapsed time.

The naming of these services (characterised by product latencies) are in common with those of the Sentinel-3 ocean surface topography mission. Also the availability of High Resolution altimeter measurements (also known as SAR mode) and the wider services within the Copernicus program affected the rationale behind some product definitions.

5.4 Near Real Time altimetry service (ALT-NRT)

The Near Real Time altimetry product service (ALT-NRT) delivers Level 2 products within 3 hours after sensing. These products will be produced using the best possible algorithms, external data and orbit determination that are available in short time span. Because of the reduced time allowed for the generation of NRT and STC data, it will often be necessary to rely on alternative data sources (e.g., predicted or climatological values) for auxiliary data like altimeter range corrections. The quality of the orbit determination will also be reduced for the shorter latencies. Nonetheless, the algorithms used for the production of Level 2 data from Level 1 are expected to be the same in all cases.

In addition, to provide NRT data in the fastest possible way, data will not be provided in consolidated products with a length of half an orbit (as is the case for STC and NTC), but will rather be produced in smaller granules.

This service requires dissemination to Numerical Weather Predication (NWP) centres and is mainly used for marine meteorology, air–sea interaction studies, and real time operational oceanography.

As well as serving operational users, these NRT products may be used in the generation of some auxiliary data (e.g., bias corrections) for STC and NTC products. The main objective of the ALT-NRT product service is to provide information on the sea-state, e.g. significant wave height and wind speed, but also on sea surface height.

5.5 Short Time Critical altimetry product service (ALT-STC)

The Short Time Critical altimetry product service (ALT-STC) delivers Level 2 products within 36 hours after sensing, which enables consolidation of some auxiliary data (e.g. preliminary restituted orbit data). Products are mainly used for operational oceanography and geophysical studies.

These products will be produced using the same algorithms as the top-quality NTC products and they will have the same data structure. The difference between the products is in the latency requirement, which determines the acceptable delay for the provision of external data and orbit determination. By reducing the allowed time for the generation of these data, their quality is expected to reduce accordingly. This is likely to be particularly true for the orbit determination.

The main objective of the ALT-STC product service is to support operational oceanography, i.e. improve ocean state analysis, forecasts, and hindcasts produced by numerical ocean prediction (NOP) systems assimilating sea surface height measurements derived from a multi-mission constellation of spaceborne altimeters.

Level 3 products contain geophysical parameters that have been spatially and/or temporally resampled or corrected. This may include averaging over multiple measurements. They are primarily intended for ocean modelling services. At this point, Level 3 data will only be provided with Short Time Critical latency.

5.6 Non Time Critical altimetry product service (ALT-NTC)

The Non Time Critical altimetry product service (ALT-NTC) delivers Level 2 products within 60 days after sensing, this additional delay allowing the further consolidation of some auxiliary data (e.g. precise orbit data, radiometer calibration) leading to higher accuracy of SSH products.

These products will be subject to regular reprocessing as better information about instrumentation biases, precise orbits, and geophysical corrections become available.

The main objective of the ALT-NTC product service is to provide information on ocean topography and mean sea level in support of ocean and climate monitoring services.

5.7 Near Real Time Radio Occultation product service (RO-NRT)

The Near Real Time radio occultation product service (RO-NRT) delivers Level 1b and Level 2 products less than 3 hours after sensing, for direct assimilation into NWP models. It will be provided by the US partners of the programme.

The main objective of the RO-NRT product service is to provide bending angles or refractivity profiles, which contain information on atmospheric temperature, pressure, and humidity, for assimilation by NWP models. Further RO-NRT Level 2 products are e.g. tropopause height, planetary boundary layer height and ionospheric information (gravity wave information is also being discussed).

5.8 Non Time Critical Radio Occultation product service (RO-NTC)

The Non Time Critical Radio Occultation product service (RO-NTC) delivers Level 1b and Level 2 products within 60 days after sensing. This additional delay allows using longer time series of the instrument to obtain improved precise orbit determination and clock data for the satellite, as well as to use updated auxiliary data (e.g. precise orbit and clock data for the GNSS satellites).

The main objective of the RO-NTC is to deliver the same products as the RO-NRT service but with higher precision, making this service particularly valuable for climate studies, including assimilation in re-analysis models.

Two parallel services will be providing this data. They both start from Level 0 and thus allow to e.g. estimate uncertainties introduced by the processing setup. On the European side, processing up to Level 1b is performed at EUMETSAT and the Radio Occultation Meteorology Satellite Application Facility (ROM SAF) is responsible for processing this data further to Level 2 (and also to Level 3 within their climate service). The other RO-NTC service will be provided by the US partners of the programme.

6 Interleaved SAR mode

As indicated in Sect. 4, the Poseidon-4 radar altimeter system can operate in conventional pulse-width limited (LRM) and a synthetic aperture radar (SAR) processing simultaneously. Hence both Brown echoes and SAR radar echoes will be generated simulteanously in the ground processing. This is loosely called the interleaved mode, because the transmit and receive pulses are "interleaved" just like in LRM altimetry but at a much higher rate (9 kHz), see Fig. 3. This is in contrast to the burst mode operation of CryoSat-2 and Sentinel-3, which transmit and receive alternatively, each approximately one third of the time. This high rate interleaved pulsing of the Jason-CS altimeter has the following advantages:

- The original (Jason-2/3) low resolution processing is maintained simultaneously to higher resolution products, thereby ensuring full continuity of services with Jason-3, based on pulse-width limited processing with an along-track resolution of approximately 7 km.

- The range noise of SAR processed altimeter echoes will be reduced by a factor 1.7 compared to Sentinel-3 since more independent echoes are received owing to the continuous pulsing of Jason-CS compared to the burst mode of Sentinel-3 (and CryoSat-2).

- The availability of much higher along track resolution (approximately 300 m) and, when averaged, a lower range measurement noise will enable an enhanced use especially in coastal areas.

- This enables continuous and direct comparison of LRM and SAR measurements (which is neither available from Sentinel-3 or Cryosat-2) and makes Sentinel-6 a reference for all SAR altimetry missions.

- More details and background of the interleaved mode can be found in, e.g., Phallipou et al. (2012) and Gommenginger et al. (2013).

7 Performance budget

7.1 Altimeter performance

As indicated above, the general end user requirement for Jason-CS is to "perform at least as well as Jason-2" in terms of RMS error in the retrievals of sea surface height, significant wave height and wind speed (with the latter directly relating to the retrieval of the ocean backscatter coefficient). Because the statement "as least as well as Jason-2" is not sufficient to build an altimeter system on, this requirement had to be quantified and broken down into the individual components that make up the measurement of sea surface height: altimeter range, orbital altitude, atmospheric corrections, and sea state bias. A thorough analysis was done on the current state of the art of Jason-2, and the requirements currently set for the soon-to-be-launched altimeter missions of Jason-3 and Sentinel-3. All these numbers are gathered in Table 5. One will notice that the Jason-2 requirements (as reported by NASA, 2011) have mostly been copied straight into the Jason-3 requirements (Couderc, 2015), except for the orbit error, which has been adjusted given the intervening improvements in POD. However, other advances in atmospheric modelling were ignored, even though they are evident when we look at the actual Jason-2 performances (NASA, 2011).

A further review of the performance of Jason-2, expected performances of the Poseidon-4 altimeter, and current POD performances led to the establishment of the Jason-CS requirements listed in Table 5, with some more challenging goals to be met for all products later in the mission. Overall, the Jason-CS requirements for the RSS sea surface height error for LRM measurements closely meet the established Jason-2 performances, whereas SAR measurements will clearly outperform Jason-2, because of the reduction in measurement noise. The only exception are the orbit performances, which are kept conservatively similar to Jason-3 requirements. However, the performance goals of orbit determination are likely to be met and are at least equal to Jason-3 performances.

Although the requirements for SWH, wind speed, and backscatter have been kept somewhat less restrictive than the claimed Jason-2 performance, they are still vastly tighter than the requirements for Jason-3 and Sentinel-3, which are regarded as far too cautious.

7.2 Radio Occultation performance

The GNSS-RO will track Global Navigation Satellite System (GNSS) signals from the American Global Positioning System (GPS) and the Russian GLObal NAvigation Satellite System (GLONASS). GNSS-RO is a modified receiver as also used for the COSMIC-2 mission (e.g. Kramer, 2015) and tracks signals on the L1 and L2 GNSS frequencies. The POD antenna will only observe GPS signals for orbit prediction, while two occultation antennas, facing in satellite velocity and anti-velocity direction, will observe GPS and GLONASS. A potential upgrade to include also the European Galileo signals will be investigated once enough Galileo satellites are available.

The GNSS-RO will observe occultations over the Straight Line Tangent Altitude (SLTA) Range from -300 km to 500 km, where the SLTA is the minimum elevation above the reference ellipsoid of an imaginary straight line connecting Jason-CS and the occulting GNSS satellite. This is negative in the lower atmosphere since the refraction bends the ray behind the horizon. As a secondary payload, the GNSS-RO will not be able to observe the upper atmosphere up to orbit altitude due to data size limitations.

The occultation tracking rates are 50 Hz for GPS and 100 Hz for GLONASS in the lower atmosphere, while higher up a 1 Hz tracking is foreseen. Open loop tracking is enabled from a configurable SLTA altitude downwards. With no Ultra Stable Oscillator available, occultation processing will rely on single differencing with respect to a reference GNSS satellite to be tracked simultaneously.

Based on simulations with a constellation of 31 GPS and 24 GLONASS satellites and assuming an antenna coverage of $\pm 55^{\circ}$ in azimuth, the Jason-CS satellite will be observing about 1100 occultations per day, about 600 from GPS and about 500 from GLONASS. Contrary to e.g. the EUMETSAT Polar System (EPS) and the EPS-Second Generation (EPS-SG), Jason-CS will fly in a non sun-synchronous orbit, providing measurements at various local solar times, cycling through a full 24 hours every 118 days.

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8 Summary

The Sentinel-6 mission, consisting of two consecutively flying altimeter satellites, Jason-CS A and Jason-CS B, will ensure the continuation of the decades long time series of sea level as recorded by TOPEX/Poseidon, Jason-1, Jason-2, and soon, Jason-3, from 2020 to 2030. Since the radar altimeter will be able to serve simultaneously as a conventional LRM altimeter, and as a SAR altimeter, it not only provides compatibility with the previous mission that is vital to the accurate cross-calibration of Jason-CS and Jason-3, but it will also improve sampling of the coastal areas with a much higher resolution, and providing the ability to measure closer to the coast line.

The Sentinel-6 mission will be the first of the "reference missions" for which not only Level 2 will be provided to users. In fact, the mission will provide a wide range of Level 1, Level 2P, and Level 3 products as well, aiming not only at operational meteorological and oceanographic modellers, but also giving altimeter specialist the opportunity to further advance altimeter technologies that will be provided by the unique altimeter flown on the Jason-CS satellites.

Sentinel-6 will also include a secondary radio occultation payload, which makes use of GPS and GLONASS satellites to observe up to about 1100 occultations per day (prior to quality control).

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Table 1. Parameters of the Jason-CS orbit.

Quantity	Value
Semi-major axis	7714.4278 km
Eccentricity	0.000095
Argument of perigee	270.8268°
Inclination (non-sun-synchronous)	66.039°
Reference altitude (equatorial)	1336 km
Nodal period	6745.72 s
Orbits per day	12.81
Repeat cycle	9.9156 days
Number of orbits per cycle	127
Number of passes per cycle	254
Ground track separation at Equator	315 km
Acute angle at Equator crossings	39.5°
Orbital velocity	7.2 km s^{-1}
Ground track velocity	5.8 km s^{-1}

Table 2. Mapping of the main application areas on the altimetry product services (Level 1 and Level 2). The mapping for Level 3 products is equivalent to the one of the Level 2 products ($+$ = essential; $\square$ = beneficial; $-$ = less important).

Application Category	NRT		STC		NTC	
Product level	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
Marine meteorology	$-$	$+$	$-$	$-$	$-$	$-$
Operational oceanography	$-$	$+$	$-$	$+$	$-$	$+$
Climate change	$-$	$-$	$-$	$-$	$-$	$+$
Research and remote sensing science	$-$	$\square$	$\square$	$\square$	$+$	$+$

Table 3. Mapping of the main application areas on the radio occultation product services ($+ =$ essential; $\square =$ beneficial; $- =$ less important).

Category	NRT		NTC	
Product level	Level 1	Level 2	Level 1	Level 2
Numerical weather prediction	$+$	$+$	$-$	$-$
Climate change	$-$	$-$	$+$	$+$
Research and remote sensing science	$\square$	$\square$	$+$	$+$

Table 4. Summary of the Sentinel-6 product suite for altimetry and radio occultation.

Resolution	Service Name	Format	User Data Access			
			EUMETCast	GTS	ftp	Archive
Low (LRM)	NTC	NetCDF	–	–	–	L1b, L2
	STC	NetCDF	–	–	L1b	L1b, L2, L2P, L3
	NRT	NetCDF	L2 (std + red)	–	–	L0, L2
	NRT	BUFR	L2 (red)	L2	–	L2
High (SAR)	NTC	NetCDF	–	–	–	L1b, L2
	STC	NetCDF	–	–	L1a, L1b	L1a, L1b, L2, L2P, L3
	NRT	NetCDF	L2 (std + red)	–	–	L0, L2
	NRT	BUFR	L2 (red)	L2	–	L2
Radio Occultation	NTC	NetCDF	–	–	–	L1b, L2
	NTC	BUFR	–	–	–	L1b, L2
	NRT	NetCDF	–	–	–	L0, L1b, L2
	NRT	BUFR	–	L1b, L2	–	L1b, L2

std = standard product with 1 and 20 Hz data; red = reduced product with 1 Hz data only; Ln = Level n.

Table 5. Overview of the requirements and actual performances of Jason-2 (NASA, 2011), the requirements for Jason-3 (Couderc, 2015), the requirements for the Sentinel-3 SRAL (Ferreira, 2009; Donlon, 2011) and the requirements and goals for Jason-CS. In each column either a single value is presented if it applies equally to NRT, STC and NTC. If a triplet of numbers is given, it applies to NRT/STC/NTC. Numbers are in centimeters, unless indicated otherwise.

	Jason-2		Jason-3	Sentinel-3	Jason-CS	
	req.	actual	req.	req.	req.	goals
Ku-band range noise LRM [a]	1.7	1.8	1.7		1.5	1.0 [b]
Ku-band range noise SAR [a]				1.3	0.8	0.5 [b]
C-band range noise [a]			4.6		4.6	
Ionosphere [c]	1/0.5/0.5	0.3	1/0.5/0.5	0.7	0.5	0.3 [d]
Sea state bias	3.5/2/2	2	3.5/2/2	2.0	2.0 [e]	1.0 [b]
Dry troposphere	1/0.7/0.7	0.8/0.7/0.7	1/0.7/0.7	0.7	0.8/0.7/0.7	0.5 [b]
Wet troposphere	1.2	0.8	1.2	1.4	1.2/1.2/1.0	0.8 [d]
RMS orbit [g]	10/2.5/1.5	3.0/1.5/1.0	5/2.5/1.5		5.0/2.0/1.5	3.0/1.5/1.0 [b] [d]
Total RSS sea surface height LRM	11.2/3.9/3.4	4.2/3.3/3.1	6.8/3.9/3.4 [f]		5.79/3.53/3.20	3.46/2.29/1.99
Total RSS sea surface height SAR					5.65/3.29/2.94	3.35/2.12/1.80
Significant wave height	50 cm or 10 % [h]	12 cm or TBD % [h]	50/40/40 cm or 10 % [h]	20 cm or 4 % [h]	15 cm + 5 % [k]	10 cm +5 % [b] [k]
Wind speed	1.6/1.5/1.5 $\mathrm{m\,s^{-1}}$	0.9 $\mathrm{m\,s^{-1}}$	1.6/1.5/1.5 $\mathrm{m\,s^{-1}}$	2 $\mathrm{m\,s^{-1}}$ [l]	1.5 $\mathrm{m\,s^{-1}}$	1.0 $\mathrm{m\,s^{-1}}$ [b]
Sigma naught	0.7 dB	0.1 dB [i]	0.7 dB	1 dB	0.3 dB [j]	0.3 dB [b]

[a] After ground processing, averaged over 1 s, for 2 m wave height.
[b] Goals from CNES System Performances Budget Study.
[c] Derived from Ku- and C-band range difference, averaged over 200 km.
[d] Jason-2 actual performance (NASA, 2011).
[e] Could also be expressed as 1 % of SWH.
[f] The RSS values for the NTC products given in Couderc (2015) have been corrected.
[g] NRT/OGDR orbit from real-time DORIS on-board ephemeris.
[h] Whichever is greater.
[i] After calibration to Jason-1.
[j] After cross-calibration with other altimeter missions.
[k] For 0.5–8 m SWH range.
[l] For 3–20 $\mathrm{m\,s^{-1}}$ wind speed range.

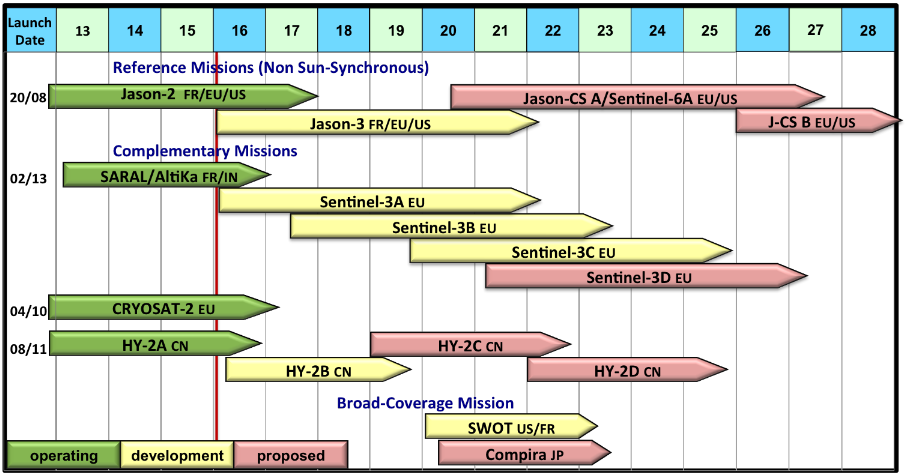

Figure 1. Overview of the current and future satellite altimeter missions (Sources: WMO and CEOS).

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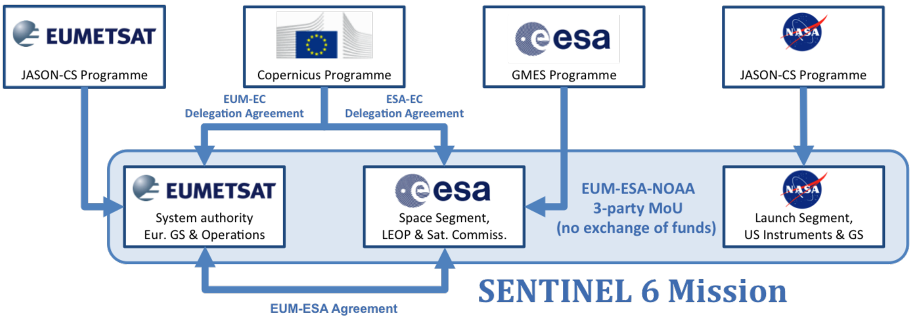

Figure 2. The multi-partner programme and agreement set-up underlying the Sentinel-6 mission.

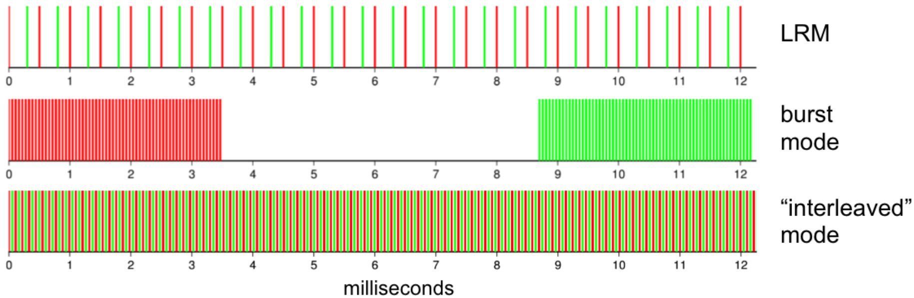

Figure 3. Schematic diagram of the timing of transmit (red) and receive (green) pulses in case of conventional LRM altimetry (e.g. Jason-2, top), SAR burst mode altimetry (e.g. Sentinel-3, middle), and interleaved mode (Jason-CS, bottom).