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Sentinel 6 Next Generation: Status of Mission definition and next steps

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& S6NG Ad-Hoc Expert Group

The Sentinel-6 mission

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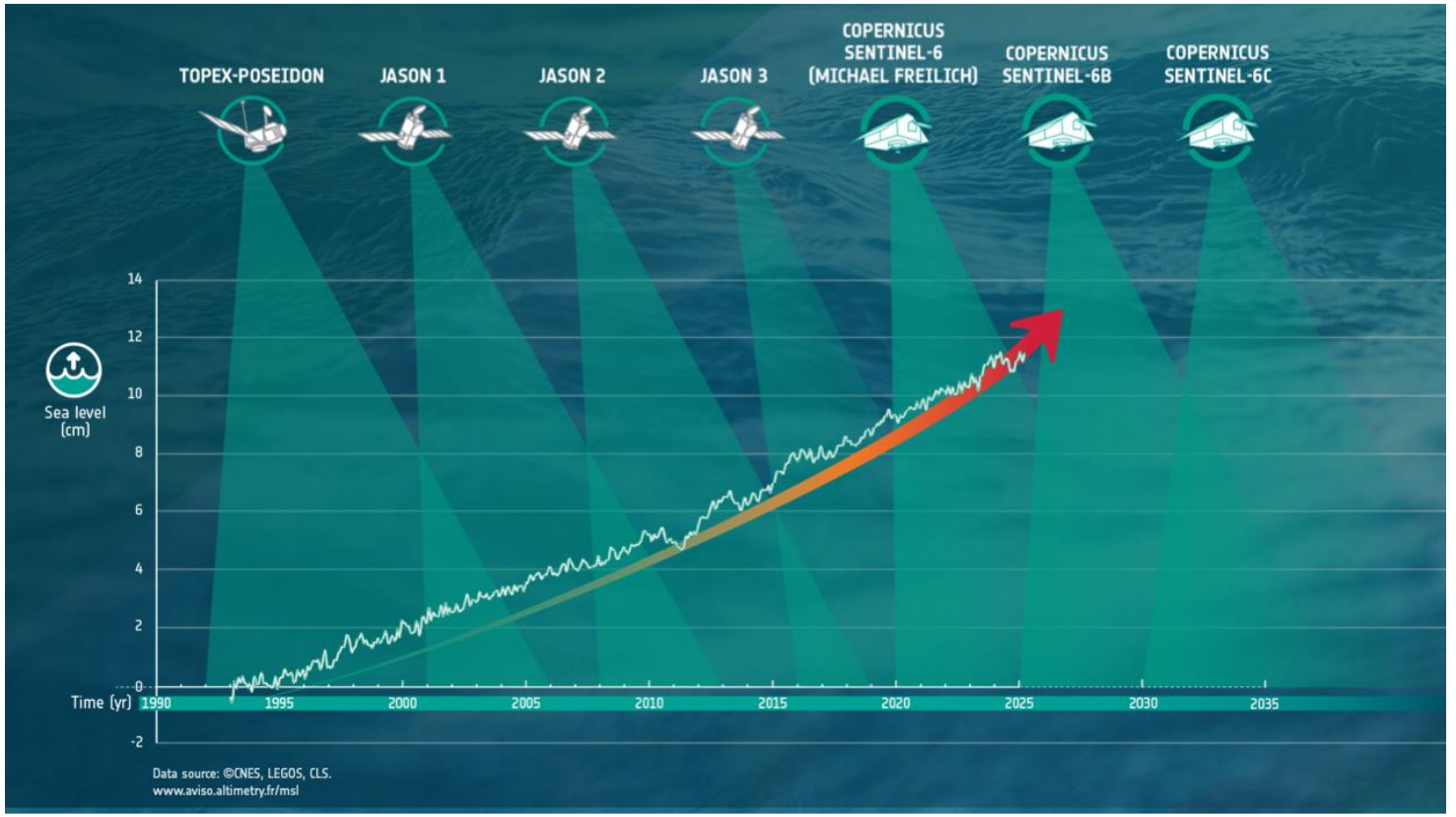
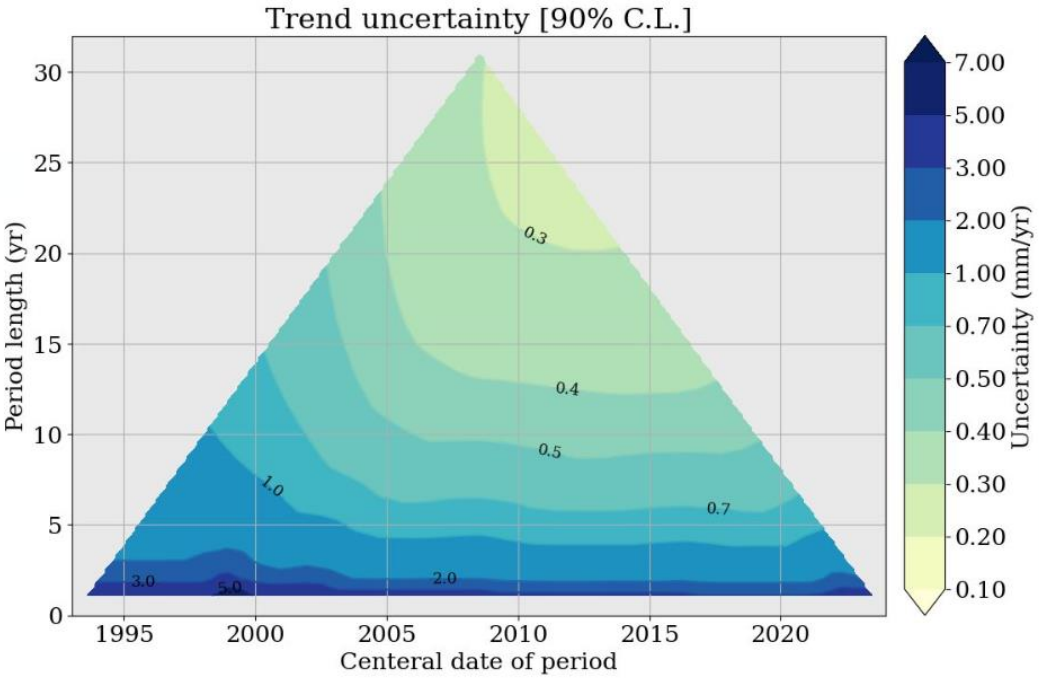


Sentinel-6 is the current reference altimeter mission, in charge of maintaining the geodetic data record for sea level.



Courtesy Magellium, ASELSU Project

Thanks to the long record of reference altimeter missions the uncertainty in the trend over the whole period (1993-2025) is around 0.3 mm/yr over a 20-year period.

Sentinel-6 Next Generation Key Science Drivers

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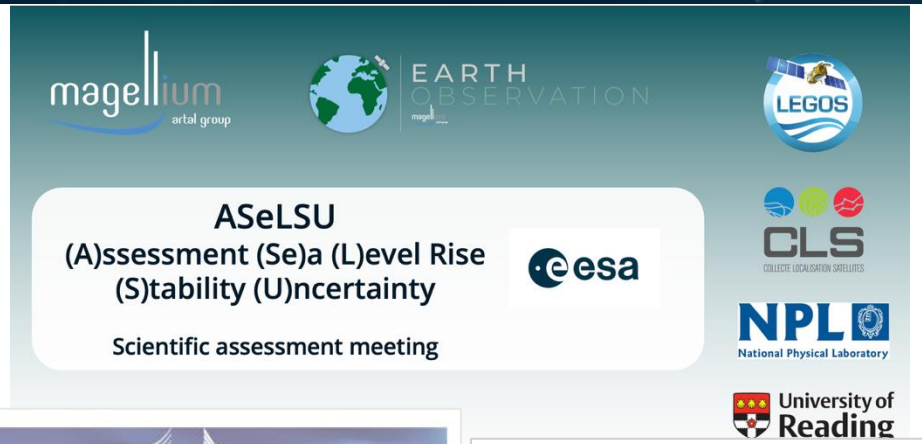

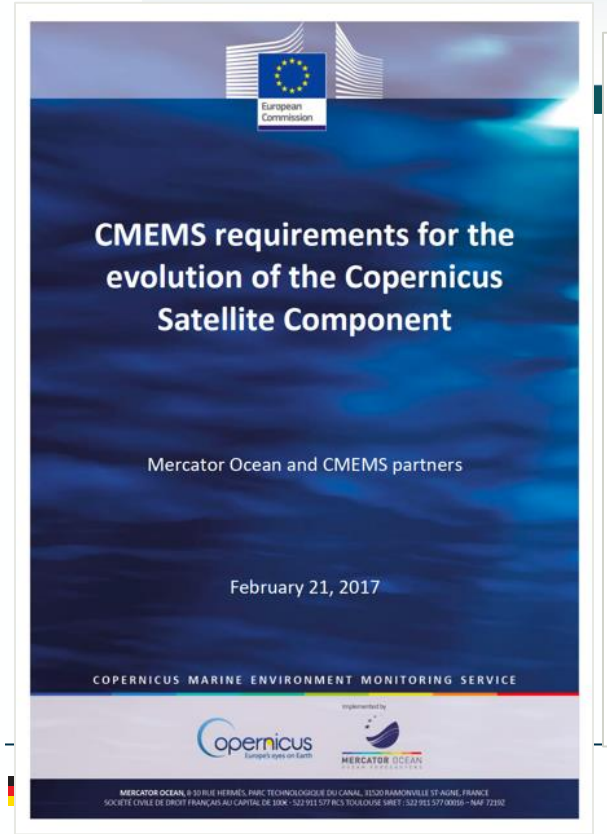

EUROPEAN COMMISSION
DIRECTORATE-GENERAL DEFENCE INDUSTRY AND SPACE

Space
Earth Observation

Brussels,
defis.ddg.c.3(2020)2050202/
Mr. Craig Donlon
European Space Agency
KeplerLaan 1
NL-2201 AZ Noordwijk
Netherlands

(by email)

Subject: User needs for Copernicus 2.0 next generation of Sentinel topography Missions

Dear Mr. Donlon,

In order to support the experts' work performed by the ad-hoc expert group settled by ESA for the NG Topography Constellation family, please find attached a set of relevant documents that should be considered to define the mission assumptions and technical requirements for the topography family of sentinels (Sentinel3-NG, Sentinel-6-NG and possibly Cristal-NG if relevant).

The following documents have been consolidated through many years of studies and data collected with representative user communities and analyzed in order to identify which physical observations would be required to address user needs. In addition the Copernicus core services completed the exercise bringing their own detailed requirements with expected performances, to ensure the continuity and improvement of their services in due time, targeting first core users expectations. The following is delivered for first analysis:

- The staff working document of the Copernicus user needs;
- The extract of the Copernicus user requirements that can be potentially addressed by topography missions (at large) separated into core users' requirements and additional non-priority requirements for other relevant users;
- The extract of the Copernicus observation requirements analyzed and linking to topography missions;
- A note summarizing all the requirements expressed by the Copernicus core services.

At this stage, the Commission does not take any assumptions in terms of technical and operational feasibility from the space component point of view. As such needs are

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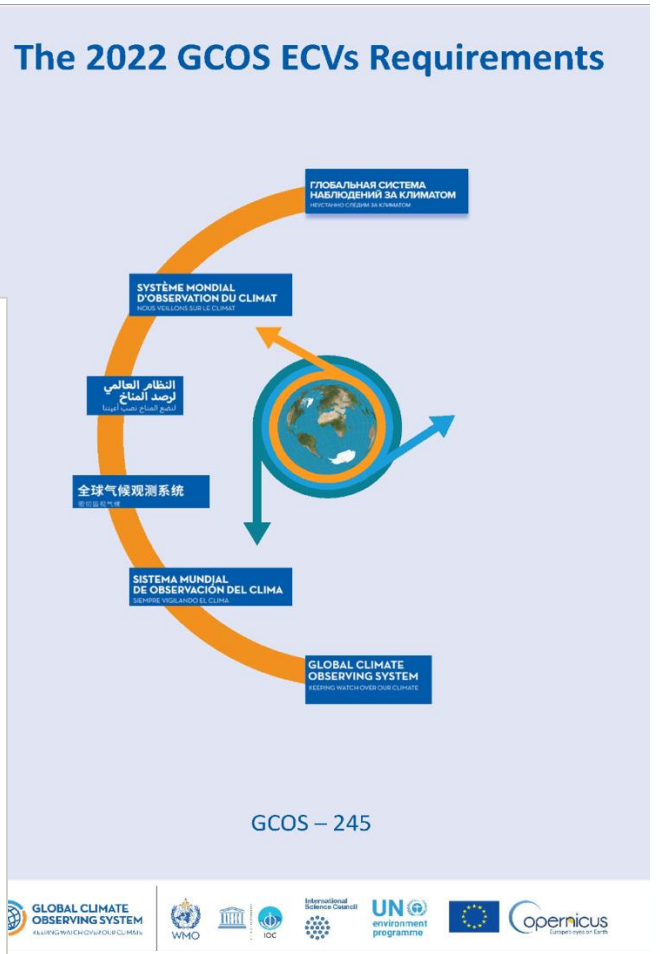

nature climate change

Perspective

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How accurate is accurate enough for measuring sea-level rise and variability

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Check for updates

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Sea-level measurements from radar satellite altimetry have reached a high level of accuracy and precision, which enables detection of global mean sea-level rise and attribution of most of the rate of rise to greenhouse gas emissions. This achievement is far beyond the original objectives of satellite altimetry missions. However, recent research shows that there is still room for improving the performance of satellite altimetry. Reduced uncertainties would enable regionalization of the detection and attribution of the anthropogenic signal in sea-level rise and provide new observational constraints on the water–energy cycle response to greenhouse gas emissions by improving the estimate of the ocean heat uptake and the Earth energy imbalance.

Sea-level estimates derived from high-precision satellite altimetry measurements have now reached a level of maturity that is unprecedented. Among the essential climate variables that are routinely monitored, sea level is arguably one of the most advanced, with quasi-global coverage, a very low ratio of missing or corrupted data (<4%), an advanced estimate of the uncertainties at global and local scales that accounts for the time correlation in errors, and robust validation through both comparisons with tide gauge records and regular assessments of closure of the sea-level budget[1]. Sea-level data quality is evaluated by a detailed analysis of the altimetry measurement uncertainty budget, and it shows a very low uncertainty level (for example, ±0.3 mm yr^{-1} in 20 yr and longer trends) that exceeds the altimetry missions' requirements[2]. This low level of uncertainty raises the question of whether there is a need of further research to improve the sea-level record. Simply put, the question is: how accurate is accurate enough? This question is important for the ocean surface and topography science community and the general ocean science community, as an important amount of resources is currently used to continuously refine and improve knowledge of the sea-level record uncertainty.

Here we explore the uncertainty that should be targeted by future satellite altimetry constellations for global mean and regional sea-level estimates. We review the literature and find that three major science questions still need an improved sea-level measurement performance that is higher than currently available from satellite altimetry systems today. First, can improvements close the sea-level budget? Second, is it possible to detect and attribute the signal in sea level that is forced by GHG emissions? Third, will this allow estimation of the current Earth energy imbalance (EEI) mean and variability? Although the uncertainty of satellite altimetry measurements is close to the limits of the current capacity of the altimetry system, we argue that there is still room for improvement. Improved performance would bring important insights on the three science questions, particularly at large spatial scales (>1,000 km). However, locally, at smaller scales, spatially random errors do not average out, and the level of uncertainty is too high to expect to tackle the three science questions. To meet regional-scale requirements, important changes to the altimetry system would be needed, such as better long-term measurement stability of wet tropospheric delay derived from microwave radiometer instruments

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Sentinel-6 Next Generation Key Science Drivers

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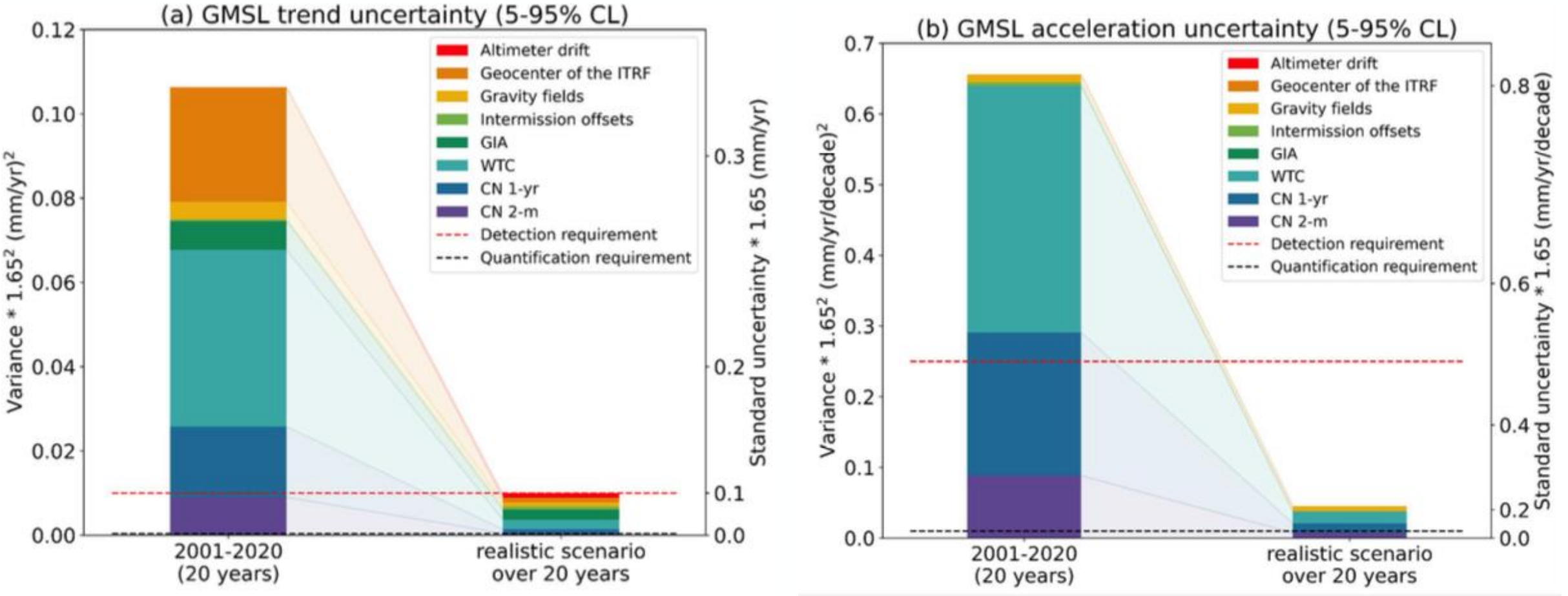
		GMSL rates	GMSL acceleration	SL (~100 km) rates
Current uncertainty over 20 years (Guérou et al., 2022; Prandi et al., 2021)		0.3-0.5 mm/yr	0.7-1.2 mm/yr/decade	0.78-1.22 mm/yr
GCOS (2011) requirements		< 0.3 mm/yr	Not defined	< 1 mm/yr
New requirements for scientific questions (Meyssignac et al., 2023)	**Closing the sea level budget**	Detection: **±0.1 mm/yr** Quantification: ±0.02 mm/yr		Detection: ±0.3 mm/yr Quantification: ±0.07 mm/yr
	Detecting and attributing signal forced by greenhouse gas emissions	Detection: ±1.5 mm/yr Quantification: ±0.7 mm/yr		Detection: **±0.5 mm/yr** Quantification: ±0.01 mm/yr
	Estimating the EEI	Detection: ±0.1 mm/yr Quantification: ±0.03 mm/yr	Detection: **±0.5 mm/yr/decade** Quantification: ± 0.1 mm/yr/decade	

Requirements and state-of-the-art estimates for the global mean and local sea level (SL) stability uncertainty (5-95 % confidence interval). Values in bold font indicate the values set as requirements within the ASELSU project. Values over decadal timescales.

Sentinel-6 Next Generation Key Science Drivers



Current GMSL trend and acceleration uncertainty over 20 years and possible scenario to reach the requirements with future altimetry missions (Meyssignac et al., 2023).

Setinel-6 Next Generation Key Mission Drivers

1. Compliance with the space debris regulation.
2. State of the Art stability and performance for Microwave Radiometer and Radar Altimeter.
   - Triple-frequency altimeter (for improved ionosphere and Sea State Bias); multi-frequency Microwave Radiometer for improved Wet Tropospheric Correction.
   - Platform performance: Orbit determination, Attitude (pointing accuracy & knowledge), etc.
3. Satellite design lifetime from the 5 to 7.5 years, in line with the other Copernicus missions.
4. Need to maintain global and regional MSL trend uncertainty stability to comply with science requirements; the role of S6NG as a reference altimeter for all other altimeter missions.
5. Comply with programmatic conditions reflected in the May 2025 Copernicus Long-Term Scenario (ESA/PB-EO(2025)30)

> ***Key Question:*** *Is it necessary to operate with a higher inclination orbit to cover a larger portion of the Arctic and Southern ocean and/or to a lower orbit to extend the mission lifetime, whilst meeting de-orbiting requirements?*

The S6NG mission in the CSC Long Term Scenario Current baseline

Current Sentinel-6 mission

- Implemented as a partnership ESA, EUMETSAT, NASA, NOAA under the frame of a dedicated MOU
- Spacecraft design lifetime: 5.5 years
- 5-year separation between the launches of the recurrent satellites in line with the design lifetime
- Deployment: Sentinel-6B (November 2025), Sentinel-6C (end 2030, TBC)

Sentinel-6 Next Generation

- The Sentinel-6 Next Generation mission is foreseen in the Copernicus Space Component (CSC) Long Term Scenario (LTS) as the mission in-charge of guaranteeing continuity of the Sentinel-6 reference altimetry capability for the 2035-2050 time frame;
- The S6NG mission responds to evolving user requirements, to enhance the current measurement performance capabilities within the Copernicus Topographic family: the CRISTAL, S3NG-Topo and S6NG missions.
- It could be considered to make Sentinel-6 NG a dual-spacecraft constellation like the other Copernicus missions. This would greatly improve the robustness of the reference altimeter system, as well as enhance the revisit time.

S6NG CSC Long Term Scenario Implementation baseline

Sentinel-6 NG high-level implementation phases outline

Phase 0:

- ESA Future Missions and Architecture Dept. lead, support from industry, duration 12 months, start in July 2024
  - Altimeter (TAS-F) and Radiometer (OHB-IT, ADS-ES).
  - Establish high level paper concepts and their costing.
  - ESA led Concurrent Design Facility Q2/2025 leading to a costing input to the CMIN-25.
- Funded: ESA Future-EO

Phase A/B1:

- two parallel studies, duration 24 months, ITT Q1/2026 kick-off in Q4/2026
- Funded: ESA Future-EO for subscription CMIN-25

Phase B2/C/D:

- open ITTs, duration 12m (Phase B2), 28m (Phase C), 34m (Phase D), kick-off in Q4/2029, QAR in Q4/2035
- co-funded: CSC-5 subscription CMIN-28 and EU MFF 2028-2034

Sentinel-6 Next Generation ESA Phase-0 Activities

- Two industrial phase 0 studies initiated with parallel contracts for the microwave radiometer and to a single contractor (TAS-F) for the radar altimeter.
- The Phase 0 Activities finalised with the System Study in ESA's Concurrent Design Facility (CDF), in Q3 2025.
- As part of this Phase-0, *ESA is considering all options for the implementation of the mission, to fulfil the requirements we currently have, taking into consideration technical and programmatic constraints.*
- *Final orbit option to be selected during Phase-A as an input to the Preliminary Concept Review (tentatively Q1/Q2 2027)*.

S6NG CDF Overview

- System Activity at ESA/ESTEC Concurrent Design Facility (CDF)
- CDF study from April until mid-June (Final presentation 11th and 12th June)

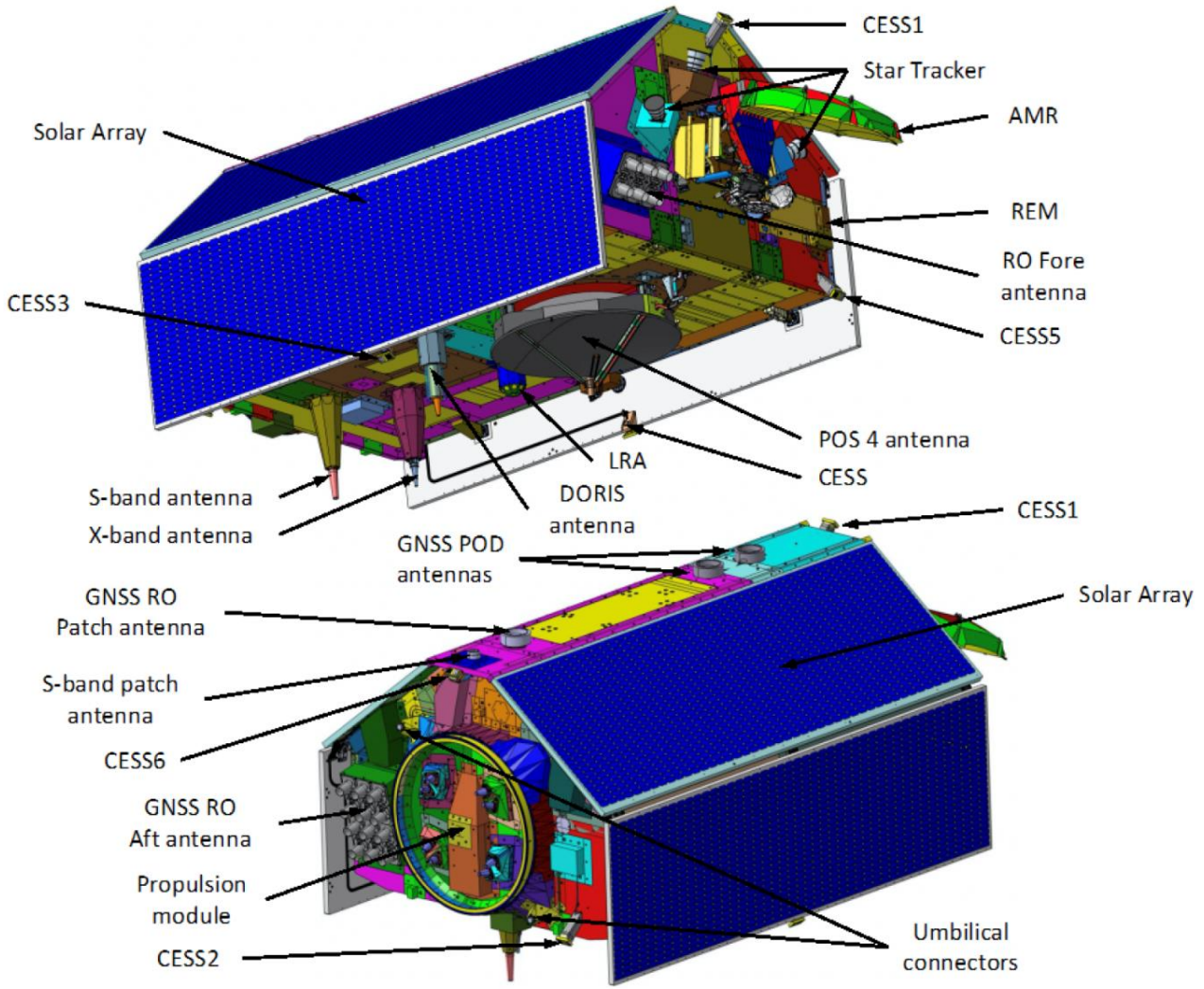
- Main Objectives System Activity at CDF:
  - Accommodation of Radiometer & Altimeter concepts on platform.
  - System trade-off analysis (e.g. orbit altitude)
  - System performance and compliance with MATER
  - Spacecraft preliminary design & system budgets
  - TRL status and definition of potential technology developments
  - Programmatic assessment
  - Preliminary baseline system concepts

- CDF outcomes together with the altimeter and radiometer phase-0 studies will result in S6 NG Phase 0 baseline system concept(s) and programmatic assessment – internal costing assessment still on-going.

Design Drivers

European Launcher – Vega-C	Constrains **volume** of the spacecraft
Performance requirements	Pointing knowledge, POD solution, ground track maintenance, availability/latency of the data **-> Impact on AOCS, Structure, GNSS, Communications, ConOps**
Operational Orbits	Reference Orbit (heritage from past altimetry mission) vs. Lower Altitude Orbits (lower delta-V budget) -> Impact on propulsion, Structure, Power, Radiation (lifetime)
Selection of Instruments concept	Alimeter tri-band antenna (s) : New Development vs. Existing Technology **-> Impact on Configuration, interfaces, Power and Mass requirements**
Satellite(s) Lifetime	Increased lifetime: 7.5 years + 5 years extension **-> Impact on Power, Structures, delta-V budget, etc**
Space Debris Policy	New Space Debris Mitigation Requirements: increased delta-V budget for controlled reentry **-> Impact on propulsion subsystem, dry mass of the satellite and orbit selection**
Cost	Cost Cap puts constraints on programmatics

Sentinel 6 platform as basis for S6NG



Lifetime:

5.5 years operational life with additional 2 years extension

Mission Orbit:

LEO, non sun-synchronous

Altitude = 1,336 km

Inclination = 66°

Launch Vehicle:

Falcon-9 (US)

Spacecraft:

Dimensions

Stowed Conf. = 5.1 x 2.6 x 2.3 m

Flight Conf. = 5.1 x 4.3 x 2.3 m

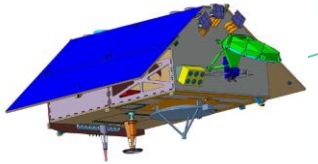
Mass = 1,190.7 kg (wet) incl. 230 kg of hydrazine; 960.7 kg (dry)

Power = 891 W average consumption

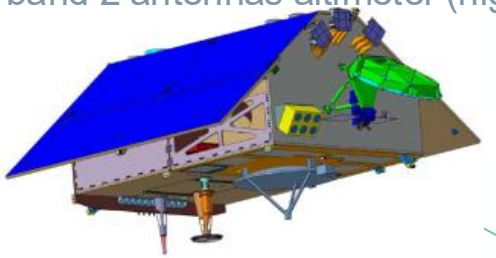
Data Volume = 1,200 Gbit/day

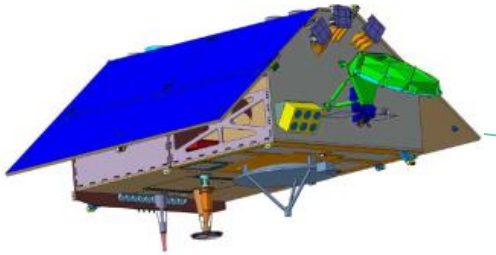
Options studied during CDF

Closest possible to existing S6 design.
Dry mass: 1351 kg
Power: 1287 W (300W higher than S6)
1 pressurised N2H4 tank
Tri-band Cassegrain altimeter (low TRL)



Larger platform to accommodate 2 altimeter antennas
Dry mass: TBD kg (Structure TBD)
Power: 1287 W -> TBC
2 OST-25 tanks needed
Tri-band 2 antennas altimeter (high TRL)





Larger platform to accommodate 2 altimeter antennas
Dry mass: TBD kg (Structure TBD)
Power: 1287 W -> TBC
Lower delta-V -> one tank only, smaller wet mass
Longer lifetime
Tri-band 2 antennas altimeter (high TRL)

S6NG Phase-0 Science Activities

- An Ad Hoc Expert Group (AHEG), formed by 10 external experts together with CNES, EUMETSAT and EC representative, was put in place to advise ESA on the preparation of the Sentinel-6 Next Generation (S6NG) mission.
- Mission Assumptions and Technical Requirements Document (MATER)
  - Requirements consolidated with AHEG and from feedback of studies during phase-0.

- ASELSU phase-2 project will establish uncertainties for Global and regional Mean Sea Level (GMSL) trends for the reference mission and intermission offset uncertainties.
- Study to assess performance of a triple-frequency altimeter and MWR performances based on a data-drive approach (DPAAR) is on-going.
- Study to assess the impact of a potential change of orbit of the reference mission on the uncertainty and stability of global and regional mean sea level trends (ORBITAS).

The DPAAR Study

- DATA-DRIVEN PERFORMANCE ASSESSMENT OF ALTIMETERS AND RADIOMETERS FOR NEXT-GENERATION ESA ALTIMETRY MISSIONS (DPAAR).
- The objective of this study is twofold:
  - to establish the benefit of a triple frequency nadir altimeter, and establish an optimum choice of frequency bands for the microwave radiometer instrument, with special focus on the wet tropospheric correction for open ocean, coastal zones and inland waters;
  - to provide inputs to the S6NG mission Phase 0 activities, related to the consolidation of the mission performance.
- The assessment to be developed within this study will be based on state-of-the-art models, data from in-flight altimeters, radiometers, high resolution models, and in-situ observations.
  - isardSAT S.L, ES, selected as prime contractor, with NPL, UK, Fluctus, FR, Informus, DE.

The ORBITAS Study

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- REFERENCE ALTIMETER **ORB**IT **I**MPACT ON SEA LEVEL **T**REND AND **A**CCELERATION **S**TABILITY UNCERTAINTY (**ORBITAS**).
- Activity progressing nominally:
    - Kick-off on 11th July, PM1 8-9th September .
    - Consortium formed by Magellium (prime), CLS, NERCS, LEGOS, U-Hamburg, NPL.
    - Duration: 18 months.
- The objective of this study is to evaluate if a new reference orbit for the S6NG mission could further enhance the capabilities of the altimeter constellation, enabling the achievement of the rigorous scientific requirements previously mentioned, and assess any potential impacts of such an orbital change on the stability uncertainty of the sea level geodetic data record.

Take Away Messages

- Sentinel-6 is the current Copernicus mission in-charge of maintaining the trend uncertainty stability of the global and regional mean sea level geodetic data record (reference altimeter).
- The CSC LTS baseline identifies the Sentinel-6 Next Generation mission to maintain the geodetic data record in the 2035-2050+ timeframe.
- ESA is designing the mission to meet the stringent science and programmatic requirements.

- Pending programmatic assessment, viable solutions for the mission have been found for all orbit configurations.

- The various S6NG orbit options are under consideration, the decision on the final orbit will come after Phase-A1 study, prior to the Preliminary Concept Review (Q1/Q2 2027).

Any questions ?

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