# The Sentinel-3 Next Generation Topography Copernicus Altimetry Mission: Enhancing Continuity, Performance and Observational Capabilities

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SWOT Science Team Meeting
17-10-2025

S3D: 2027/8+ (TBC)

S3C: 2026 (TBC)

Copernicus Sentinel-3 First Generation
20 years of consistent Operational measurements

S3B: 2018-

S3A: 2016-

→ A BIGGER PICTURE FOR COPERNICUS

# Classical altimetry topography products derived from Sentinel-3 up to 81.5 deg N/S
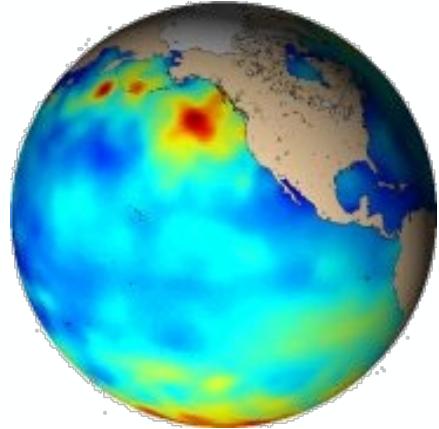
Wind and Waves

Sea Surface Height

Sea level rise

DEM, Tides, Hydrology, MSS ...

Arctic sea-ice thickness Jan-Feb 2011
Extent of multi-year ice
Ice thickness, in metres

Source: CPOM/UCL/ESA/METNO

Sea ice and Ice sheets
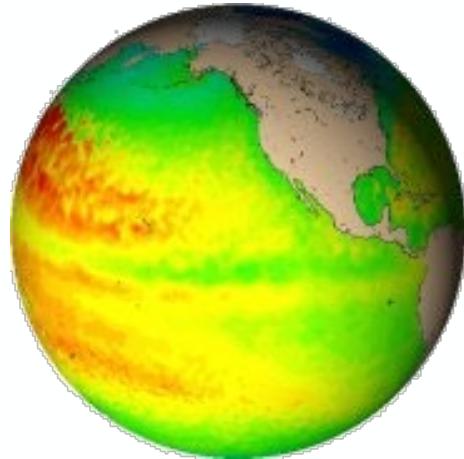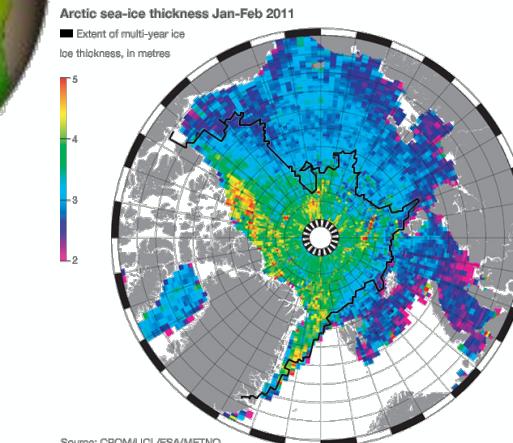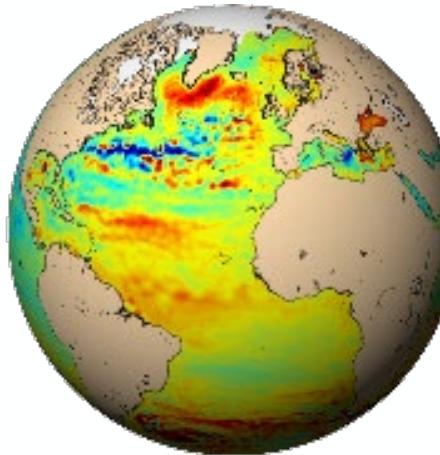
## The World's Water
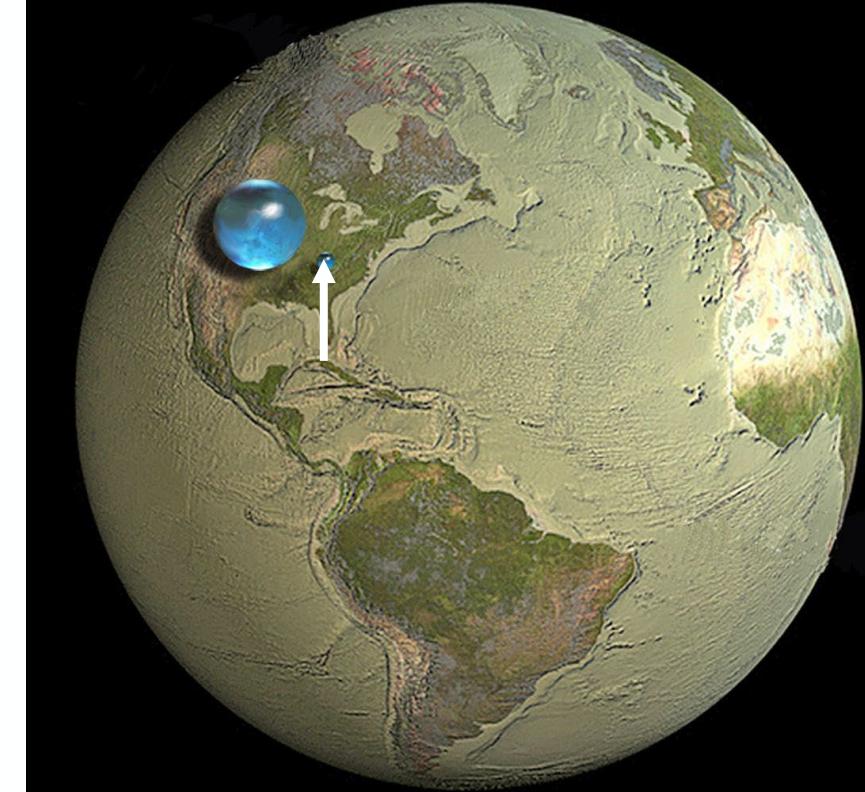
All water on, in, and above the Earth
Liquid fresh water
Fresh-water lakes and rivers

Howard Perlman, USGS,
Jack Cook, Woods Hole Oceanographic Institution,
Adam Nieman
Data source: Igor Shiklomanov
http://ga.water.usgs.gov/edu/earthhowmuch.html

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# Copernicus User Needs

- **User Needs are sourced from Official European Commission Documents**
  - Wide ranging needs that, at high time and space resolution, cannot always be met
- Nevertheless, we can see strong and clear User Needs **for Topography** (i.e. SSH, Hs, winds, River and lakes, sea level, continuity of the altimeter reference mission, 2D-wave spectra, Ice sheet elevation and dynamics, sea ice thickness, Surface ocean currents (TSCV for marine plastic debris etc)…)
- **ESA Analysis of User Needs provided by the European Commission provides the justification and traceability for S3NG-Topo.**

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## Copernicus Sentinel-3 Next Generation Topography (S3NG-T) Mission Requirements Document (MRD)

| | |
|---|---|
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| Distribution | ESA Unclassified – For Official Use |



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# S3NG-T Mission Aim and Objectives



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- Mission aim and Objectives stem from the analysis of User needs and Copernicus Space Component Long Term Scenario

- Target is to **guarantee the continuity of S3 today**
  - For **ALL** topography variables SSH, Hs, U10, Sigma0, sea ice, land ice, river and lakes…

- **Then, to enhance S3** and address:
  - **Sampling and coverage → time AND space sampling (#1 User Need – for everyone working with altimetry)**
  - **Hydrology** sampling and performance (now primary Objective by EC request)
  - Provide **new products** to meet evolving Copernicus User Needs.

## 4  S3NG-T MISSION AIMS AND OBJECTIVES

### 4.1  S3NG-T Mission Aim

Considering the User needs expressed by the European Commission and concisely articulated in the previous sections, the **aim** of the Copernicus Next Generation Sentinel-3 Topography (S3NG-T) Mission is:

*To ensure continuity of Sentinel-3 in flight performance topography capability in the 2030-2050 timeframe.*

### 4.2  S3NG-T Objectives

Mission requirements are then derived from mission Objectives.

The primary objectives of the S3NG-T mission are to:

PRI-OBJ-1.  **Guarantee continuity of Sentinel-3 topography measurements** for the 2030-2050 time frame with performance at least equivalent to Sentinel-3 in-flight performance as defined in Table 2.4-1 ('baseline mission').

PRI-OBJ-2.  Respond to evolving user requirements and **improve sampling, coverage and revisit** of the Copernicus Next Generation Topography Constellation (S3NG-T and Sentinel-6NG) to ≤50 km and ≤5 days (CMEMS, 2017) in support of Copernicus User Needs.

PRI-OBJ-3.  **Enhance sampling coverage, revisit and performance for Hydrology Water Surface Elevation measurements** in support of Copernicus Services.

PRI-OBJ-4.  Respond to evolving user requirements and **enhance topography Level-2 product measurement performance**.

The secondary objectives[9] of the S3NG-T mission are to:

SEC-OBJ-1.  Provide directional wave spectrum products that address evolving Copernicus user needs.

SEC-OBJ-2.  Provide new products[10] that address evolving Copernicus user needs.

# S3NG-T Mission Status

- A competitive phase A/B1 feasibility study derived the mission concept, with two consortia in parallel, ADS and OHB.

- The Mission Gate Review (MGR) –with inputs from CNES, NASA/JPL from SWOT in-flight performance and Phase A/B1 studies– endorsed the baseline mission implementation option.

- ITT released for implementation phase B2/CD, with mandatory providers for the swath and nadir altimeters (TAS-FR) and for the microwave radiometer (Airbus-ES).

- Kick-off of the industrial consortium Q2 2026

- Satellite PDR Q2 2029

- Satellite QAR end 2033

# S3NG-T Mission Concept

50 Km    20 Km    50 Km

SAOOH Swath    POS-5 Beam    SAOOH Swath
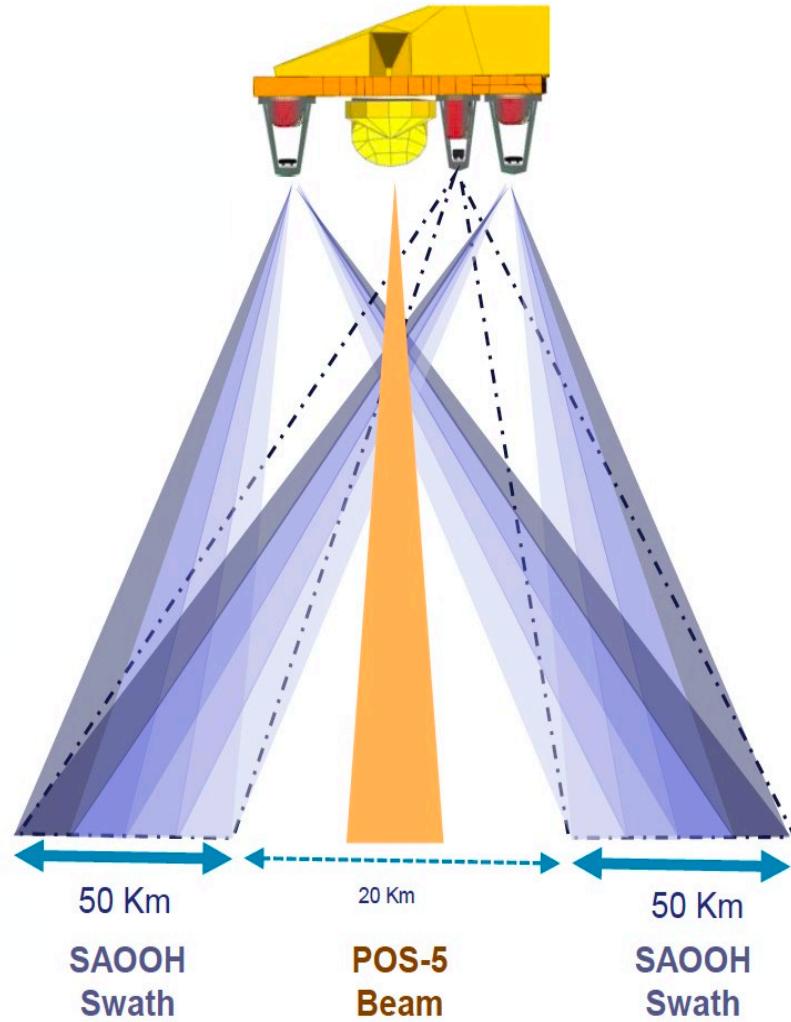
Constellation of **2 large satellites,** flying in formation **in sun-synchronous dawn-dusk (LTAN 6pm) orbit.** Same ground-track as Sentinel-3 A/B.

SAOOH, ka-band across-track interferometer:

> 2 operation modes: LR for open ocean and land ice, and HR for ocean and hydro/sea ice.

POS-5 Ku-band Nadir SAR altimeter, provides baseline continuity.

3-Beam multi-frequency microwave radiometer (MWR).

Constellation can achieve global 5-day revisit with an effective ocean spatial resolution of 50 km (key driving requirements for mission design).

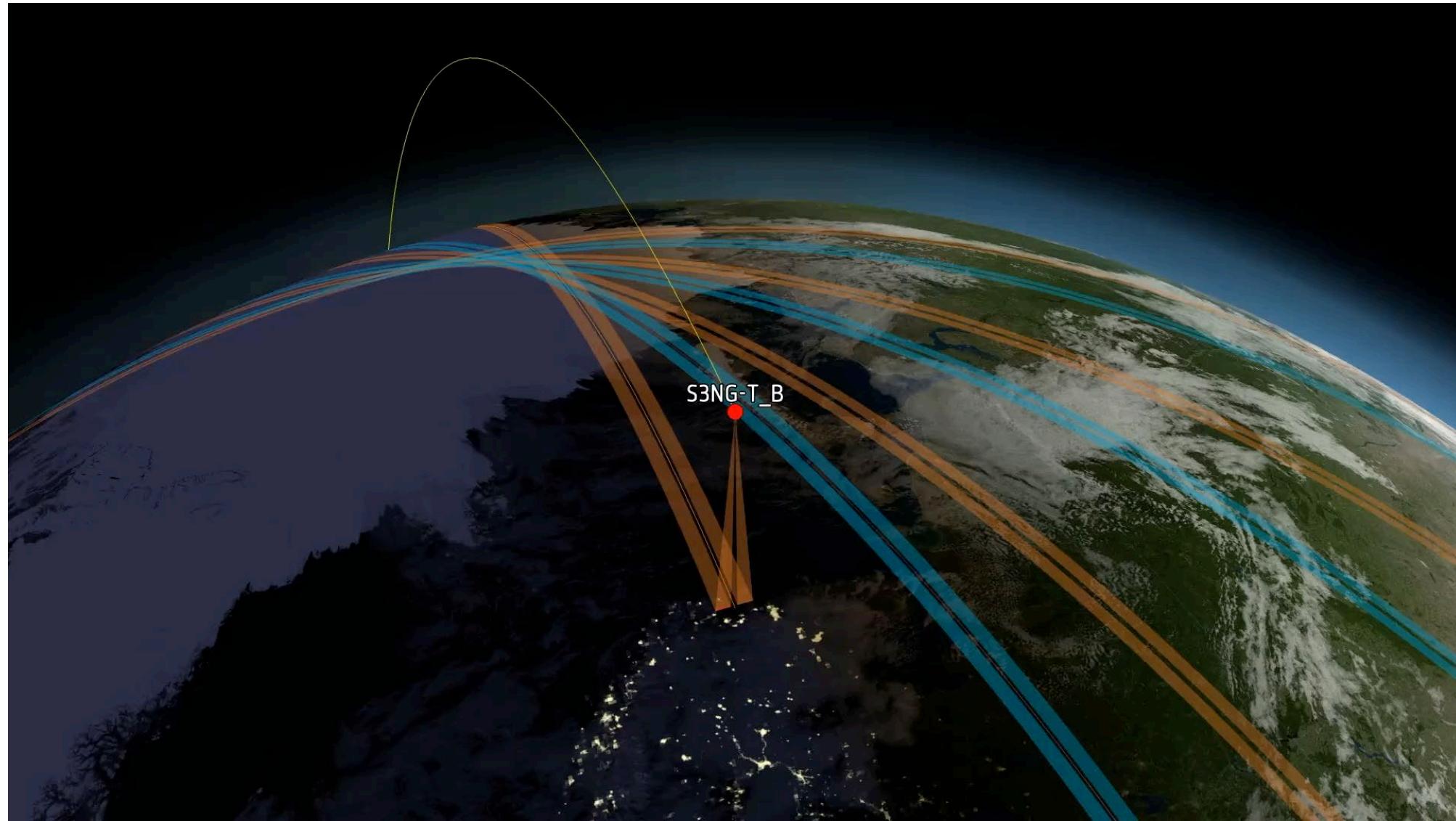# S3NG-T Baseline Orbit Configuration: Sentinel-3 A/B ground tracks

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# Orbit configuration achieves coverage requirement: 80% in 5 days / 50 km resolution.
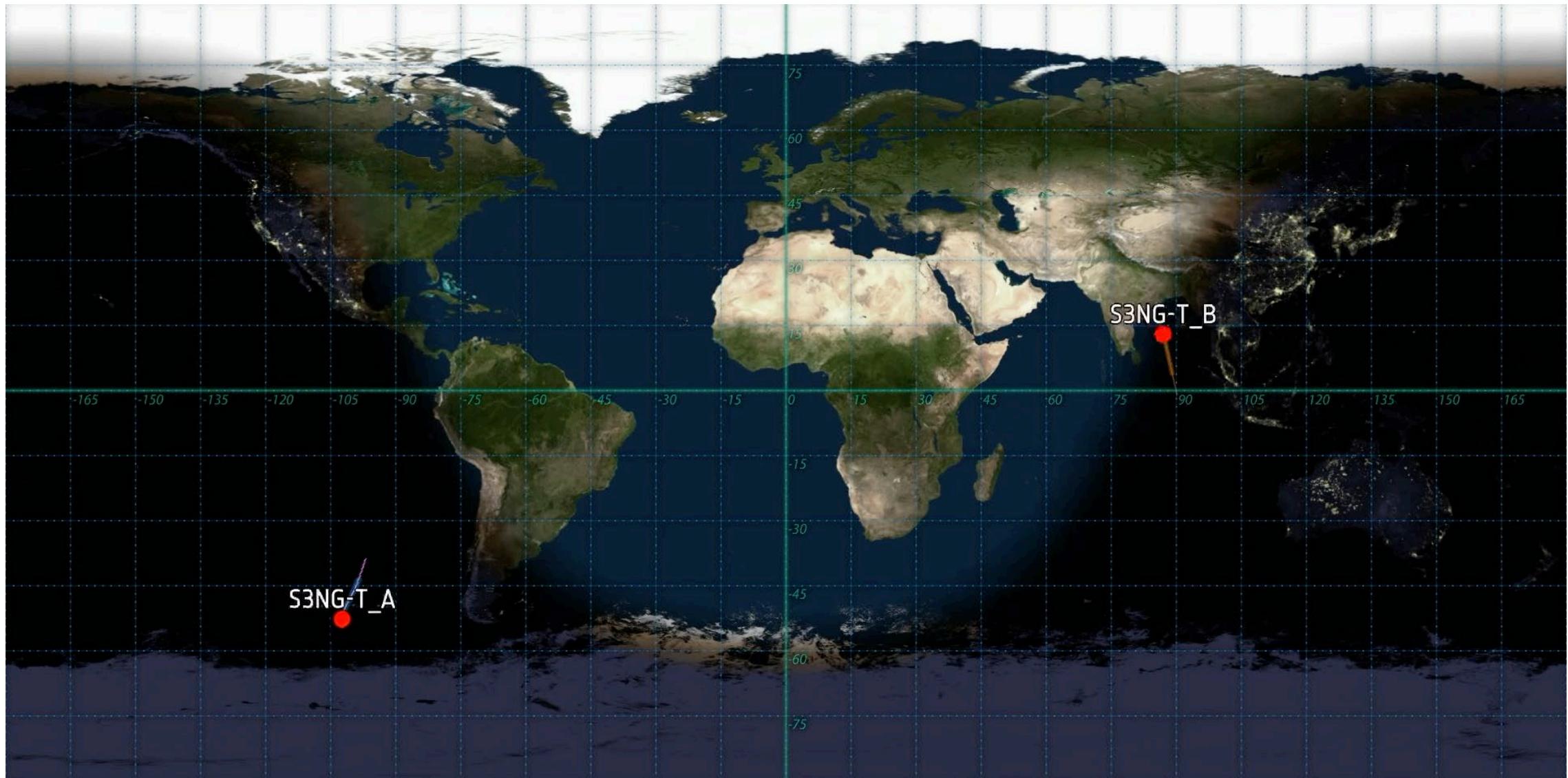
# S3NG-T Baseline Acquisition Scenario

- Continuous acquisitions over different Areas of Interest
  - SAOOH has different modes depending on the Area of Interest
  - POS-5 performs continuous acquisitions over all areas
  - MWR provides continuous acquisitions
- SAOOH RAW data acquisitions upon request, only planned during commissioning.
- SAOOH Wave Mode ensures continuous access to wave spectrum over ocean across the swath.
- SAOOH can activate the swath beams independently, providing flexibility to the mission.
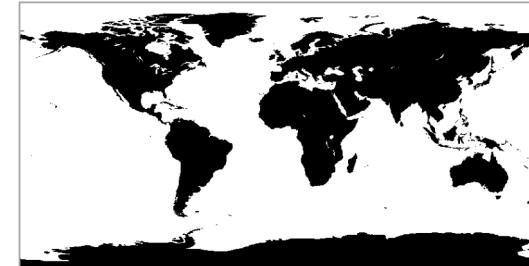

Open Ocean
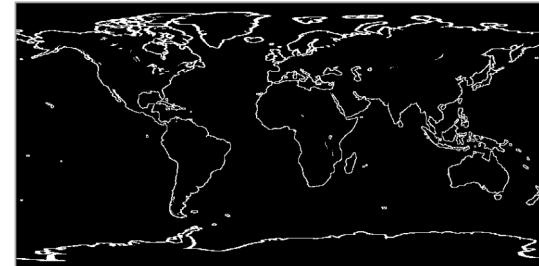

Coastal
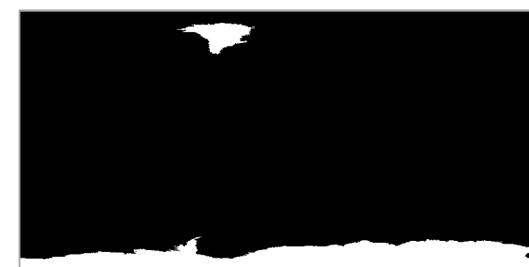

Land Ice
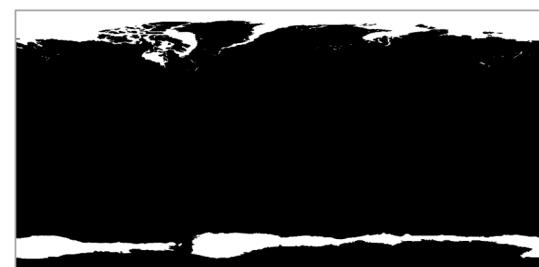

Sea Ice

| Instrument | Ocean | Land Ice | Coastal | Sea Ice | In-land acquisitions | RAW |
|---|---|---|---|---|---|---|
| POS5 | Nominal | Nominal | Nominal | Nominal | Nominal | Nominal |
| SAOOH | Ocean/Wave | Ocean | Ocean/Wave + HR | Ocean + HR | HR | RAW1 |
| MWR | Nominal | Nominal | Nominal | Nominal | Nominal | Nominal |
| Data Rate | 137 Mbps | 131 Mbps | 802 Mbps | 796 Mbps | 729 Mbps | ~15 Gbps |

# The S3NG-T SAOOH Instrument



*Courtesy TAS-F*



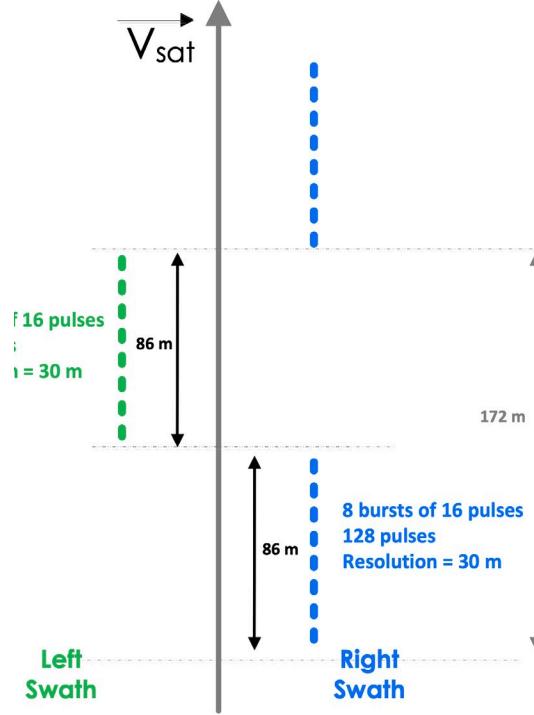Labels in diagram: $V_{sat}$, 16 pulses, = 30 m, 86 m, 172 m, 8 bursts of 16 pulses, 128 pulses, Resolution = 30 m, 86 m, Left Swath, Right Swath

*Courtesy TAS-F*

- S3NG-T/SAOOH design tailored to mission requirements.

- Similar acquisition geometry to SWOT: two swaths of 50 km with a 20 km gap around nadir, covered by the SAR nadir altimeter.

- Each swath is illuminated alternatively (single-side swath mode (HRFF) with continuous chronogram also available).

- Four Rx beams per sub-swath for better SNR with a non deployable antenna.

- 200 MHz bandwidth for a cross-track resolution ranging from 60m (inner swath) to 10 m (outer swath)

- 128 consecutive pulses on each swath allow along-track resolution of 30 m.
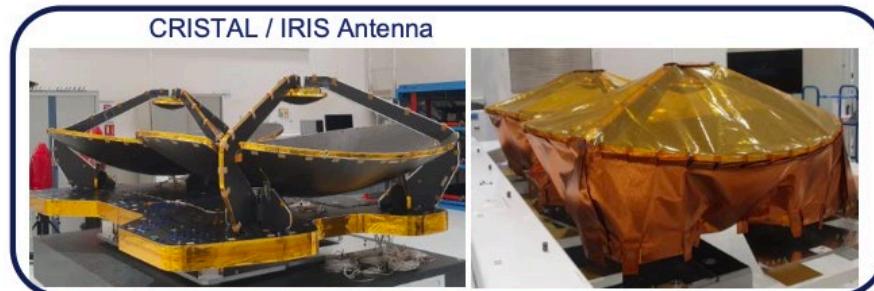
# The S3NG-T SAOOH Instrument
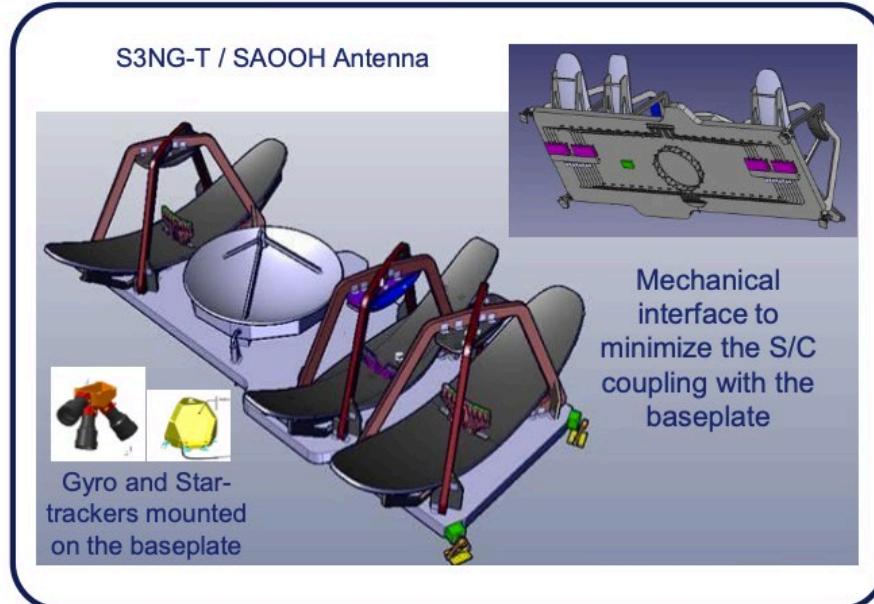


*Courtesy TAS-F*

- SAOOH features a more compact baseline on a stable antenna bench

- All elements mounted on a reference carbon fibre baseplate, including the Gyro and Star Trackers

- POS5 antenna shares the same baseplate

- Accommodation based on central ring: decouple platform thermo-mechanical variation during the mission

- Ultra-stable baseplate, reflectors and structure technology inherited from the Ku/Ka band radar interferometer IRIS on Copernicus CRISTAL mission

- Optimal gain, adapted to acquisition geometry , enable steady random error in whole swath.

# SAOOH Instrument CBE meets mission requirements with margin

**Random Height Error at 1km²**

- SAOOH Worst case + 3dB system margin
- SAOOH CBE typical
- SWOT in flight

Random Height Error (mm) vs Ground Range (km)
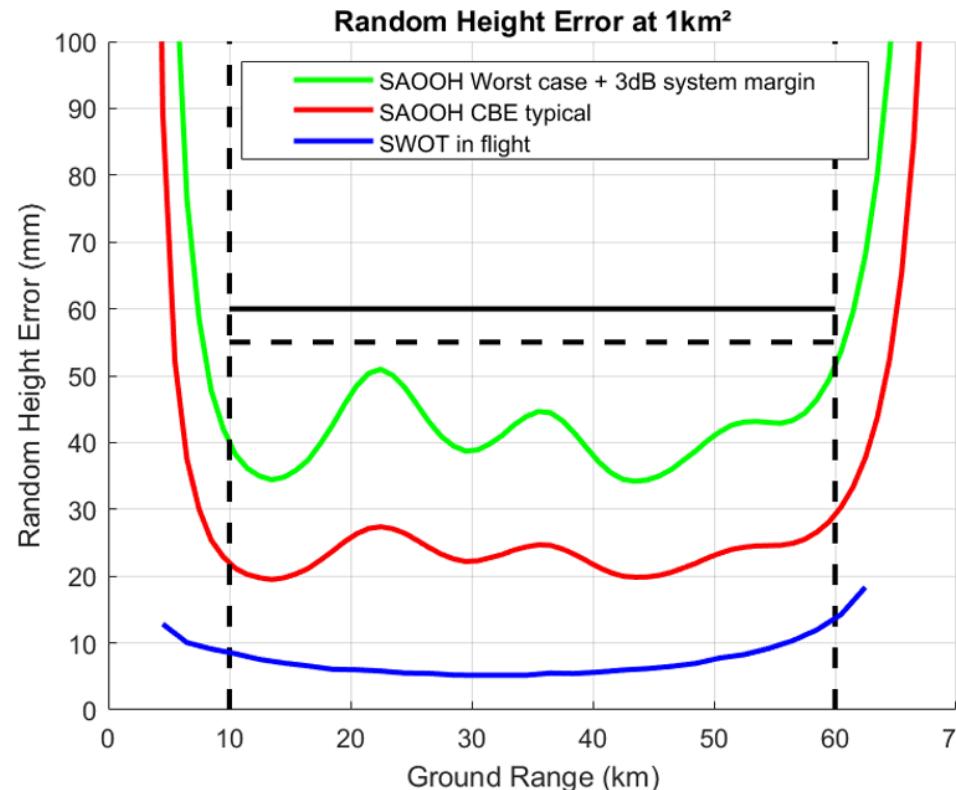
**SSH Random error (1km², U10 = 8.9 m/s, SWH = 2 m)**
**Solid black line = total mission error requirement**
**Dash line = allocation to the random error**

*Courtesy TAS-F*



- SAOOH systematic instrument error (including GSE)
- GSE error
- SAOOH thermal+TED

SAOOH error (cm) vs wavelength (km)

HF Gyro-Stellar attitude knowledge error

Orbital thermal variations

Seasonal thermal variations
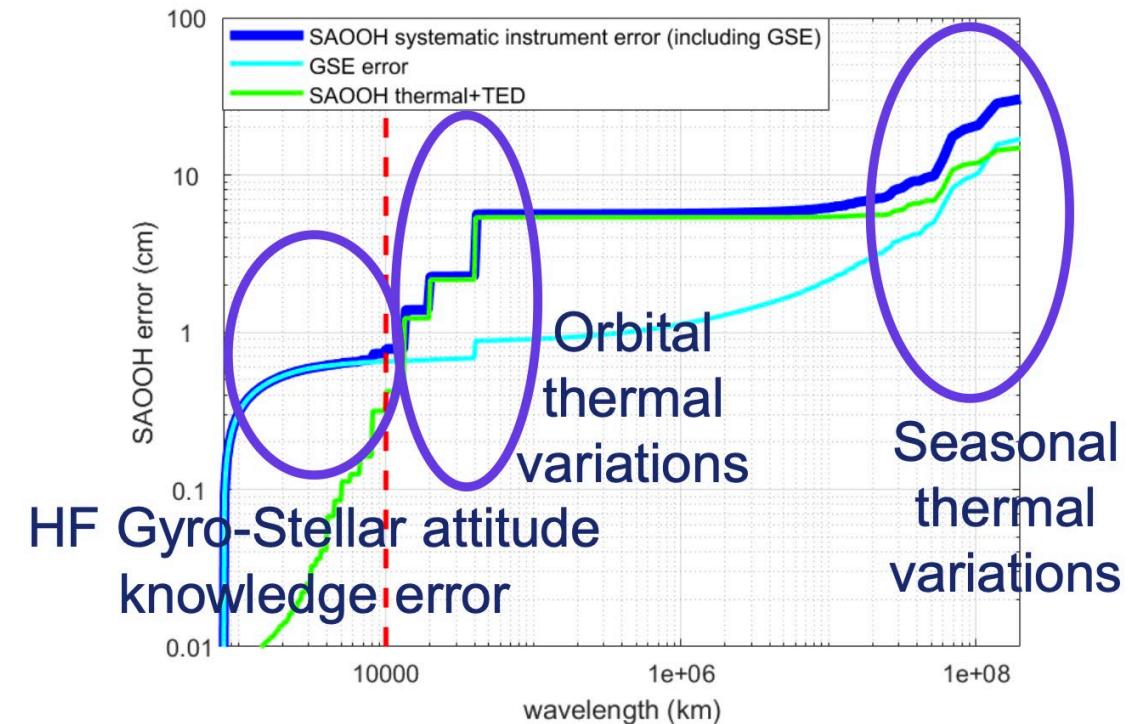
**SSH Systematic errors before cross-calibration are below 1 cm for wavelengths lower than 10000 km, thanks to antenna stability and last generation Star Trackers / Gyro**

*Courtesy TAS-F*

# S3NGT End-to-End Simulations

Numerical (*) spatial integration of the complex radar equation

On-Board Processing chains prototype

Complex raw data (@PRF, radar resolution)

telemetry

Ground Processing chains prototypes (L1 & L2)

Performance Assessment

L2 geophysical estimates
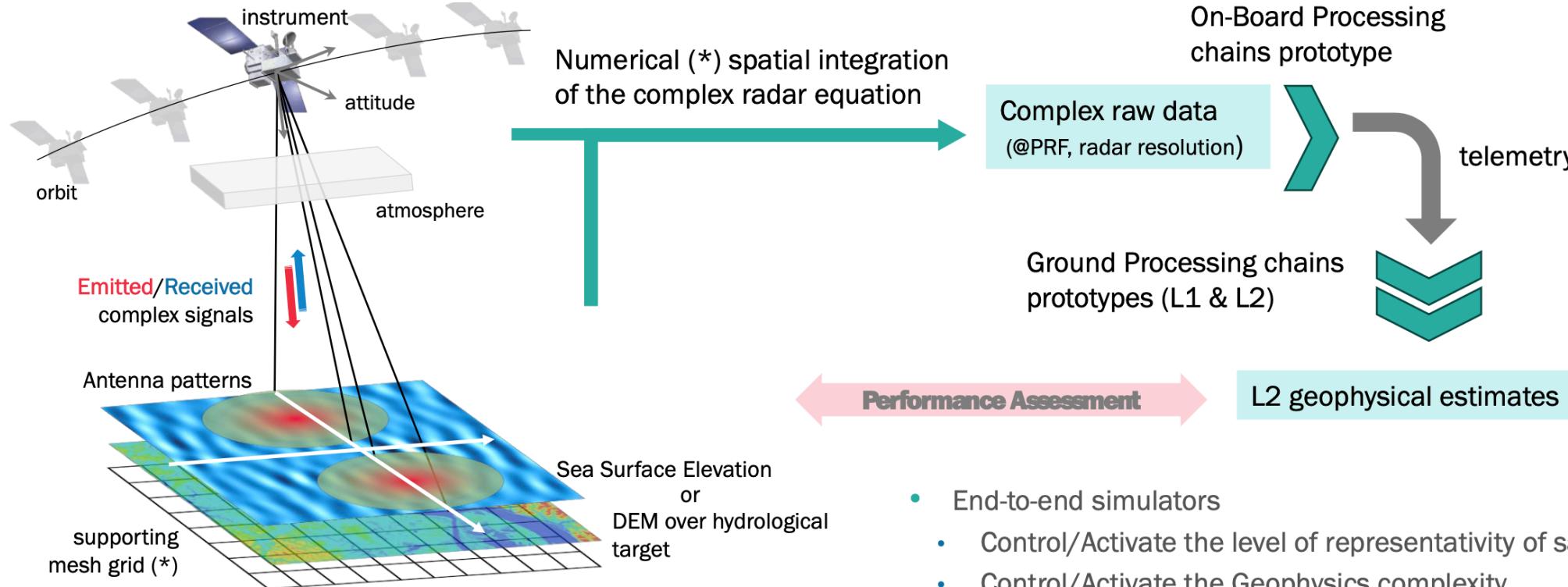
instrument

attitude

orbit

atmosphere

Emitted/Received complex signals

Antenna patterns

supporting mesh grid (*)

Sea Surface Elevation or DEM over hydrological target

- natively encompass instrument, surface & OB to L2 processing impacts on performance.
- are considering 3dB of system margins with the Current Best Estimate

- • End-to-end simulators
  - • Control/Activate the level of representativity of satellite
  - • Control/Activate the Geophysics complexity
- • (*) The sampled/gridded resolution of a continuous spatial integral implies the use of 2-scale modeling, One is at the size of the facet and above and is resolved. The other one is under the size of the facet and is unresolved (or statistically accounted for).
  - • In the instrument performance assessment, the grid resolution is tight (~1m): length of simulations is constrained by substantial simulation time.

*Courtesy CLS*

# S3NGT End-to-End Simulations
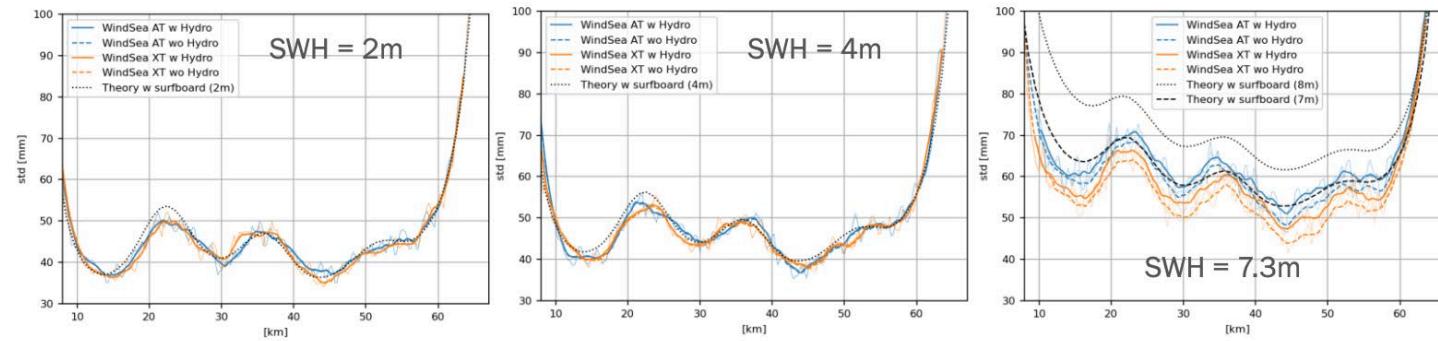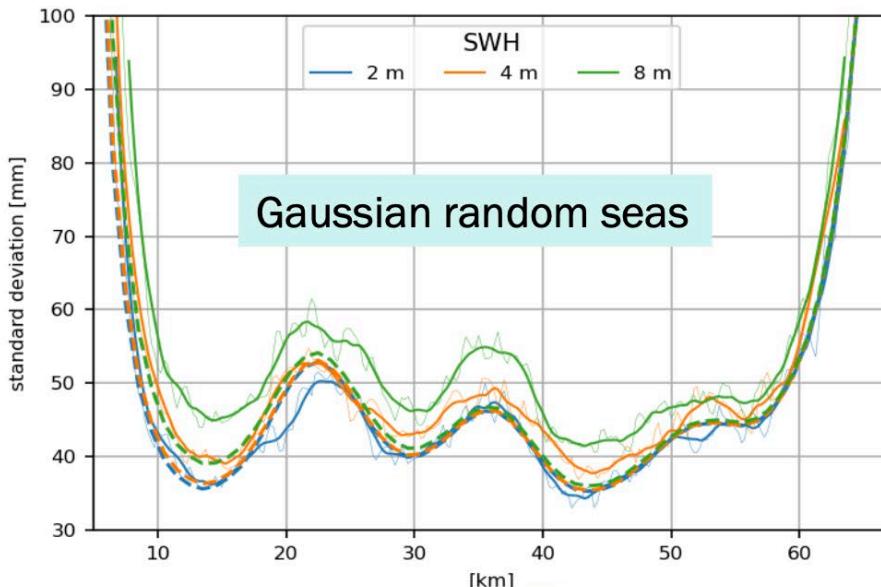## SSH performance over ocean



Gaussian random seas

Spectral waves seas (geometry + nonlinearities)

SWH = 2m

SWH = 4m

SWH = 7.3m

- Excellent agreement between the random noise model/theory (dashed) and e2e simulator performance estimates (solid lines)
- The random noise that is accounted for in the SAOOH error budget is the mean value along the four beams of SAOOH (4,5 cm at 1km², SWH=2m) integrated over 12.5×6,5km → 0.5 cm

At a given SWH:
- The waves induced random noise (from volumetric decorrelation) is lower than for SWOT (it is a baseline effect)
- The surfboard effect impact on performance is comparable to the one of SWOT (instrumentally speaking, it depends mainly on the elevation angle).

*Courtesy CLS*

# S3NGT End-to-End Simulations
## WSE performance over hydro

- Dedicated Hight Resolution hydrology processing chain (starting at OB processing), not comparable to ocean (LR) data.
- Sensitivity study of On-Board Processing configuration: Doppler beam selection, Bit Floating Point Quantifier



**Performance @1km²**

Legend (left plot):
- No BFPQ, 5 beams
- No BFPQ, 9 beams
- No BFPQ, 16 beams
- TAS No BFPQ, 5 beams
- TAS No BFPQ, 9 beams
- TAS No BFPQ, 16 beams

y-axis: height std [mm] · x-axis: Across-track [km]

Legend (right plot):
- No BFPQ, 5 beams
- BFPQ, 5 beams
- TAS No BFPQ, 5 beams

x-axis: Across-track [km]
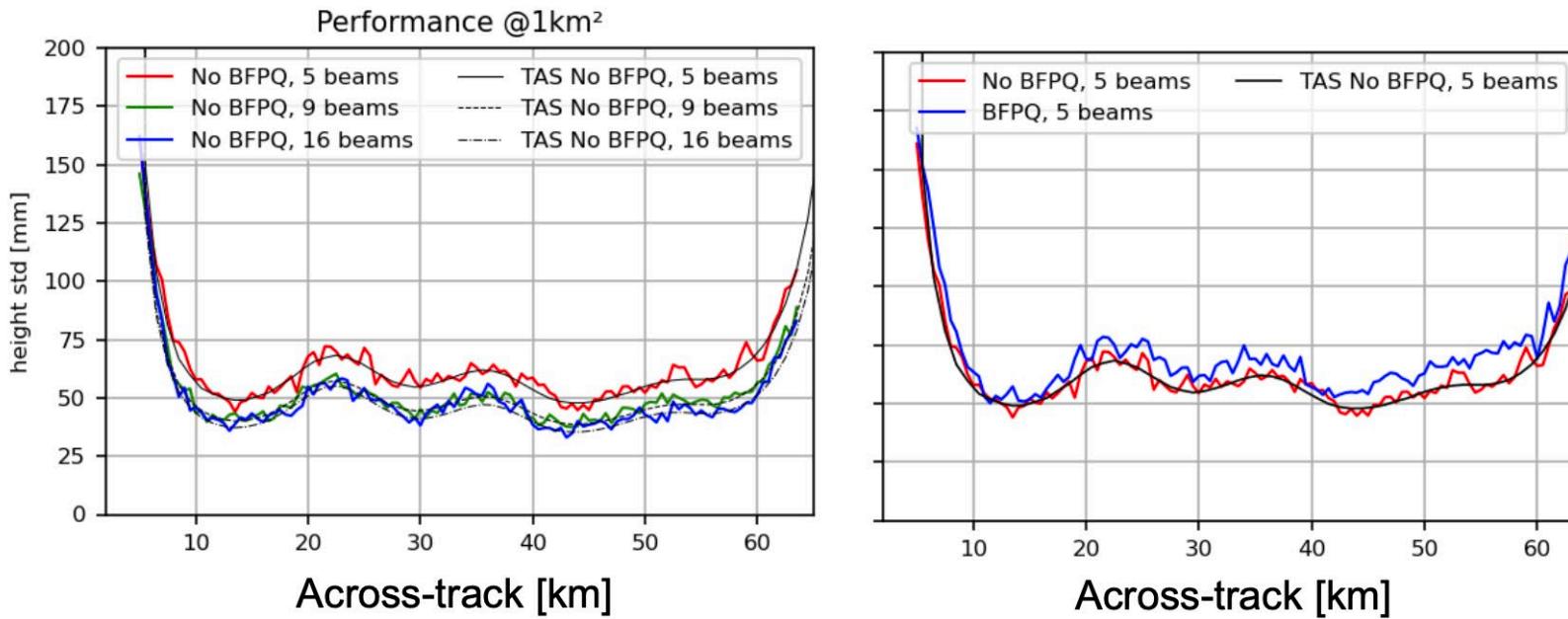
Excellent fit between the e2e simulations and the random noise theory → mean error in the swath of about 6 cm

*Courtesy CLS*

# S3NGT Systematic Errors

❑ Systematic errors have multiple sources: an <u>imperfect knowledge of the attitude</u> (imperfect roll angle used in the interferogram for topography reconstruction), <u>an error in the interferometric phase or group delay</u>, <u>an imperfect knowledge of the true baseline length</u>. Their amplitude before calibration might be as large as tens of centimeters. Their signatures on the measurements can be a bias, linear or quadratic in the swath, with varying time scales along the track.

❑ The systematic errors can be reduced using a L2 data-driven calibration (Dibarboure, 2022) or L3 algorithms (Dibarboure, 2025)

❑ In phase B1, the objective is to assess the level of residual errors after L2 data-driven calibration has been applied.
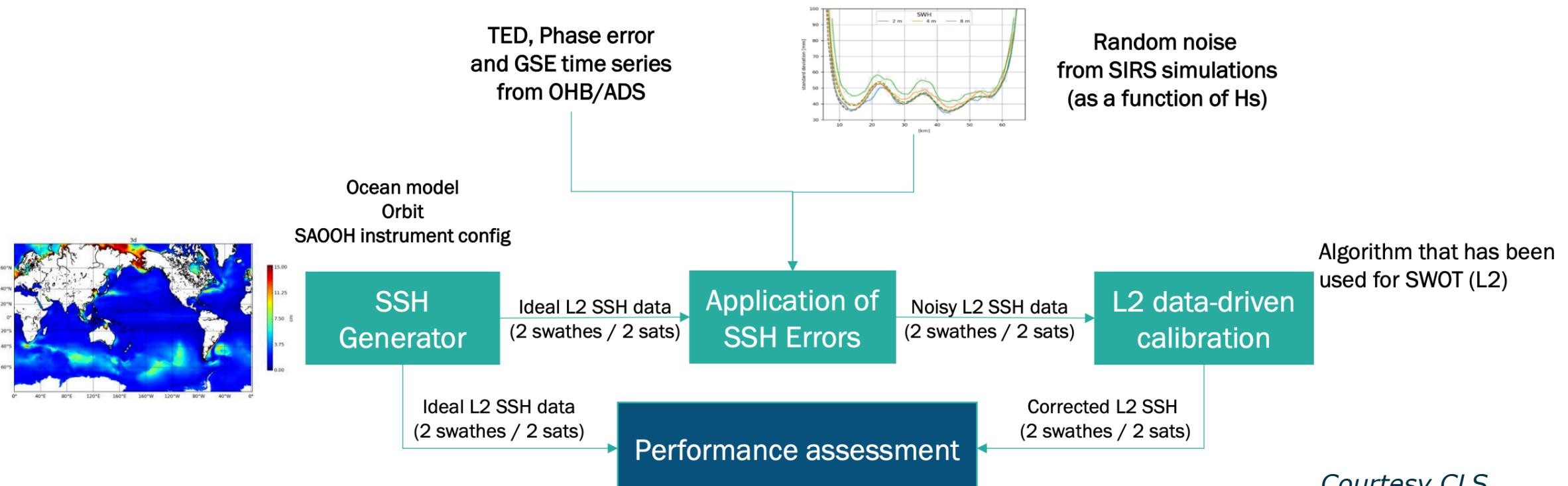


TED, Phase error and GSE time series from OHB/ADS

Random noise from SIRS simulations (as a function of Hs)

Ocean model
Orbit
SAOOH instrument config

Algorithm that has been used for SWOT (L2)

**SSH Generator** → Ideal L2 SSH data (2 swathes / 2 sats) → **Application of SSH Errors** → Noisy L2 SSH data (2 swathes / 2 sats) → **L2 data-driven calibration**

Ideal L2 SSH data (2 swathes / 2 sats) → **Performance assessment** ← Corrected L2 SSH (2 swathes / 2 sats)

*Courtesy CLS*

# S3NGT Systematic Errors

❑ Illustrations with the one satellite case, random noise function of SWH, Non Time Critical products, 2 different GSE configurations



HYDRA

2.8 cm (typical)

1.50 cm (typical)

ASTRO-XP

1.50 cm (typical)

0.80 cm (typical)

[cm] — 0 ... 5
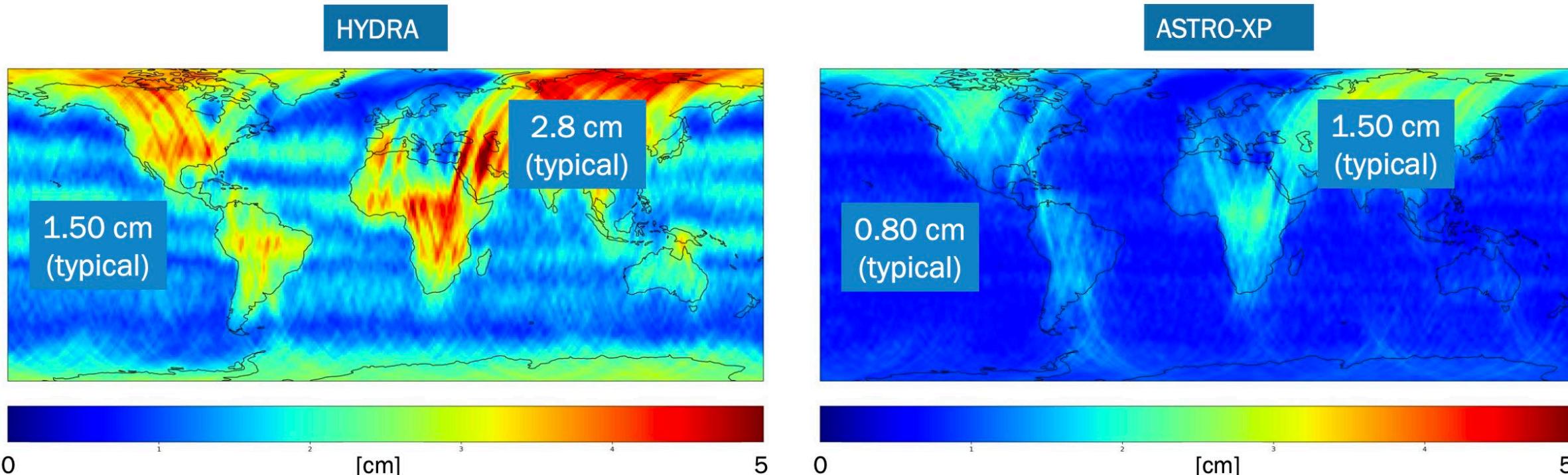
- ❑ Much better performances obtained with ASTRO-XP GSE wrt HYDRA GSE
- ❑ ASTRIX 200+ gyroscope has excellent performance and systematic errors are already very limited
- ❑ HYDRA and ASTRO-XP star-tracker solutions very consistent for wavelengths <1000km
- ❑ ASTRO-XP errors much reduced wrt HYDRA for wavelengths > 5000km
- ❑ As expected, data driven calibration (as implemented) allows reducing errors beyond #5000km

*Courtesy CLS*

## Sentinel-3 Next Generation Topography Mission Performance and Uncertainty Assessment (S3NGT-MPUA)

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S3NGT-MPUA is a project funded by the European Space Agency.

The project is aimed at assessing the S3NG-T mission performance from a metrological perspective.

Uncertainty budget is being put in place to combine all elements of the mission.

Uncertainty/Performance assessment based on SWOT data (tailored to S3NGT mission characteristics) and simulations. Approach complementary approach to industry studies.

First results confirm the fitness for purpose of the mission and compliance with Mission Requirements.

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# Conclusions

- The Sentinel-3 Next Generation Topography Mission is progressing very well. Procurement process for the satellite B2CD Phase on they way. Main instruments mandatory providers selected.

- With two-swath altimeters flying in formation, S3NGT follows in the footsteps of the SWOT mission.

- Performance assessment in Phase A/B1 studies and the S3NGT-MPUA project is showing that the current mission implementation baseline is meeting the Mission Requirements.

Any questions ?
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