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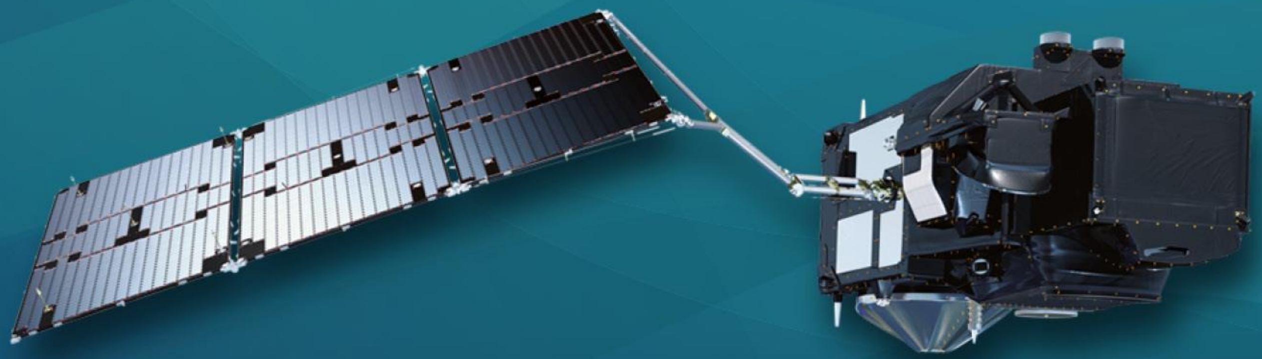

9th Sentinel-3 Validation Team meeting 2026

30 March–01 April 2026 | ESA–ESRIN | Frascati (Rome), Italy

Insight into validation methods of Sentinel-3 Hydrology Thematic products

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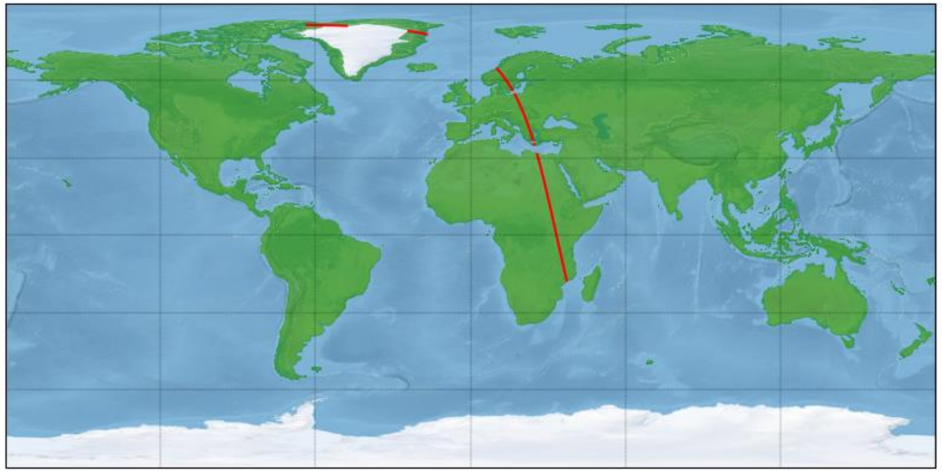
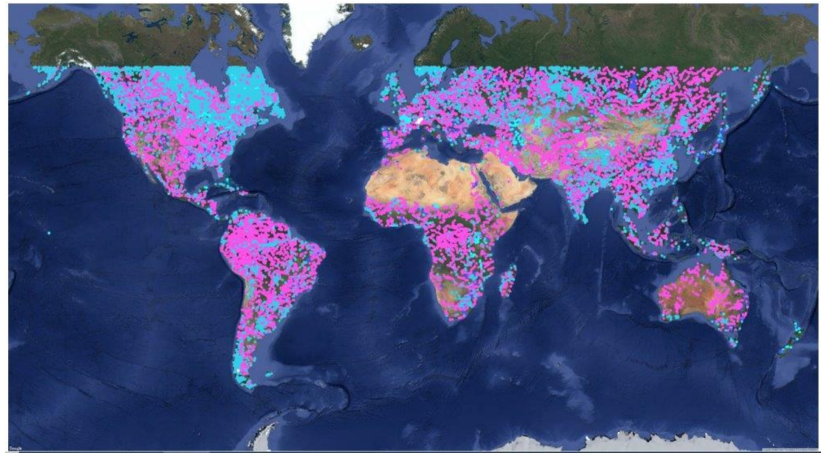
Hydrology Thematic products

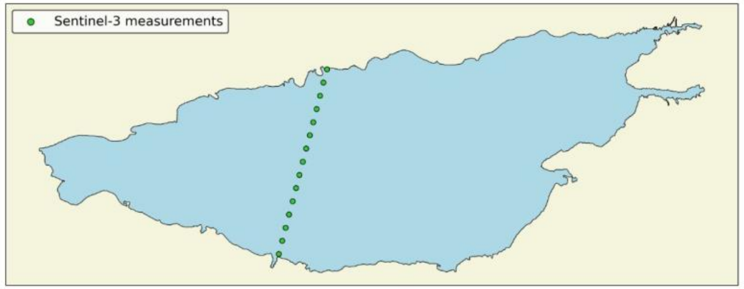
- **MPC** team has developed specific processing chains over hydrological areas, leading to the operational generation of **Hydrology Thematic products**
- In addition to **OLTC** command and dedicated hydrology mask, delay-Doppler processing now includes **hamming window** and **zero-padding techniques.**
- The Hydrology Expert (**HY-ESL**) evaluates the **Water Surface Height (WSH)** using dedicated **validation methods** and proposes **potential enhancements** to the Hydrology Thematic products.



Hydrology mask used for Hydrology Thematic products



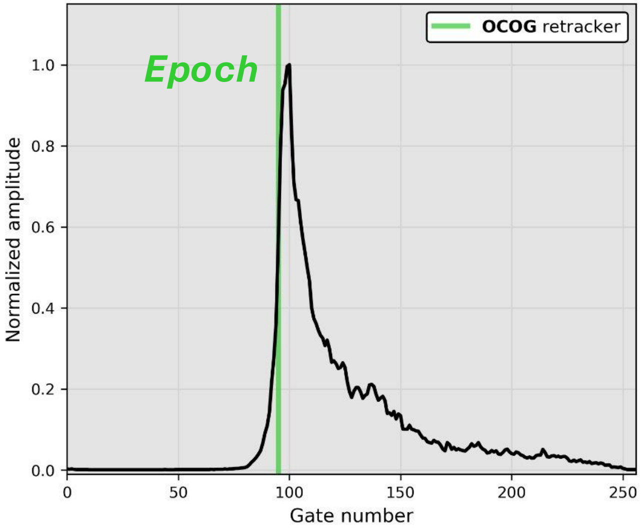
OLTC database (blue: lake, pink: rivers) (Le Gac et al. (2021))



- Computation of ***WSH*** with the nadir altimetry equation:

$$WSH = H - \boxed{R} - Geoid - C_g$$

with H the satellite altitude, C_g the geophysical corrections, ***R*** the **range** estimated from the **epoch** using retracking algorithms



Example of waveform over the Issykkul lake

- **WSH uncertainties** are primarily driven by errors in the **range *R***, induced by multiple sources

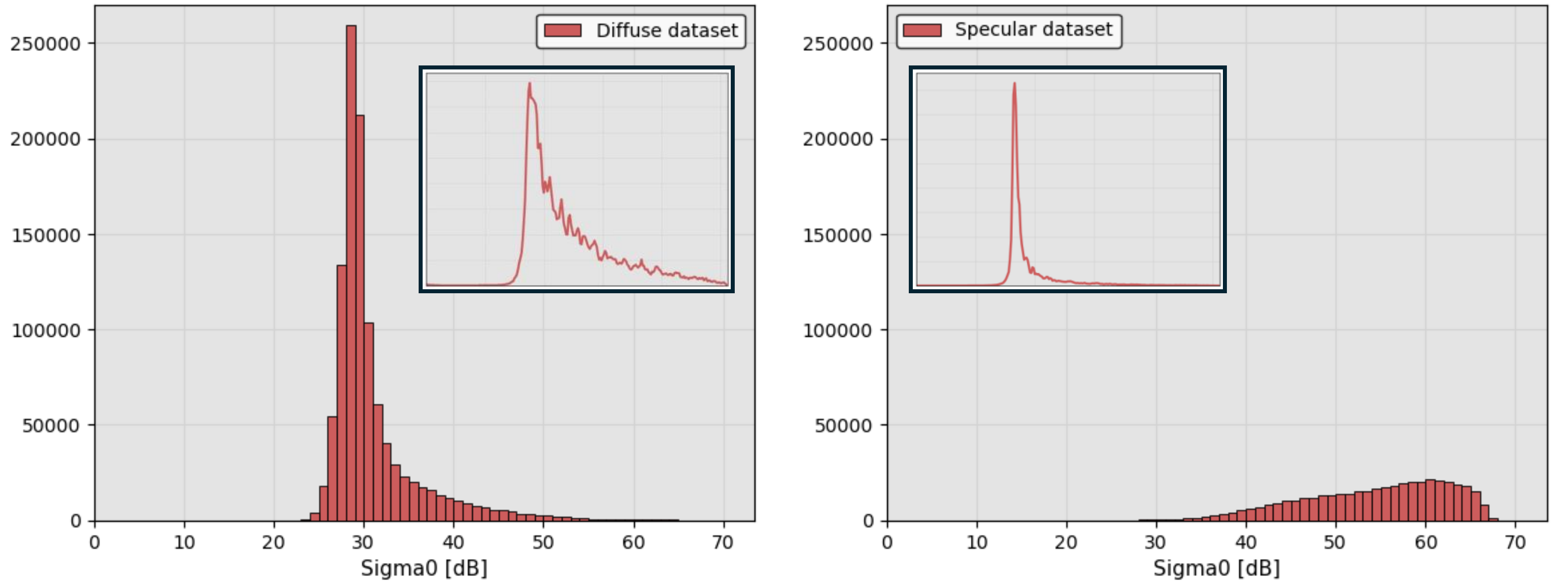
✓ **Objective –** development of validation methods to quantify **these uncertainty sources** over lakes and rivers

Range noise over lakes

- WSH uncertainties are induced by **multiple sources**:

1. **Range noise:**

- Sentinel-3 measurements are selected over lakes to create two datasets - **diffuse** and **specular** - to represent the lower and upper bounds of **lake surface specularity**
- Selection of Sentinel-3 measurements is based on **waveform classification algorithm**



Sigma0 of consecutive measurements with similar waveform class sampling the same lake (2024-2025 period)

Range noise over lakes

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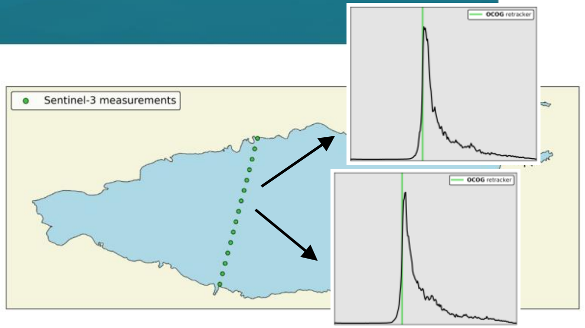
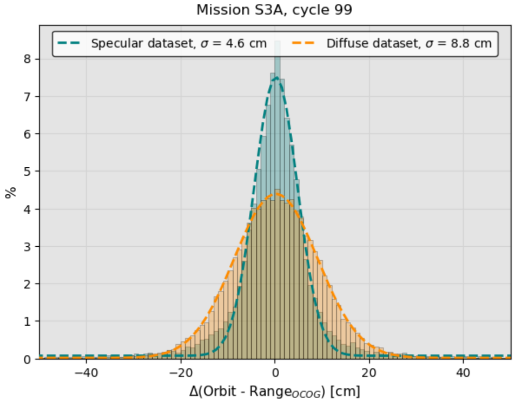
1. **Range noise:** quantified using consecutive 20Hz measurements sampling the same water body

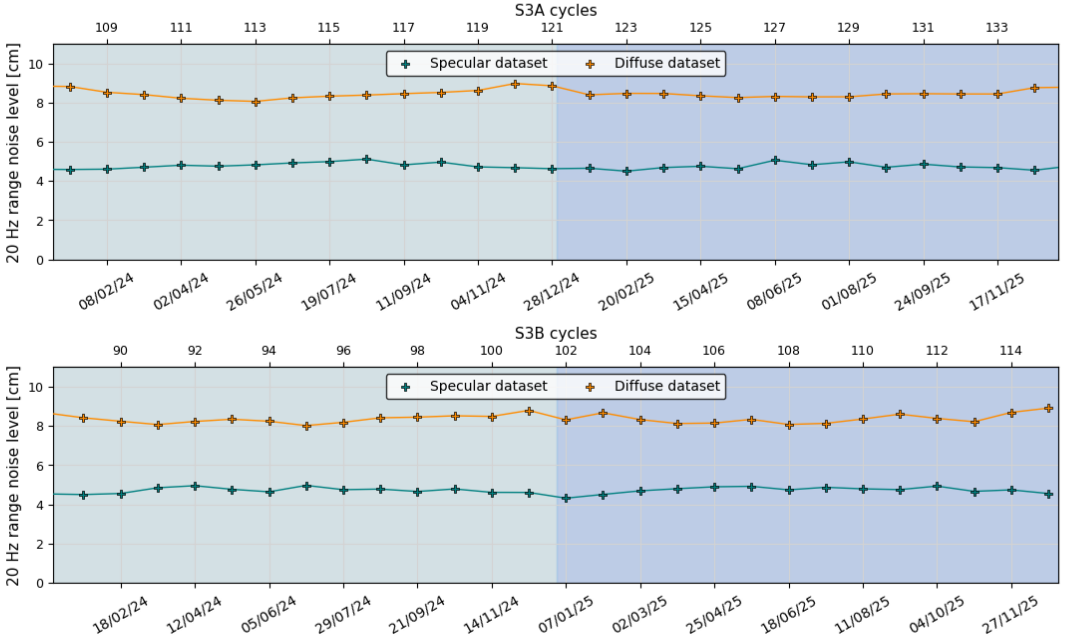


- For a transect *t* of N measurements, ***N-1* Δ(H - R)** values are computed: $\mathbf{\Delta(H - R)_{tn}} = (H - R)_n - (H - R)_{n+1}$ where *n* and *n+1* are two consecutive measurements **with the same waveform class**.

- Applied on thousands of lakes, **range noise** is estimated as the **standard dev. of Δ(H - R)**



Δ(H - R) distribution for cycle 83 of S3B



Range noise level timeseries for the two datasets

- Range noises are **stable over cycles**, with values from 5 to 8 cm for specular and diffuse datasets

- **WSH uncertainty** induced by **range noise** is of **at least 5 cm**, and depends on water body **specularity**

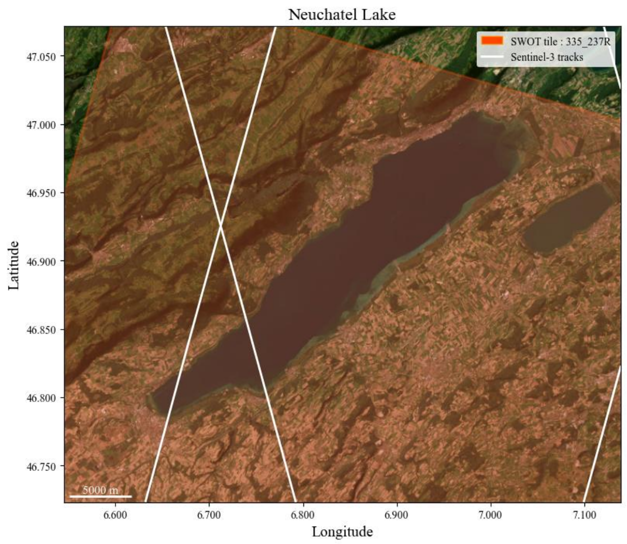
Range bias over lakes

- WSH uncertainties are induced by **multiple sources**:

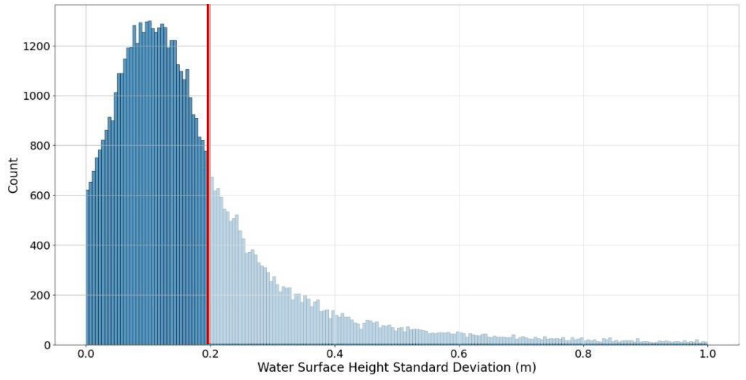
2. **Range bias:** quantified using reference datasets with the **same height reference**

- Benefits of cross-validation with **SWOT LakeSP products** over lakes:

    I. WSH observations over more than **70% of worldwide lakes every 21-day**
    II. Same **height reference** as Sentinel-3 measurements to address the issue of WSH bias



Neuchatel lake observed by SWOT and Sentinel-3



Standard deviation of ICESat-2 WSH timeseries over PLD lakes

- To consider SWOT LakeSP products as **reference measurements**, selection of lake subset:

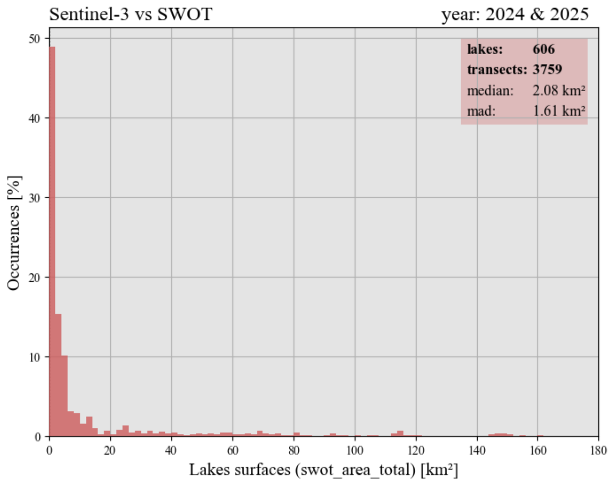
    I. **Synchronized acquisition times**: < 5 days between S3 and SWOT applied on ***"stable"* lakes** (std of ICESat-2 WSH timeseries < 20 cm)

    II. **LakeSP quality**: use of LakeSP **quality flags** to avoid SWOT WSH outliers

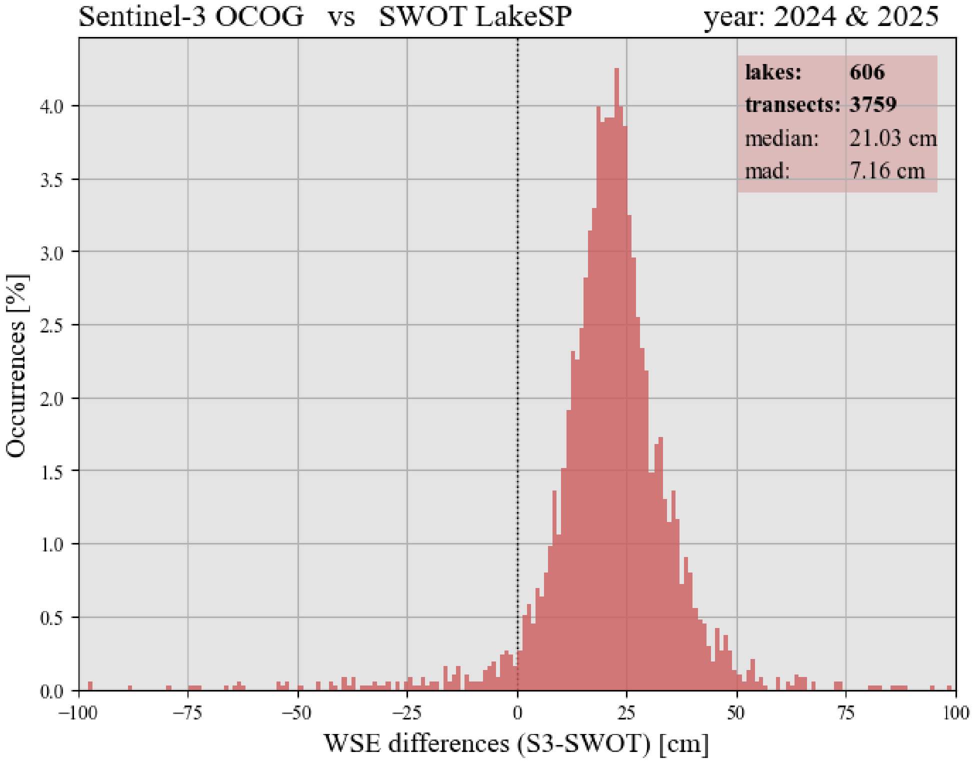
Range bias over lakes

2. Range bias: quantified using reference datasets with the **same height reference**

- **Cross-validation** of Sentinel-3 measurements with **SWOT LakeSP products** over lakes



Distribution of lake surfaces

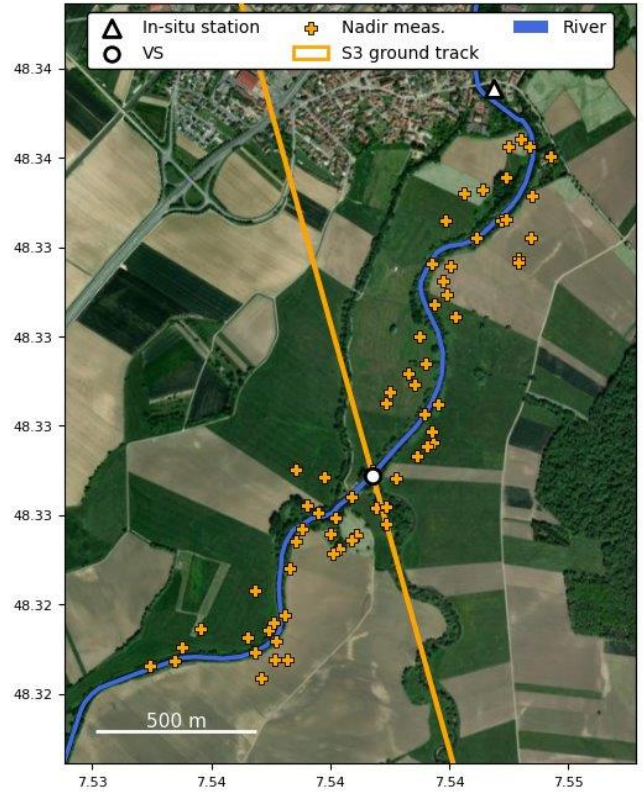


- L2 Hydrology Thematic products provide **WSH** based on **threshold OCOG/ICE-1 retracker**
- Distribution of the **WSH difference** between S3 and SWOT measurements, with **the range bias inferred from the median** of the distribution
- **OCOG bias of ~+20 cm**, in agreement with OCOG bias found using **simulated SAR waveforms** (*Boy et al. (2022)*)

Range bias over rivers

2. **Range bias:** quantified using reference datasets with the **same height reference**

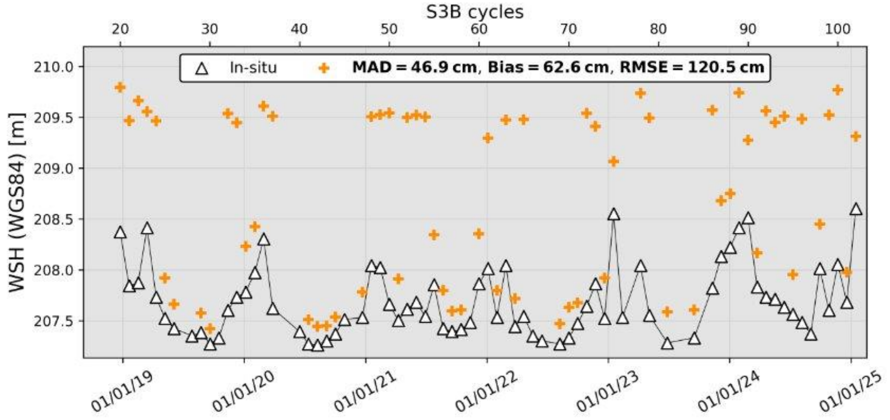
- Standard validation over **rivers**: comparisons of nadir WSH timeseries against **in-situ WSH timeseries**



Nadir selection for successive S3B cycles over the Ill river (France)

- **Nadir selection**: for each orbit cycle, selection of **the nearest S3 measurement to the river** around the **VS** (virtual station)

- Limitation: due to the orbit excursion, **S3 WSH** is estimated on **different locations** on the river, while in-situ station provides **WSH at the same location** → river **slope-induced error**



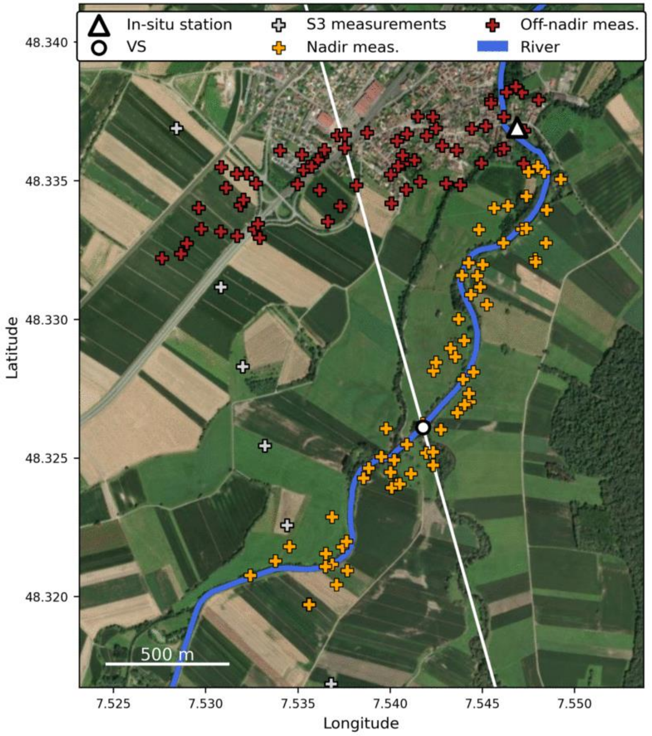
Nadir selection for successive S3B cycles

- Nadir WSH timeseries **cannot clearly distinguish** WSH uncertainties due to the **range bias** and **slope-induced error**

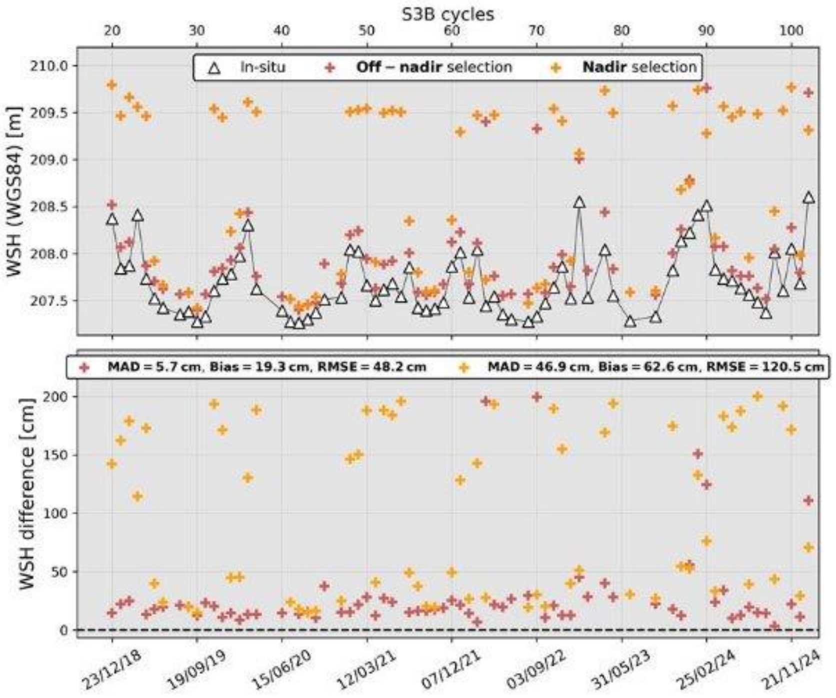
Range bias over rivers

2. Range bias: quantified using reference datasets with the **same height reference**

- Innovative validation over **rivers**: comparisons of **off-nadir** WSH values against **in-situ WSH** measurements (*Renou et al. (2025)*)



Nadir and off-nadir selections for successive S3B cycles over the Ill river (France)



- Shape of the SAR footprint (**SAR band**) implies that backscatter signals from near **cross-track** direction contribute to the **waveform**

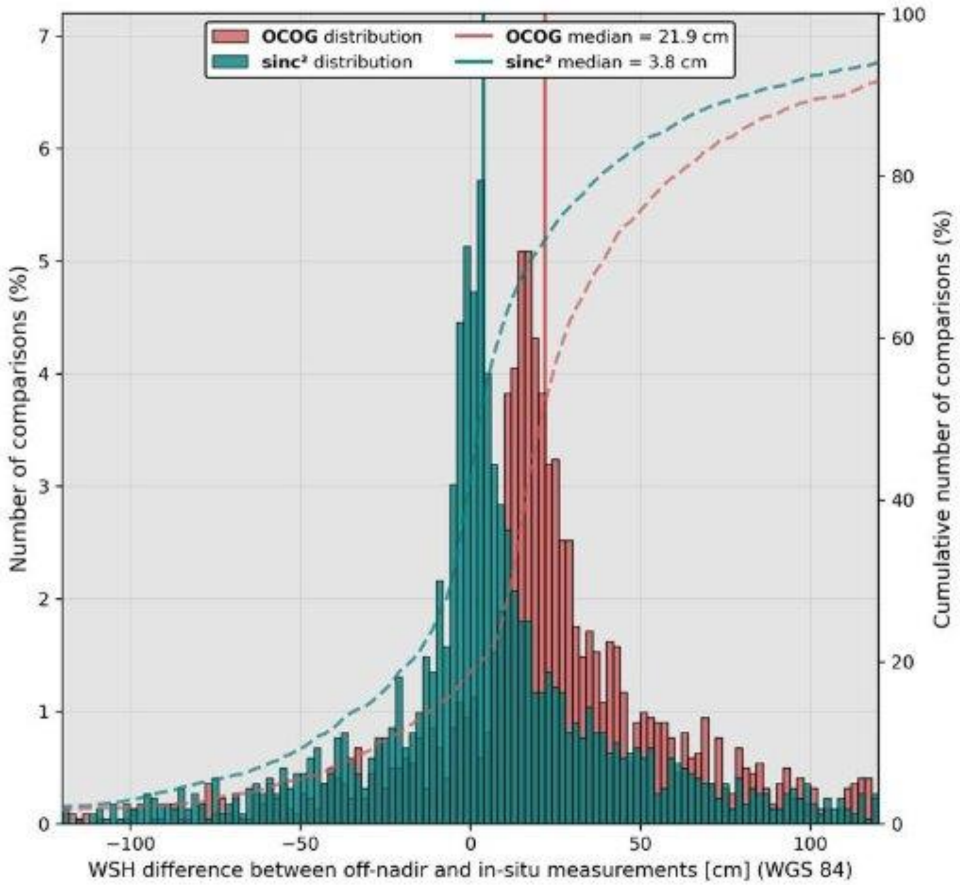
- **Off-nadir selection**: measurement with **SAR band** intersecting the **position of the in-situ** station, with **off-nadir correction** added into the WSH computation

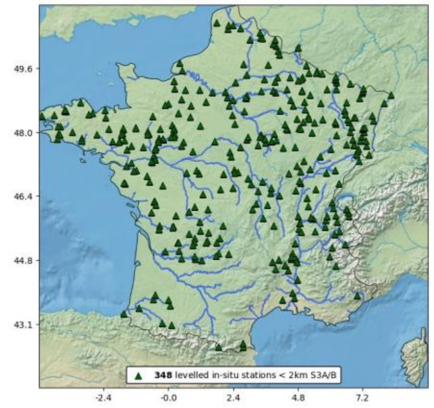
- **Slope-induced** error is **reduced,** WSH uncertainties due to the **range bias can be assessed**

Range bias over rivers

2. Range bias: quantified using reference datasets with the **same height reference**

- Validation over **rivers**: comparisons of **off-nadir** WSH values against **in-situ WSH** measurements (*Renou et al. (2025)*)





- Dataset of **S3 off-nadir measurements** to be compared to measurements from in-situ stations near S3A/S3B tracks (< 2km)

- After **selection** of S3 measurements (based on waveform classification and water mask), computation of the **WSH difference between S3 and in-situ measurements**, with the range bias inferred from the median of the distribution

- **OCOG bias of ~+20 cm**, in agreement with cross-validation with SWOT products over lakes, and **bias reduction using sinc² retracker**

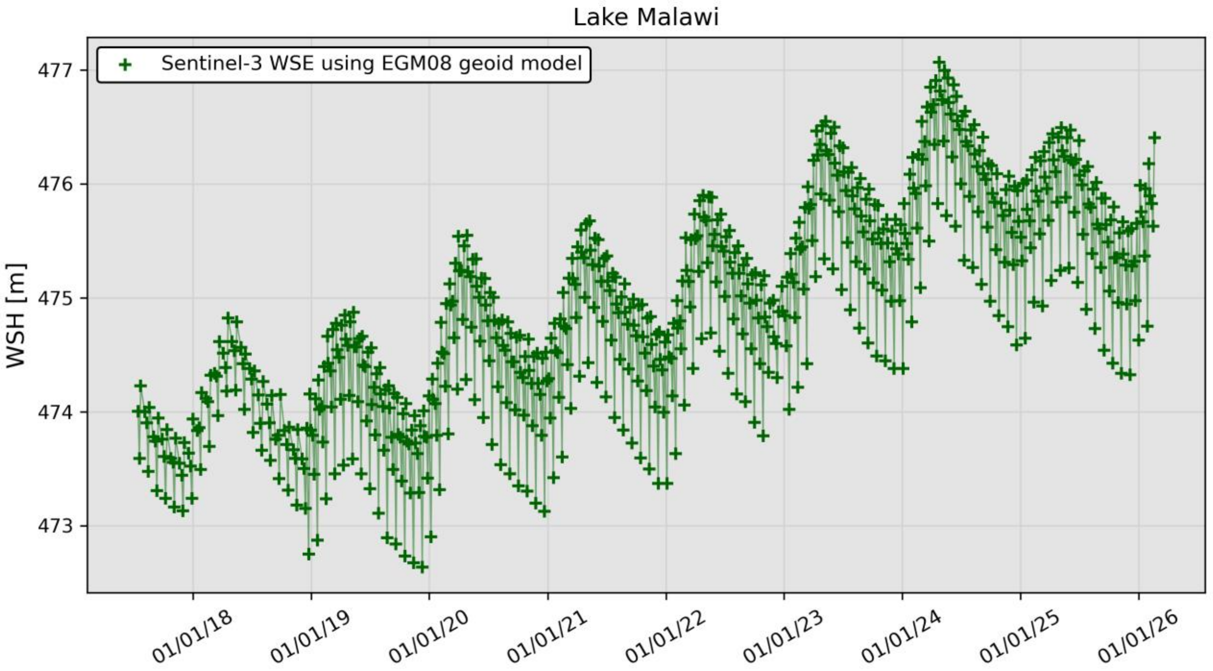
Geoid errors

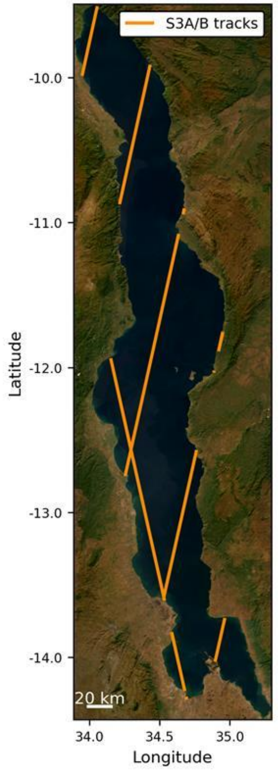
- Computation of ***WSH*** with the nadir altimetry equation:

$$WSH = H - R - \boxed{Geoid} - C_g$$

- Resolution of the **geoid models** does not capture short wavelength variations of the gravity field, leading to **additional WSH uncertainties** when combining WSH estimates from various ground tracks

- For large lakes located above gravity anomaly variations, **geoid correction** does not ensure a **uniform height**





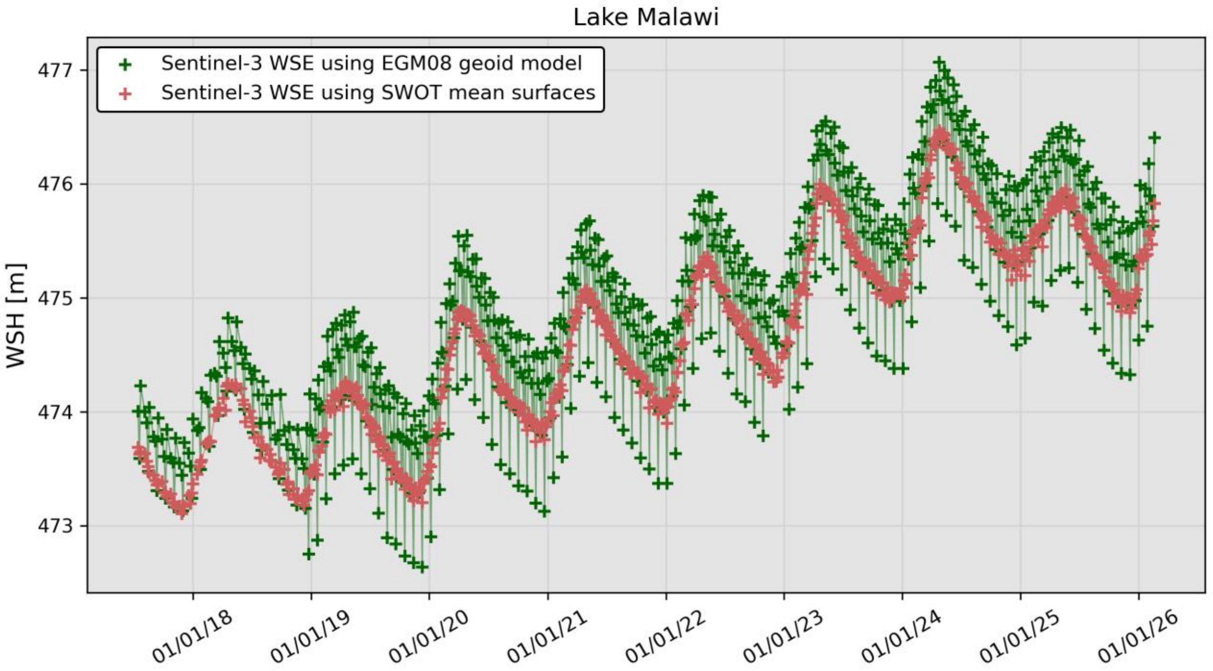
S3A/S3B tracks over the Malawi lake

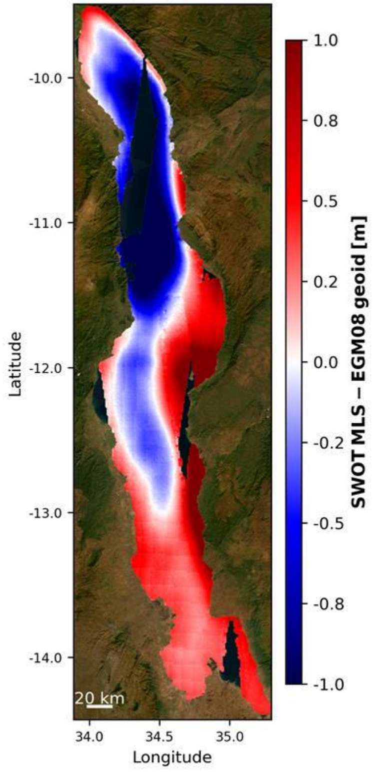
- As computation of **L3 WSH timeseries** combines S3 measurements from tracks located on different parts of the lake → **oscillations of WSH due to geoid error** (dm!)

Geoid errors

3. **Geoid errors**: quantified with **mean lake surfaces** using the 2-D **SWOT measurements** (CNES Alti-lacs project)

- **Mean Lake Surface (MLS)**: lake average elevation (mean state) over its hydrological cycle, mimicking the equipotential surface of the gravity field (= ***Geoid***)
- Combination of **SWOT L2 100x100m products** since the beginning of the mission (March 2023) over large lakes





Height difference between SWOT MLS and EGM08 geoid over the Malawi lake

- **WSH oscillations** using EGM08 geoid model are drastically **reduced** when using SWOT MLS
- For Lake Malawi, the **standard deviation** of the WSH timeseries is **reduced by 8 cm**, due to reduced geoid errors.

Conclusions and perspectives

I. Conclusions

- Some contributors of the WSH uncertainties, such as the range noise and bias, are quantified depending on water body specularity
- Opportunities arising from future S3C tandem phase(s): range noise could also be quantified over rivers
- Alternative validation techniques over rivers limit the river slope impact and show bias reduction using sinc² retrackers
- Preliminary work on geoid error reveals promising results, to be confirmed before recommending the integration of SWOT mean surfaces into L2 products
- Contaminant-related noise remains the largest error contributor when more than one water bodies are sampled within the SAR band, and is not yet quantified. On-going R&D activities: retracking multiple off-nadir elevations over rivers (JA Daguzé's presentation tomorrow)

II. Example of future validation activities in the frame of the MPCS3

- Evaluation of SAMOSA+ and sinc² retrackers for larger range of lake/rivers sizes, to quantify range bias evolution as a function of specularity
- Extend the validation to estuaries (in common with CRISTAL validation plan)