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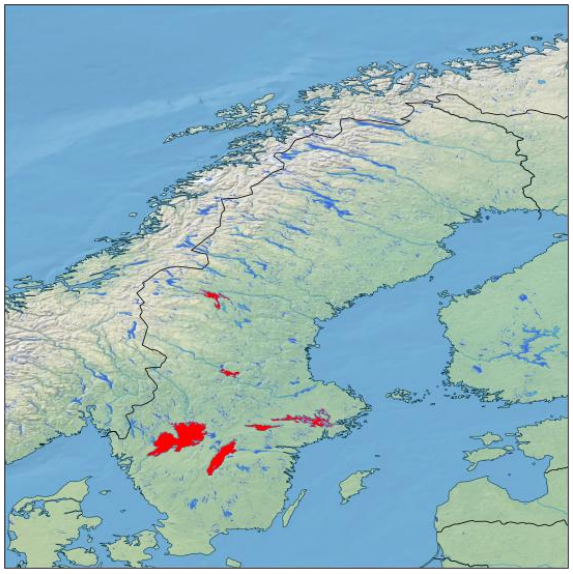
Improved Inland Water Level Retrievals from CryoSat-2: Enhanced Spatial Coverage and Uncertainty Characterisation for Hydrological Applications



Jérémy Guilhen (CLS) – Angelica Tarpanelli (IRPI) – Karina Nielsen (DTU) – Alessandro Di Bella (ESA)

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Cryo-TEMPO

Overview of Inland Water products and processing baseline

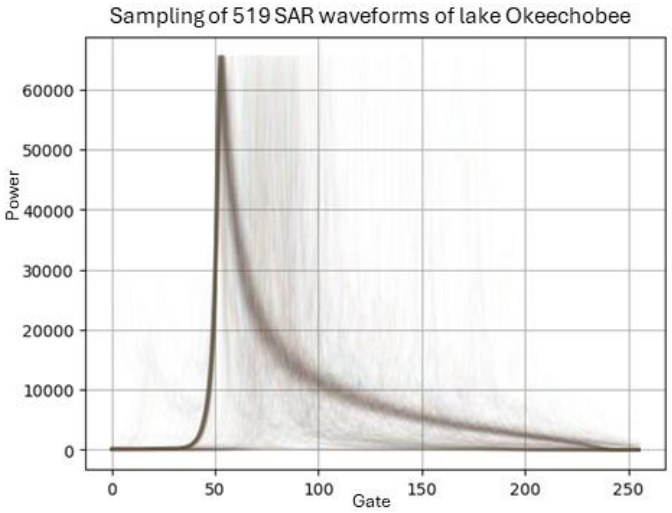
Inland water product contains **high-rate altimetry (L2)** data on inland water surfaces (**rivers and lakes**) and is distributed in a format for users outside the altimetry community. The input data are the PDGS **Ice Processing Baseline E** data.

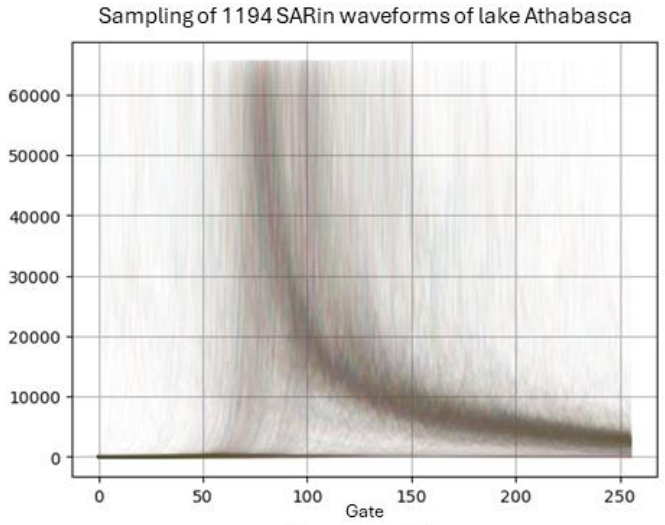
.nc file content

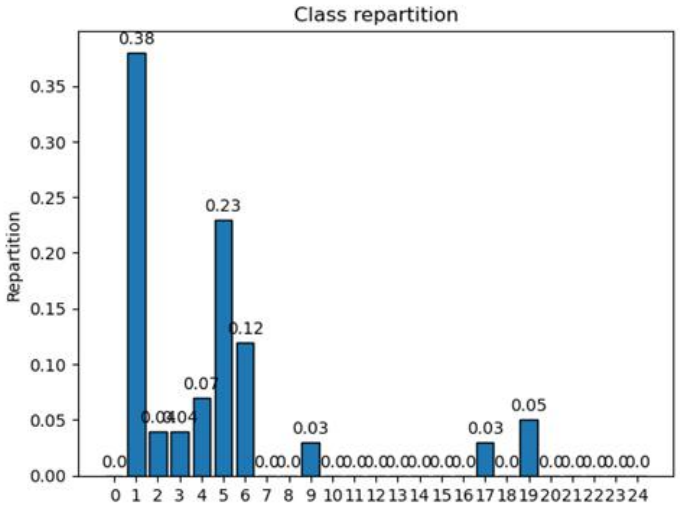
- Time
- Latitude
- Longitude
- **Water Surface Height (WSH tfmra, samosa+, MWaPP, OCOG)**
- Geoid height
- Instrument mode
- **Uncertainty of water heights**
- Quality flag **(waveform classif.)**
- Land water occurrence

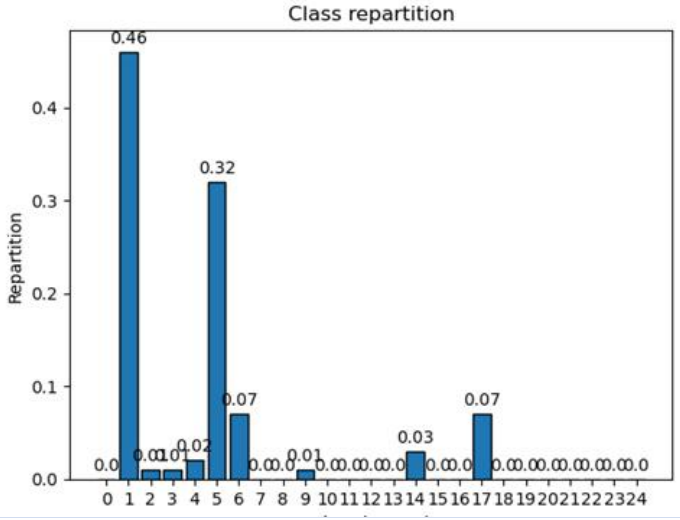
- ✓ Available on the whole duration of CryoSAT-2 mission (2011 – 2026)
- ✓ Cover 4 rivers: Po, Tiver, Danube and MacKenzie
- ✓ And 89 lakes over Canada, USA and Sweden
- ✓ State of the Art L2 water level products

Quality improvements – SARin waveforms classification & quality flag









- Truncation of SARin waveforms to SAR size between gates 175 & 431
- Comparison to SAR distribution of Waveform classification
- SARin quality flag is linked to WF classification which returns a substantial amount of disturbed WF

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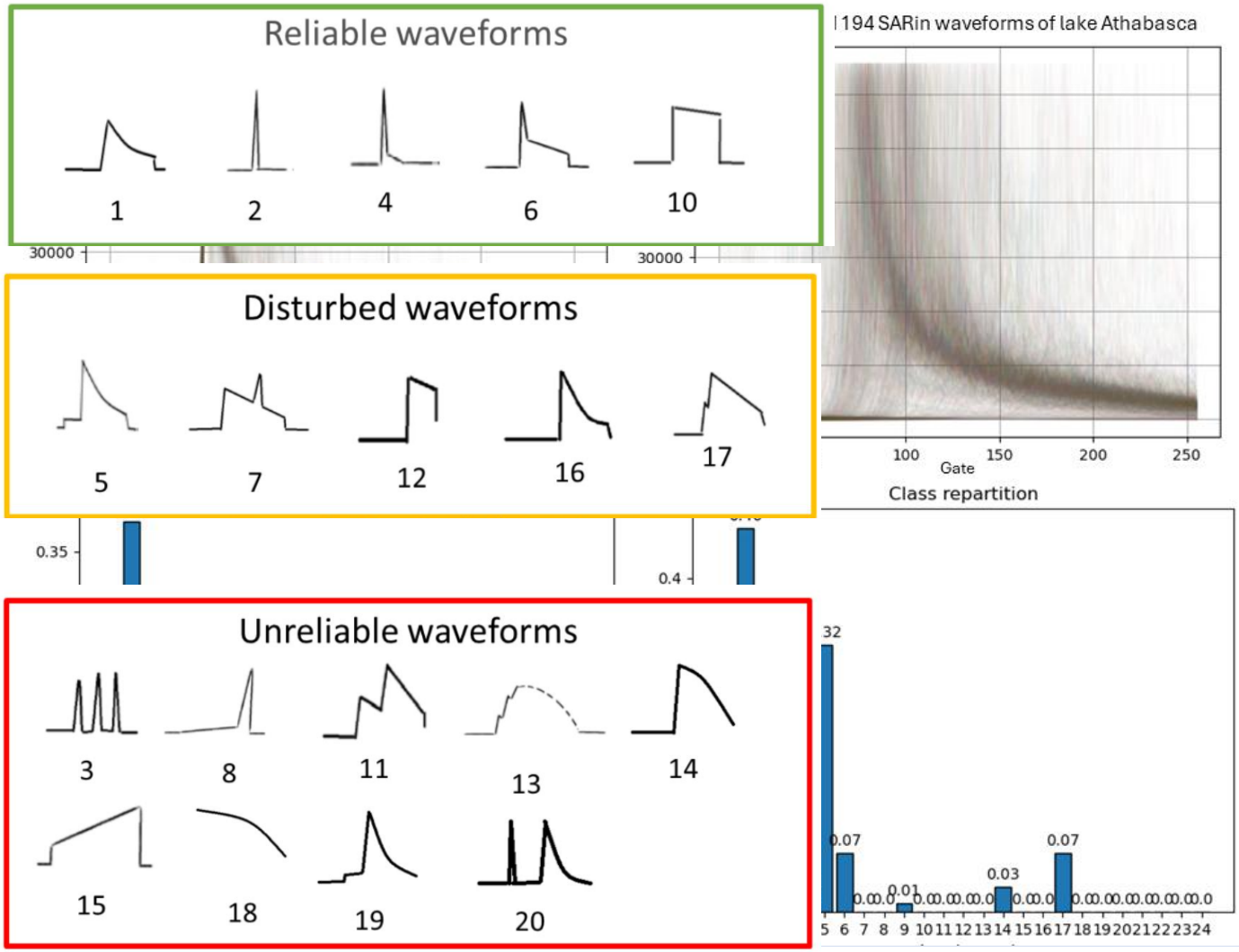

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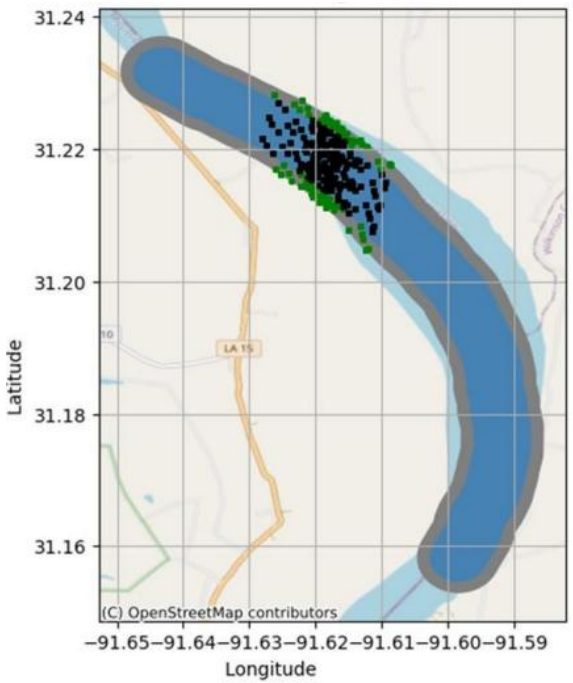
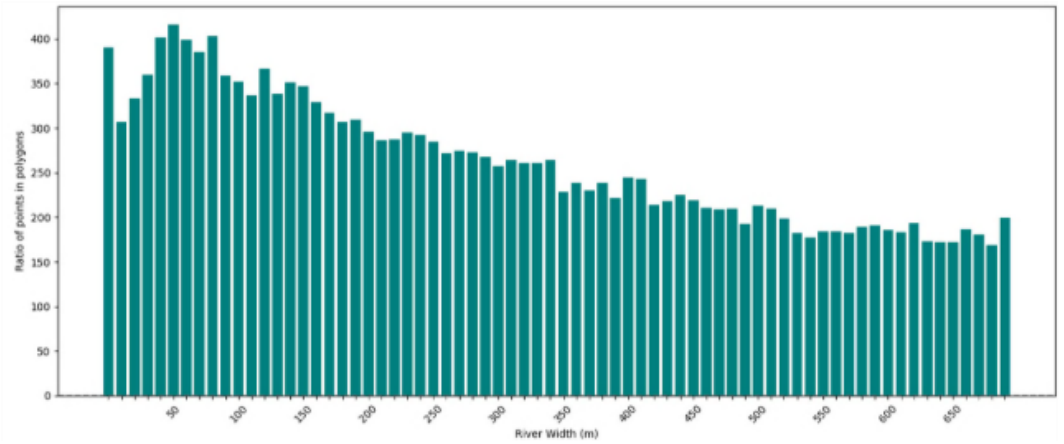
Selection of L2 water levels over river systems

Selection of L2 measurement for Rivers over the SWORD database *(Messager et al., 2016)*

- Implementing the 300-meter buffer → increase in recorded measurements



Relationship between the width of the river and the number of points with the SWORD buffer

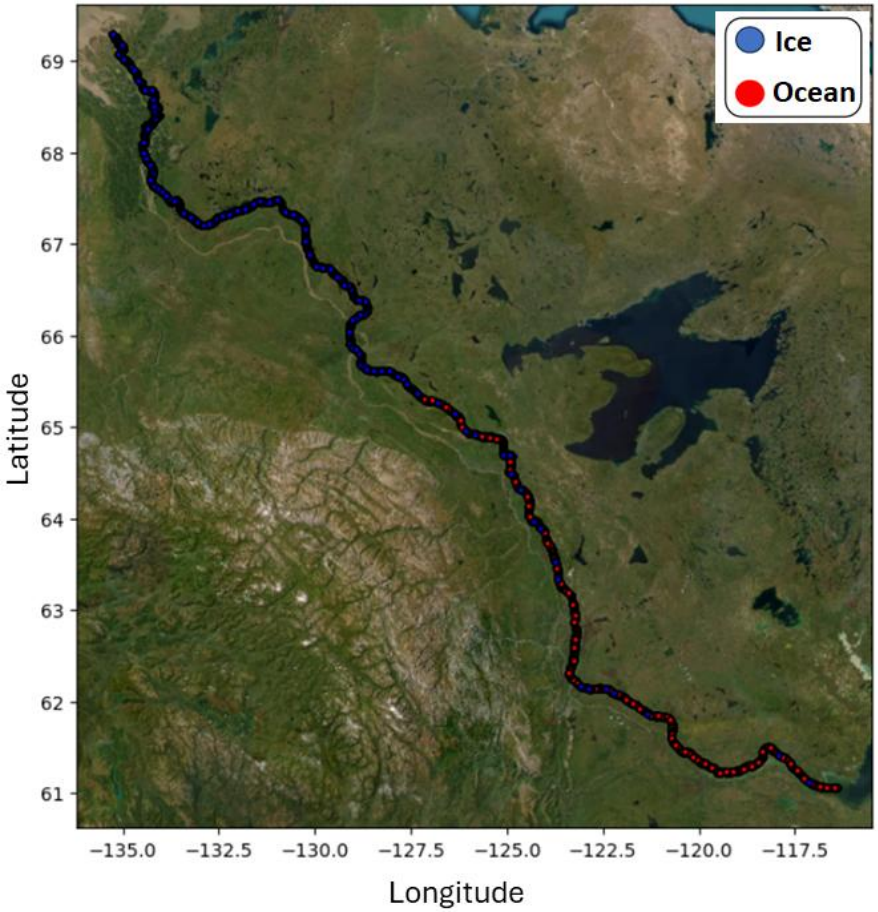


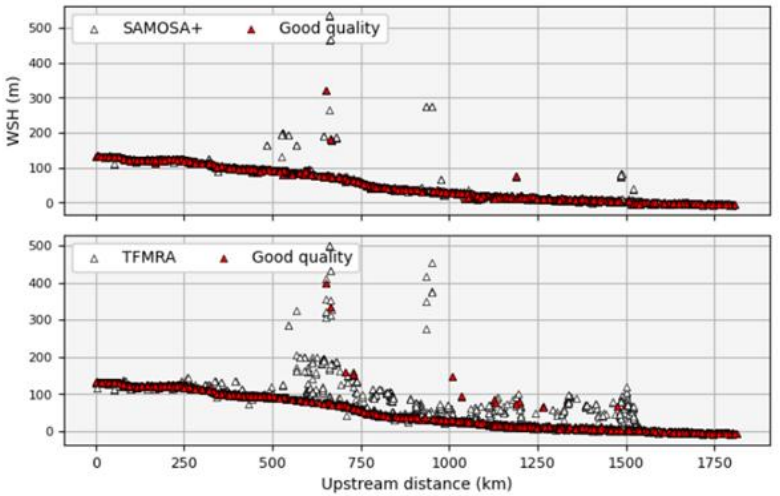
Effect more predominant for “narrow” rivers.

250 – 400% more points

Cryo-TEMPO
Inland Water

Improvement of data coverage





Spatial coverage of the TDS extracted over the SWORD database for the MacKenzie river (left), the Danube River (top right) and the Po river (bottom right). The red dots refer to the L2 measurements extracted in Phase 3.2. The blue lines represent the river line string from Phase 3.1.

- Increasing of the spatial coverage of about 66% over the Mackenzie River
- We estimated that average loss of points due to that feature is about 7 to 8% for the four in head waters
- Using the SWORD database increased the number of L2 measurements by a factor 5

Overview of Inland Water products and current status of Phase 3.2

Developed with NPL (S. Behnia, E. Wooliams) in FDR4ALT-FO

Redefinition of uncertainties

(1)

$$h = h_{\text{sat}} - R - C_{\text{WT}} - C_{\text{DT}} - C_{\text{io}} - C_{\text{Earth tide}} - C_{\text{pole tide}}$$

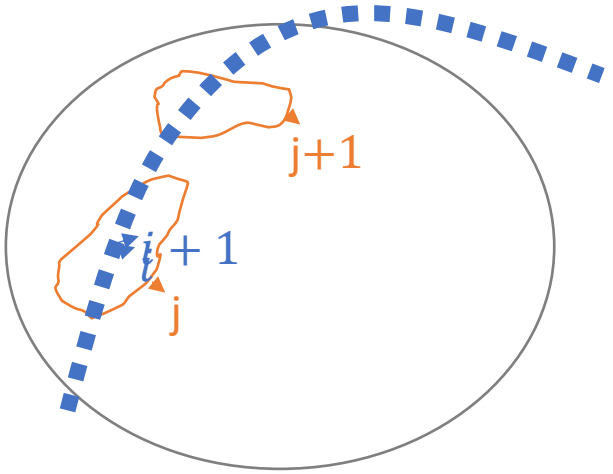
?

?

no correlation
fixed uncertainties

from POD

$$u^2(h) = (1 \quad \dots \quad 1) \begin{pmatrix} u^2(h_{\text{sat}}) & \cdots & u(h_{\text{sat}}, C_{\text{pole tide}}) \\ \vdots & \ddots & \vdots \\ u(h_{\text{sat}}, C_{\text{pole tide}}) & \cdots & u^2(C_{\text{pole tide}}) \end{pmatrix} \begin{pmatrix} 1 \\ \vdots \\ 1 \end{pmatrix}$$



(2) $$\Delta H_i = (h_{sat_i} - h_{sat_{i+1}}) + (R_i - R_{i+1})$$

assuming that $$\mathbb{E}\left(\sum_{j=1}^{m} \sum_{i} |\Delta H_{ij}|\right) = 0$$

Uncertainties are calculated:

- A single hydrological target
- A unique cycle/track
- 2 consecutive points of the same quality

Correction	Uncertainty (cm)
DTC	0.3
WTC	3
IC	2
ET	0.3
PT	0.3

Table for the geophysical corrections uncertainties.

Overview of Inland Water products and current status of Phase 3.2

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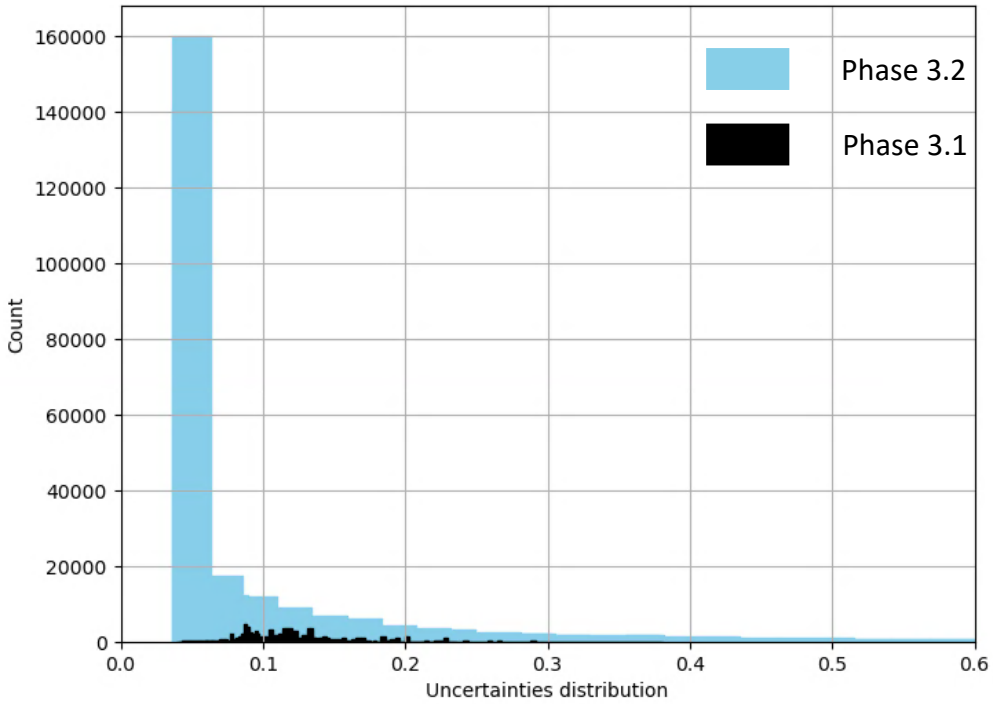


Comparison of the uncertainties distribution from TFMRA and SAMOSA + retrackers from Phase 3.2 (blue) and Phase 3.1 over the river dataset of CryoTEMPO.

- Smaller and more tightly clustered uncertainty values
- Most values falling below 0.05 → strong concentration of L2 measurements with low uncertainty
- More consistent results across the dataset → limiting the occurrence of highly uncertain measurements.

Evaluation over lakes

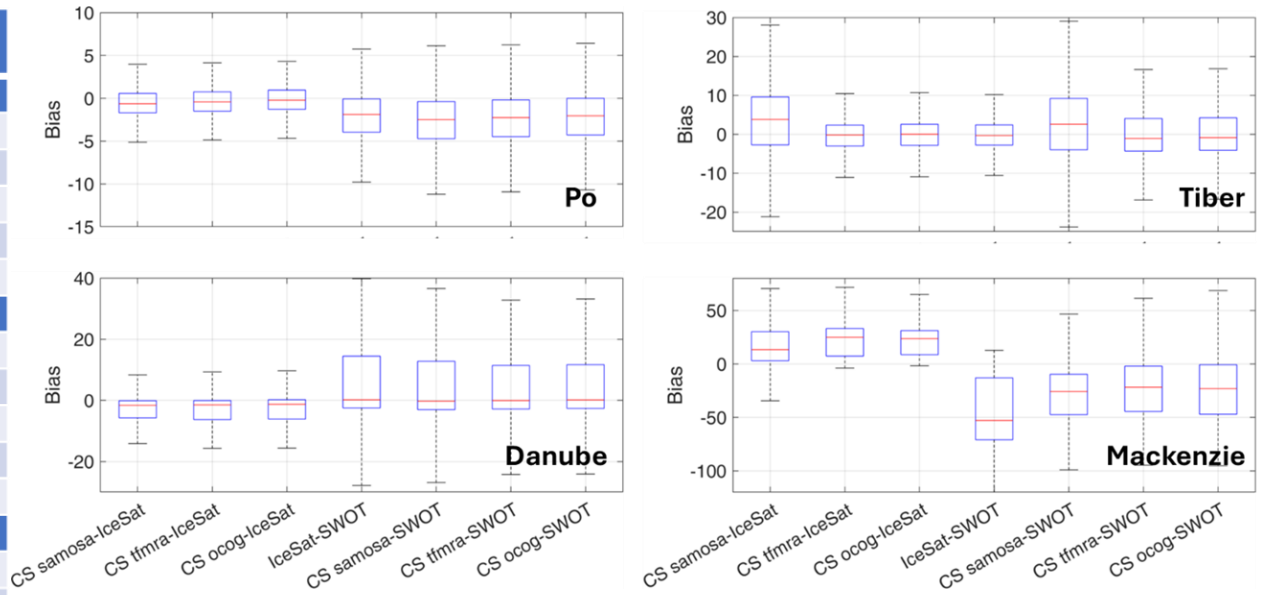
- The assessment is done via a gauge comparison at 56 lakes covering the period 2016-2024
- Evaluation of the water surface elevation based on the 4 retrackers OCOG, SAMOSA+, TFMRA, and MWaPP. More specific we examine:
  - The quality w.r.t the previous data version
    - SAMOSA+, TFMRA, OCOG v3.2 vs v2.2
    - MWaPP v3.2 vs DTU implementation

retracker	#Pairs	RMSE [m]	Corr	Pvalid [%]	Hsd [m]
MWAPP	17	0.30	0.72	63	0.17
OCOG	78	0.24	0.82 ↓	77	0.12
SAMOSA	27	0.18	0.90	83	0.10
TFMRA	81	0.28 ↑	0.79 ↓	75 ↑	0.12

V3.2

Evaluation over rivers

	TFMRA	SAMOSA	OCOG	MWAPP
TIBER				
BIAS	-7.0	-10.6	-7.2	-5.6
MAE	7.6	12.4	7.7	7.4
RMSE	10.5	14.6	10.7	10.3
NSE	0.94	0.89	0.94	0.94
R2	0.97	0.95	0.97	0.96
PO				
BIAS	1.11	1.32	0.90	-4.14
MAE	2.12	2.29	2.09	5.35
RMSE	3.88	4.35	3.86	8.92
NSE	0.99	0.99	0.99	0.86
R2	0.99	0.99	0.99	0.98
DANUBE				
BIAS	-3.25	-3.80	-3.45	-
MAE	4.25	5.23	4.32	-
RMSE	17.98	19.38	19.71	-
NSE	-0.54	-0.79	-0.85	-
R2	0.38	0.35	0.37	-
MACKENZIE				
BIAS	-5.71	1.44	-7.48	-
MAE	6.26	2.00	7.81	-
RMSE	11.63	4.83	13.71	-
NSE	0.92	0.99	0.89	-
R2	0.94	0.99	0.92	-



- Generally, high NSE and R^2 values.
- Outliers strongly influence the RMSE and MAE due to their large deviation from the mean profile.
- Negative bias, (substantial underestimation) for the Tiber
- Good results for the Po River
- For the Danube and Mackenzie rivers, the underestimation is more pronounced, (uncertainties in the geoid for in situ stations)

Summary and conclusion

- All evolutions implemented in the CryoTEMPO:
  - → Use of SWORD database on rivers
  - → Improvement of uncertainty over all hydrological targets
  - → Implementation of OCOG and Mwapp retrackers

- Data cover the whole CryoSAT-2 mission period (2011 – 2026)

Stay tuned as CryoTEMPO is going full globe for the next release (Q2 2027)

Data available → https://cs2eo.org/