IMPROVING SENTINEL-3 SAR MODE PROCESSING OVER LAKE USING NUMERICAL SIMULATIONS

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Examples of S3 radargrams over lakes

Measuring inland water heights with altimeters?

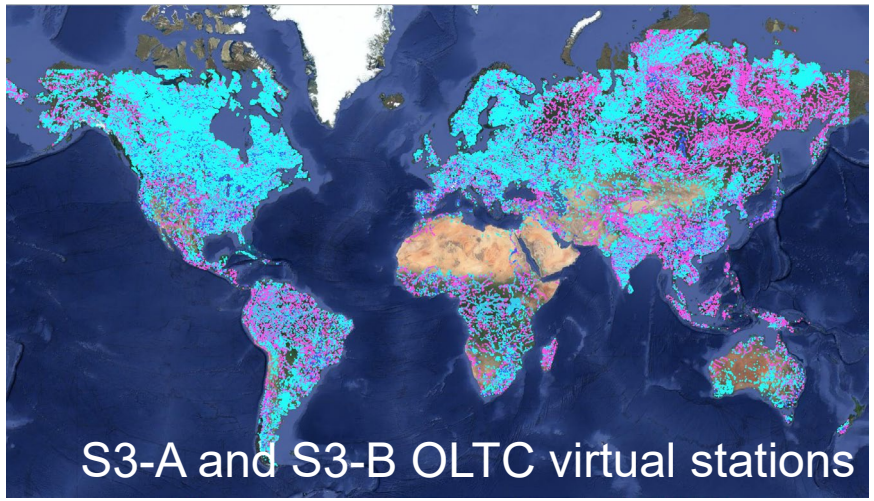
Inland waters = critical resources of fresh water to be monitored in the framework of Climate Change [Williamson et al., 2009]

Altimetry: **two major upgrades** in the new altimetry missions (S3, S6) allowing for **accurate** and **worldwide** inland water height estimation

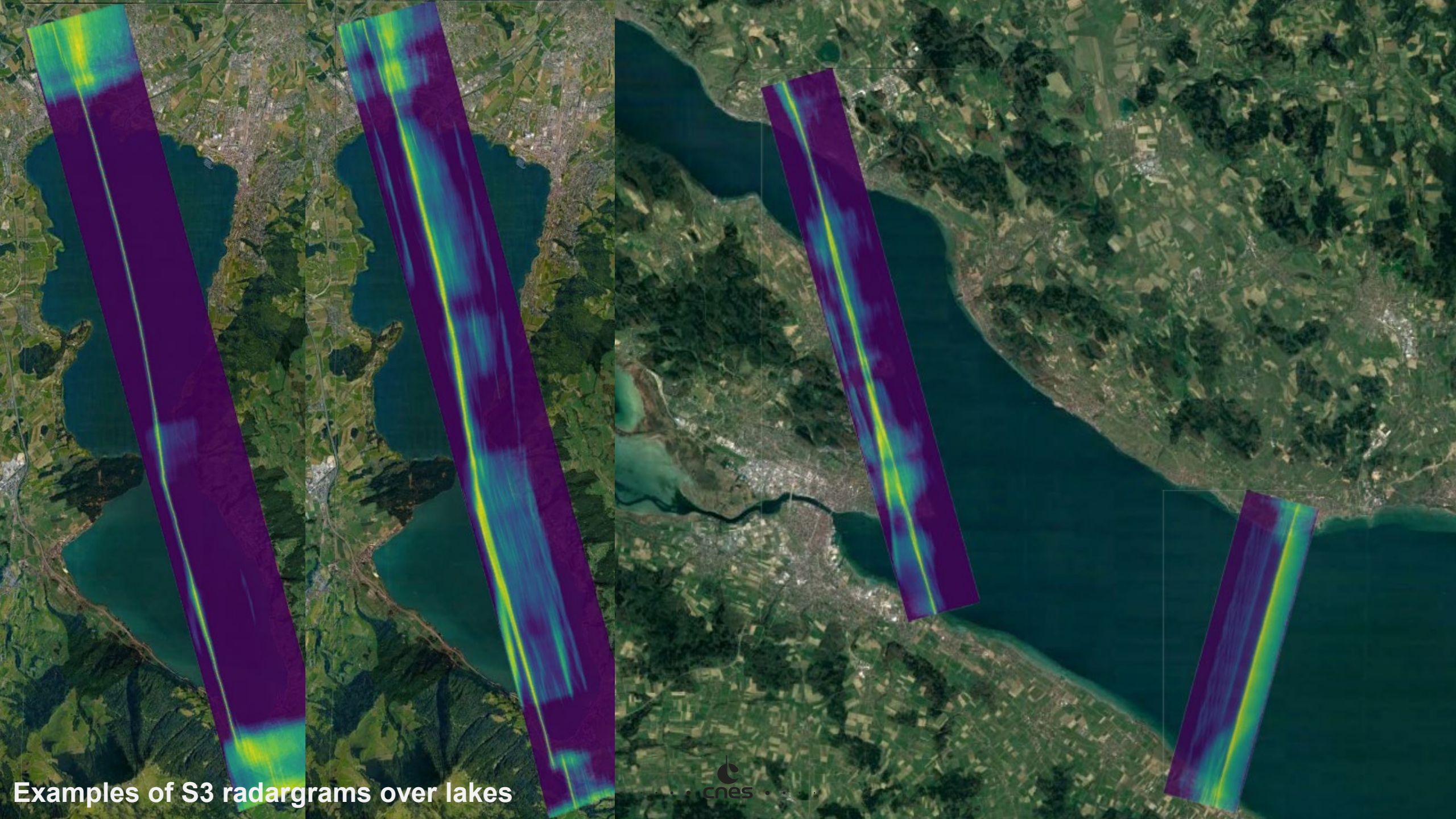
- **OLTC mode**
  - On-board elevation to assure signal acquisition above lakes/rivers
- **SAR mode**
  - High resolution along the azimuth, noise reduction
- **State-of-the art: large lakes RMSE ~0.1m-0.3m** [Nielsen et al. 2020, Okeowo et al. 2017]**, with ocean physical retracker or empirical retracker + filtering of land range gates: RMSE =0.16 m over Ribarroja reservoir** [Gao et al, 2010]

Focus of this presentation

- **Phenomenology of hydrological waveforms**
- **New physical "retracker" for lakes**
- **Validation on small lakes (Occitanie, France) and mountainous lakes (Swiss)**
  - Highly demanding context to challenge the algorithm



OLTC= Open Loop Tracking Command
RMSE = Root Mean Square Error


Examples of S3 radargrams over lakes
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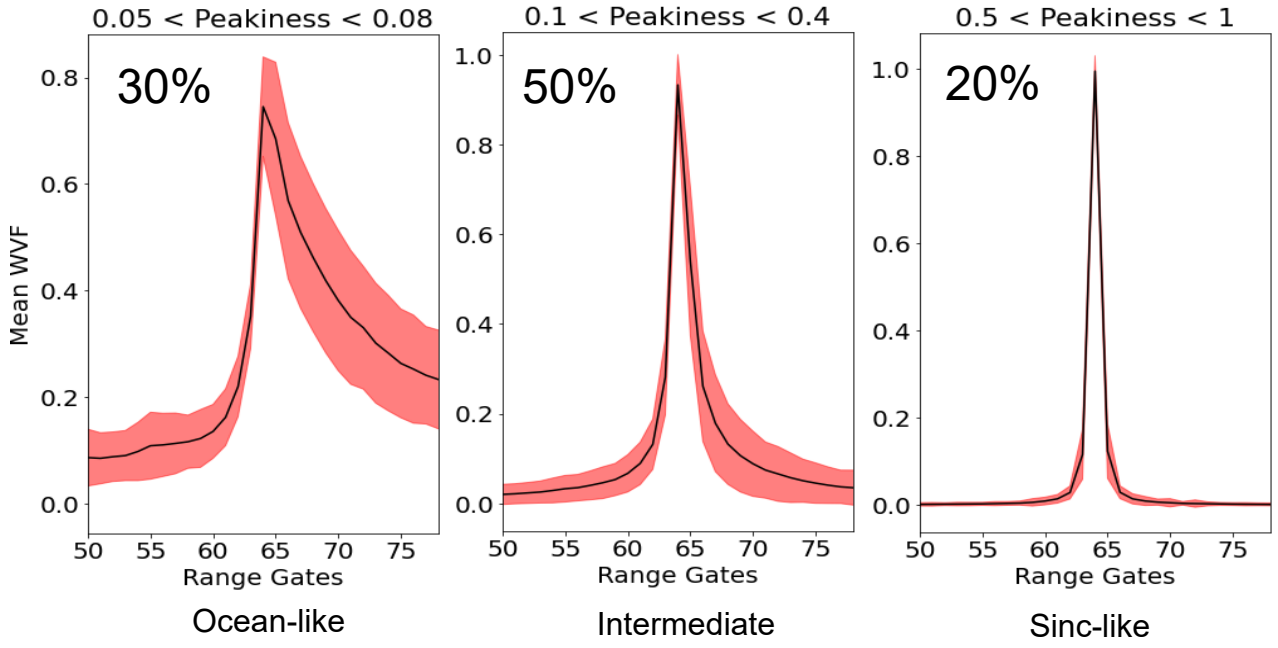
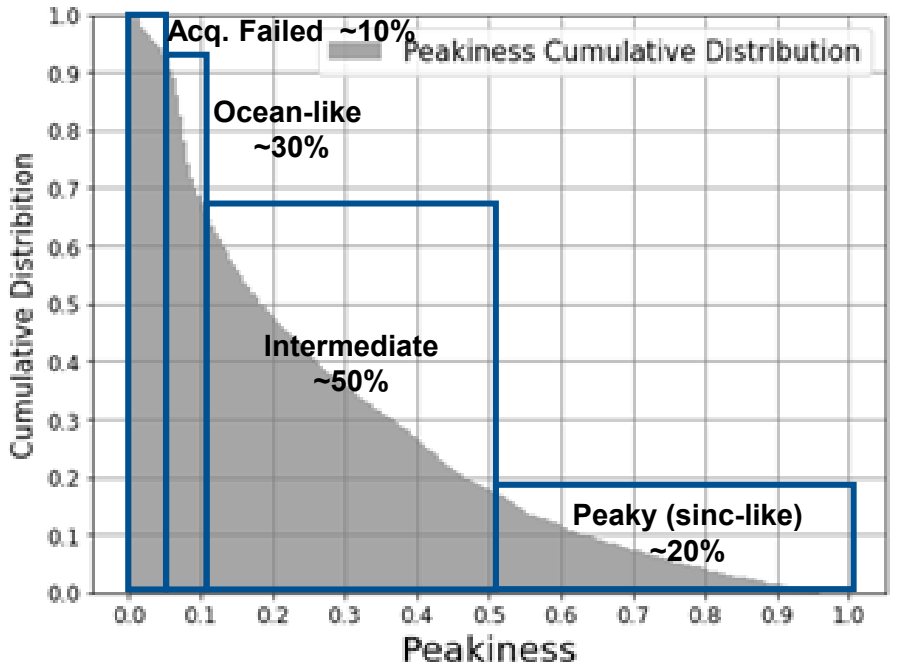
Altimetry waveforms over lakes (1/2)

Analysis of waveforms shapes over lakes described by a virtual station in the OLTC DTM

- **Use of the peakiness criterion:** $peakiness = \frac{\max(w_i)}{\sum_{i=1}^{n} w_i}$
- **Statistical analysis on all lakes identified in the on-board DTM and on the complete S3 time series**





Retracking algorithm = estimate the **water surface height** from the altimetry waveforms

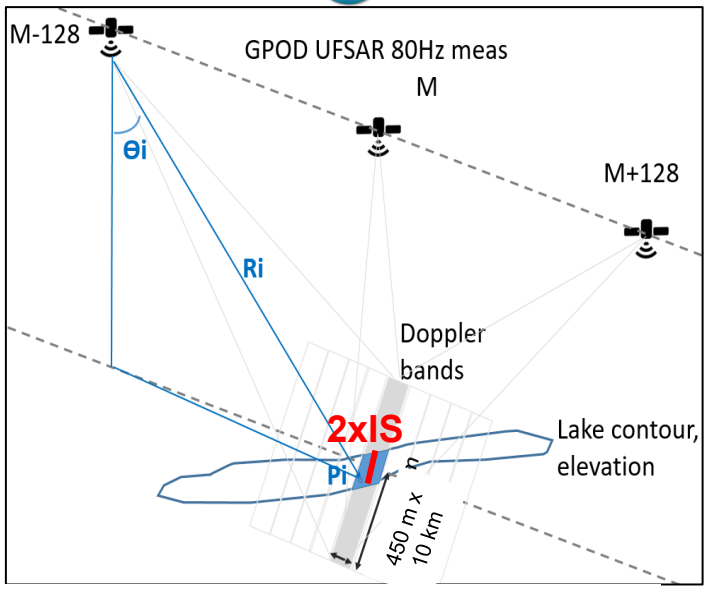
First conclusions:

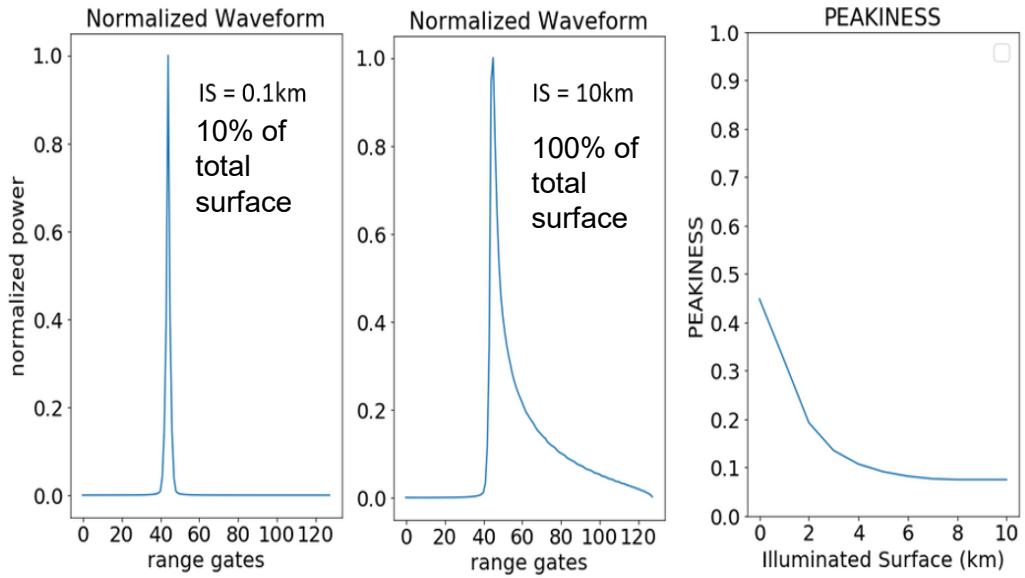
- ➔ Very large variety of waveform shapes
- ➔ Need of a physical model to inverse them properly (empirical models cannot describe all these situations)
- ➔ Exploit the 2D information

Measuring water heights with altimeters (2/2)

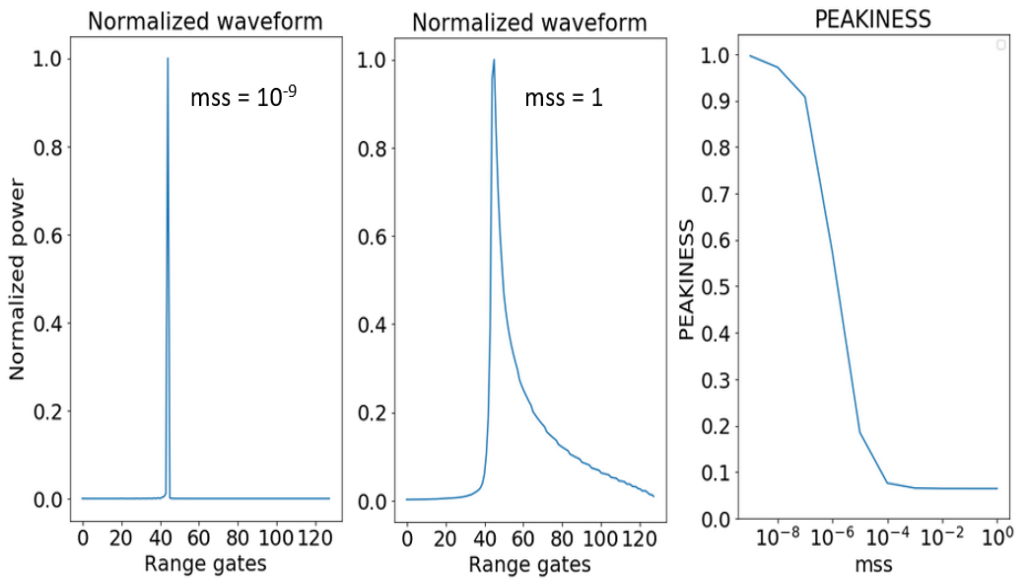
The echo shape is tuned by <u>two major parameters</u>

- **The Illuminated Surface (IS):** represents the percentage of water surface area included in the radar footprint
- **The roughness of the surface (mss)**





IS impact

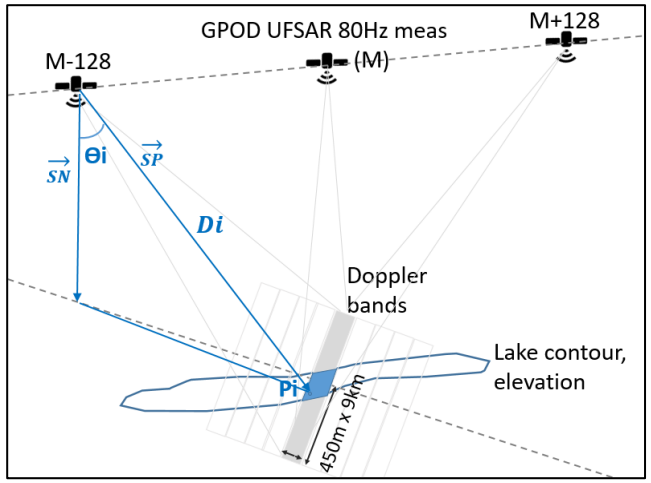


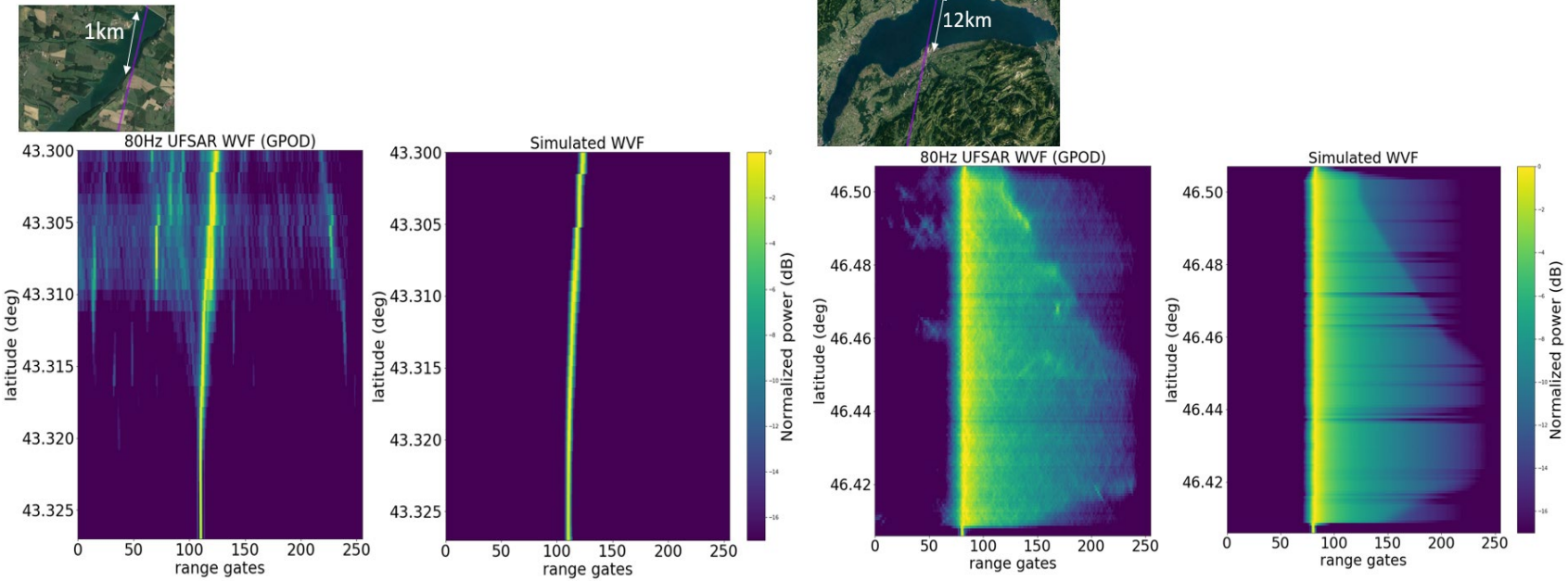
Mss impact

Retracking based on numerical simulations (1/3)

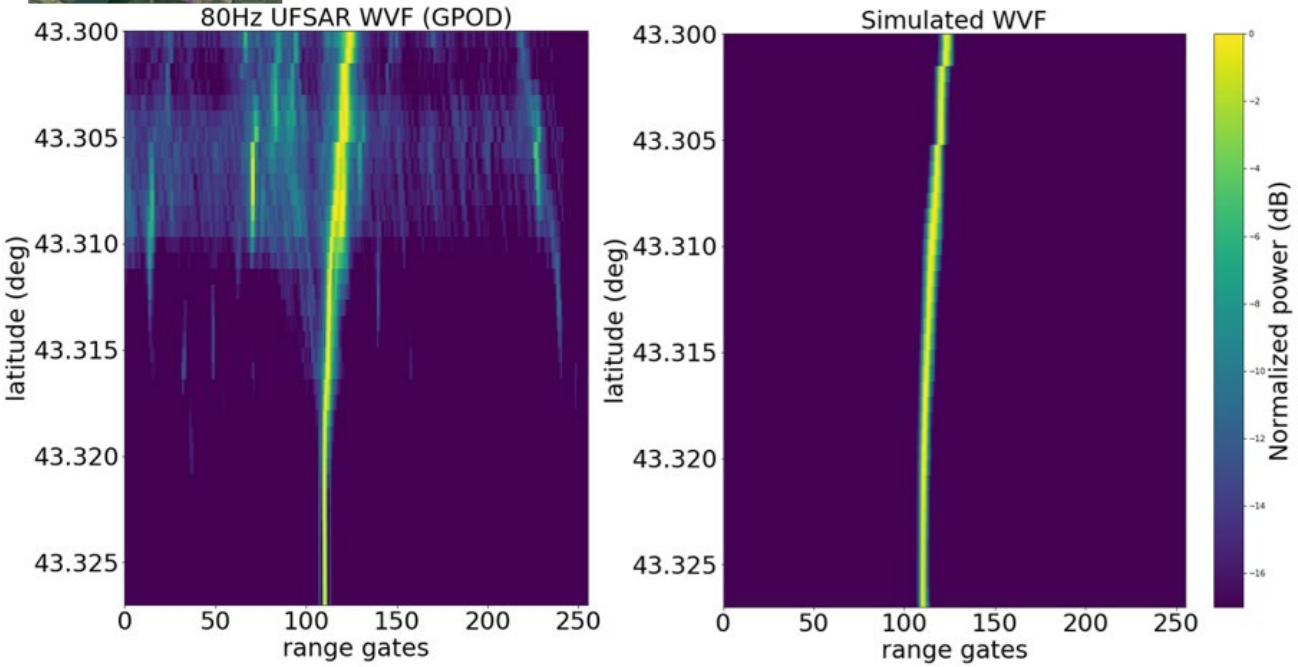
Definition of a physical retracker based on numerical simulations (LPP) [Boy et al, 2017; Boy et al, 2022]

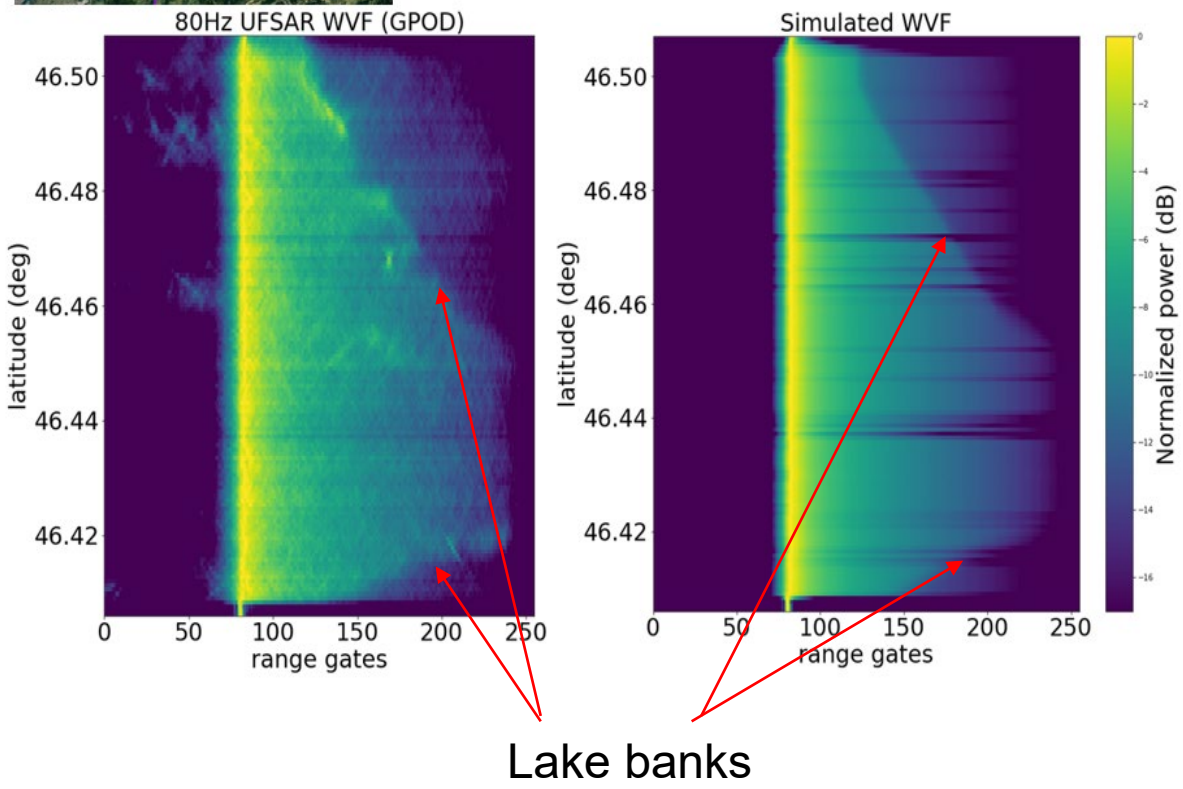
- **All instrumental/satellite characteristics are accounted for**
  - Antenna pattern, range impulse response, radar tracker, satellite altitude & positions, UFSAR processing
- **Observation geometry is giving using contours from Lake database**
  - From CARTHAGE database [Pella et al., 2006] for French lakes and from SWOT Lake database [Sheng et al., 2016] for Swiss lakes.
- **Surface roughness is modelled using Optics geometry** $\sigma 0(\theta) = \sigma 0(0) e^{-\frac{\sin(\theta)^2}{mss}}$



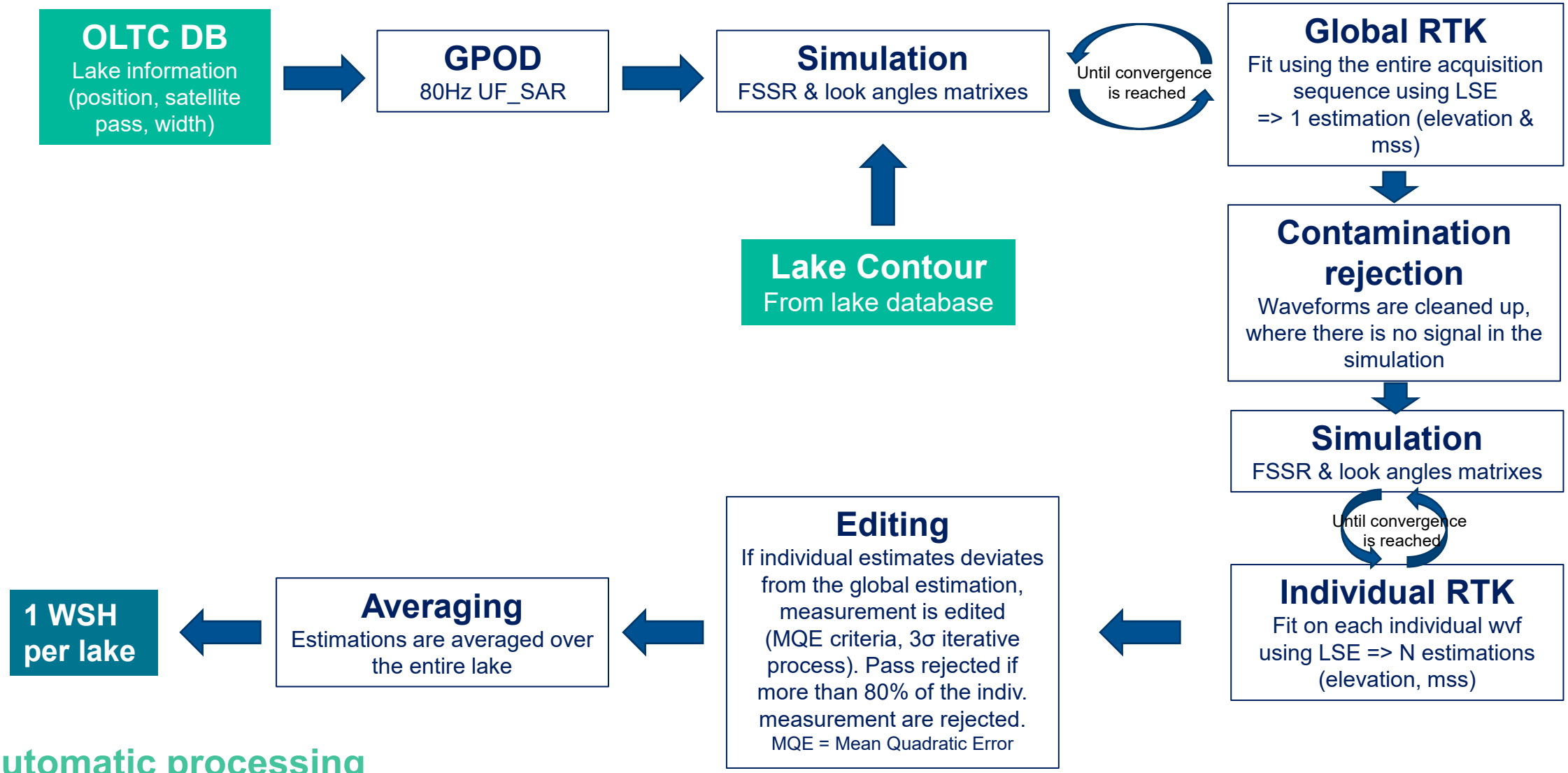


Retracking based on numerical simulations (2/3)





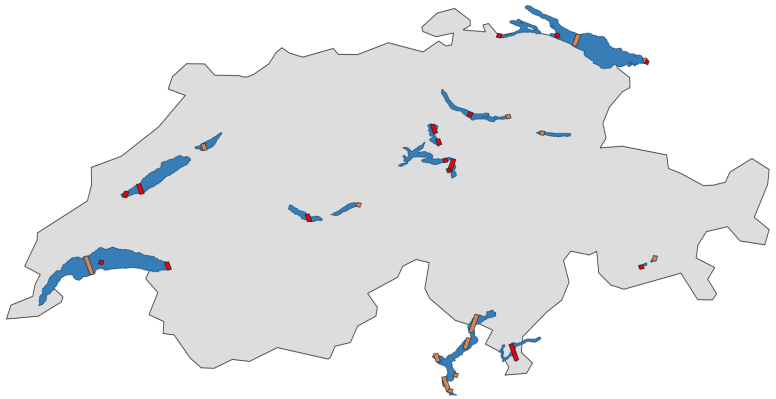
Retracking based on numerical simulations (3/3)



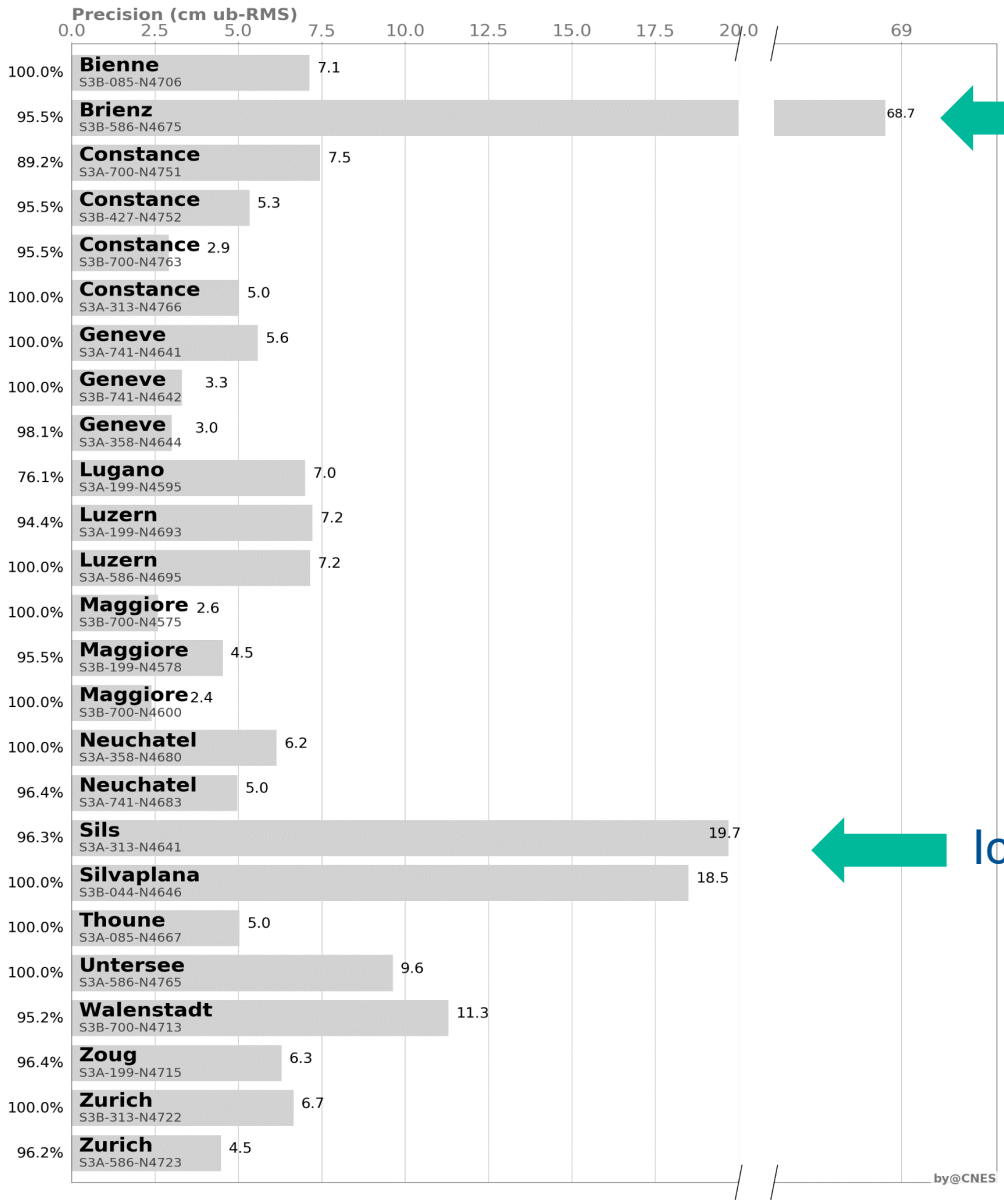
Automatic processing

Validation on Swiss lakes (1/2)

17 lakes – mountainous region – areas between 2.7 km² to 580 km²



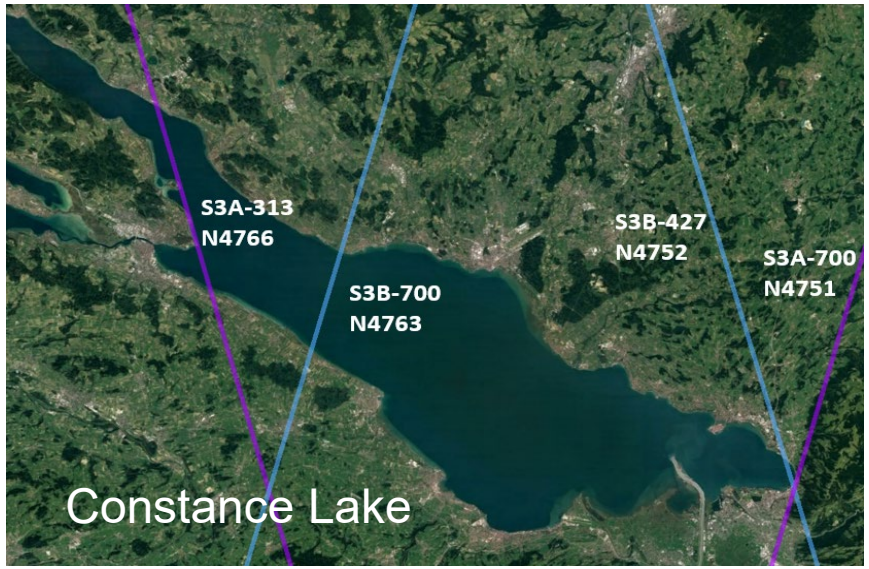
Processing of the entire Sentinel-3A and Sentinel-3B time series for all lakes (52+21 passes)



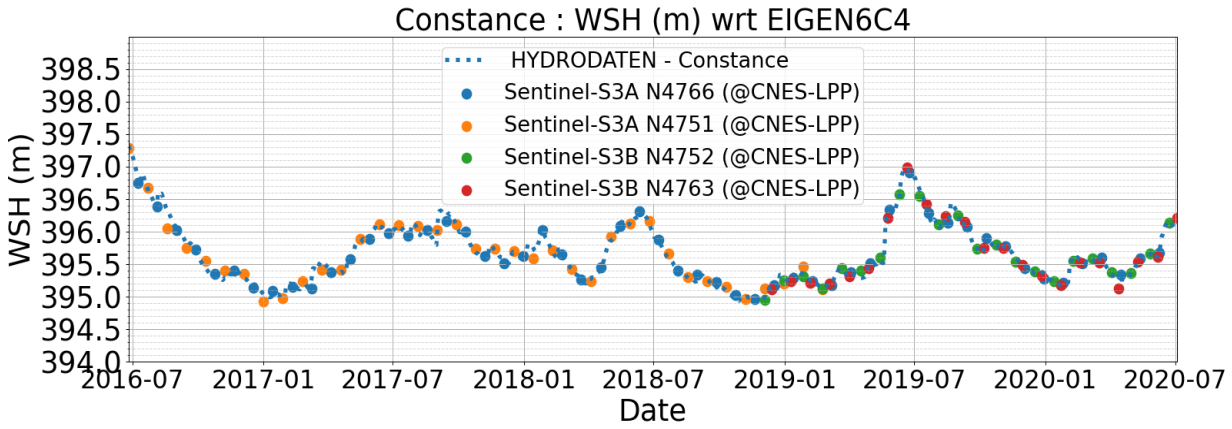
Under investigation (5 meas. out of bonds)
Strong mss variations?

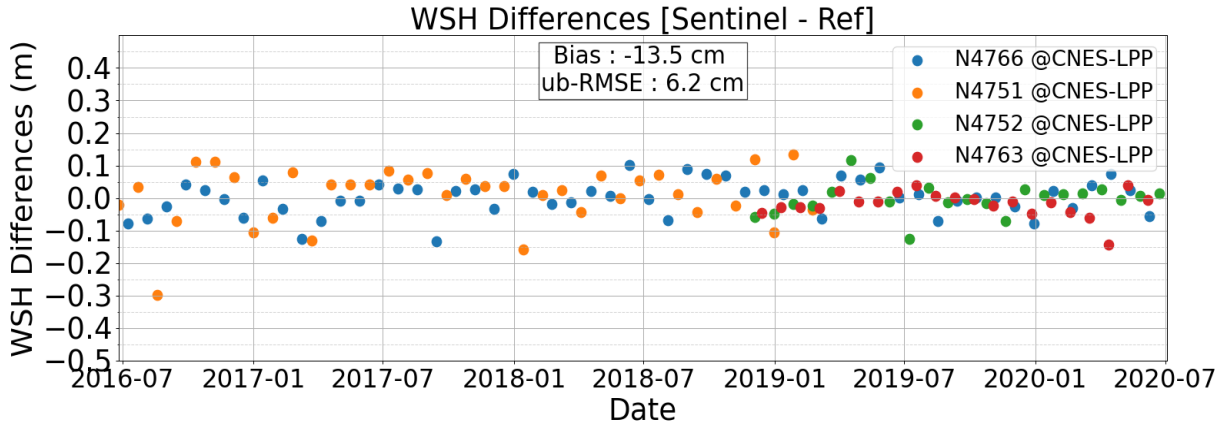
Icy lakes in winter

Validation on Swiss lakes (2/2)



Mission/Pass/VS	Bias (cm)	Unbiased RMSE (cm)
S31/313/N4766	-9.6	5
S3B/700/N4763	-13.5	2.9
S3B/427/N4752	-12.1	5.3
S3A/700/N4751	-12.4	7.5



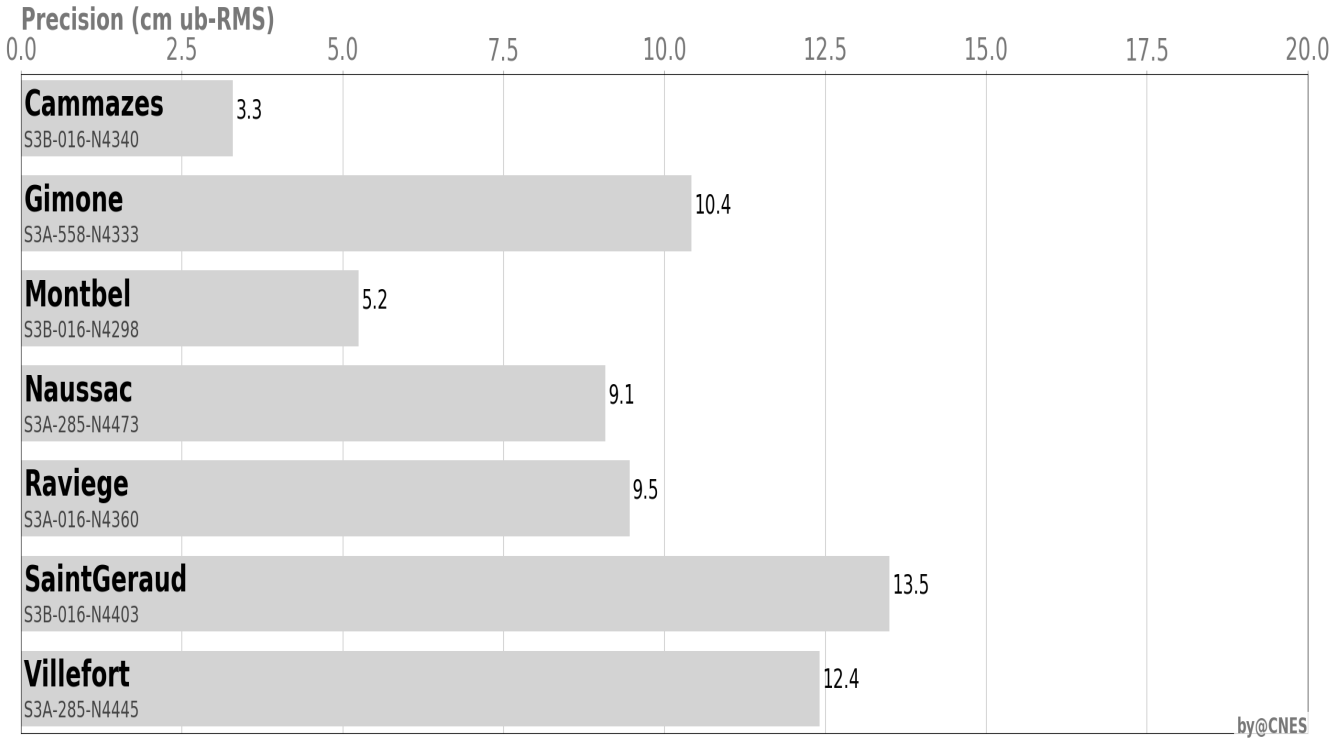


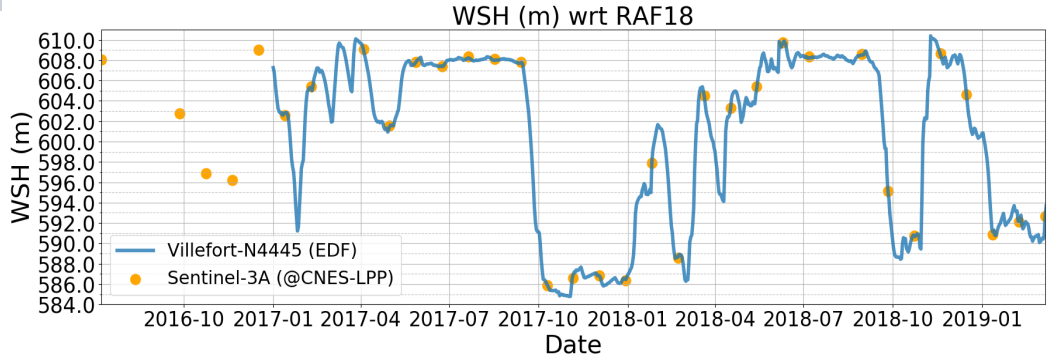
- Very similar biases for the 4 tracks
- S3A-700: very accurate despite off-nadir measurements
- Low geoid errors on this lake allowing for immediate merging

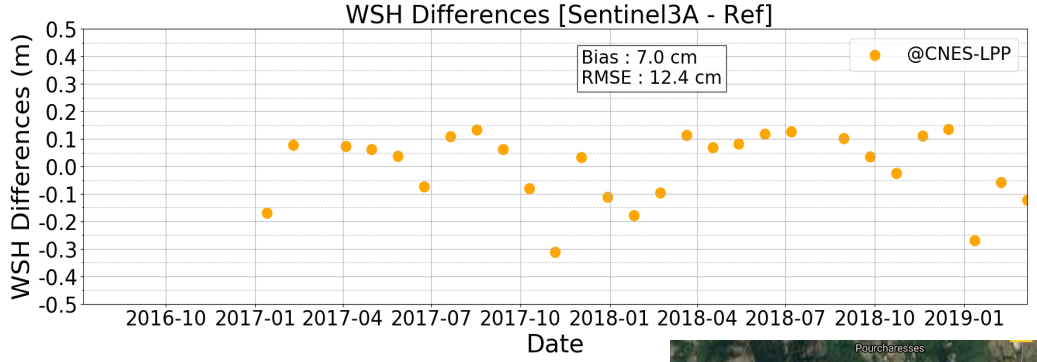
➔ **Combination of several tracks with no further inter-tracks alignment**

Validation on Occitan lakes (France)

Lakes	Cammazes	Gimone	Montbel	Naussac	Raviege	Saint Géraud	Villefort
Areas	0.4 km²	2.8 km²	5 km²	10.8 km²	4.38 km²	0.2 km²	1.27 km²







Villefort Lake

Conclusion

Demonstration of the **amazing capabilities** of new **altimeters** to measure **water surface heights** of lakes

- **RMSE < 14 cm for Occitan lakes (very small lakes of 0.4 km² to 5km²) and RMSE < 10 cm for 14 Swiss lakes (very mountainous area, small (2.7 km²) to large (580 km²) lakes)**
- **Comparison with HYDROWEB: over complex situations, LPP performances surpass by a factor of at least 2 those of the OCOG retracking.**

- **Very good accuracy reached with altimeters on very small lakes (few ha)**
  - As good as laser altimetry (ICESAT2) (evaluated in [Cooley et al., 2021])

Workplan

- **LPP will be used on ESA St3ART project to validate Sentinel-3 mission over lakes.**
- **1,000 lakes under S3A&S3B will be reprocessed with LPP**
- **Development of on-demand LPP processing**
- **Adaptation to Sentinel-6 mission**

More details in **IEEE TGRS**:

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