Understanding nadir altimetry measurements over continental waters

Simulations over rivers and statistical analysis of individual pulses from Sentinel altimetry missions

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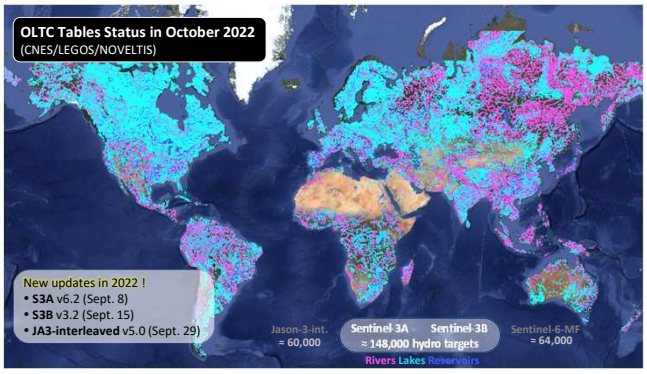
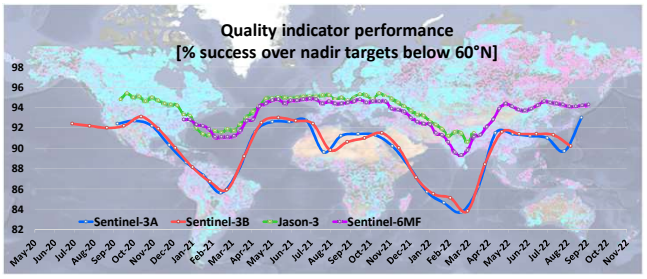
Background on altimeters' tracking capability

- Primarily designed for ocean measurement, nadir altimeters also provide measurements over land surfaces.
- The **Open-Loop Tracking Command (OLTC)** allows to set the reception window of radar echoes, using on-board tables containing:
  - ➢ Position along the orbit
  - ➢ **Reference elevation command H_0 for each target**





Current data processing algorithms and limitations

Altimeters tracking capability

→ **Massive amount of data available** for hydrology users thanks to the current altimetry missions !

Retracking algorithms

- Waveforms need to be converted into geophysical parameters e.g. **water surface height (WSH)**
- **Current retracking algorithms applied to build Level-2 products use models that are not specific to waveforms observed over hydrology**
  - ❍OCOG (or ICE1) retracking uses an empirical method (Offset Centre Of Gravity of the waveform)
  - ❍SAMOSA uses a model designed for ocean waveforms. Suited for (large) lakes but not for rivers !

→Retracking errors over hydrology (in particular rivers) can reach tens of centimeters and more !
e.g. *Jiang et al. 2020*

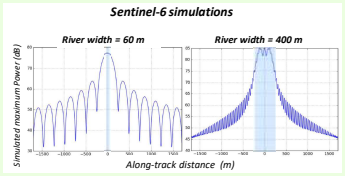
Understanding the specifics of the signal over hydrology and in particular, over rivers

- Radar echoes over rivers are very different over ocean or even large lakes
- *Abileah et al. (2017, 2021)* refers to the « **specular flash** » **observed over rivers** and defines a model

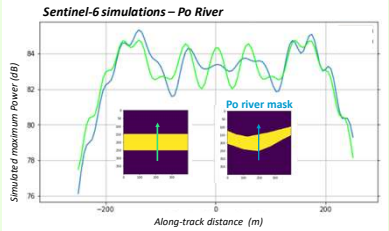
→ Simulations are useful to understand the specifics of these signals and compare with real data

Simulation tools

- Simulation tools developed at CNES using binary surface mask (simple or real) and altimeter configuration
- Coherent sum of complex I&Q samples, then $|(I,Q)|^2$ = **waveforms**
- Various river widths



- Sinc² shape of echoes *[Abileah et al. 2017, 2021]*
- Different spatial extent of signal power in function of river widths (and mission parameters – mainly altitude and frequency)

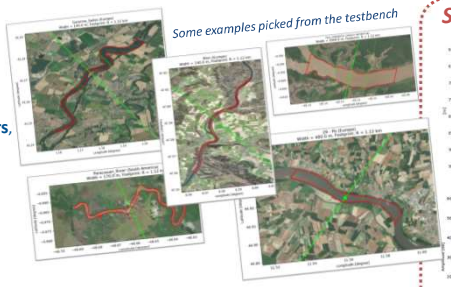


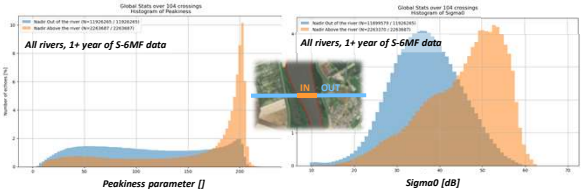
Diving into Sentinel-6-MF data : a 100+ rivers testbench

Sentinel-6 *Michael Freilich* satellite was successfully launched in November 2020, and stands out as the new reference altimetry mission since April 2022 (end of commissionning phase). S6-MF is also **very promising for hydrology !**

In the frame of a CNES-CLS study, we built a **testbench of ca. 100 rivers**, consisting of :

- **River « contours »** built from Google Earth imagery, ±3km across Sentinel-6-MF theoretical track
- **Sentinel-6-MF individual echoes** in HR-RAW mode (complex I&Q samples) during approx. 3 seconds over each river, from Level-1A PDGS Land product, **more than 1 year of data** !

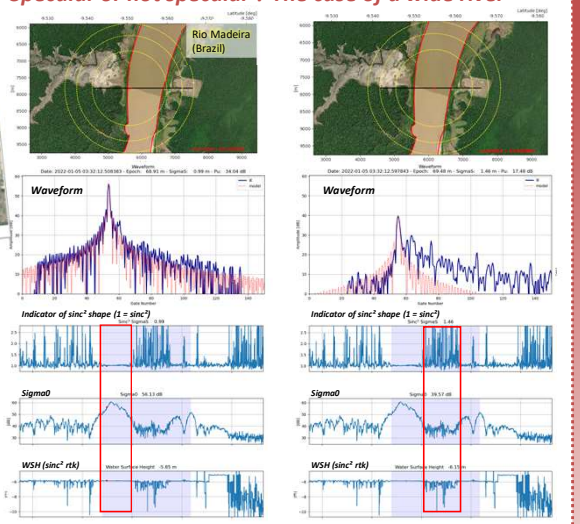




[Left] The « peakiness » parameter is a simple indicator of the radar **echoes shape** → Sentinel-6 MF echoes are **very peaky**, mostly **similar to a sinc²**

[Right] Very powerful echoes → **High Sigma0 values (>40dB)** over rivers but also outside of the river mask

Specular or not specular ? The case of a wide river



- **Specular echoes** are observed in this part of the river (nadir point over water, near the riverbanks)
- Sigma0 reaches 60 dB
- WSH profile is flat
- → very good performance of sinc² retracking

- **Rough echoes** are observed in this part of the river (nadir point over the centre of the river !)
- The waveform exhibits a noisy trailing edge
- Sigma0 suddenly loses 20 dB, very noisy
- WSH profile very noisy and more than 2.5 meters error!

→ **A single river can exhibit multiple behaviors (specular to rough)** with associated variability of returned power

→ **Using a model accounting for roughness improves the WSH retrieval:** no more transitions between specular and rough echoes

→ **The Adaptive retracker** *(Tourain et al. 2021)* **is also very efficient over this case !**

What we learned…

Processing of nadir altimetry over hydrology can be impacted by other several factors, including :

➢ **Nature of the surface**

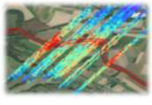
- **Sand banks** : when wet, sand is very reflective. It can generate powerful peaks in the waveform (before the peak corresponding to the water level)
- **Heterogeneous surface** (mix of river/canals/ponds/buildings/…): multi-peaks in the waveform

→**Better knowledge/characterization of the observed surface using external data (synergy)**

➢ **Observing system**

- **Orbit keeping :** when the satellite track deviates from the theoretical track, the river is not observed at the same crossing point (slope of the river needs to be accounted for).
  e.g. median river **slope 60cm/km** ; track ±1km → **range error up to 20 cm RMS !**

→**More strict requirement on orbit keeping in future hydrology missions ?**



Perspectives for inland waters monitoring and future missions

Process more.

Nadir altimetry now provides **more quality data over inland waters than ever** before.
This is an unique opportunity to build an extensive dataset and **compare satellite-based and in-situ** gauge data !
Also very useful for data assimilation in hydrological models.

Process better.

Current « re-tracking » techniques have **limitations** and do not reach the required performance (e.g. <10 cm as stated by GCOS for lakes). **Innovative processing algorithms using LRM and SAR altimetry data** need to be applied at basin and global scales and **multi-source data analysis** initiatives such as ESA St3TART project must be developed!

Going further.

In preparation for the **SWOT mission** Cal/Val, the current nadir altimeters constellation holding OLTC tables stands out as a unique asset for building a precious water level dataset. More **in-situ** and **UAV-based** measurements are also crucial for the validation of data and monitoring of water bodies worldwide.