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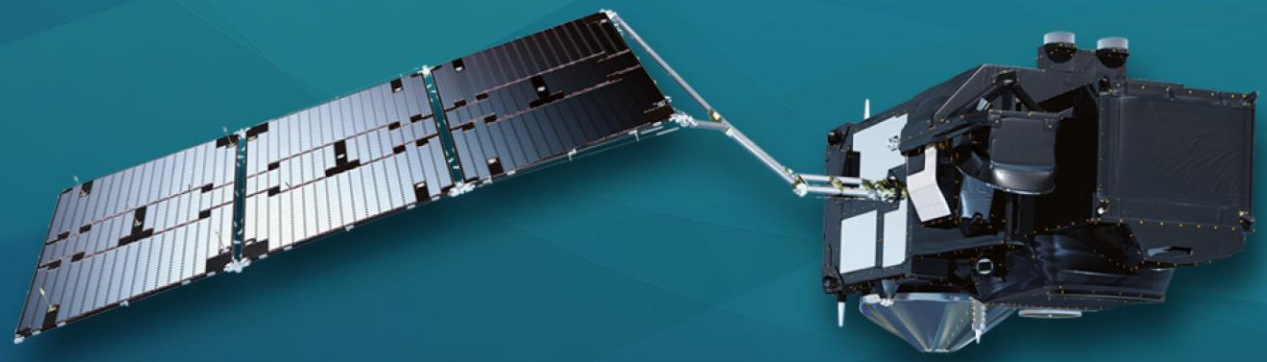

9th Sentinel-3 Validation Team meeting 2026

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

Retracking multiple off-nadir elevations over rivers with Sentinel-3 missions

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CLS
COLLECTE LOCALISATION SATELLITES
cnes

❑ *AsteriX: A Level-2 PICTA-based algorithm for retrieving multiple off-nadir elevation over rivers*

- First Polygon-Informed Cross-Track Altimetry (PICTA) introduced on Fully focused SAR data only (Ehlers et al, 2025, Chen et al, 2025)
- Off-nadir elevation retrieval reduces slope-induced error for validation of altimetry virtual station (VS) (Renou et al. (2025))

We present our new **A**ltimetry **S**ystem **T**o **E**stimate **RI**ver levels **X**-track, called ***AsteriX***, that automatically estimates off-nadir river WSE from UnFocused SAR altimeter waveforms.

Using UFSAR Sentinel-3A/B Hydrology waveforms over rivers

Comparison with *in situ* data over the French network

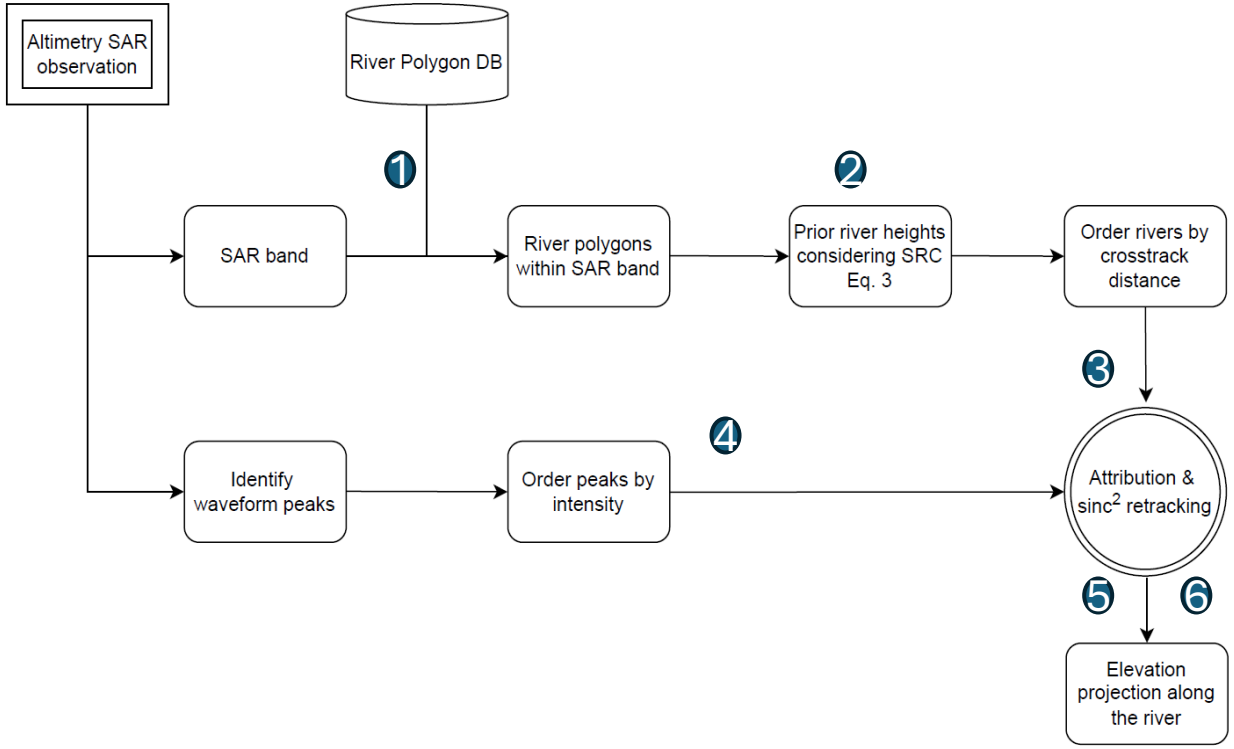
Towards a global application

ALGORITHM WORKFLOW

❑ AsteriX logicalflow:

For every 20Hz SAR measurement, we compute:

1. **The Intersection** between SAR band and river geometry
2. **Compute** the **Slant Range Correction** and related uncertainty
3. **Projection** of prior elevation in the range domain
4. **Waveform peak** detection (sorted by intensity)
5. **Retracking** based on a sinc2 fitting function
6. **Assign each peak to water bodies** within a chosen search range intervall. (iterative process over water bodies)



(from Calassou et al, 2026 (submitted, under review)

METHODOLOGY

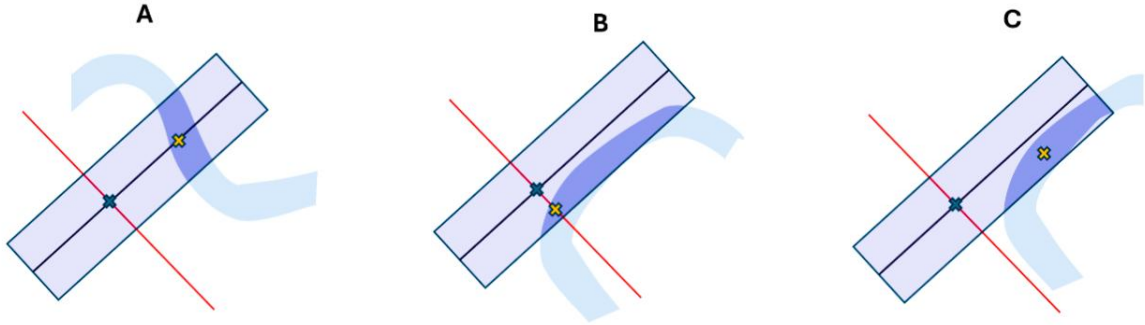
❑ **Step #1:** Intersection between the SAR band with river contour

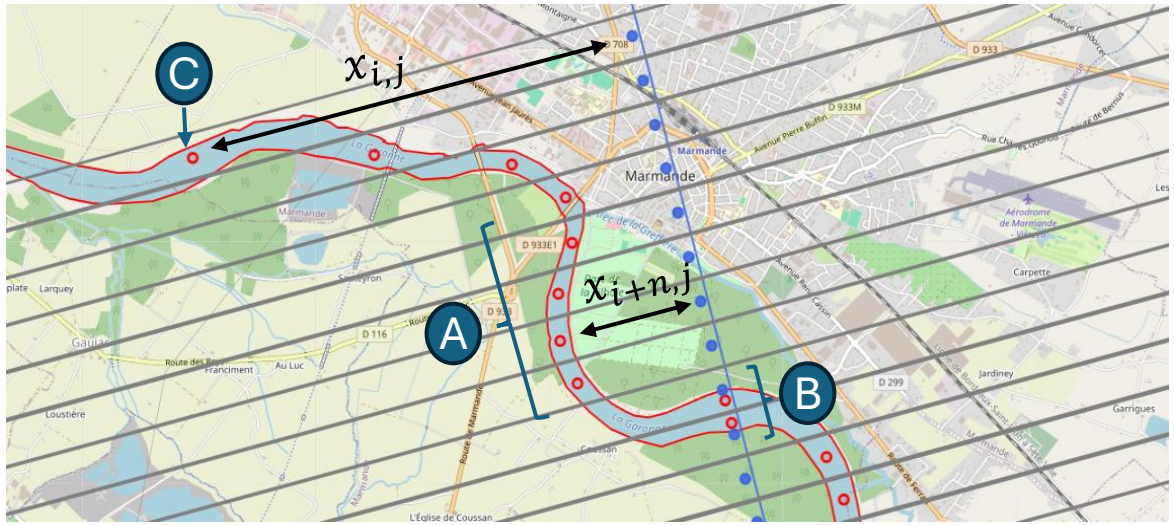
Goal: To determine the theoretical position of the basckscattering then used for the slant range correction (SRC) computation

Case A → Point in the middle of the river width, assuming constant width along-track within the SAR band.

Case B → If no cross-track intersection but only along-track

Case C → Using the pole of inaccessibility of the intersected river section: Guarantees that the point remains inside the polygon.





(from Calassou et al, 2026 (submitted, under review)

METHODOLOGY

❑ **Step #2:** Cross-track altimetry equation and slant range correction

Over rivers, water surface height WSH can be approximated as :

$$WSH = H_s - R + K.x^2$$

$$\text{with } K = (2H_s)^{-1} + (2R_e)^{-1}$$

$K.x^2$ the slant range correction term

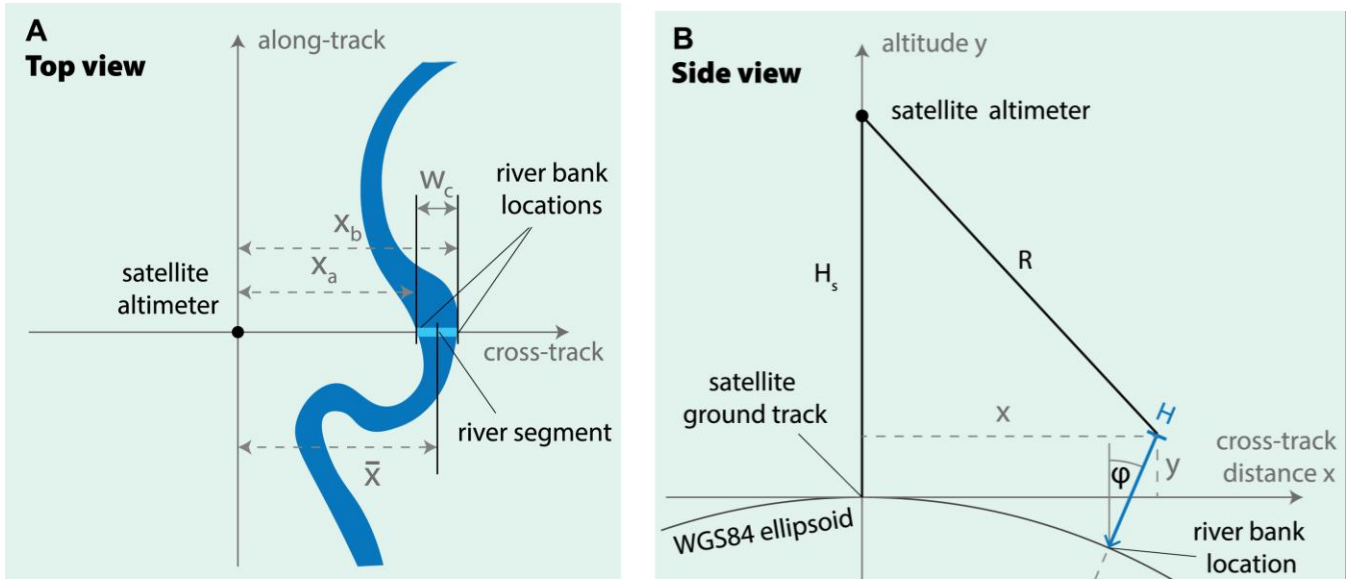
H_s : Satellite orbit

R : Altimeter range estimate

x : Carthesian distance [ground track – river]

R_e : Earth radius

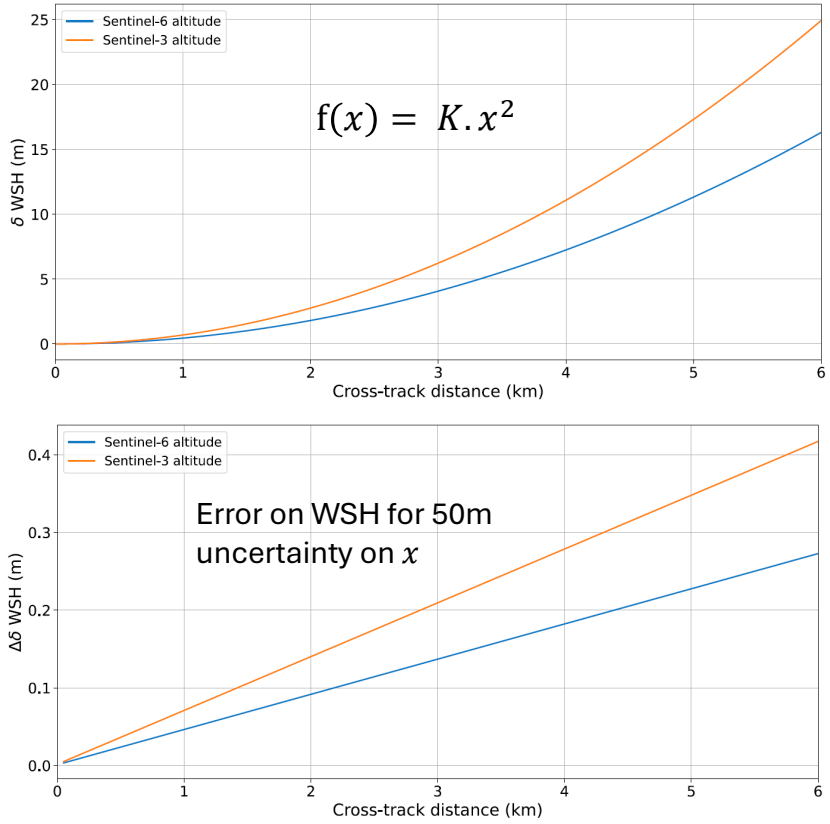
Assuming geophysical correction included in R



(from Ehlers et al, 2025)

METHODOLOGY

❑ **Step #2:** Slant range correction and uncertainty



→ Meter-scale correction

→ The more precisely x is known , the more accurate is WSH

→ Decimeter-scale error for $x > 1.5km$

Error budget

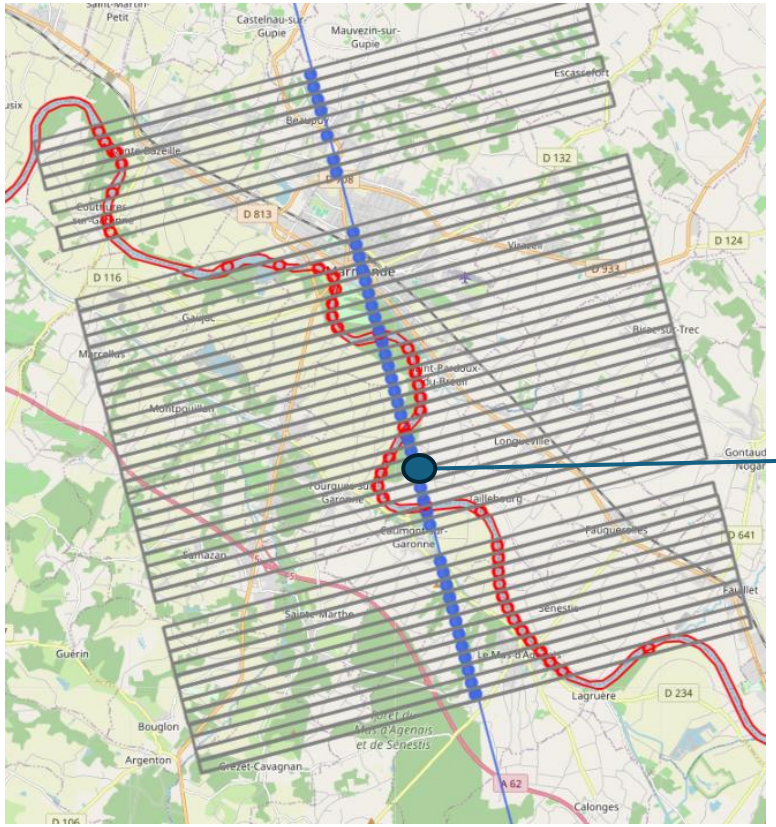
Source	Range uncertainty
Altimeter noise	~ 1.5 cm
Ionosphere	< 1 cm
Dry troposphere	< 1 cm
Wet troposphere	~ 1.5 cm
Radial orbit error	~ 2 cm
SRC	cm/dm scale

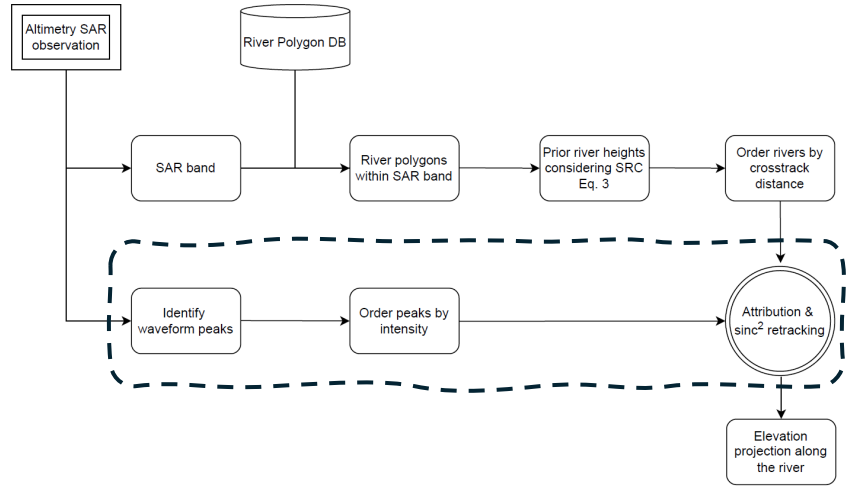
(Illustration from Calassou et al, 2026 (submitted, under review)

METHODOLOGY

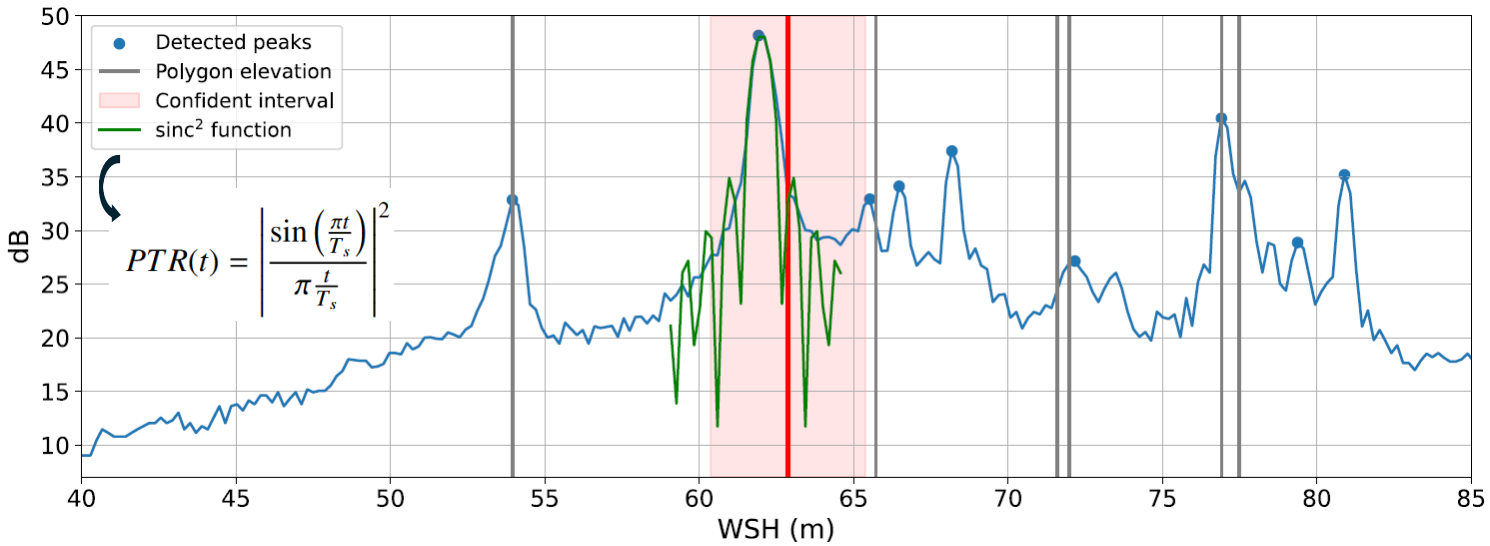
❑ **Step #3 to #6 :**

Peak detection, retracking and peak-to-wb assignation: iterative process over peaks and water bodies for each 20Hz measurement.



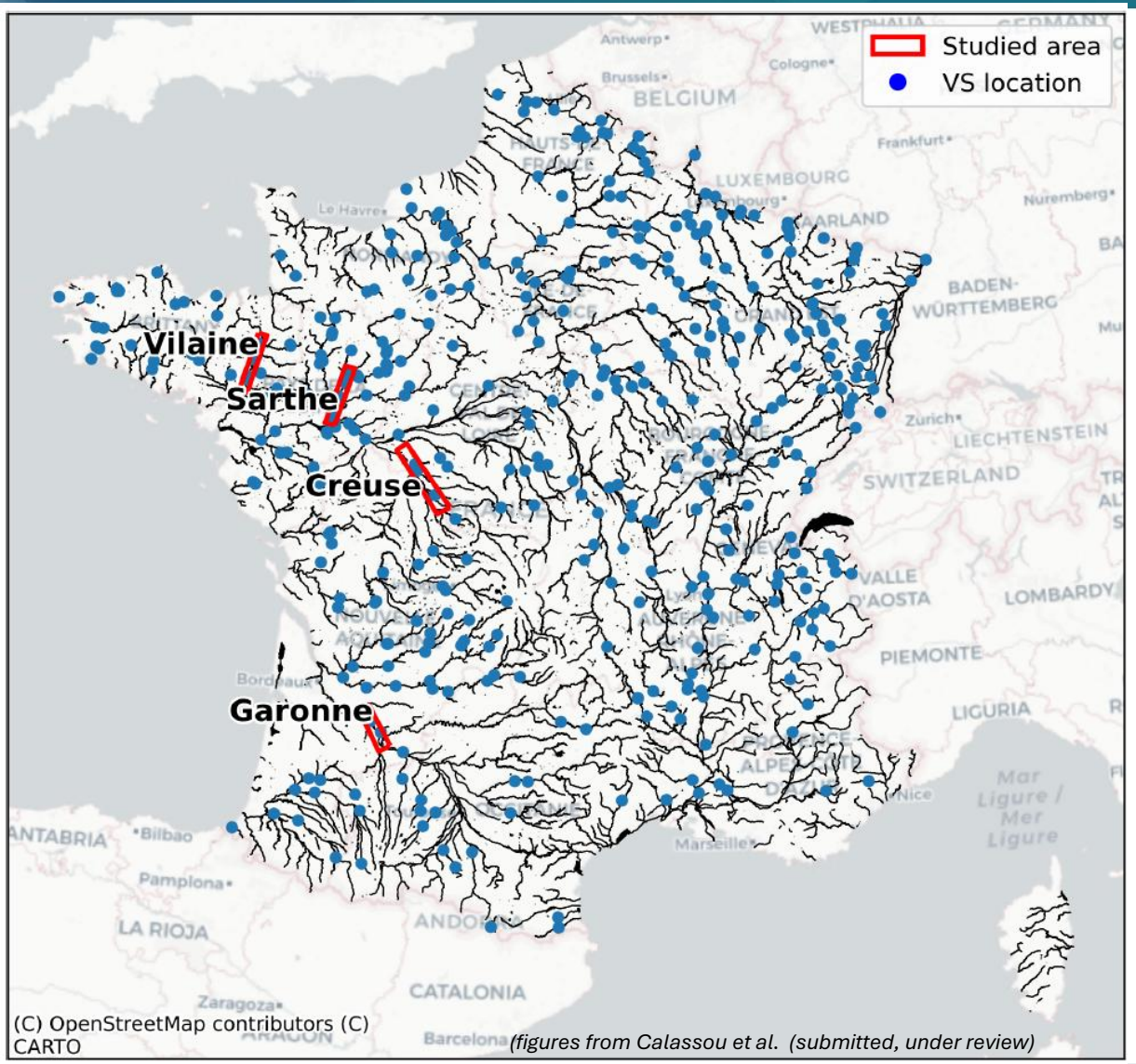


S3 Thematic Hydrology waveform (BC005)



(from Calassou et al, 2026 (submitted, under review)

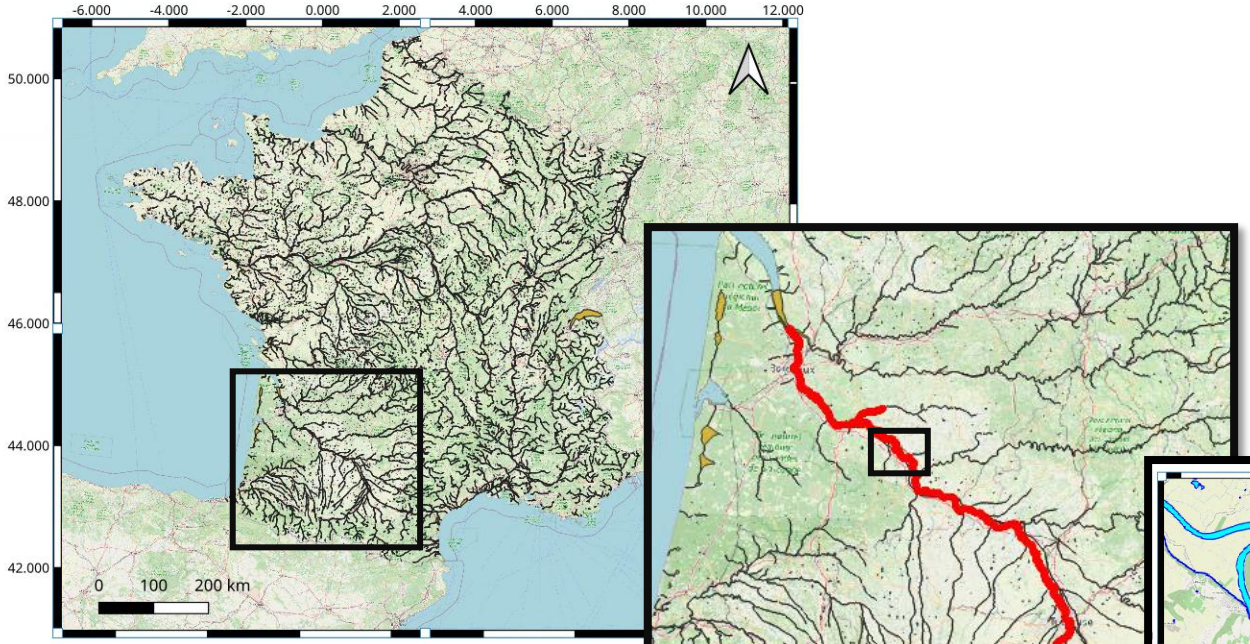
VALIDATION SITES

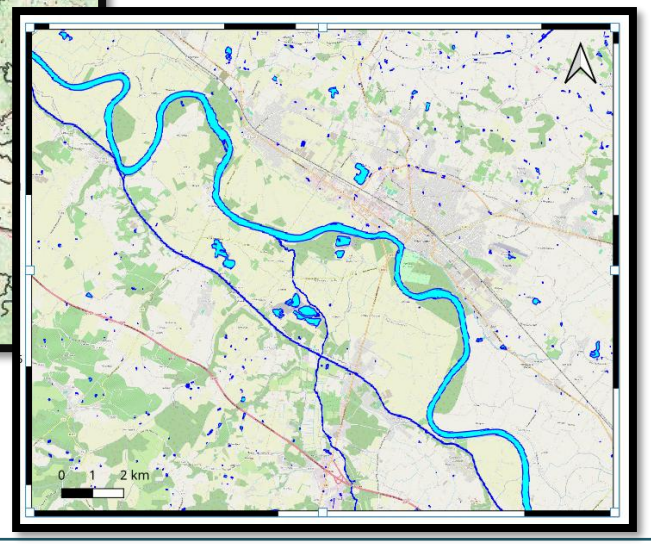


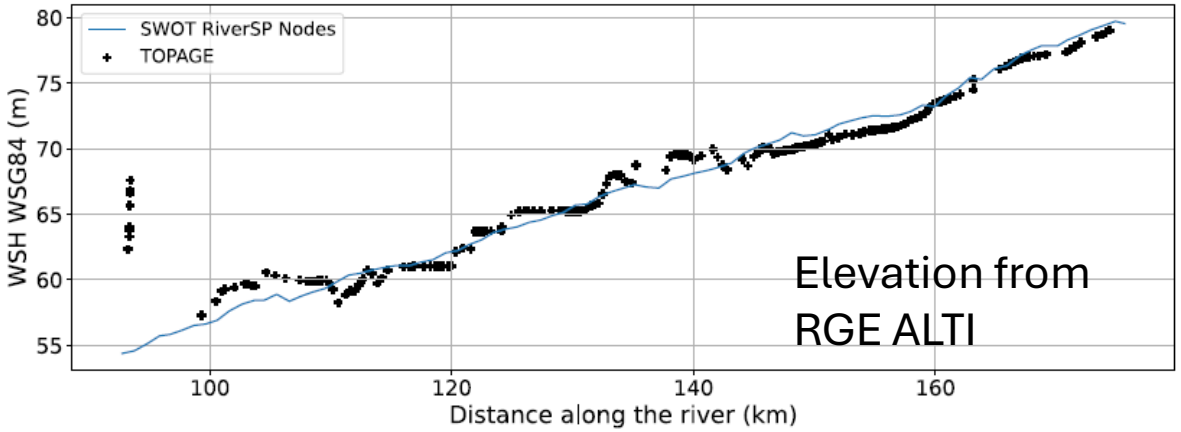
(figures from Calassou et al. (submitted, under review)

HYDROGRAPHIC DATABASE

Topage Database® (from IGN)







Zoom In
Garonne River

Reference altitude: IGN 1969

Horizontal precision (x,y): 1m

Vertical precision (z): 1m

Polygons &Linestring of various Water bodies

RESULTS OVER FRENCH RIVERS

❑ **Results** over two S3A/B case study:

Location:

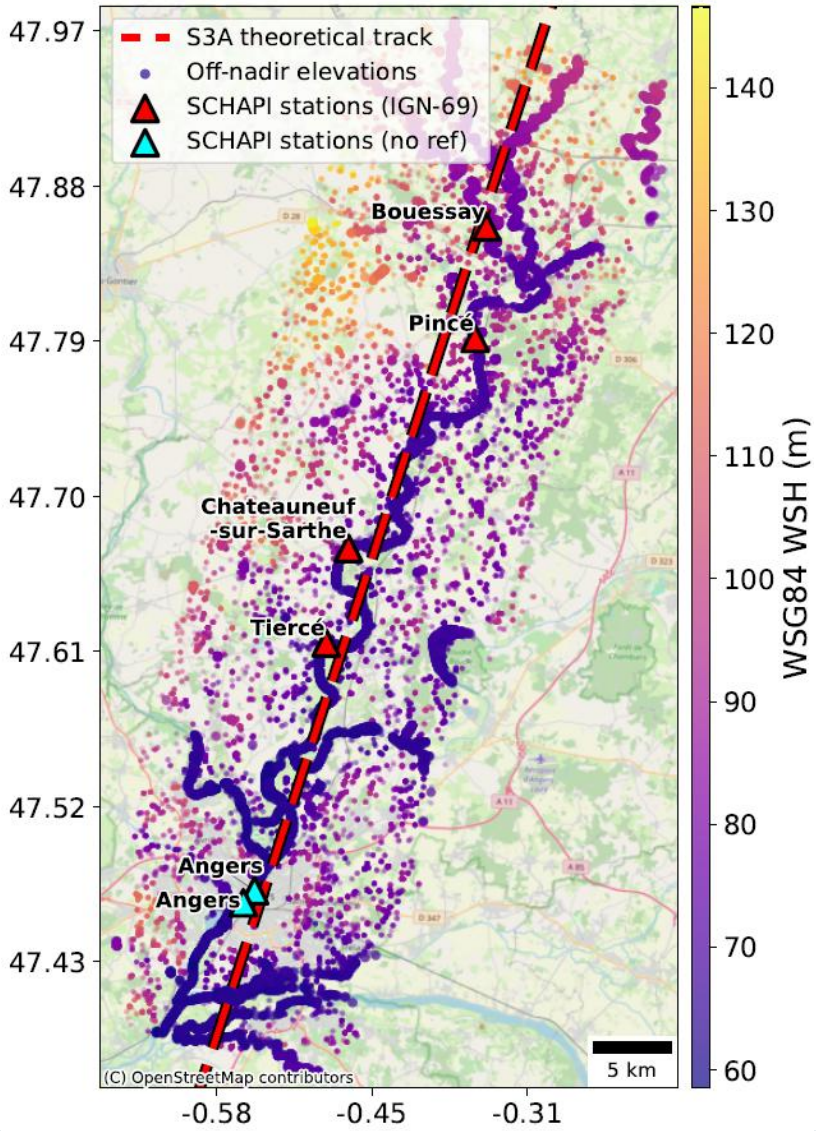
- Left**: Sarthe** river
- Right **Vilaine** river

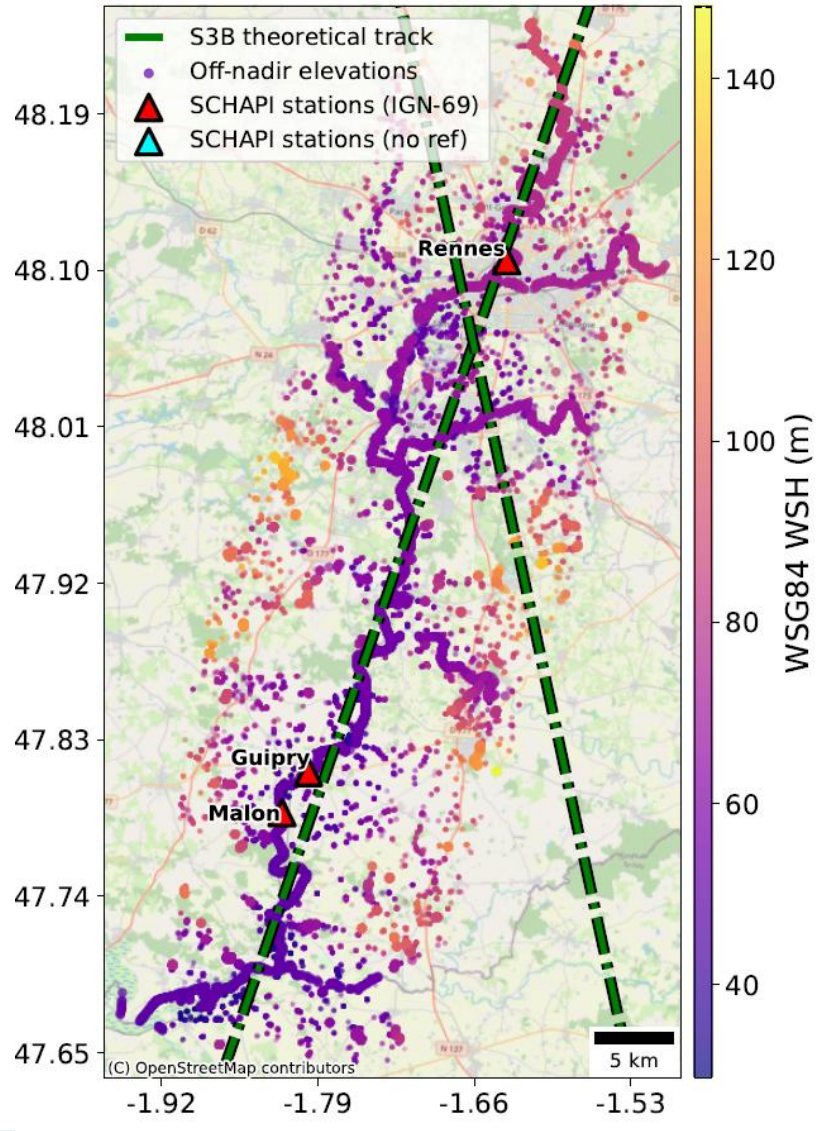
Time period:

- S3A: cycles 20 to 121
- S3B: cycles 20 to 101

✓ Retrieving multiple cross- track elevations

✓ For multiple water bodies





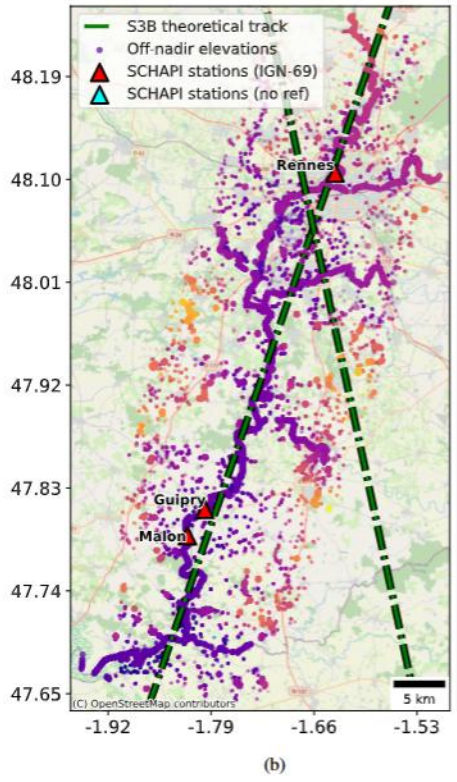
(from Calassou et al, 2026 (submitted, under review)

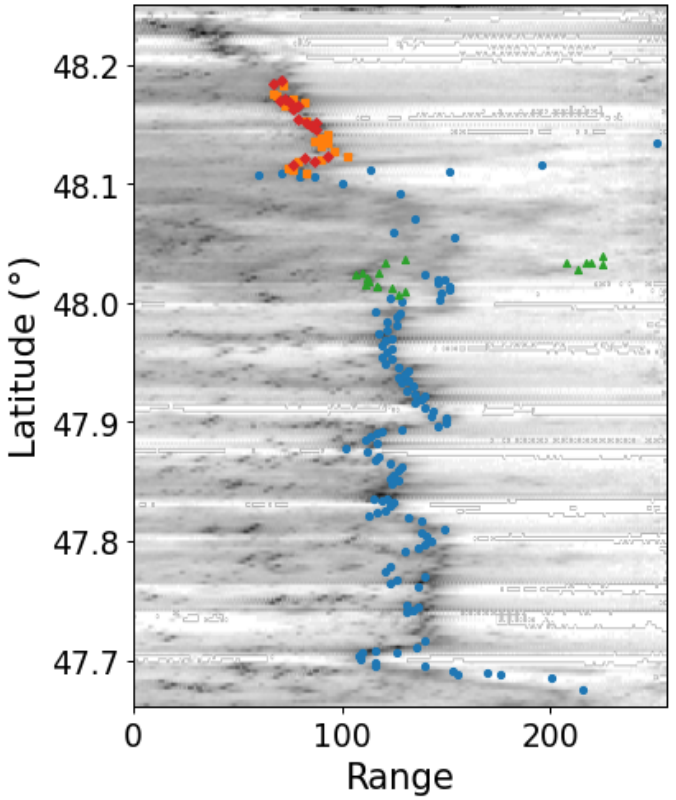
RESULTS OVER FRENCH RIVERS

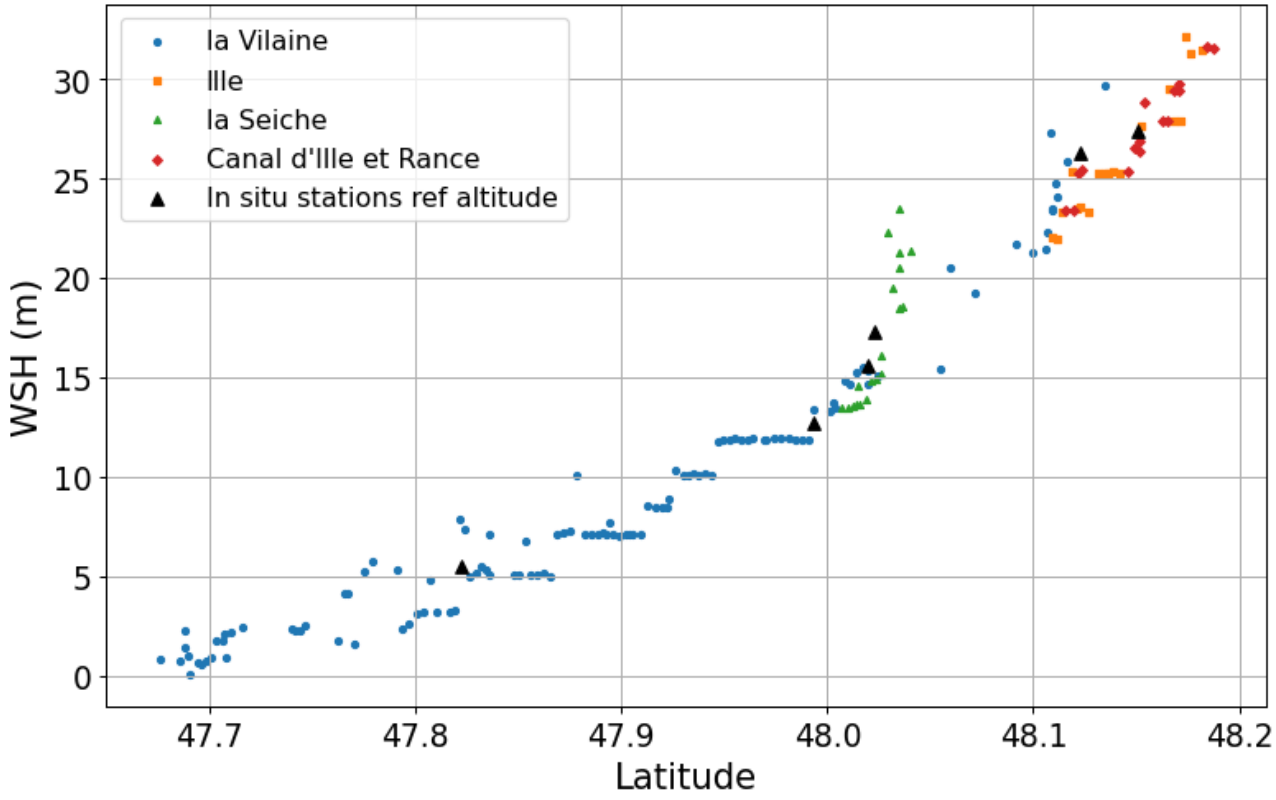
- Results over Vilaine for cycle 80 of Sentinel-3B:

- Retrieving multiple river profiles for cycle 80

- Taking the measurement within 200m from the *in-situ* station for comparison

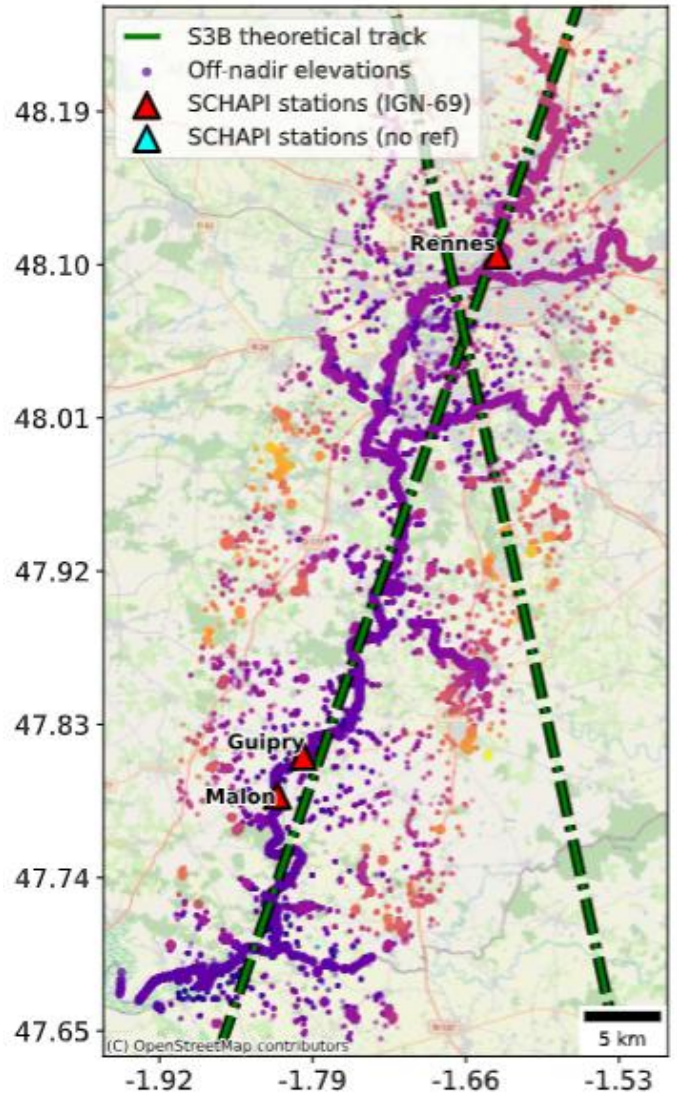


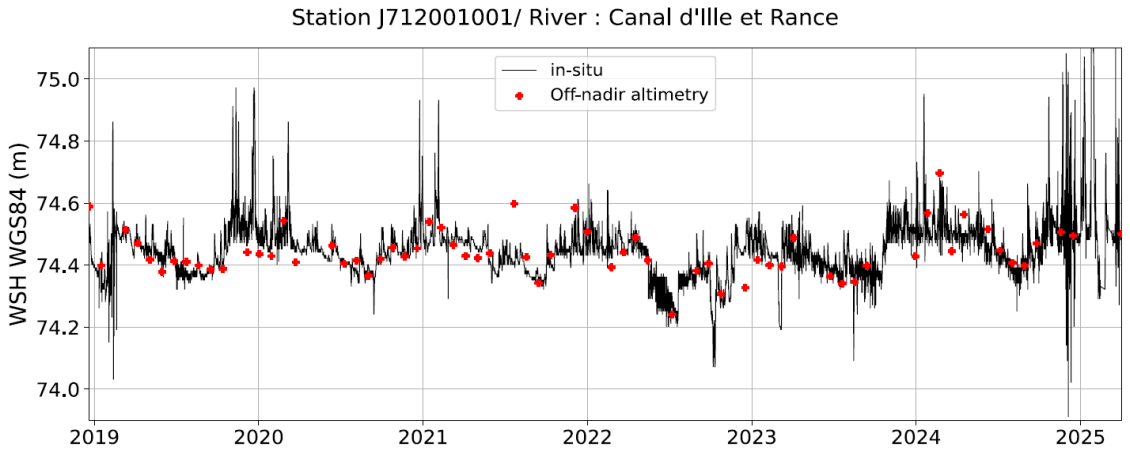




(figures from Calassou et al. (submitted, under review)

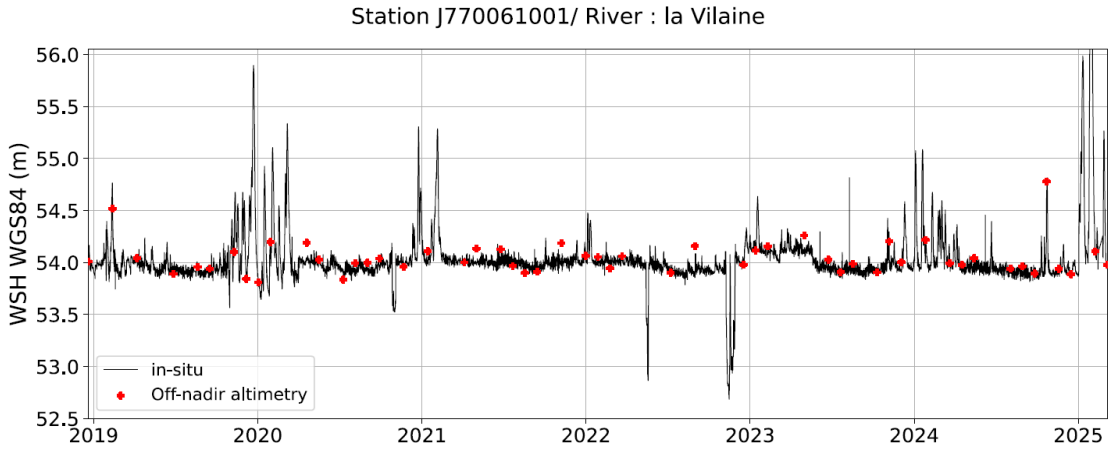
RESULTS OVER FRENCH RIVERS





(a) Rennes timeseries

X-dist: 2.8km
bias: 0cm
std : 6cm



(b) Guipry timeseries

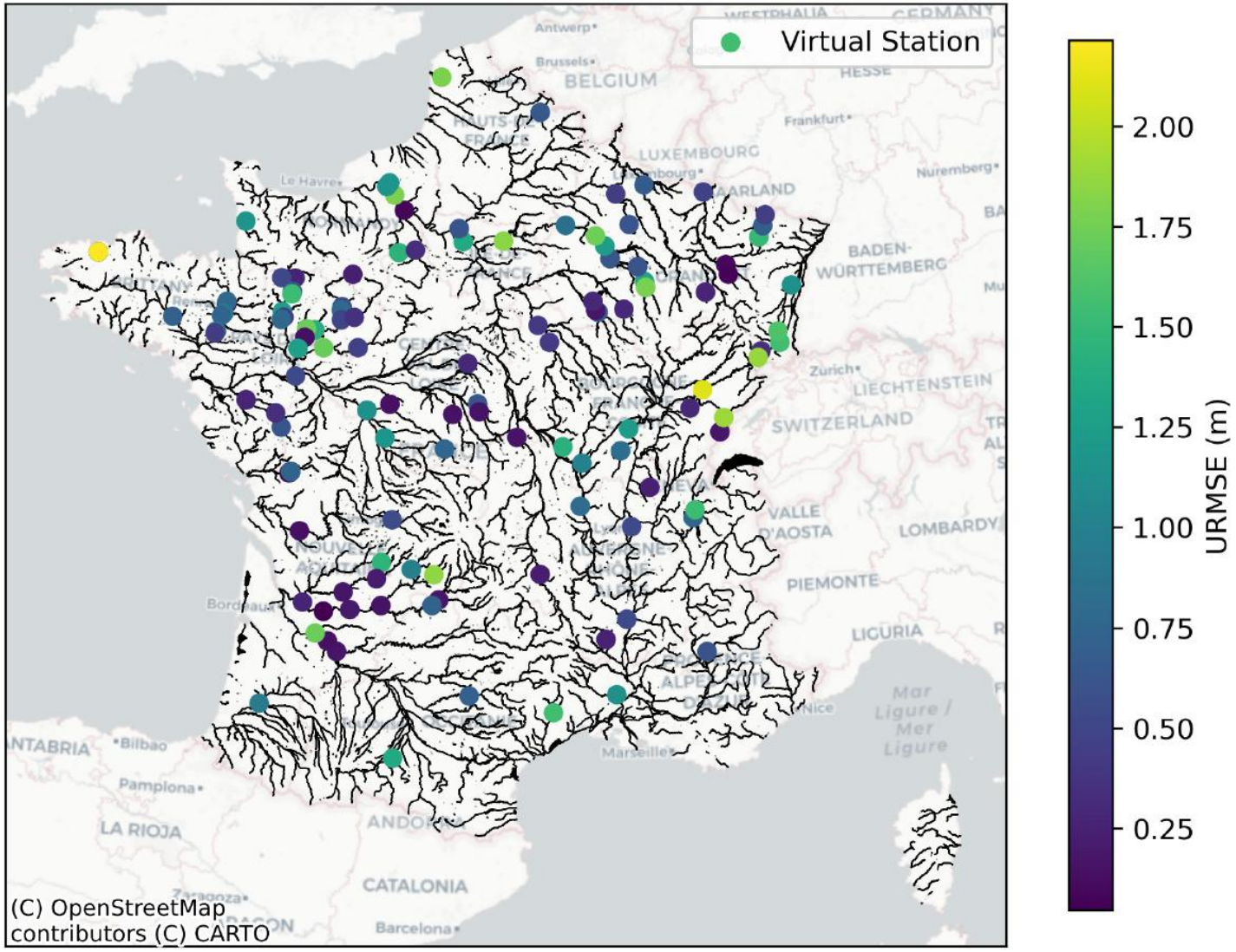
X-dist: 1km
bias: 4cm
std : 6 cm

(figures from Calassou et al. (submitted, under review)

RESULTS OVER FRENCH RIVERS

- ❑ Comparison over 116 VS
- Including Sentinel-6A sites
- See our preprint for more details

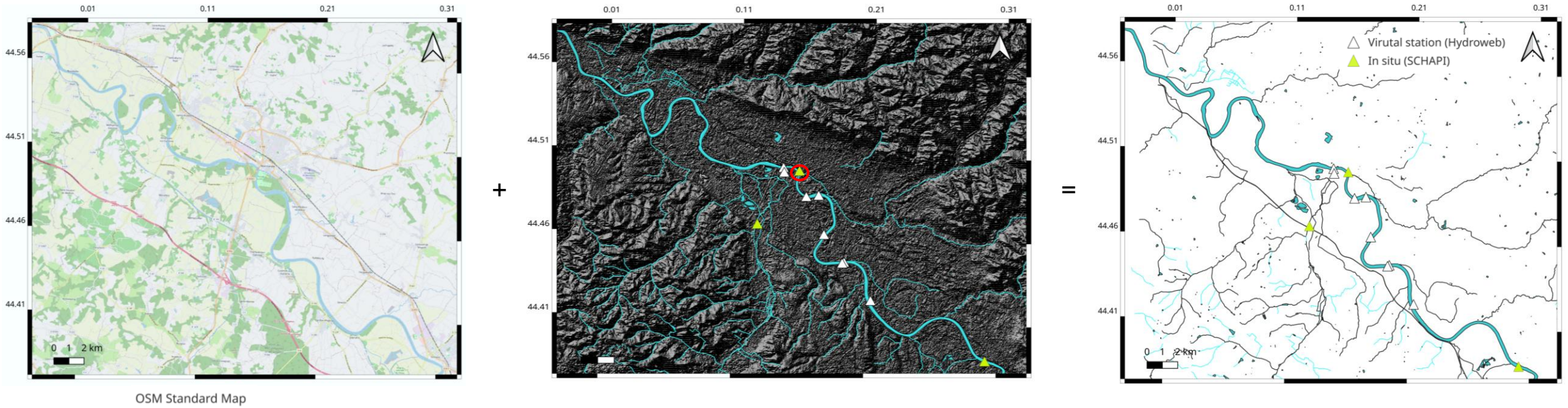
https://hal.science/view/index/docid/5573705



TOWARDS GLOBAL APPLICATION

❑ Toward a global application: Same method but different inputs

- ➢ Open Street Map (OSM) for water bodies polygons
- ➢ COPERNICUS DEM 30m resolution to project elevation on the polygons

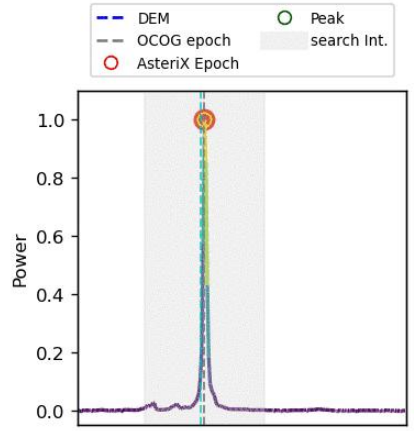


OSM Standard Map

TOWARDS GLOBAL APPLICATION

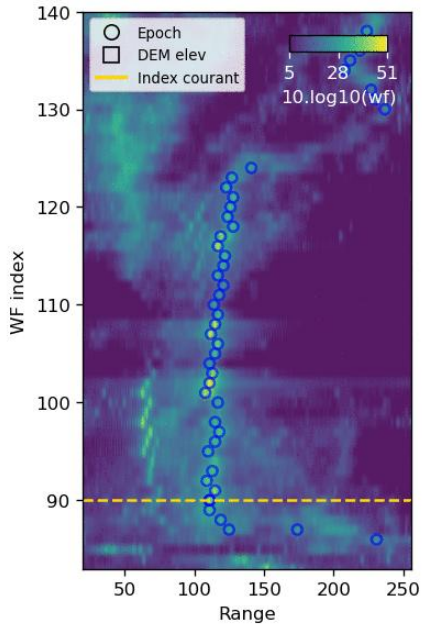
- Garonne, France

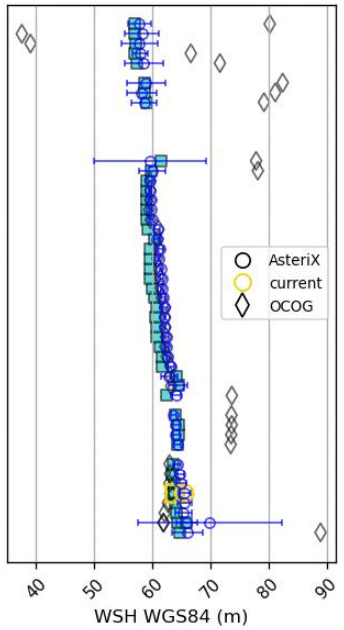
S3A, cycle 71, Pass 599 — River La Garonne / meas. 90

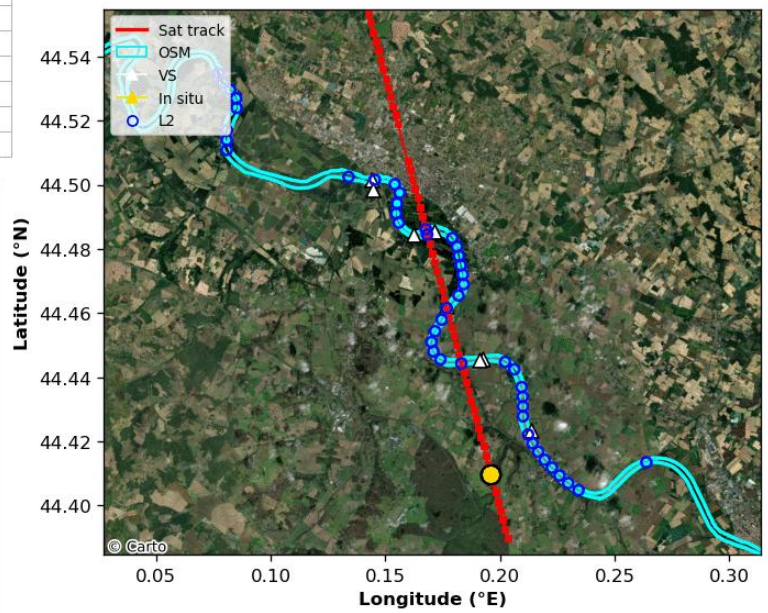


AsteriX outputs

Variable	Value
WSH estimate (m)	65.456
DEM Height (m)	63.704
Geoid (m)	48.089
Dist (m)	1938.942
Dmin (m)	1736.179
Dmax (m)	2166.006
Nb bodies in SAR band	5
Nb peaks	1
Nb candidates	7
selected peak (gate)	111
Offset	0.294
Sigma0 (dB)	40.377



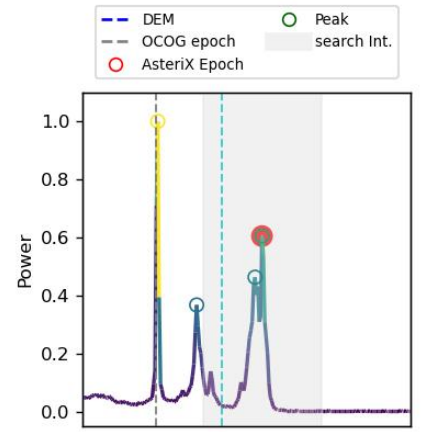




TOWARDS GLOBAL APPLICATION

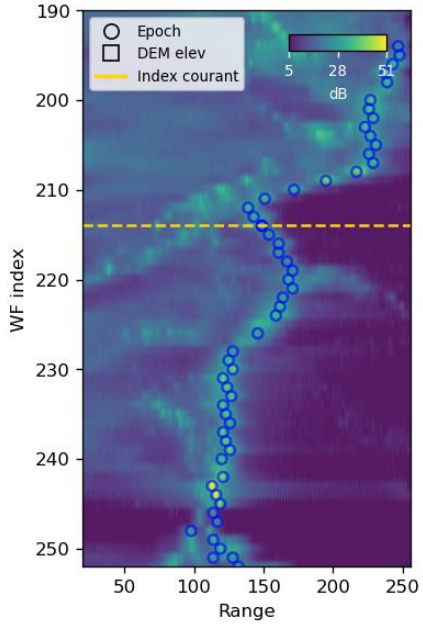
- Kasai, Congo

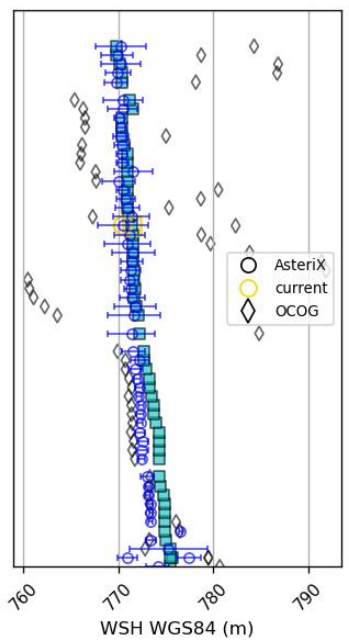
S3B, cycle 71, Pass 156 — River Kasaï / meas. 214

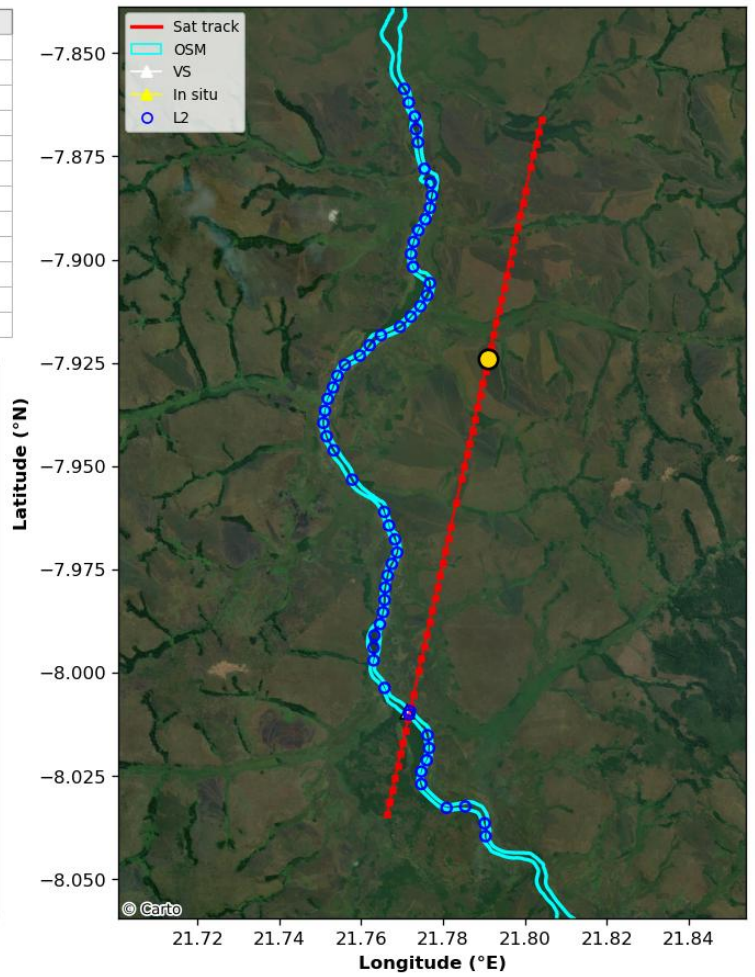


AsteriX outputs

Variable	Value
WSH estimate (m)	770.493
DEM Height (m)	771.371
Geoid (m)	-3.533
Dist (m)	2957.638
Dmin (m)	2510.074
Dmax (m)	3257.910
Nb bodies in SAR band	0
Nb peaks	4
Nb candidates	1
selected peak (gate)	149
Offset	0.686
Sigma0 (dB)	28.096







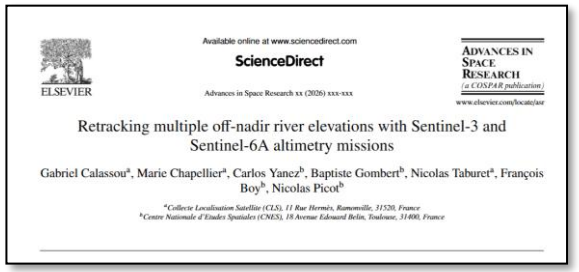
❑ Conclusions

✓ Estimates longitudinal river profile from UFSAR altimetry waveforms provided by ESA for the Sentinel-3 mission

✓ It strongly reduces the river slope influence when compared with a classical nadir-based approach because it can sample closer to the VS. Could be used to defined new off-nadir VS.

✓ Fully automated with few processing parameters and polygons of the water bodies.

✓ Applicable at global scale (ex: OSM + global DEM) and provide SRC uncertainties and information that can be used for data flagging and determining off-nadir VS



(under review)

❑ Perspectives

❖ Refining the peak-to-wb assignation process

❖ Waveform modelling currently not suited for large river in cross-track geometrie (waveform widening)

❖ Prior information from SWOT River SP database (200m spacing) and SWOT PIXC for narrow river

❖ Applicable for the upcoming S3C and CRISTAL !

LET'S GO BEYOND NADIR !

THANK YOU