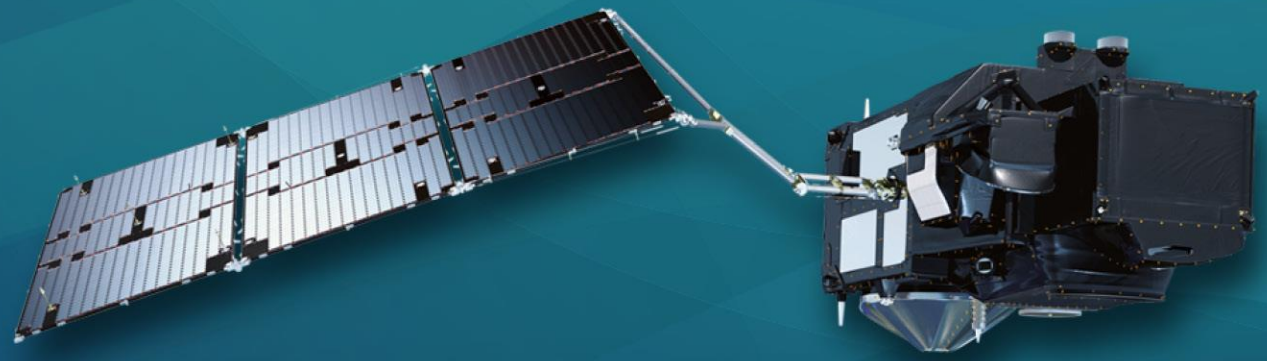
PROGRAMME OF THE EUROPEAN UNION

opernicus Europe's eyes on Earth

EUMETSAT

co-funded with esa



9th Sentinel-3 Validation Team meeting 2026

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

Deciphering river backscatter signals of Sentinel-3 using SWOT Sigma0 estimates

Renou Julien[1], Daguzé Jean-Alexis[1], Calmettes Beatriz[1], Gombert Baptiste[2], Boy François[2], Picot Nicolas[2]
[1]CLS, [2]CNES

cnes

CLS COLLECTE LOCALISATION SATELLITES

Challenges for validation Sentinel-3 measurements over rivers

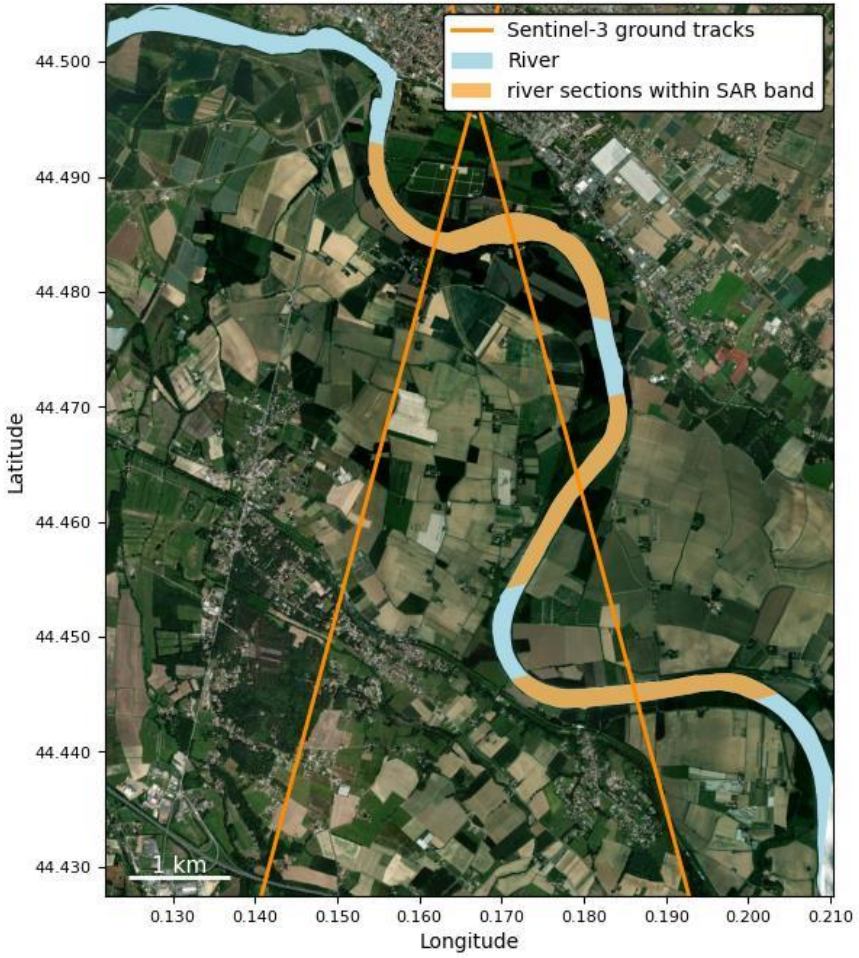
- Computation of the Water Surface Height (***WSH***) with the nadir altimetry equation:

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

with H the satellite altitude, C_g the geophysical corrections, ***R*** the **range**

- Sources of **WSH uncertainties** are primarily driven by errors in the **range *R***:

1. **Range noise + bias** → MPC's presentation from yesterday
2. **Contaminant-related noise** → Secondary water bodies sampled within the SAR footprint JA Daguzé's presentation
3. **Heterogeneous backscatter properties** within the SAR footprint (= **SAR band**) → Sentinel-3 measurements sample river sections of hundreds of meters, thus WSH estimates are **not** necessarily at nadir

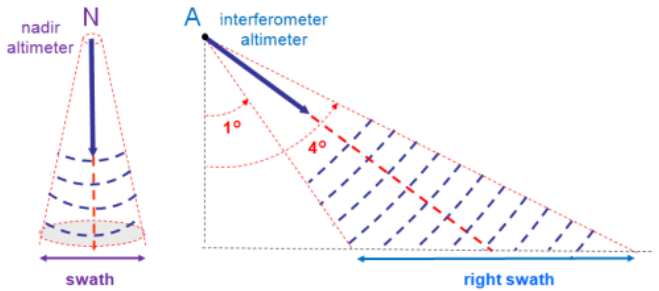


Marmande Cal/Val super-site over the Garonne river and river sections sampled within the SAR footprints

SWOT *Sigma0* as an indicator of river backscatter heterogeneities

- The two cross-track swaths of SWOT produce **2-D observations over inland water bodies**, such as WSH but also ***Sigma0* estimates**

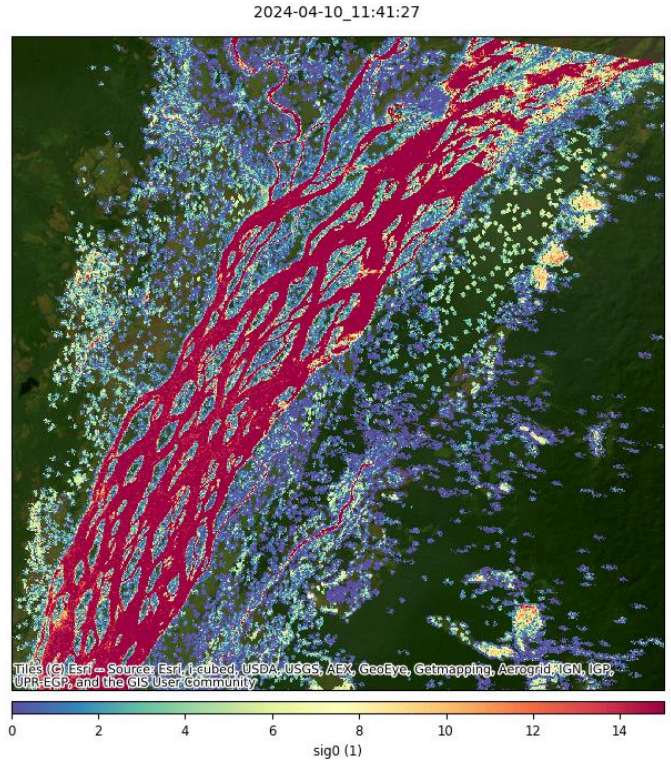
- **SWOT *Sigma0*** estimates can be used to better characterize river sections sampled by Sentinel-3 SAR footprints, but **relationship** between backscatter signals in **nadir** and **near-nadir swath** altimetry **is not clearly established**



Source: AVISO

✓ **Objectives** : 1. Comparison between *Sigma0* from nadir and near-nadir altimetry: **FF-SAR** Sentinel-6 measurements and **SWOT PIXC** products over the Garonne river near Marmande

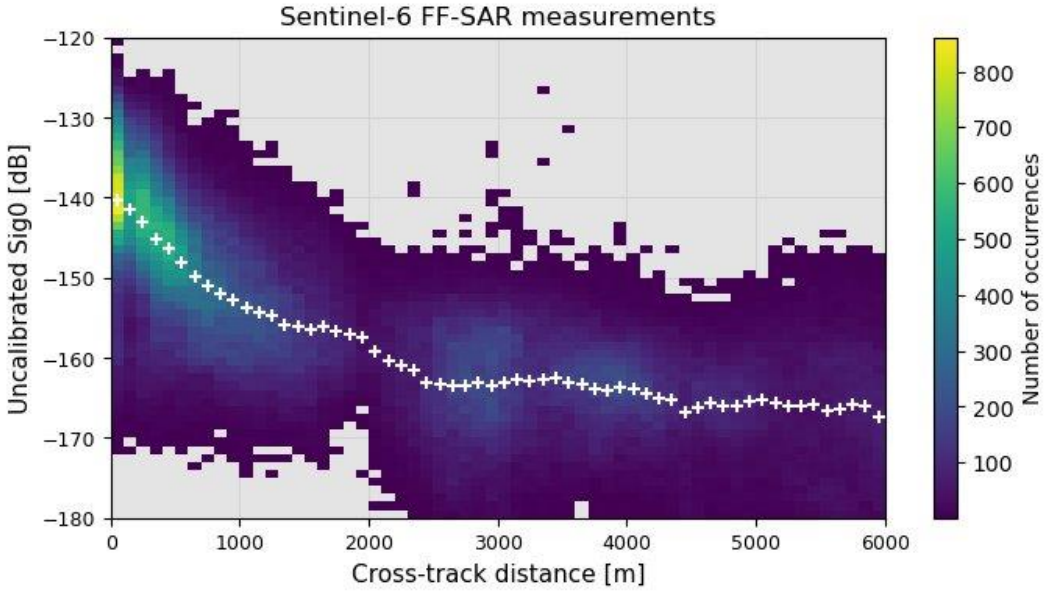
2. Generation of **SWOT *Sigma0* maps** and preliminary application on Sentinel-3 Cal/Val sites



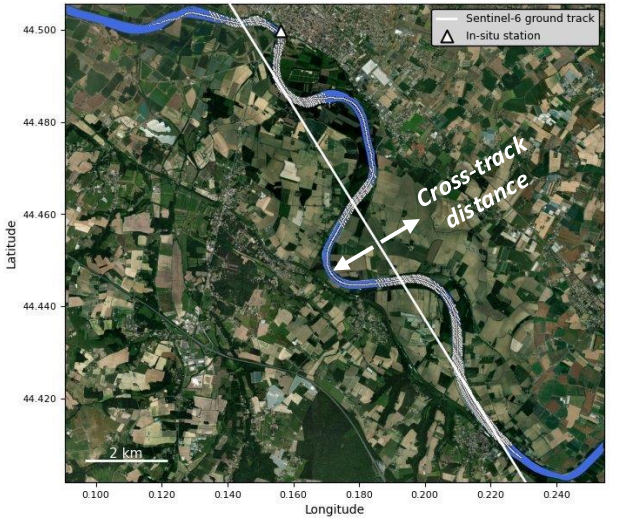
SWOT Sigma0 over the Congo basin (M. Vayre, CLS)

Sentinel-6 FF-SAR river profiles

- For robust comparison with SWOT measurements, use of the **FF-SAR processing on Sentinel-6 measurements**, benefiting from its high along-track resolution and good signal-to-noise ratio
- Based on **cross-track measurements,** consecutive along-track measurements are used to infer **river profiles** of WSH and ***Sigma0* estimates** over the Garonne river near Marmande (*Boy et al., (2022), Daguzé et al., (2023), Elhers et al., (2025)*)
- Data: FF-SAR 500Hz from the beginning of 2021 to the end of 2024 (> 100 profiles)



Sigma0 decrease of the combined profiles as a function of the cross-track distance

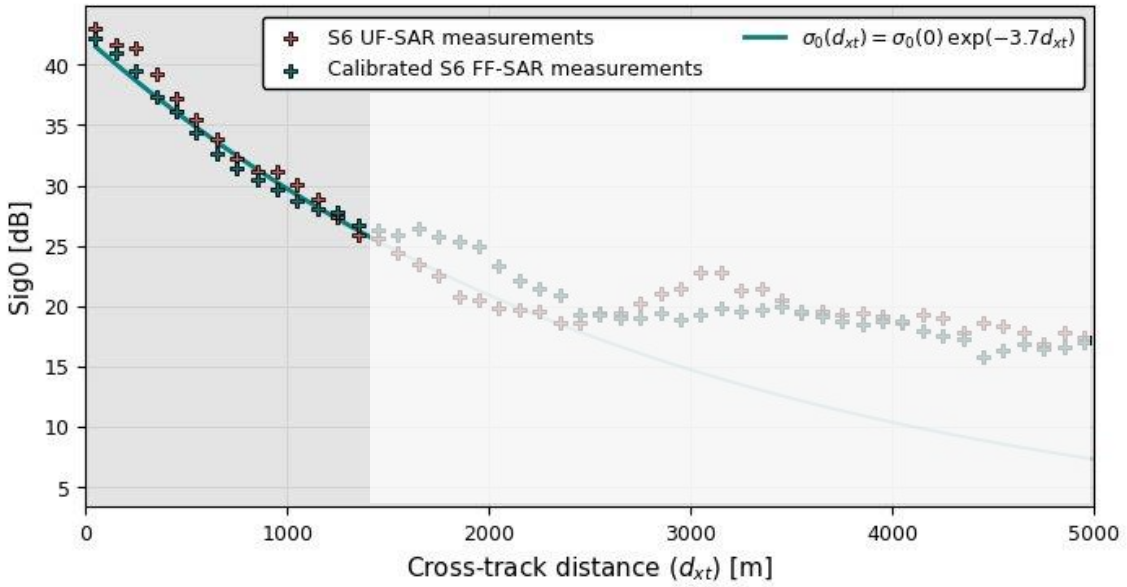


Projected FF-SAR measurements along the Garonne river

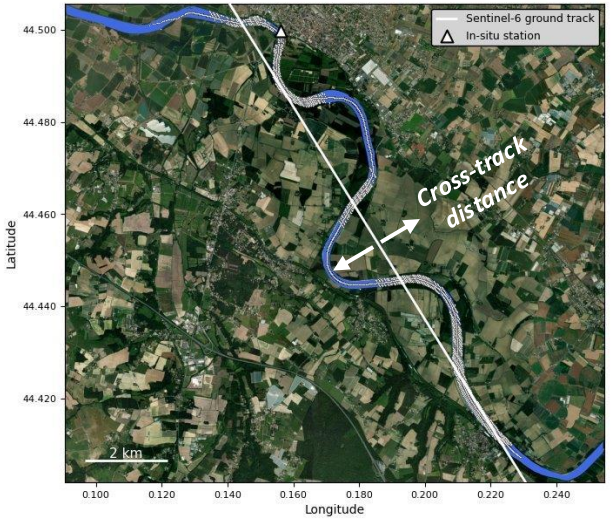
- **Post-processing** on *Sigma0* estimates is required as Sentinel-6 measurements are located at **various cross-track distances** of the river

Sentinel-6 FF-SAR river profiles

- For robust comparison with SWOT measurements, use of the **FF-SAR processing on Sentinel-6 measurements**, benefiting from its high along-track resolution and good signal-to-noise ratio
- Based on **cross-track measurements,** consecutive along-track measurements are used to infer **river profiles** of WSH and ***Sigma0* estimates** over the Garonne river near Marmande (*Boy et al., (2022), Daguzé et al., (2023), Elhers et al., (2025)*)
- Data: FF-SAR 500Hz from the beginning of 2021 to the end of 2024 (> 100 profiles)



Fit of the Sigma0 decrease w.r.t cross-track distance

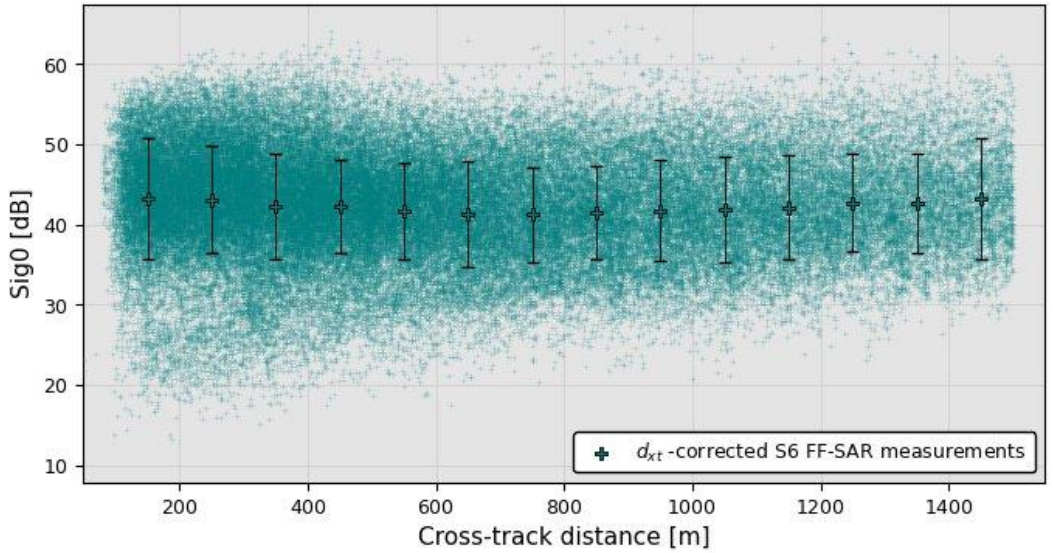


Projected FF-SAR measurements along the Garonne river

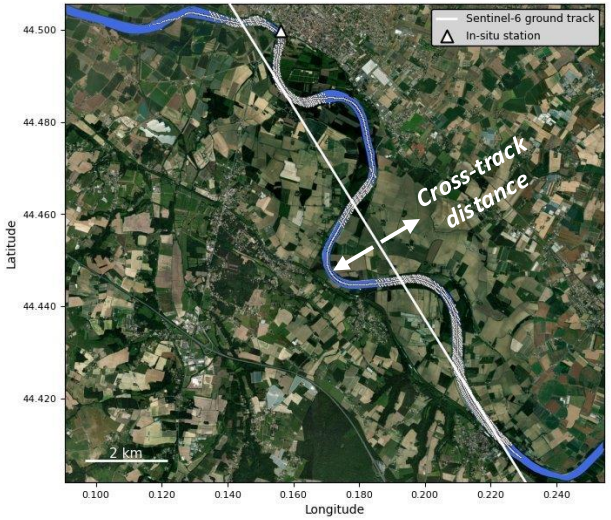
- **Post-processing** on *Sigma0* estimates is required as Sentinel-6 measurements are located at **various cross-track distances** of the river
- Decrease of the *Sigma0* w.r.t cross-track distance is **estimated and corrected** for near cross-track distance (<1.5 km) → specular regime

Sentinel-6 FF-SAR river profiles

- For robust comparison with SWOT measurements, use of the **FF-SAR processing on Sentinel-6 measurements**, benefiting from its high along-track resolution and good signal-to-noise ratio
- Based on **cross-track measurements,** consecutive along-track measurements are used to infer **river profiles** of WSH and ***Sigma0* estimates** over the Garonne river near Marmande (*Boy et al., (2022), Daguzé et al., (2023), Elhers et al., (2025)*)
- Data: FF-SAR 500Hz from the beginning of 2021 to the end of 2024 (> 100 profiles)



S6 FF-SAR Sigma0 estimates along the Garonne river

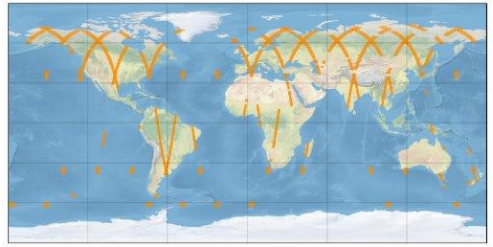


Projected FF-SAR measurements along the Garonne river

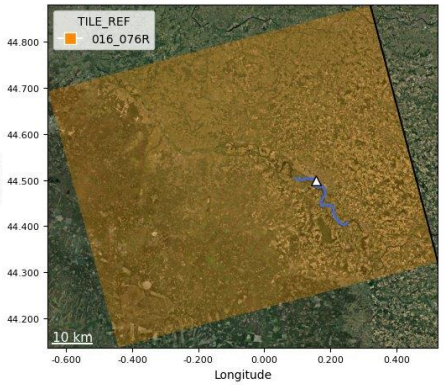
- **Post-processing** on *Sigma0* estimates is required as Sentinel-6 measurements are located at **various cross-track distances** of the river
- Decrease of the *Sigma0* w.r.t cross-track distance is **estimated and corrected** for near cross-track distance (<1.5 km) → specular regime
- Final *Sigma0* estimates should only be **representative of river backscatter heterogeneities**

Sentinel-6 FFSAR river profiles during the SWOT Science phase

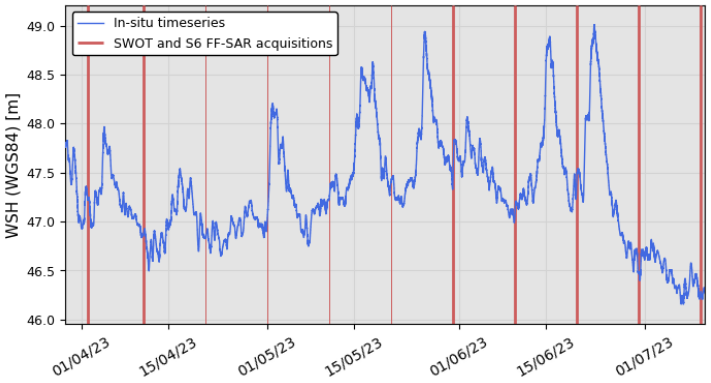
- To investigate the **spatial distribution** of *Sigma0* values, the comparison is performed during the SWOT Cal/Val period, when the Garonne river is **observed daily** by SWOT
- 7 SWOT and Sentinel-6 acquisitions on the **same day**



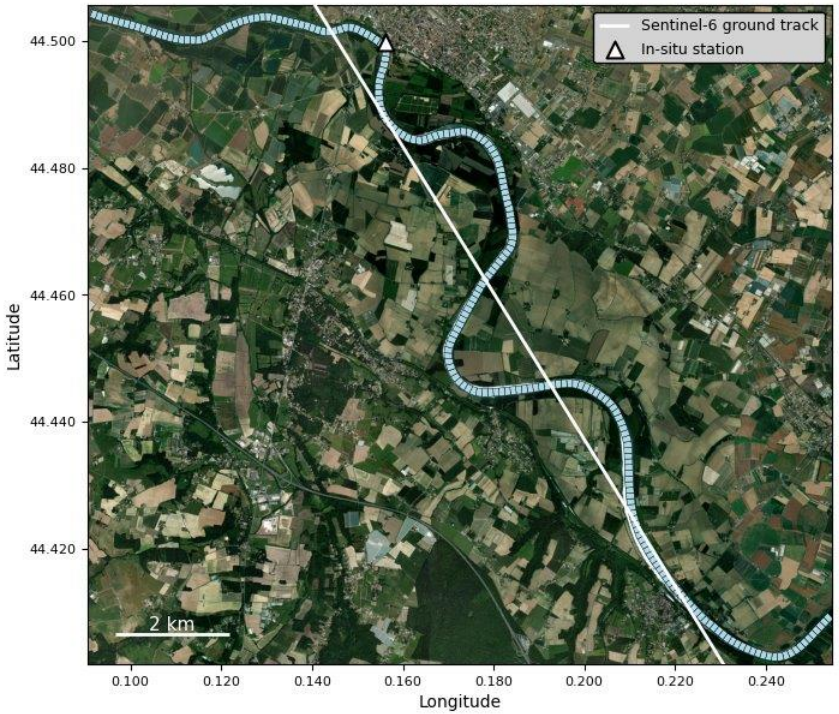
SWOT Cal/Val mask



SWOT tile over Marmande



In-situ timeseries in Marmande during the SWOT Cal/Val phase



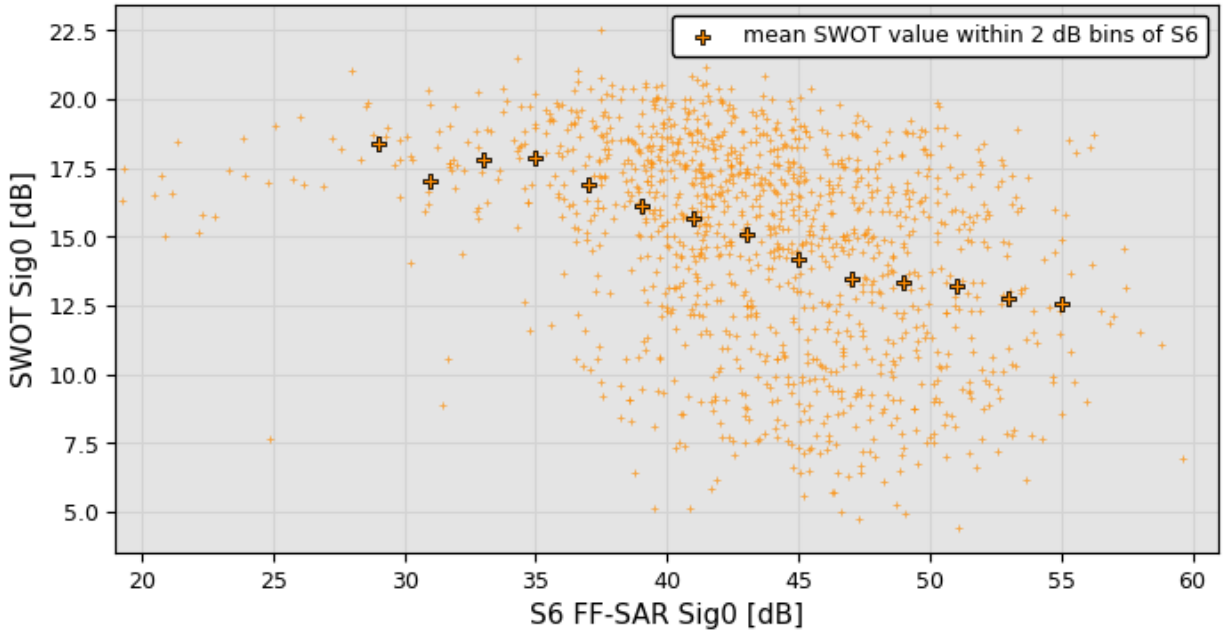
20 m segmentation along the river

- **Analysis of spatial *Sigma0* correlation:**

1. Selection of **SWOT PIXC and S6 FF-SAR** measurements within the **river polygon** and **segmentation** into 20 m curvilinear **reaches**
2. Editing of SWOT measurements based on quality flags and PIXCVec products
3. **For each acquisition day**, **mean Sigma0 values** from SWOT and Sentinel-6 are computed **for each reach.**

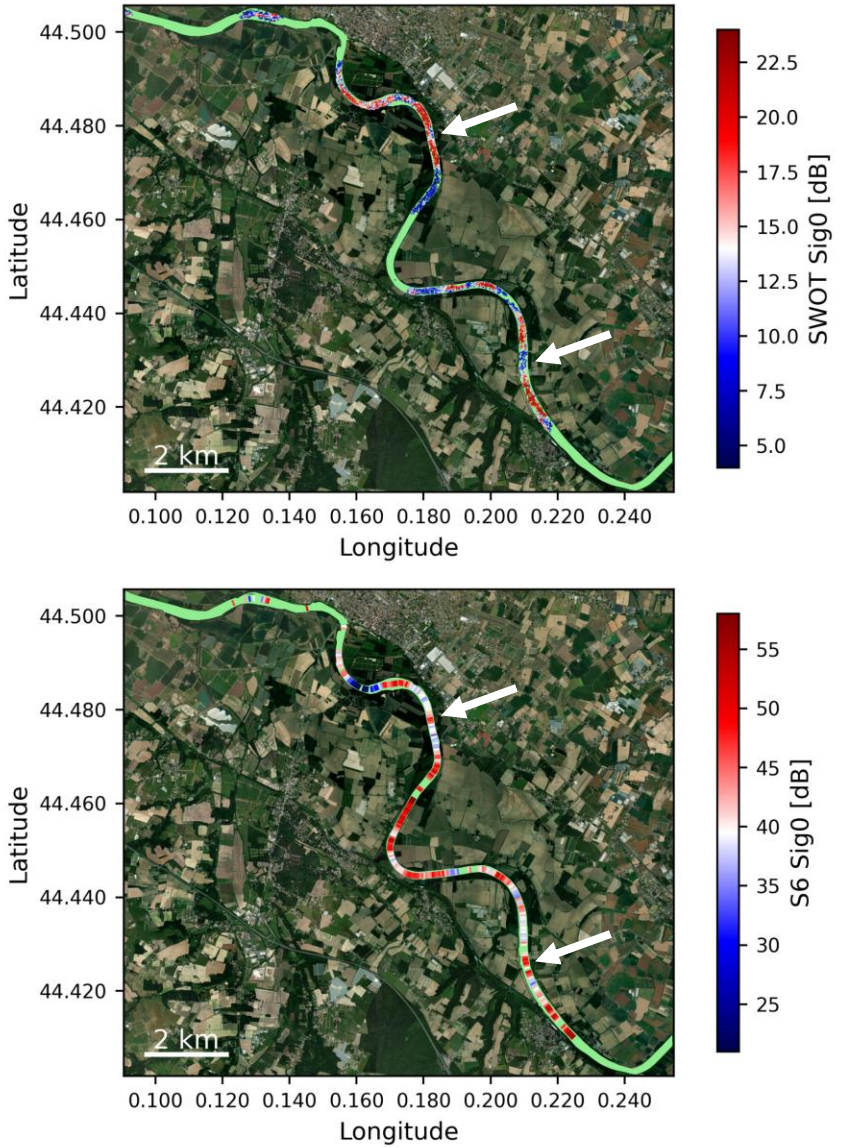
Implications for validation of Sentinel-3 measurements

- **S6/SWOT *Sigma0 values*** from the combination of the 7 days of synchronous acquisitions
- **Spatial anti-correlation** along the river section between **S6/SWOT *Sigma0 values***



Spatial anti-correlation between SWOT and S6 Sigma0

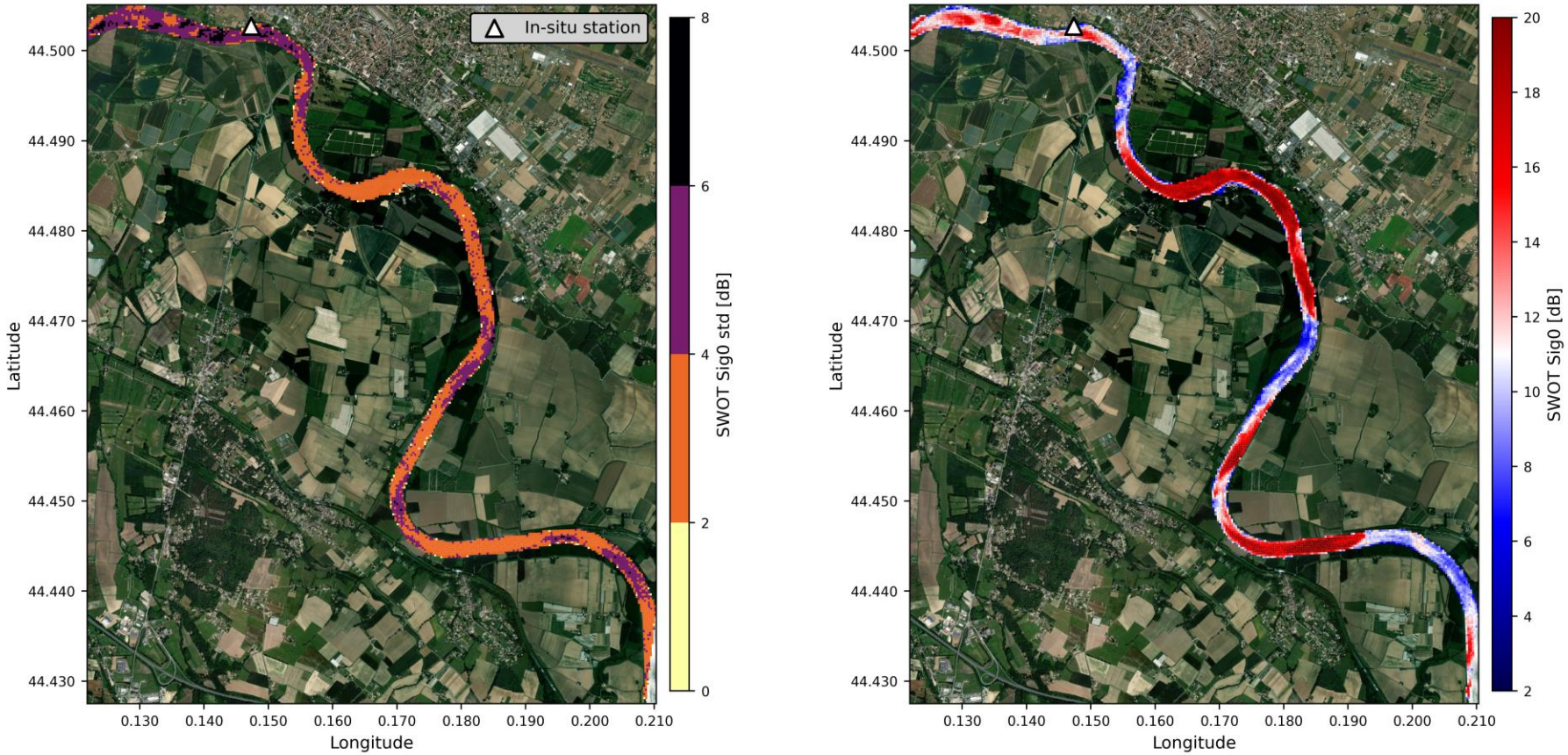
- **First result**: **SWOT *Sigma0*** might be an indicator of the river backscatter heterogeneities affecting the signal of the **nadir observations**.



Example of short-scale anti-correlation for 1 day of synchronous acquisition

Implications for validation of Sentinel-3 measurements

- Using successive **SWOT *Sigma*0 values** over the **entire Cal/Val phase**, *Sigma0* mean/std per element for each river element are computed

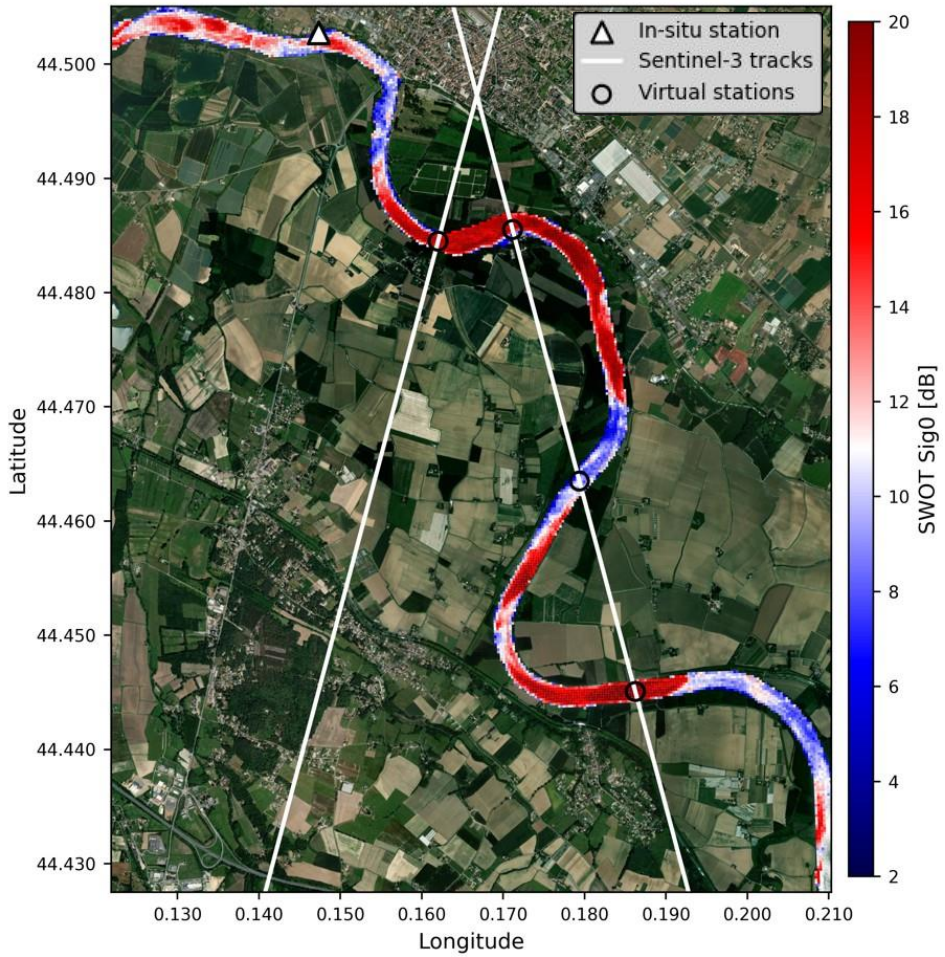


Standard deviation and mean SWOT Sigma0 values per box of 50x50 m within the river

- **Second result**: while the causes of the spatial variability of **SWOT *Sigma0*** within the river are not yet well understood, mean values remain **relatively stable over time** (low std)

Preliminary application on Sentinel-3 Cal/Val sites

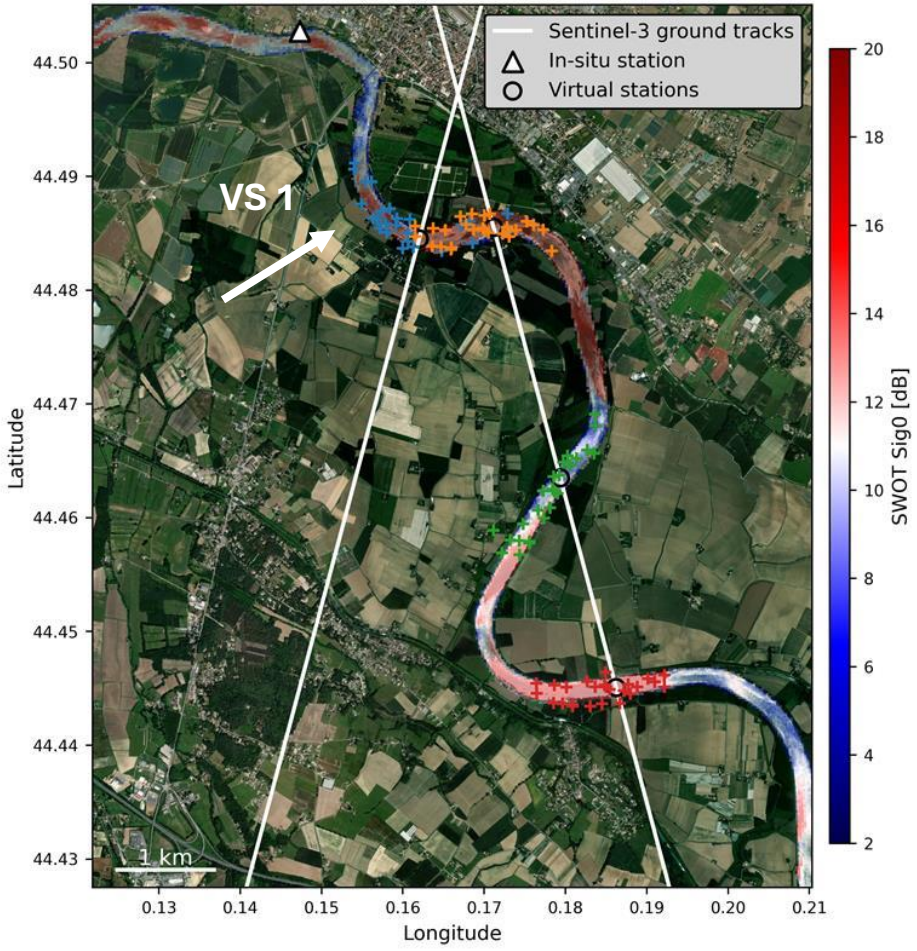
- **Application for validation of Sentinel-3 measurements**: Marmande is also a **Sentinel-3 Cal/Val supersite** (ESA St3TART-FO project), where deployment of in-situ provides Fiducial Reference Measurements (**FRM**)



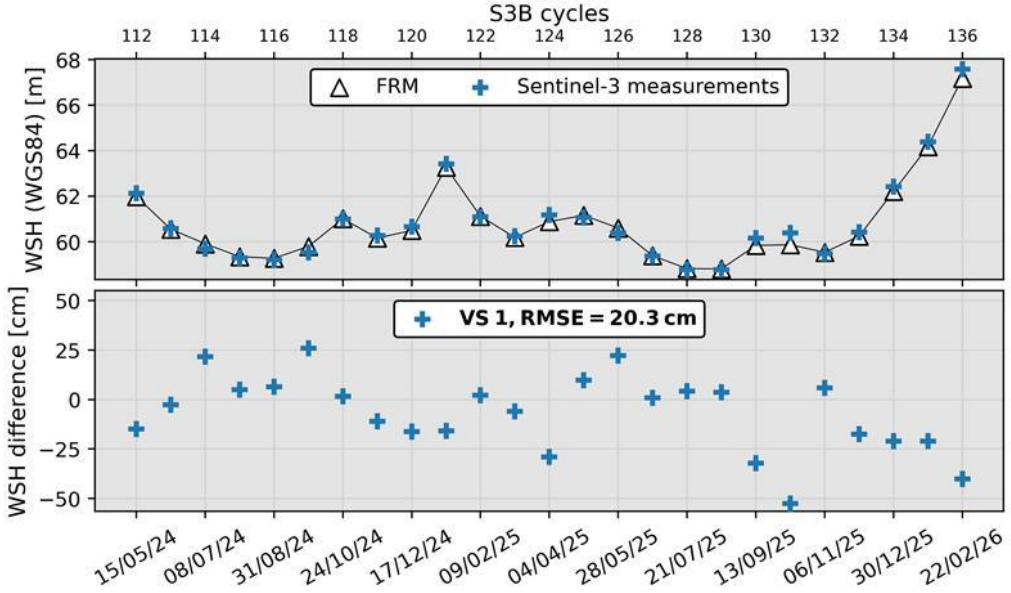
- **S3 WSH** timeseries to be compared with **FRM WSH** timeseries for **4 Sentinel-3 Virtual Stations (VS)** sampling **various SWOT *Sigma0* patterns**

Preliminary application on Sentinel-3 Cal/Val sites

- **Application for validation of Sentinel-3 measurements**: Marmande is also a **Sentinel-3 Cal/Val supersite** (ESA St3TART-FO project), where deployment of in-situ provides Fiducial Reference Measurements (**FRM**)

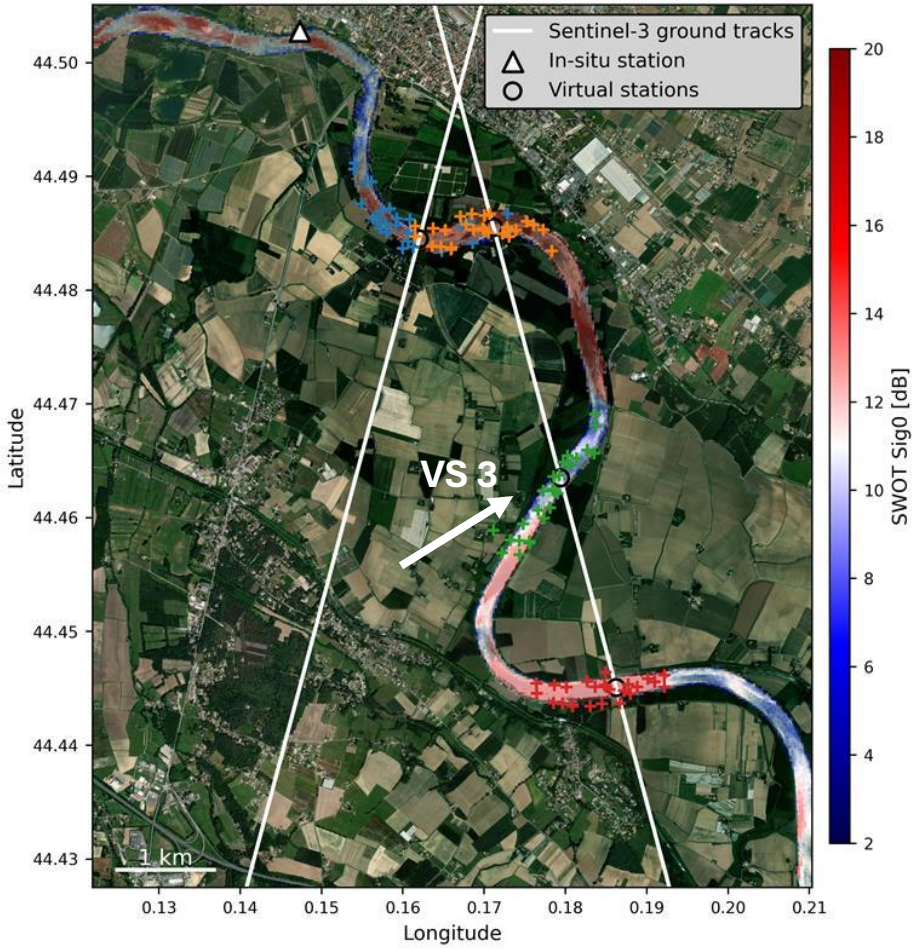


- **S3 WSH** timeseries to be compared with **FRM WSH** timeseries for **4 Sentinel-3 Virtual Stations (VS)** sampling **various SWOT *Sigma0* patterns**
- **Performance** of Sentinel-3 WSH timeseries for each VS is assessed through the computation of **RMSE value**

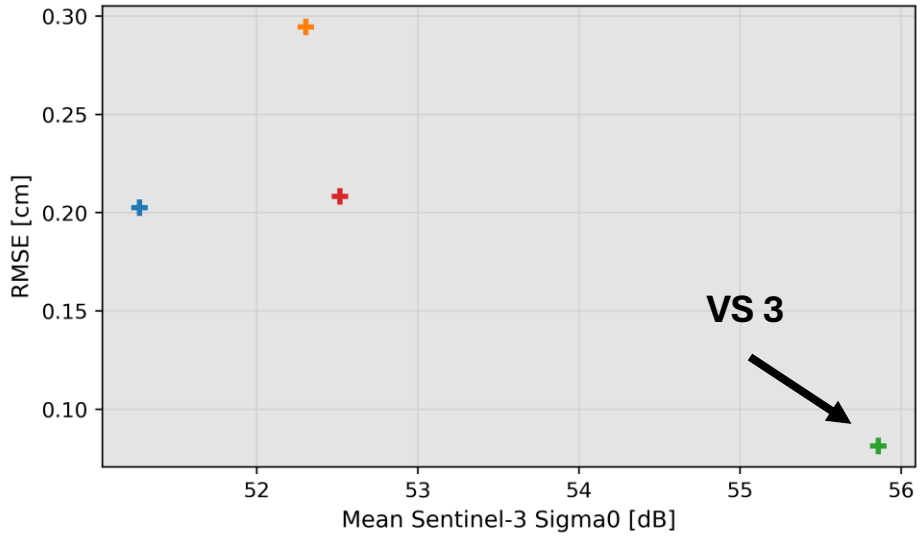


Preliminary application on Sentinel-3 Cal/Val sites

- **Application for validation of Sentinel-3 measurements**: Marmande is also a **Sentinel-3 Cal/Val supersite** (ESA St3TART-FO project), where deployment of in-situ provides Fiducial Reference Measurements (**FRM**)



- **S3 WSH** timeseries to be compared with **FRM WSH** timeseries for **4 Sentinel-3 Virtual Stations (VS)** sampling **various SWOT *Sigma0* patterns**
- **Performance** of Sentinel-3 WSH timeseries for each VS is assessed through the computation of **RMSE value**



- River section with **low SWOT *Sigma0*** ***is*** associated to **high S3 *Sigma0*** and better **WSH estimates** (= lower RMSE)

First conclusions and perspectives

I. First conclusions

- This preliminary study shows spatial anti-correlation along river sections between the *Sigma0* of Sentinel-6 FF-SAR and SWOT measurements
- Over the Garonne river near Marmande, SWOT *Sigma0* maps reveal backscatter heterogeneities which remain relatively stable over time
- These heterogeneities affect the correct derivation of Sentinel-3 WSH estimates, which could be useful for identifying river sections where WSH estimates of high quality are expected

II. Non-exhaustive perspectives

- Generate SWOT *Sigma0* maps on other St3TART-FO Cal/Val supersites to confirm these results
- Extend the investigation on river sections within the Sentinel-3 footprints only, to better locate the exact position the backscattered river signal
- Use SWOT *Sigma0* to detect contaminant water bodies that affect WSH derivation of the river of interest

20 m segmentation along the river