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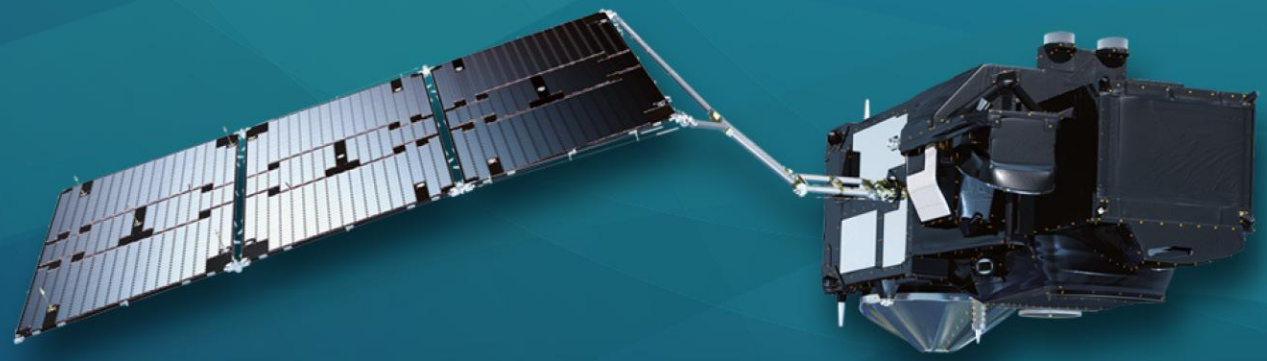

9th Sentinel-3 Validation Team meeting 2026

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

Development of an integrated method to validate SWATH altimetry over inland water: A new approach from SWOT Cal/Val first results

cnes

VORTEX-IO

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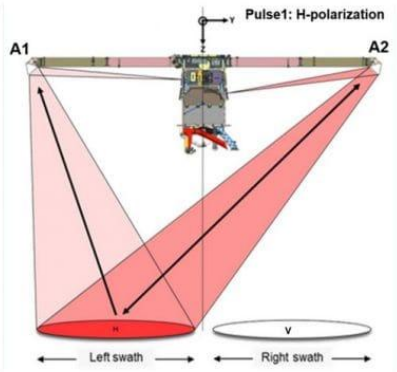
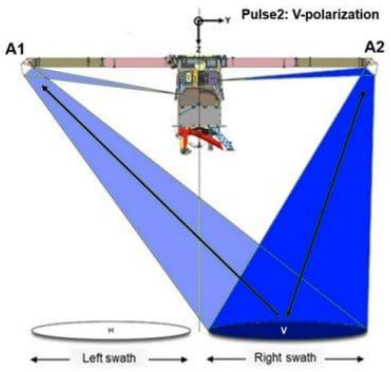
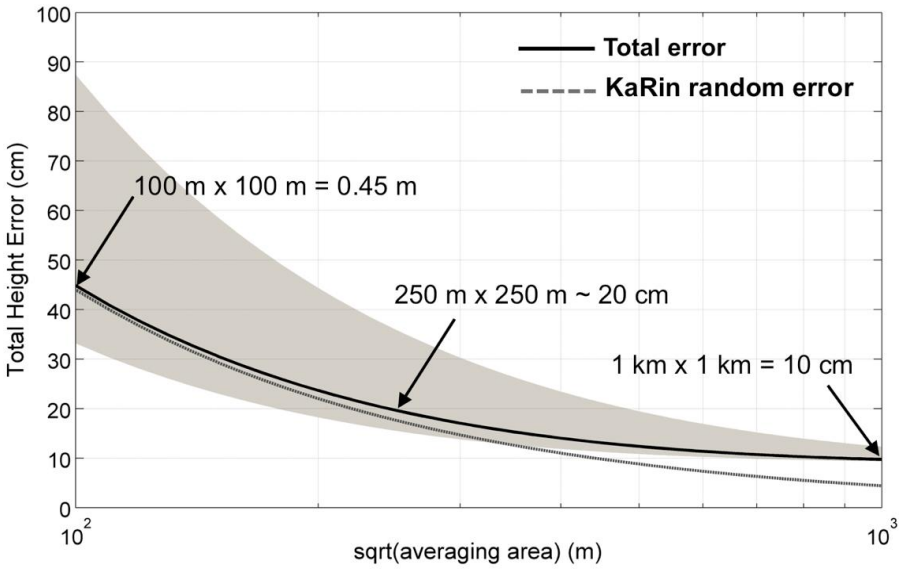
Introduction

- In 2022 a new science mission was launched (SWOT) by **NASA and CNES**, with a new instrument : **KaRIn, a SWATH altimeter**
- The benefits of **SWATH altimetry:**
  - Measurements over a wide swath (~120 km wide) instead of a single track
  - Enables **continuous 2D mapping of the water surface height and sigma0**
- **vorteX-io** contributed to the calibration and validation of SWOT within the **French hydro team led by CNES**
- This led to the **development of a new way to validate these data**



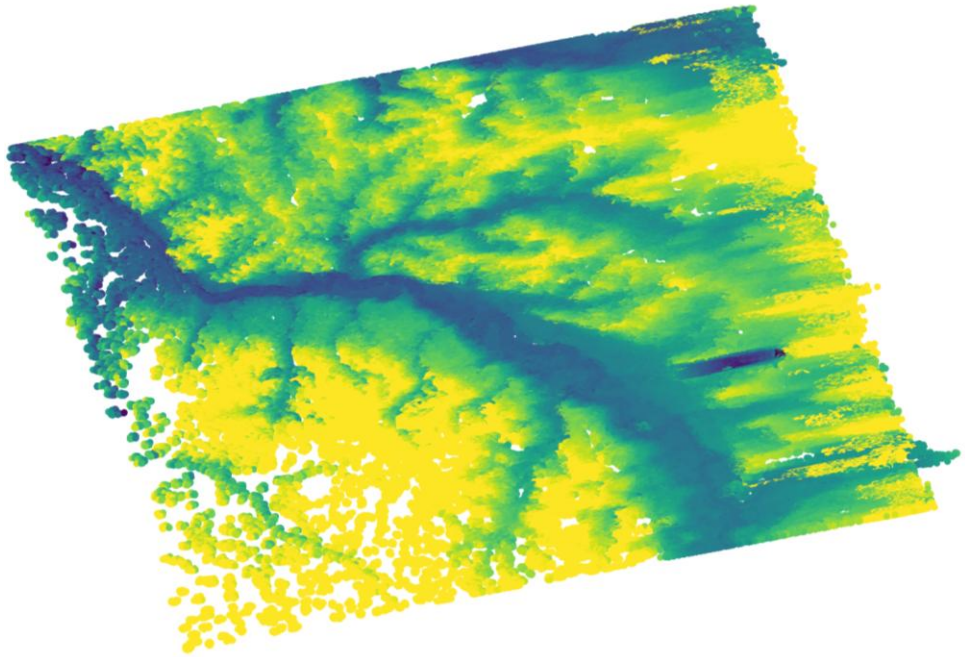




Challenge of swath altimetry validation

- **The SWOT hydrology products**
- Raw measurements of 2D-height (Pixel Cloud) & sigma0
- Water level measurements generated every 200 m along a stretch of river by aggregating the pixels
- Each **node** corresponds to a localized measure of the water surface height
- Provides continuous mapping of water levels along river

How to validate 2D height measurements ?



Pixel cloud height from SWOT over the Garonne River

Challenge of swath altimetry validation

Fixed in-situ sensor

- Use the existing networks of in-situ sensors to produce comparison between swath altimeter and ground truth
- This strategy produces many time series of punctual comparisons
- **Drawbacks of the method**
  - Few points compared to all the localisation of swath altimetry measurements

Sparse in space !

Moving sensor

- Perform river topography measurements at the same date as the Swath altimeter for direct in-situ comparison
- This strategy produces a topography almost directly comparable with the swath altimeter measurements
- **Drawbacks of the method**
  - The moving sensor measurement is slower than the swath altimeter
  - Complex fields missions that are not scalable

Sparse in time !

We need a combined approach to perform dense validation in time and space

Strategy implemented for SWOT Cal/Val

We developed a new method to perform regular validation of SWATH altimetry

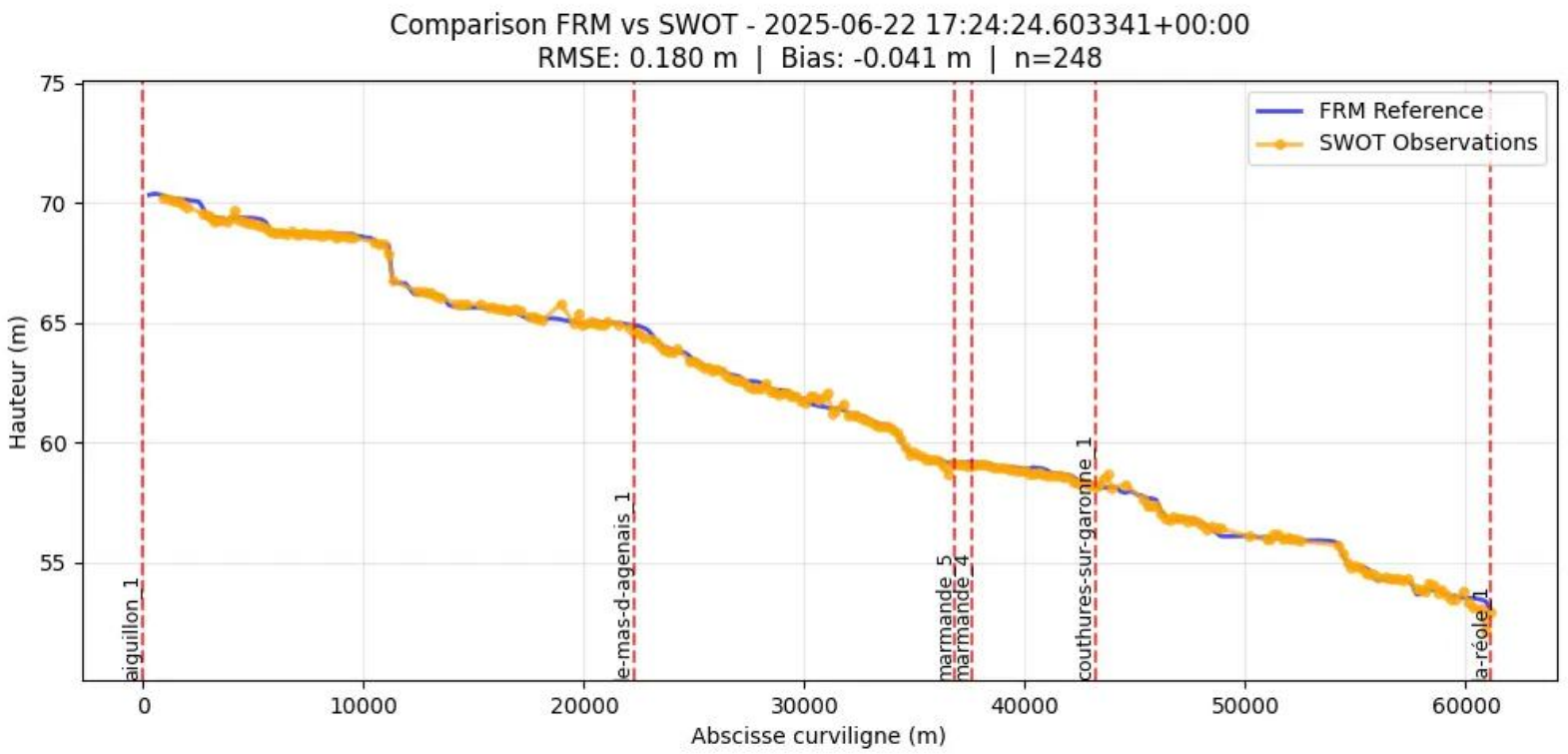
In-situ instrumentation

- **Super sites (~50 km)** with multiple in-situ sensors and river topography measurements in between
- The **in-situ sensors** (vorteX-io micro-stations) are distributed all along the linear
- The river topography is measured at different seasons to **cover the evolution of topography with the water discharge evolution**

Interpolation method

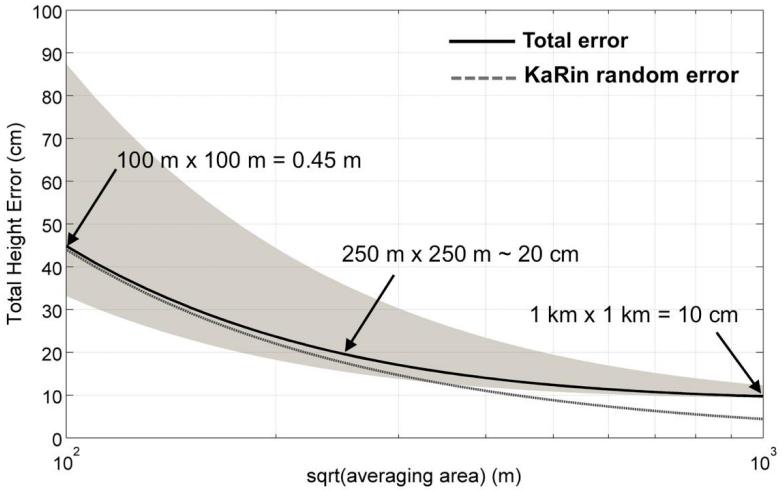
- Create a **river profile** for every swath altimeter measurement **point at every time step**
- Combination of the **fixed in-situ** measurement at the **time of the satellite** with **multiple moving sensor measurement** from the past
- We can use this method to also validate linear topography measurements from **FFSAR processing of Sentinel-6**

Comparisons with SWOT measurements

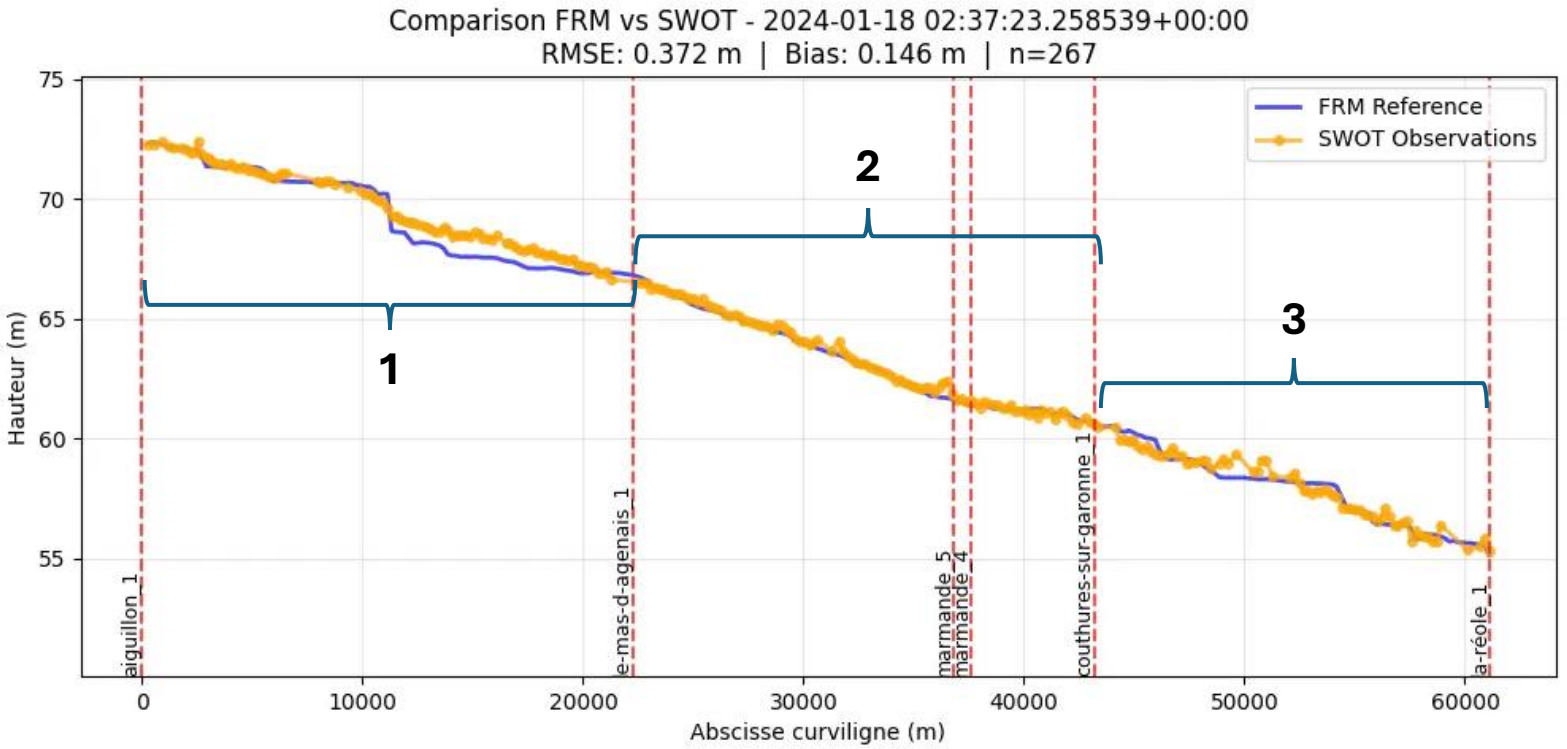


Comparison between **SWOT River Nodes** products and reference data over Garonne Aval super sites for one cycle of Cal/Val orbit at low water regime

- Excellent agreement between **SWOT data** and **reference measurements**
- We produced **around ~250 reference measurements** on a full river reach for one **SWOT overpass**
- The comparison metrics are good
  - A **bias of -4 cm** on the whole river reach
  - A RMSE of **18 cm**
- This result is coherent with **the mission requirements**



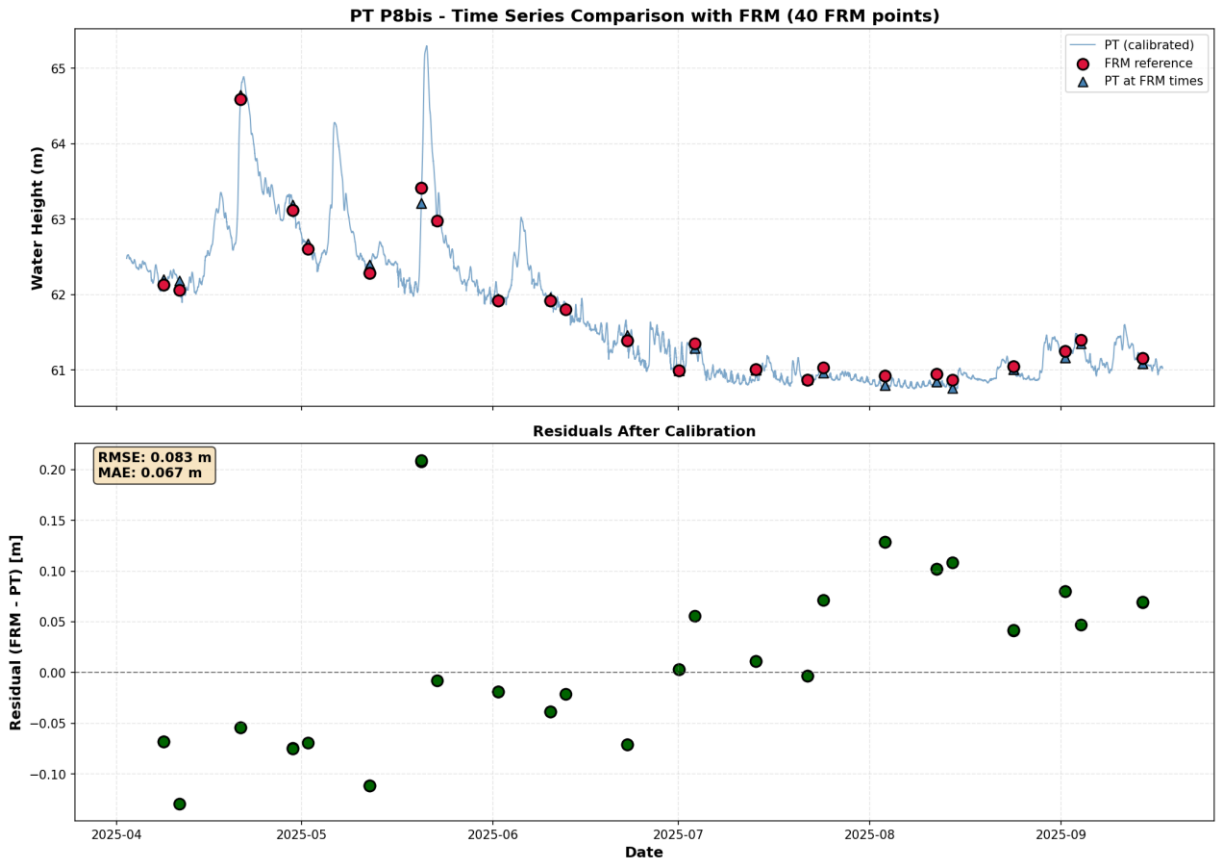
Comparisons with SWOT measurements



Comparison between **SWOT River Nodes** products and reference data over Garonne Aval super sites for one cycle of Cal/Val orbit at **high water regime**

- The performances are **poorer at high water regime**
  - The bias increases to **14,6 cm**
  - The RMSE to **37,2 cm**
- These differences are not only explained by differences in **SWOT performances**
- **On zone 1 and 3** of the super-sites we only performed **1 topography measurement** (By airborne LiDAR) at low water regime
- **On zone 2** we performed **several topography measurements** at different **water regime** for both SWOT Cal/Val and St3TART-FO project
- The **performance seems to be better** with **multiple topography measurements**

Method validation against additional in-situ sensors



Comparison between a **PT relative water height** measurement and **reference measurements** computed at its location

- We need to **assess the performance** of this method and evaluate the **impact of having multiple topography measurements** at different water regimes
- We used the data of **Pressure Transducers** deployed by **CNES and Hydro Matters** in the framework of SWOT Cal/Val
- We performed **relative comparisons** as the PTs have not been levelled yet

PT ID	River topography measurement	MAE	RMSE
P-6bis	Airborne	8.1 cm	10.4 cm
P-8bis	Airborne	10,1 cm	14.8 cm
P8bis	Drone + Airborne	6.7 cm	8.3 cm
P10	Drone + Airborne	6.4 cm	8.9 cm
P12	Drone + Airborne	8 cm	6.6 cm

The performances are **better for the PTs** located on the zone with **3 topography measurements.**

First results from SWOT Cal/Val Hydro paper

First results from the **SWOT Hydro paper** for Version C of SWOT products – **paper to be published**

Product	Set	GNSS (concurrent)				GNSS (stage-matched)				PT				vortex.io			
		|68%|	50%	n	n_u	|68%|	50%	n	n_u	|68%|	50%	n	n_u	|68%|	50%	n	n_u
Node (relative)	BASE	36	2	3922	561	36	1	12650	194	55	-2	5456	118	17	-2	18490	208
Node (relative)	FILTERED	26	2	2577	364	15	1	5875	130	11	-1	2654	104	14	-2	17420	208
Reach (relative)	BASE	17	0	91	17	31	4	427	15	31	0	1588	27	10	2	275	3
Reach (relative)	FILTERED	13	0	40	9	19	-1	239	13	17	-2	613	19	8	3	228	3
Node (absolute)	BASE	48	-7	9755	3556	36	1	14420	689	35	-1	5639	119	29	4	30160	1599
Node (absolute)	FILTERED	41	-9	7876	2994	17	-2	6249	393	13	-3	2686	109	27	5	19210	1383
Reach (absolute)	BASE	33	-2	117	37	34	7	448	30	N/A				22	7	293	17
Reach (absolute)	FILTERED	26	-3	60	21	25	5	250	20	N/A				20	9	241	13

WSE Results Table. |68%ile| and median (50%ile) differences are in cm. The total number of paired observations is denoted as n, while the number of unique nodes or reaches observed is denoted as nu.

The result obtained by the NASA-JPL team to assess SWOT performances with our data are excellent with an overall **|68%ile| difference of 17 cm** on **18 500 relative comparisons**

- The NASA-JPL team oversees the assessment of the **overall performances of SWOT products**
- We provided a complete validation dataset over **2 super-sites on the Garonne River** to the NASA-JPL team
- The dataset obtained by this method is used for assessing **SWOT Hydro products performances** along in-situ measurements collected by SWOT Cal/Val team

A use for Sentinel-3 Hydro products validation ?

- This methodology can be used now to improve the regular validation of **Sentinel-3 Hydro products**
- When we compare to Sentinel-3, there is **still an uncertainty coming from the exact location of the satellite measurement** inside the radar footprint (refer to Julien presentation)
- With this approach we can go further than a **single point FRM** and provide '**FRM Nodes**' all along the river reaches. Validation team from MPC could perform a **finer selection of the FRM on the river reach**
- This approach can also support **off-nadir validation activities** to increase the number of comparisons between Sentinel-3 and FRMs
- The Hydro MPC team recommended to use **this approach as R&D activity** in the framework of **St3TART-FO project**. It is on the workplan for 2026.

A use for future missions ?

S3NG-Topo

- The **S3NG-T** is the mission that will follow the **Sentinel-3 mission**
- Following the recent results of the SWOT mission, a **swath instrument** will be integrated into the S3NG-T mission
- This mission will have the **operational requirements** for regular validation as the actual Sentinel-3 mission with **St3TART-FO project** for Inland Waters
- **The method** we developed **for SWOT validation** could help to perform the **regular validation** of this future mission

CRISTAL

- This approach **has been proposed** for the **inland waters Cal/Val** of future mission **CRISTAL**
- CRISTAL will **follow a drifting orbit** that will change the location of the **virtual station at every sub-cycle**
- Reference measurements must be produced on **very different locations** for regular validation
- This method is a very **flexible way** to produce FRM at **every location** of long river reaches
- It can answer the **issue caused** by the **drifting orbit** with a **minimum** need of **in-situ sensors**

Conclusion

- SWOT mission demonstrated by its excellent results that **Swath altimetry is well-designed for Hydrology targets** and paved the way for S3NG-T that will use the same technology
- In the framework of SWOT Cal/Val, we developed a **flexible way** to perform the **validation** of continuous measurements along **a river profile**
- This method relies on **strong in-situ instrumentation** with both fixed and moving sensors that we combine to produce **reference height all along the river profile**. The method needs multiple topography measurements to cover different water regimes
- This methodology has shown **good results for SWOT Cal/Val** and is used for the global product validation
- This method **could also be used now for Sentinel-3 validation** to increase **the number of comparisons** and improve the validation robustness