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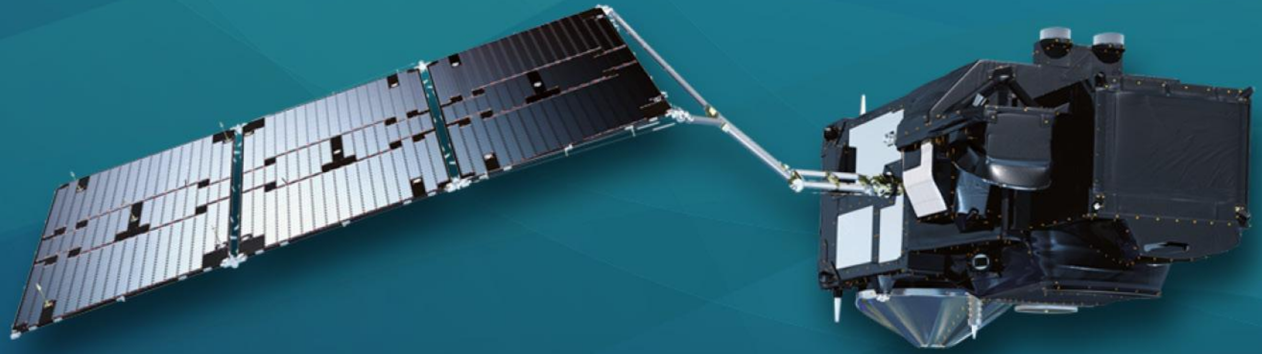

9th Sentinel-3 Validation Team meeting 2026

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

Provision of operational Fiducial Reference measurements for Sentinel-3 over inland waters: the St3TART Follow-On project

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1 vorteX-io, 2 NOVELTIS, 3 CLS, 4 CNR-IRPI, 5 SERTIT, 6 GIS, 7 ESA-ESRIN

esa

St3TART
FRM for Sentinel-3
Land Altimetry

SCAN HERE

Project overview

Project objectives for Inland Waters

- **Produce and provide Fiducial Reference Measurements** for Sentinel-3 over Inland water **as a service based on in-situ instrumentation**

- The main **end users of St3TART FO** data is **ESA MPC project team** for recurrent **Cal/Val activities**

Super sites

- **Advanced in-situ sensors** installation (WSH measurement, schedulable …)
- We **manage the super sites ourself** to ensure the **operationality** of the FRM production
- Fully controlled super site to compute **uncertainties on FRMs**

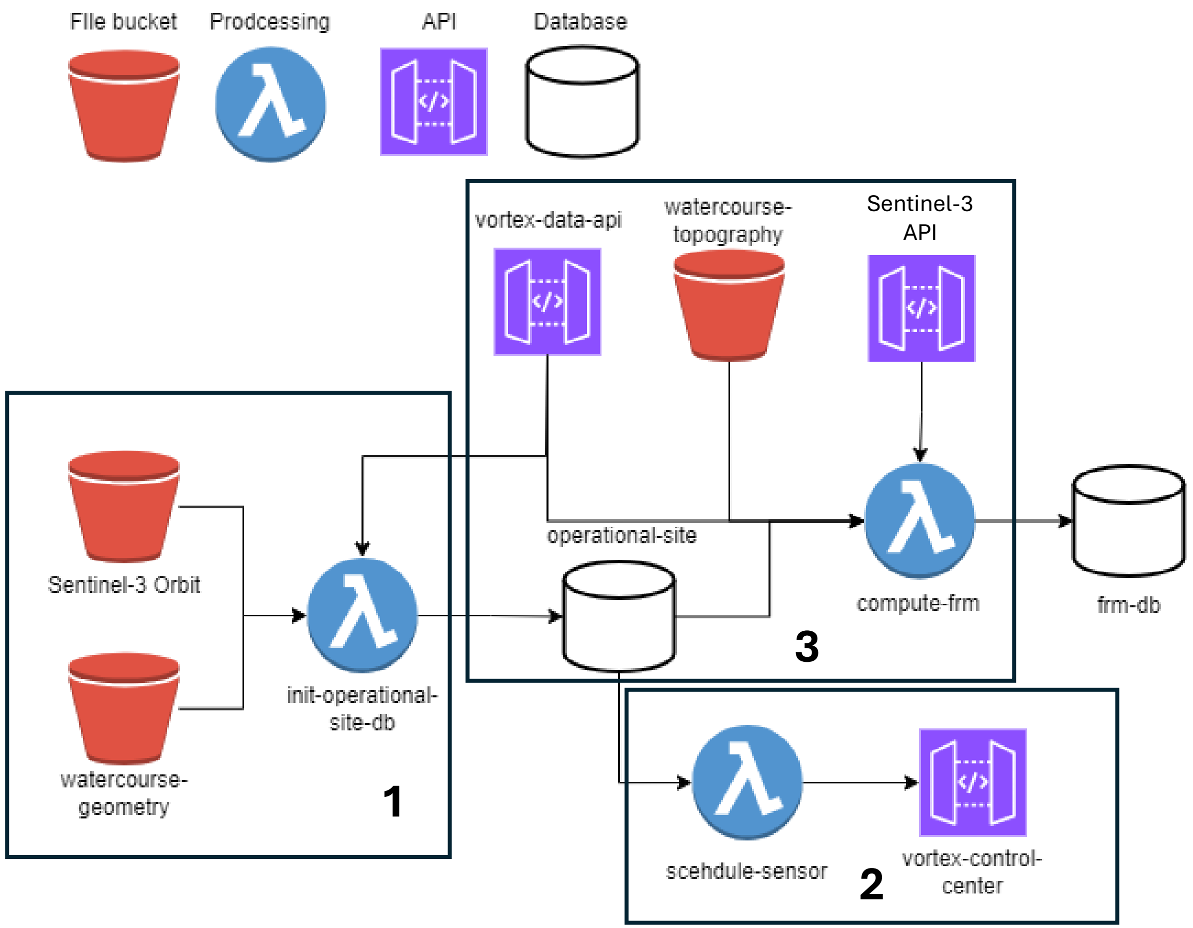
Data for deep analysis

Opportunity sites

- Use of **existing in-situ networks** from different countries
- **Very large number** of opportunity sites !
- **No homogeneity** between the in-situ networks sensors
- Impossible to ensure **data continuity** and **operationality**

Data for statistical analysis

Presentation of the processing chain



- **Automatic processing chain** deployed on a Cloud infrastructure
  1. Automatic process for **site selection and database setup**
  2. Daily processing to **schedule the micro-stations measurements** for super-sites
  3. **FRM automatic computation** within 6 days to support operational validation activities

- **Continuous robustness improvement**
  - **Changelog of the processing chain** to inform user of FRM updates
  - Reliable **FRM versioning** ensuring full traceability
  - **Waterways IDs from SWOT** database distributed as FRM metadata

FRM computation strategy

Complexity level 0 / Opportunity sites	Complexity level 1	Complexity level 2	Complexity level 3
$FRM(t) = WSH_{IS}(t)$	$FRM(t) = WSH_{IS}(t) + WSH_{MS}$	$FRM(t) = WSH_{IS}(t + \delta_t) + WSH_{MS}$	$FRM(t) = WSH_{IS}(t + \delta_t) + WSH_{MS}$

FRM computation strategy

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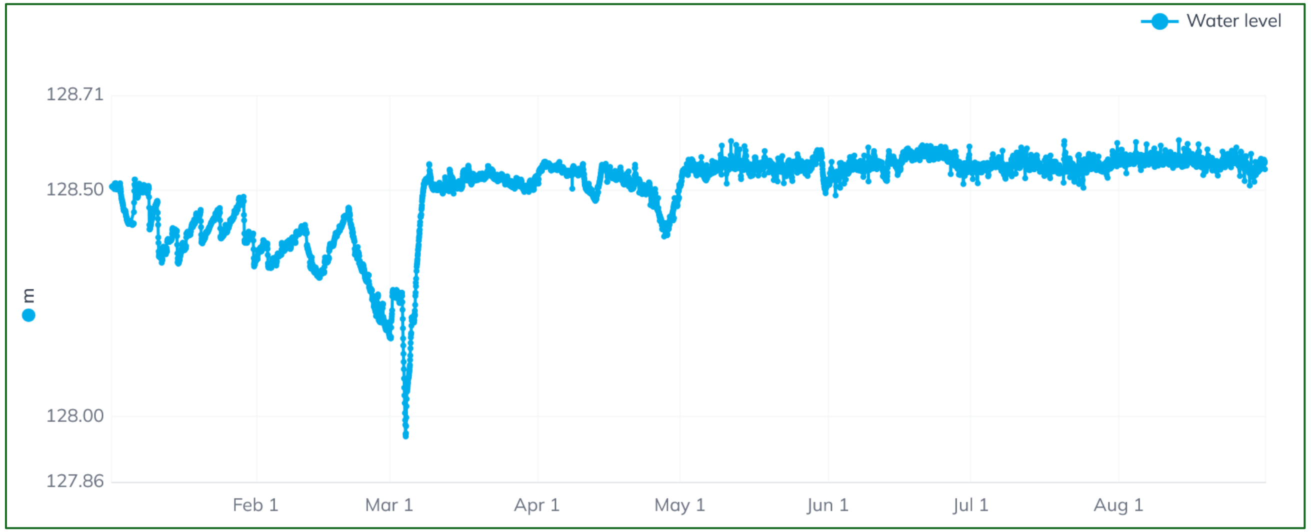

- The FRM directly corresponds to **the in-situ sensor measurement** acquired at the same date as the satellite
- On super-sites, the micro-station **is scheduled to acquire its measurements on** the exact same date as Sentinel-3

FRM computation strategy

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Complexity level 0 / Opportunity sites	Complexity level 1	Complexity level 2	Complexity level 3
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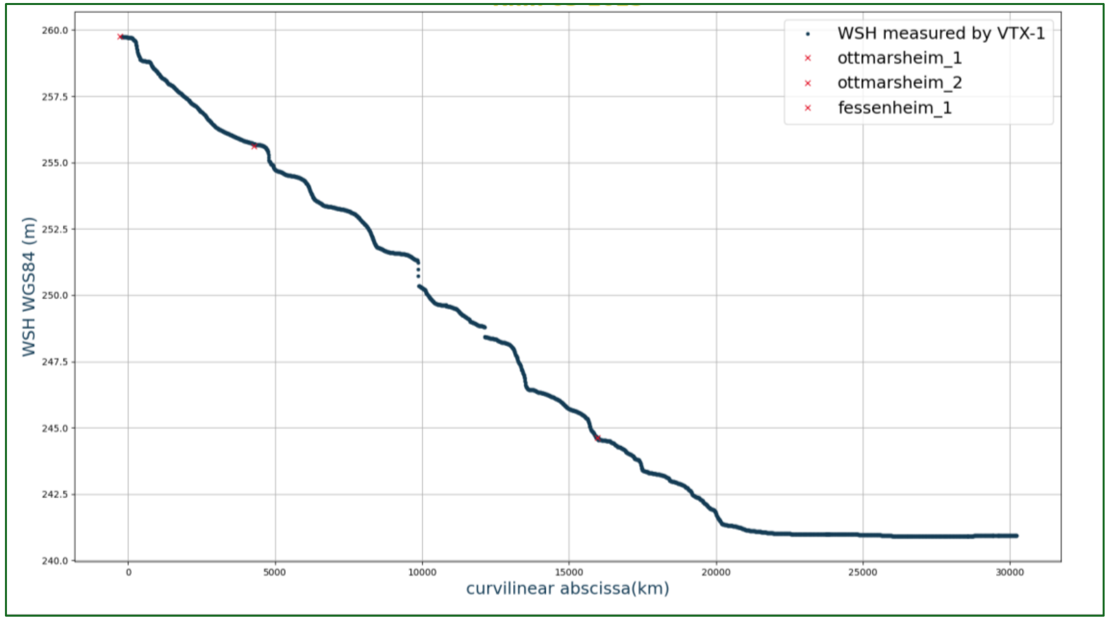
- The satellite measurement is not located close to the in-situ sensor
- The river has a slope that must be considered when computing the FRM
- The topography is measured by a moving sensor
- The river topography is used to compute slope correction after obtaining Sentinel-3 measurement location



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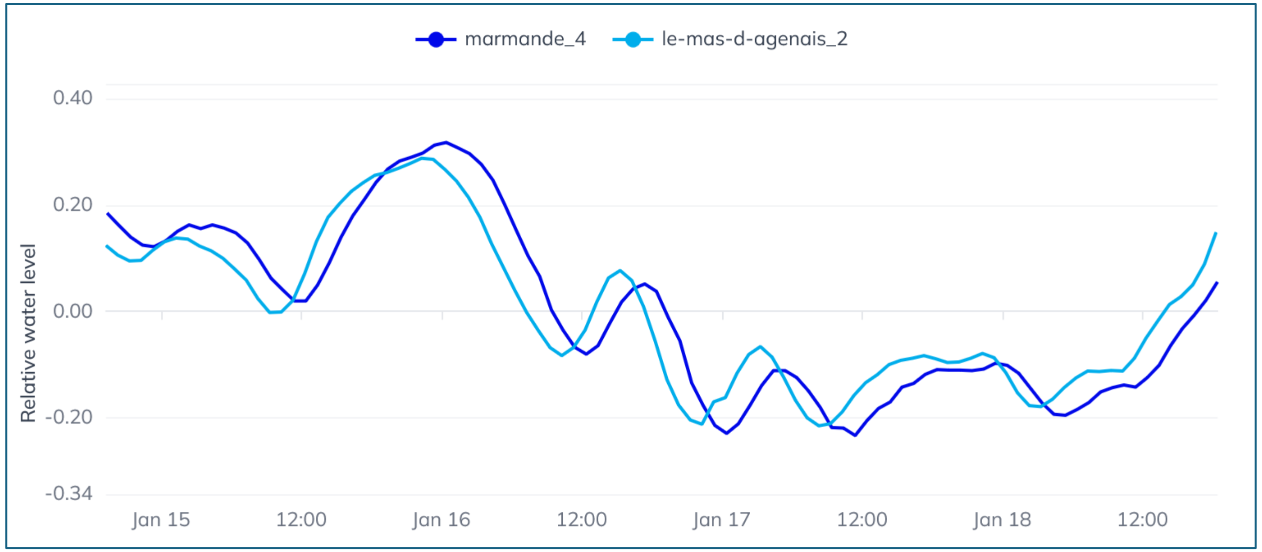
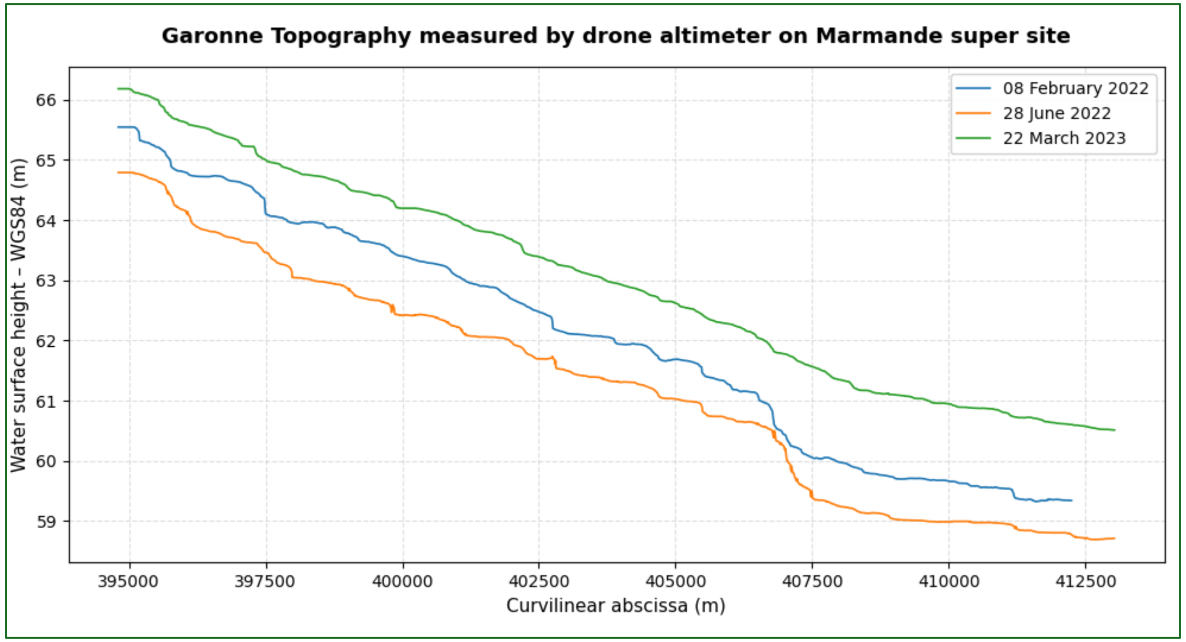


- The river has **a strong dynamic** and the river height evolution must be accounted for to compute FRMs
- We estimate the propagation time by **phasing in-situ sensors measurements** upstream and downstream of the virtual station
- This approach leads to an estimation of **the delay (δ_t)** used to **schedule the micro-station** measurements

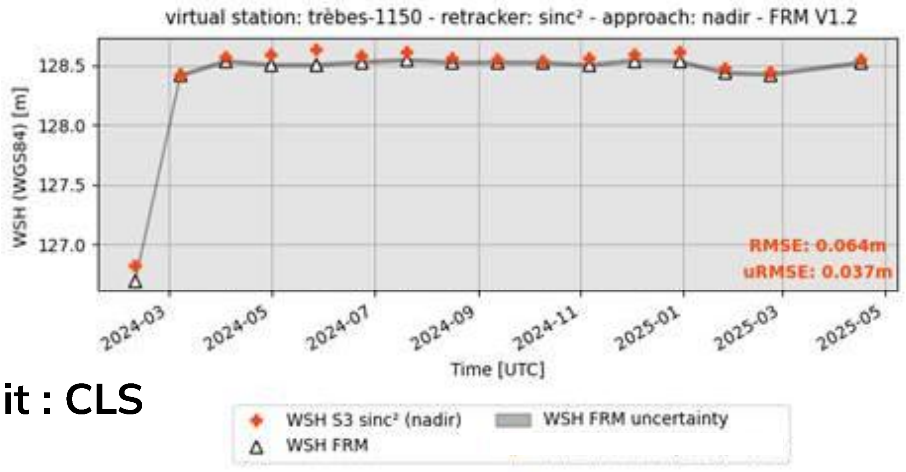
FRM computation strategy

Complexity level 0 / Opportunity sites	Complexity level 1	Complexity level 2	Complexity level 3
$FRM(t) = WSH_{IS}(t)$	$FRM(t) = WSH_{IS}(t) + WSH_{MS}$	$FRM(t) = WSH_{IS}(t+\delta_t) + WSH_{MS}$	$FRM(t) = WSH_{IS}(t+\delta_t) + 2\,WSH_{MS}$

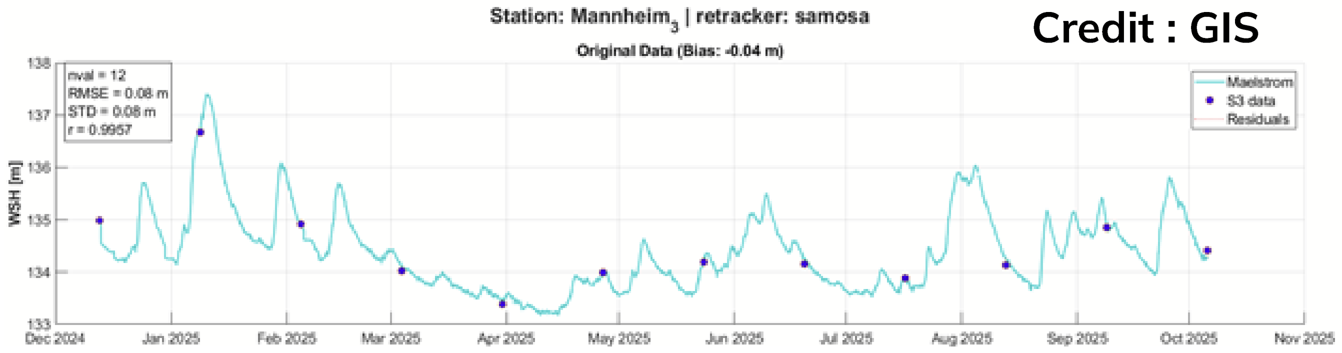
- The **river topography** evolves according to the **river discharge**
- To improve the FRM computation, we perform **multiple river topography** measurements at different seasons
- We **interpolate between 2 topography measurements,** using the in-situ value as a reference, to **compute the slope correction**



Sentinel-3 Hydro products validation activities



Credit : CLS



Credit : GIS

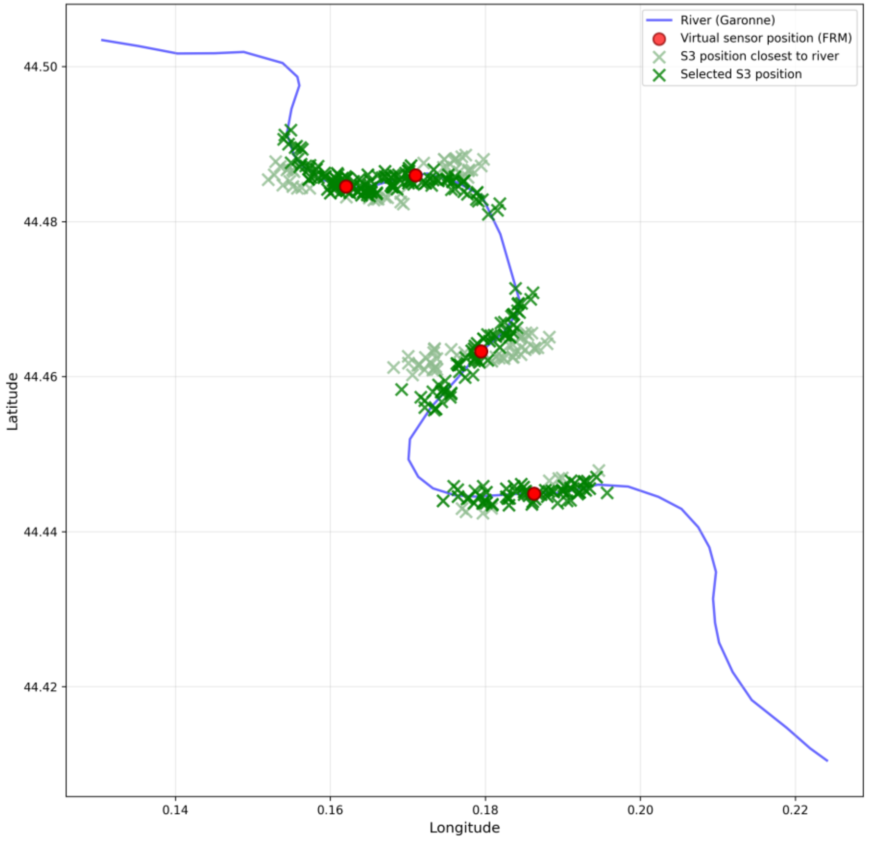
Analysis performed by CLS team on Trèbes and GIS team on Manheim

- **CLS team provides** all the St3TART-FO Inland waters team with **expertized Sentinel-3 L2 Hydro products**
- These expertized products used **different types of retracker** (SAMOSA and Sinc² in addition of the official OCOG products)
- It enables to perform comparisons studies of the performance of the retracker to provide ESA team reliable conclusions
- Each partner (**GIS, CLS, SERTIT, CNR-IRPI**) performs validation activities over their regional super-sites

Processing chain evolution
→ FRM V2 release

Continuous evolution of the processing chain

- **Major evolution developed in the end of 2025** and deployed on the operational processing chain in March
- We account for **Sentinel-3 excursion** to select the exact FRM location
- We use the **Short Time Critical** products for operational FRM production, and **Non Time Critical** products for historical reprocessing
- This evolution was **planned since the beginning of the project** following MPC team recommendation
- This process leads to a **difference up to 500 m on FRM location** and can have a strong impact on FRM values



FRM location over Marmande 4 virtual stations with Sentinel-3 excursion

Processing chain evolution → FRM V2 release

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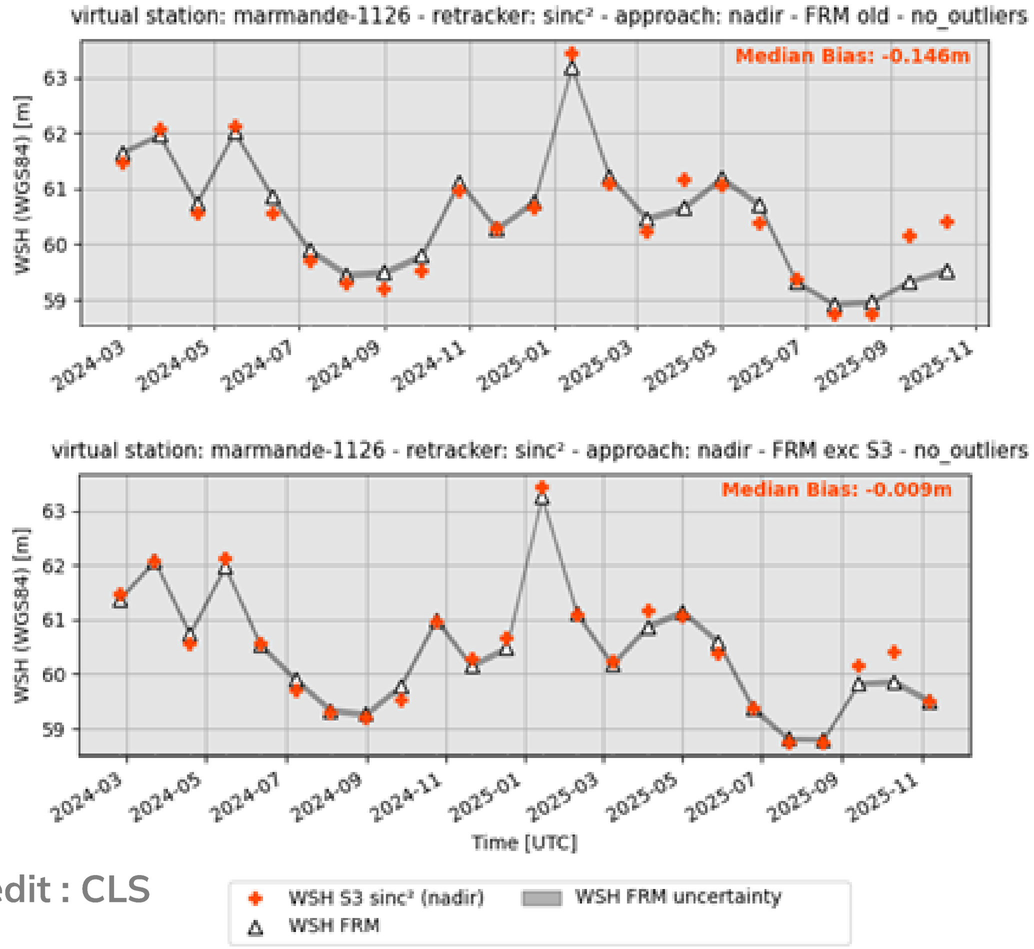
Example of FRM improvement at a virtual station of Marmande when accounting for the Sentinel-3 excursion



Credit : CLS

- Accounting for the satellite excursion has a **strong impact on the FRM** computation on super-sites impacted by significant river topography variation
- The slope correction applied **varies from cycle to cycle**, depending on the **magnitude of the satellite excursion** for each Sentinel-3 overpass.
- On the left there is the comparison between **FRMs and Sentinel-3 L2 HY** products, without the excursion on top and with the satellite excursion below
- On this site, performances were significantly improved, reducing the median bias from **-14 cm to -1 cm**

Work conducted on FRM uncertainties

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CEOS FRM definition: *"A suite of independent, **fully characterized**, and **traceable** (to a community agreed reference ideally SI) measurements, tailored specifically to address the calibration and validation needs of a class of satellite borne sensor and that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO)."*

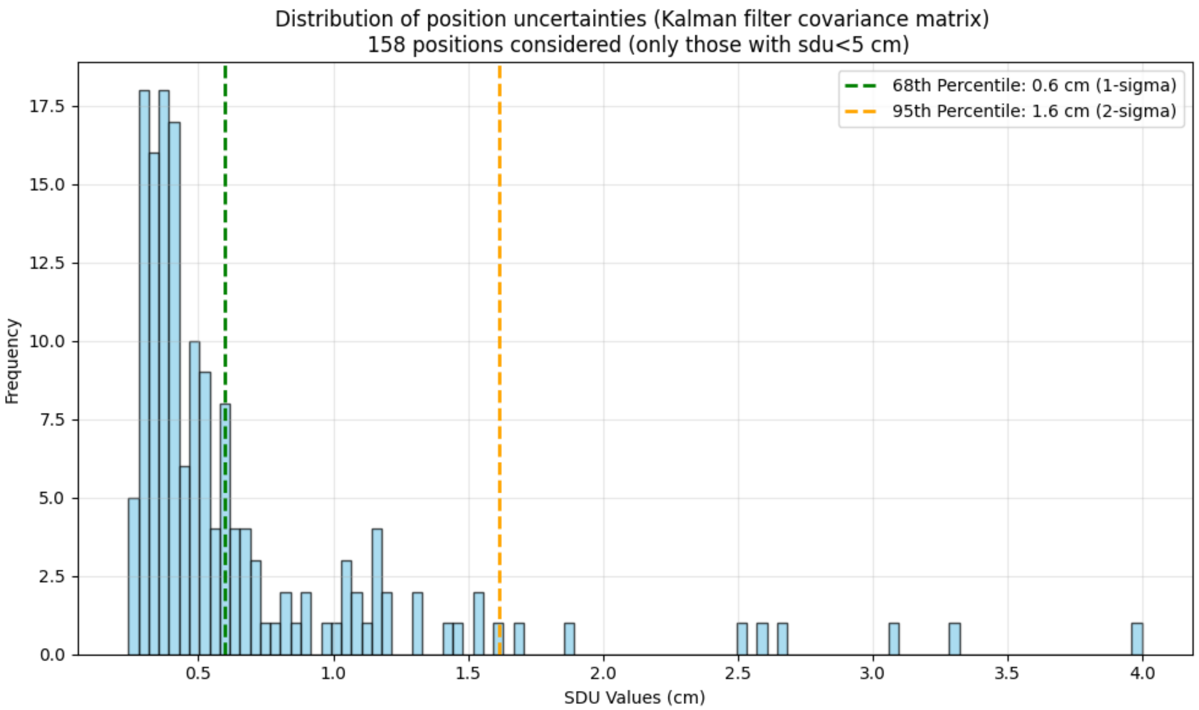
For the FRM **characterization and traceability** we need to assess the uncertainties.
For the most complex case, the FRM formula is :

$$\boldsymbol{FRM(t) = WSH_{IS}(t + \delta_t) + 2\,WSH_{MS}}$$

Key points for uncertainty assessment :

- WSH_{IS} → Micro-station **instrumental uncertainty**
- WSH_{MS} → Drone altimeter **instrumental uncertainty**
- t → Does the scheduled date generate error on FRM computation ?
- δ_t → Does the time lag estimation generate errors on FRM computation ?

Micro-station uncertainties first assessment



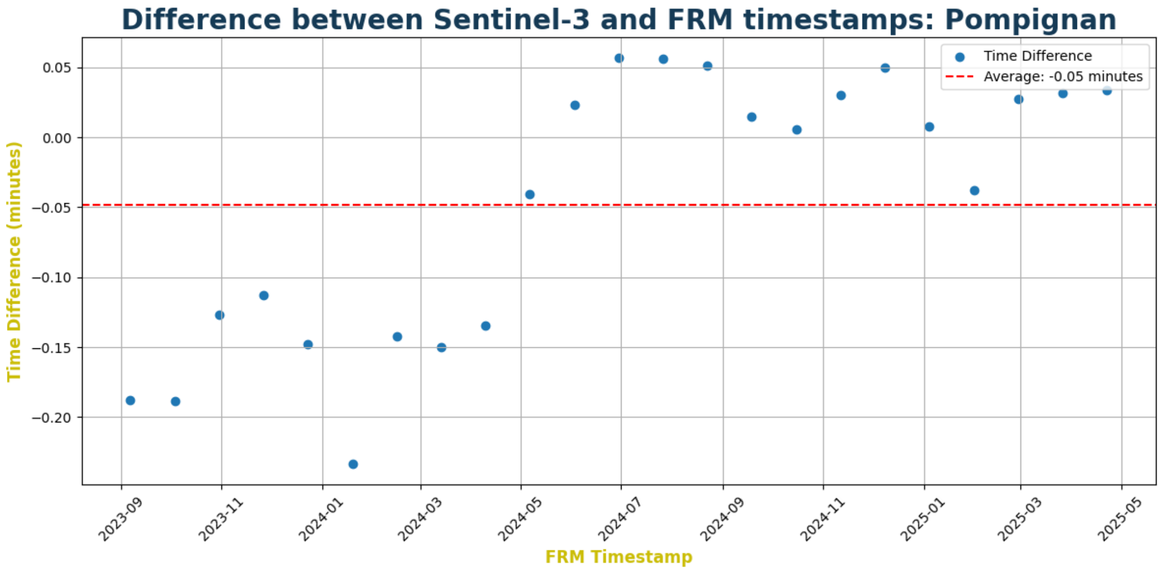
Ongoing work to continue to **improve GNSS uncertainty assessment** with project partners **(NPL, GIS)** by comparing different positioning methods

- The micro-station measurement is the combination of **GNSS leveling and LiDAR air drought measurement**
- The measurement theoretical uncertainty is the **quadratic sum of both uncertainties**
- Assessment of **GNSS uncertainty** → Computed from the Kalman filter residuals (SDU) → **0.6 cm**
- Assessment of **LiDAR uncertainty** → Computed from the $\boldsymbol{\sigma}$ of the raw **LiDAR beams** values → **1.2 cm**
- We aggregated these figures at the micro-station network scale to obtain generic values
- **Final computation** → $\Sigma_{MS} = \sqrt{\Sigma_{GNSS}^2 + \Sigma_{LiDAR}^2}$ **= 1.3 cm**

Next step → Same analysis on the **vorteX-io drone altimeter**

Micro-station scheduling error budget

- For all the super sites we **compute the satellite measurement** date and **schedule the sensor accordingly**
- To assess the error budget, we compared the **sensor scheduled date** with the **Sentinel-3 measurement date**
- Depending on the site, the average time error can be from **10 seconds to 6 minutes**

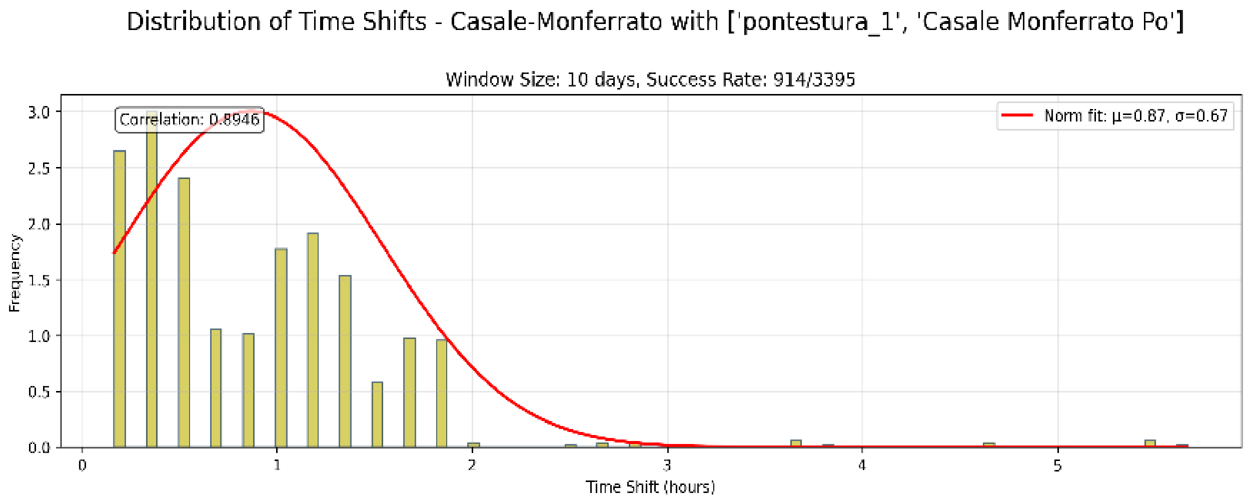


Super-site name	Sentinel-3 to FRM Date difference	Corresponding water level variability (cm)
Casale-Monferrato	-0.61 minutes	<0.1 cm
Marmande	-6.06 minutes	0.3 cm
Trèbes	-3.79 minutes	0.1 cm
Pompignan	-0.05 minutes	<0.1 cm
Pierantonio-Umbertide	-0.08 minutes	<0.1 cm
Ottmarsheim	-0.08 minutes	<0.1 cm

- We obtain a **time error budget** → we need a **height error budget**
- We computed a **global height variability** for each sensor by analyzing **the sensor time serie**
- The height error budget is computed from the **time error budget** and **sensor height variability**

Propagation time error budget

- To estimate the time lag, we performed multiple runs on different time windows
- The uncertainty on the time lag is considered as the standard deviation of the time lag obtained by the multiple runs
- We obtain a **time error budget** → we need a **height error budget**



Super-site name	std of hourly variation Δh_{hourly} (cm)	$\Delta T_{uncertainty}$ (hours)	Distance between stations for ΔT (km)	height uncertainty by distance from micro-station (cm/km)
Marmande	3.4	0.96	15	0.218
Casale-Monferrato	3.3	0.67	10	0.221
Isola-Pescaroli	2.1	1.86	26	0.150
Ottmarsheim	4.4	0.77	16	0.212
Pierantonio-umbertide	1.7	0.89	8.5	0.178
Deruta	3.3	0.87	5	0.574

- We rely again on **the height variability** for each sensor
- With the time **error budget from time lag computation**, we obtain a height uncertainty
- We use the distance between the sensors to obtain an **error budget in respect with curvilinear distance**.
- **We combine this value** with the **distance** between in-situ sensor and FRM location to obtain **final the error budget**

Conclusion

Next project steps

- Continue **collecting in-situ measurement**
  - **River topography** measurements
  - Deployment of **additional in-situ sensors**
- Improve the drone uncertainty assessment to ensure better **FRM uncertainty provision**
- Work on the **MPC team recommendations** for the FRM provision →
  - **Extend opportunity site selection** to enable off-nadir validation
  - **R&D activity** for provisioning **'FRMs nodes'** to allow flexible validation

Project key points

- **Operational provision of FRM as a service** with an automatic processing chain and distributed through the FRM Data Hub by NOVELTIS
- **Continuous development** on the processing chain to improve robustness and implement **S3 MPC recommendations**
- Validation activities conducted by **the Inland Waters** team to improve the knowledge on Sentinel-3 measurements over inland water and **discuss FRM processing improvement**