Assimilation of SWOT nodes products into basin-scale hydraulic models

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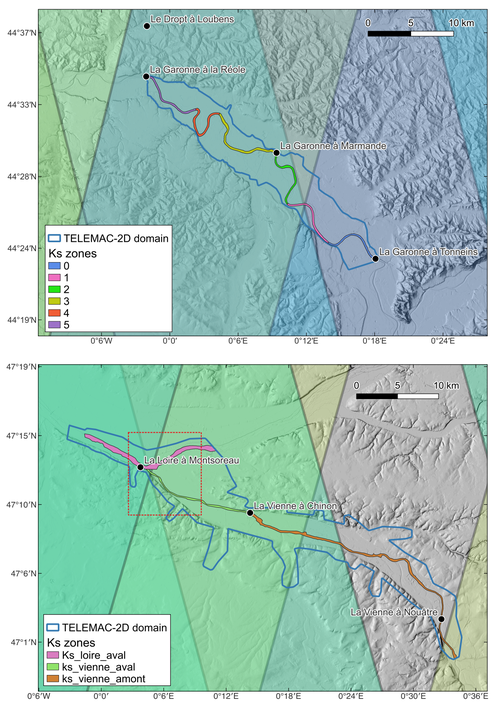
Abstract

This study leverages the capabilities of the SWOT mission–particularly its RiverSP node products–to improve riverine flood forecast. Using an ensemble Kalman filter framework, several strategies are tested to sequentially update hydraulic model parameters. Evaluations against Sentinel-1 and Sentinel-6 data show that SWOT observations alone enhance model accuracy, while their combination with in-situ water level data yields the best representation of flood dynamics. Experiments conducted on Garonne River (France), Loire River (France) and Ohio River (US) confirm the robustness of this approach. The joint assimilation of SWOT water surface elevation and other EO data also enables improved flood extent representations, offering promising perspectives for integrating these datasets into global hydrological and routing models to advance large-scale flood monitoring systems.

Keywords: Fluvial floods, Data assimilation, EnKF, TELEMAC-2D, Sentinel-1, SWOT, `L2_RiverSP_Node`.

Study Area

Fig. 1: TELEMAC-2D model over Garonne and Vienne-Loire.



Observations

a. Surface Water and Ocean Topography

With KaRIn, SWOT main river data products are delivered as pixel clouds (PIXC), RiverSP nodes, reaches, and rasters. In this work, node-averaged water surface elevation (WSE) and rasterized water masks are utilized.

`Tools4SWOTsims`: a set of Python scripts to map 1D/2D hydrodynamic model outputs into 2D WSE rasters that is compatible with SWOT simulators.

`SWOT-HR` simulator to render the WSE rasters into PIXC.

`RiverObs` package to generate RiverTile products.

b. In-situ water level observations

In-situ gauging stations are maintained by the national obsering network within the catchments providing WSE time-series data with high temporal resolution.

c. Copernicus Sentinel-1 observations

SAR is efficient at monitoring flood extents due to all-weather day-and-night imaging capabilities. Flood extents can be derived from C-band SAR Sentinel-1 (S1) images using a Random Forest classifier. **WSR** is the ratio between the number of wet pixels and the total number of pixels within each of the floodplain subdomains.

References

1. C. Emery et al. (2022), Tools4SWOTsims and SMURF, *AGU Fall Meeting 2022*, OS22A-21, Chicago, IL.
2. Q. Bonassies et al. (2025), Assimilation of SWOT Altimetry Data for Riverine Flood Reanalysis: From Synthetic to Real Data, `https://arxiv.org/abs/2504.21670`.
3. Q. Bonassies et al. (2025), A Comprehensive Study of Surface Water and Ocean Topography Pixel Cloud Data for Flood Extent Extraction, `https://ssrn.com/abstract=5355221`.

Method

Fig. 2: SWOT river products on 2024-03-31T15:16:15.

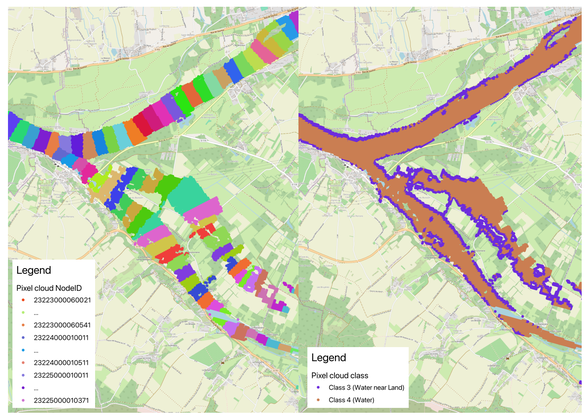


Fig. 3: Proposed Workflow

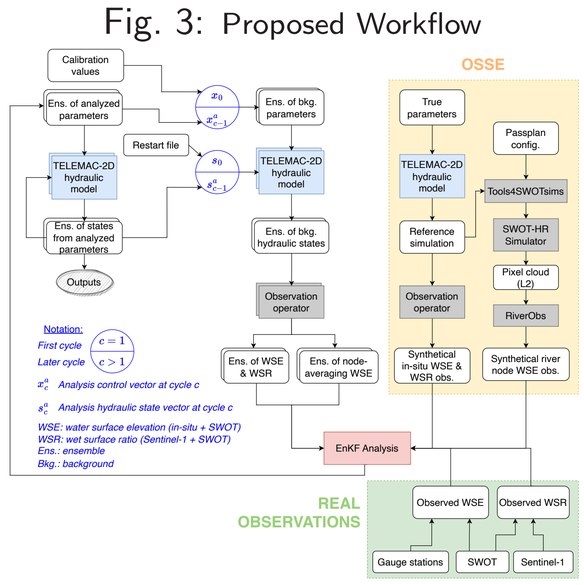


Table 1: Experimental setting.

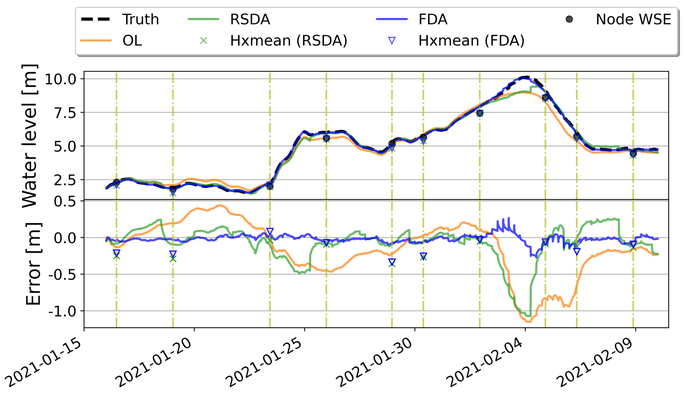
Exp. name	Assimilated obs. SWOT WSE	In-situ WSE	Sentinel-1 WSR	Control vector
OL	☐	☐	☐	-
RSDA	☑	☐	☑	Ks, Q, dH
FDA	☑	☑	☑	Ks, Q, dH

Table 2: RMSE [m] of simulated WSE at observing stations. Left: Garonne; Right: Vienne-Loire.

Exp.	TON	MD0	LR0	CHN	MSR
OL	0.449	0.301	0.195	0.854	0.232
RSDA	0.491	0.261	0.383	1.143	0.417
FDA	0.127	0.073	0.080	0.129	0.063

Three experiments: 1 open-loop (OL) and 2 data assimilation (RSDA & FDA) with 96 members.
Control vector: Strickler friction coefficients Ks, parameter μ to correct inflow discharge Q, and floodplain corrective state variables dH.

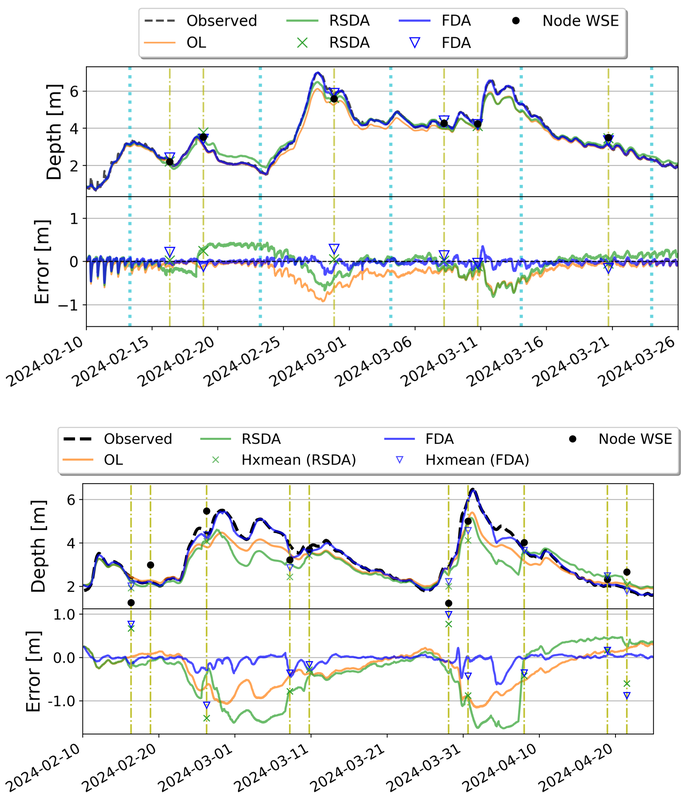
Fig. 4: Simulated WSEs at gauge stations (OSSE).



SWOT observations at the nearest node to the gauge are denoted by ●, simulated by × RSDA and ▽ FDA.

Experimental Results

Fig. 5: Simulated WSEs at gauge stations. Top panel: Garonne; Bottom panel: Vienne-Loire.



SWOT observations at the nearest node to the gauge are denoted by ●, simulated by × RSDA and ▽ FDA.

Fig. 6: Simulated WSEs at along rivers.

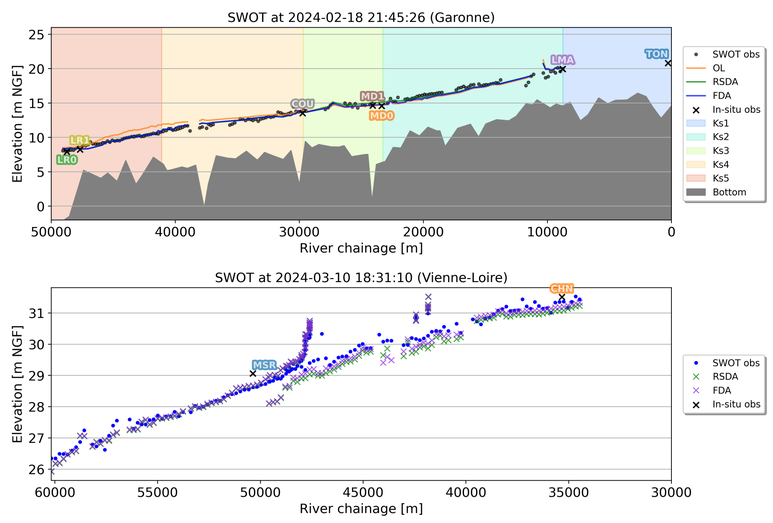
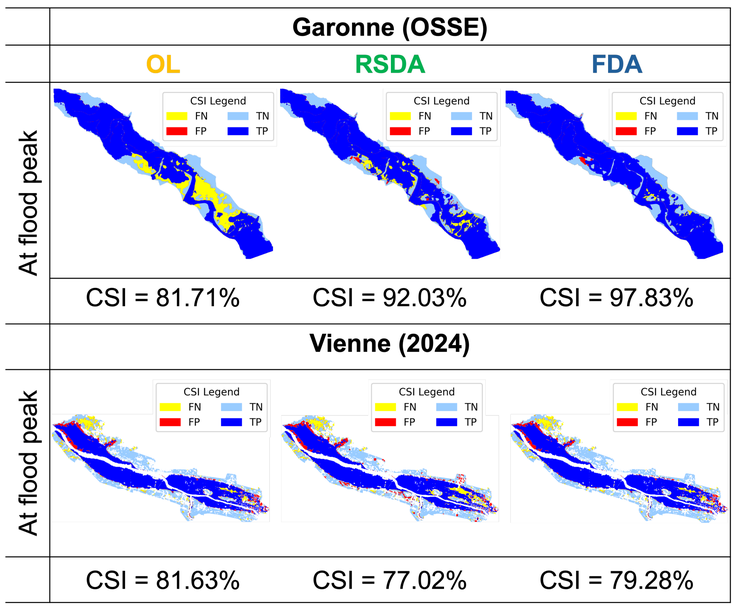


Fig. 7: Contingency maps w.r.t observed flood extents.



→ The assimilation of SWOT WSE + Sentinel-1 WSR improves flood extend representations.

Conclusions

- ☑ Merits of leveraging heterogeneous observations from Sentinel-1 SAR and SWOT data;
- ☑ Ensemble-based DA allows improving reanalysis and forecast in the riverbed and floodplain;
- ☑ Merits of SWOT data over poorly-gauged catchments (e.g. Niles, Juba-Shabelle basins).

Perspectives

- ☐ Assimilating other observations, e.g. water surface velocity, S-/L-/P-band SAR (NiSAR, ROSE-L, BIOMASS);
- ☐ Investigating merits of daily satellite observations (e.g. SMASH, S3-NG-TOPO);
- ☐ Exploiting RS-derived flood fronts.

← Link to papers

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