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# Combining Sentinel-1 Flood Extent & Sentinel-6 Altimetry for Flood Forecasting

T. H. Nguyen[1,2], S. Ricci[1], A. Piacentini[1], F. Boy[3], S. Le Gac[3], R. Rodriguez Suquet[3], S. Peña Luque[3], and S. Munier[4]

[1]CECI, CERFACS/CNRS UMR 5318, Toulouse, France - [2]LIST, Esch-sur-Alzette, Luxembourg - [3]CNES, Toulouse, France - [4]CNRM, UMR 3589, Toulouse, France

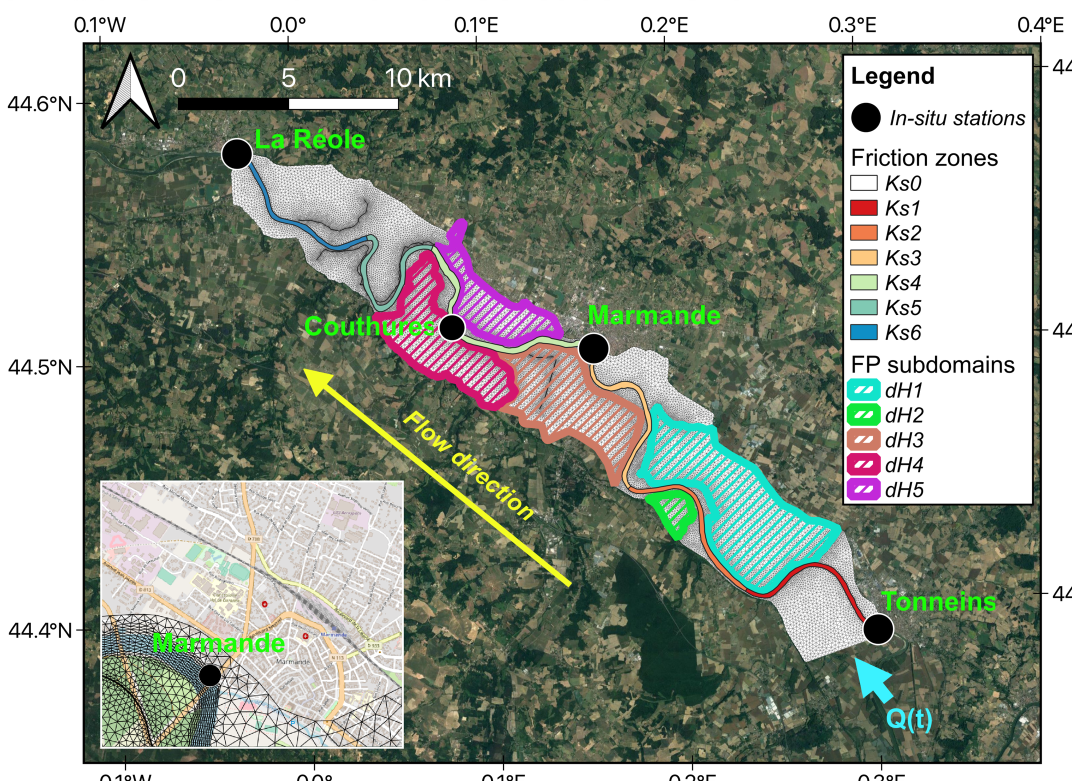
## Abstract

Floods are one of the most common and devastating natural disasters worldwide. In this regard, the volume of data from space missions have been increasing considerably in recent years. Heterogeneous and relevant flood observations have been provided by altimetry, optical and SAR satellites. This work focuses on the assimilation of multisource remote sensing (RS) data, namely 2D flood extent maps derived from Sentinel-1 (S1) SAR imagery data and Sentinel-6MF (S6) altimetry data. An Ensemble Kalman Filter (EnKF) with a state-parameter dual analysis is implemented on top of a 2D hydrodynamic model TELEMAC-2D (T2D) model. The proposed strategy is applied over the 2022 flood event over the Garonne Marmandaise catchment. This work paves the way towards near-real-time flood forecast making the most of the large volume of heterogeneous data from space.

**Keywords:** Fluvial floods, Data assimilation, EnKF, TELEMAC-2D, Garonne, Sentinel-1, Sentinel-6, FFSAR.

## Study Area, Data, Model

**a. Garonne Marmandaise catchment**




The hydrodynamic model, developed by EDF R&D, covers a 50-km catchment of the Garonne River (France). Its boundary conditions include the upstream hydrograph and the downstream rating curve. To extend the forecast lead time beyond the hydraulic network transfer time, the upstream BC $Q(t)$ can be described by a large-scale hydrologic model, namely ISBA-CTRIP.

**b. In-situ observations from VigiCrue network**

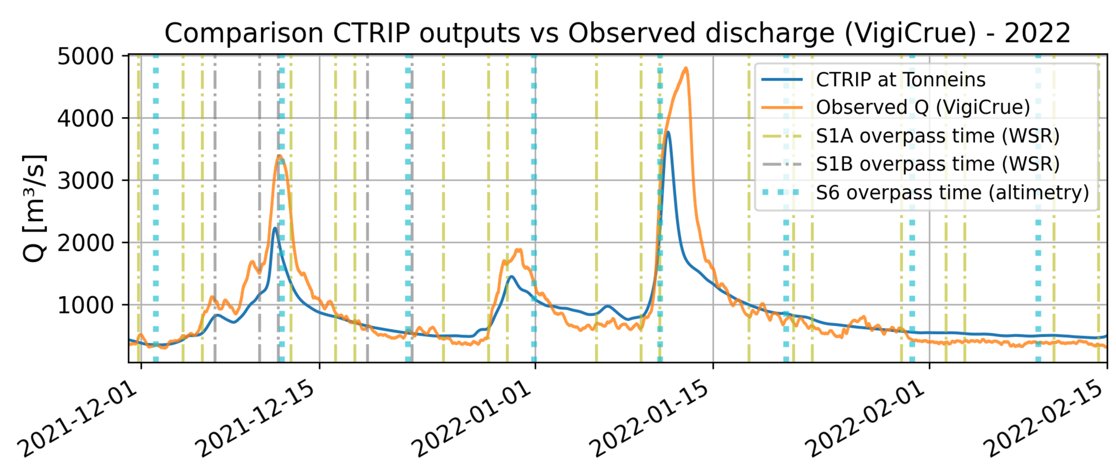
Three in-situ water level gauging stations are maintained by the VigiCrue network within this catchment, at Tonneins, Marmande, and La Réole, providing time-series of WL data. Another Vortex.IO station at Couthures-sur-Garonne provides additional WL data and surface velocity measurements, only used for validation.

**c. Copernicus remote-sensing 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 S1 images (vertical dash-dotted lines) using a Random Forest classifier.

Using Fully-focused SAR (FFSAR) processing applied on Sentinel-6 data, water surface elevation (WSE) over a segment of the Garonne River can be reconstructed (cyan dotted lines) with a high along-track resolution (10 m).

Fig. 1: Forcing data




## References

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2. T. H. Nguyen et al. (2023), Flood Forecast with Chained Hydrologic-Hydraulic Modeling and Data Assimilation, *TELEMAC-MASCARET User Conference 2023*, Karlshure, Germany, 11-13 Oct 2023.

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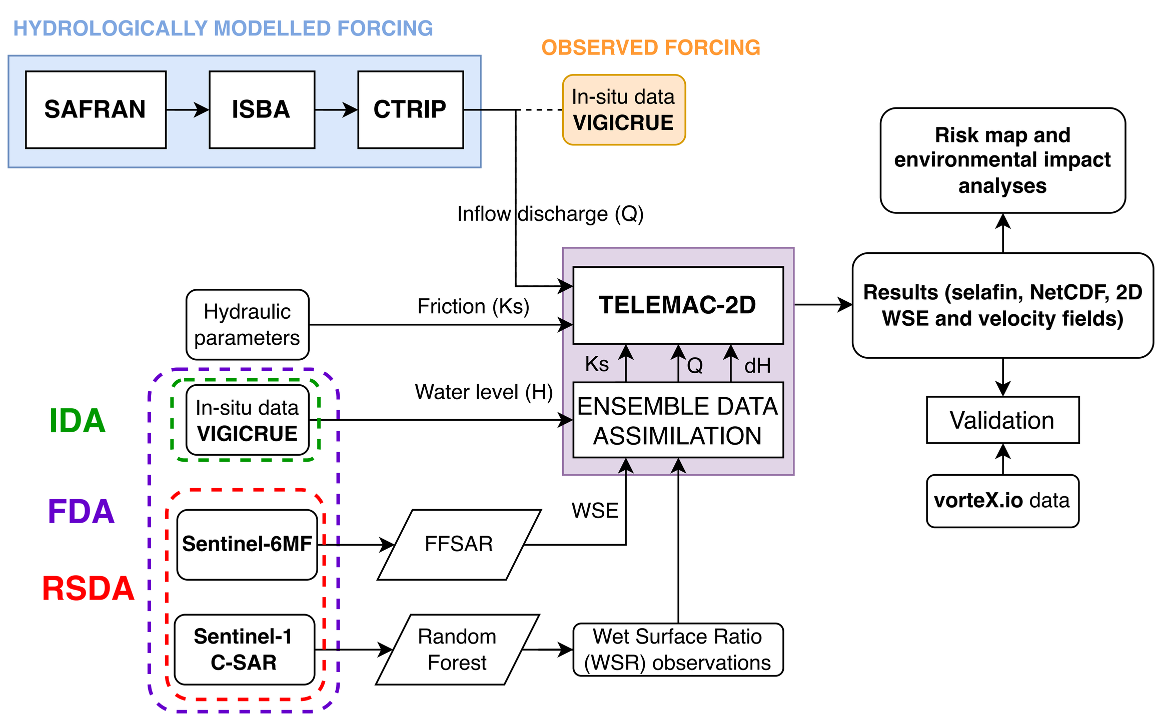
**Contact:** thanh-huy.nguyen@list.lu

## Method and Experimental Results

Fig. 2: General Workflow




**Large-scale ISBA-CTRIP model:** the hydrologic model results from the coupling of the ISBA land surface model and a CNRM-modified version of the TRIP river routing model. ISBA is defined at global scale on a $0.5^\circ \times 0.5^\circ$ grid to establish the energy and water budget over continental surfaces, whereas CTRIP is defined on a $1/12^\circ$ grid and follows a river network to transfer water laterally from one cell to another.

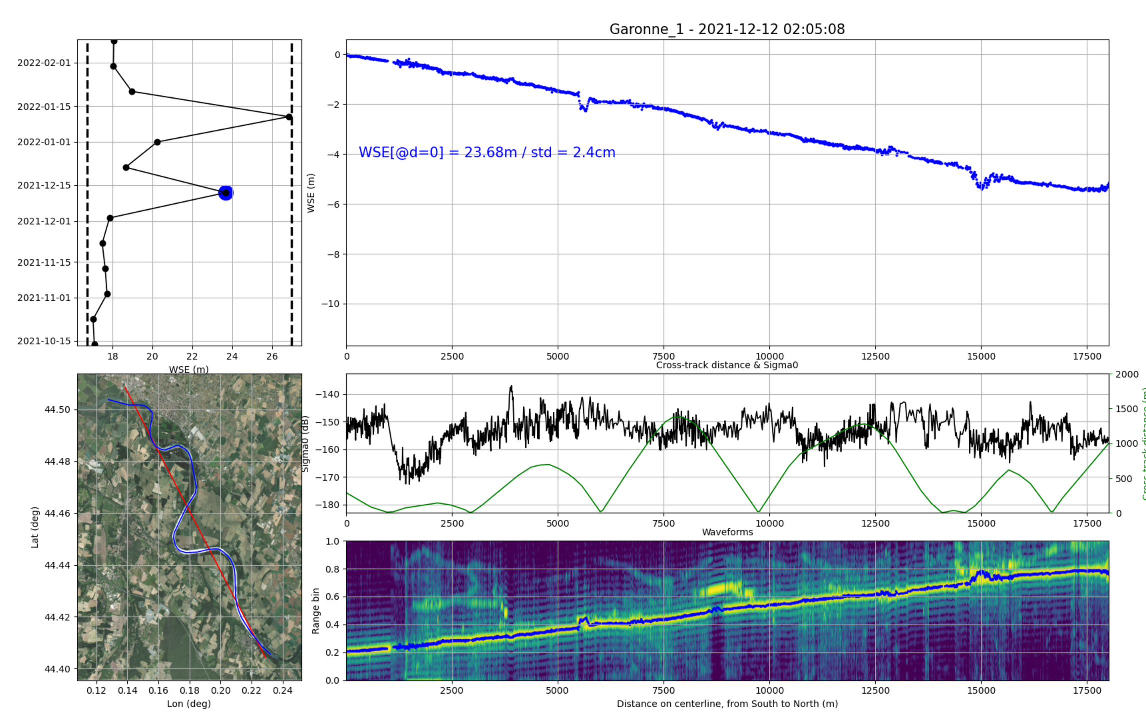
**Control vector:** 7 Strickler friction coefficients Ks, 1 parameter $\mu$ to correct inflow discharge Q, and 5 floodplain corrective state variables dH. These state corrections are implemented in the 5 floodplain zones in order to account for the evapotranspiration, ground infiltration and rainfall processes.

**Random Forest-based flood extent detection:**

- Inputs: Sentinel-1 VV-VH images and MERIT DEM
- Random Forest classifier trained on Copernicus EMSR samples having >90% water occurrence
- Test result: $F_2$-score averages 86.86% on 5 test sites

**WSR** is the ratio between the number of wet pixels and the total number of pixels within each of the 5 floodplain zones.

Fig. 3: Sentinel-6MF Fully-focused SAR processing




**FFSAR S6 for river WSE profile:** limited to rivers with

- width < 200 m and ground distance to S6 < 2 km → constrain slant-range uncertainties < 15 cm
- one single cross-over with the S6 track → avoid ambiguity

**Four experiments:** 1 open-loop (OL) and 3 data assimilation (IDA, RSDA, FDA) with 75 members.

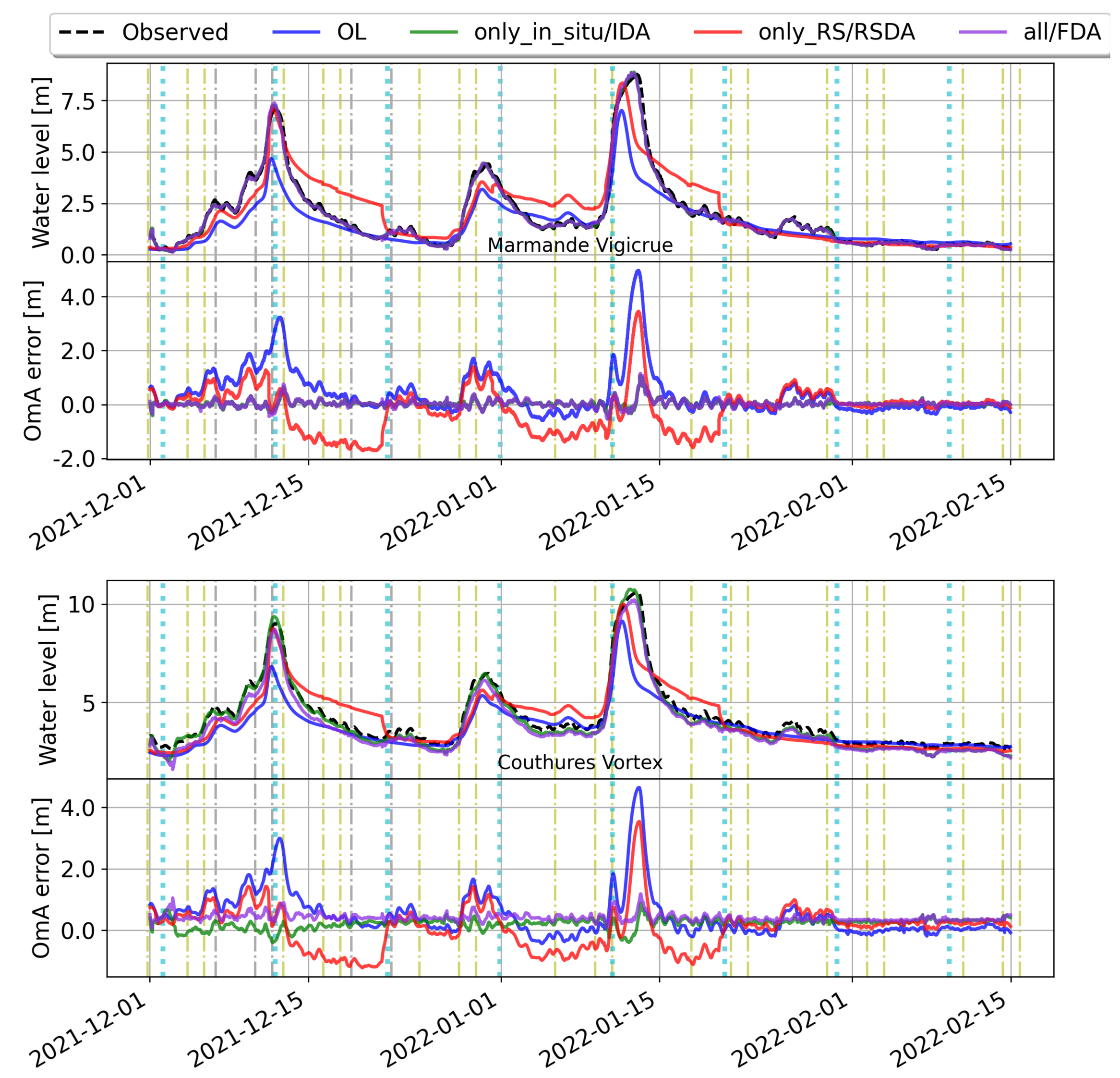
Table 1: Experimental Settings

| Exp. name | In-situ WL (Assimilated obs.) | S1 WSR (Assimilated obs.) | S6 WSE (Assimilated obs.) | Control vector |
|---|---|---|---|---|
| OL | ☐ | ☐ | ☐ | - |
| IDA | ☑ | ☐ | ☐ | Ks, Q |
| RSDA | ☐ | ☑ | ☑ | Ks, Q, dH |
| FDA | ☑ | ☑ | ☑ | Ks, Q, dH |

Table 2: RMSE [m] of simulated WSE at in-situ stations

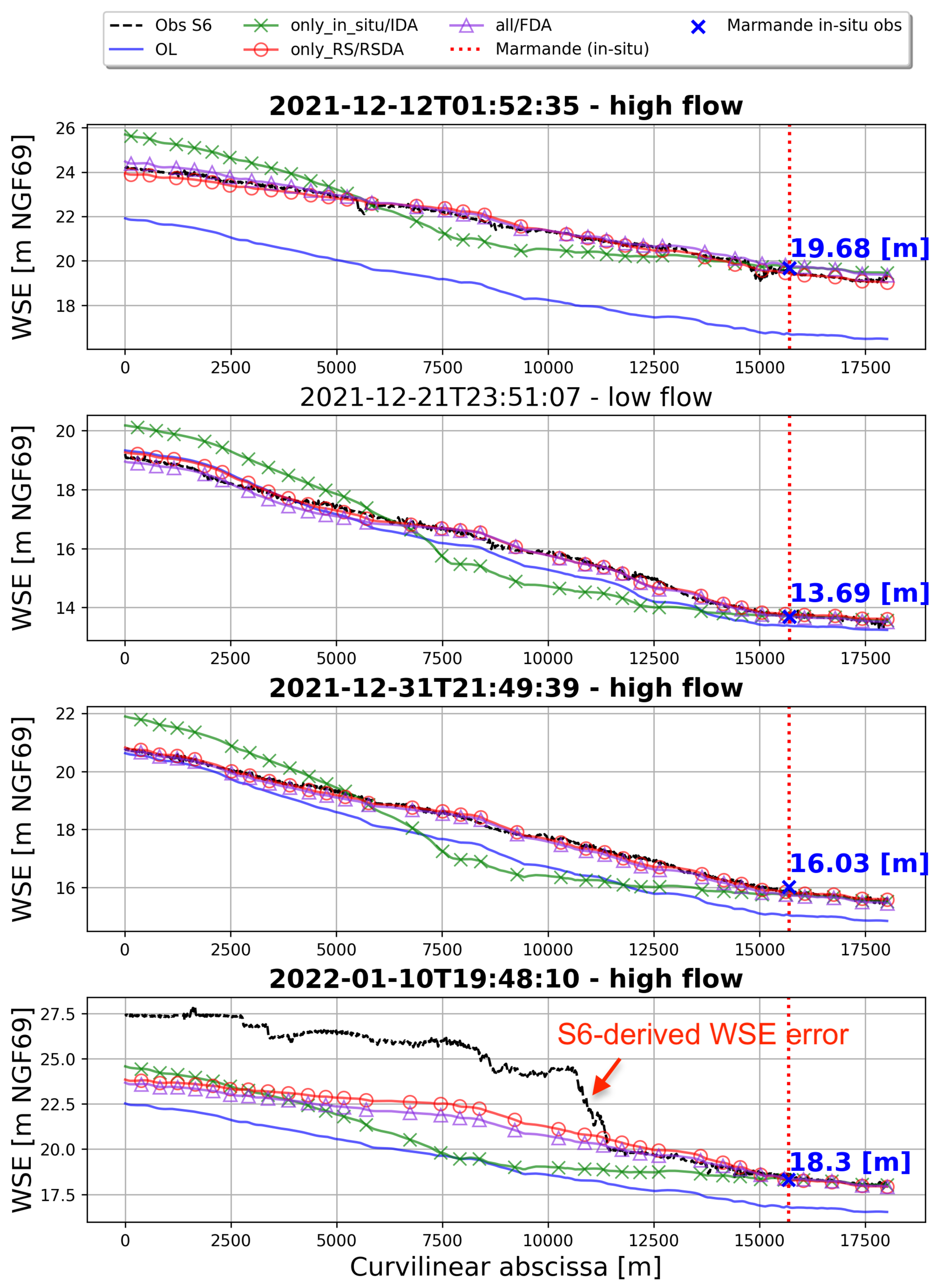
| RMSE | Tonneins | Marmande | La Réole | *Couthures* |
|---|---|---|---|---|
| OL | 1.168 | 0.946 | 0.945 | *0.789* |
| IDA | 0.189 | 0.137 | 0.140 | *0.280* |
| RSDA | 0.877 | 0.829 | 0.994 | *0.647* |
| FDA | 0.191 | 0.150 | 0.158 | *0.410* |

Fig. 4: WLs at Marmande (analysis, top) and *Couthures* (*validation*, bottom)




→ The assimilation of frequent in-situ WL significantly improves the hydraulic state at the observing stations, but in the vicinity of the station only.

Fig. 5: WSE profile at river centerline




→ The assimilation of spatially dense S6-derived WSE improves the hydraulic state along the entire river, but at S6 observation time only.

## Conclusion

- ☑ Merits of leveraging heterogeneous observations from Sentinel-1 SAR data and Sentinel-6 data;
- ☑ Ensemble-based DA allows improving reanalysis and forecast in the riverbed and floodplain;
- ☑ Observing time is crucial to flood forecasting performance → Importance of in-situ data.

## Perspectives

- ☐ Assimilating other types of observation, e.g. water surface velocity, S-/L-band SAR, etc.;
- ☐ Increase RS flood observing frequency with multiple data sources (SWOT/WISA, SMASH);
- ☐ Exploiting RS flood observations as front-type data & Other catchments.