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Leveraging SWOT data to analyze river hydrodynamic and coastal interactions during extreme events: A case study of the Po River

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Acronyms

CNES .... Centre National d'Études Spatiales
CSA .... Canadian Space Agency
DAWG .... Discharge Algorithm Working Group
KaRIn .... Ka-band Radar Interferometer
KGE .... Kling-Gupta Efficiency
NASA .... National Aeronautics and Space Administration
NSE .... Nash–Sutcliffe Efficiency
SWORD .... Surface Water and Ocean Topography River Database
SWOT .... Surface Water and Ocean Topography
WSE .... Water Surface Elevation
UKSA .... UK Space Agency

Objectives

- Evaluation of the accuracy of SWOT WSE data during its overall operational period, by comparing them with in-situ measured data over Po River;
- Evaluation of the accuracy of SWOT WSE data within a two-month event, by comparing them with hydraulic model simulations, over 165 km of Po River;
- Assessing the impact of SWOT data quality levels on the reliability of satellite observations for river monitoring

The SWOT Mission

The SWOT mission (https://swot.jpl.nasa.gov/), launched on Dec 16, 2022, is a joint initiative through a collaboration between NASA, CNES, CSA, and UKSA, with the primary goal of enabling the first high-resolution mapping of nearly-global 2D observations of surface water bodies. SWOT addresses limitations of prior altimetry techniques by using the advanced KaRIn technology to map WSE and decimeter-level vertical accuracy, representing a significant advancement over previous radar and laser altimetry missions, and hence, marking a transformative leap in hydrology and surface water monitoring. Key features of SWOT for river studies are summarized in the table below:

Feature	Description
KaRIn Radar	Interferometric SAR measuring water surface height with decimeter-level accuracy
Swath Width	120 km with a nadir gap of ~20 km (see **Fig. 1**)
Temporal Resolution	21-day revisit time
Spatial Coverage	Nearly global, between 78°S to 78°N, observing rivers wider than 100 m
Data provided	WSE, width, slope, and discharge estimates

Table 1 SWOT key features for river studies

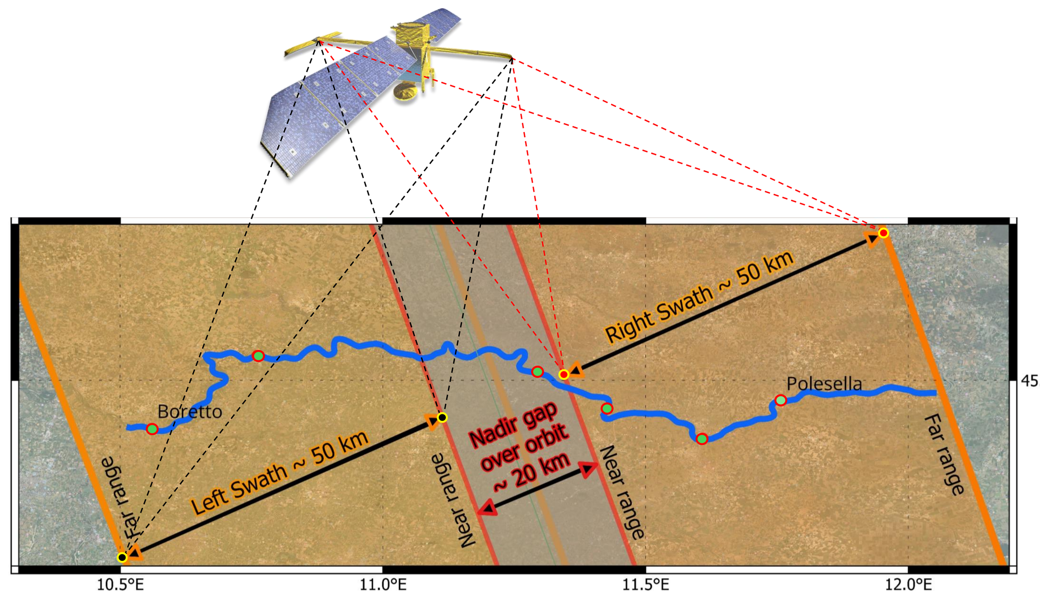

Fig. 1 SWOT orbit with Pass ID. 208, with its both swaths. This orbit has the maximum coverage over the study area, providing data for ~800 SWORD nodes; green dots represent the gauging stations considered in the study.

The current study focuses on Level 2 High-Rate hydrology products, specifically **L2_HR_RiverSP**, which are vector products of processed pixel cloud data, for a database of previously defined rivers, **SWORD**. The SWORD database defines the rivers by means of ~200 m spaced **nodes** within ~10 km segmented **reaches**. The discharge estimates, generated using algorithms developed by the DAWG, will be made available following data processing. In SWOT river node data, the quality of the observations is determined using the ***node_q*** flag, which is a summary quality indicator, whose values of 0, 1, 2, and 3 refer to good-, suspect-, degraded-, and bad-quality, respectively.

Case study

The Po River, located in Northern Italy, is the country's largest river system, with a drainage basin covering approximately 71,000 km^2 (**Fig. 2**). The main river channel stretches about 650 km from west to east, originating from the Alps and flowing into the Adriatic Sea. Its central portion traverses the flat Padana Plain, where the river adopts a relatively uniform, single-channel structure with channel widths ranging from 200 to 300 meters, reaching up to 500 meters in some locations. This analysis is carried out for a river reach of **165 km**, from the gauged stations of Boretto to the beginning of the river delta (yellow box in **Fig. 2**). Within the stretch, the study uses **five other gauged stations**, Borgoforte, Sermide, Ficarolo, Pontelagoscuro, and Polesella for calibration of the hydraulic model. Along this portion, the lateral floodplains are delimited by a system of major embankments and may reach up to 5 km.

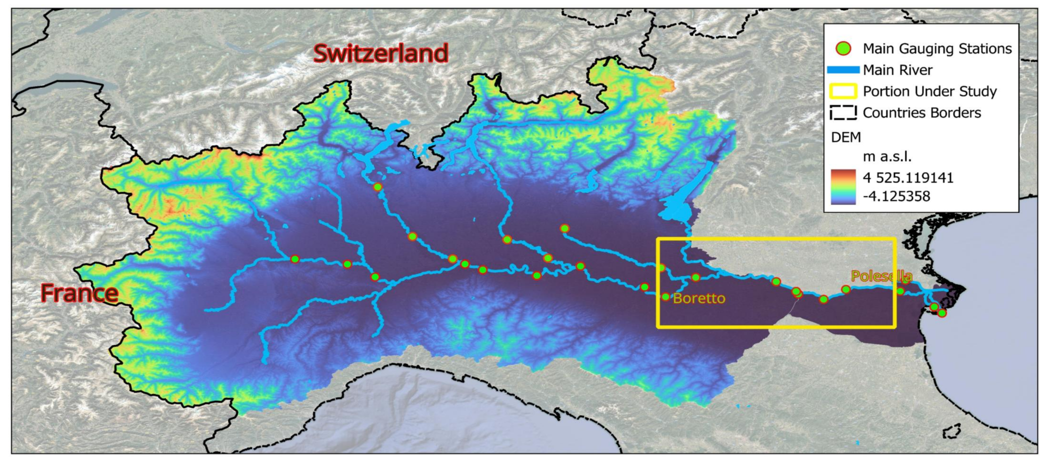

Fig. 2 Po River basin: in evidence the main river network, gauging stations (green dots), river reach of interest (yellow box).

A **2-month event**, starting from a minimum flow of 1'000 m^3/sec on Sep 25th, 2024, is selected for the upstream boundary condition at Boretto station (**Fig. 3**). During this period, the river experiences several peaks with a max value of **6'380 m^3/sec on Oct 21st**, allowing for evaluation of different possible conditions.

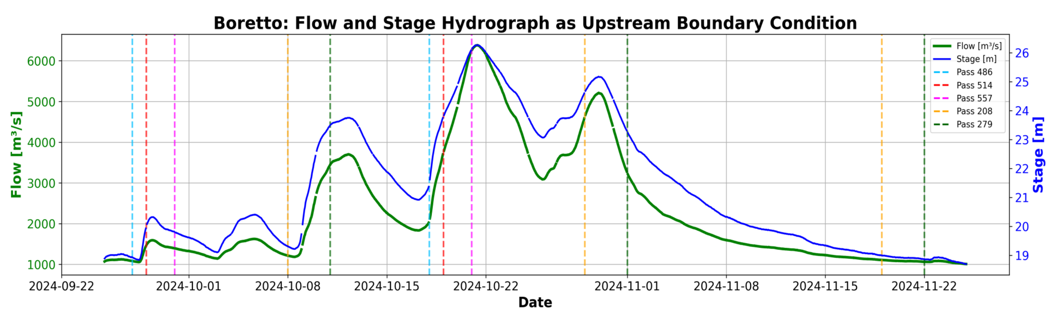

Fig. 3 Flow hydrograph as upstream boundary condition at Boretto station, used for the study

Looking at **SWOT**, the river stretch under investigation is intercepted by **12 passes** of **five orbits**: 486, 514, 557, 208, and 279 (see **Fig. 4**). Pass 208 (**Fig. 1**) provides the data for about 800 SWORD nodes while other orbits partially observe the stretch of interest.

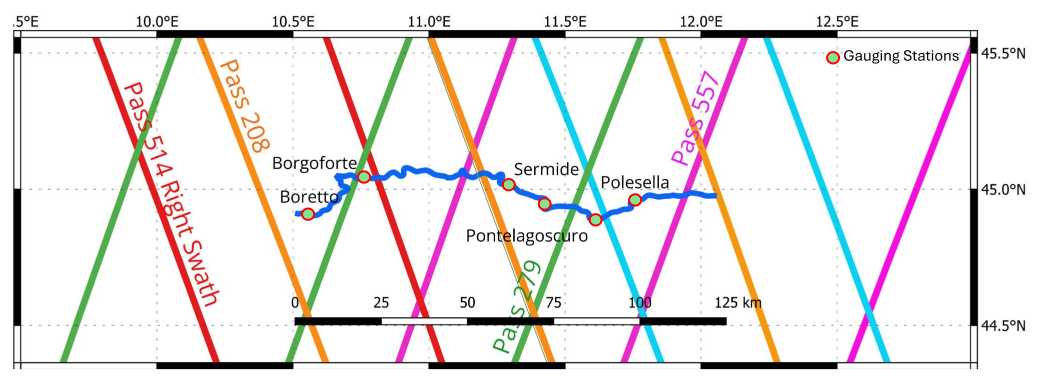

Fig. 4 Satellite orbits and swaths (different colours) over the river portion of interest (yellow box in **Fig. 1**); with their Pass IDs; green dots represent the gauging stations considered in the study.

Table 2 summarizes the details of the pass dates and times of orbits, as well as the corresponding SWORD number of nodes they provide the data for, over the spatial and temporal window of the study.

SWOT Passes within the event under study

Pass ID	No. of passes	Pass Date / Times	No. of Nodes
486	2	2024/09/27 20:39:28 2024/10/18 17:24:32	199 200
514	2	2024/09/28 20:40:08 2024/10/19 17:25:12	201 202
557	2	2024/09/30 09:58:37 2024/10/21 06:43:40	440 478
208	3	2024/10/08 19:02:24 2024/10/29 15:47:20 2024/11/19 12:32:25	760 815 820
279	3	2024/10/11 08:21:32 2024/11/01 05:06:35 2024/11/22 01:51:41	378 456 465

Table 2 Details of SWOT Observation

Methodology

To comprehensively evaluate SWOT WSE data, a twofold comparison approach is adopted: first, SWOT observations are assessed against in-situ gauge measurements at discrete stations over its operational period; then, to extend the analysis along the river profile—including ungauged sections—they are compared against hydraulic model simulations. As shown in **Fig. 5**, a combined 1D/2D HEC-RAS model is developed to simulate the hydrodynamics of 165 km of the river and its main tributaries. Over 50 floodplain storage areas are connected to 865 1D cross sections, primarily aligned with SWORD nodes. Cross sections are extracted from 1m-resolution LiDAR data, covering riverbanks and floodplains up to the levees.

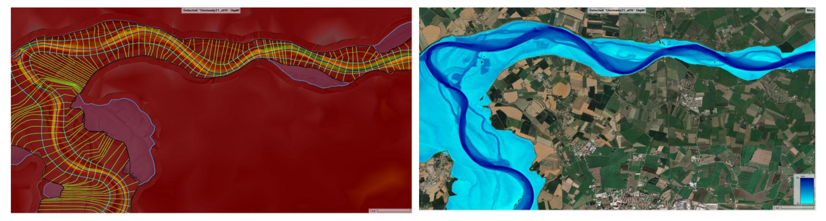

Fig. 5 HEC-RAS 1D/2D combined model used for simulation of the river hydrodynamics. Left figure shows the composition of cross-sections and right one shows the water flow at max depth

Hourly flow and stage hydrographs are used to define the upstream boundary condition at Boretto, while the calibration along the downstream is performed using data from the five gauging stations along the stretch (**Fig. 6**).

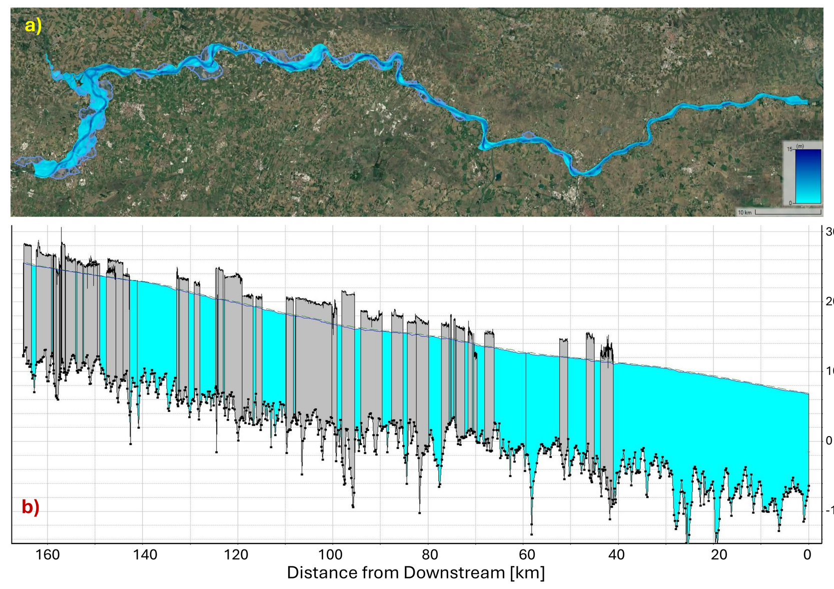

Fig. 6 Results of the calibrated model. **a)** water propagation at max depth along the river; **b)** water surface and slope results of the calibrated model.

Horizontally and vertically variable Manning's roughness coefficients were used to account for hydraulic behaviour according to the land use and flow levels. Manning's n ranged from 0.075 to 0.105 for floodplains, and from 0.019 to 0.034 for riverbanks, based on land cover characteristics and model performance.

Fig. 7 shows the performance of the model with respect to the observed stage hydrographs across gauged stations. KGEs ranging from 0.995 for Borgoforte (33 km from upstream) to 0.875 for Polesella (24.4 km from downstream).

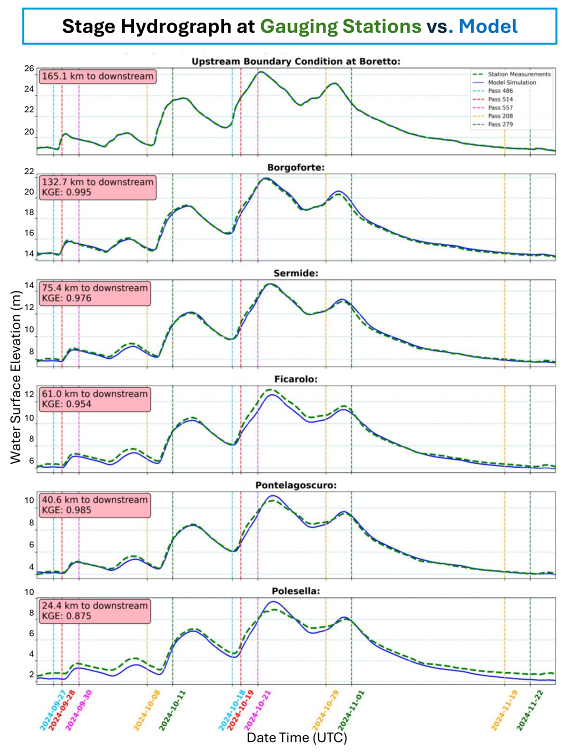

Fig. 7 Calibration results based on stage hydrographs at gauging stations. The red dashed lines, show the passage of SWOT within the time span of the study.

Results

Fig. 8 compares the SWOT WSE data during its operational period (up to Dec 31, 2024), with gauge measurements at eight stations along the Po River. Time series examples of two stations in **Fig. 8a**, show a good agreement of SWOT, despite the general bias observed in the scatterplots in **Fig. 8b**. Boxplots in **Fig. 8c** summarize the statistics over 8 selected stations, highlighting the importance of considering SWOT data quality flags.

Fig. 9 focuses on the comparison of SWOT WSE against the model results. **Fig. 9a** shows that SWOT "good" and "suspect" data (dark and light green dots) closely follow the model results and WSE trend (generally within ±0.5–0.8 m), while "degraded" and "bad" data exhibit larger discrepancies (up to 2.5 and 10 m), as also highlighted in plots of other passes. **Fig. 9b** summarizes the variations of SWOT against model results across all passes, excluding low-quality observations, with red dashed lines marking variations with gauge measurements.

Fig. 9c presents boxplots for different aggregations of quality levels. Being on average, only 16% of data as "good" quality, with three passes having no "good" data, almost all the metrics highlight the importance of quality-based selection of SWOT data. For instance, increased median RMSE from ~0.6 to ~1 m. While a similar pattern can be seen by other metrics, a general bias is observed among all SWOT WSE data, also confirmed by scatterplots in **Fig. 8**.

WSE: SWOT vs. Gauge Measurements: Eight Stations along Po, within 1.5 years

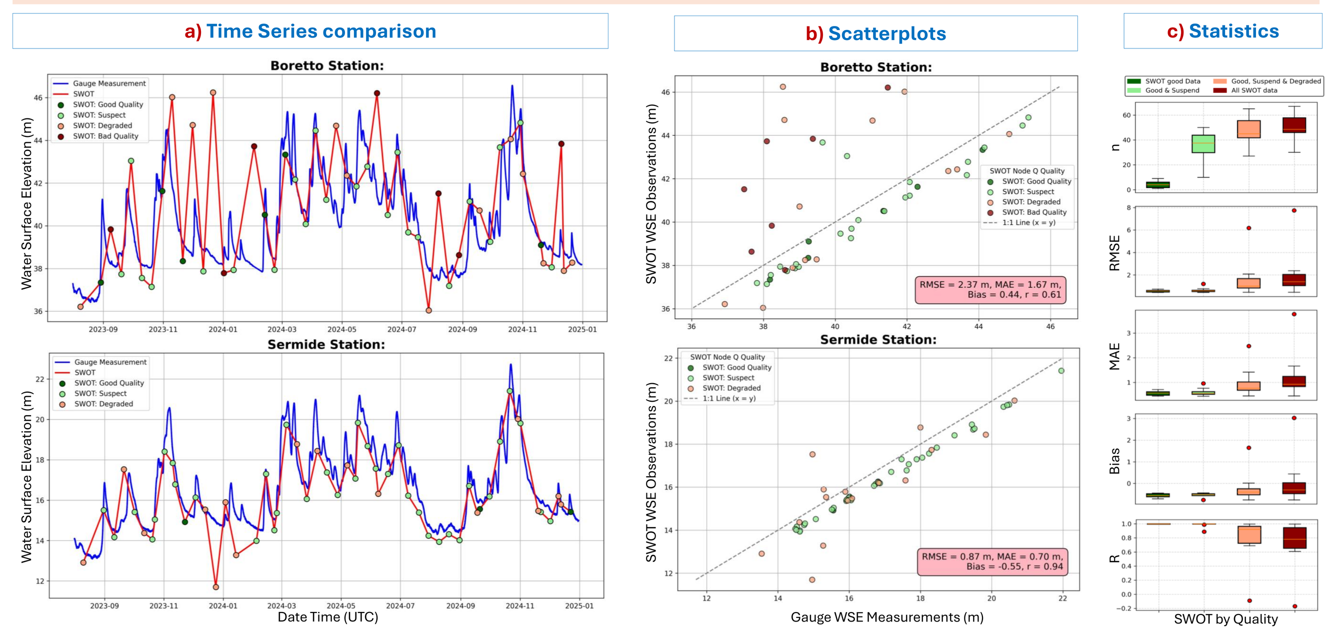

Fig. 8 WSE comparison of SWOT and gauge data at 8 Po stations, over ~1.5 years. **a)** time series at Sermide and Boretto; **b)** corresponding scatterplots; **c)** boxplots showing statistical differences by SWOT data quality.

WSE: SWOT vs. Model Simulations

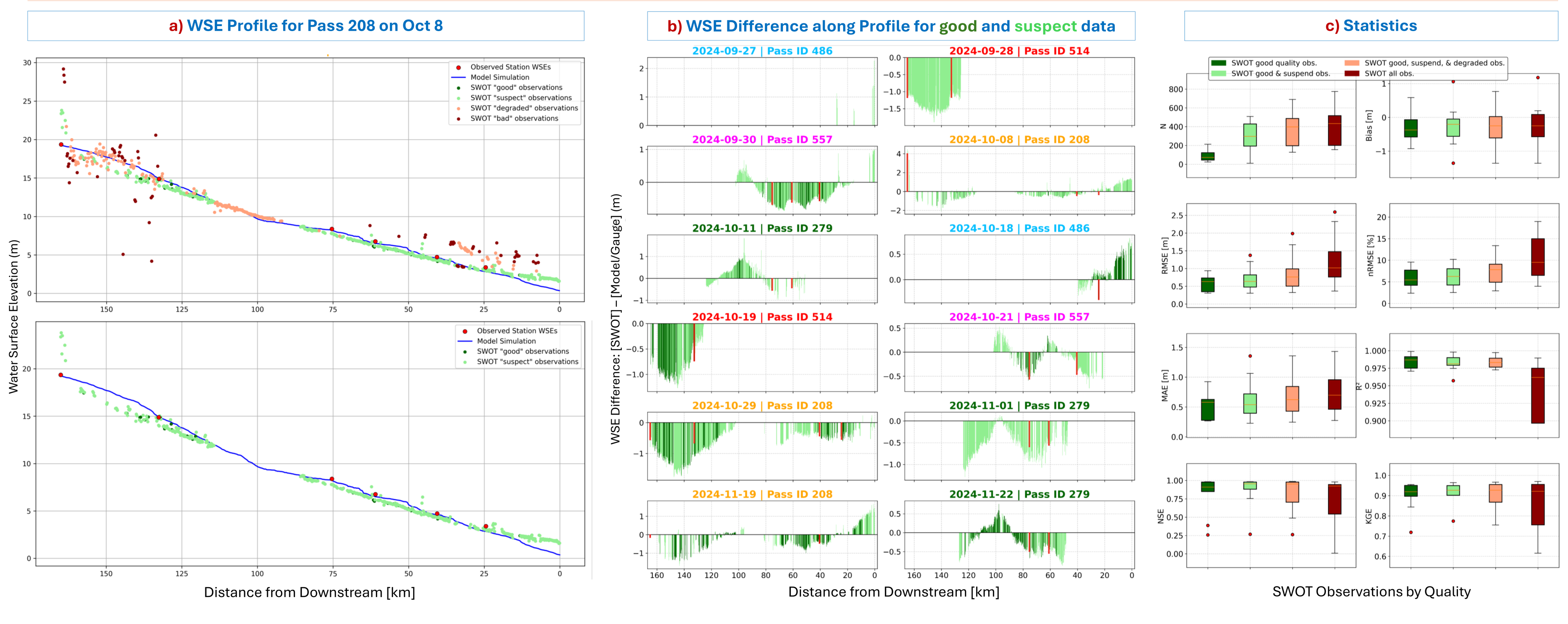

Fig. 9 WSE comparison of SWOT and model results. **a)** longitudinal profile for Pass 208 (Oct 8) with 760 nodes, color-coded by data quality; degraded/bad data excluded in the lower plot. Blue dots show HEC-RAS results; red marks gauge data; **b)** WSE spatial variations for all 12 SWOT passes vs. model, with dashed red lines showing differences from gauge data; **c)** boxplots summarizing WSE differences across passes by SWOT data quality level.

Conclusion & Discussion

This study demonstrates the strong potential of SWOT for high-resolution river monitoring, using Po River as a case study. SWOT-derived WSE data show good agreement with a calibrated 1D/2D HEC-RAS model and in-situ measurements, especially when filtered for high-quality observations. Nonetheless, accuracy assessments should account for SWOT data quality flags, as lower-quality data can introduce substantial deviations. With proper data filtering and integration with modeling, SWOT offers a powerful framework for large-scale hydrological applications.

Future Directions

- Assessment of discharge estimation and evaluation of SWOT performance in flow monitoring;
- Incorporating more advanced 2D hydraulic models to better capture riverine dynamics, including interactions with oceanic tidal influences;
- Generalizing the methodology for applications in global river systems under varying hydraulic conditions and extended timescales.

- Zhao, Y., Fu, J., Pang, Z., Jiang, W., Zhang, P., & Qi, Z. (2025). Validation of Inland Water Surface Elevation from SWOT Satellite Products: A Case Study in the Middle and Lower Reaches of the Yangtze River. Remote Sensing, 17(8), 1330. https://doi.org/10.3390/rs17081330
- Belloni, R., Camici, S., & Tarpanelli, A. (2021). Towards the continuous monitoring of extreme events through satellite radar altimetry observations. Journal of Hydrology, 603, 126870. https://doi.org/10.1016/j.jhydrol.2021.126870
- Schneider, R., Tarpanelli, A., Nielsen, K., Madsen, H., & Bauer-Gottwein, P. (2018). Evaluation of multi-mode CryoSat-2 altimetry data over the Po River against in situ data and a hydrodynamic model. Advances in Water Resources, 112, 17–26. https://doi.org/10.1016/j.advwatres.2017.11.027