Estimating Daily Discharge Using SWOT Data

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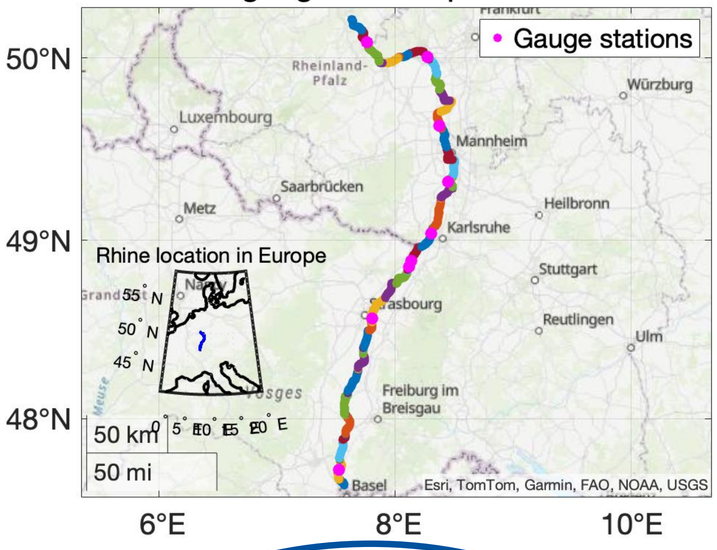
The SWOT satellite mission is the first to conduct a global survey of the Earth's surface waters, measuring water surface height, river width, and water surface slope, based on which river discharge is estimated. At mid-latitudes, the repeat orbit design of SWOT only allows a sampling of twice per repeat cycle, which is considered too low for most hydrological applications. To address the spatiotemporal limitations of SWOT, we develop a method that assimilates SWOT observations for daily discharge estimation across continuous reaches within a single-branch river network. We build a linear dynamic system that includes a process model based on a physically based spatiotemporal discharge correlation model and observation equations utilizing SWOT products. We solve this dynamic system using a Kalman filter, which is executed in the time domain to obtain daily discharge.

Building on the strong performance of the method with synthetic data, we apply this algorithm using SWOT measurements on the Rhine River, where we validate its performance by comparing the estimates against gauge discharge data. These efforts aim to unlock the potential of SWOT data for daily discharge estimation in diverse river networks globally.

The results indicate that the proposed method delivers reliable daily discharge estimates that are comparable to in-situ measurements. These findings underscore the potential of Kalman filter-based assimilation frameworks to overcome the limitations of SWOT's spatiotemporal sampling.

Test case: River Rhine

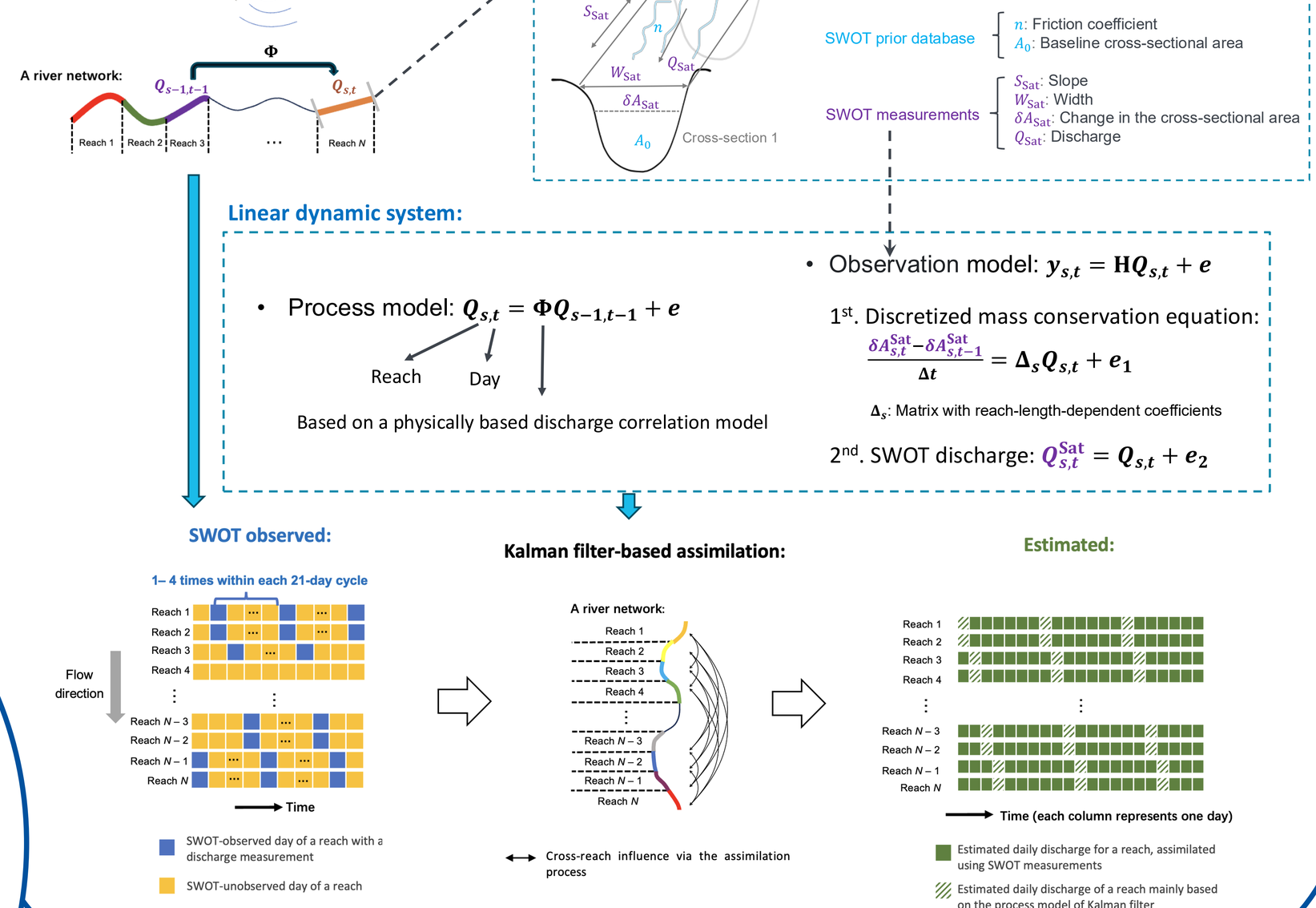
Reach and gauge station positions on Rhine



Data

- From SWOT
  - $\boldsymbol{Q_{Sat}}$: Three discharge products are on Rhine available: $\boldsymbol{Q_{SIC4DVar}}$, $\boldsymbol{Q_{MOMMA}}$ and $\boldsymbol{Q_{neoBAM}}$ (Version: SoS unconstrained v005 or constrained v002)
  - $\boldsymbol{\delta A_{Sat} = W_{SWORD}[H_{Sat} - median(H_{Sat})]}$
- From gauge station: $\boldsymbol{Q_{Gauge}}$ as reference
- Test time span: Jan-01-2024 to Nov-31-2024 during SWOT Science Orbit Phase

Methodology



Linear dynamic system:

- Process model: $\boldsymbol{Q_{s,t} = \Phi Q_{s-1,t-1} + e}$

  Reach, Day

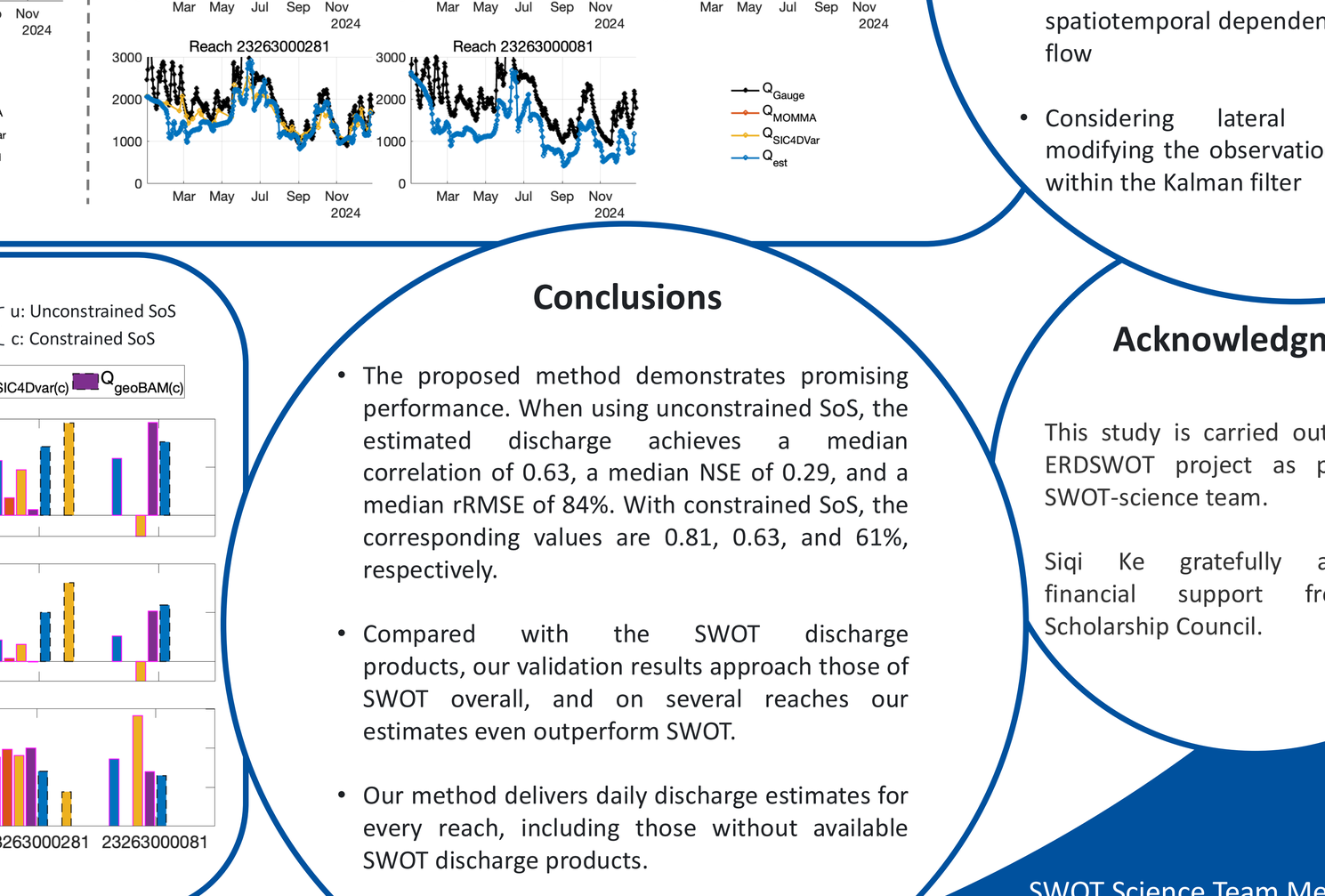
  Based on a physically based discharge correlation model

- Observation model: $\boldsymbol{y_{s,t} = HQ_{s,t} + e}$

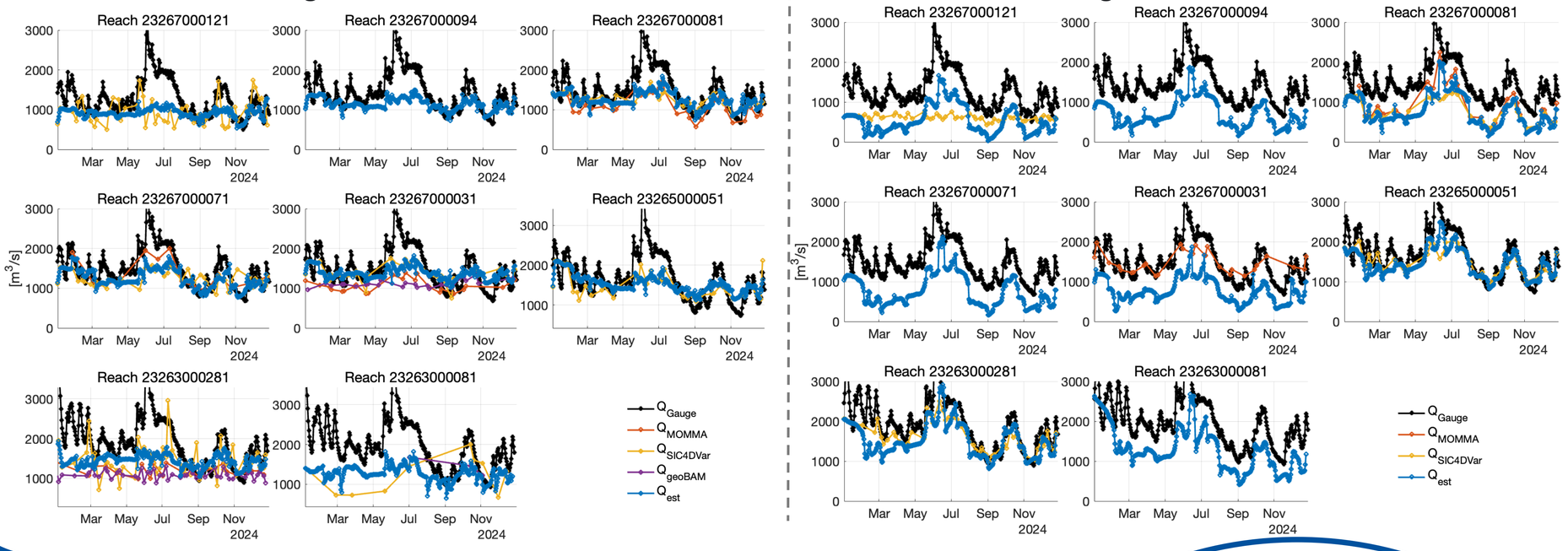
  1st. Discretized mass conservation equation: $\frac{\delta A_{s,t}^{Sat} - \delta A_{s,t-1}^{Sat}}{\Delta t} = \boldsymbol{\Delta_s Q_{s,t} + e_1}$

  $\boldsymbol{\Delta_s}$: Matrix with reach-length-dependent coefficients

  2nd. SWOT discharge: $\boldsymbol{Q_{s,t}^{Sat} = Q_{s,t} + e_2}$



Estimated discharge time series plot

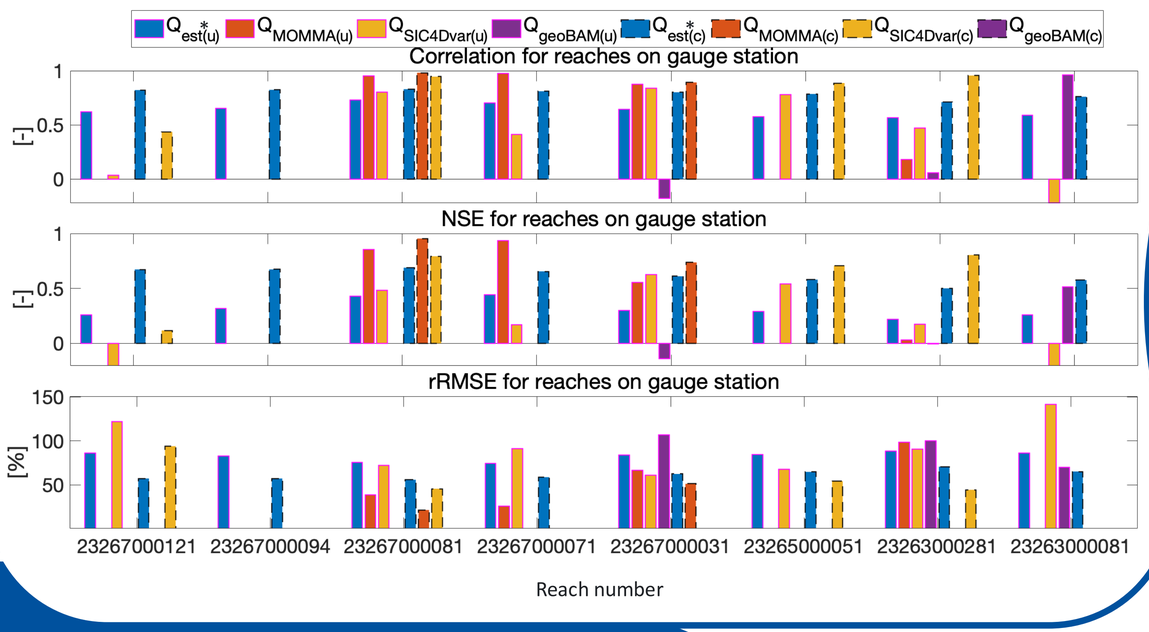


Outlook

- Applying the method globally with longer time series
- Benefiting from priors derived by machine-learning based models (ML prior)
- Considering tributaries by including the confluences on the spatiotemporal dependence of stream flow
- Considering lateral inflow by modifying the observation covariance within the Kalman filter

Validation

* u: Unconstrained SoS; c: Constrained SoS



Conclusions

- The proposed method demonstrates promising performance. When using unconstrained SoS, the estimated discharge achieves a median correlation of 0.63, a median NSE of 0.29, and a median rRMSE of 84%. With constrained SoS, the corresponding values are 0.81, 0.63, and 61%, respectively.
- Compared with the SWOT discharge products, our validation results approach those of SWOT overall, and on several reaches our estimates even outperform SWOT.
- Our method delivers daily discharge estimates for every reach, including those without available SWOT discharge products.

Acknowledgment

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