River discharge and bathymetry estimation from variational assimilation of SWOT altimetry observations

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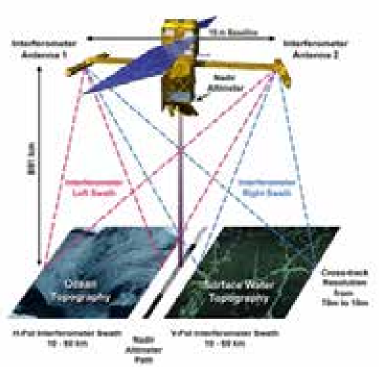
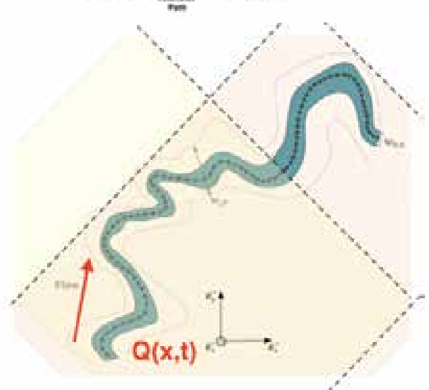
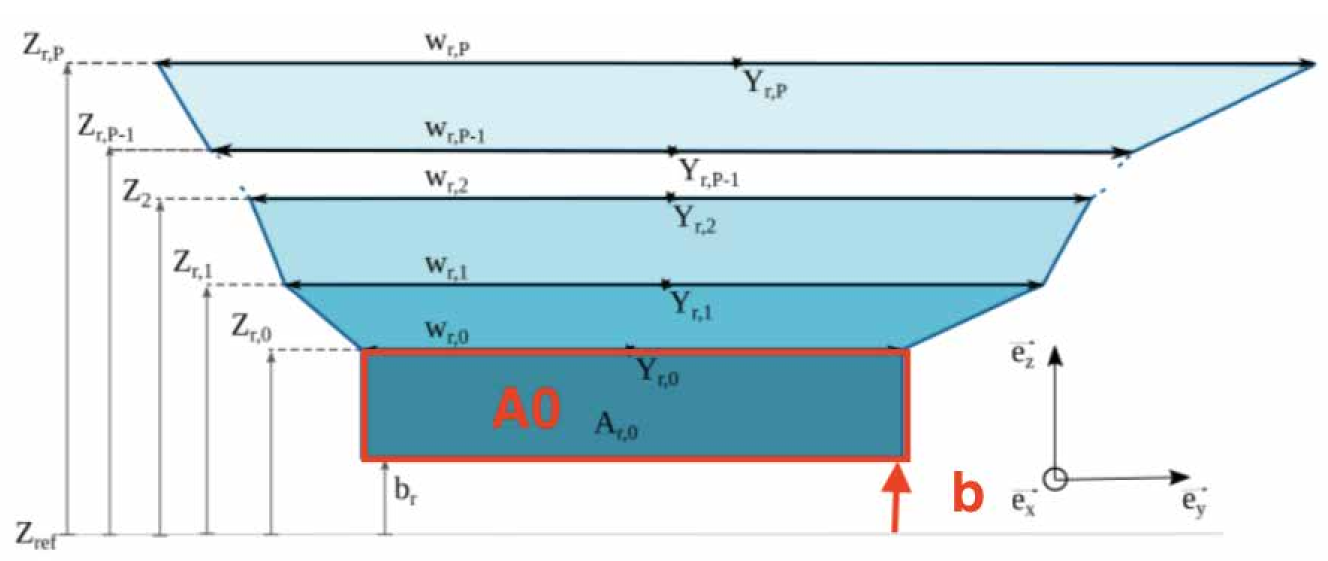
Methods

- Data and inverse problem
  - Data : SWOT-like measurements
    - Synthetic errors or Instrument Simulator error budget
    - ***Zr,p***, $\boldsymbol{W_{r,p}}$ at RiverObs node scale (~ 200m) (+ $\boldsymbol{S_{r,p}}$ at reach scale)
  - Inverse problem
    - Infer discharge $\boldsymbol{Q_{r,p}}$ as well as $\boldsymbol{A_{r,0}}$ and Strickler coefficient $\mathbf{K_r}(\boldsymbol{h})$







Methods

- Hierarchical modeling and optimization
  - 1D full Saint-Venant in (A,Q) variables - Preissmann or HLL scheme - Variaionnal Data Assimilation (VDA)
    - Unknowns :

      $$c = [(Q_{in,0},\ \ldots,\ Q_{in,P});\ (b_1,\ \ldots,\ b_R);\ (\alpha, \beta)]^T$$

    - Optimization problem :

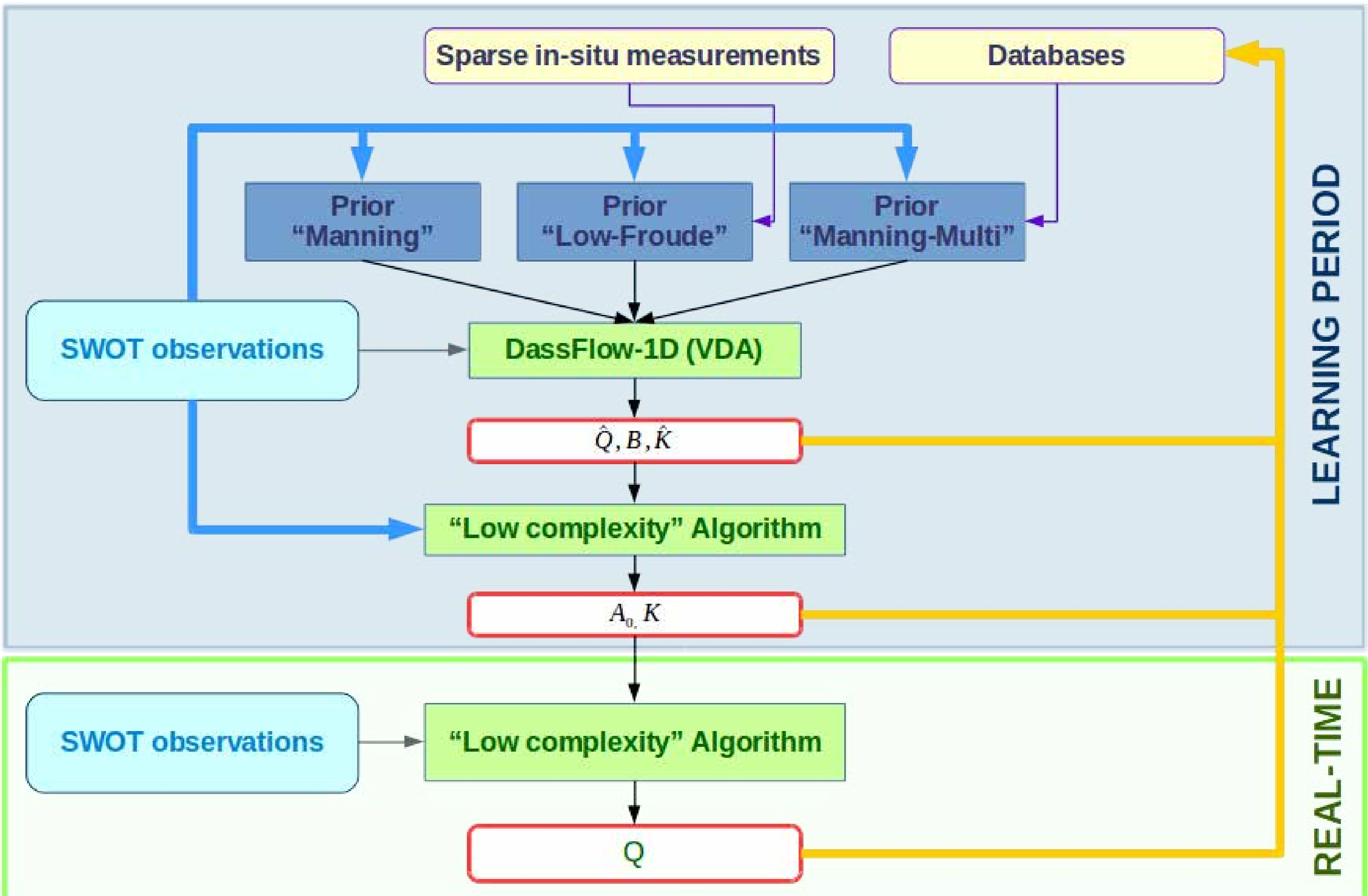
      $$min_c j(c) = \frac{1}{2} \|(Z(\mathrm{c}) - Z_{obs})\|_R^2 + \gamma\, j_{reg}(c)$$

    - Preconditioning using *a-priori* covariance operators.
  - *low-complexity* (0.5D) model - Low-Froude assumption

$$c_{r,p} \cdot K_{r,p}^{3/5} A_{r,0} + d_{r,p} \cdot K_{r,p}^{3/5} = Q_{r,p}^{3/5}, \quad \forall (r,p)$$

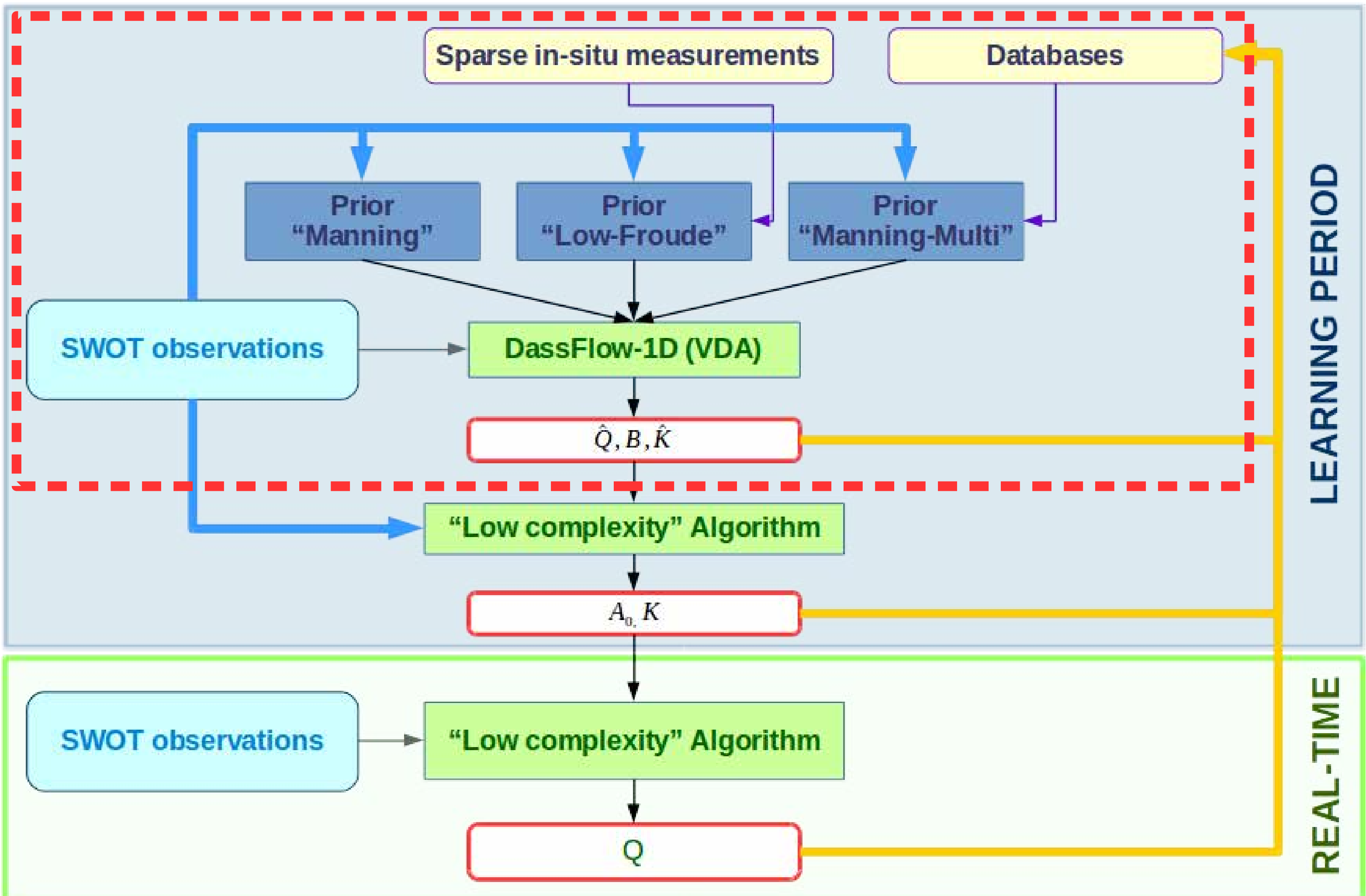
- Operational chain for estimations of discharge globally

Methods

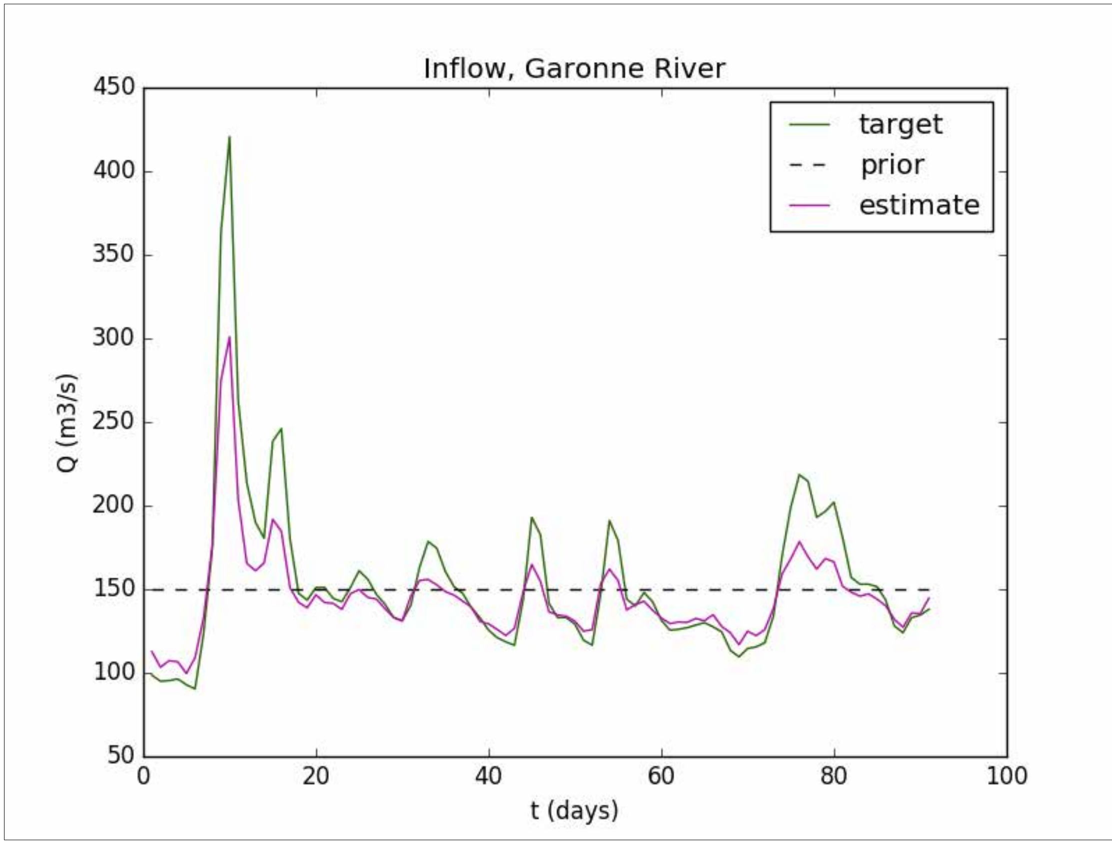


Sparse in-situ measurements
Databases
Prior "Manning"
Prior "Low-Froude"
Prior "Manning-Multi"
SWOT observations
DassFlow-1D (VDA)
$\hat{Q}, B, \hat{K}$
"Low complexity" Algorithm
A_0, K
SWOT observations
"Low complexity" Algorithm
Q
LEARNING PERIOD
REAL-TIME

Numerical Results (1)



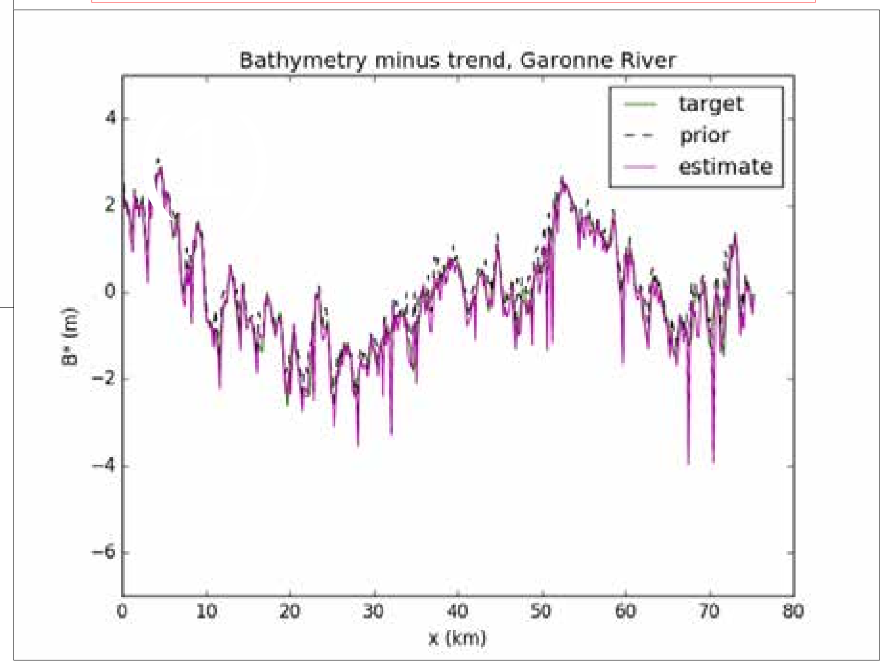
Numerical Results (1)



<u>Data and Setup</u>
<u>- time window : 90 days</u>
- length : 76 km

- RiverObs nodes (~200m)

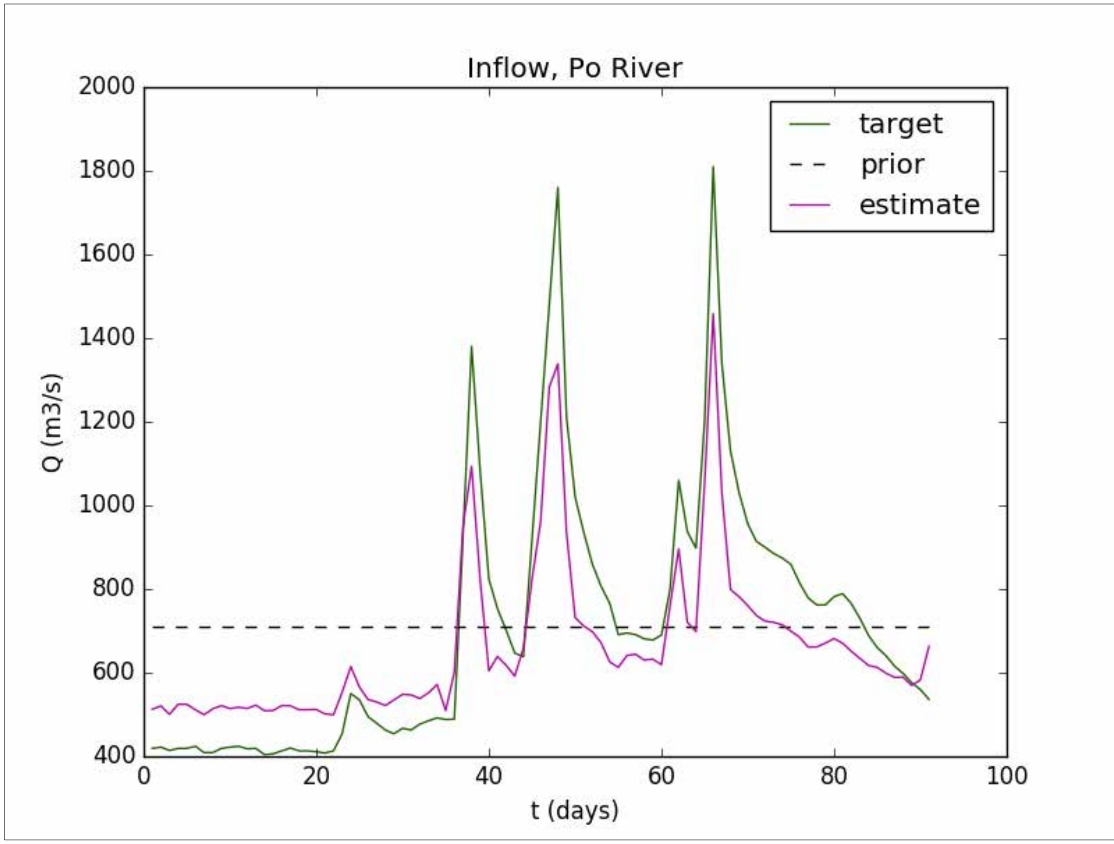
- **Twin-experiment**
  - Noise: $\mathcal{N}(0, 0.25^2)$
  - Observations : dt=1 day



	$rRMSE_B^{prior}$	$RMSE_Q$	$rRMSE_Q$	$rRMSE_B$
Manning	39 cm	22.1 m3/s	9.1 %	31 cm
Manning-Multi	42 cm	17.9 m3/s	8.5 %	22 cm
Low-Froude	35 cm	19.4 m3/s	9.1 %	27 cm

- Both priors perform well on this setup.

Numerical Results (1)



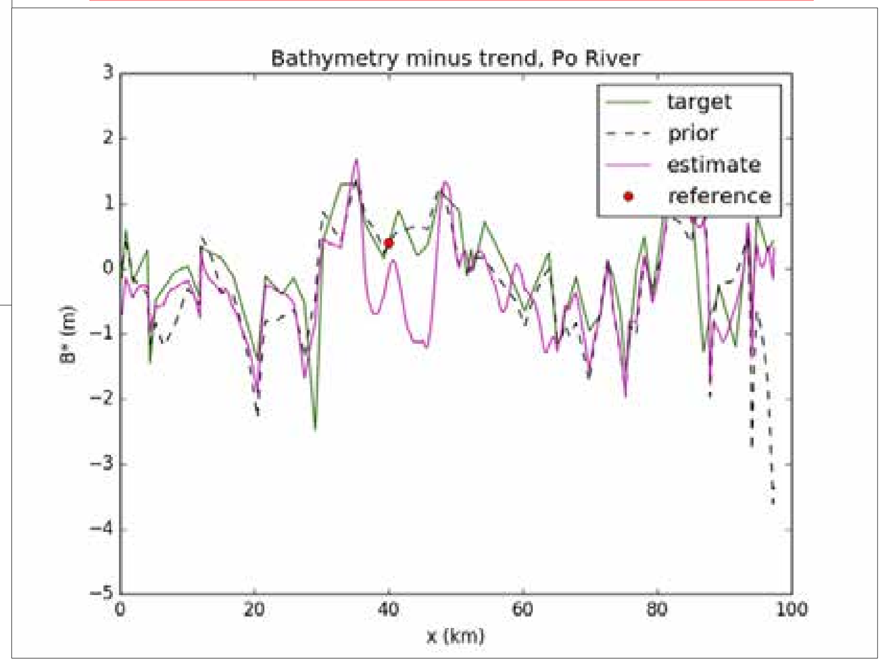
<u>Data and Setup</u>

- time window : 90 days
- length : 93 km

- RiverObs nodes (~200m)

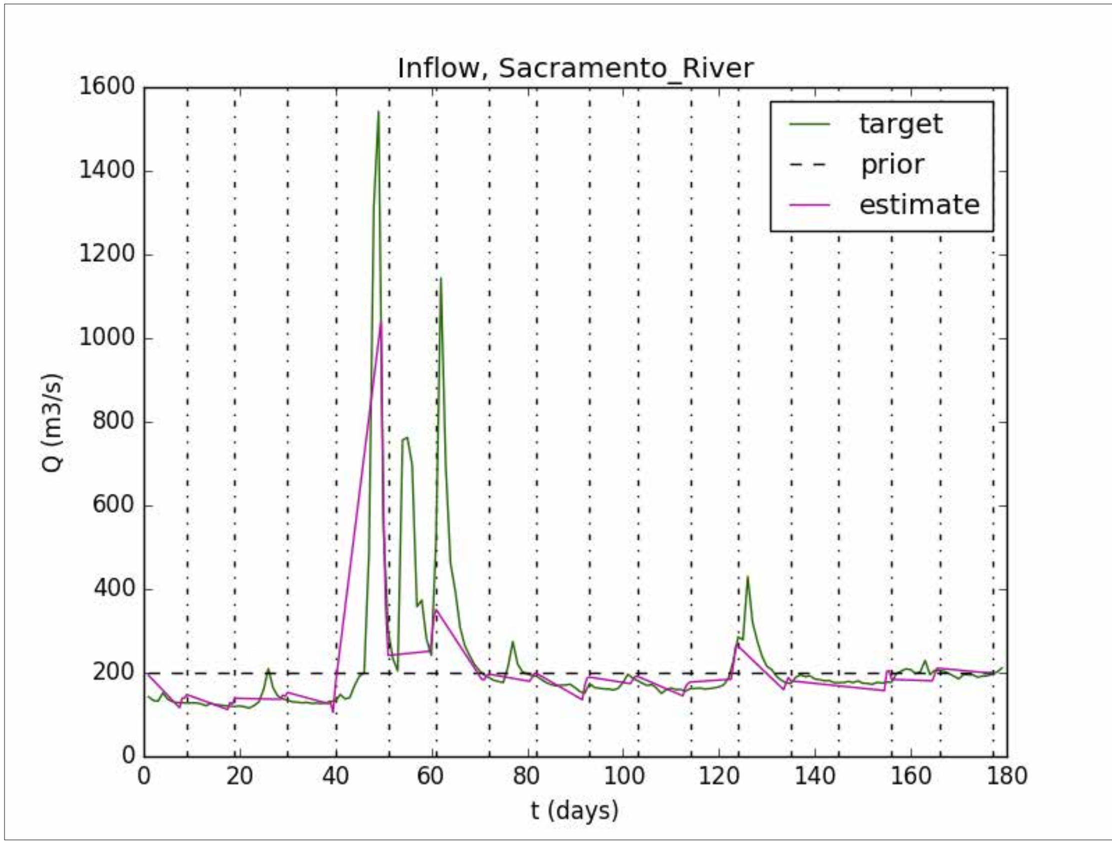
- **PEPSI 1 challenge**
    - Noise : $\mathcal{N}(0, 0.25^2)$
    - Observations : dt=1 day

	$rRMSE_B^{prior}$	$RMSE_Q$	$rRMSE_Q$	$rRMSE_B$
Manning	92 cm	215.2 m3/s	24.8 %	104 cm
Manning-Multi	83 cm	183.7 m3/s	24.3 %	107 cm
Low-Froude	64 cm	144.8 m3/s	18.3 %	60 cm



- Better accuracy with the Low-Froude prior.

Numerical Results (1)

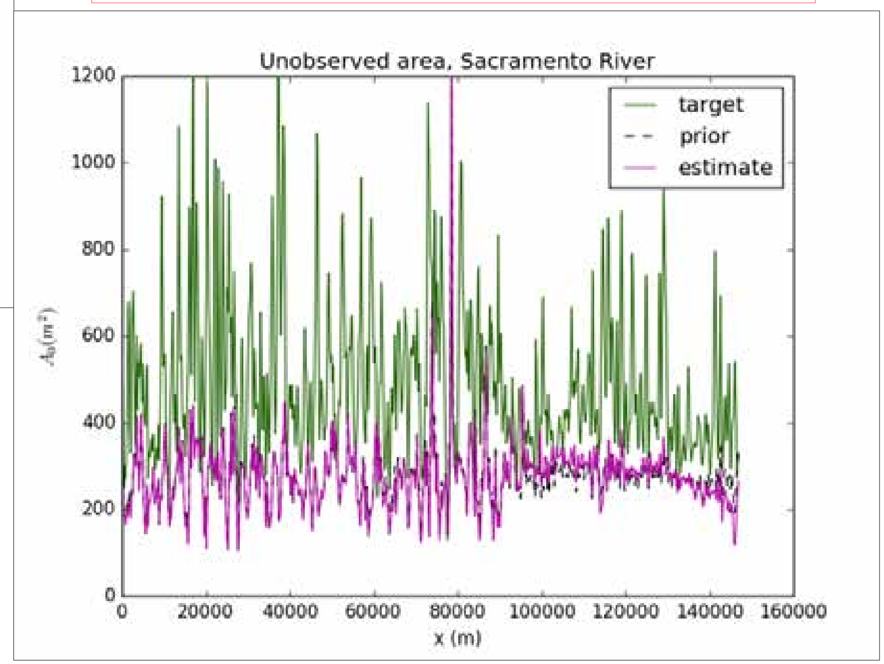


Data and Setup

- time window : 183 days
- length : 93 km

- RiverObs nodes (~200m)

- **SWOT Instrument simulator**
    - Noise: $\sigma_Z = 0.35m$
    - 2 passes per cycle



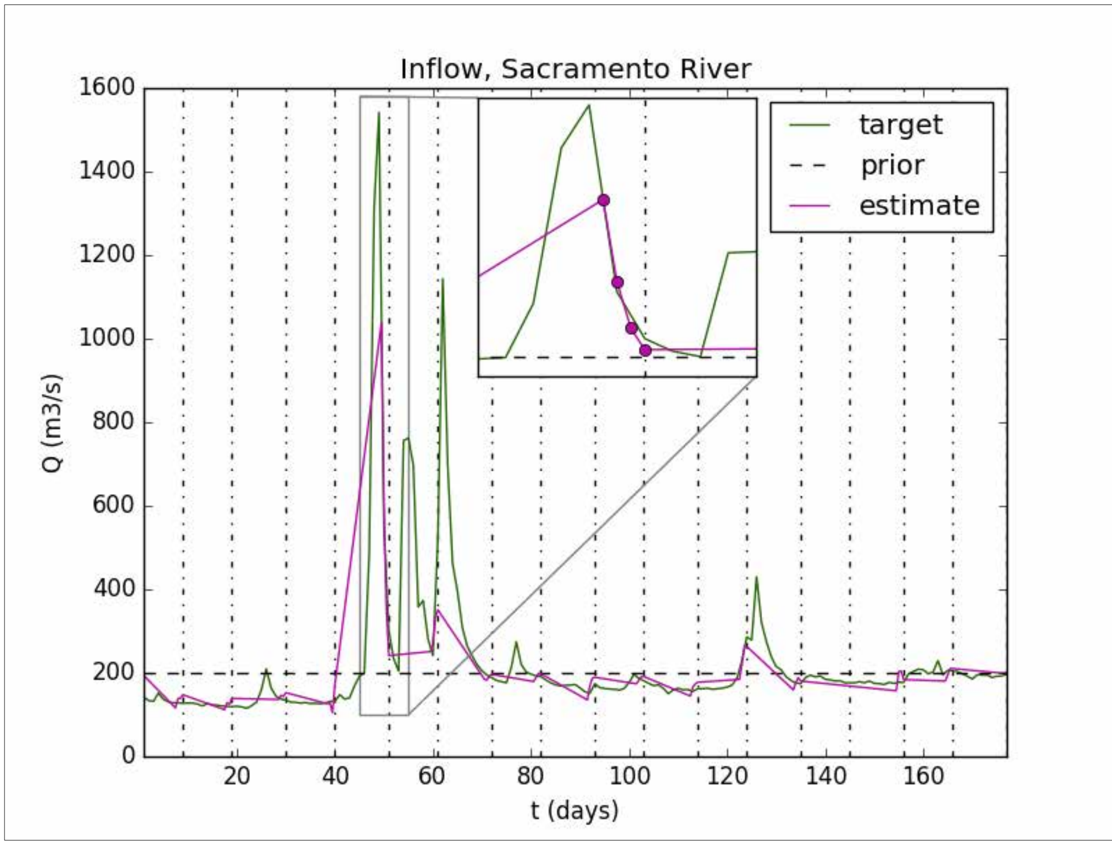
	$rRMSE_B^{prior}$	$RMSE_Q$	$rRMSE_Q$	$rRMSE_B$
Manning	245 cm	124.7 m3/s	19.3 %	249 cm
Low-Froude	184 cm	141.2 m3/s	20.2 %	182 cm

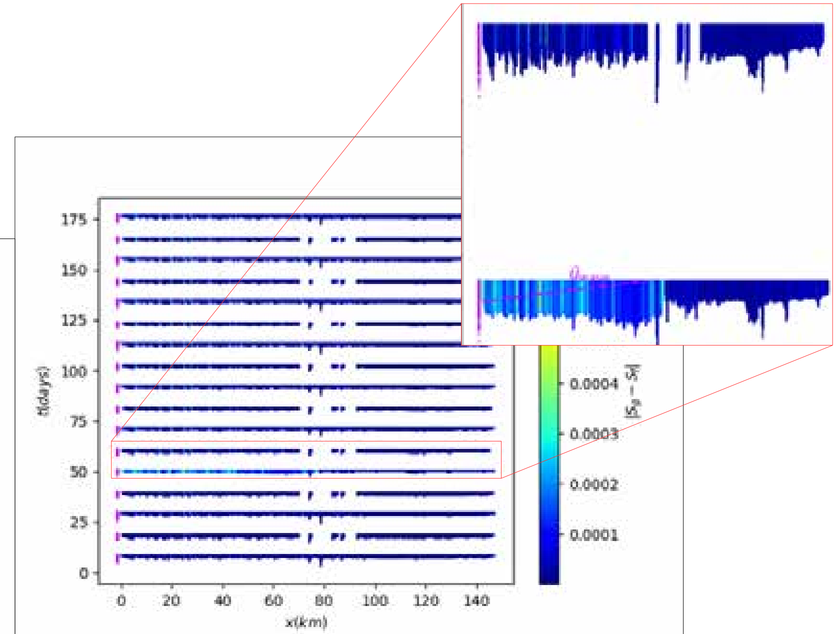
- Both priors perform well on this setup.

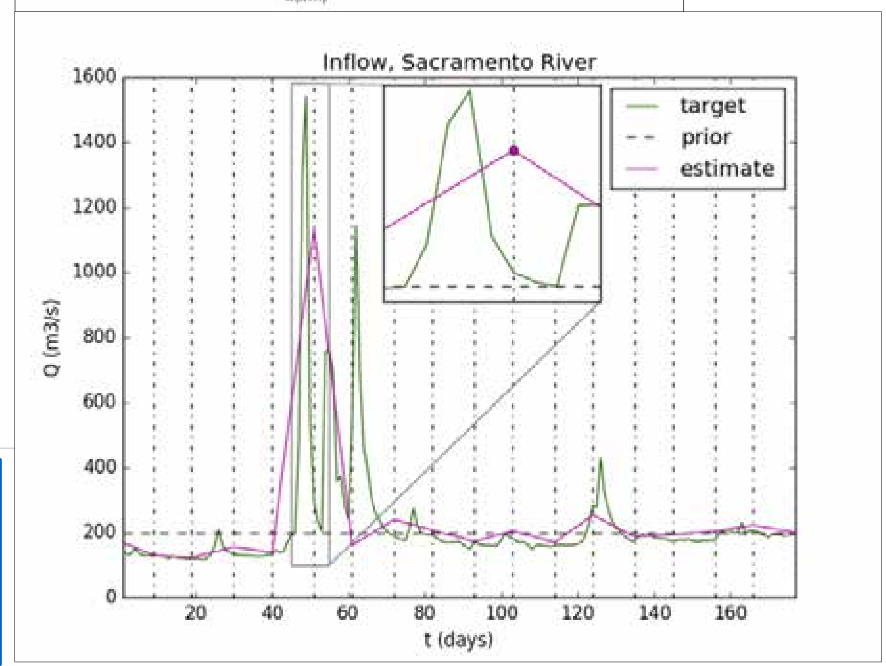
Numerical Results (1)

- Sacramento River (US)

Identifiability maps

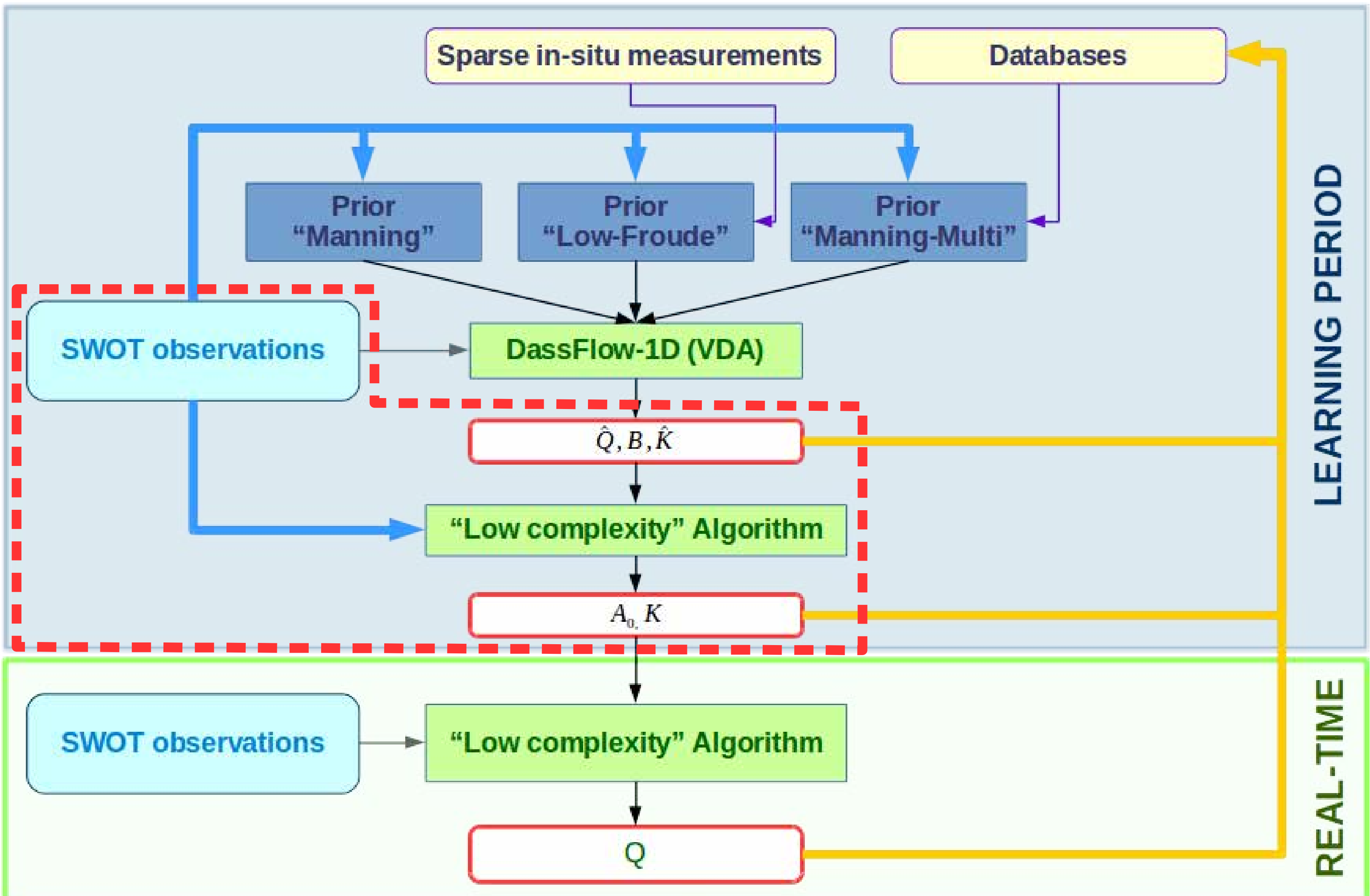






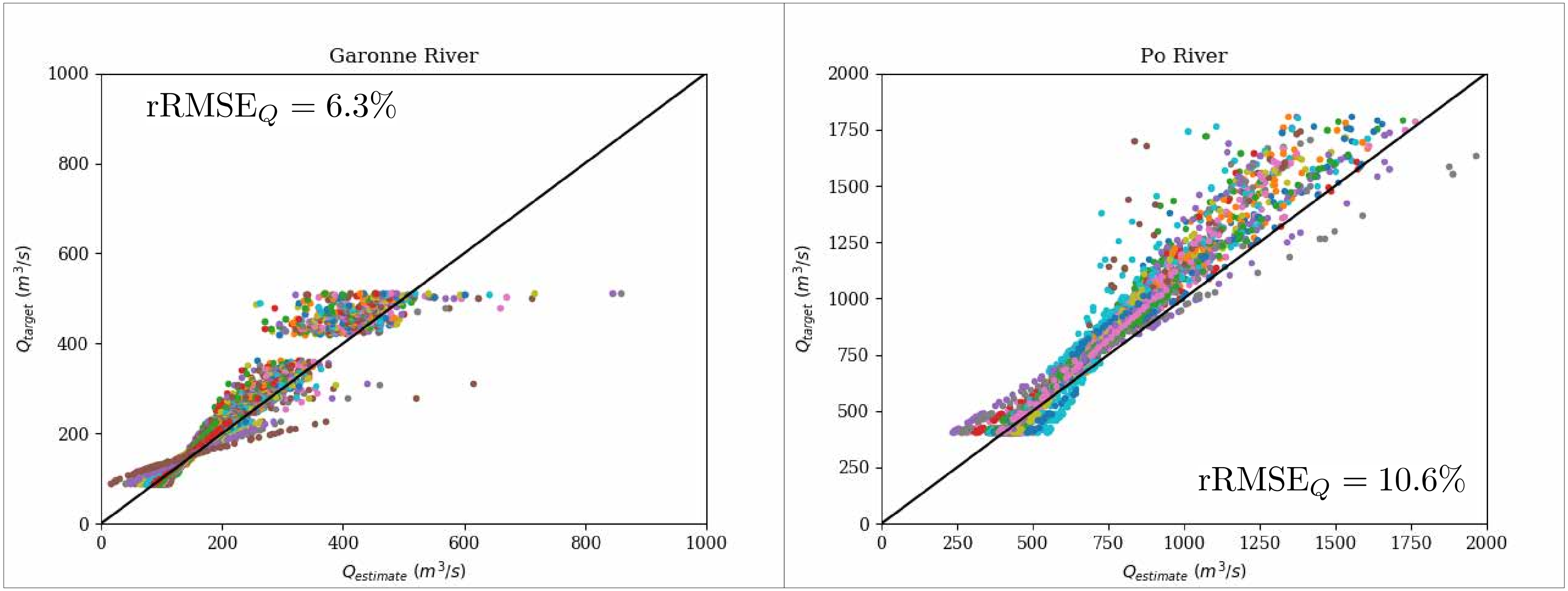
- Accuracy greatly improved with identifiability.
- Inference between overpasses.

Numerical Results (2)



Numerical Results (2)

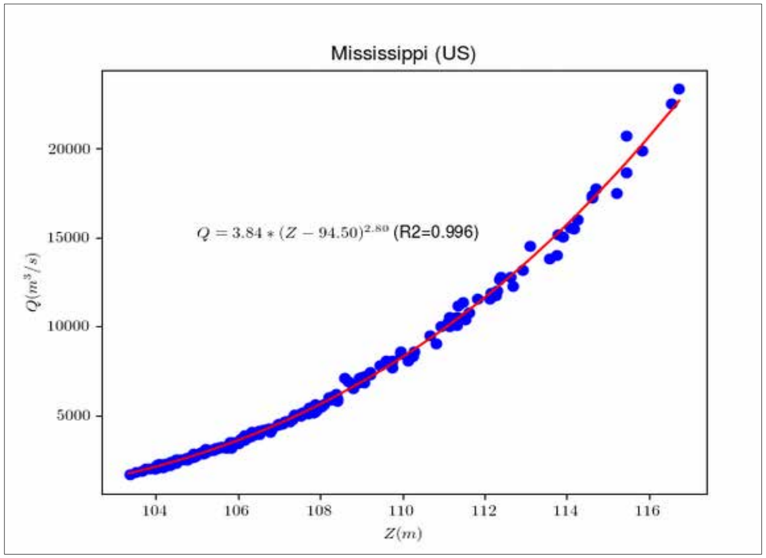
- Validation of the "low-complexity" model
  - Calibration using VDA results
  - Validation on remaining observations in datasets (9 months)



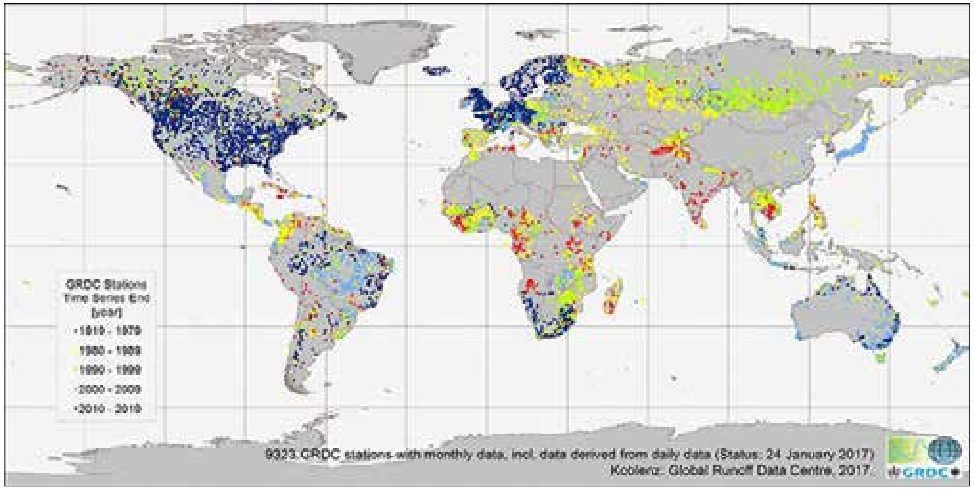
- Good accuracy of the inferred discharge values using complete chain.
- Low-complexity model is really fast (~5 microseconds / reach / pass).

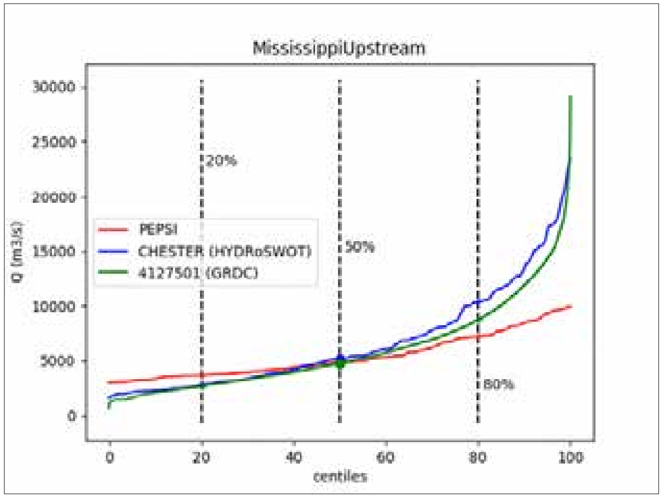
Towards global application

- Global/Local databases are available
  - HYDRoSWOT (**North America**)
    - Discharges and Stages
      - Rating curves
      - **Low-Froude** and **Manning-Multi** priors



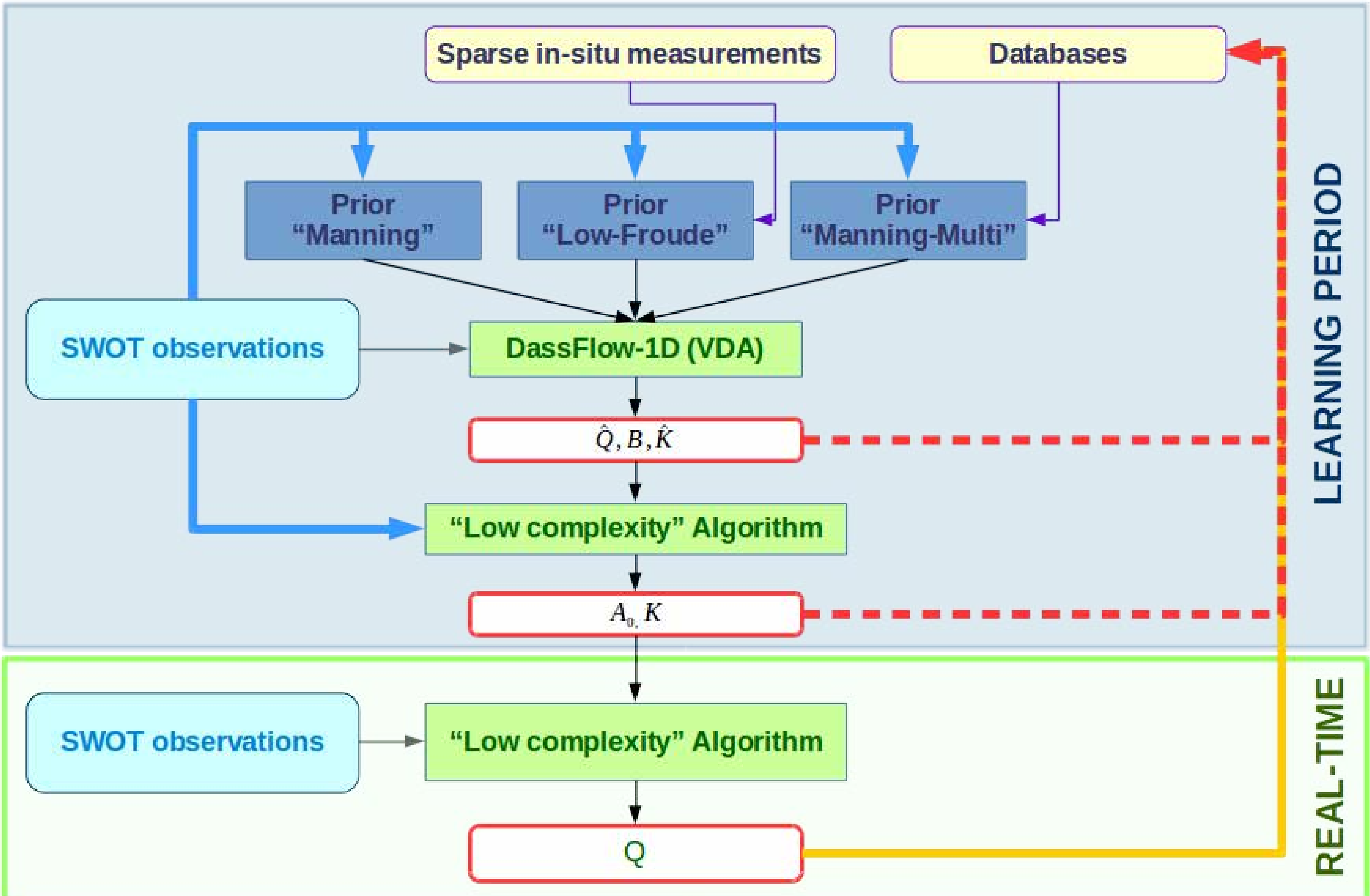
  - GRDC (**Global**)
    - Discharges only
      - Statistical rating curves
      - **Manning-Multi** priors





Towards global application

- Enrichment of the SWOT river database



- Infered A_0 and K for the low-complexity model can be applied to other models.
- Spatial interpolation/extrapolation using global databases.

Conclusion and perspectives

- Conclusion
  - Robust hierarchical 0.5D-1D modeling.
  - Accuracy improved using priors derived from the low-complexity (0.5D) model and ancillary databases.
  - Identifiability maps improve the accuracy and allow estimation of discharge between overpasses.
  - Real-time estimation is possible globally using the low-complexity model.
- Perspectives
  - Sensitivity to priors.
  - Global estimations of the parameters.
  - AirSWOT and in-situ data.

References

- K. Larnier, J. Monnier, P.-A. Garambois. "River discharge and bathymetry estimations from swot altimetry measurements". *Submitted*.

- P. Brisset, P.-A. Garambois, J. Monnier, H. Roux. "Identifiability and assimilation of sparse altimetry data in 1D Saint-Venant river models". *Accepted* in Advances in Water Ressources.

- P.-A. Garambois, J. Monnier. "Inference of effective river properties from remotely sensed observations of water surface". Advances in Water Ressources, 79, 103-120, 2015.