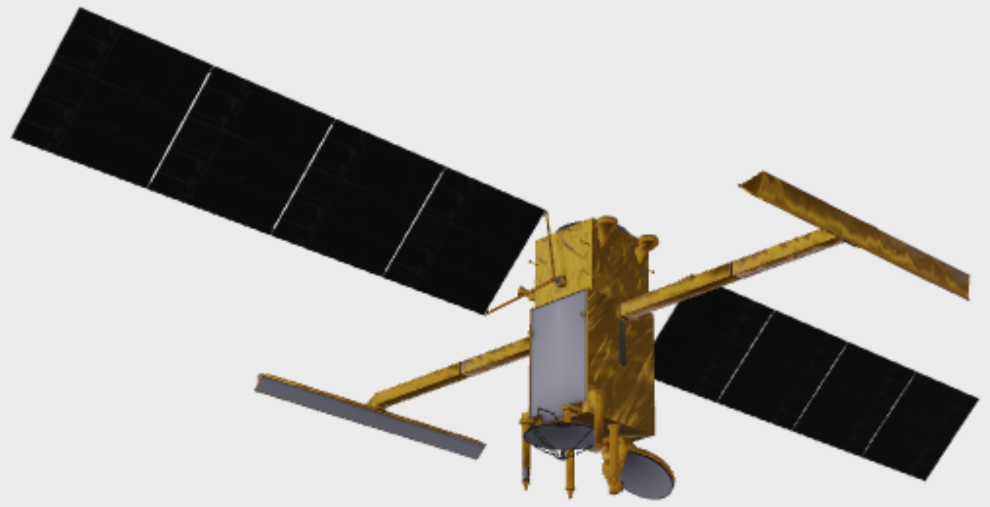
Discharge Algorithm Working Group Update

SWOT Science Team • September 15, 2021 • Zoom

Working Group Leads:
Michael Durand, Colin Gleason, Kevin Larnier, Pierre Olivier Malaterre

Olentangy River, Columbus, Ohio

Estimating discharge from SWOT



SWOT: A', W, S

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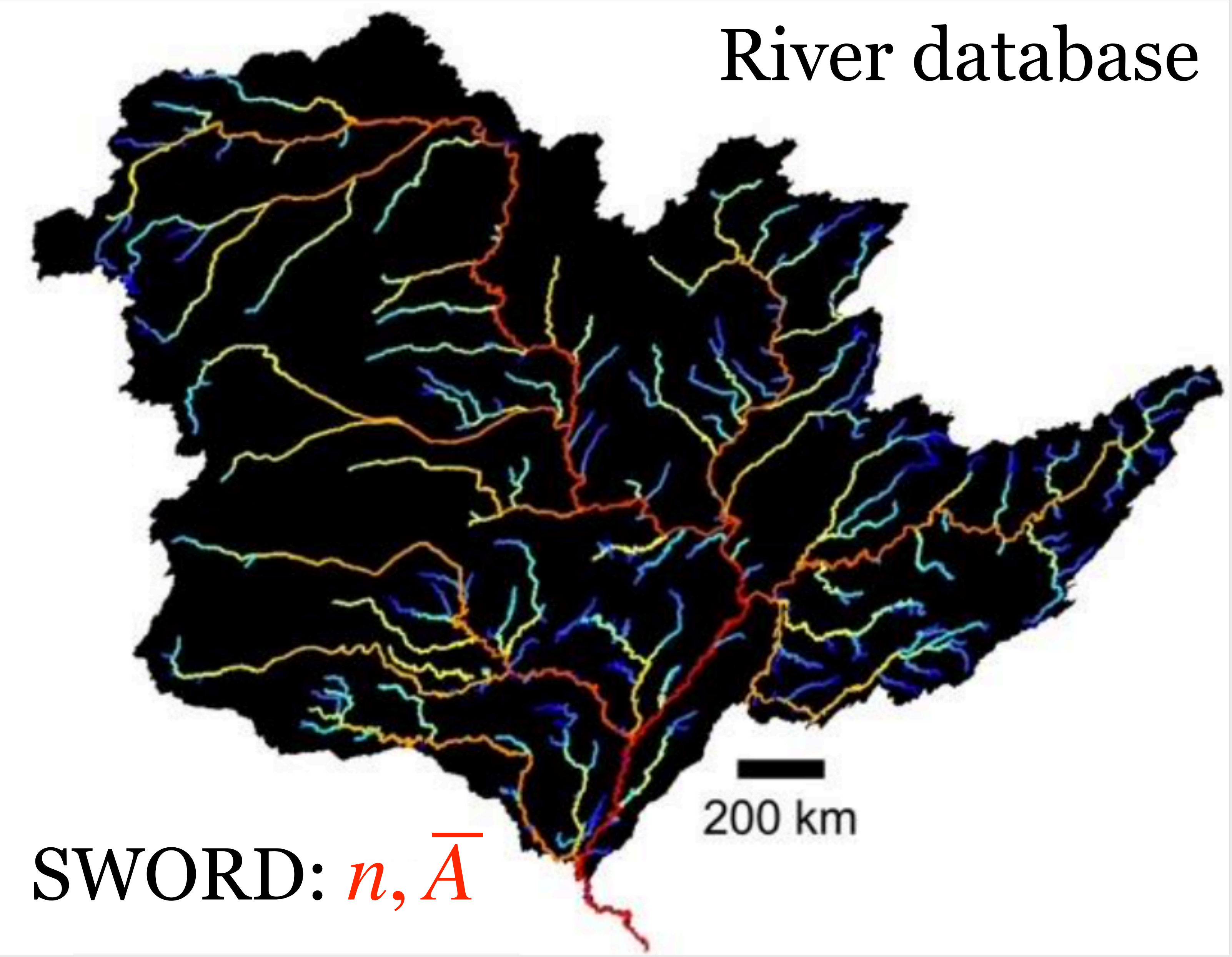

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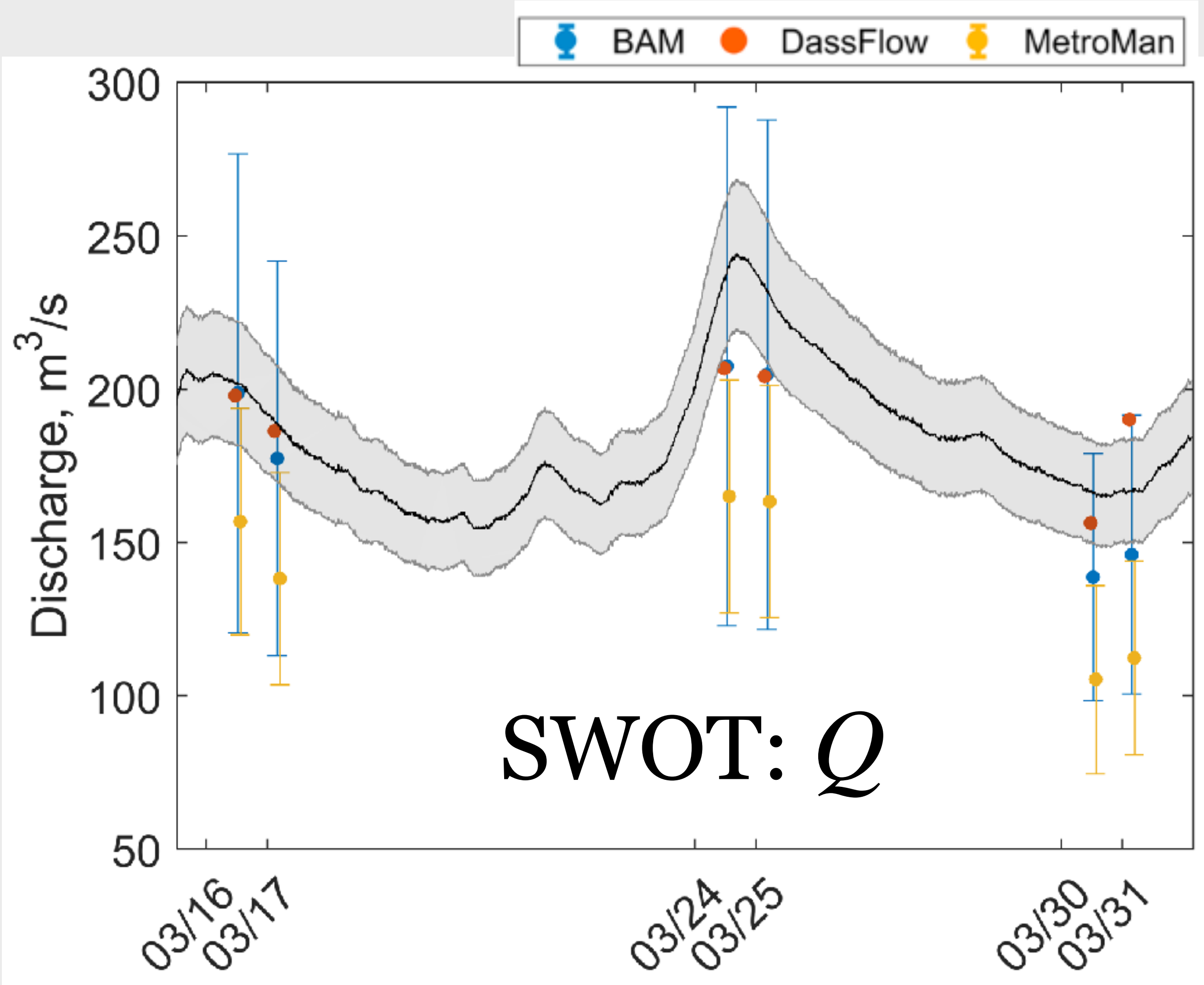

AirSWOT example: Tuozzolo et al. *GRL*, 2019

Paradigm: **observations** (A', W, S) from each SWOT overpass and **flow law parameters** (e.g. $n, \bar{A}$) stored in SWORD give discharge using e.g.:

$$Q = \frac{1}{n}\left(\bar{A}+A'\right)^{5/3} W^{-2/3} S^{1/2}$$

note: current parameterizations let n vary in time

Flow Law Parameter Estimation (FLPE) enables SWOT Discharge

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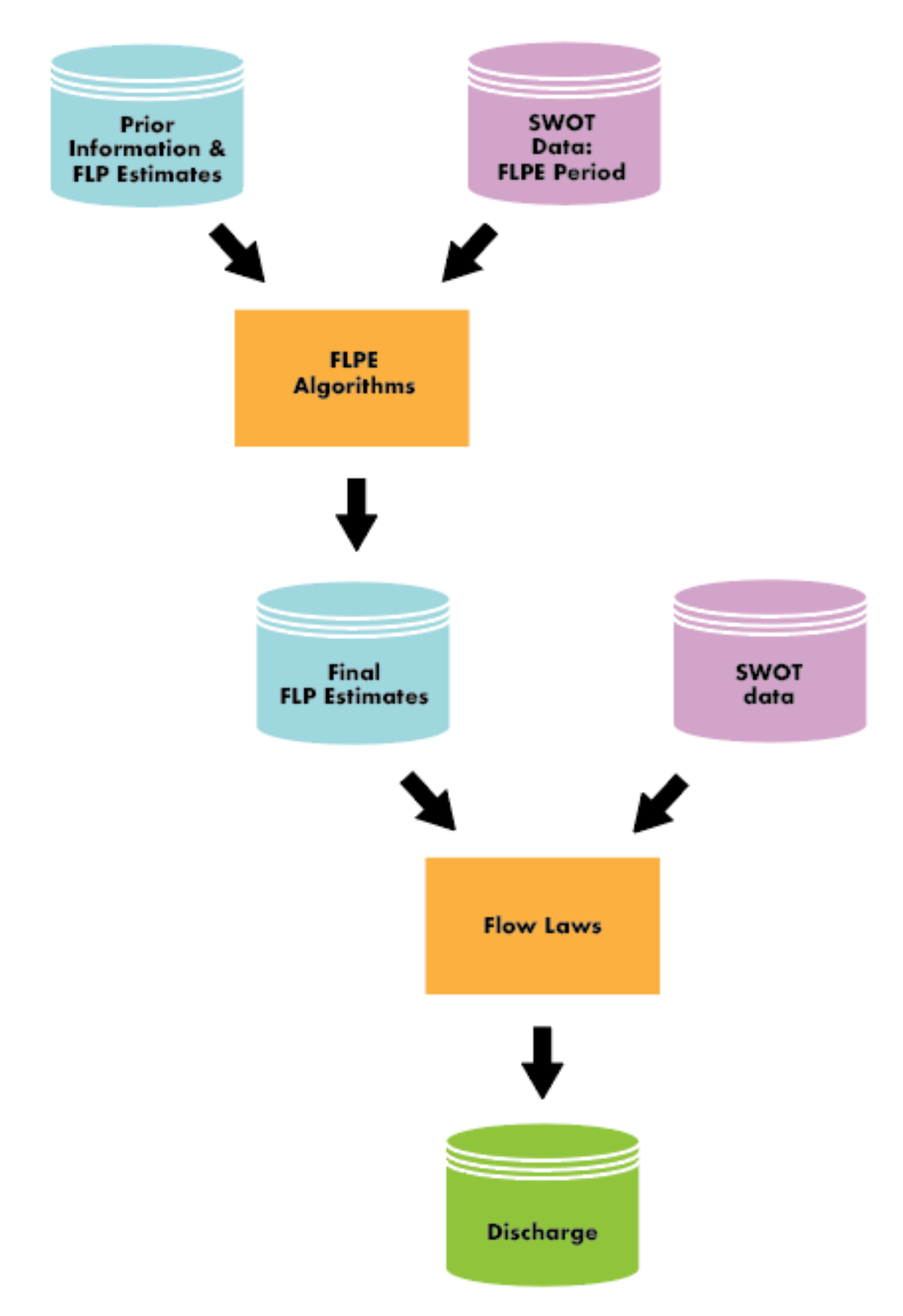

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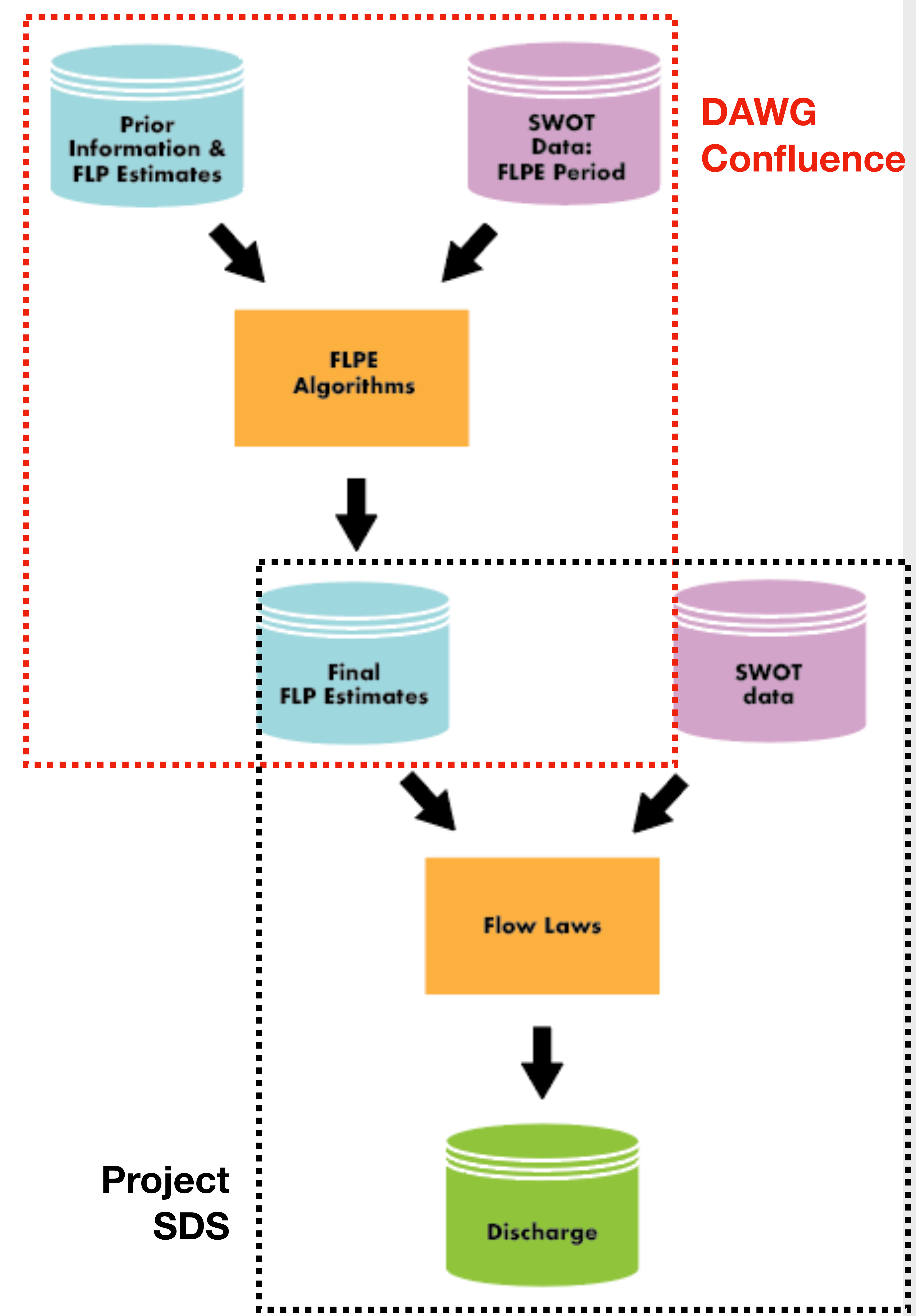
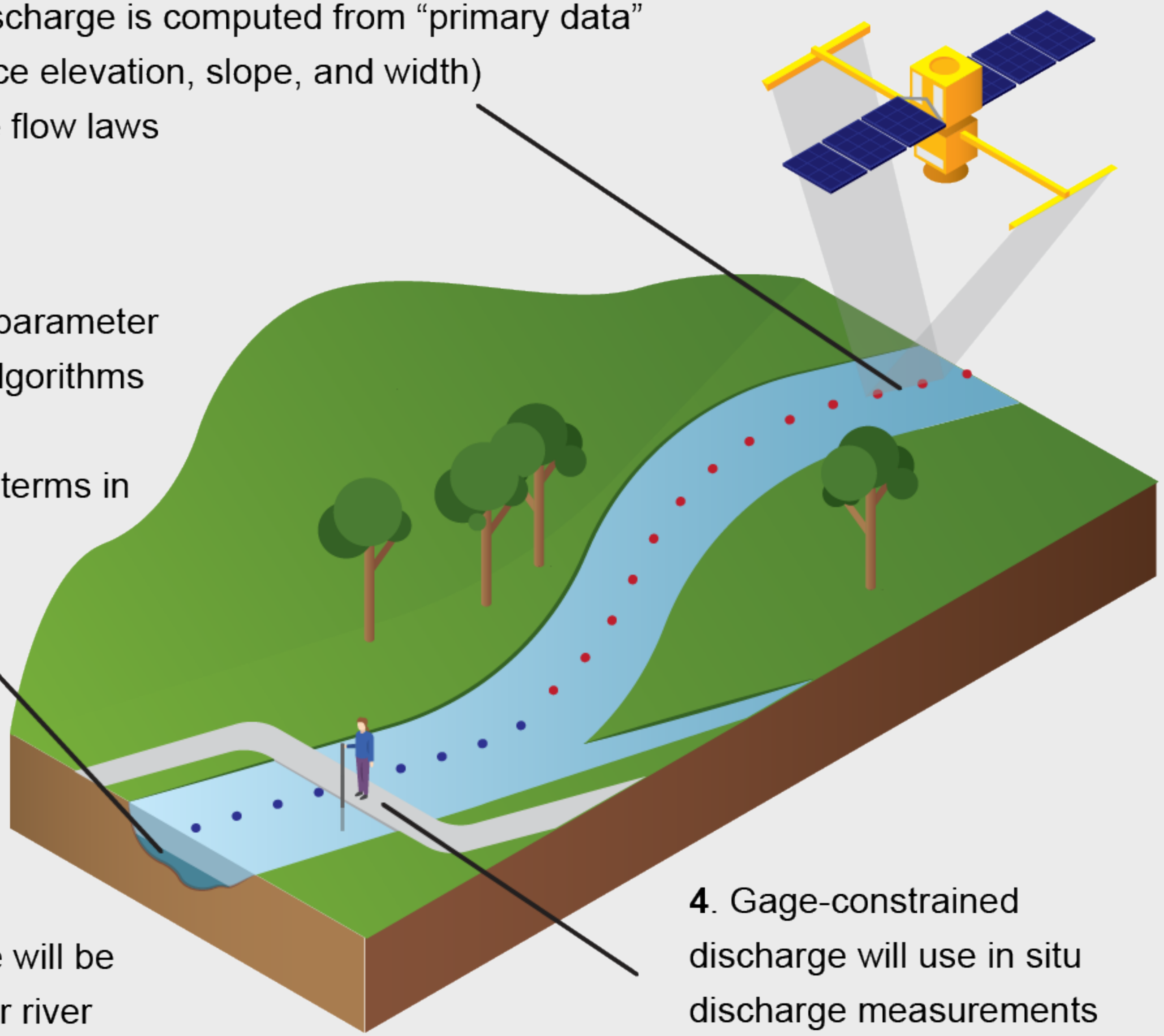


SWOT Discharge Philosophy

1. SWOT discharge is computed from "primary data" (water surface elevation, slope, and width) using simple flow laws

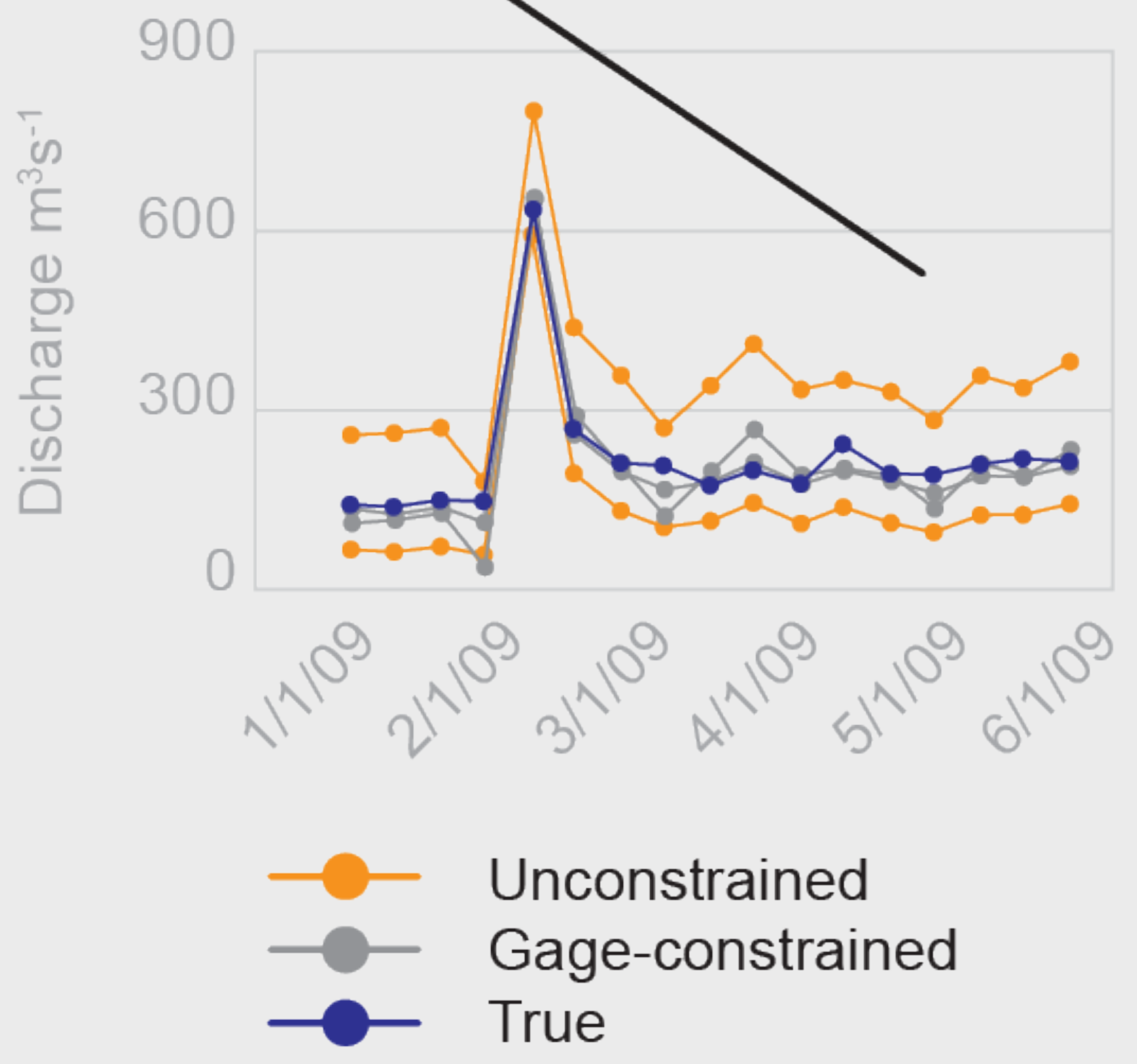
2. Flow law parameter estimation algorithms will estimate unobserved terms in flow laws.



3. Discharge will be computed for river reaches approximately 10 km in length.

4. Gage-constrained discharge will use in situ discharge measurements to constrain flow law parameters

5. An ensemble of discharge estimates is computed for each reach, and for both the constrained and unconstrained branches



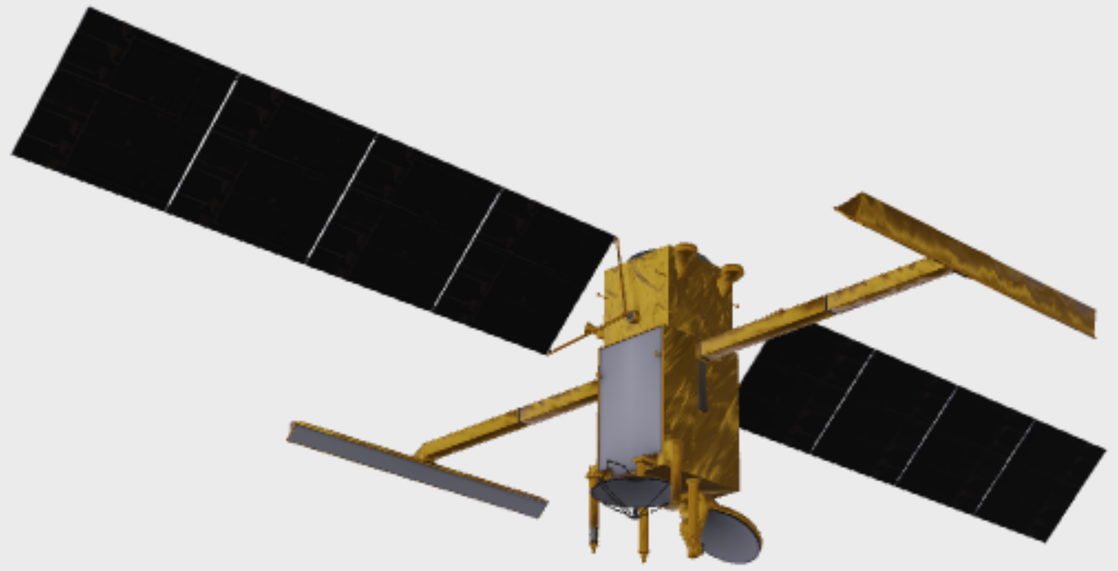
Flow Law Parameter Estimation is key to SWOT discharge accuracy

Findings: SWOT discharge accuracy is governed by parameter error which manifests as timeseries bias. FLPE parameter accuracy is highly sensitive to prior accuracy.

Goal: Maximize scientific impact of SWOT discharge, through rapid adoption of SWOT discharge by hydrologic community.

Strategy: Optimize FLPE accuracy by leveraging prior information and algorithm advances in a common computational framework (Confluence).

Two branches of SWOT discharge data products



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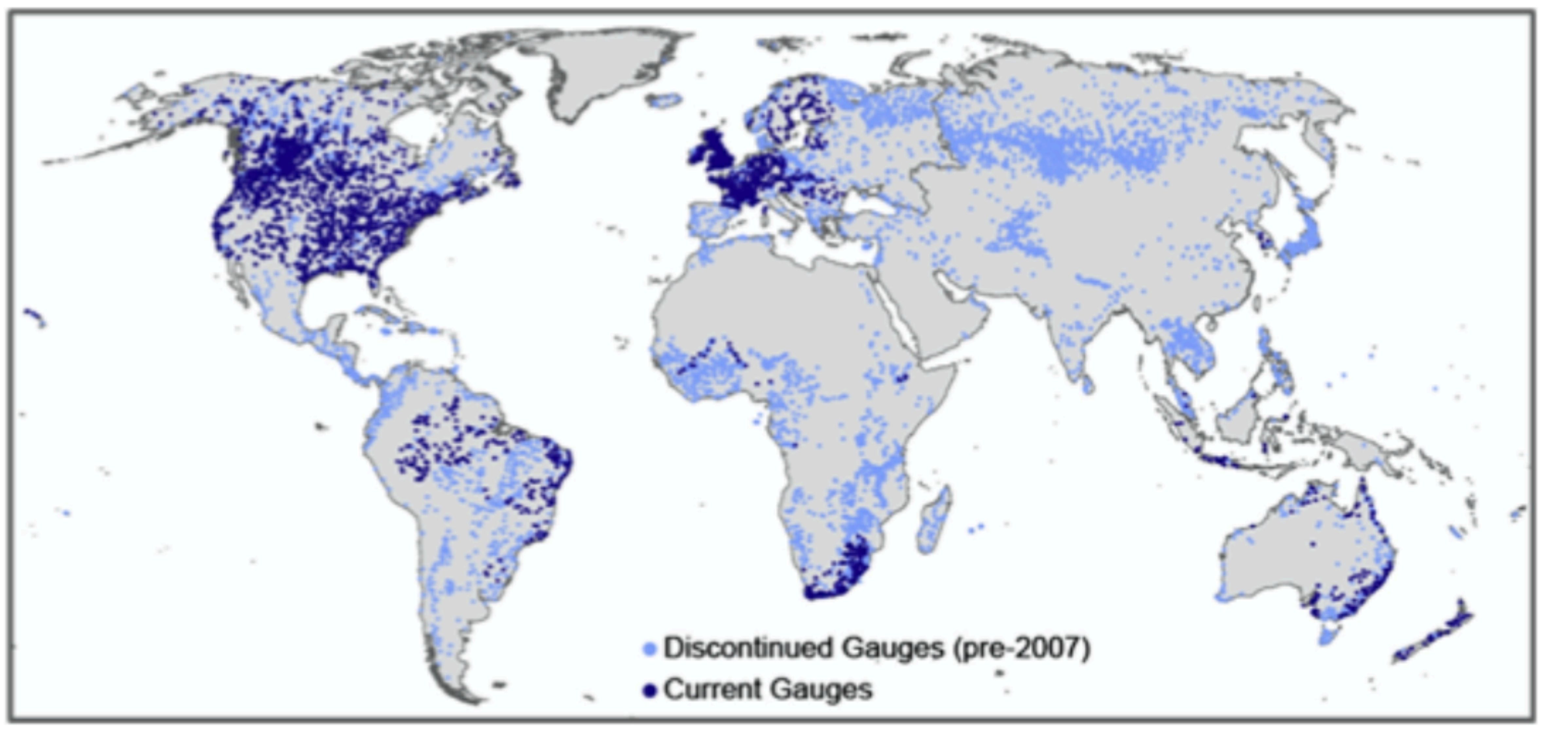


GRDC gages: via Pavelsky et al. 2014

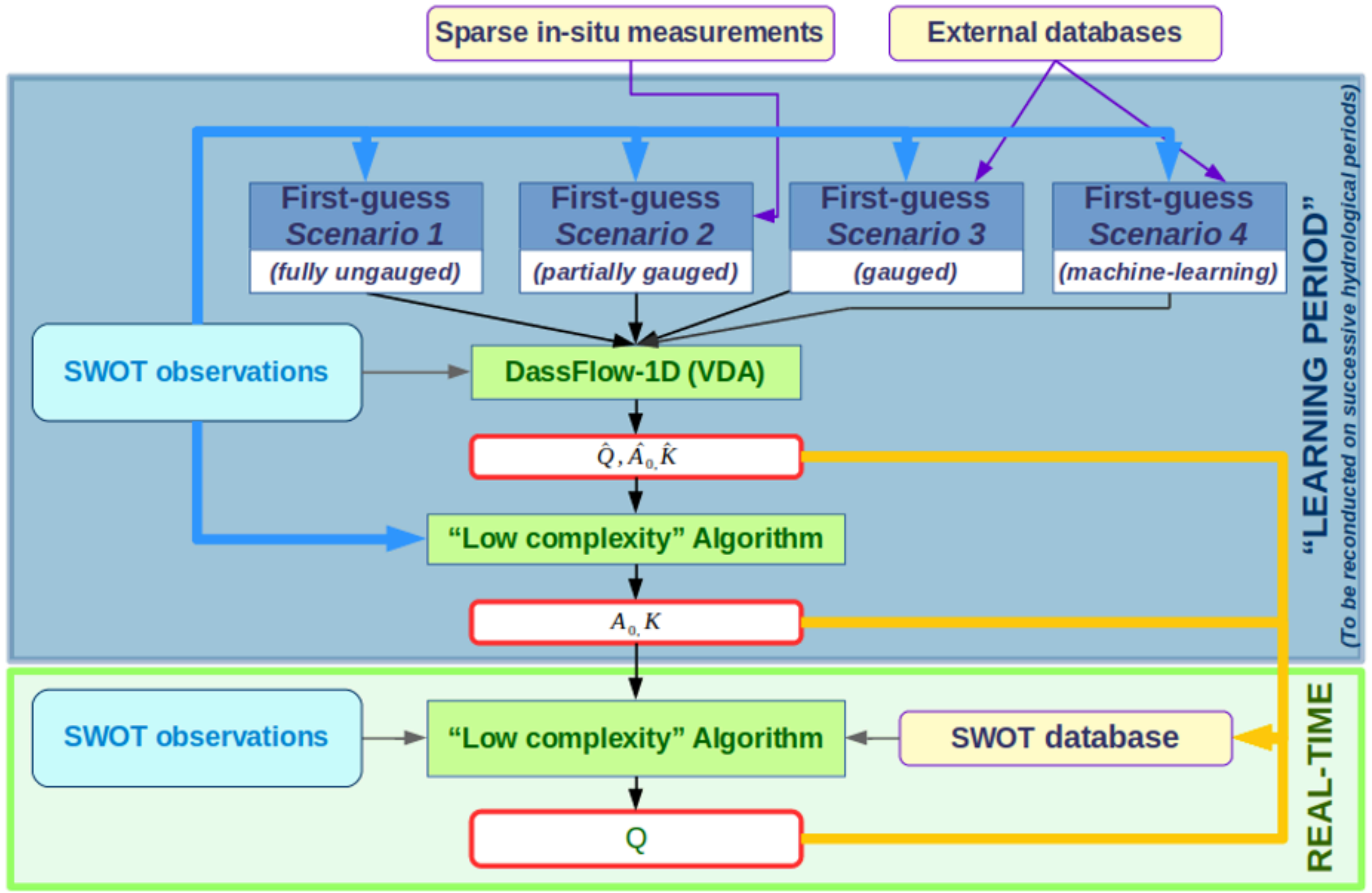
1. Unconstrained: DOES NOT USE stream gage data to constrain SWOT discharge
2. Gage-constrained: USES stream gage data to constrain SWOT discharge (while reserving enough gage measurements for independent validation)

DAWG Research Highlights

1. H2iVDI: K Larnier and J Monnier
2. Tides and estuarine discharge: Pascal Matte
3. Mapping discharge datasets onto SWORD: Steve Coss and Mike Durand, Ohio State
4. Developing width-based rating curves at GRDC gauges to be used with SWOT: Ryan Riggs, George Allen, Colin Gleason, Mike Durand, Tamlin Pavelsky, Jida Wang, Cedric David
5. LakeFlow: Ryan Riggs, Jida Wang (PI), George H. Allen (Co-PI), Safat Sikder, Michael T. Durand, Colin J. Gleason, and Tamlin Pavelsky
6. Estimation of River Discharges from SWOT Observations using Data Assimilation and Hydraulic Models: Sophie Ricci
7. Improving SWOT Discharge Uncertainty Estimates: Renato Frasson, Mike Turmon, Cedric David, Mike Durand
8. Confluence: Bringing everything together (*see Colin Gleason and Nikki Tebaldi presentation later today*)

H2iVDI (*Hybrid Hierarchical Variational Discharge Inference*)

By K. Larnier & J. Monnier (Toulouse, France)



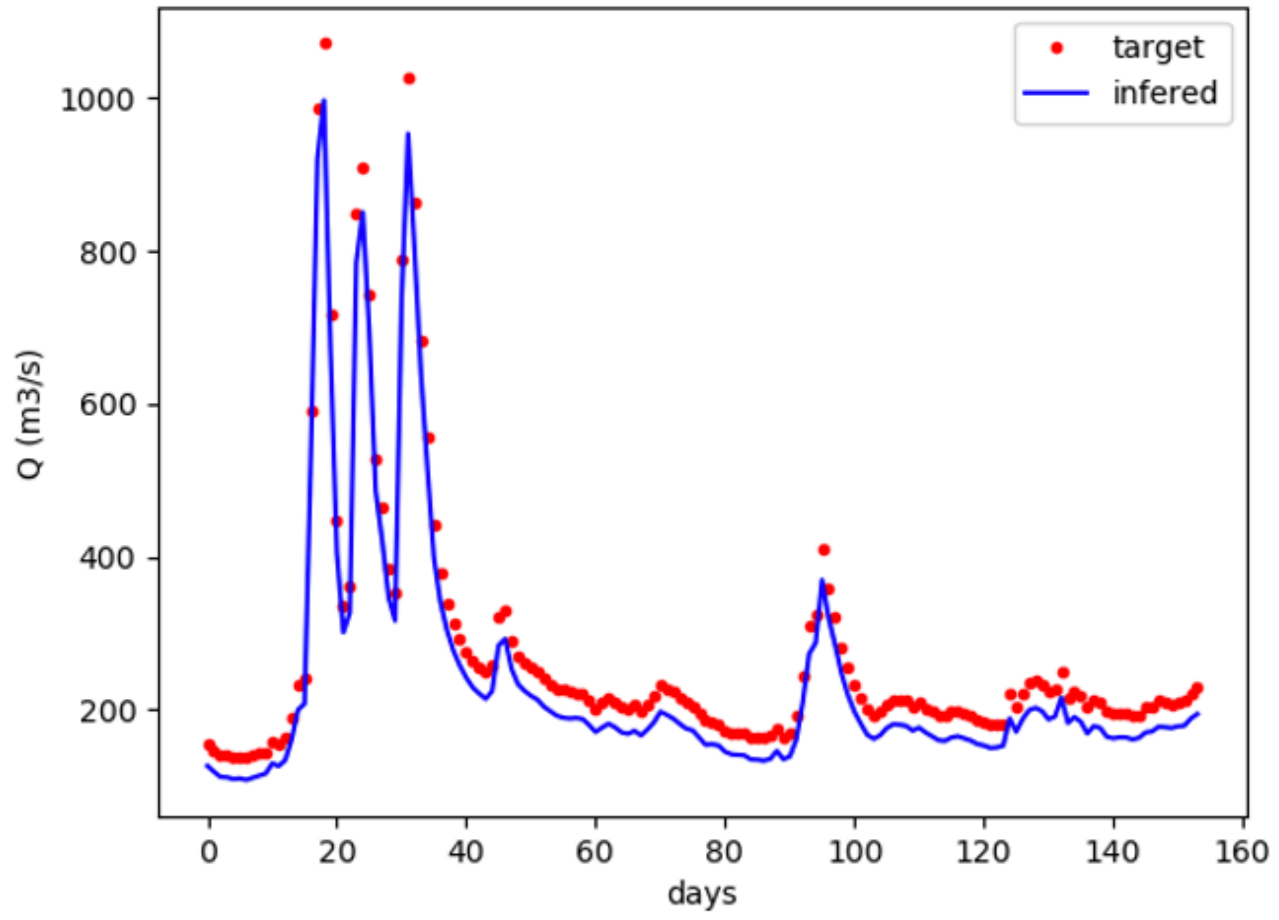
The inference of **(Q, K, A_0)** with **only SWOT observations** is a-priori ill-posed.

H2VIDI strategy : hierarchy of models + ML

Ingredients:

- Deep Learning
- 1D Saint-Venant (DassFlow) + VDA
- 0.5D Low-Froude system + Bayesian method

No discharge prior is needed



Downstream Sacramento

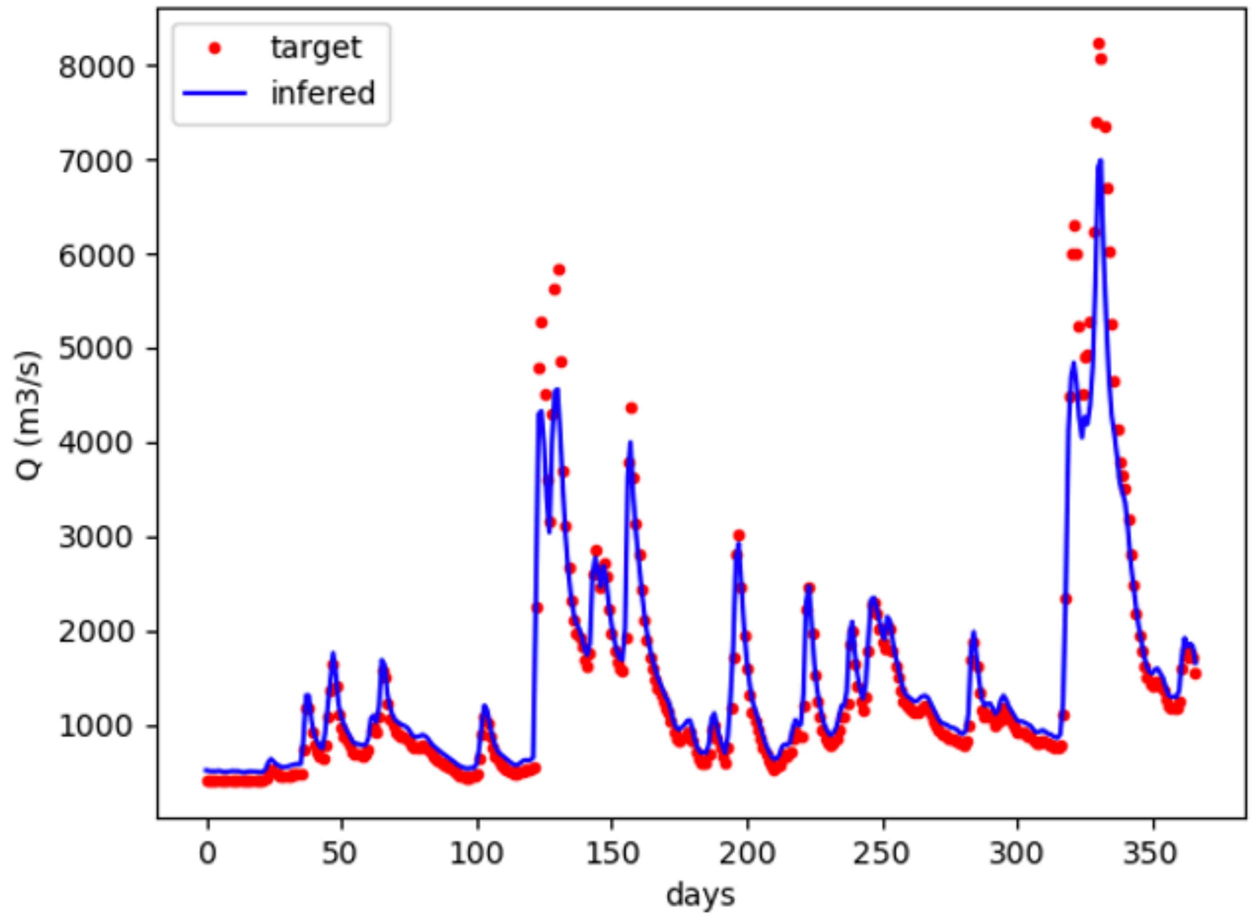
nRMSE = 13.9%

NSE = 0.95

Po River

nRMSE=22.8%

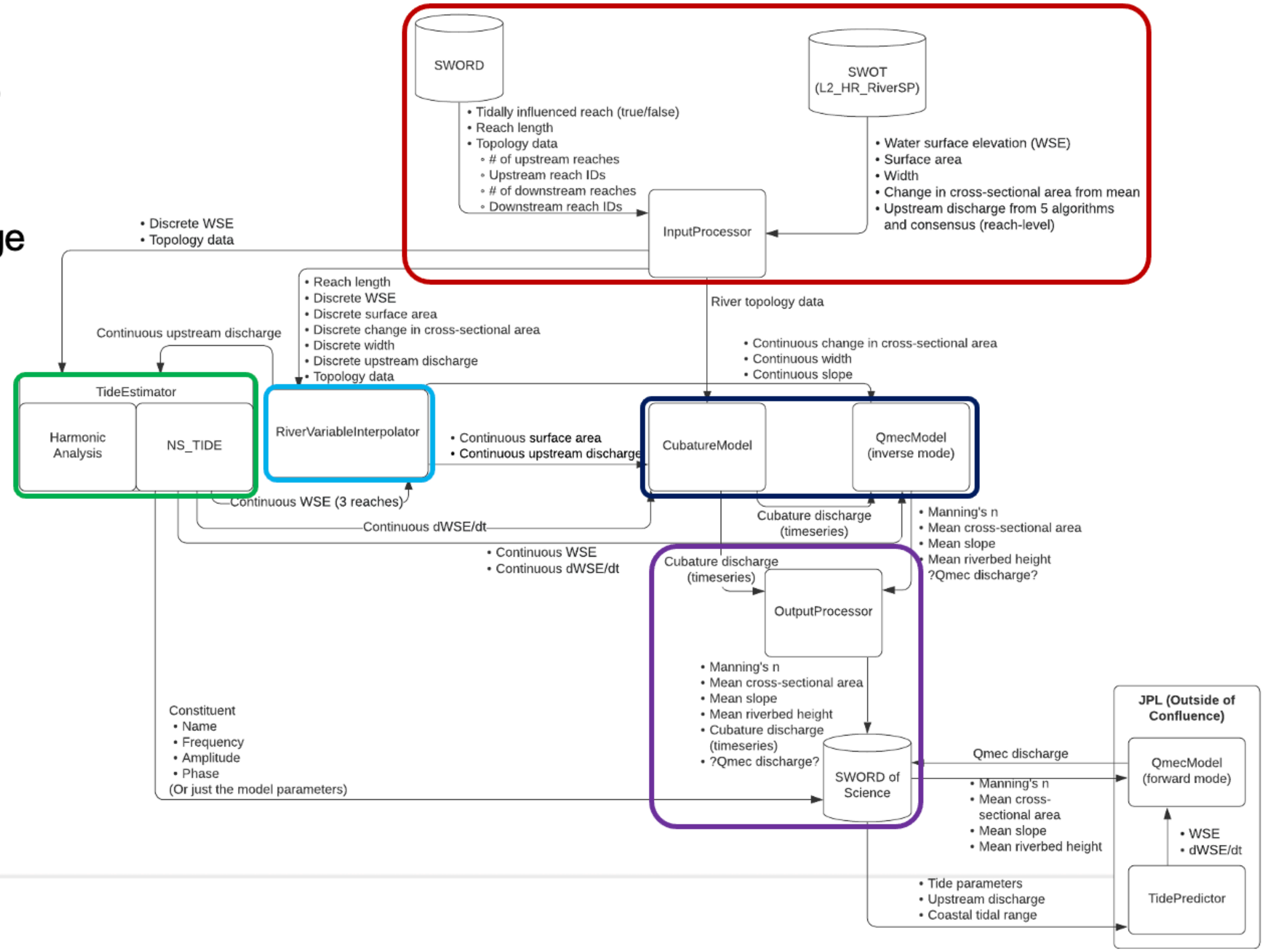
NSE = 0.94



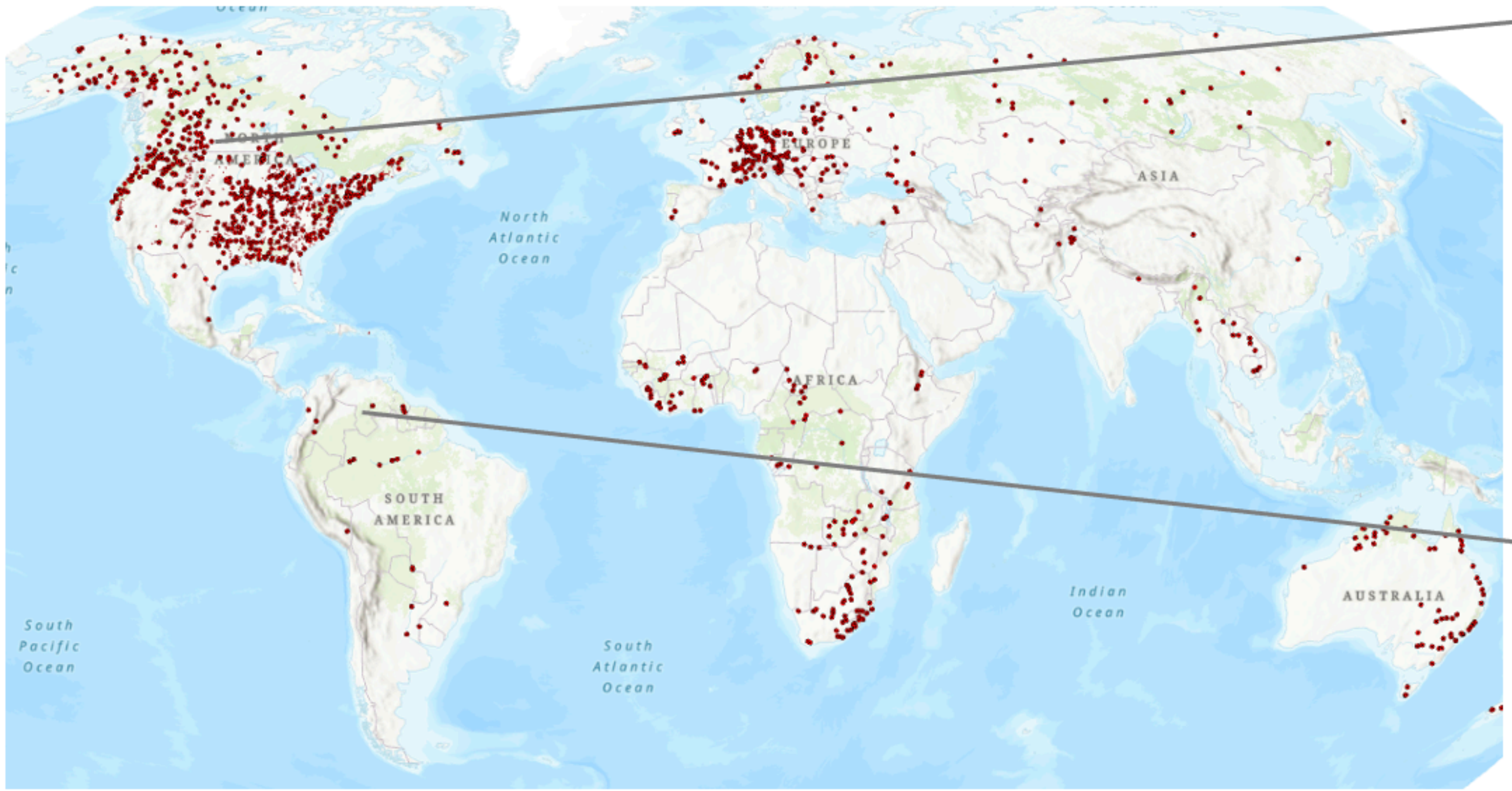
SWOT RIVER TIDES AND ESTUARINE DISCHARGE

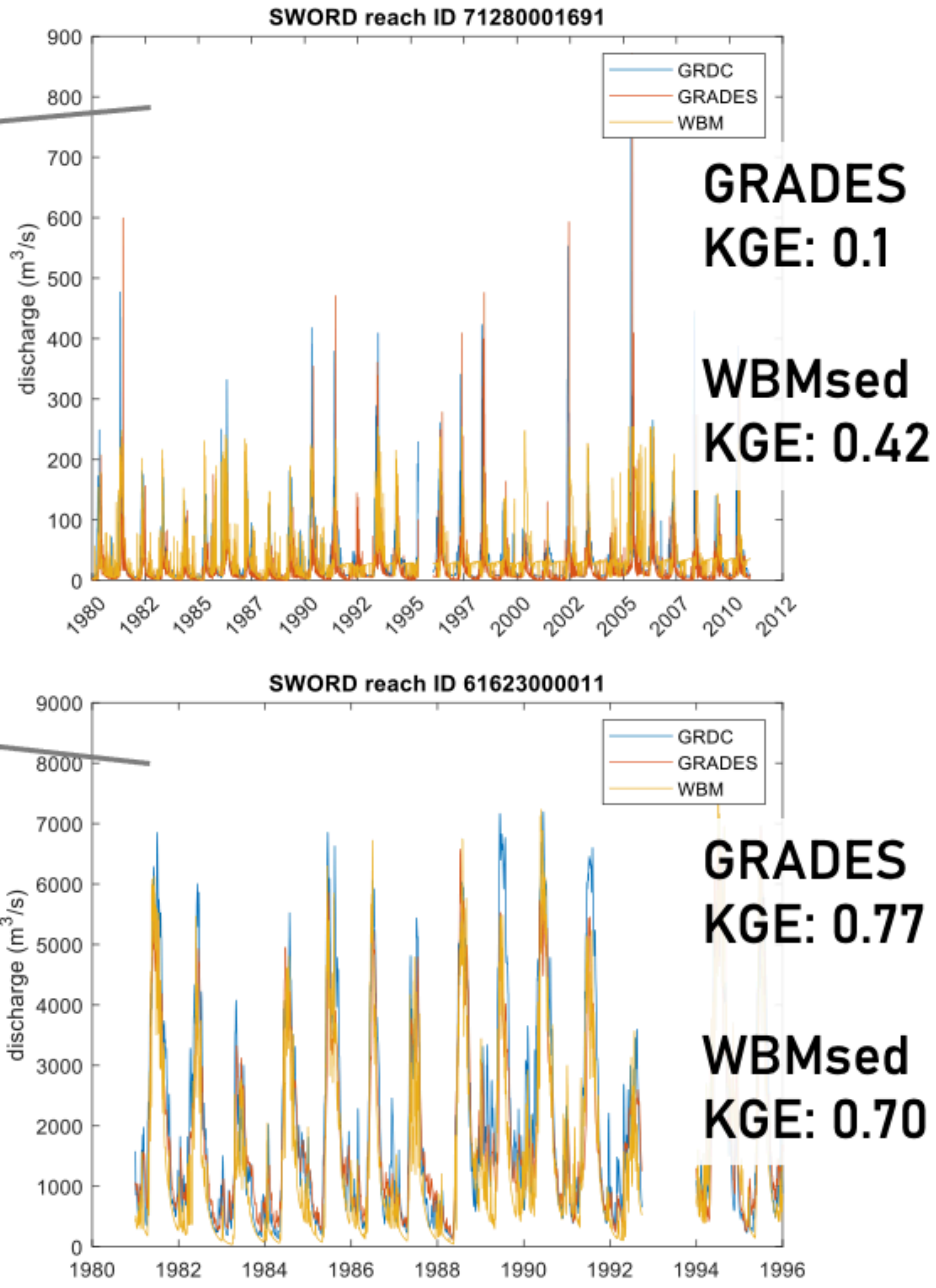
Pascal Matte et al., Environment and Climate Change Canada (ECCC)

- Objectives:
  - Develop an ancillary algorithm for *Confluence* adapted to tidal rivers and estuaries
  - Include tide reconstructions accounting for river flow effects as well as unsteady discharge computations
- System Design:
  - Input processor
  - Tide estimator
  - River variable interpolator
  - Discharge algorithms
  - Output processor



Mapping discharge datasets onto SWORD



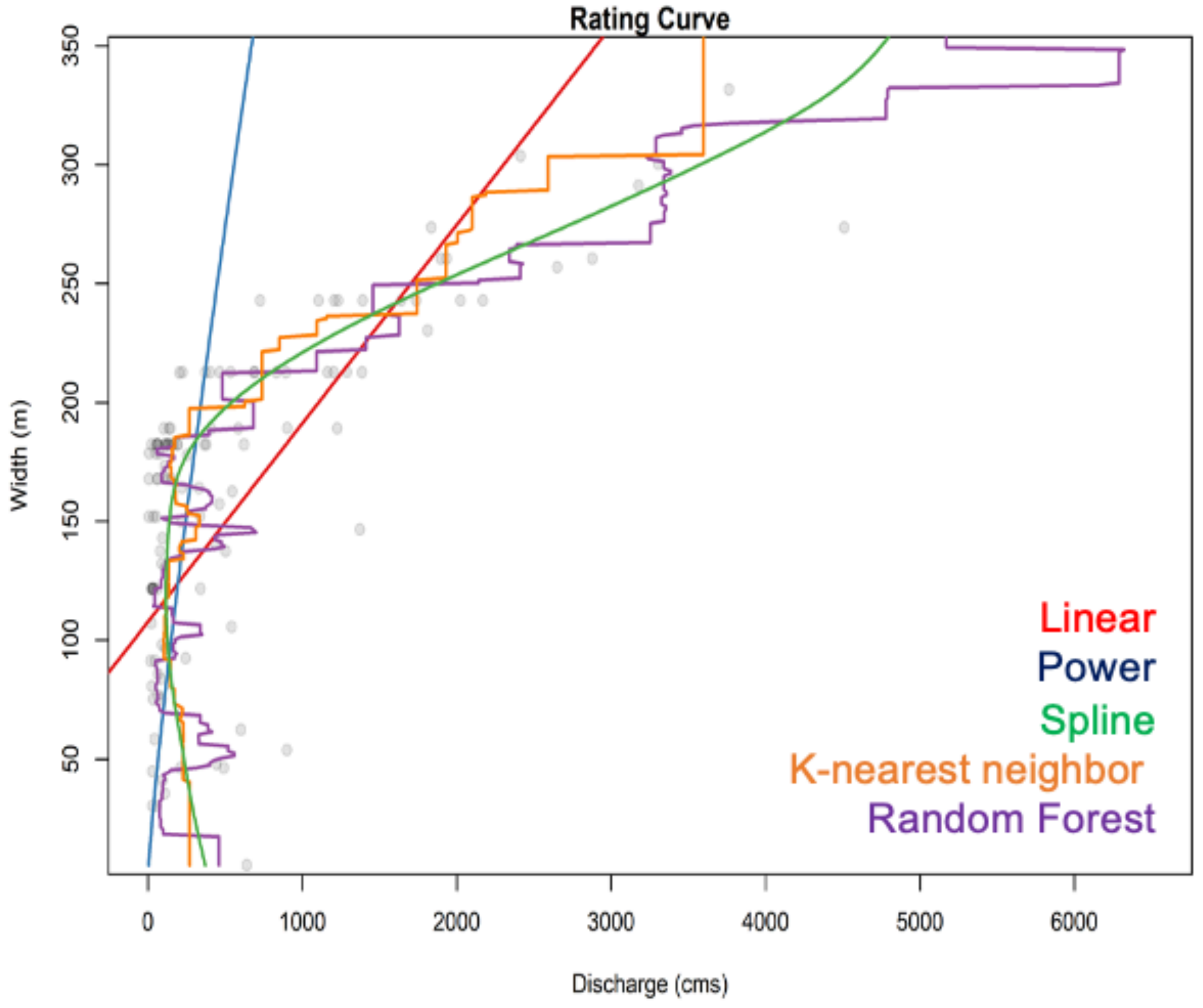


GRDC and USGS gages, and GRADES and WBM models have been connected with SWOT rivers (SWORD) for prior information for discharge algorithms. Two of several thousand example gages shown.

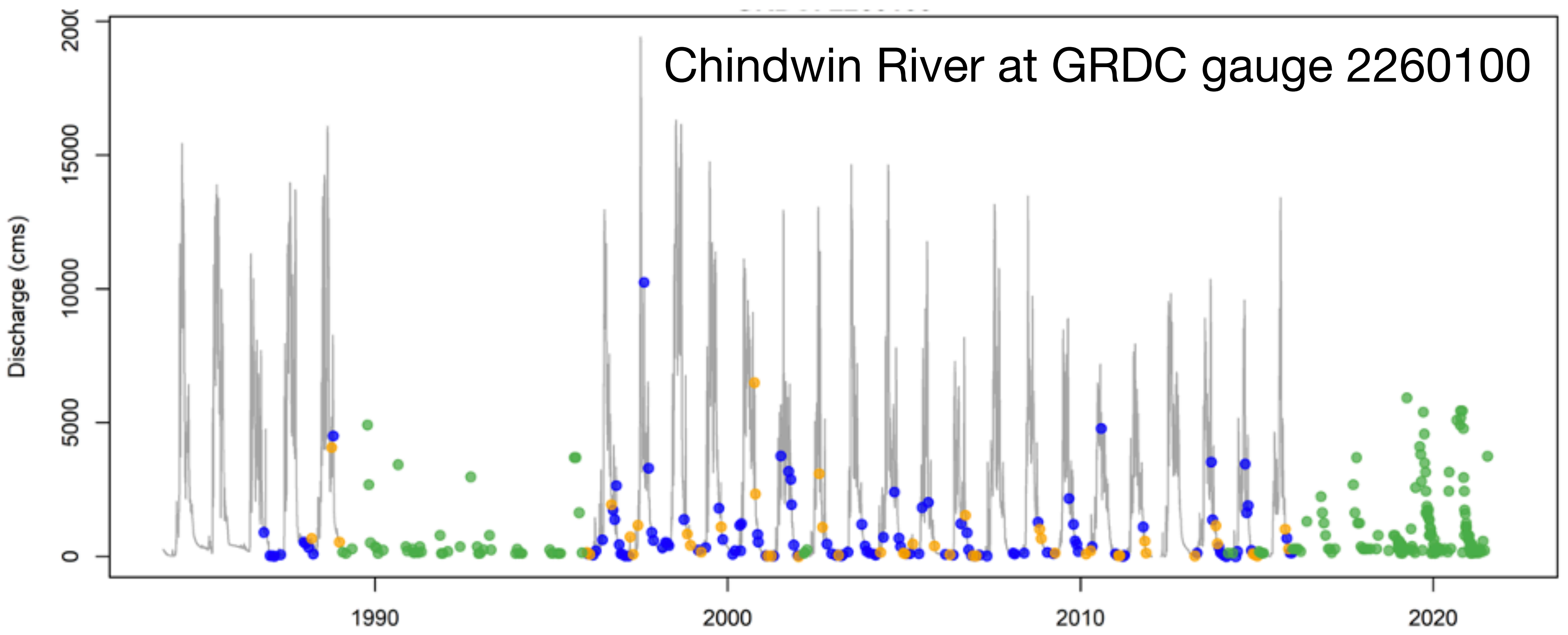
Courtesy Steve Coss, Ohio State

Developing width-based rating curves at GRDC gauges to be used with SWOT

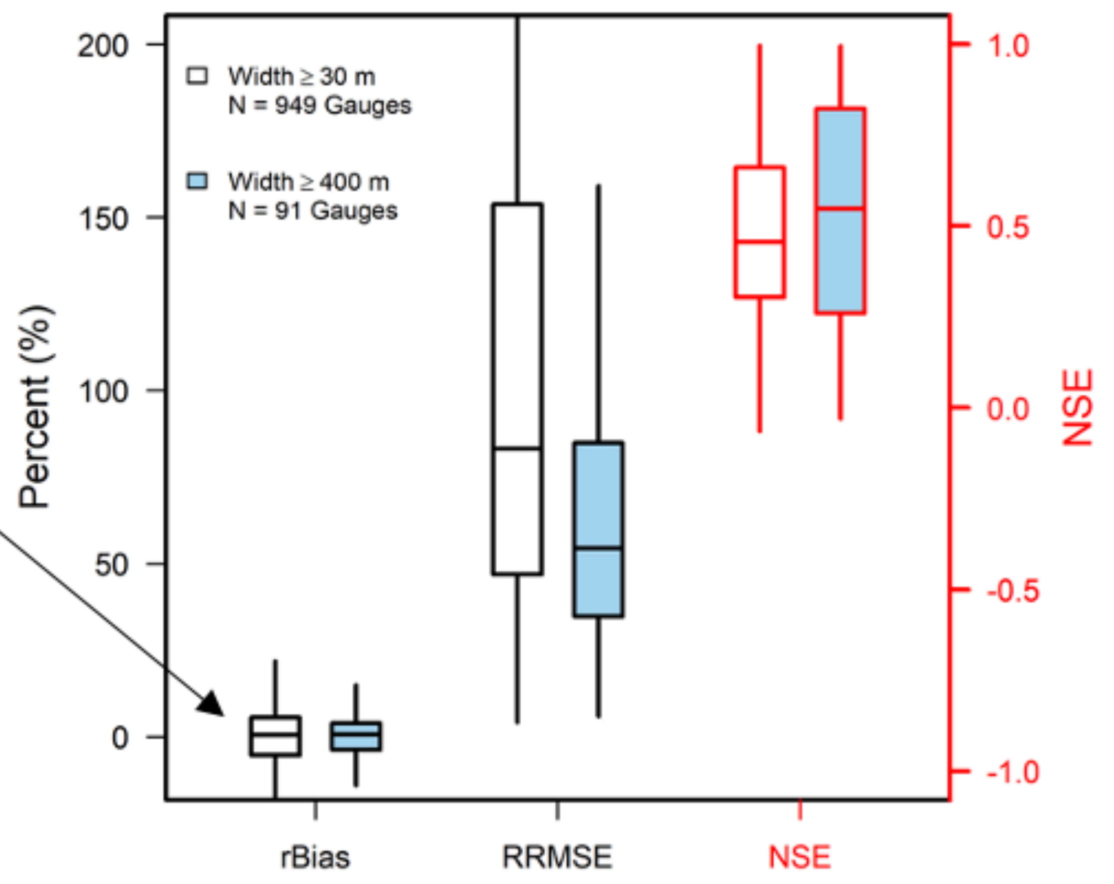
1. Method – Pair historical gauge discharge and satellite imagery (Landsat + Sentinel-2) to develop rating curves at each GRDC gauge



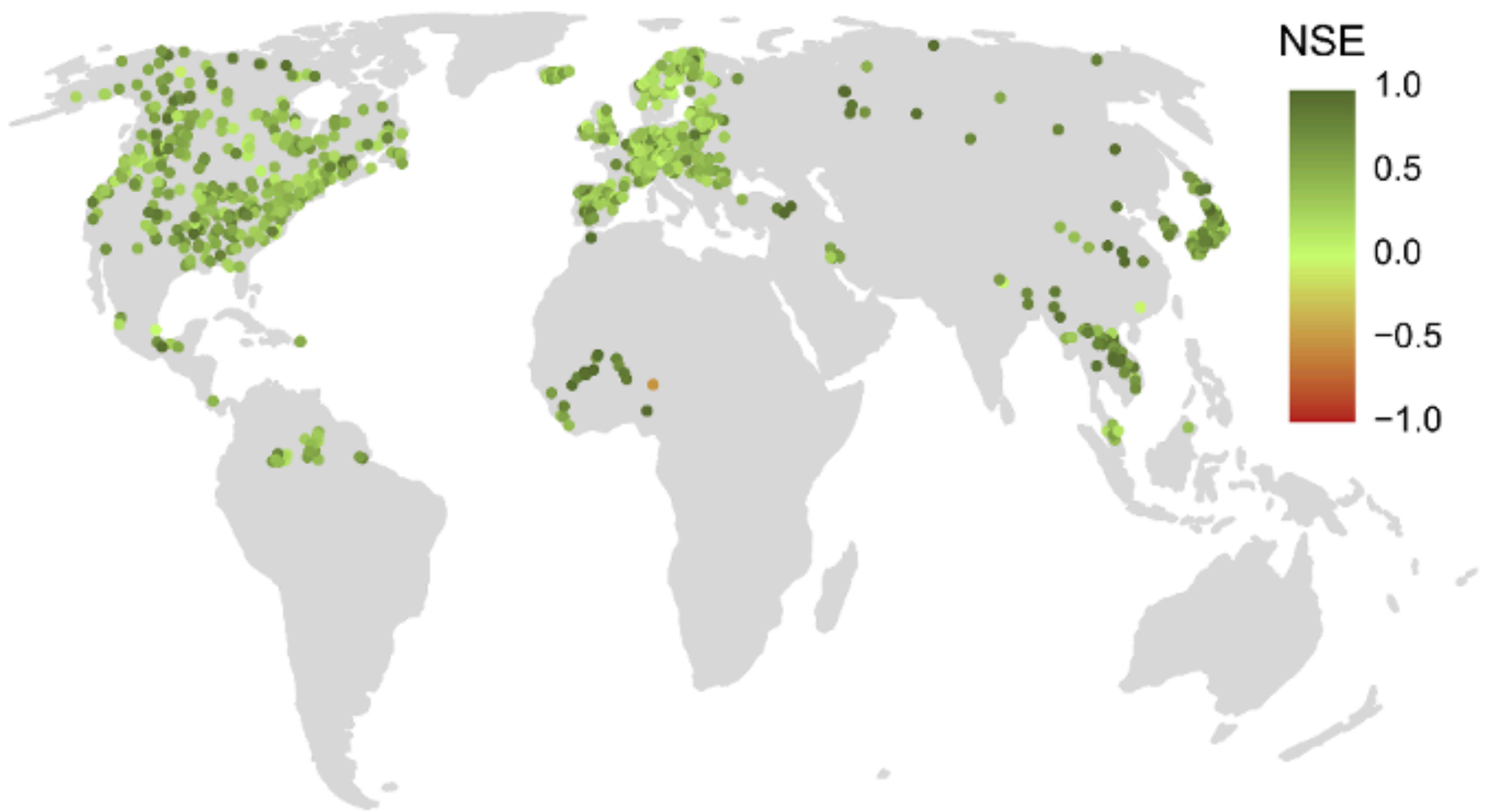
2. Example – Filling in the gauge record with satellite observations. **Calibration**, **Validation**, **Estimated**



3. Preliminary Results show very low bias



4. Map of performance across 949 GRDC gauges



5. Conclusion: This method can be used to estimate discharge at GRDC gauges within Confluence

Courtesy Ryan Riggs, George Allen, TAMU

Developing *Lakeflow* that accounts for lake-river mass conservation

1. Concept – Use lake-river mass conservation to improve flow-law parameters of the inflow and outflow reaches.

Net lake storage change = river inflow – river outflow

$$dV = \frac{1}{n_i}(A_{oi} + dA_i)^{5/3} W_i^{-2/3} S_i^{1/2} - \frac{1}{n_o}(A_{oo} + dA_o)^{5/3} W_o^{-2/3} S_o^{1/2}$$

Observed by SWOT
W = surface water width
S = surface water slope
dA = change in cross-section area

Not observed by SWOT
n = roughness coefficient
A_o = Cross-section area at baseflow

2. Data – Synthetic data for testing and gauge data for validation

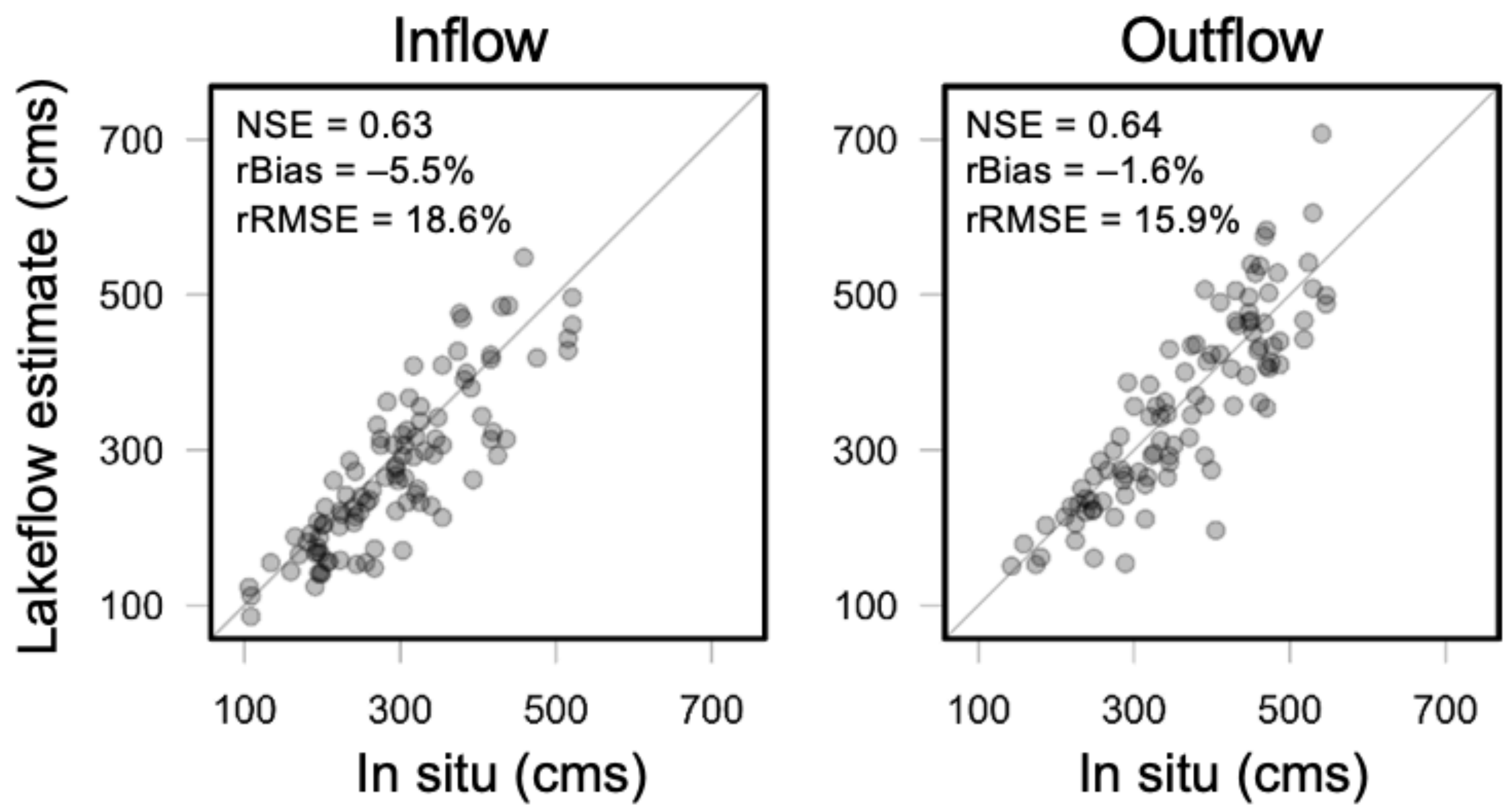
- Synthetic SWOT data with expected error ranges:
  - Cross-sectional area = 15% error
  - Width = 15% error
  - Slope = 1.7 cm/km error
- 7-day sampling gaps
- *In situ* inflow and outflow from USGS stations for validation

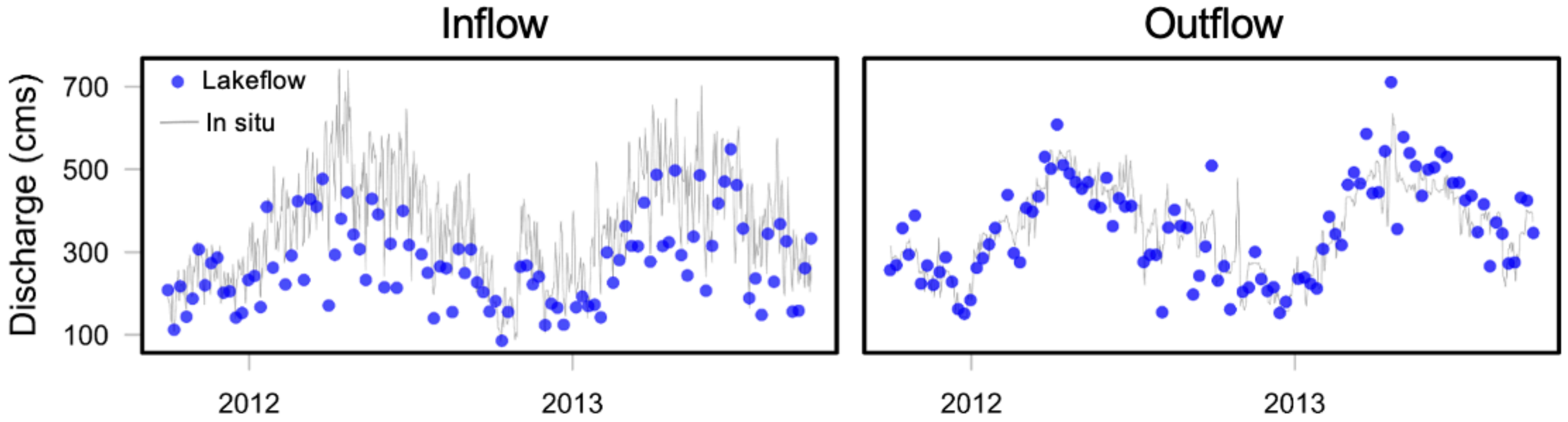
3. Method

- We use a genetic algorithm to optimize the mass conservation and estimate flow-law parameters n_i, n_o, A_{oi}, and A_{oo}.
- We input the estimated flow-law parameters into Manning's equation along with the synthetic SWOT data, to estimate inflow and outflow and validate with same-day *in situ* measurements.

4. Example – Lake Mohave, Nevada/Arizona, US

Parameter	Estimated	Actual
n_i	0.040	0.035
A_{oi}	198	164
N_o	0.041	0.035
A_{oo}	343	299





Courtesy Jida Wang, Kansas State

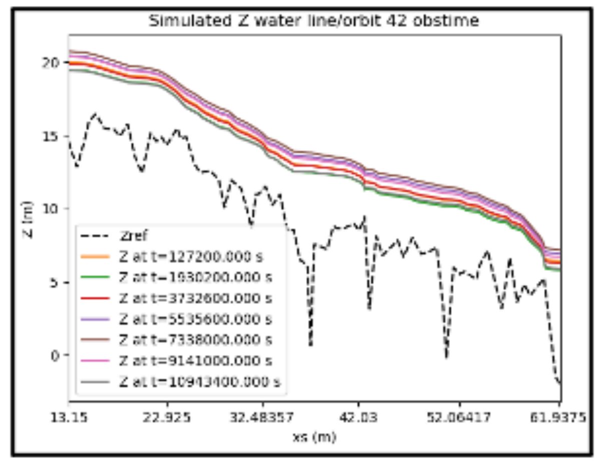
Project: Estimation of River Discharges from SWOT Observations using Data Assimilation and Hydraulic Models

⇒ **Need of river-based SWOT-like products to develop SWOT discharge algorithm (e.g. SIC4DVAR , HiVDI, McFli) and prepare for data assimilation of SWOT products in hydraulic models (e.g. Mascaret-SMURF, Telemac2D-EnKF)**

Hydraulic simulations (1D, no geolocalisation) → **ToolBoxSWOT** → *True scene*: WSE map (2D, raster, WGS84) → SWOT-HR simulator (JPL) → SWOT-like river products

⇒ **ToolBoxSWOT:** Processing chain (Python) to turn hydraulic model outputs into SWOT-HR input format:
https://gitlab.com/cerfacs/toolboxswot

- « Known » rivers – e.g. here downstream Garonne with Mascaret



Longitudinal simulated WSE from Mascaret seen by SWOT (orbit CNES 42)

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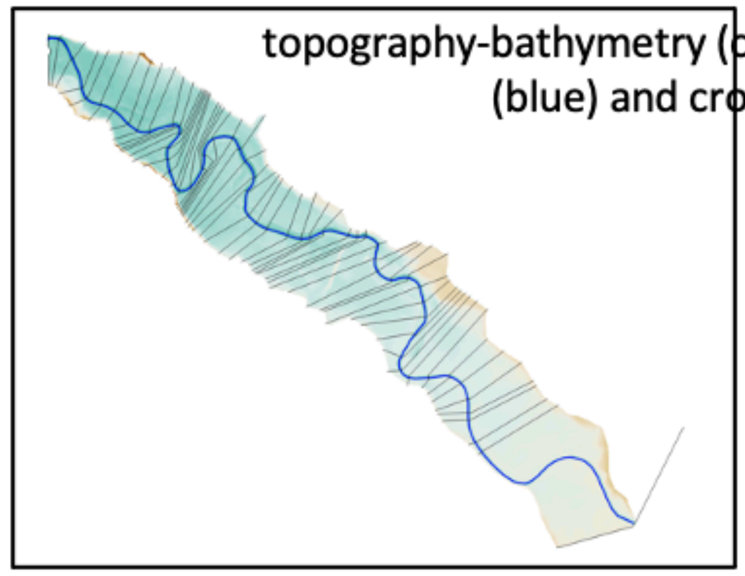
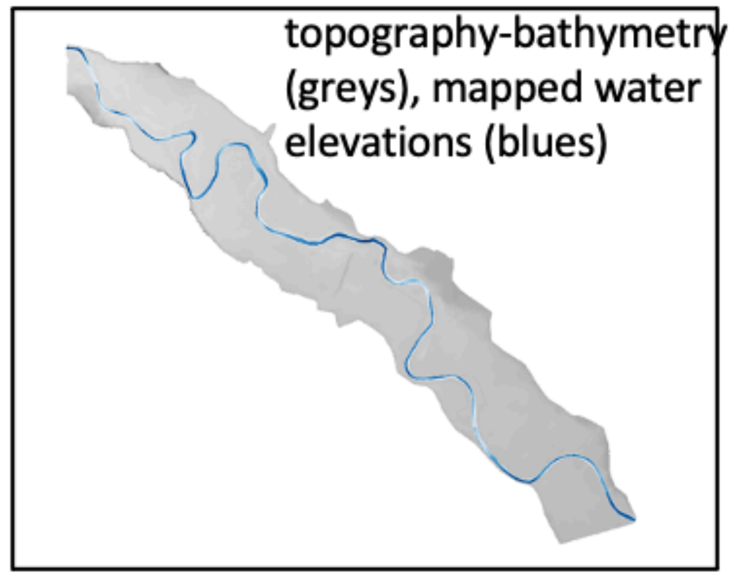


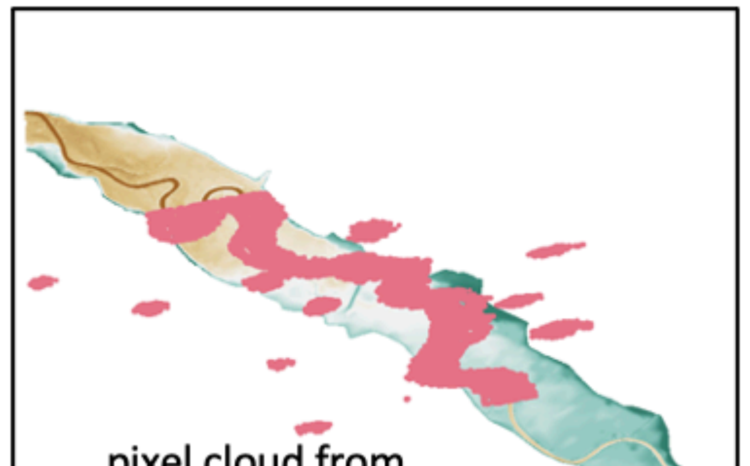
topography-bathymetry (colors), centerline (blue) and cross-section (black)

ToolBoxSWOT →



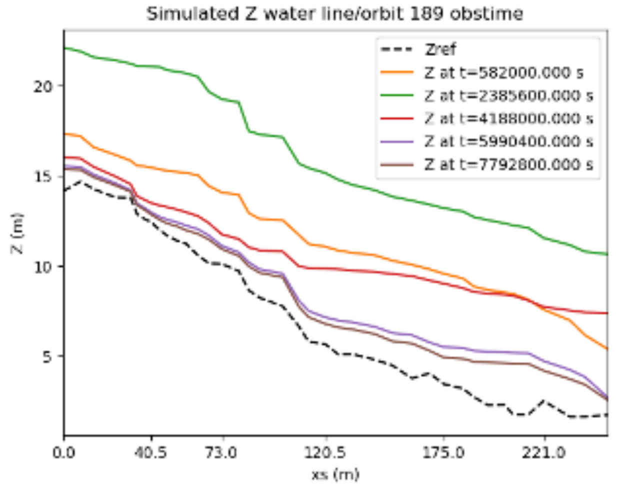
topography-bathymetry (greys), mapped water elevations (blues)

SWOT-HR →



pixel cloud from SWOT-HR (pink, under orbit CNES 42)

- « Unknown » rivers – e.g. here Brahmaputra reach from PEPSI data and SIC



Longitudinal simulated WSE from SIC seen by SWOT (orbit CNES 189)

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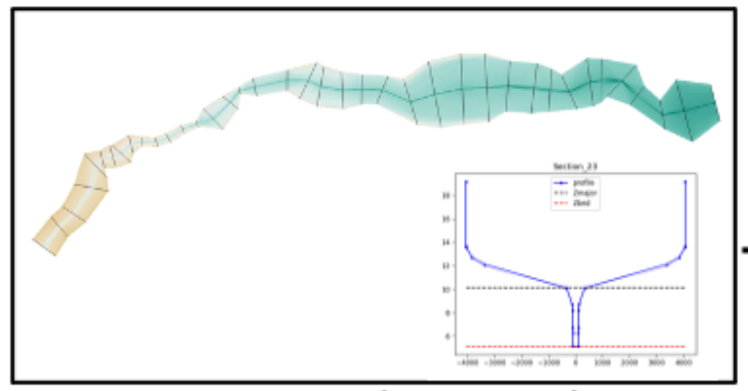
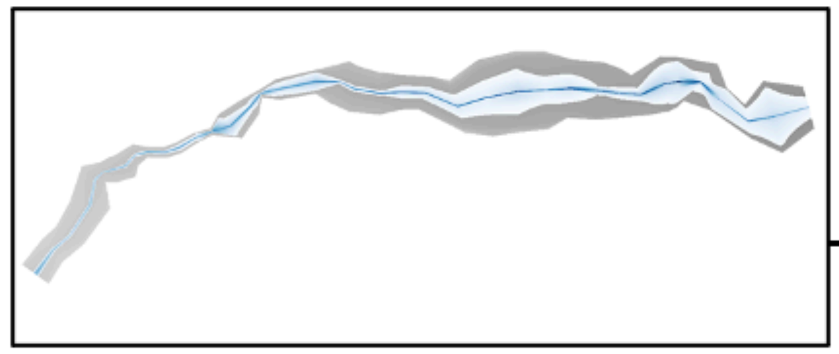


Reconstructed topography-bathymetry (colors) from cross-section (black + corner plot)

ToolBoxSWOT →



topography-bathymetry (greys), mapped water elevations (blues)

SWOT-HR →

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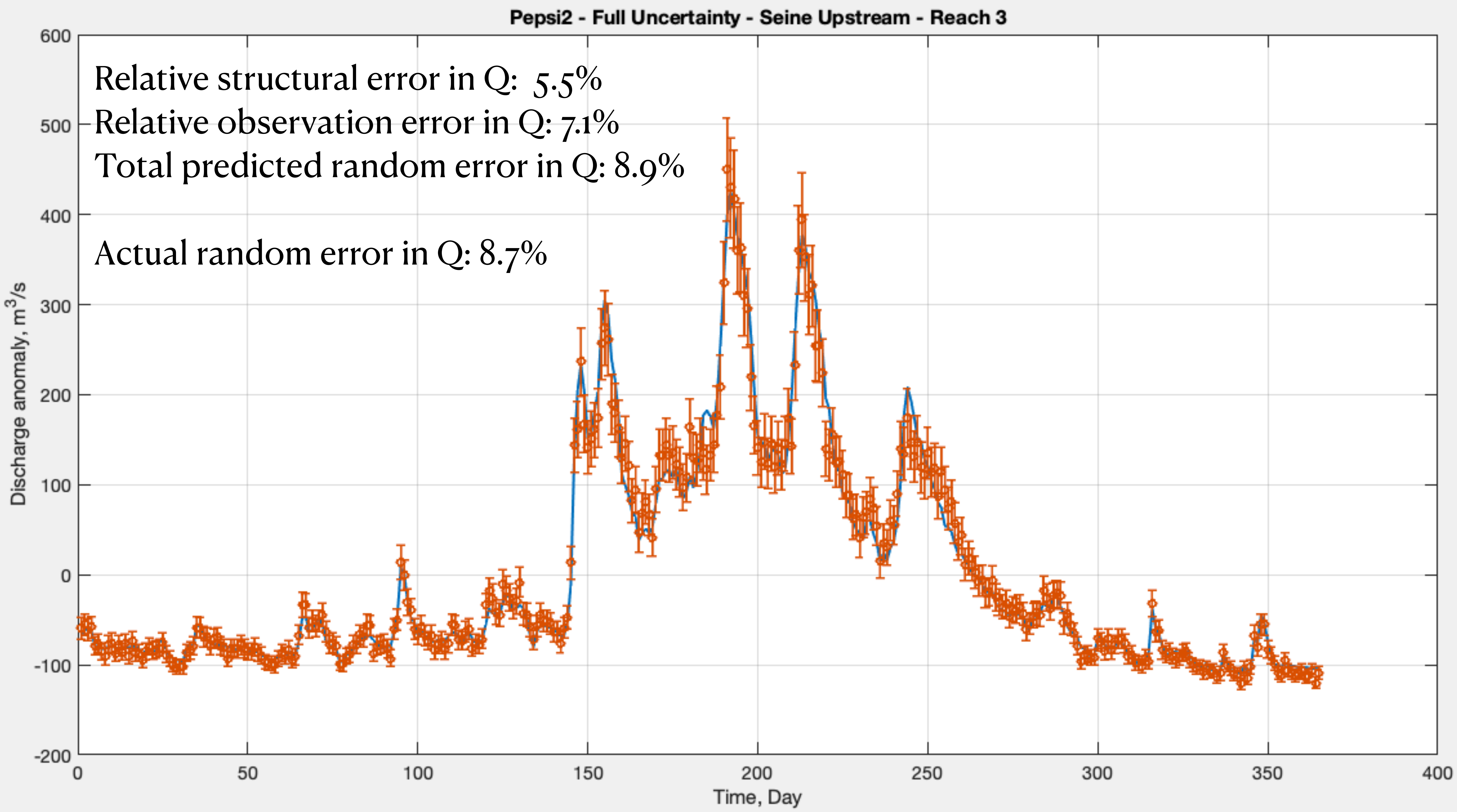
INRAE, UMR G-eau – CECI, CERFACS/CNRS UMR 5318, CSGROUP-France

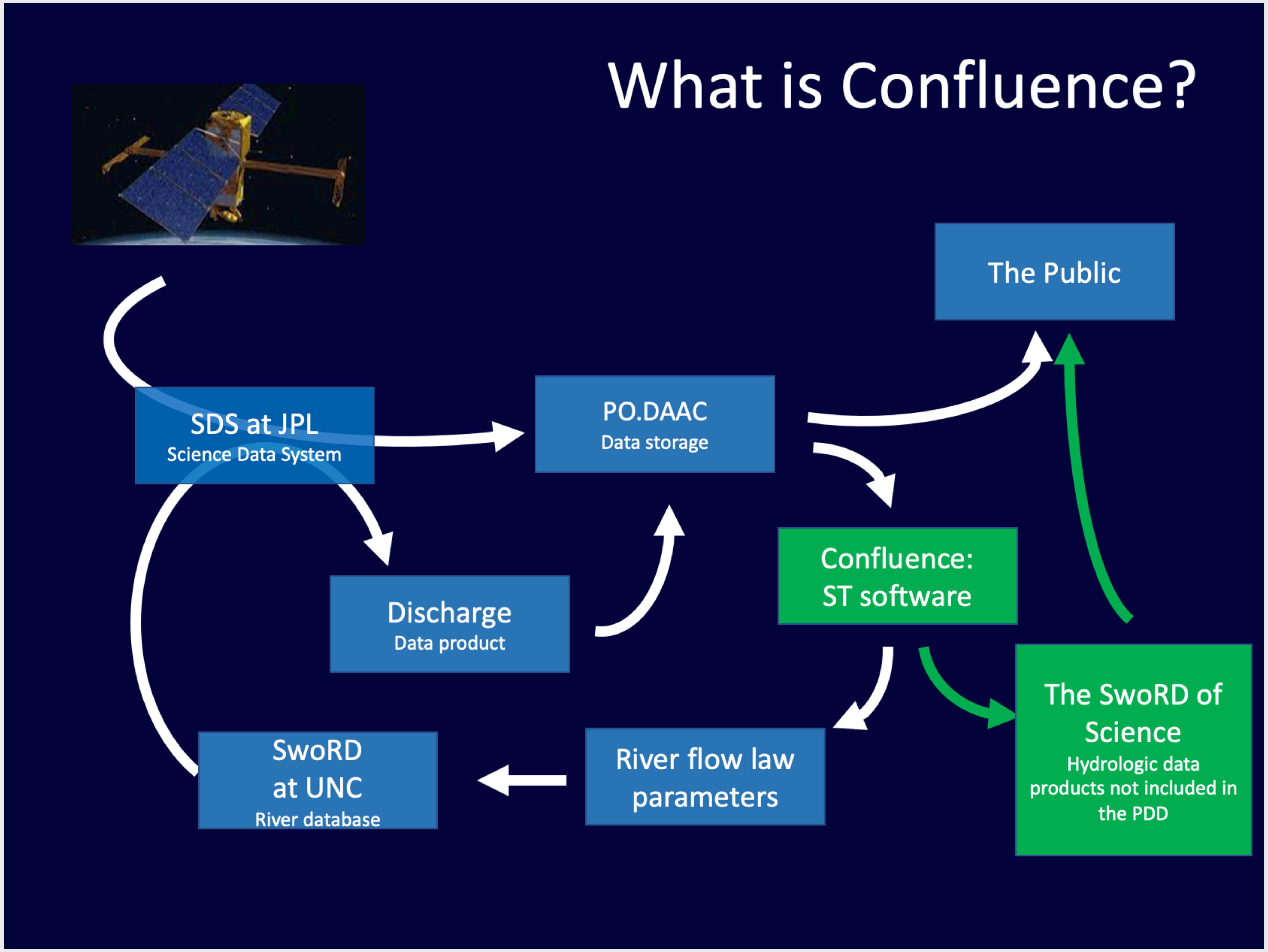
CS Group - Document Interne

Courtesy Sophie Ricci CNRS

Ongoing effort to better understand, partition, and predict discharge accuracy. Several approaches to discharge uncertainty quantification are being explored.



Renato Frasson, Mike Turmon, Cedric David, Mike Durand



Courtesy Colin Gleason & Nikki Tebladi. *See their talk later today!*

Confluence is the engine that brings together algorithm components, enabling DAWG to do global optimal FLPE