Observability of Global Rivers with Future SWOT observations

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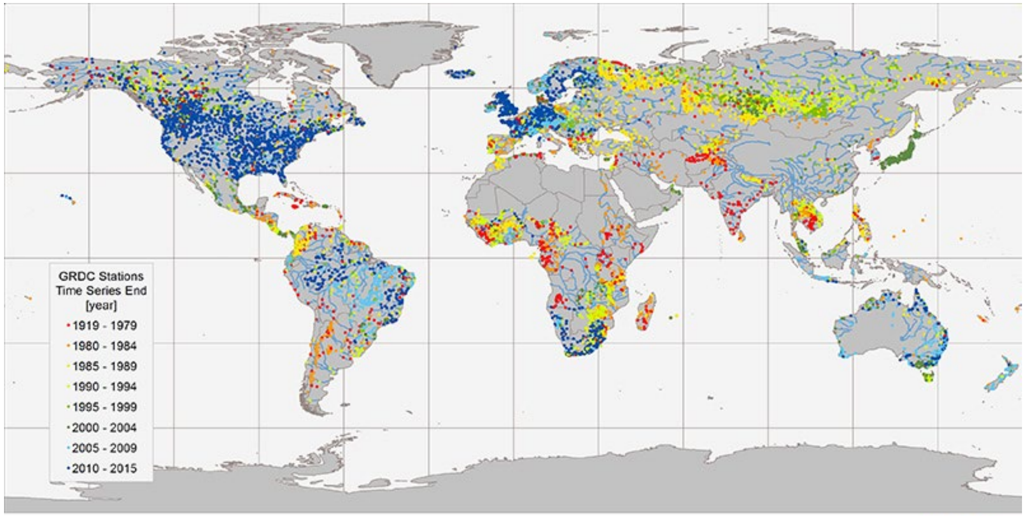
Motivation

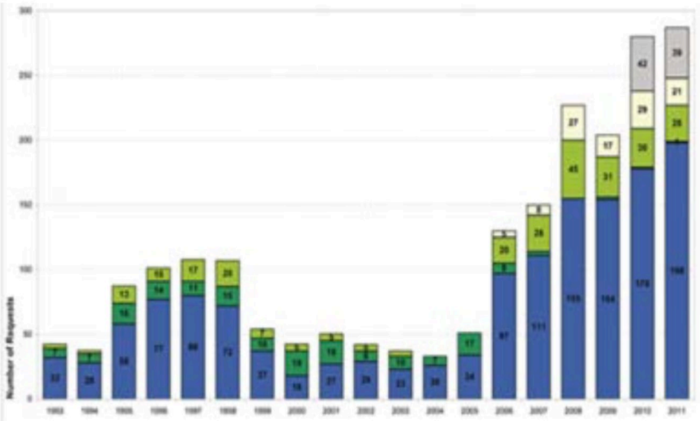
- River discharges are poorly monitored in many regions
- Lack data to **properly constrain runoff** in LSMs and **predict discharge** in ungauged basins



9213 GRDC stations with monthly data, incl. data derived from daily data (Status: 27 May 2015)
Koblenz: Global Runoff Data Centre, 2015.

- What **new data** and **methods** could fill this void?

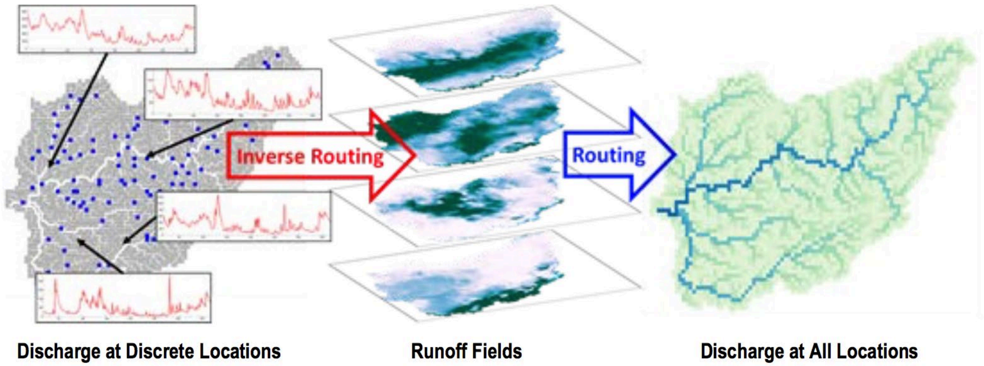
- SWOT has the potential, but how do we make the best use of the data for global scale modeling/forecasting applications?



[Looser, 2012]

Motivation

- How can we use this data source to better predict spatially and temporally consistent records of runoff and discharge?
  - Statistical interpolation techniques (Paiva et al., 2015)
  - Data assimilation with hydrodynamic model (Pan and Wood, 2013, Inverse Streamflow Routing)

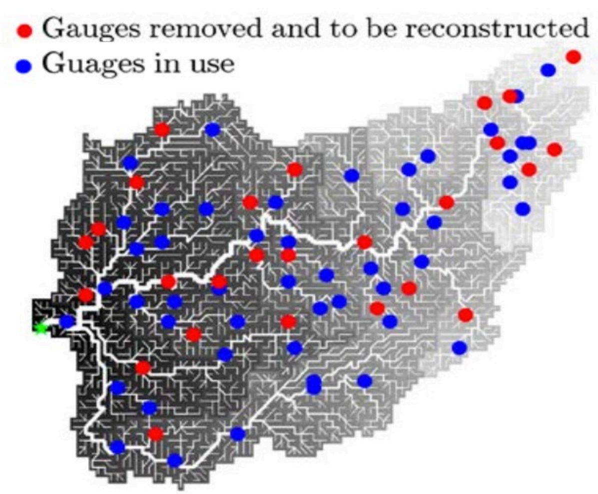


- How does the potential orbit and spatial orientation of basins constrain our usage?

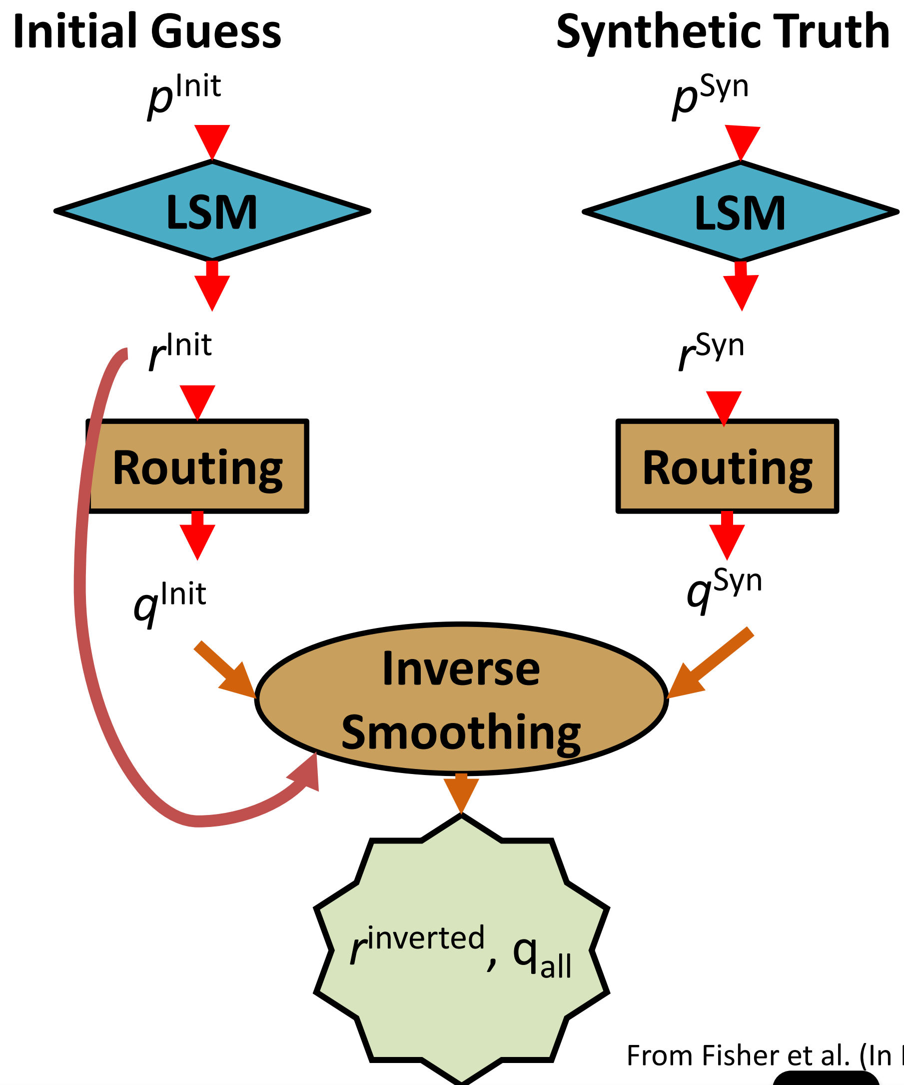
Inverse Streamflow Routing

Experiments with theoretical SWOT observations to construct basin wide discharge:

- Utilizes a Kalman Filter & Smoother
- Linear routing model (Lohmann)
- ~150 crossing "gauges" assimilated
- 25 crossing "gauges" evaluated



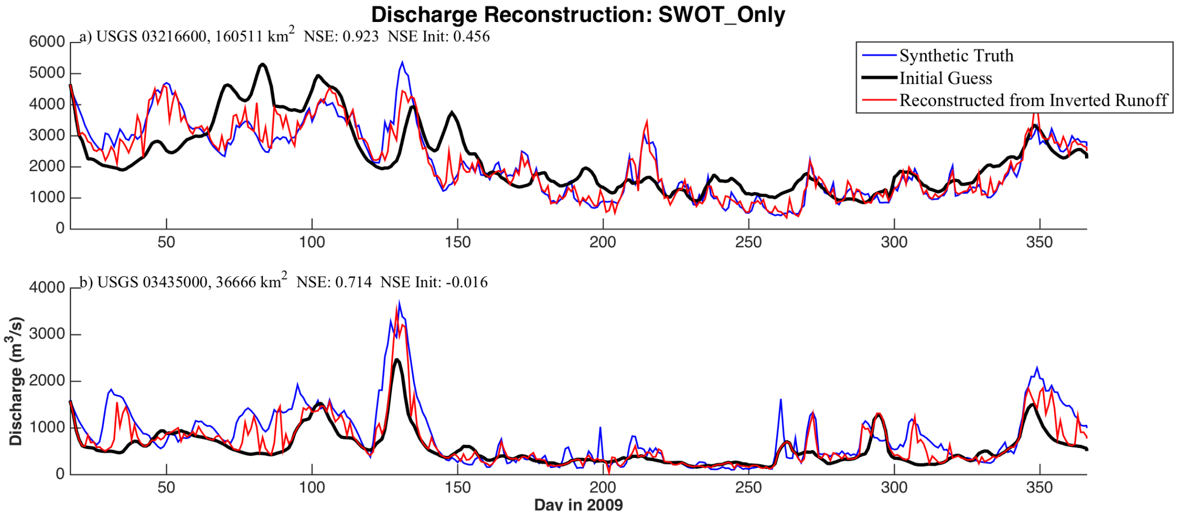
Idealized Experiment



From Fisher et al. (In Prep.)

ISR – SWOT Assimilation

- Previous application of Inverse Streamflow Routing to Ohio river basin illustrated ability to assimilate SWOT obs.



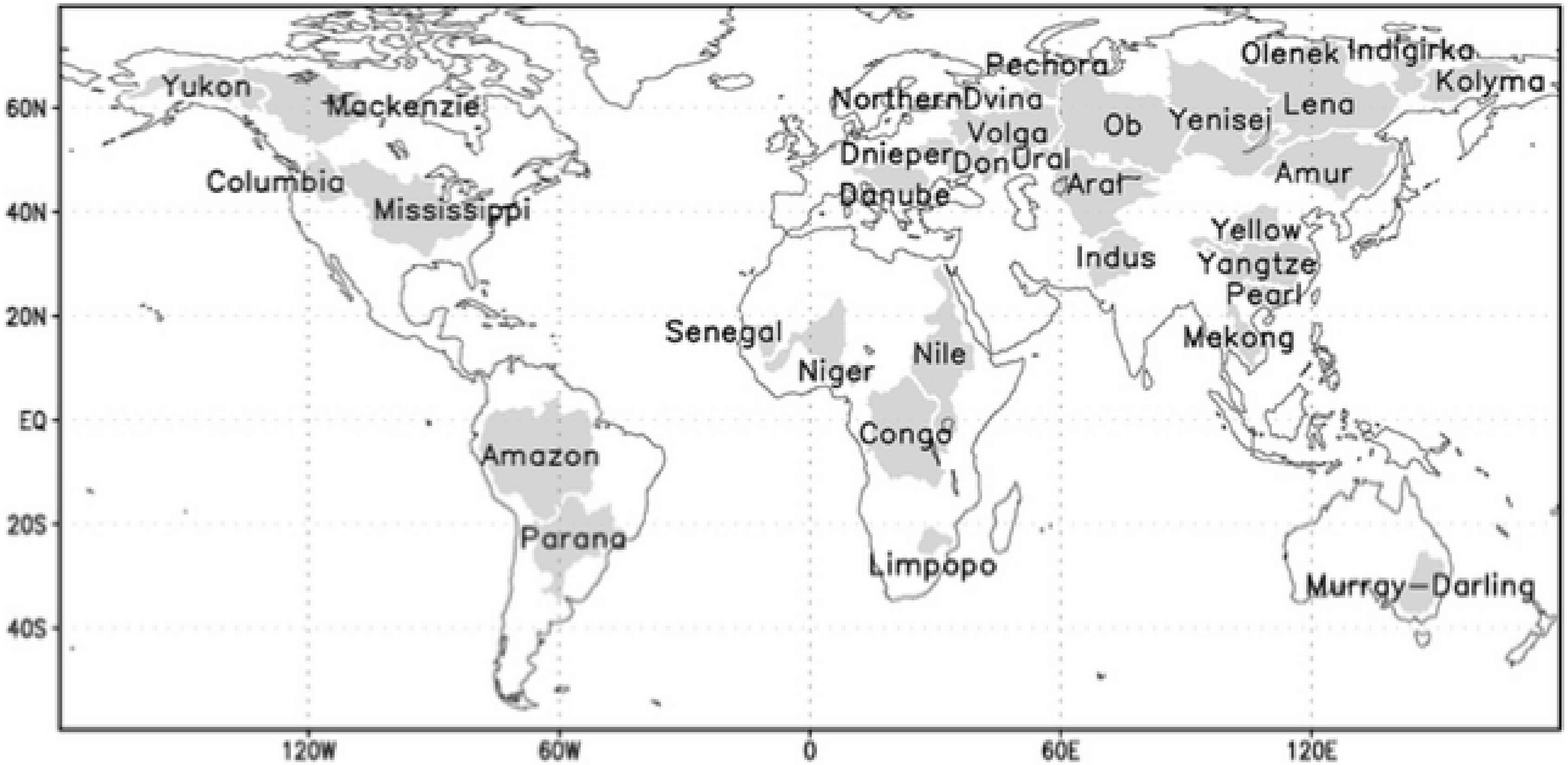
- Performance constrained by spatial and temporal coverage:

- **How will SWOT observe other river basins?**
- **How will their location and spatial properties affect the assimilation?**

From Fisher et al. (In Prep.)

Global Basins

- Inverse Streamflow was applied to 32 large global basins
  - Representative of a wide range of hydrologic and geographic properties



Synthetic Experiments

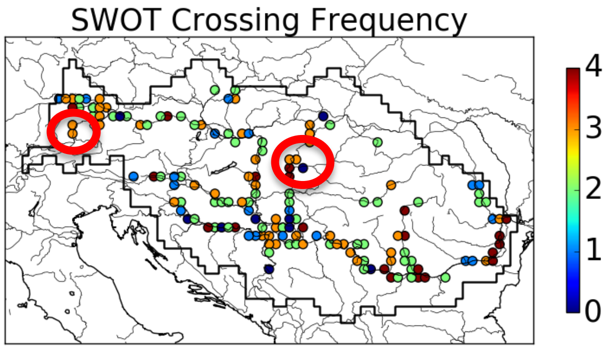
Discharge Data Assimilated

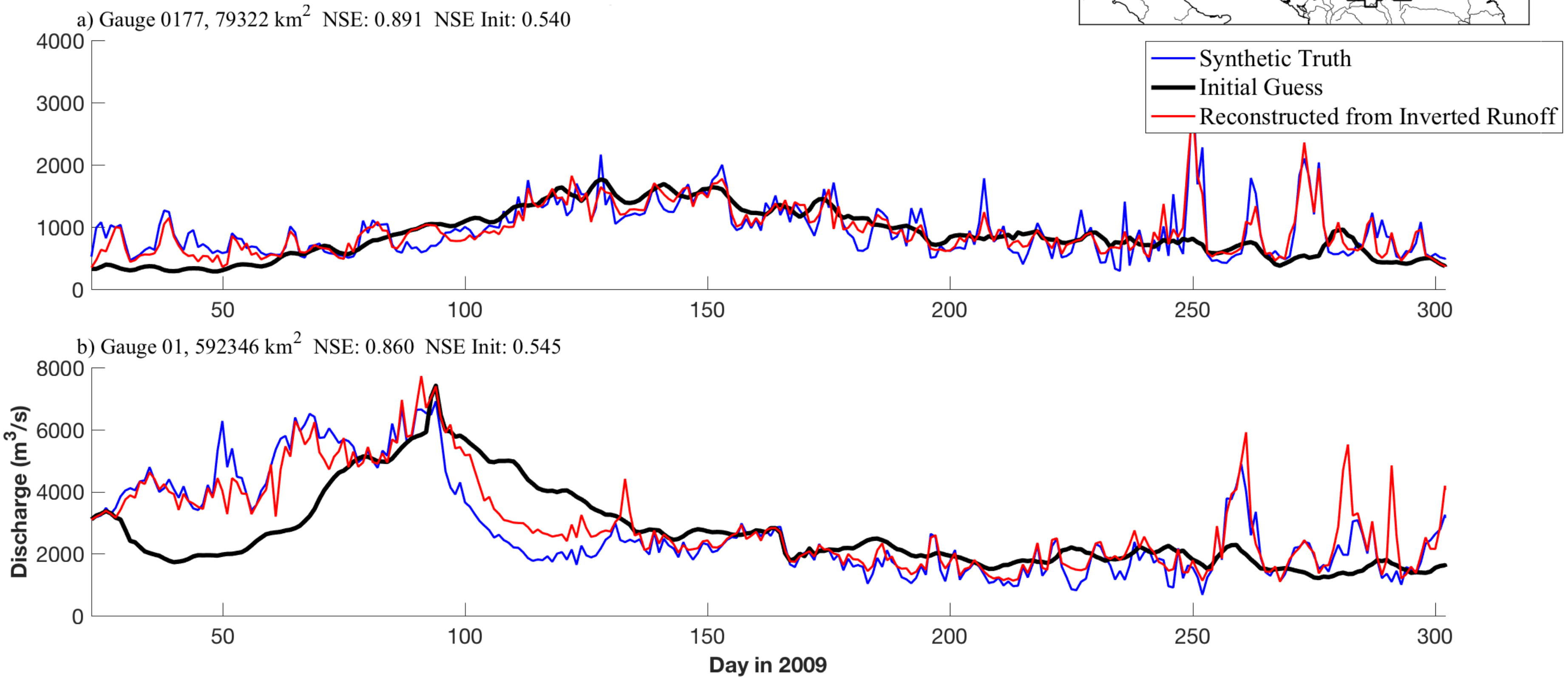
Initial Runoff Conditions	All Gauges	SWOT Only	Mixed Gauges and SWOT
Long Term Basin Mean	**In-Situ** Discharge & **Min.** Runoff Info	**SWOT** Discharge & **Min.** Runoff Info	**Mixed** Discharge & **Min.** Runoff Info
Daily Climatology	**In-Situ** Discharge & **Some** Runoff Info	**SWOT** Discharge & **Some** Runoff Info	**Mixed** Discharge & **Some** Runoff Info
TMPA Real Time	**In-Situ** Discharge & **Obs.** Runoff Info	**SWOT** Discharge & **Obs.** Runoff Info	**Mixed** Discharge & **Obs.** Runoff Info

- Model Setup:
  - Initial conditions → VIC LSM forced with runoff climatology
  - Discharge observations → VIC LSM forced with Princeton Global Forcing
  - Theoretical SWOT observations → Model discharge sampled from theoretical 21-day, 890 km altitude, 77.6° inclination orbit
  - 0.25° spatial res. & daily temporal res.
  - ~30% errors for observations based on current retrieval methods

Discharge Interpolation

Assimilation using runoff climatology + SWOT sampled discharge time series for the Danube

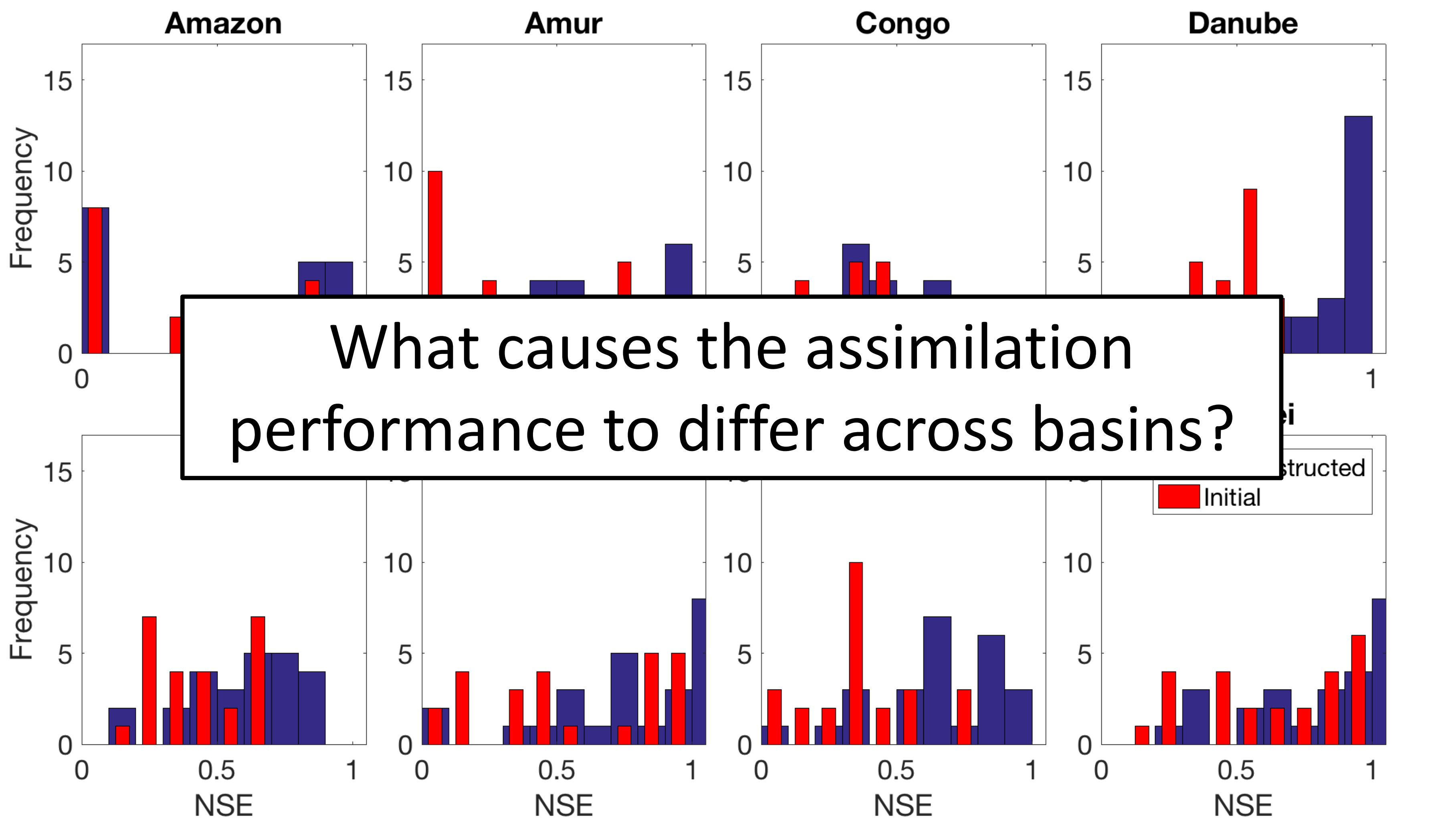




From Fisher et al. (In Prep.)

Global Interpolation Performance

Nash-Sutcliffe Efficiencies (NSE) for reconstructed gauge discharge time series

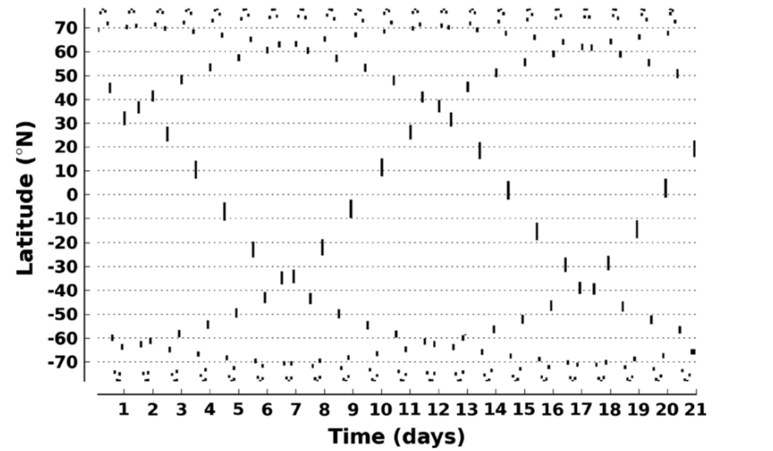


What causes the assimilation performance to differ across basins?

From Fisher et al. (In Prep.)

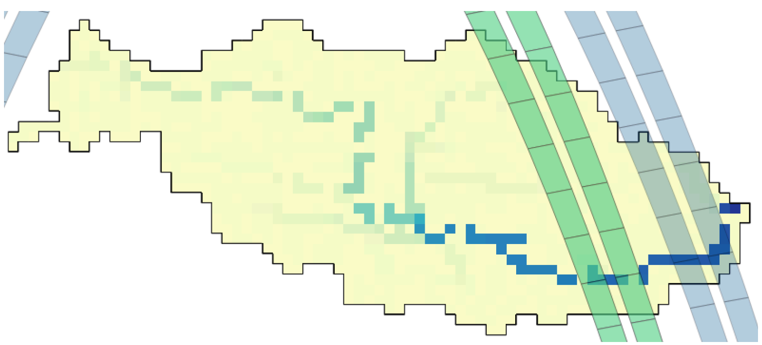
SWOT orbit dictates the availability of data for assimilation

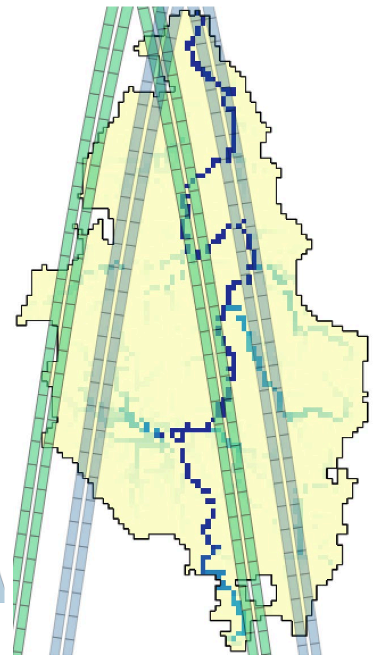
- Depends on River:
  - Latitude
  - Size (length, width and basin area)
  - Orientation

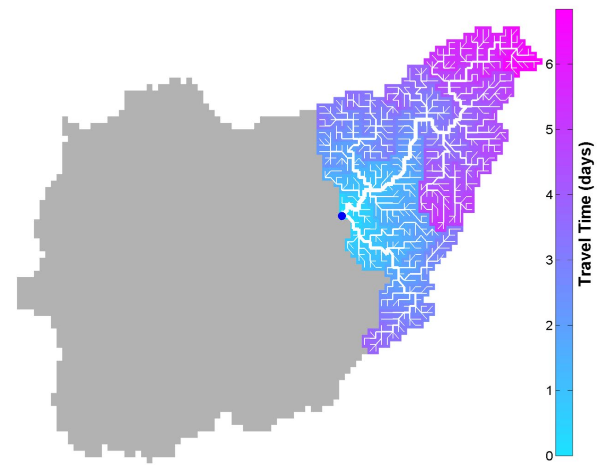


Biancamaria et al., 2015

Day 1 and 2 Crossings for the: Danube & Nile





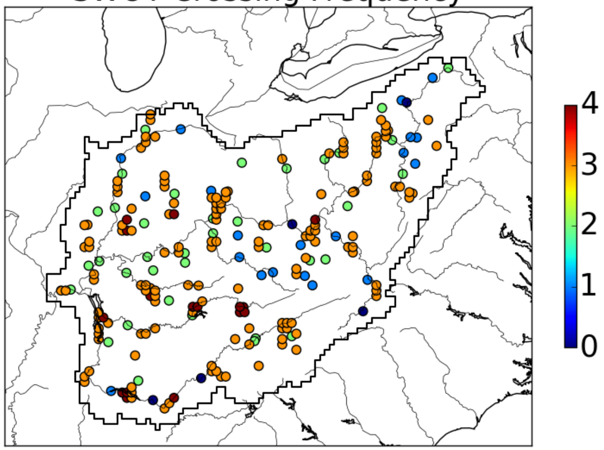


From Fisher et al. (In Prep.)

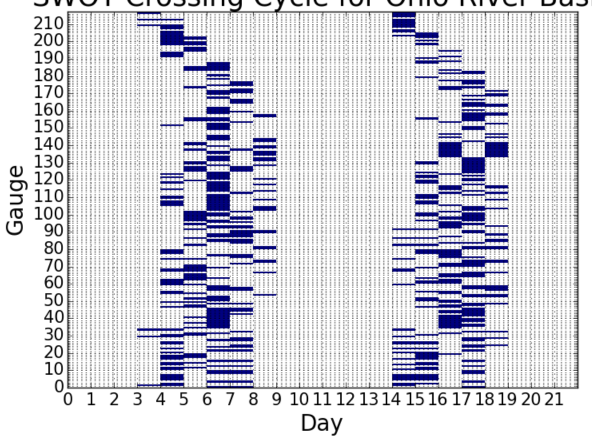
Observation Patterns

Ohio River

SWOT Crossing Frequency

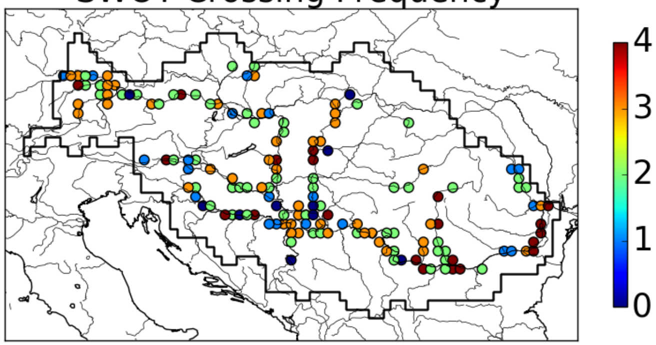


SWOT Crossing Cycle for Ohio River Basin

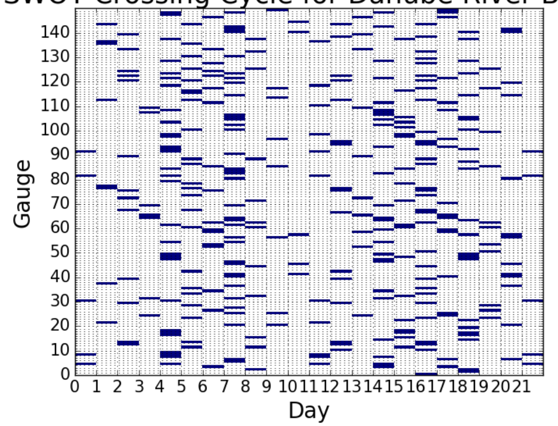


Danube River

SWOT Crossing Frequency

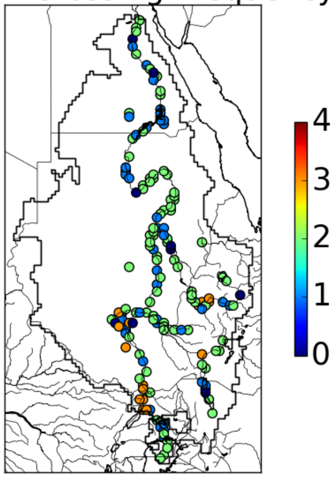


SWOT Crossing Cycle for Danube River Basin

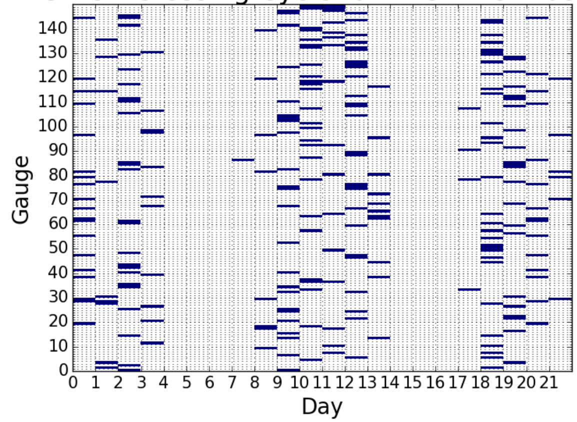


Nile River

SWOT Crossing Frequency

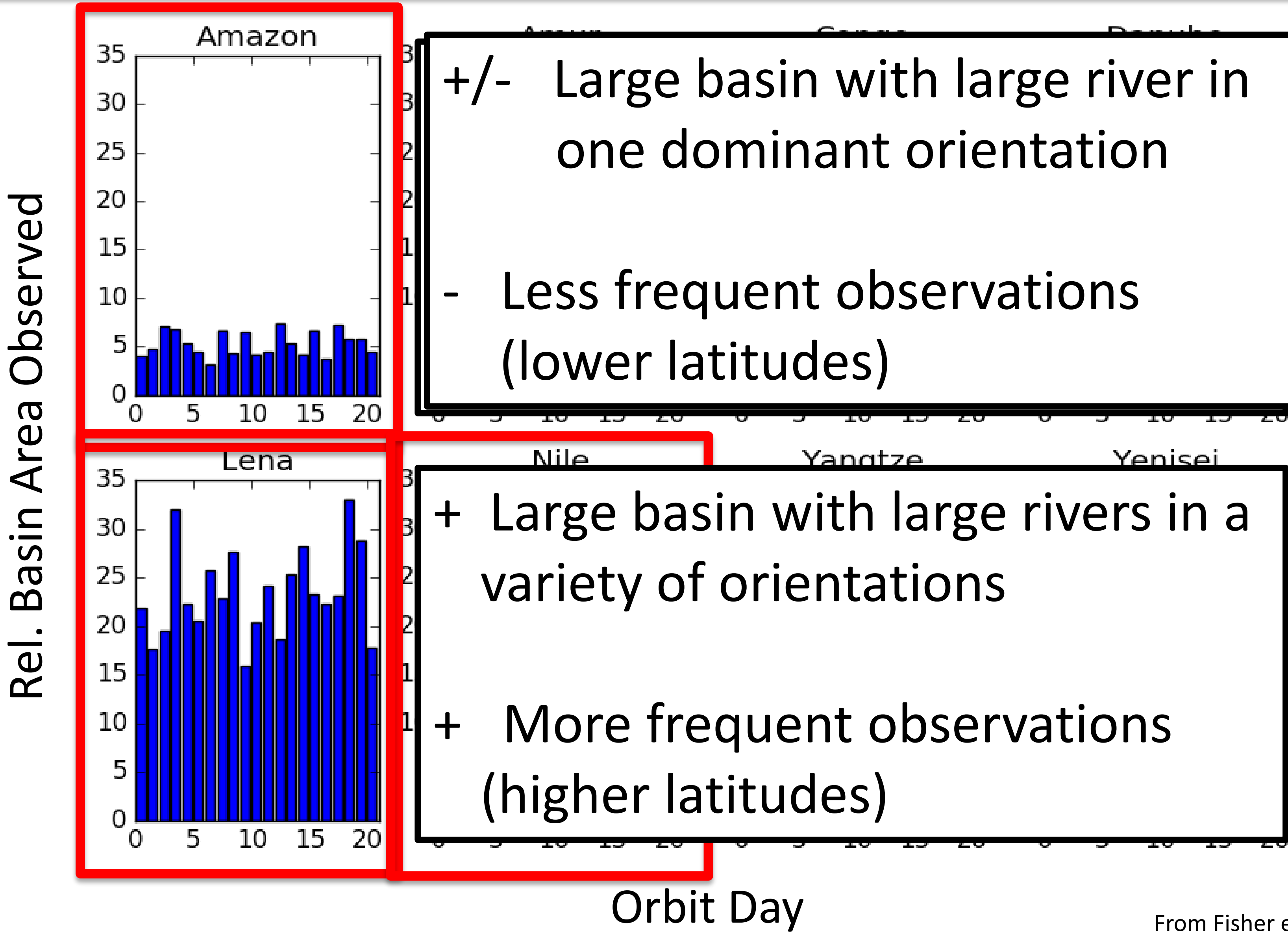


SWOT Crossing Cycle for Nile River Basin



From Fisher et al. (In Prep.)

Information Content from Observations



+/- Large basin with large river in one dominant orientation

- Less frequent observations (lower latitudes)

+ Large basin with large rivers in a variety of orientations

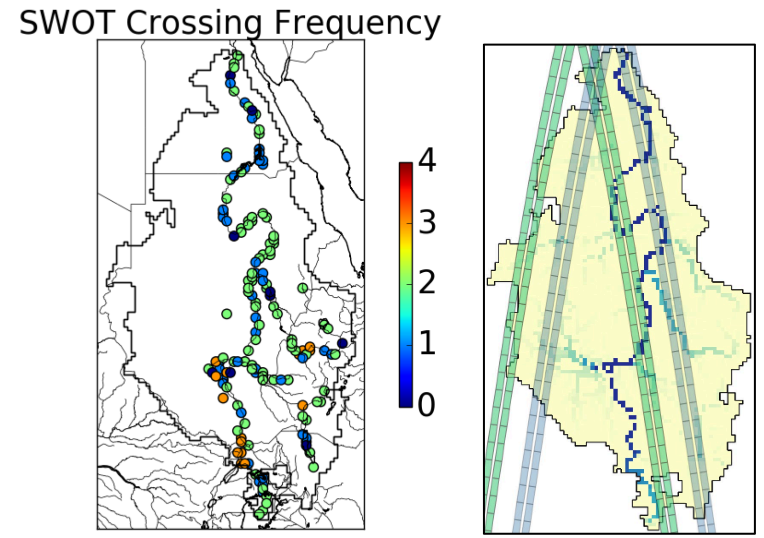
+ More frequent observations (higher latitudes)

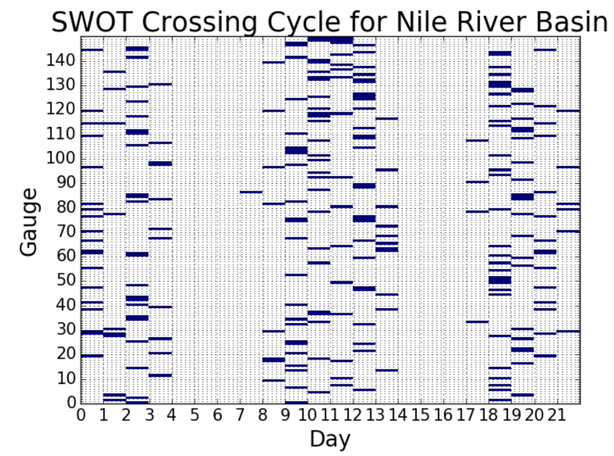
From Fisher et al. (In Prep.)

Conclusions

- For most basins we are able to use ISR reconstruct spatially and temporally consistent discharge
  - Also reconstruct runoff fields
- Utilization of SWOT observations will be dependent on:
  - Timing and orientation of overpasses
  - Basin geometry and orientation
  - Availability of in-situ discharge or runoff information to aid in the assimilation
- Future work is also needed to:
  - Better quantify orientation of rivers relative to orbit
  - Differentiate observations of rivers and floodplain areas
  - Incorporate human influence

Nile River





Thanks to:

- The members of the Terrestrial Hydrology Group and the Princeton CEE Department for their support in completing this research
- Sylvain Biancamaria for providing the theoretical SWOT orbit

References:

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Thank you,
Questions?

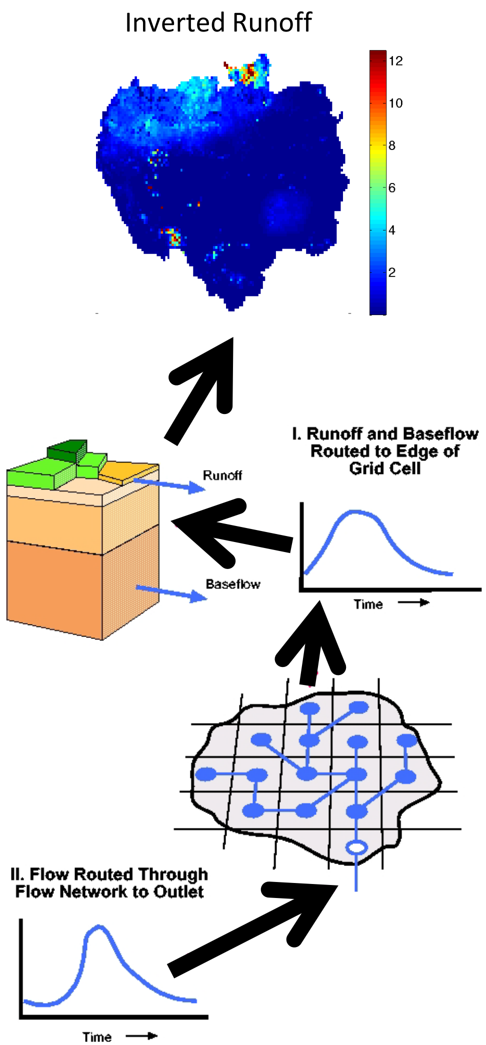
Kalman Smoother

Forward model (Linear Routing): $\mathbf{y} = \mathbf{H}\mathbf{x}$

Where H = Green's Impulse Response Function (Lohmann, 1996)

The integrated routing process can then be given a linear form:

$$\mathbf{y}_t = \mathbf{H}_0\mathbf{x}_t + \mathbf{H}_1\mathbf{x}_{t-1} + \cdots + \mathbf{H}_k\mathbf{x}_{t-k} + \varepsilon_t \qquad \mathbf{y}_t = \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_m \end{bmatrix}_t \qquad \mathbf{x}_t = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{bmatrix}_t$$



Inversion is done through a Kalman Filter & Smoother:

$$\hat{\mathbf{x}}''_t = \hat{\mathbf{x}}'_t + \mathbf{K}_t(\mathbf{y}'_t - \mathbf{H}'\hat{\mathbf{x}}'_t - \mathbf{L}'\hat{\mathbf{x}}'_{t-k})$$

The weight of the correction (Kalman Gain) is determined as:

$$\mathbf{K}_t = \mathbf{P}_t\mathbf{H}'^T\left(\mathbf{H}'\mathbf{P}_t\mathbf{H}'^T + \mathbf{R}_t\right)^{-1}$$

Smoothing window of **2x max flow length (days)** was used for this study