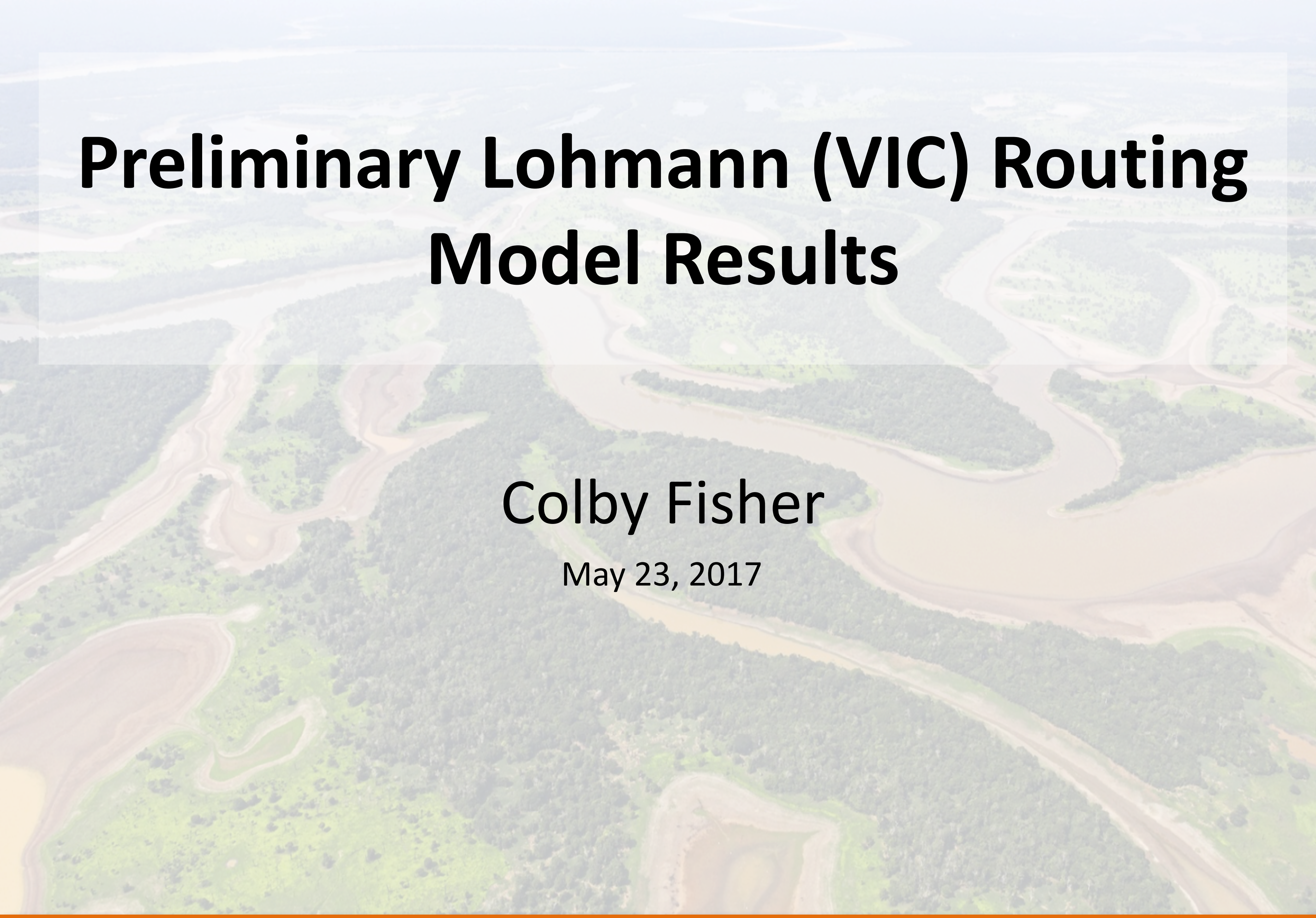


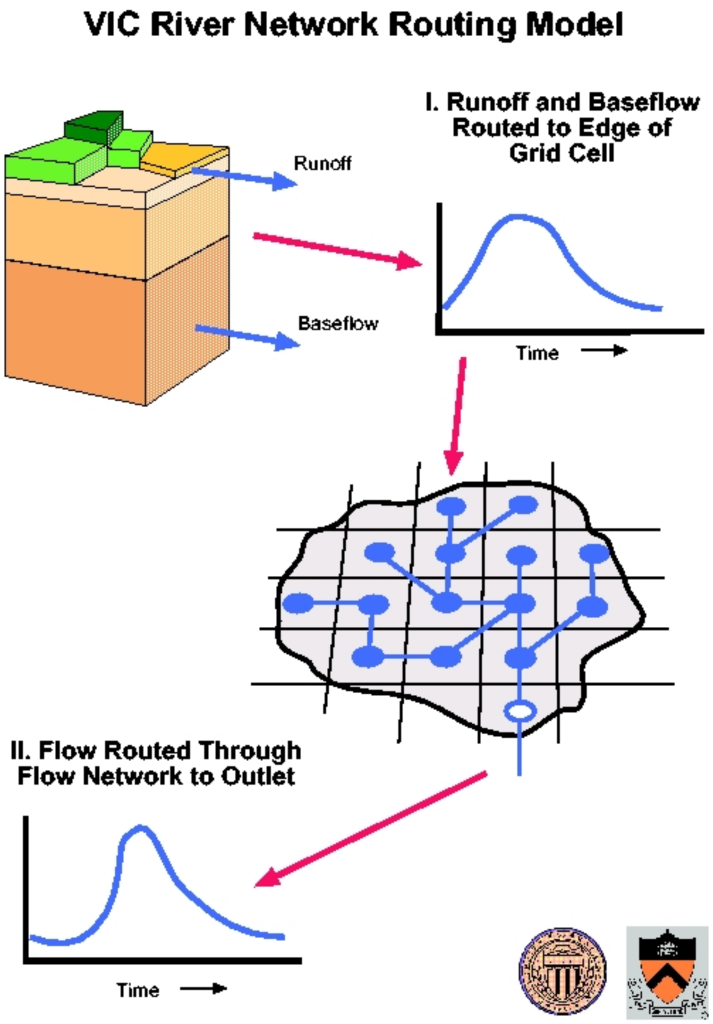
Preliminary Lohmann (VIC) Routing Model Results

Colby Fisher

May 23, 2017

RVIC - Lohmann Routing

- Routing is performed separately from the land surface simulation, using a separate routing model ([Lohmann, et al. (1996; 1998)](#))
- Each grid cell is represented by a node in the channel network
- Total runoff and baseflow from each grid cell is first convolved with a unit hydrograph representing the distribution of travel times to the channel network
- The grid cell's input into the channel network is then routed through the channel using linearized St. Venant's equations



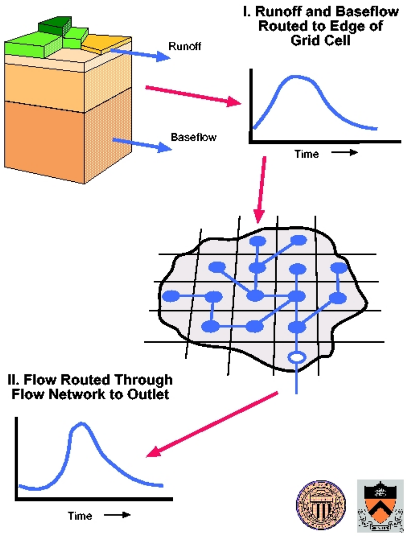
http://rvic.readthedocs.io/en/latest/about/model-overview/

Routing Model

- Routed according to the following :
  - In-grid flow concentration is given by basic unit hydrograph
  - In-channel flow is given by the Saint Venant's equation:

$$\frac{\partial q}{\partial t} = D\frac{\partial^2 q}{\partial x^2} - C\frac{\partial q}{\partial x}$$

D, C vary with geography or static



(Lohmann, 1996)

  - Solved using convolution

$$q(x,t) = \int_0^t u(t-s)h(x,s)ds$$

Of Green's (impulse response) function, given by:

$$h(x,t) = \frac{x}{2t\sqrt{\pi t D}}\exp\left(-\frac{(Ct-x)^2}{4Dt}\right)$$

Model Setup

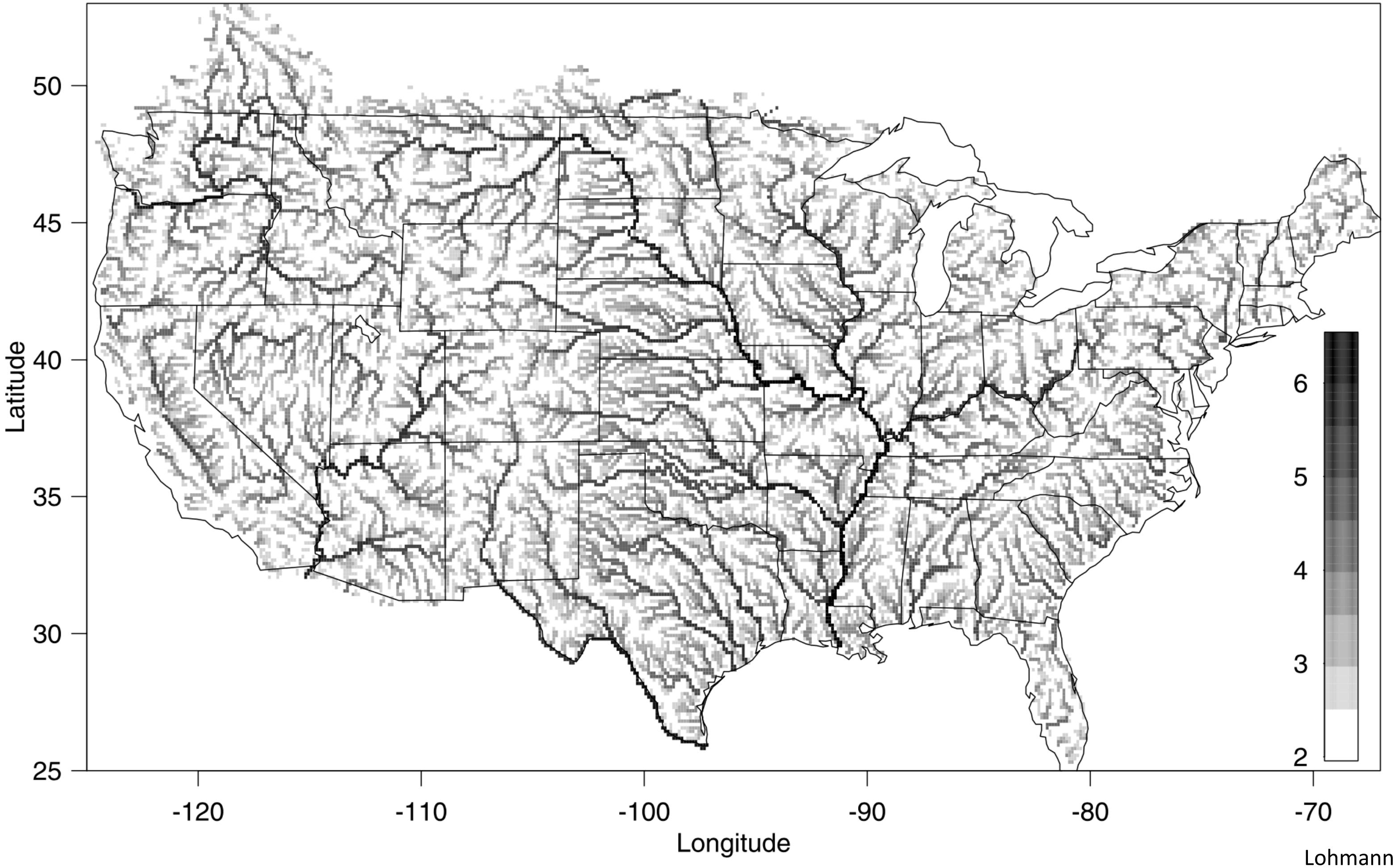
- Simulations for the Mississippi with NLDAS Runoff
    - Date: 01/01/2000 to 12/31/2009, 6 months spinup before start

- 0.125 degree resolution
- Hourly time step and averaged to daily (also run with just daily)

- Topography: SWOT-MIP setup (Direc. derived from Dai's DEM)
    - Temporarily using a different network (Legacy code thinks there is something wrong with the new DEM)

Model Setup

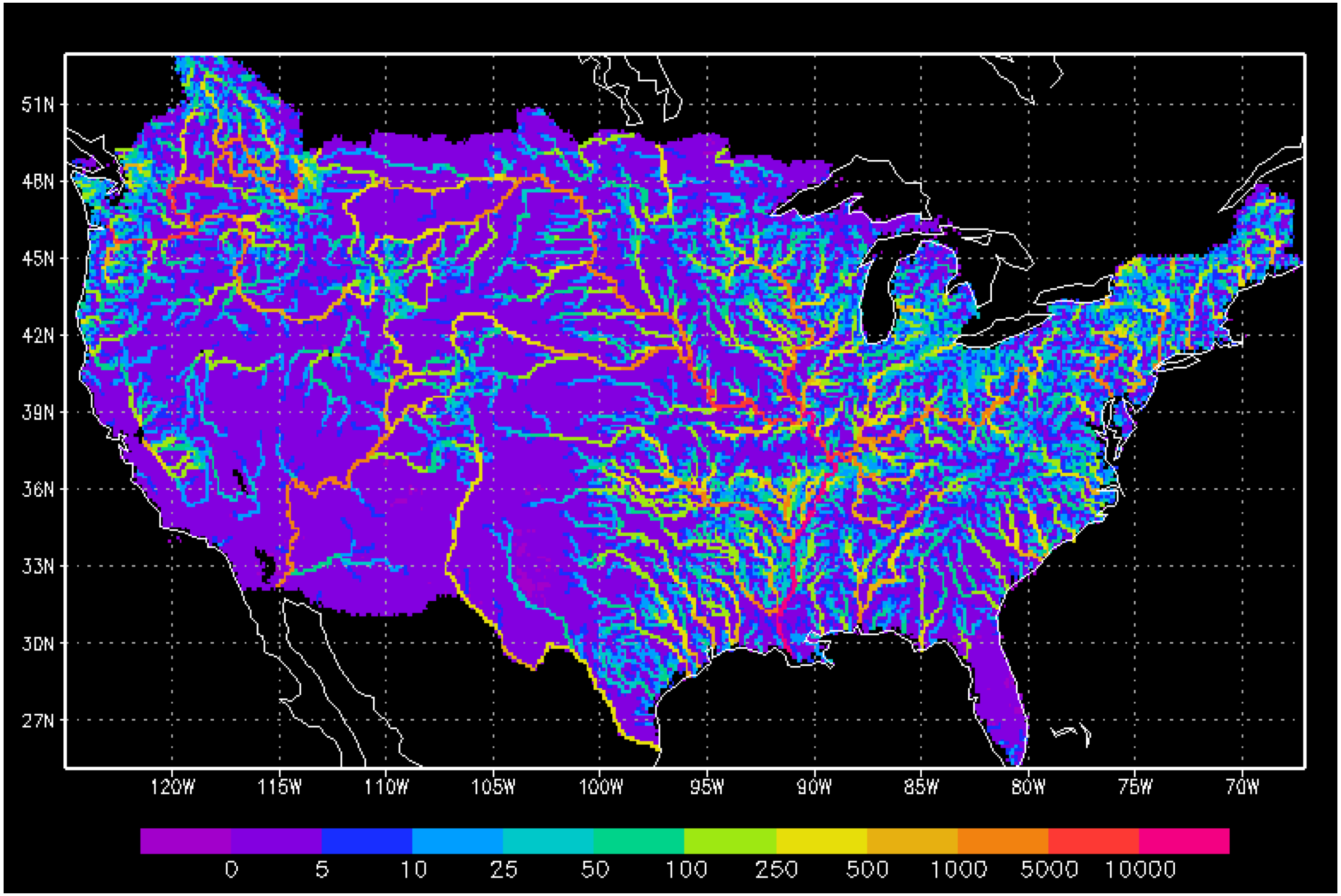
- Flow Network:



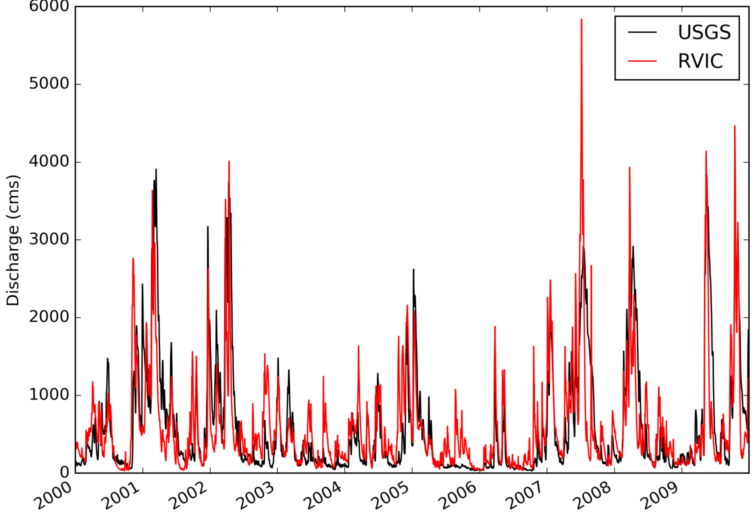
Lohmann, 1998

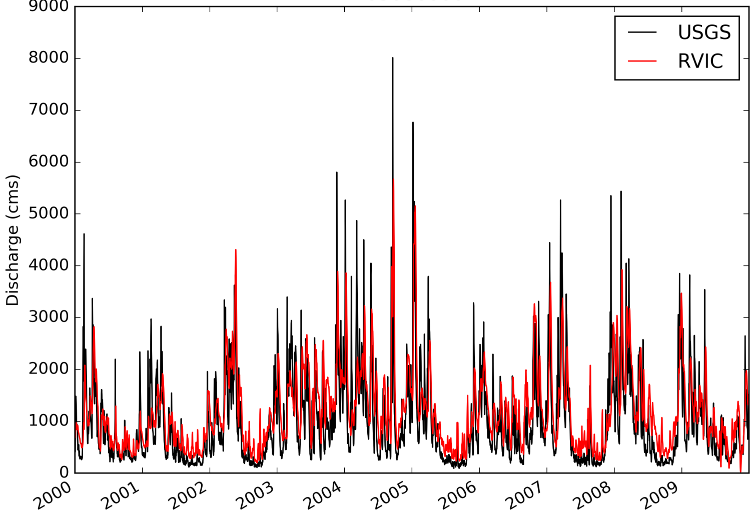
Results

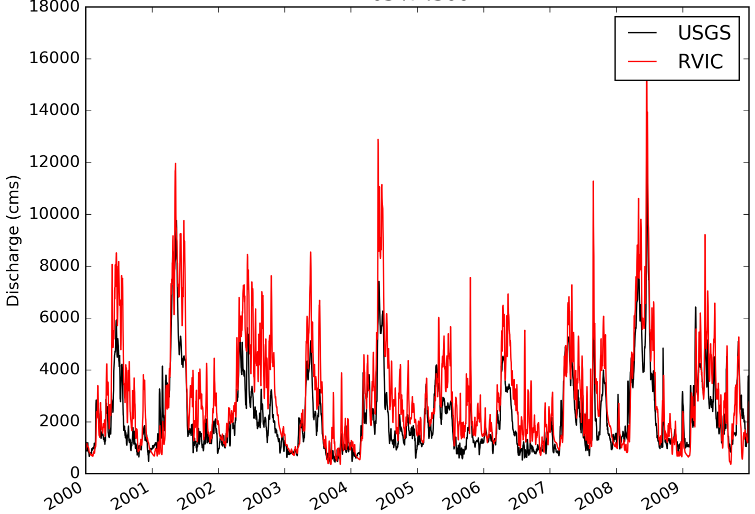
Daily Discharge Output

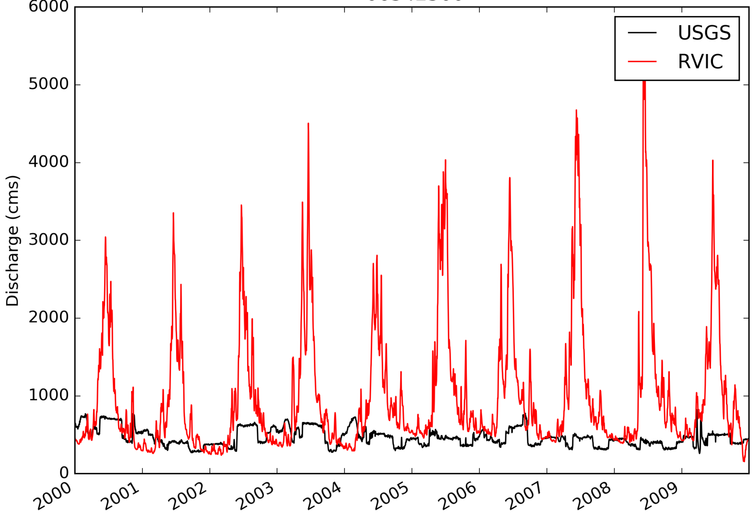


Results – Overall TS

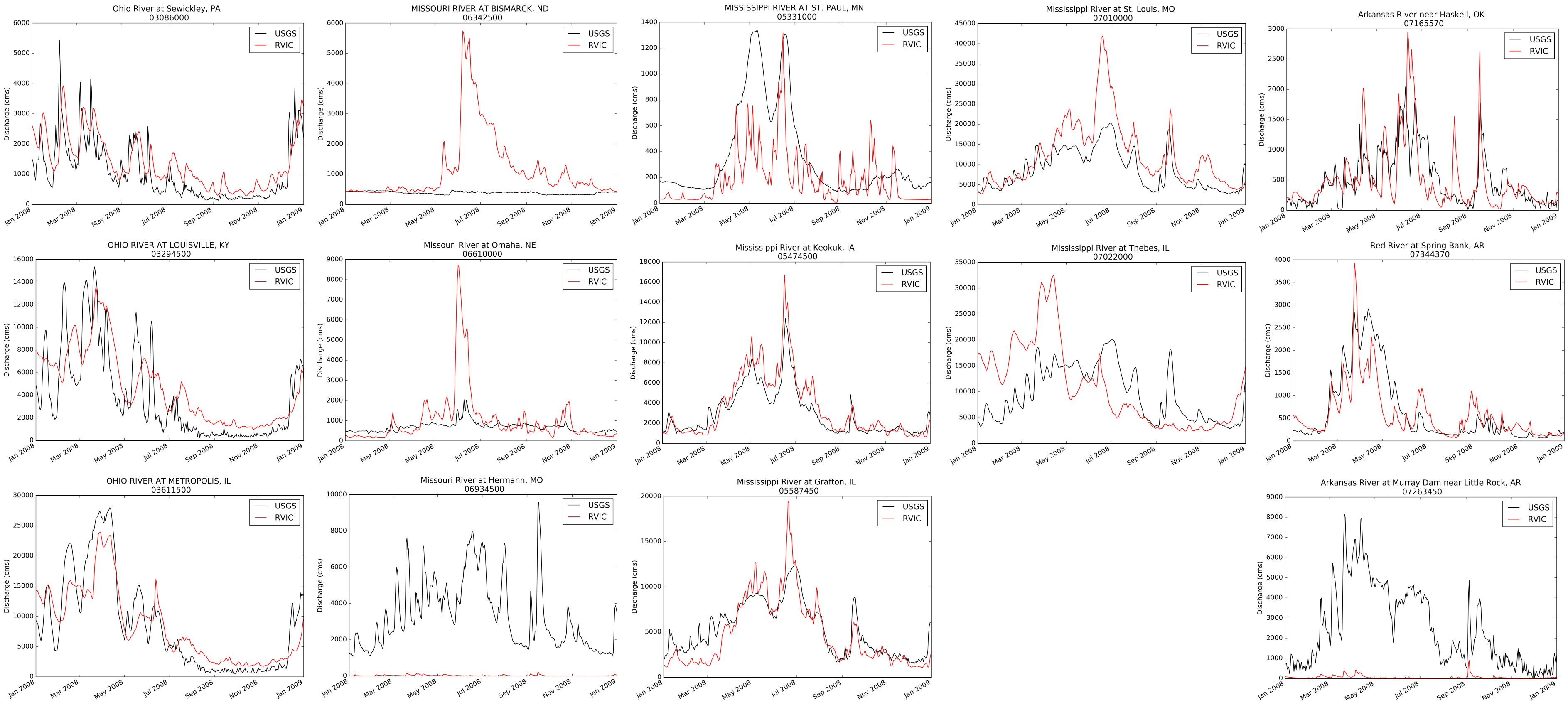

Red River at Spring Bank, AR
07344370


Ohio River at Sewickley, PA
03086000

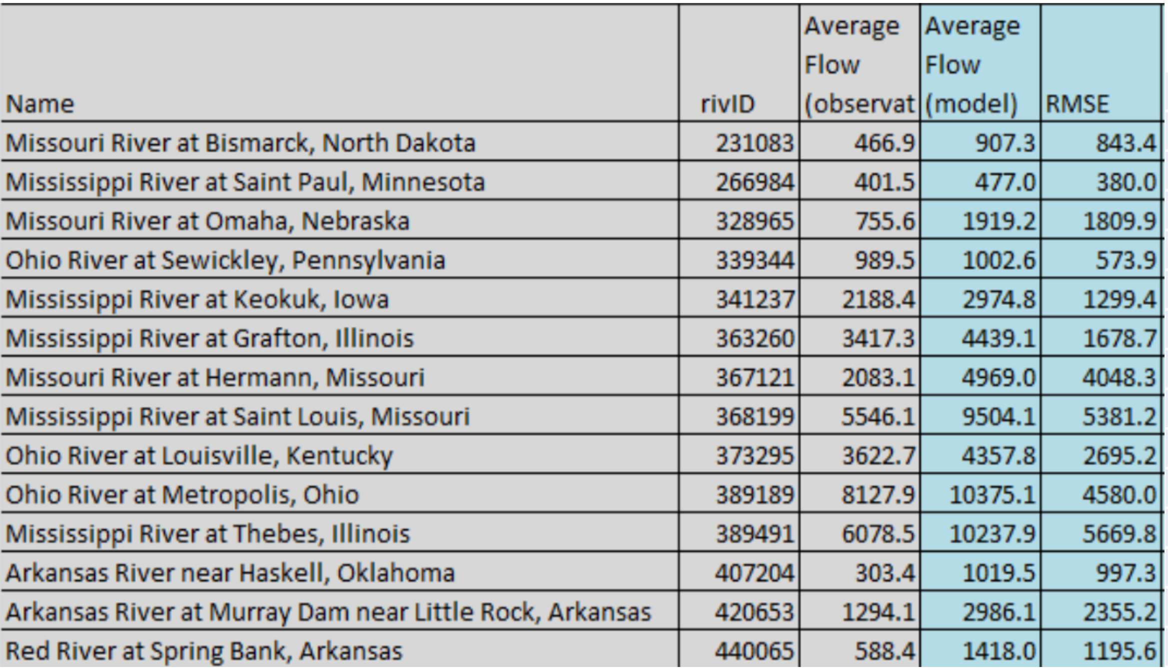

Mississippi River at Keokuk, IA
05474500


MISSOURI RIVER AT BISMARCK, ND
06342500

Results


Ohio River at Sewickley, PA 03086000
MISSOURI RIVER AT BISMARCK, ND 06342500
MISSISSIPPI RIVER AT ST. PAUL, MN 05331000
Mississippi River at St. Louis, MO 07010000
Arkansas River near Haskell, OK 07165570
OHIO RIVER AT LOUISVILLE, KY 03294500
Missouri River at Omaha, NE 06610000
Mississippi River at Keokuk, IA 05474500
Mississippi River at Thebes, IL 07022000
Red River at Spring Bank, AR 07344370
OHIO RIVER AT METROPOLIS, IL 03611500
Missouri River at Hermann, MO 06934500
Mississippi River at Grafton, IL 05587450
Arkansas River at Murray Dam near Little Rock, AR 07263450
USGS
RVIC
Discharge (cms)
Jan 2008
Mar 2008
May 2008
Jul 2008
Sep 2008
Nov 2008
Jan 2009

Results - Stats



Name	rivID	Average Flow (observat	Average Flow (model)	RMSE
Missouri River at Bismarck, North Dakota	231083	466.9	907.3	843.4
Mississippi River at Saint Paul, Minnesota	266984	401.5	477.0	380.0
Missouri River at Omaha, Nebraska	328965	755.6	1919.2	1809.9
Ohio River at Sewickley, Pennsylvania	339344	989.5	1002.6	573.9
Mississippi River at Keokuk, Iowa	341237	2188.4	2974.8	1299.4
Mississippi River at Grafton, Illinois	363260	3417.3	4439.1	1678.7
Missouri River at Hermann, Missouri	367121	2083.1	4969.0	4048.3
Mississippi River at Saint Louis, Missouri	368199	5546.1	9504.1	5381.2
Ohio River at Louisville, Kentucky	373295	3622.7	4357.8	2695.2
Ohio River at Metropolis, Ohio	389189	8127.9	10375.1	4580.0
Mississippi River at Thebes, Illinois	389491	6078.5	10237.9	5669.8
Arkansas River near Haskell, Oklahoma	407204	303.4	1019.5	997.3
Arkansas River at Murray Dam near Little Rock, Arkansas	420653	1294.1	2986.1	2355.2
Red River at Spring Bank, Arkansas	440065	588.4	1418.0	1195.6

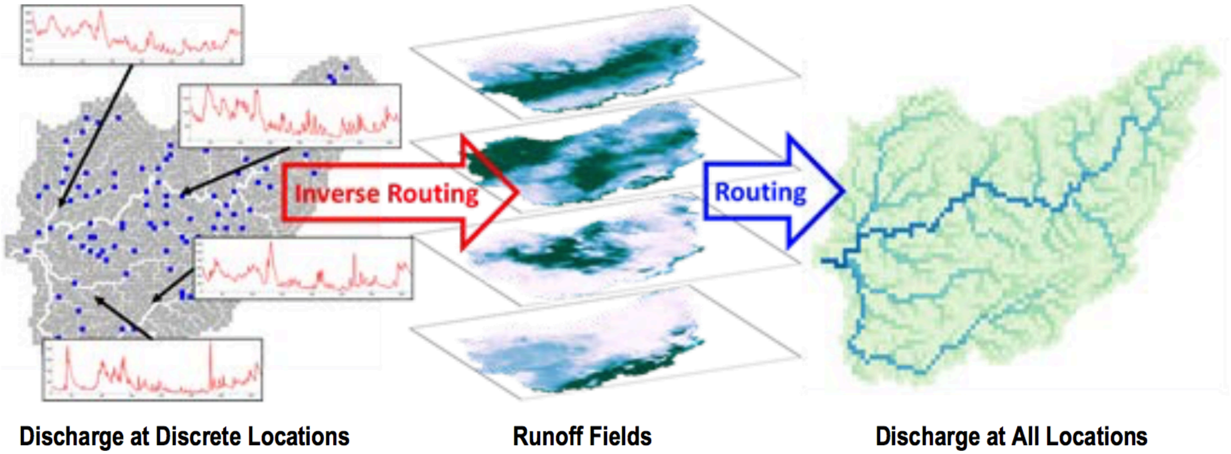
Mean Q (Obs)	Mean Q (Model)	RMSE
466.9	995.4	972.3
401.5	282.5	355.7
755.5	695.5	760.5
989.6	1180.1	633.0
2188.6	2991.0	1365.3
3418.1	3639.1	1534.8
2083.2	15.9	2497.3
5547.1	8839.3	4985.0
3623.3	4317.3	2641.6
8129.7	7239.1	4111.0
6080.4	10255.5	7225.0
303.3	287.9	354.7
1294.1	39.1	1868.8
588.6	592.4	473.8

Summary

- Acceptable results from a simple model
  - Good stats on the monthly level (for LSMs)
- Often misses timing of certain events and human influences
- Can serve as a baseline for other model results
- Still need to fix the flow direction issue to make sure everything is consistent

SWOT Assimilation Experiments

- How can we use future SWOT data 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)



Inverse Streamflow Routing

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:

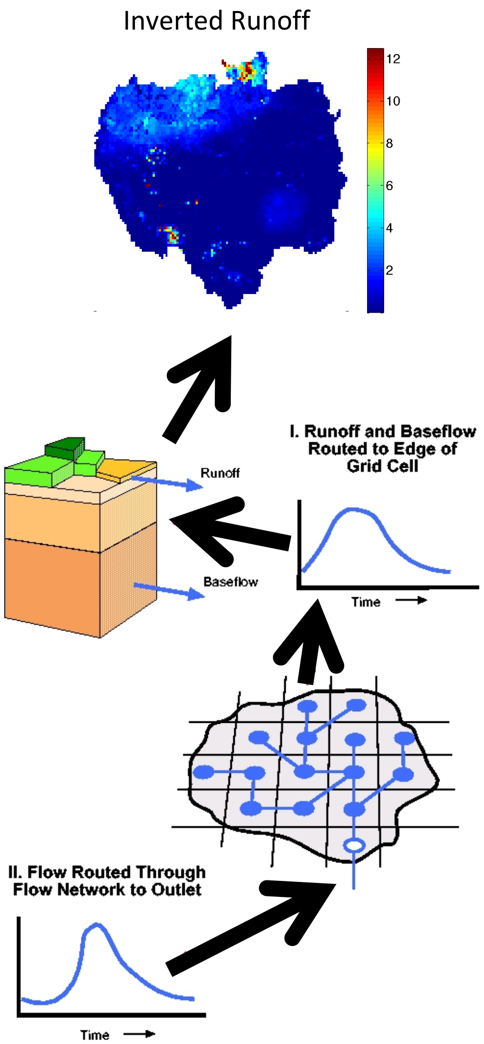
$$\mathbf{y}_t = \mathbf{H}_0\mathbf{x}_t + \mathbf{H}_1\mathbf{x}_{t-1} + \cdots + \mathbf{H}_k\mathbf{x}_{t-k} + \varepsilon_t \qquad \mathbf{y}_t = \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_m \end{bmatrix}_t \qquad \mathbf{x}_t = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{bmatrix}_t$$

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:

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

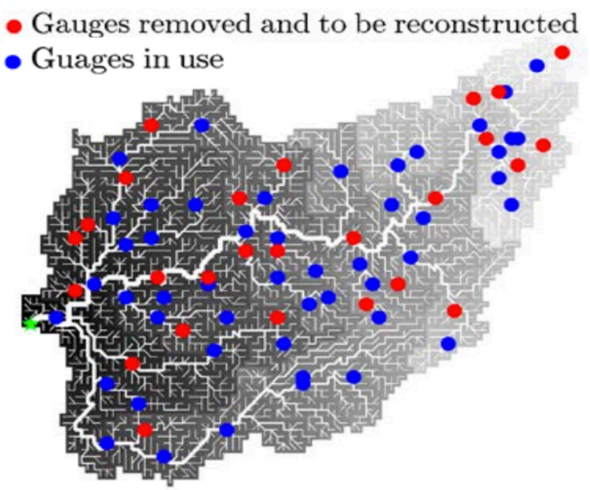


Smoothing window of **2x max flow length (days)** was used for this study

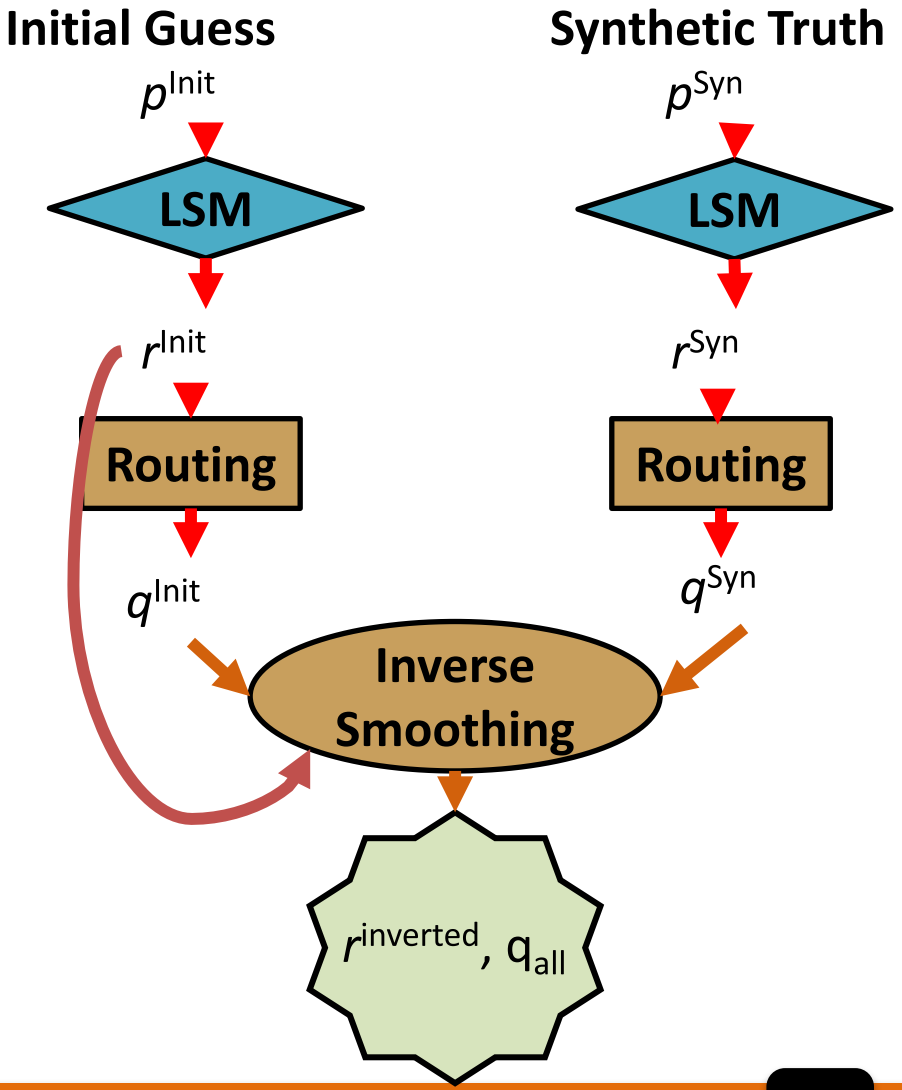
Inverse Streamflow Routing

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



Initial Guess

p^{Init}

LSM

r^{Init}

Routing

q^{Init}

Synthetic Truth

p^{Syn}

LSM

r^{Syn}

Routing

q^{Syn}

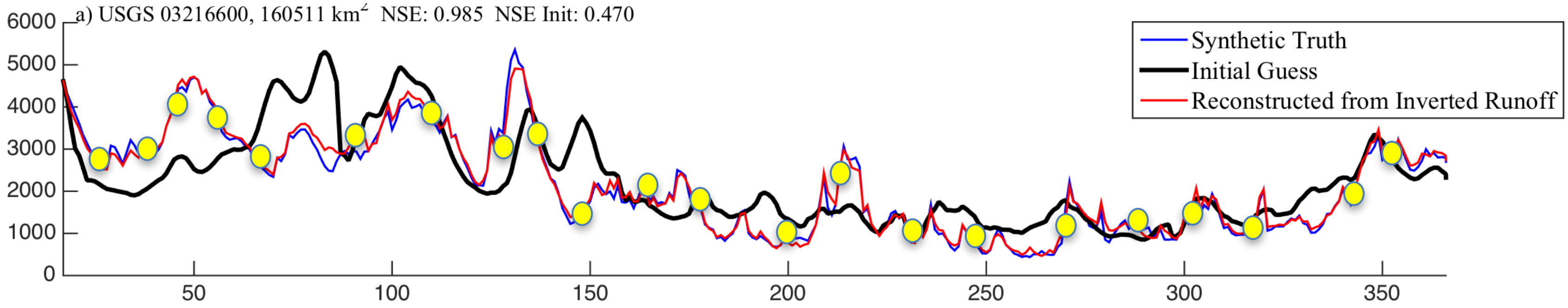
Inverse Smoothing

r^{inverted}, q_{all}

Discharge Interpolation Experiments

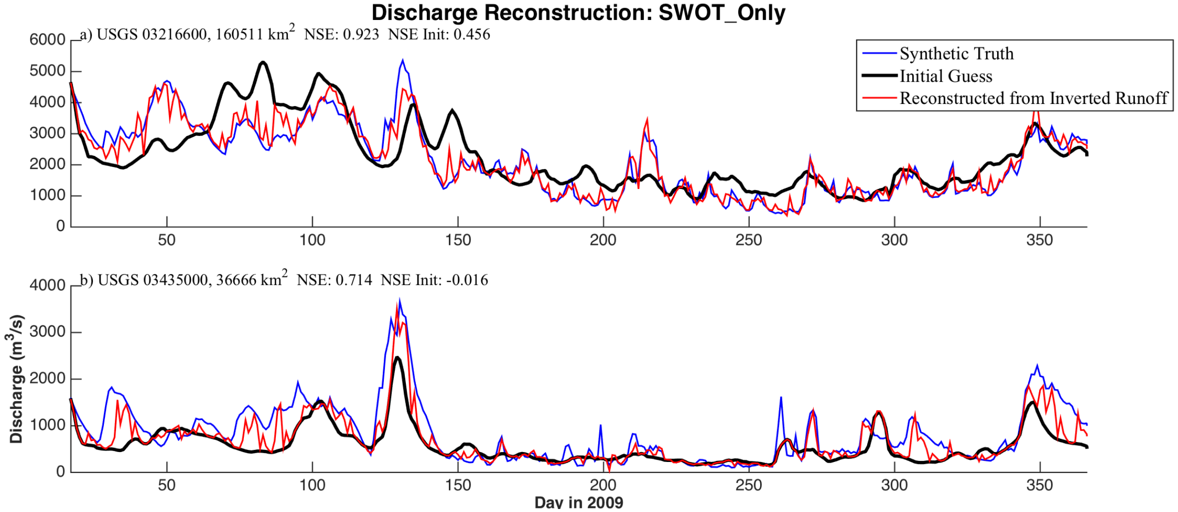
Discharge Data Assimilated

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



ISR – SWOT Assimilation

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

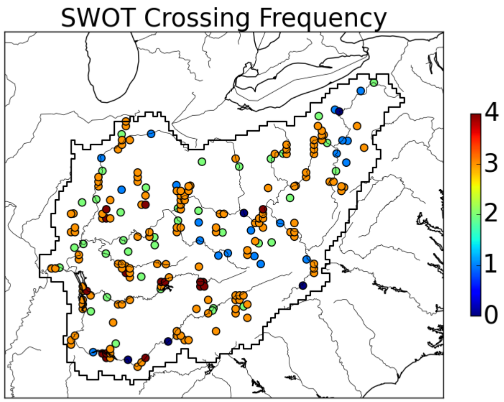


Discharge Reconstruction: SWOT_Only

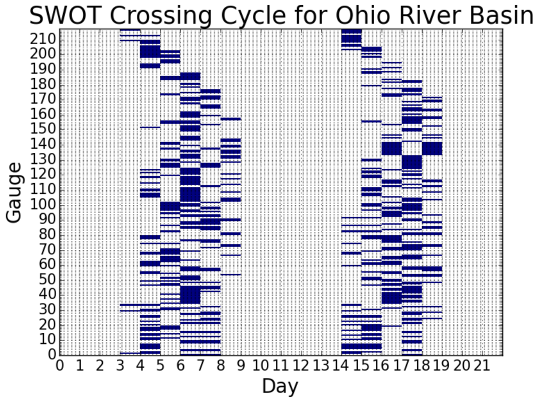
a) USGS 03216600, 160511 km^2 NSE: 0.923 NSE Init: 0.456

b) USGS 03435000, 36666 km^2 NSE: 0.714 NSE Init: -0.016

- Performance constrained by spatial and temporal coverage:



SWOT Crossing Frequency

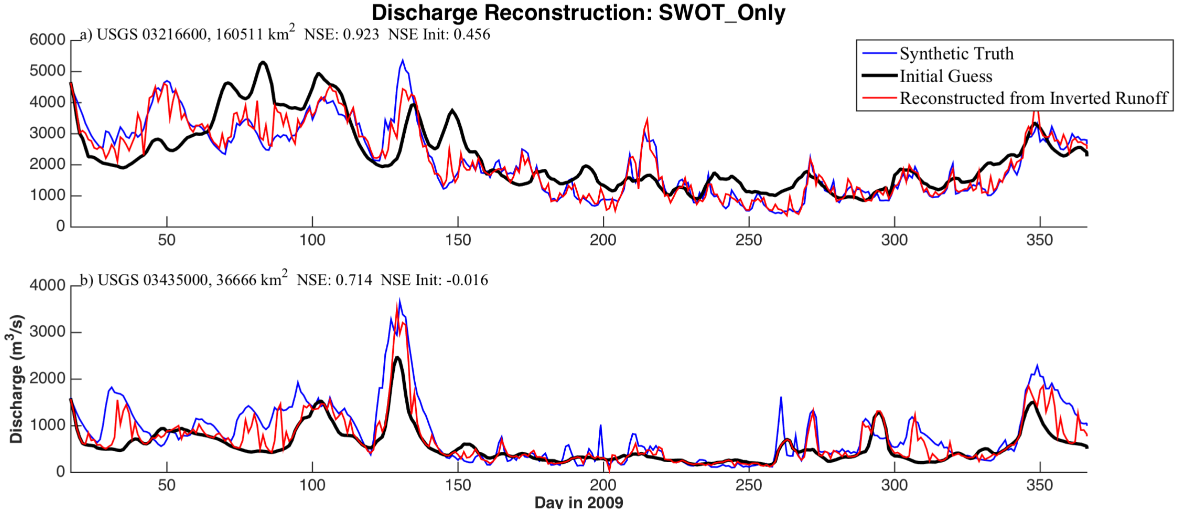


SWOT Crossing Cycle for Ohio River Basin

From Fisher et al. (In Prep.)

ISR – SWOT Assimilation

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



- Performance constrained by spatial and temporal coverage:

SWOT Crossing Frequency

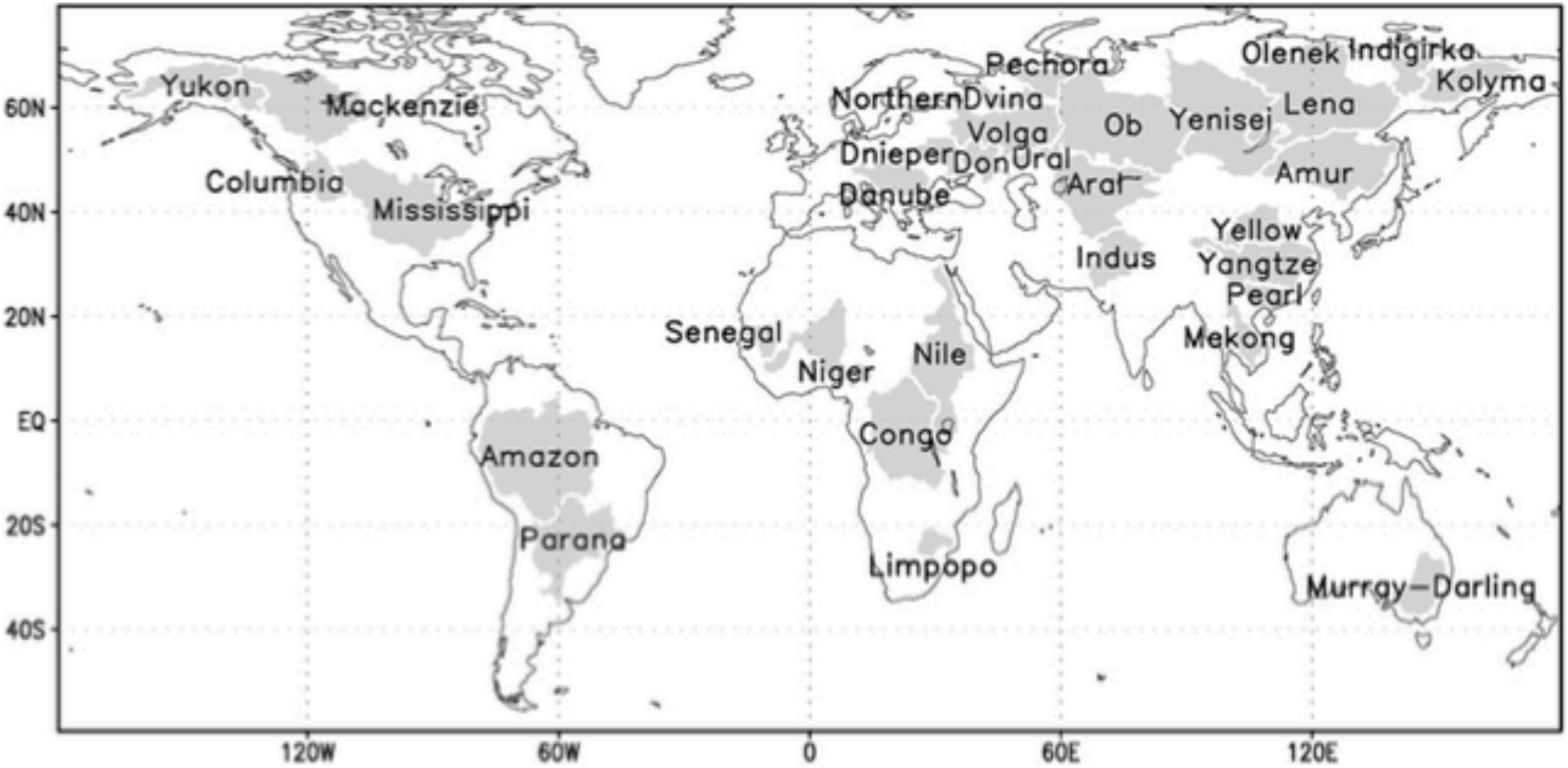
- **How will SWOT observe other river basins?**
- **How will their location and spatial properties affect the assimilation?**

Day

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

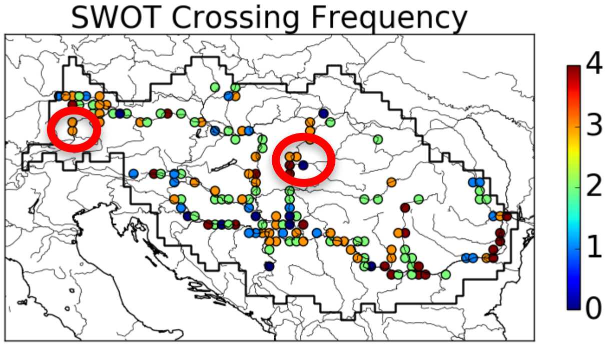
Discharge Data Assimilated

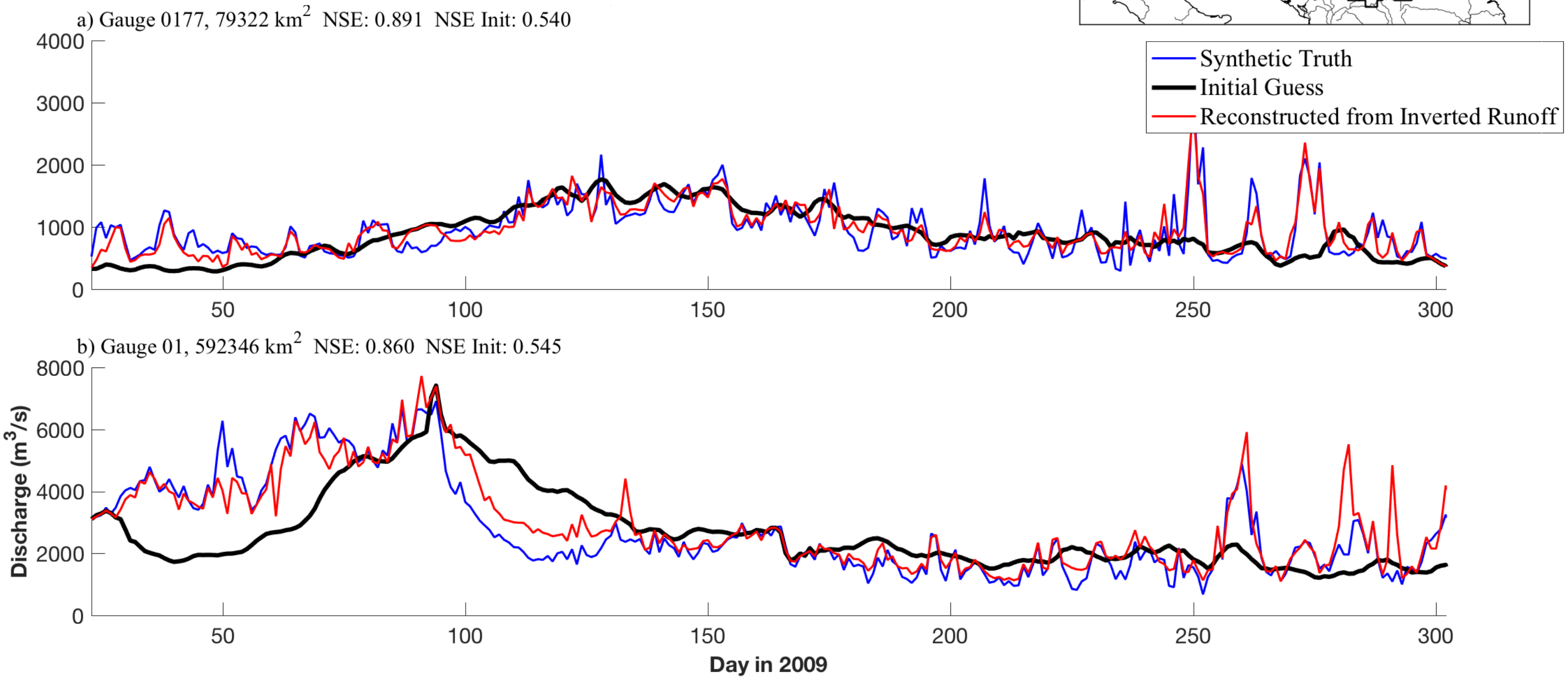
Initial Runoff Conditions	All Gauges	SWOT Only	Mixed Gauges and SWOT
Long Term Basin Mean	**In-Situ** Discharge & **Min.** Runoff Info	**SWOT** Discharge & **Min.** Runoff Info	**Mixed** Discharge & **Min.** Runoff Info
Daily Climatology	**In-Situ** Discharge & **Some** Runoff Info	**SWOT** Discharge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

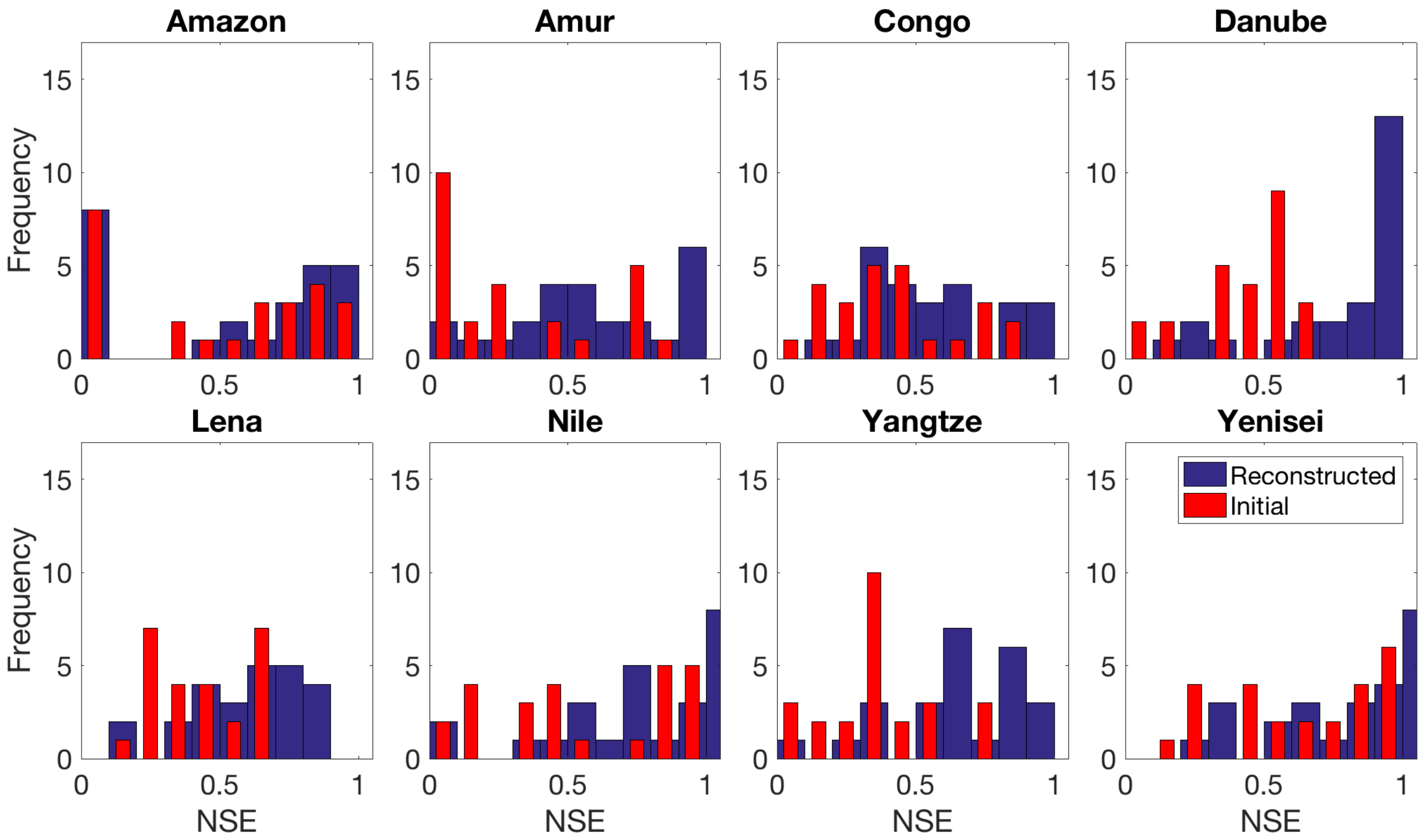
Assimilation using runoff climatology + SWOT sampled discharge time series for the Danube





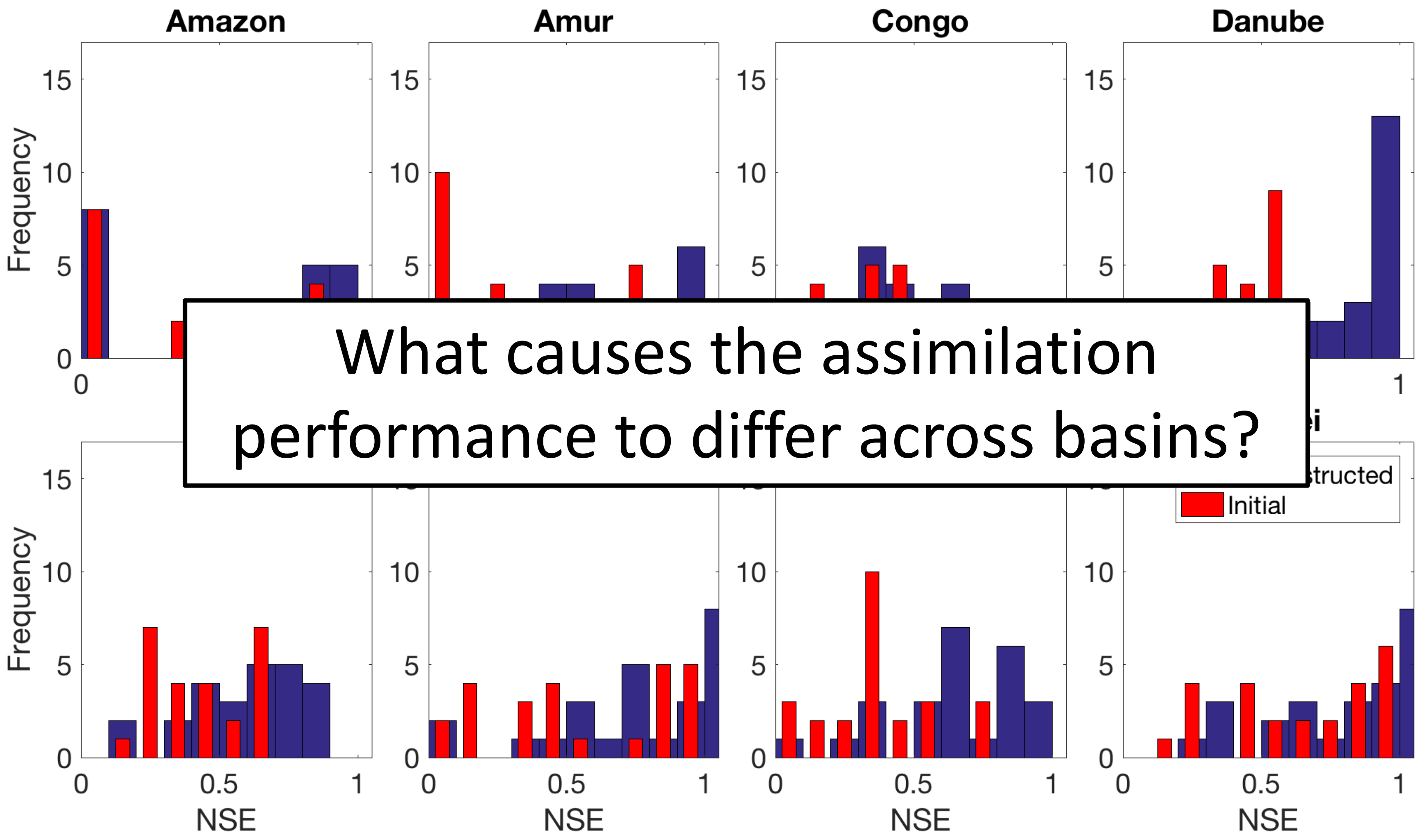
Global Interpolation Performance

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



Global Interpolation Performance

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

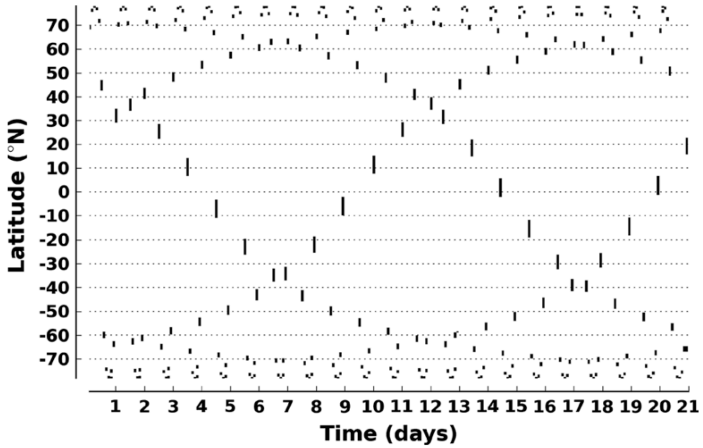


What causes the assimilation performance to differ across basins?

Global Applicability

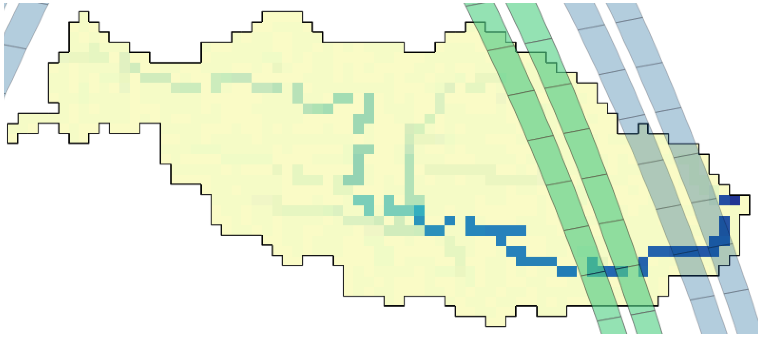
SWOT orbit dictates the availability of data for assimilation

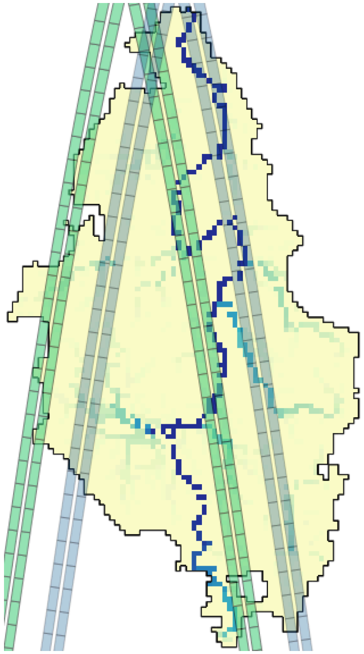
- Depends on River:
  - Latitude
  - Size (length, width and basin area)
  - Orientation

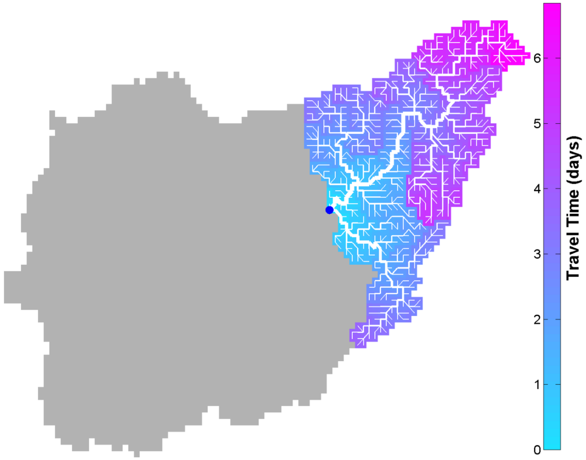


Biancamaria et al., 2015

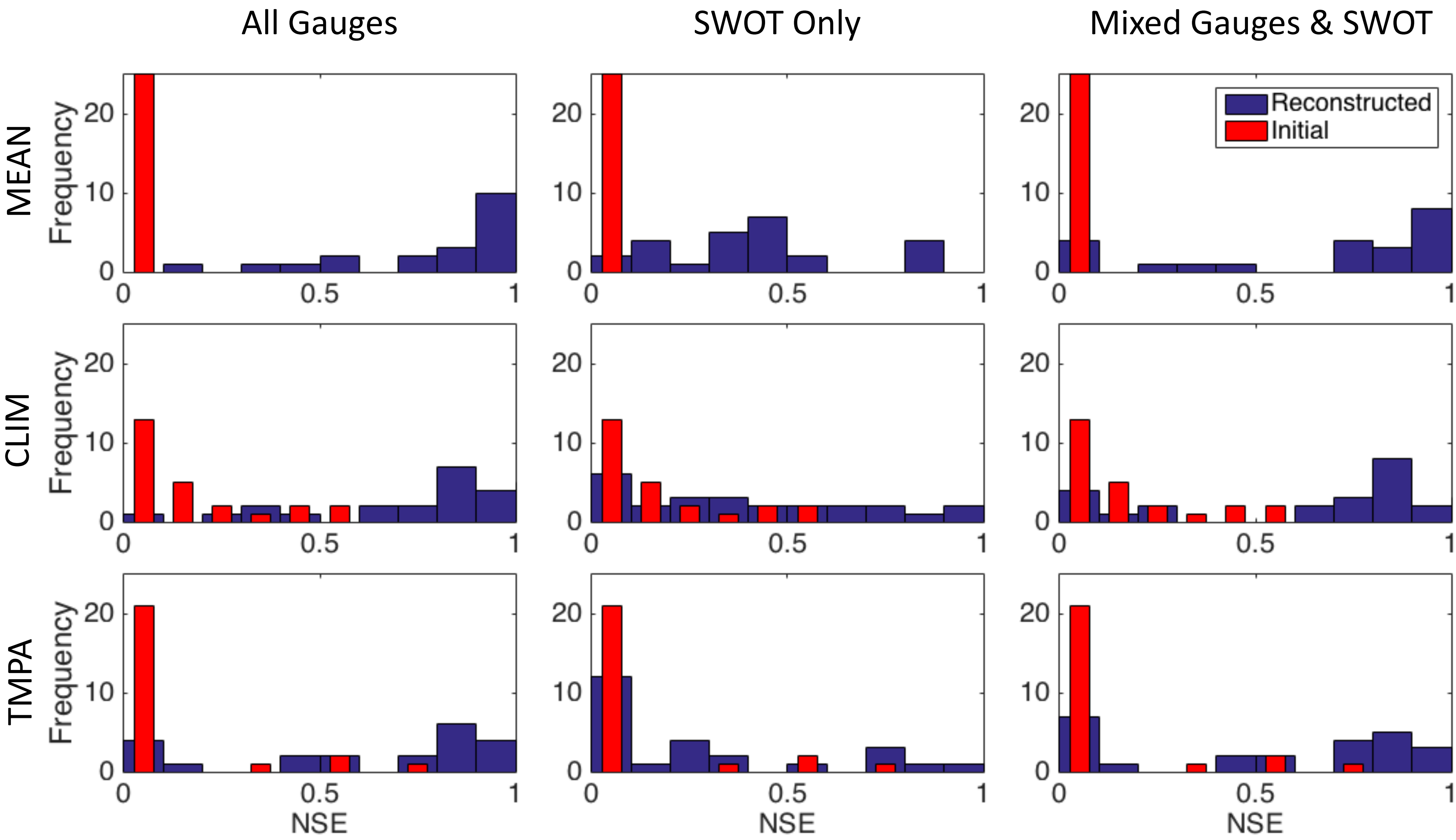
Day 1 and 2 Crossings for the: Danube & Nile







Adding in Discharge Obs.

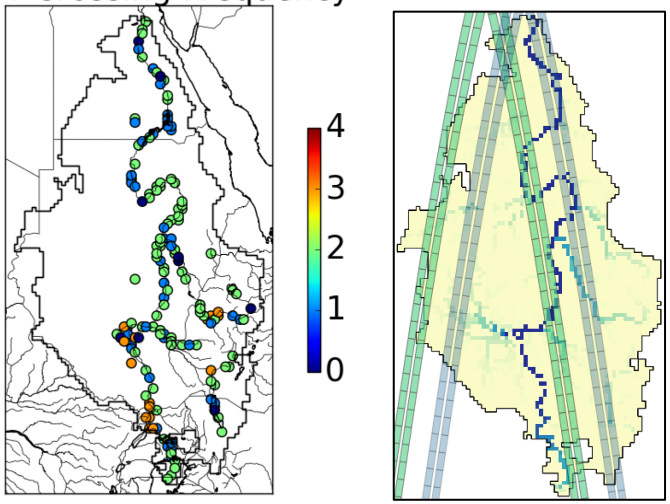


Conclusions

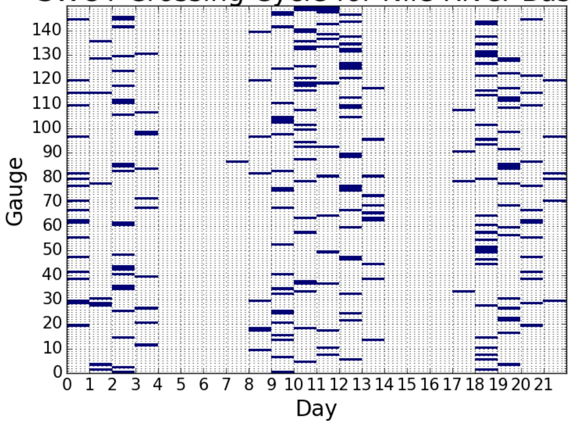
- For most basins we are able to use ISR reconstruct spatially and temporally consistent discharge
  - Also reconstruct runoff fields
- Utilization of SWOT observations will be dependent on:
  - Timing and orientation of overpasses
  - Basin geometry and orientation
  - Availability of in-situ discharge 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

Nile River

SWOT Crossing Frequency



SWOT Crossing Cycle for Nile River Basin



Thank you, Questions?

References:

- Biancamaria, S., Lettenmaier, D. P., & Pavelsky, T. M. (2015). The SWOT Mission and Its Capabilities for Land Hydrology. Surveys in Geophysics, 1–31.
- Lohmann, D., R. Nolte-Holube, and E. Raschke, 1996: A large-scale horizontal routing model to be coupled to land surface parametrization schemes, Tellus, 48(A), 708-721.
- Lohmann, D., E. Raschke, B. Nijssen and D. P. Lettenmaier, 1998: Regional scale hydrology: I. Formulation of the VIC-2L model coupled to a routing model, Hydrol. Sci. J., 43(1), 131-141.
- Paiva, R. C. D., Durand, M. T., & Hossain, F. (2015). Spatiotemporal interpolation of discharge across a river network by using synthetic SWOT satellite data. Water Resources Research, 51(1), 430–449.
- Pan, M., & Wood, E. F. (2013). Inverse streamflow routing. Hydrology and Earth System Sciences, 17(11), 4577–4588.
- Pavelsky, T. M., Durand, M. T., Andreadis, K. M., Beighley, R. E., Paiva, R. C. D., Allen, G. H., & Miller, Z. F. (2014). Assessing the potential global extent of SWOT river discharge observations. Journal of Hydrology, 519(PB), 1516–1525.