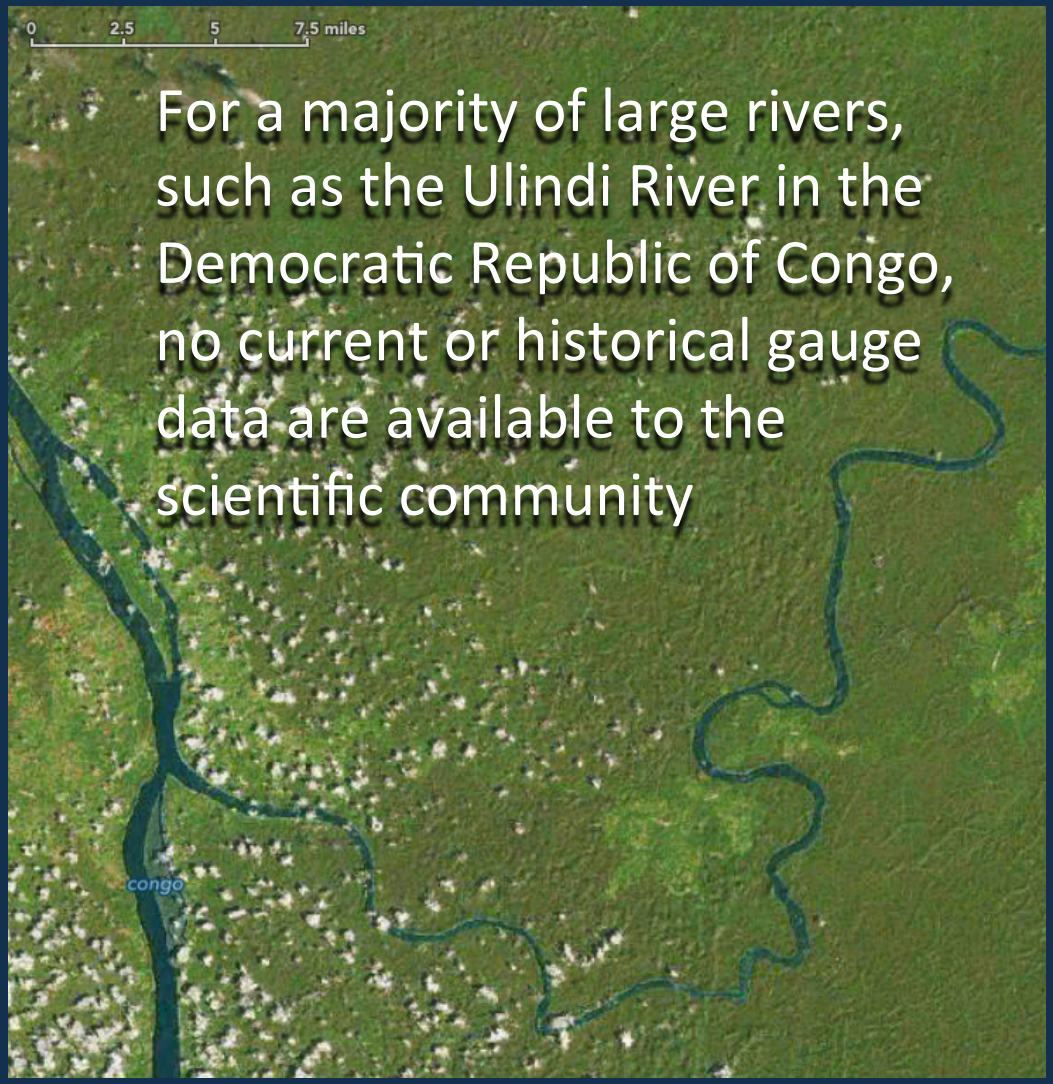
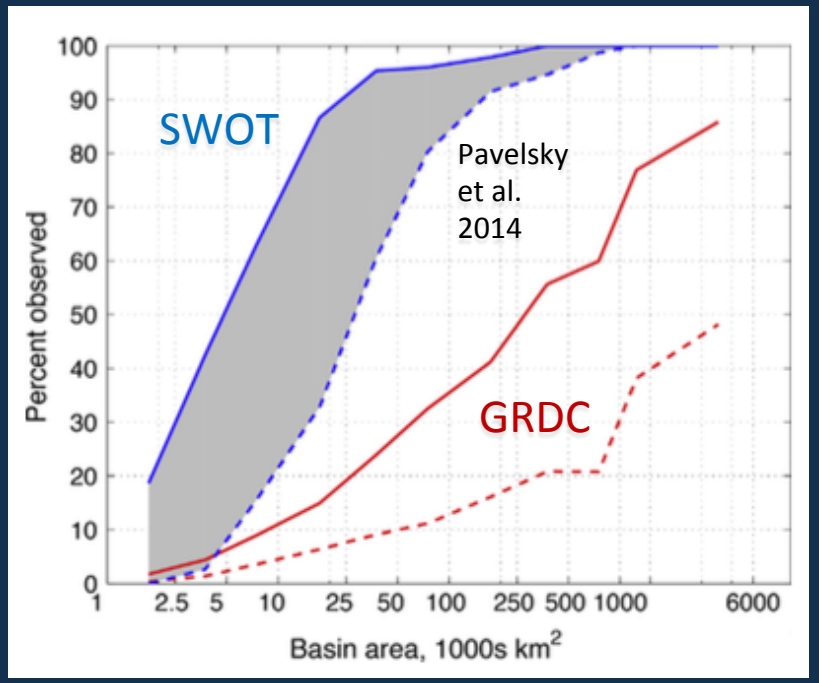
The Pepsi Challenge & Discharge Moving Forward

Colin Gleason on behalf of:
Mike Durand
Dave Bjerklie
Pierre-Andre Garambois
Jérôme Monnier
Helene Roux
and many others…

June 16, 2016

Mass-conserved flow law inversion algorithms (McFLI)





Grand challenge: Accurate discharge estimation for ungauged rivers. McFLI algorithms provide a way forward

Mass-conserved flow law inversion algorithms (McFLI)

McFLI algorithms require a flow law to hold and flow to be conserved across reaches, and solve for flow law parameters such as bathymetry and roughness

Flow laws relate discharge (Q) to observations (Y) and unknown parameters (α) at each reach or cross-section (i) and for each overpass (t):

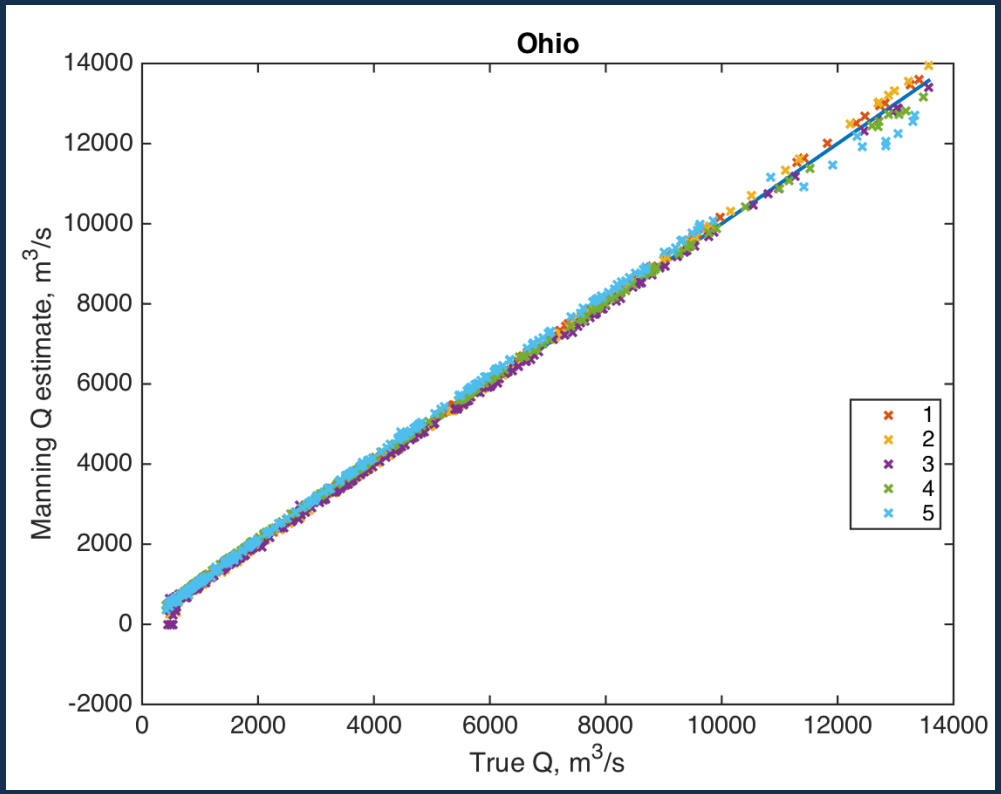
$$Q_{i,t} = f(Y_{i,t}, \alpha_i)$$

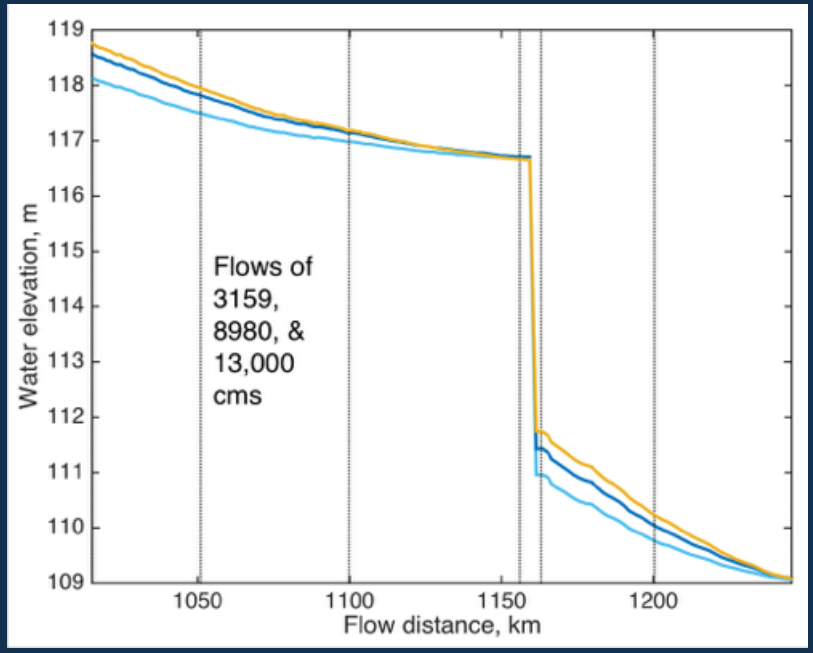
Mathematically, McFLI algorithms simply choose α to force flow laws to be consistent across reaches, and overpasses:

$$\min_{\alpha} \sum_{i,t} (Q_{i+1,t} - Q_{i,t})^2$$

Mass-conserved flow law inversion algorithms (McFLI)

We have found simple flow laws to be remarkably robust

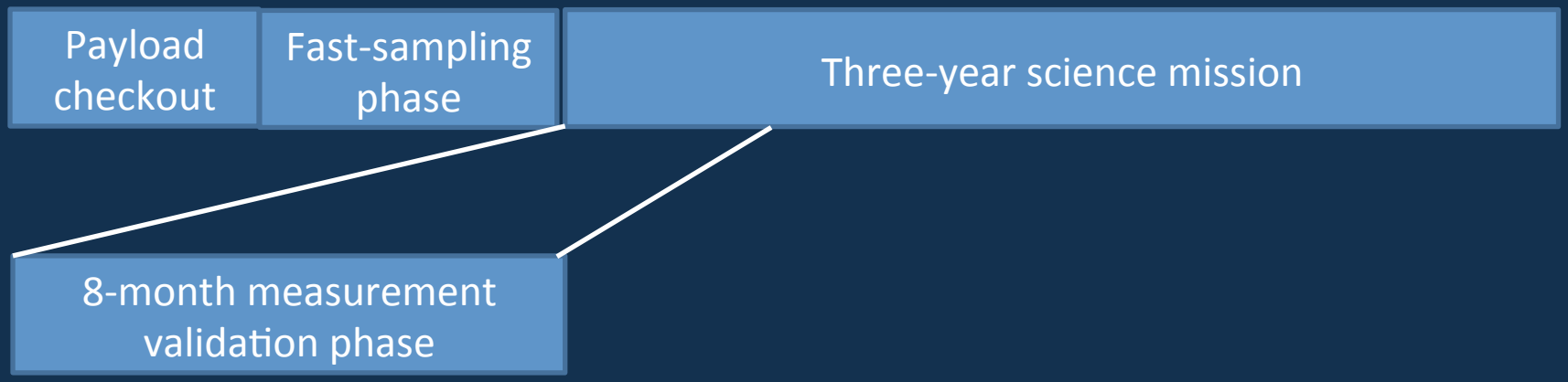




Applied to river surface slopes (the SWOT observable) Manning's equation is applicable to backwater behind low-head dams

Hydraulic geometry relationships also show surprising skill

Using McFLI algorithms with SWOT data



SWOT project will produce discharge beginning 6 months after the validation phase, using simple flow laws

The flow law parameters will be provided by the Science Team

The Science Team will estimate flow law parameters using McFLI algorithms applied to ~ 1 year of SWOT data

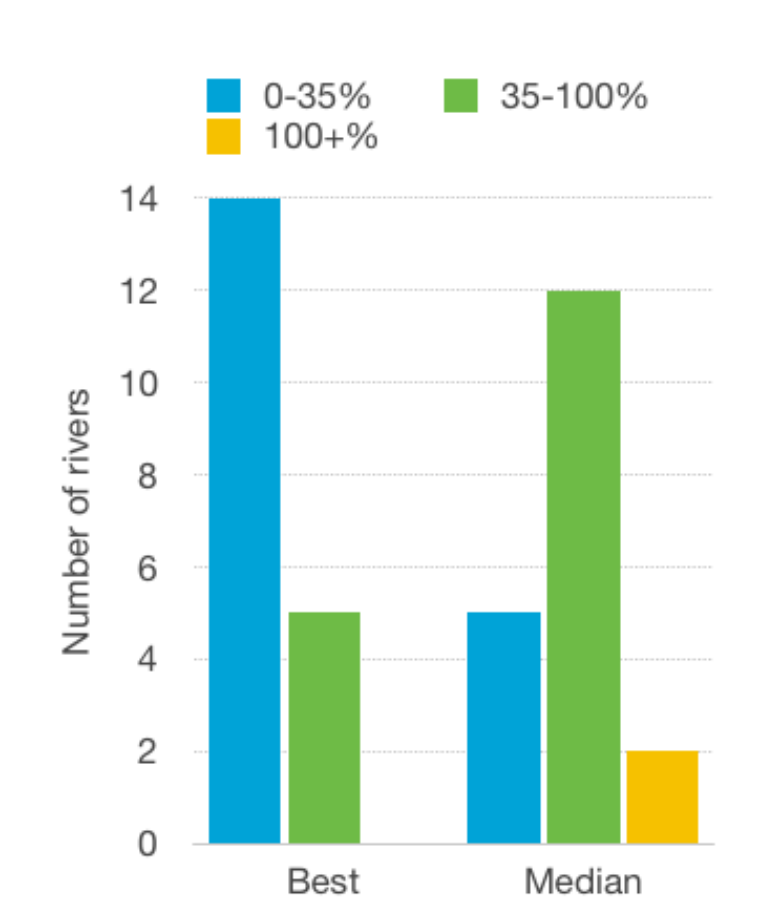
McFLI algorithm status: The Pepsi Challenge

McFLI algorithms including MetroMan, AMHG, and GaMo have been developed, and are supported by 7+ papers explaining the methods and testing on a particular river: Results all looked great!

The Pepsi Challenge was truly blind: we did not attempt to tune or tweak, but developed a feasible end-to-end process to test algorithms

Tested using model output with braided rivers, 1-D floodplains, simple multi-channel rivers, low-head dams, and some simple rivers

McFLI algorithm status: Performance bottom line



Relative RMSE
across all 19 rivers

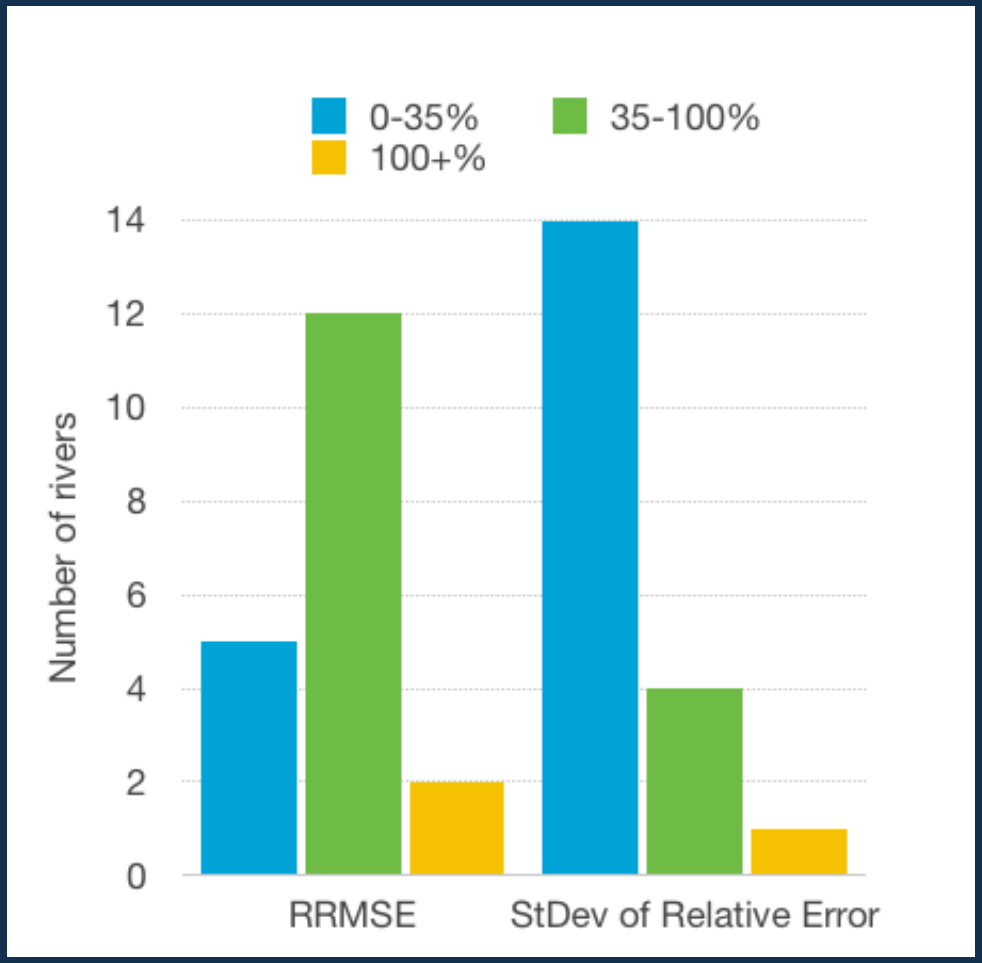
Target: < 35% RRMSE

Best-performing algorithms hit this target for 14/19 rivers, and for 14/16 non-braided rivers

No clear “best” algorithm for all rivers

Median across all algorithms hit target for only five rivers

McFLI algorithm status: Most of the error is bias



Standard deviation of the relative error hits the target in 14/19 cases

Thus even poorly-constrained flow laws can provide accurate flow variations

But goal of McFLI algorithms is to produce unbiased Q estimates…

$RRMSE^2 = Bias^2 + StDevRelErr^2$

McFLI algorithm status: Lessons learned

Some things are not hard, at least for some algorithms: low-head dams, simple multi-channel rivers, floodplain flow

Braided rivers are hard for all algorithms

Assessments needs to be more nuanced (evaluation for high versus low flow)

Roughness coefficient changes in time, due to reach averaging

Needs: Further theoretical advances, and further algorithm testing

Needed algorithm developments: McFLI Theory

Algorithms should be merged at fundamental levels

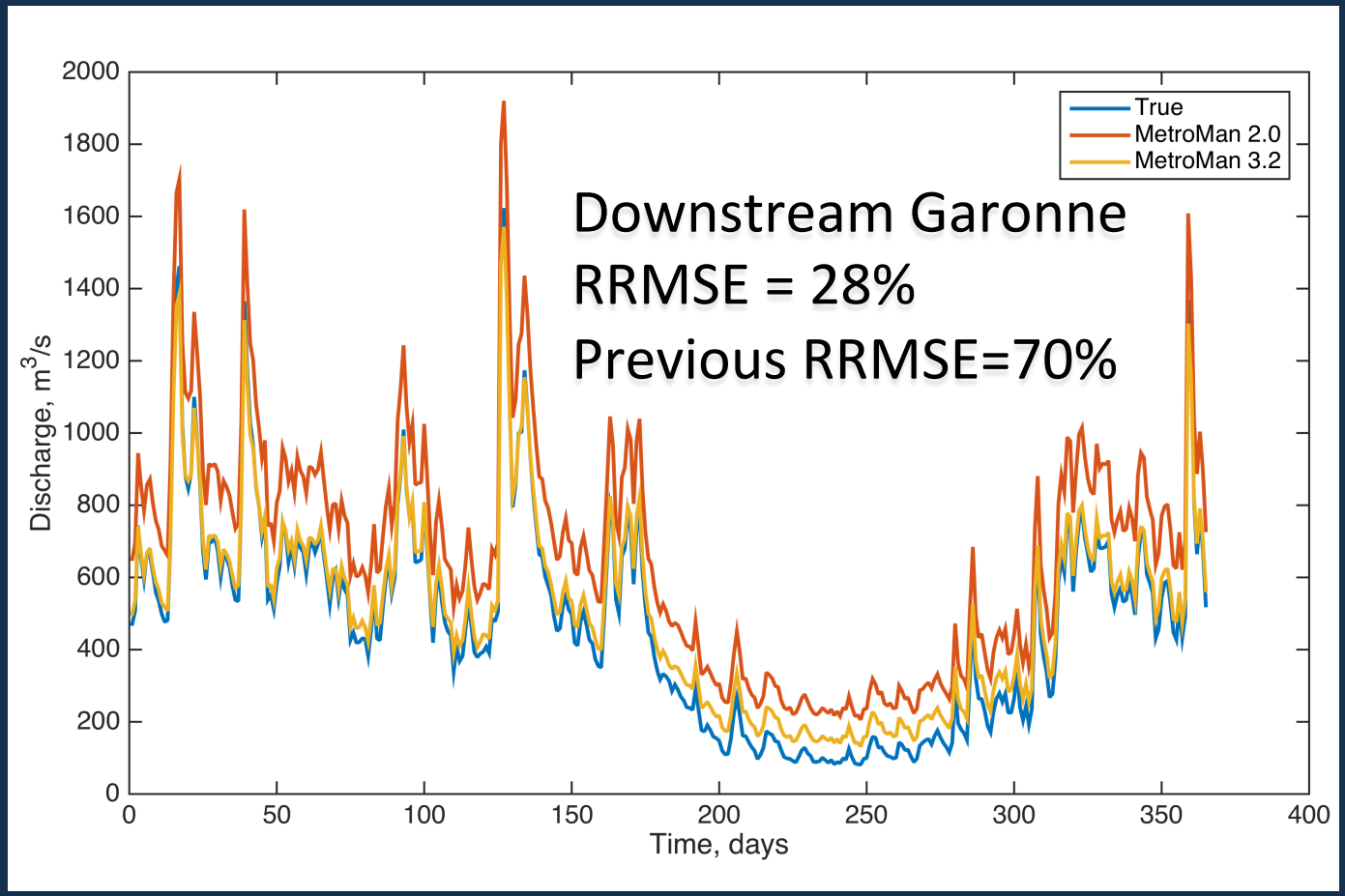
The AMHG insights, MetroMan Bayesian inversions, GaMo constrained optimization, and Bjerklie's MFG empirically-derived roughness variations each provides a piece of the puzzle. We are currently integrating these pieces into cohesive algorithms

$$Q = \frac{1}{n}\left(A_0 + \delta A\right)^{5/3} W^{-2/3} S^{1/2}$$

$$n = n_0 \left(H - H_0\right)^{x_1}$$

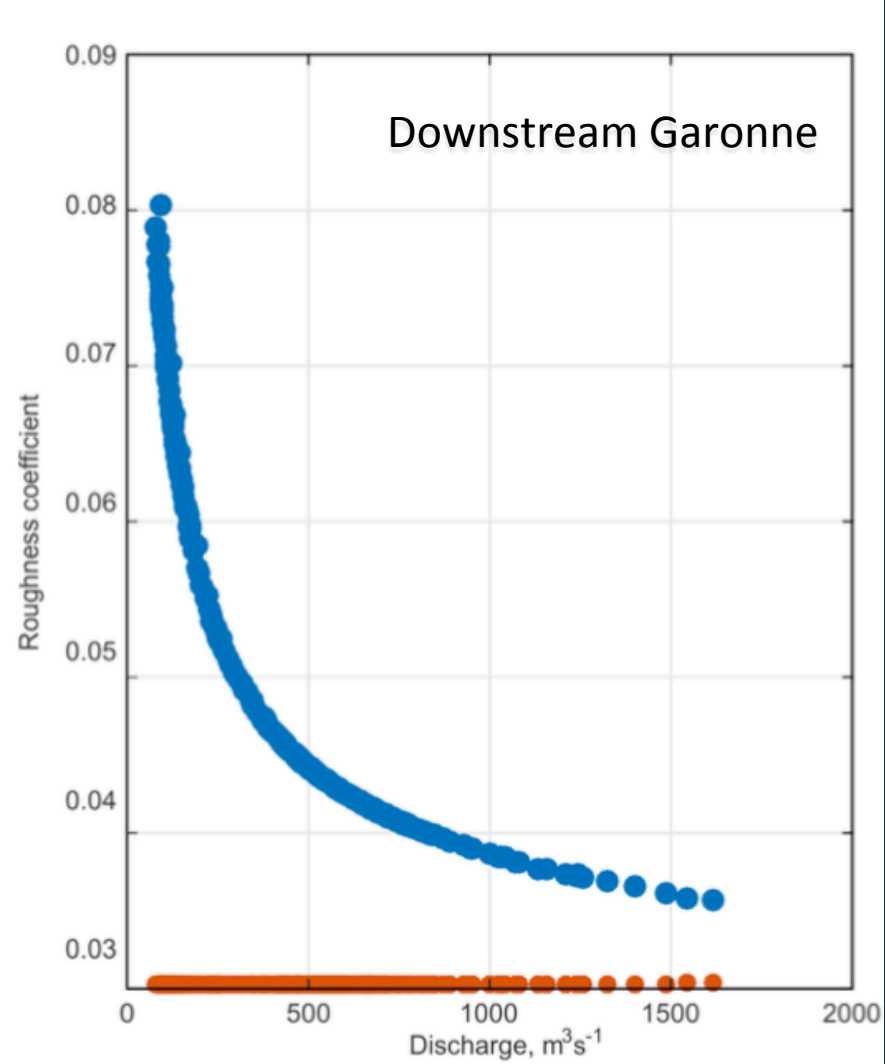
$$W = aQ^b$$

Needed algorithm developments: McFLI Theory



Preliminary result – merging Bjerklie's variable roughness coefficient with MetroMan (v 3.2) reduces large biases sometimes observed in Pepsi Challenge (v 2.0)

Needed algorithm developments: Reach averaging theory



Divergence between effective (blue) and average (red) model roughness coefficient in this model result can be explained mathematically based on reach averaging and the non-linear flow laws [Rodriguez et al., in prep.].

Such effects need to be further characterized, explained, and documented in the literature

Needed algorithm developments: Connections with data assimilation

Assimilation provides a highly complementary approach to McFLI algorithms, and the two should be explored together (see talks by Kostas Andreadis and others)

McFLI algorithms are computationally less expensive and can easily be run online by the project. Assimilation does not require as many assumptions

An interesting combination is variational assimilation, being pursued by Hind Oubanas, Pierre-Olivier Malaterre, Jerome Monier, and others

Needed algorithm developments: Four scenarios for using a priori information

1.A real-time, available gage is available within the reach reporting both stage and discharge: Simply utilize the gage to constrain flow law parameters. Still need gaining-losing estimate from models (see poster by Ed Beighley)

2.Historical gage discharge and historic altimetry or width data are available. Constrain flow law parameters directly.

3.Historical gage discharge are available. Constrain estimates to be “close” to historical data

4.Modeled discharge from past years (or real-time/current) are available. Constrain estimates to be “in the same ballpark” as the model: mean annual flow, etc.

DAWG and RAMADA need you!

If you have the following for any river….

- A calibrated channel hydraulic model
- A floodplain DEM + channel bathymetry
- Distributed in situ measurements of height, width, and slope
- Simulator outputs
- Secret AirSWOT data

WE NEED IT! Contacts:

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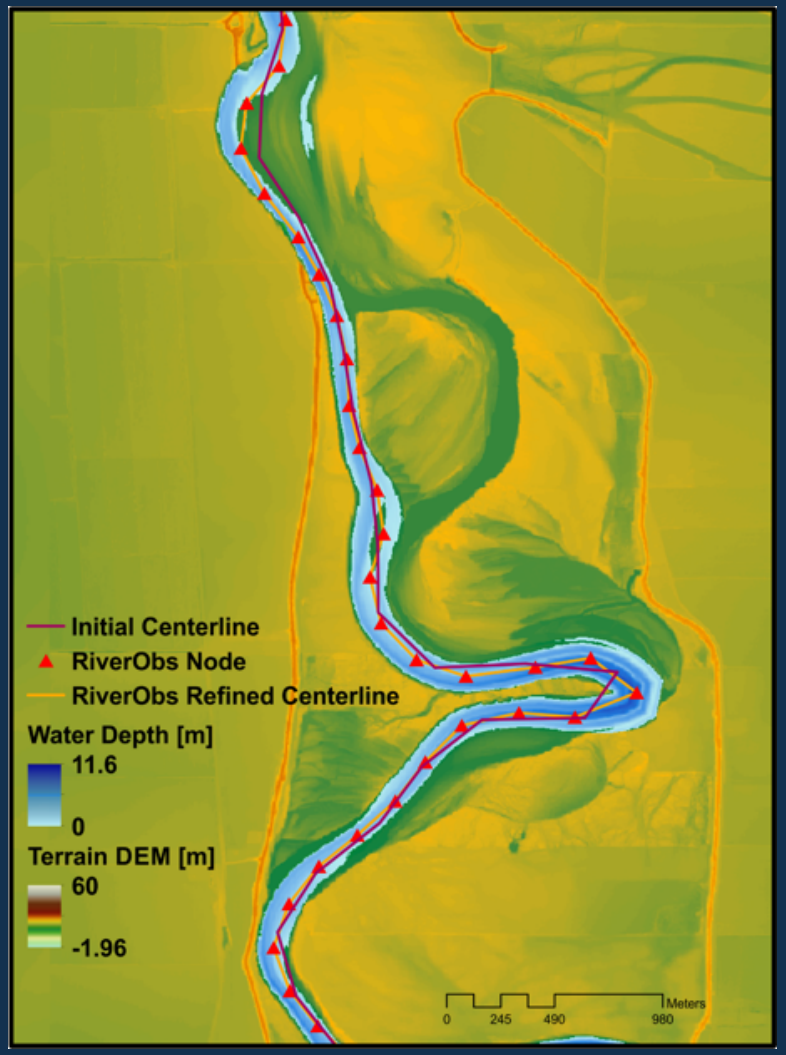
Additional algorithm testing: Call for instrument simulator dataset inputs

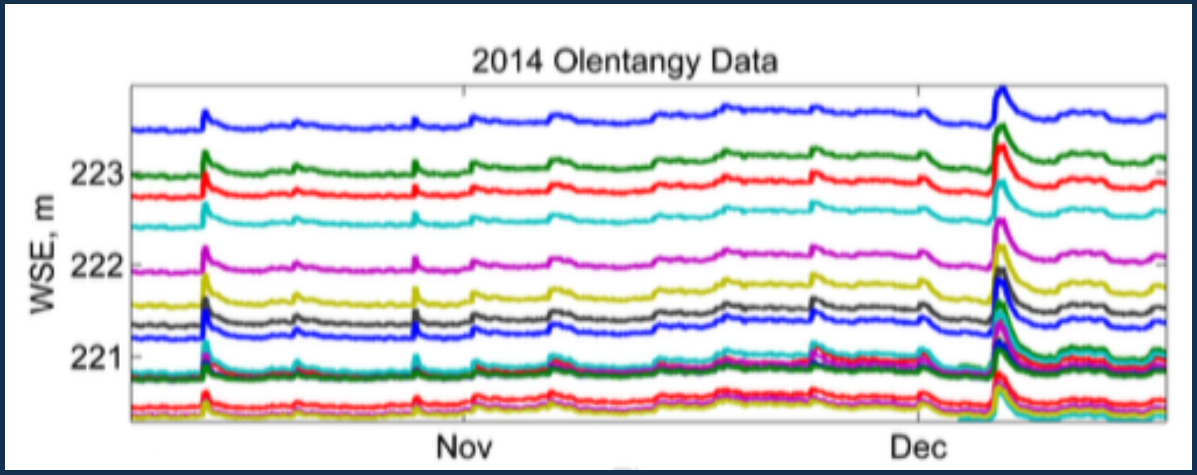
It is necessary to build a database of simulated SWOT data on many rivers. Need high-resolution (<10 m; 2 m ideal) 2-D hydraulic model in order to resolve effects of (natural & man-made) levees, in order to accurately simulate radar phenomena

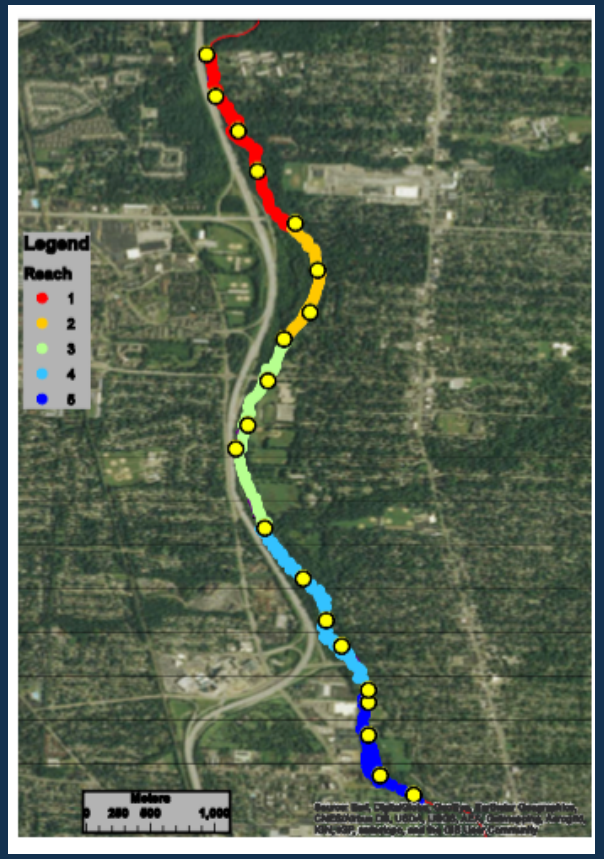
Example at right on the Sacramento River. See poster by Rui Wei, presentation by Renato Frasson



Additional algorithm testing: Testing with field observations

Need to move away from models for testing algorithms! Not many datasets include observations of slope dynamics. With high-resolution water surface elevation, and some way of handling width observation (stage-width ratings, e.g.), an in situ analog to SWOT can be developed





Olentangy River data. See poster by Steve Tuozzolo

Additional algorithm testing: how to set up a field site for discharge algorithm use

- Create a bathymetric map from a float down the reach: side-scan sonar ideal, cross sectional bathymetry ok.

- Ideally, survey in 30 transducers, spaced every 2km, throughout the reach a 60km reach. This regular spacing allows for maximum reach definition flexibility (see talk by R. Frasson)

- One gauging station must be established and active throughout collection

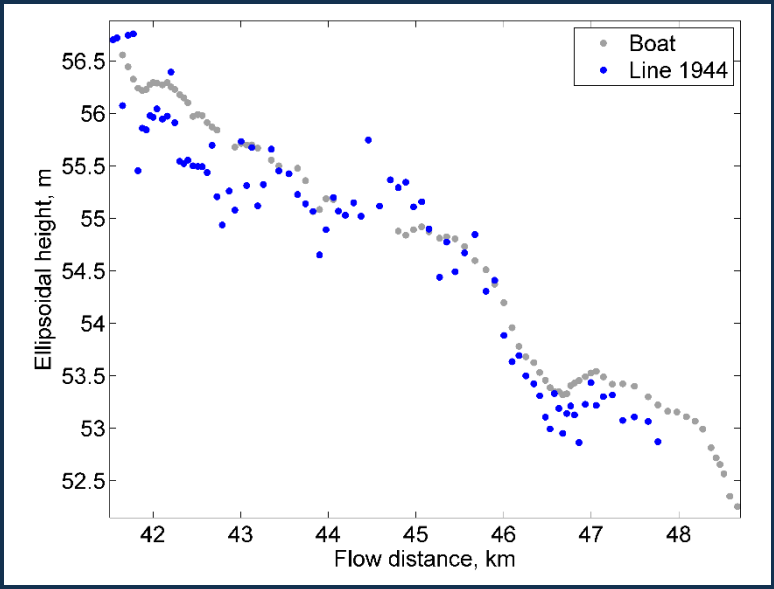
- At each transducer site, make at least one ADCP discharge measurement

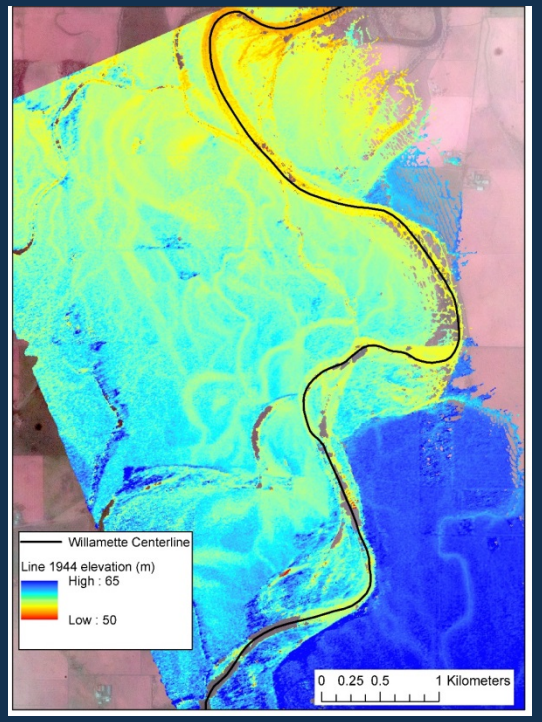
- At each transducer site, measure the cross sectional bathymetry and the cross-sectional floodplain topography. This will allow use of transducers to calculate width, and creation of a 2D model.

Additional algorithm testing: Further AirSWOT observations are crucial

AirSWOT datasets capable of testing McFLI algorithms available on the Tanana, Willamette, and Sacramento

Further datasets covering additional river cases with dynamic floodwaves moving through river channels are critical





AirSWOT data on the Willamette, courtesy Steve Tuozzolo

Proposed RAMADA collaboration

Might committing to quarterly telecons be useful for a year until the next ST meeting, to generate some exchange of ideas among the various teams?

Discharge workshop (October, details TBD)?

Continue to use the DAWG blog?

We have developed a set of SWOT-like reach-averaged data for 19 rivers. Would the assimilation teams like to try assimilating these, and characterize improvement over simpler McFLI algorithms?

McFLI papers: Extra Slide

Durand, M., E. Rodriguez, D. E. Alsdorf, and M. Trigg (2010), Estimating River Depth From Remote Sensing Swath Interferometry Measurements of River Height, Slope, and Width, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 3(1), 20–31.

Durand, M., J. Neal, E. Rodríguez, K. M. Andreadis, L. C. Smith, and Y. Yoon (2014), Estimating reach-averaged discharge for the River Severn from measurements of river water surface elevation and slope, Journal of Hydrology, 511(C), 92–104, doi:10.1016/j.jhydrol.2013.12.050.

Garambois, P. A., and J. Monnier (2015), Inference of effective river properties from remotely sensed observations of water surface, Advances in Water Resources, 79(C), 103–120, doi:10.1016/j.advwatres.2015.02.007.

Gleason, C. J., and L. C. Smith (2014), Toward global mapping of river discharge using satellite images and at-many-stations hydraulic geometry, Proceedings of the National Academy of Sciences, doi:10.1073/pnas.1317606111.

Gleason, C. J., and J. Wang (2015), Theoretical basis for at-many-stations hydraulic geometry, Geophys. Res. Lett., 42(17), 7107–7114, doi:10.1002/2015GL064935.

Gleason, C. J., L. C. Smith, and J. Lee (2014), Retrieval of river discharge solely from satellite imagery and at-many-stations hydraulic geometry: Sensitivity to river form and optimization parameters, Water Resources Research, 50(12), 9604–9619, doi:10.1002/2014WR016109.

Yoon, Y., P.-A. Garambois, R. C. D. Paiva, M. Durand, H. Roux, and E. Beighley (2016), Improved error estimates of a discharge algorithm for remotely sensed river measurements: Test cases on Sacramento and Garonne Rivers, Water Resources Research, 52(1), 278–294, doi:10.1002/2015WR017319.