Turning Lakes Into River Gauges Using the LakeFlow Algorithm

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Key Points:

- LakeFlow: an algorithm using river-lake mass conservation for discharge estimation.
- The algorithm performs well in a variety of regions (Median NSE=0.88).
- Non SWOT-observables (evaporation, tributary inflows) can improve LakeFlow discharge estimates.

1. Improving SWOT discharge coverage

- Effective water resource management depends on our ability to monitor and understand lake dynamics which are directly related to river discharge up and downstream of the lake.
- As most gauge data are unavailable in the real-time[1-2], satellite remote sensing of lakes and rivers has become increasingly important for management purposes[3-4].
- The Surface Water and Ocean Topography (SWOT) mission[5] is expected to significantly improve our capabilities for monitoring and managing water resources.
- There are numerous SWOT discharge algorithms but most have neither been assessed nor are specifically designed to run at river-lake interfaces[6-8].
- Here we present LakeFlow, a satellite based technique that leverages lake and river observations to estimate discharge at lake inflows and outflows.

2. Algorithm premise

Lake storage change = inflow - outflow

$$\delta V = n_i^{-1}(A_{0i}+\delta A_i)^{5/3} W_i^{-2/3} S_i^{1/2} - n_o^{-1}(A_{0o}+\delta A_o)^{5/3} W_o^{-2/3} S_o^{1/2} + q - e$$

SWOT observables:

- δV = Lake storage change
- W = River width
- S = Slope
- δA = Change in cross-sectional area

Non-SWOT observables:

- n = Roughness coefficient
- A = Cross-sectional area at baseflow
- q = Tributary inflow
- e = Evaporation

Apply a Bayesian optimization algorithm to solve for unobserved flow-law parameters (FLP) n and A.

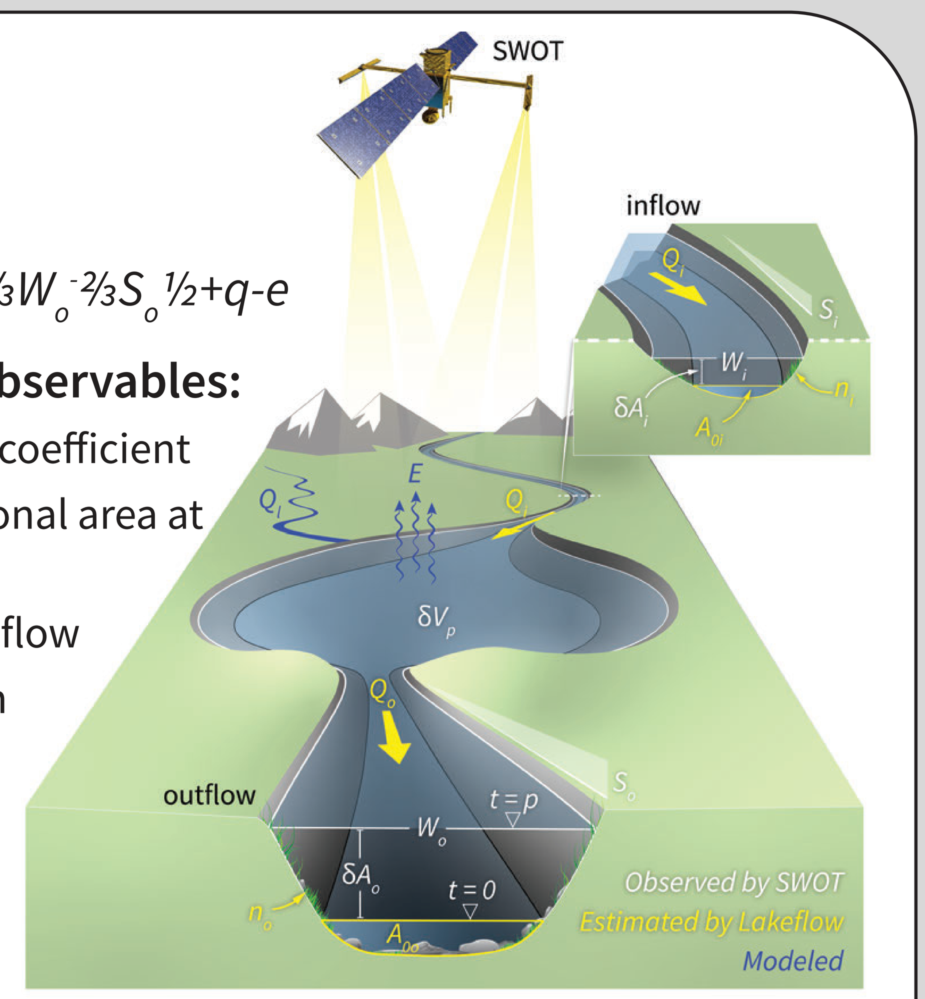

Figure 1. Conceptual diagram of the LakeFlow algorithm which uses repeat SWOT observations of lakes and rivers to estimate the inflows and outflows of lakes. Shown are two snapshots of a lake system corresponding to two SWOT overpasses (t = 0 and t = p). Note that time 0 corresponds to the minimum observed flow on record and that only SWOT observable variables are shown for t = p.

3. Methods

Study locations:

- Lake Mohave (arid).
- Tuttle Creek Reservoir (semi-arid).
- Lake Allatoona (humid).

Synthetic data:

- Built using U.S. Geological Survey[9] gauge measurements and Landsat observations.
- Corrupted with the expected 1-sigma error ranges[5].

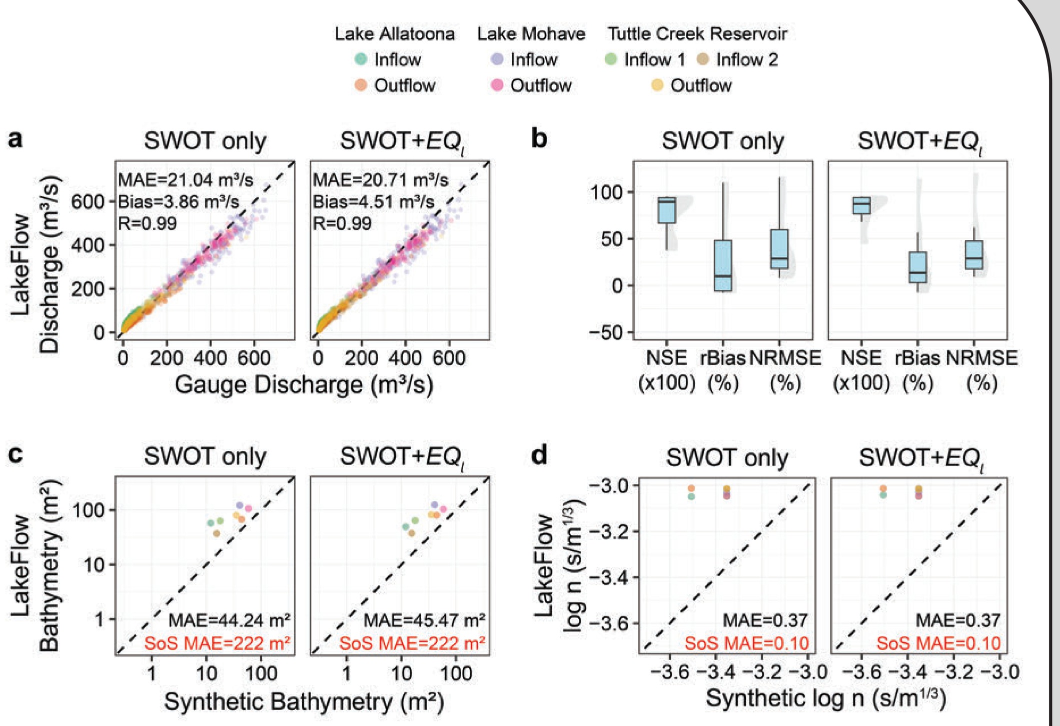

Figure 2. LakeFlow performance without ("SWOT only") and with ("SWOT + EQ") ancillary data. (a) Scatterplots of same-day gauge discharge vs LakeFlow estimated discharge. (b) Boxplots and half violin plots of LakeFlow discharge performance metrics. Scatterplots of synthetic bathymetry vs LakeFlow estimated bathymetry (c) and of log synthetic Manning's n vs log LakeFlow estimated Manning's n (d).

Non-SWOT observed ancillary data:

- Evaporation: Landsat-based evaporation dataset[10].
- Tributary inflows: Global Reach-Level A Priori Discharge Estimates from SWOT (GRADES) hydrological model[11].

4. LakeFlow results

- Provides promising results for SWOT estimates of lake inflows and outflows.
- Accurately estimates discharge dynamics.
- Performance modestly improves with the addition of ancillary data.
- Relatively accurate estimates of n and A values.

Discharge performance:

- Median NSE = 0.88
- Median NRMSE = 29%
- Median rBias = 13.5%
- |rBias| less than 15% in 5 of 7 reaches

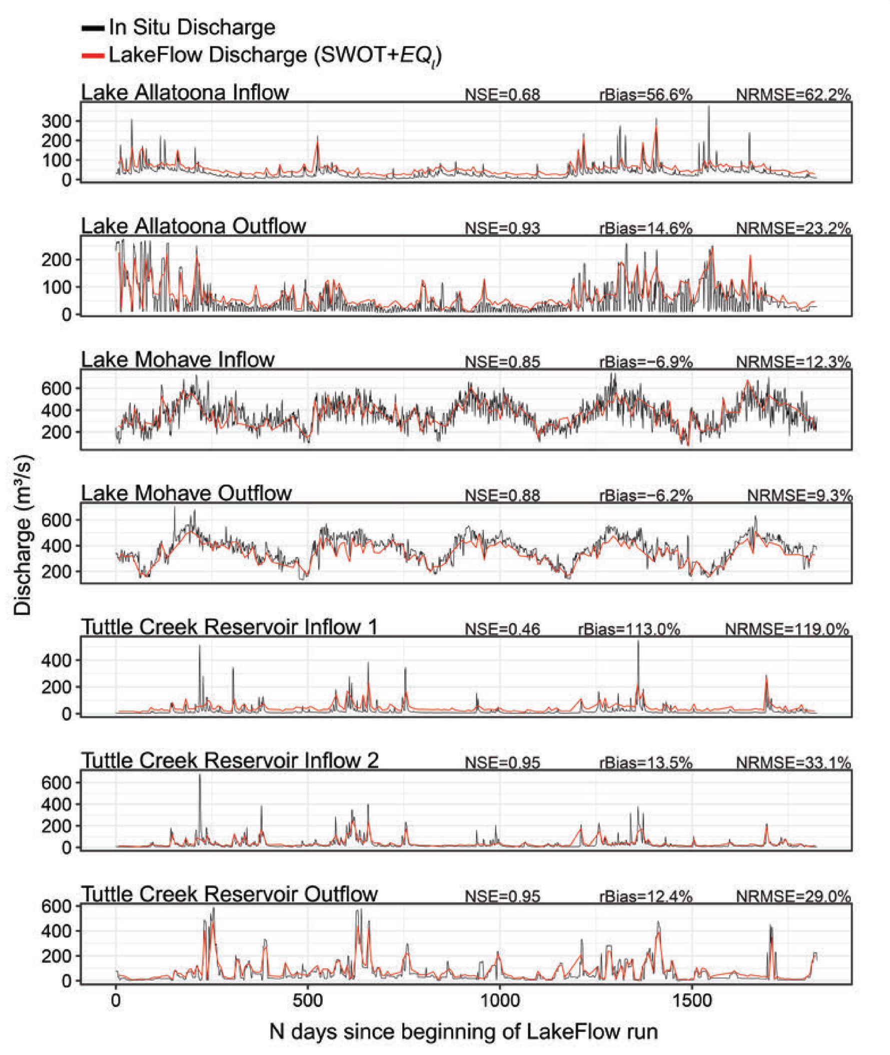

Figure 3. LakeFlow estimated discharge for all lake inflows and outflows compared to gauge records. These LakeFlow discharge estimates are produced using ancillary data ("SWOT + EQ").

5. Discussion and conclusion

- Comparable accuracy to other SWOT discharge algorithms.
- Estimates of n and A will provide geomorphic insights near river-lake boundaries.
- The algorithm could be used to estimate water residence time in lakes.
- LakeFlow could provide estimates of reservoir operations and procedures globally.
- LakeFlow may enhance our ability to monitor and understand the impact of reservoir operations on the global water cycle.

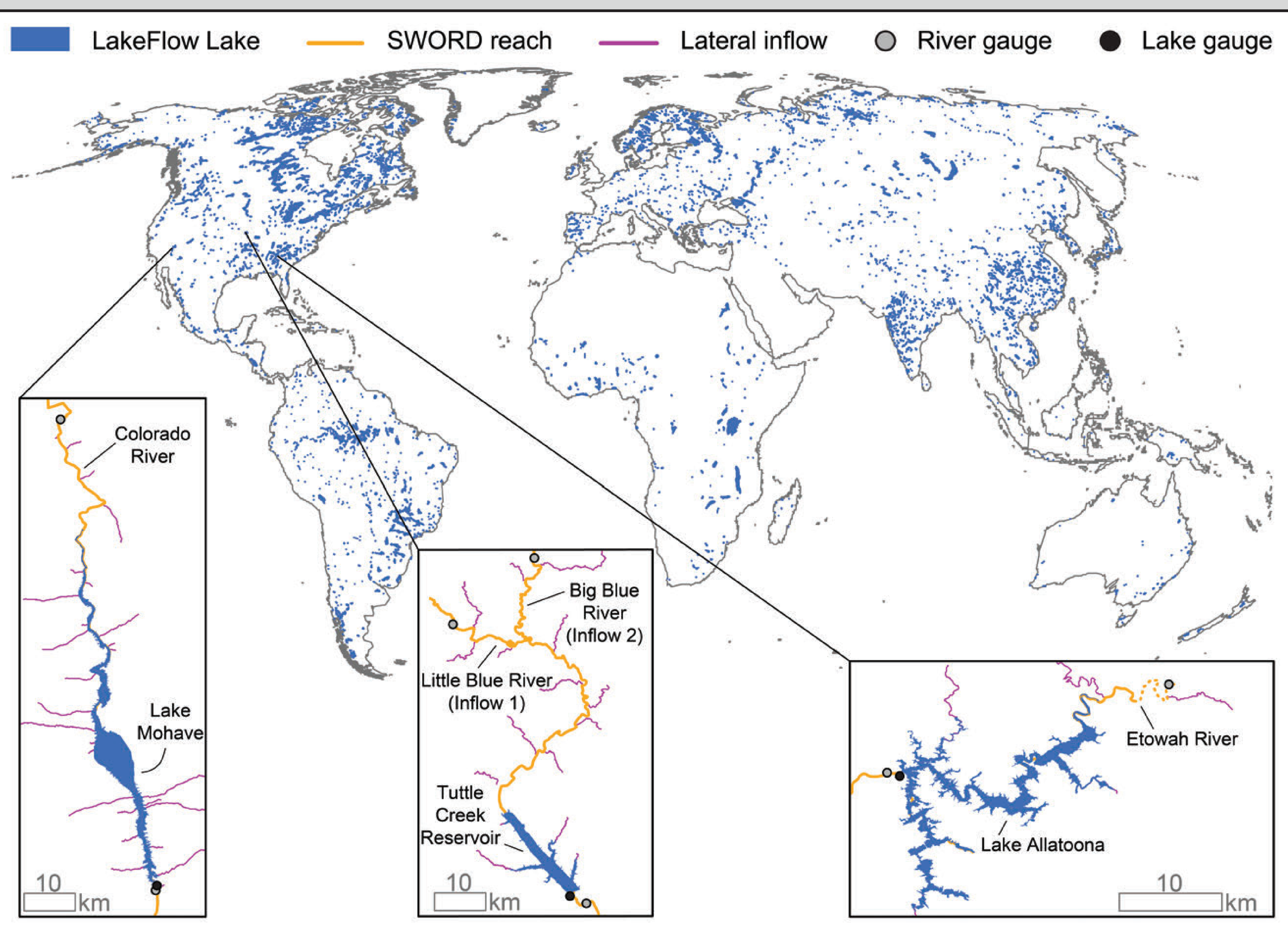

Figure 4. Global distribution of lakes suitable for LakeFlow implementation (N = 16,610) with three sample lakes highlighted. Each of these lakes is observable by SWOT and contains at least one SWOT observable inflow and one SWOT observable outflow . Note the Lake Allatoona inflow gauge is located on the inflow mainstem (dashed orange line) but is located 7 km upstream of the SWORD reach (orange line).

- River-Lake mass conservation for discharge estimates.
- Accurate SWOT-based estimates of lake inflows and outflows.

Global capabilities:

- 16,610 Lakes
- 19,380 Inflows
- 16,959 Outflows

6. Acknowledgements

This work was supported by the NASA SWOT Science Team (grant #80NSSC20K1143) and the Texas Space Grant Consortium.

7. References

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