Land Surface Model parameter regionalization with remote sensing and observations

Ben Livneh, Dennis. P. Lettenmaier.

1) University of Washington Department of Civil and Environmental Engineering Box 352700, Seattle, WA 98195.

blivneh@hydro.washington.edu

ABSTRACT

This study integrates modeling with observations in two ways. First, a land surface model (LSM) with a hydrologically-based soil moisture scheme is calibrated to observations across the continental U.S. for large river basins (on the order of USGS hydrologic regions and subregions) as well as for smaller tributary catchments. The observations include stream gauge records, as well as independent remote sensing estimates of evapotranspiration and terrestrial water storage change. This portion of the analysis serves to evaluate the extent to which remote sensing data can improve streamflow prediction and aid in the overall parameter estimation procedure. The second part of the study uses the calibrated model to derive a parameter regionalization framework using various observations as predictors. Predictors include land surface characteristics, geomorphic parameters and meteorological variables from several sources. Principal components analysis is used to establish predictive relationships between predictors and predictands. Predictands are the soil parameters of the Unified Land Model (ULM), which is a merger of the Noah LSM (used in NOAA/NCEP's numerical weather prediction and climate models) and the Sacramento Soil Moisture Accounting Model (used by NWS for operational flood forecasting and seasonal streamflow forecasting). Our major objective is to quantify the potential for the aforementioned predictands to produce model parameter sets that are capable of capturing observed patterns of streamflow, and which can be used as a priori parameter estimates over the CONUS domain. Finally, we evaluate the role of scale in model behavior and the observed physical phenomena.

Study Domain

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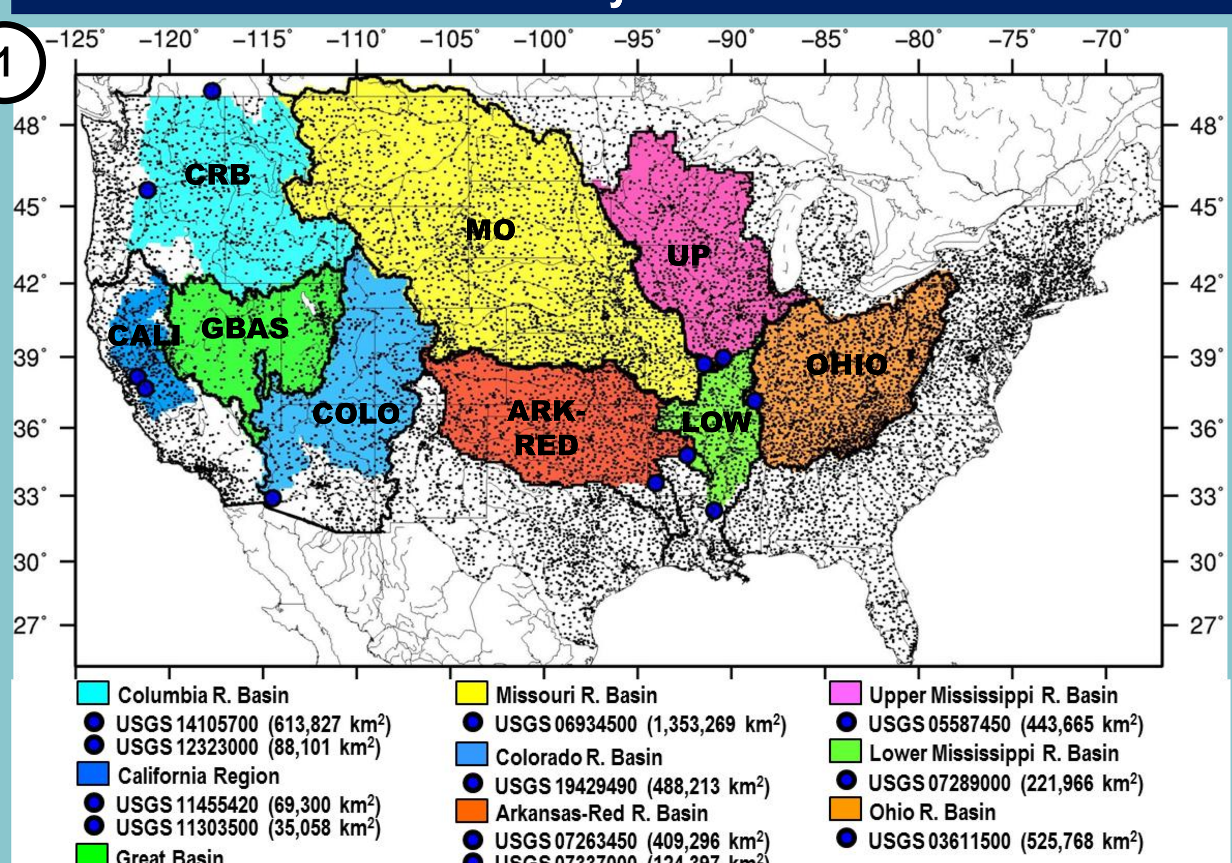

Fig. 1: Large-scale study domain, precipitation gauges (black dots), as well as major hydrologic regions that are defined through their drainage at stream gauges (blue circles).

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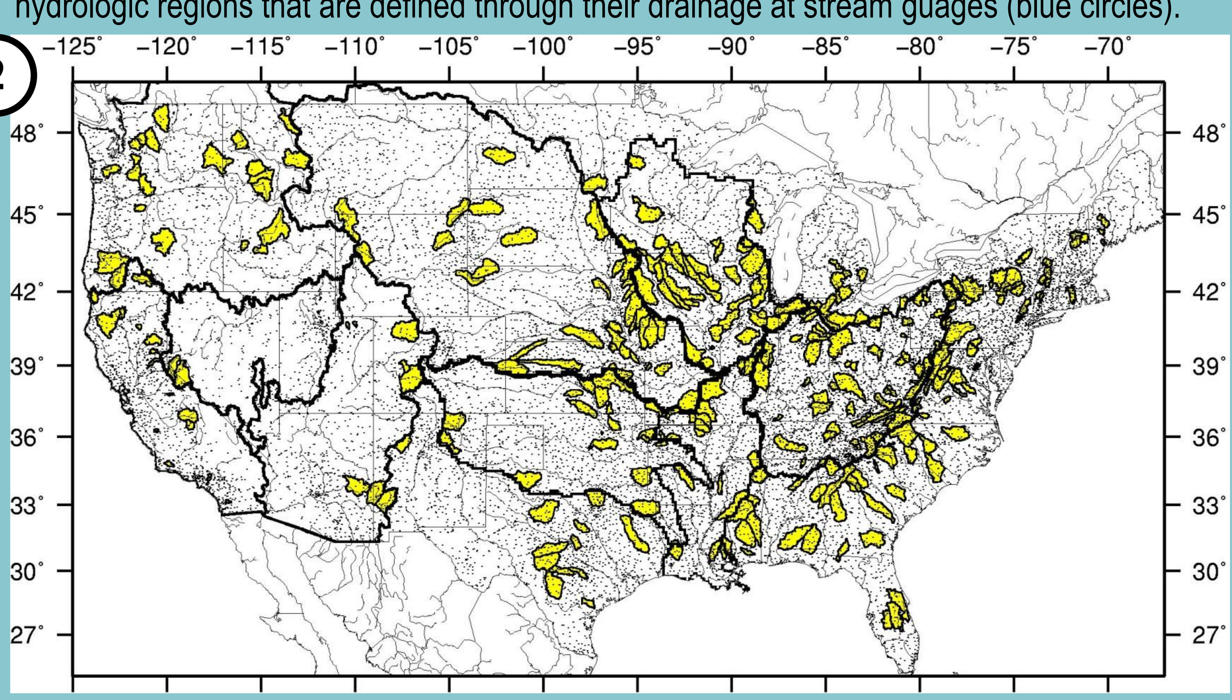

Fig. 2: Catchment-scale study domain, including approximately 300 catchments (yellow shading) with an associated precipitation gauges (black dots). Stations were identified by Schaake et al. (2006).

Model Validation and Parameter Estimation

Key scientific questions of this study:

- ***How can model performance be improved by calibration to multiple observation sources?***
- ***To what extent can calibrated model parameters be regionalized, using land surface characteristics, geomorphic parameters, and hydrometeorological attributes?***
- ***Are flood forecasts better improved by model simulations resulting from regionalization, calibration or statistical bias correction?***

Unified Land model (ULM)

Flow chart of model calibration

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Observational data for calibration

- **[1]Streamflow**
- **[2]ET from a VI-Ts method**
- **[3]ET from an atmospheric water balance**
- **[4]Terrestrial Water Storage**

↓

Calibration to individual and multiple criteria. Best set of model parameters selected by performance to each criteria (Figures 6, 7) weighted by observational uncertainty.

[1]USGS streamflow and naturalized data to remove anthropogenic impacts; [2]Tang et al., 2009; [3]NARR data used for precipitable water, convergence, precipitation from NCDC gages; [4]GRACE data aggregated to ~monthly basin-wide averages.

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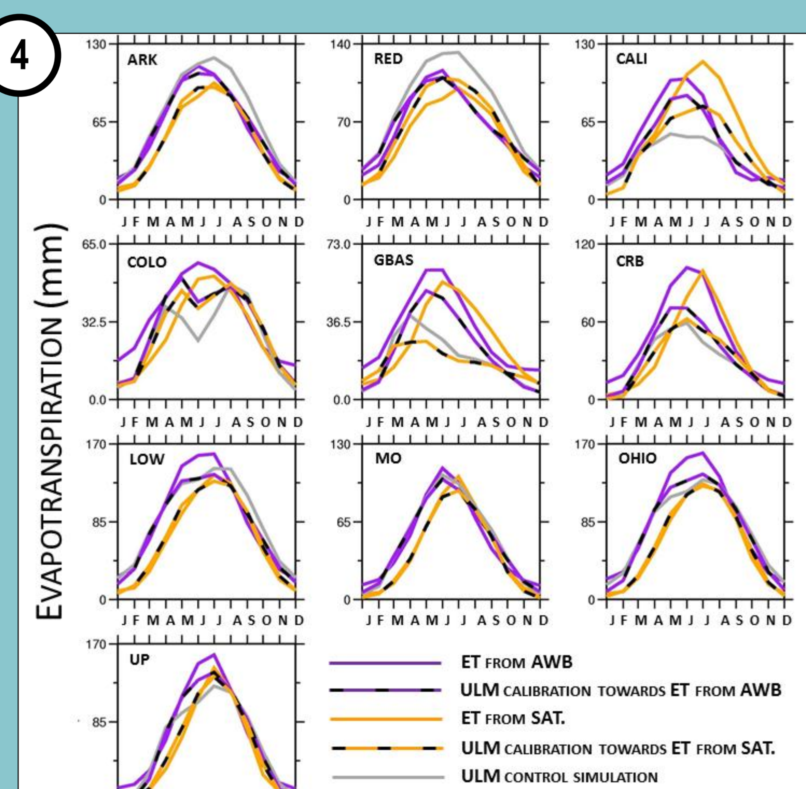

Fig. 4: Mean monthly ET (mm) for the major river basins for the period 2001 – 2010 that include two sets of calibrations, satellite-based (SAT) or atmospheric water balance-based (AWB) remote sensing products as well as the control simulation

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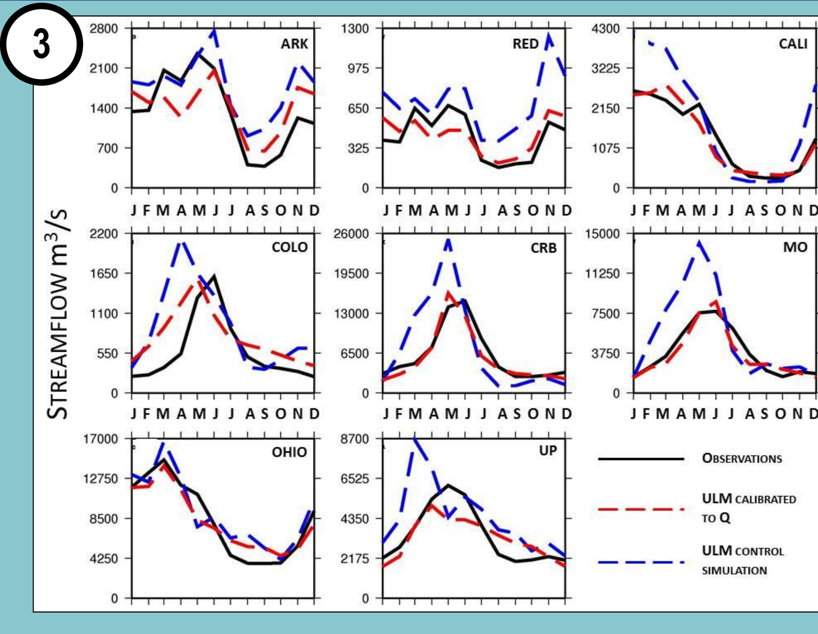

Fig. 3: Calibration results from 8 large basins in which ULM was calibrated towards streamflow for an 20 year period (1990 – 2009). For western US basins, naturalized streamflow data were used, while USGS gage data were used for the remainder of basins.

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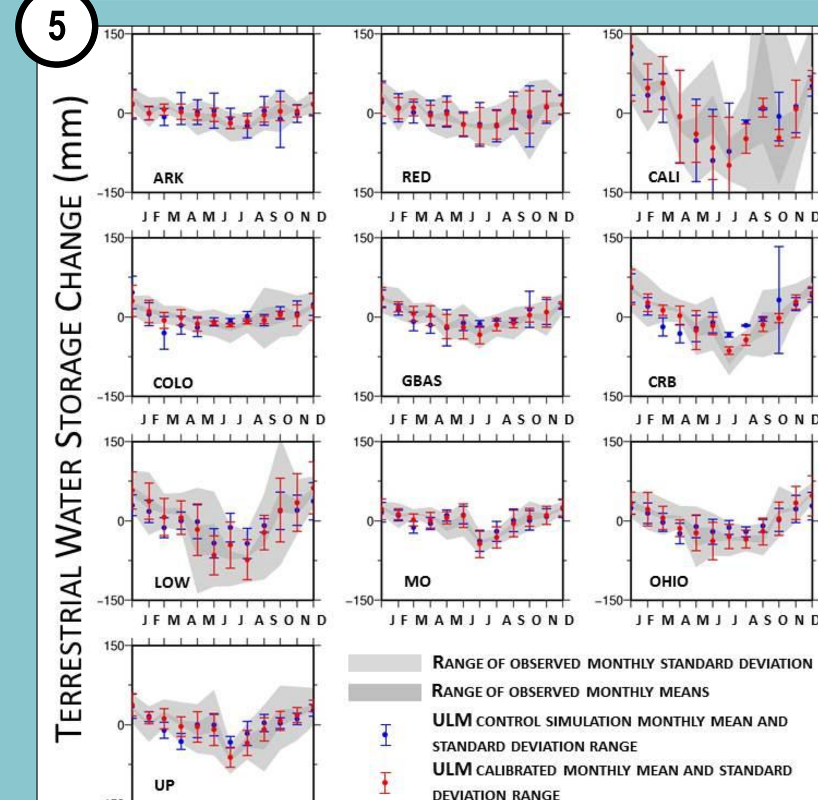

Fig. 5: Mean monthly TWSC (mm) for the major river basins for the period 2002-2010 including the control and calibrated model simulations; the range of variability for each case is shown accordingly

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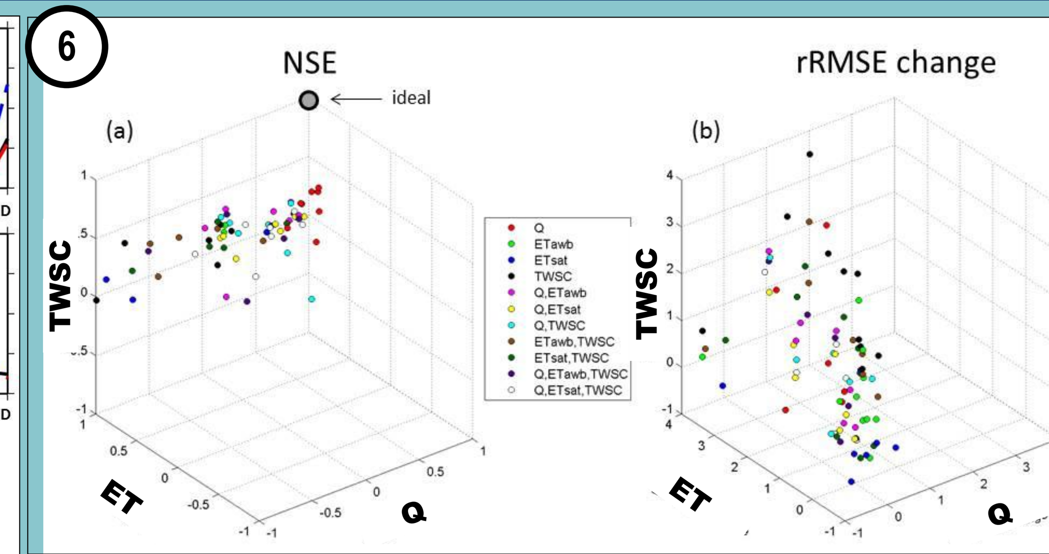

Fig. 6: Calibration results from 10 large basins, in which ULM was calibrated towards either streamflow, Q, satellite-derived evapotranspiration estimates, ET_{SAT}, atmospheric water-balance derived water balance estimates ET_{AWB}, terrestrial water storage change, TWSC, or combinations of these. Shown are the Nash-Suttcliffe efficiencies (NSE) for both criteria together, as well as the change change in relative Root Mean Squared Error (rRMSE) for these calibrations on each criteria. The degree of improvement in each criteria were variable, with Q-calibrations generally having the best combined performance

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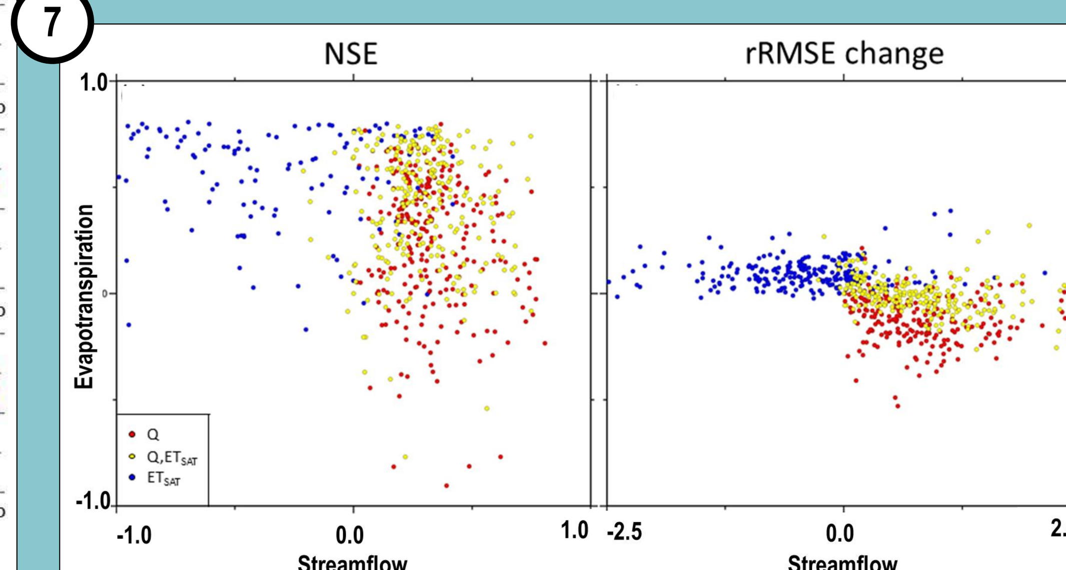

Fig. 7: Calibration results from 250 small catchments, in which ULM was calibrated towards either Q, ET_{SAT}, or both quantities simultaneously. Shown are the NSE as well as rRMSE for each calibration. For ~1/3 of all catchments, the calibrations to Q and ET_{SAT} out-perform Q calibrations, suggesting that conventional calibrations (to streamflow exclusively) serve to benefit from adding additional criteria.

Parameter Regionalization using Principle Components Analysis;

PREDICTANDS

- **Best multi-criteria calibration results**

→

PREDICTORS

- **[1]Soil texture information**
- **[1]Land surface characteristics and geomorphic variables**
- **[2]Historic meteorological information**
- **GAGES-2 basin attributes***

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Flow chart of regionalization procedure and evaluation with historical flood data

[3]PCA: derive predictive relationship → **ULM modeled streamflow with regionalized parameters** → **Assess value of modeled flow versus major historical flood events** ← **Bias-corrected ULM streamflow simulations with *apriori* parameters**

[1]Part of input parameters for ULM; [2]Derived from required forcing inputs into ULM; [3]PCA procedure involves jack-knifing and limiting the maximum number of predictor variables (dimensionality) to six; *Publicly available dataset spanning a wide range of basin attributes (Falcone, 2010).

Preliminary Results

Table 1: Estimated of flood damages (in 1995 dollar values) for a set of USGS basins (Pielke et al., 2002) that are a subset of the small-scale study domain.

USGS ID	Date	Damage ($\$10^6$)	River name, location of gauge
01556000	9/27/1975	200	Frankstown Br Juniata R. at Williamsburg PA
02387000	3/15/1964	430.1	Conasauga R. at Tilton GA
05514500	5/18/1943	802	Ciuvr R. near Troy MO
07019000	7/3/1957	5475.3	Meramec R. near Eureka MO
06820500	9/15/1961	269	Platte R. near Agency MO
07056000	2/11/1966	160.5	Buffalo R. near St. Joe AR

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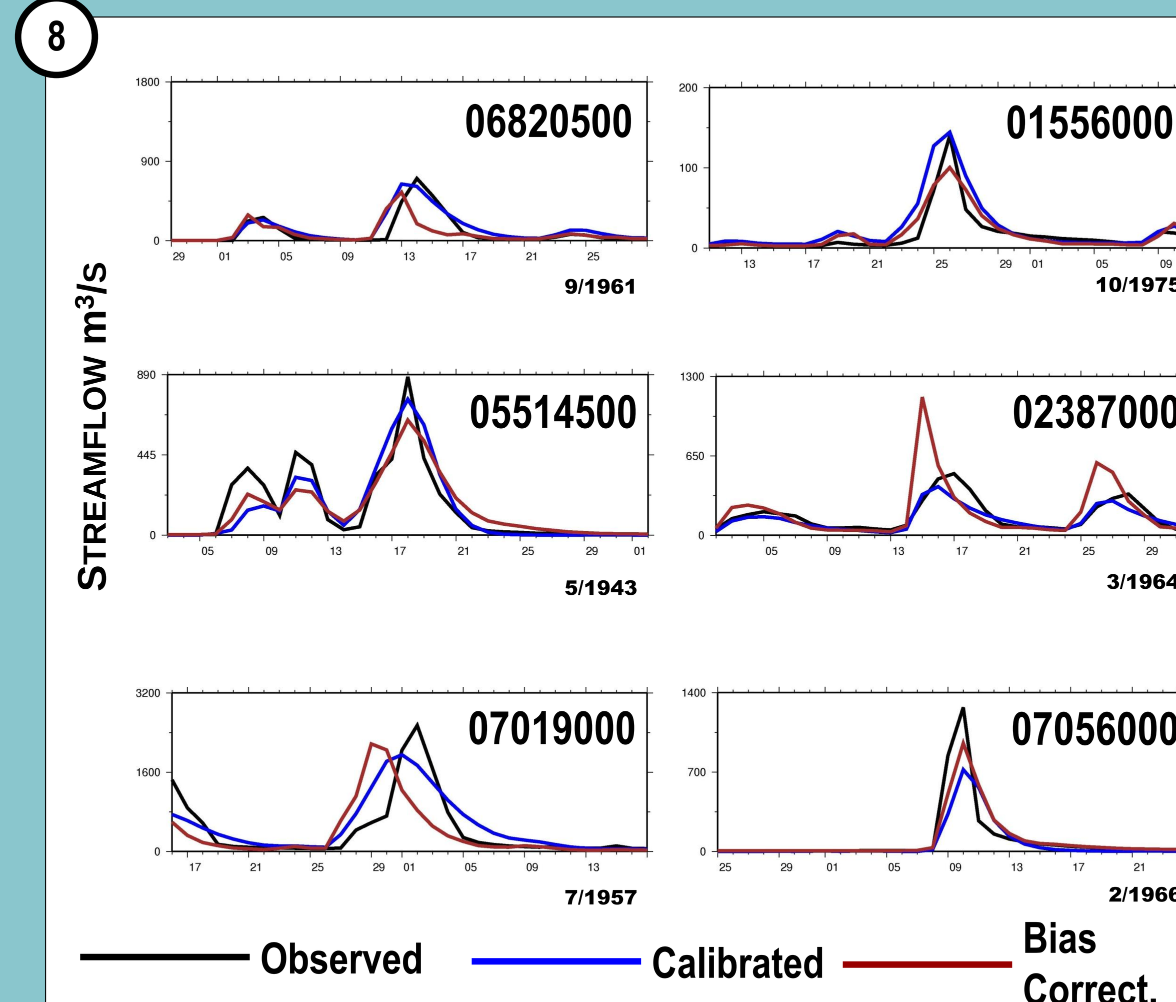

Fig. 8: Calibration results compared with bias corrected model flows using apriori parameters (using a quantile mapping procedure) for six major flood events.

Major conclusions thus far:

- ***Conventional calibration to streamflow benefits from additional observational criteria, as seen by improvements resulting from inclusion of ET information in streamflow calibrations for roughly 1/3 of the basins.***
- ***The framework for parameter regionalization is in place but will require additional analysis to establish predictive relationships and explore stronger correlations.***
- ***Statistical bias-correction of pre-calibrated model outputs show reasonable performance in many cases. However, the water balance is not preserved in the bias correction, whereas it is preserved in calibration; offset by computational tradeoffs.***

References

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Falcone J.A., D.M. Carlisle, D.M. Wolock, and M.R. Meador, 2010: GAGES: A stream gage database for evaluating natural and altered flow conditions in the conterminous United States. *Ecology* 91:621.
Pielke, Jr., R.A., M.W. Downton, and J.Z. Barnard Miller, 2002: *Flood Damage in the United States, 1926-2000: A Reanalysis of National Weather Service Estimates*. Boulder, CO: UCAR.
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