Overview of National Water Model Calibration
General Strategy & Optimization

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National Center for Atmospheric Research

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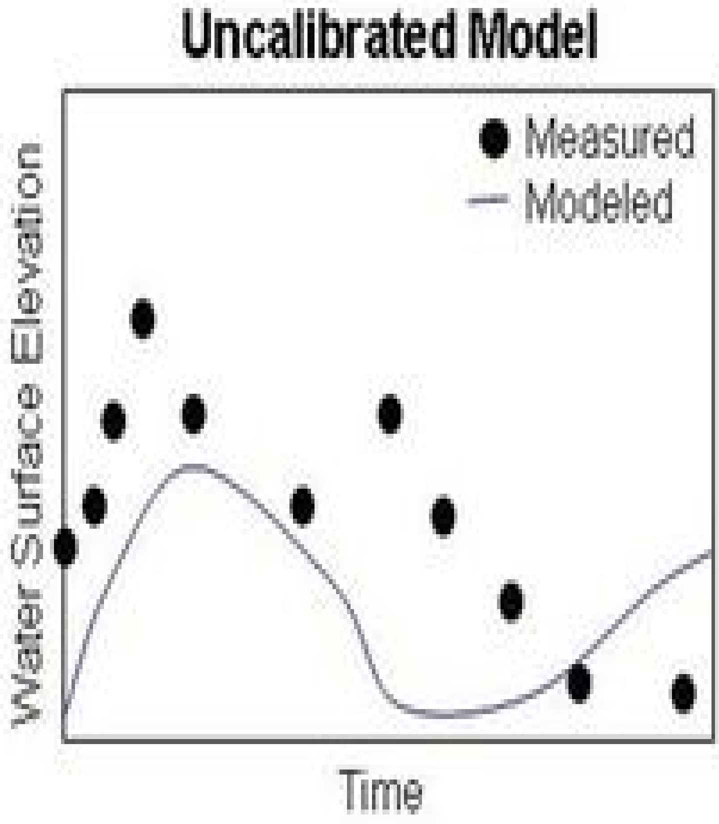
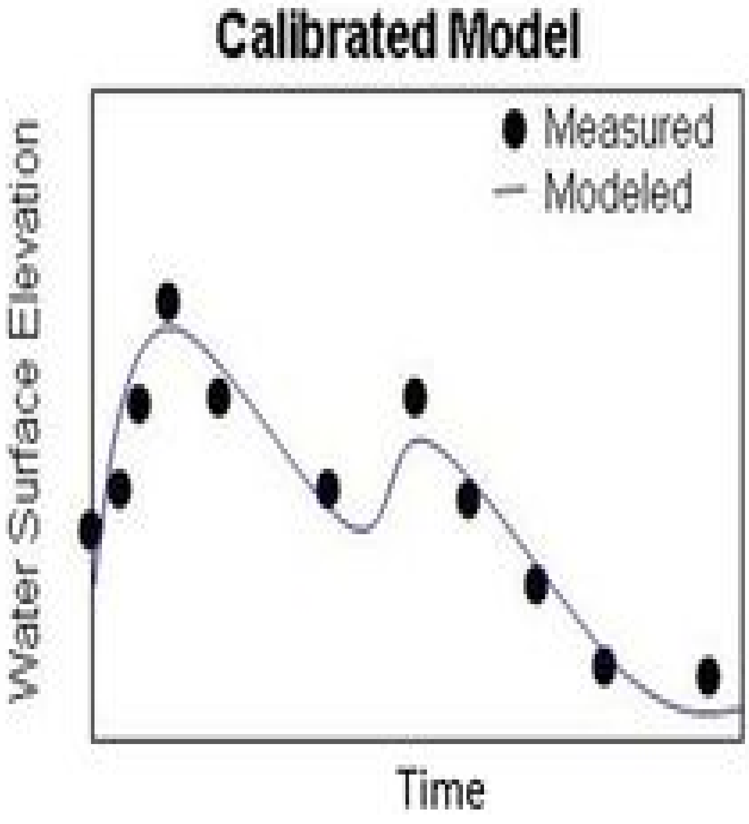
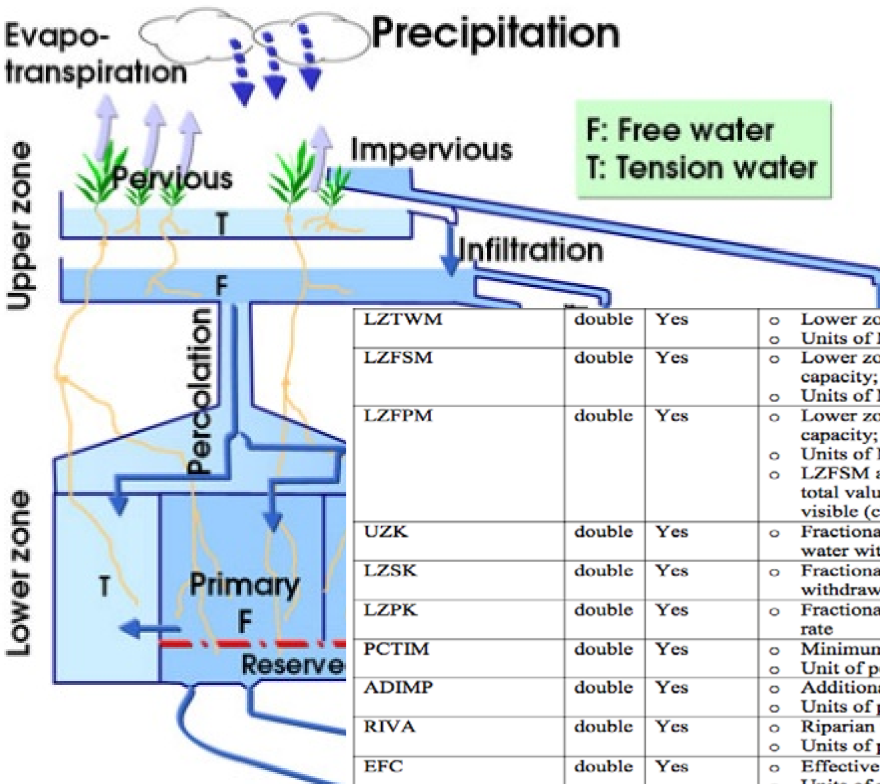
General Strategy



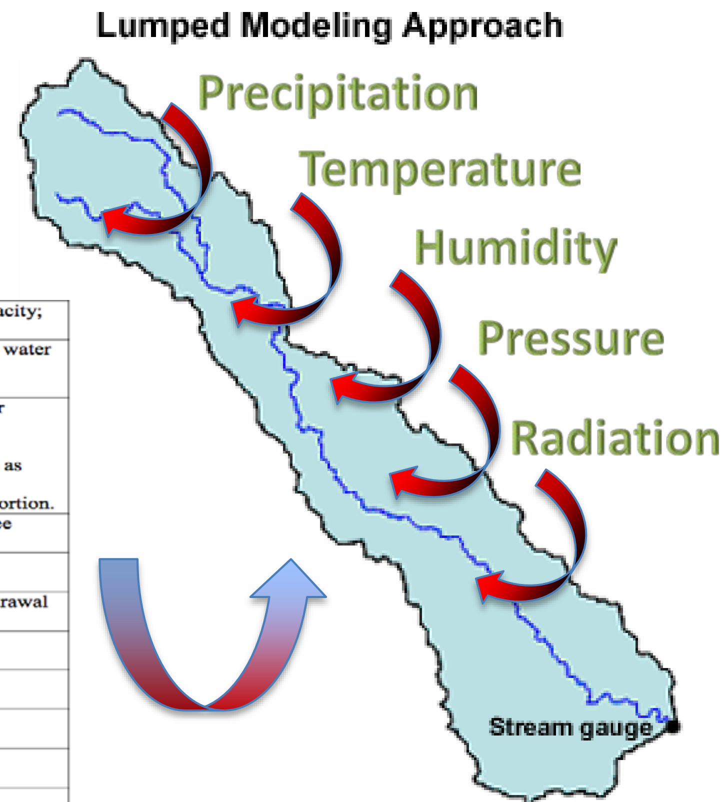


Simple enough……. Right?…….

General Strategy



LZTWM	double	Yes	o Lower zone tension water capacity; o Units of MM
LZFSM	double	Yes	o Lower zone supplemental free water capacity; o Units of MM
LZFPM	double	Yes	o Lower zone primary free water capacity; o Units of MM; o LZFSM and LZFPM are input as total values and not just as the visible (channel component) portion.
UZK	double	Yes	o Fractional daily upper zone free water withdrawal rate
LZSK	double	Yes	o Fractional daily supplemental withdrawal rate
LZPK	double	Yes	o Fractional daily primary withdrawal rate
PCTIM	double	Yes	o Minimum impervious area; o Unit of percent/100
ADIMP	double	Yes	o Additional impervious area; o Units of percent/100
RIVA	double	Yes	o Riparian vegetation area; o Units of percent/100
EFC	double	Yes	o Effective forest cover; o Units of percent/100
ZPERC	double	Yes	o Maximum percolation rate
REXP	double	Yes	o Exponent for the percolation equation
PFREE	double	Yes	o Percent/100 of percolated water which always goes directly to lower zone free water storages
RSERV	double	Yes	o Percent/100 of lower zone free water which cannot be transferred to lower zone tension water
SIDE	double	Yes	o Ratio of non-channel baseflow (deep recharge) to channel (visible) baseflow

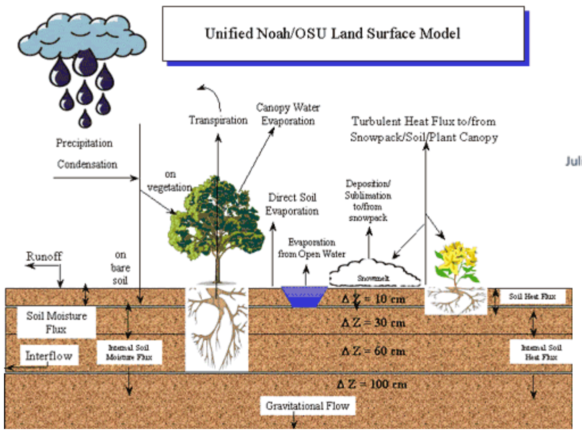


NOAA / NWS / The COMET Program

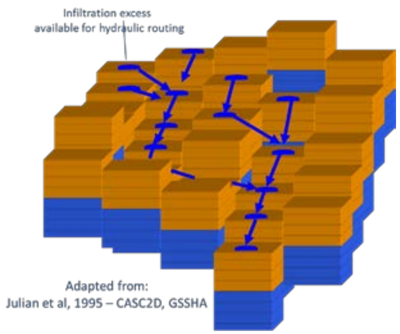
- Traditional NWS lumped hydrologic modeling....

WRF-Hydro Physics Components

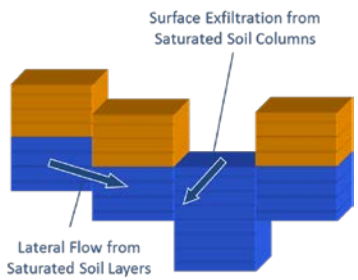
Land Surface Model



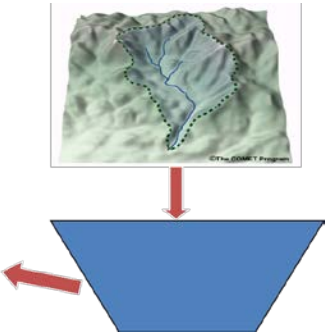
Overland Flow



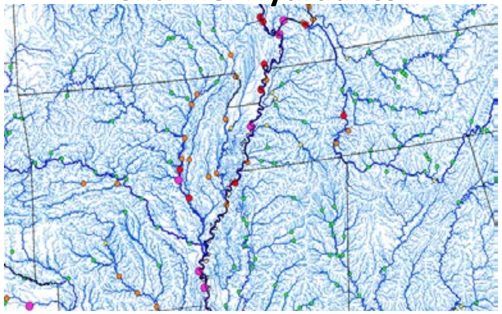
Lateral Subsurface Flow



Simplified Baseflow Parameterization



Channel Hydraulics



Simple Water Management

Calibration Strategy and NWM calibration specifics

Calibration Period and Forcing

- Spin up with the default parameters: (2007-10 to 2016-10)
- Iteration 1 to n (max number of iterations)
  - Spin up: 1 year (2007-10 to 2008-10)
  - Calibration: 5 years (2008-10 to 2013-10)
- Final Parameters
  - Validation: 3 years (2013-10 to 2016-10)
- What to use as forcing data?
  - Ideally, it is preferred to calibrated using the same forcing as what is used in for the final application.
  - Downscaled NLDAS-2 in NWMv1.1 and NWMv1.2.
  - A mountain-mapper adjustment to the precipitation data of downscaled NLDAS-2 in NWMv2.0.
  - Analysis of Record for Calibration (AORC) introduced by Kitzmiller et al. 2019 in NWMv2.1.

Basin Selection Criteria For Calibration

- **Size of the basins:** 10,000 km^2 as an upper bound for the basin size

- **Completeness of the streamflow observation:** 50% completeness in calibration period in order to include some of the seasonal gages also. When criteria was not met, we checked the daily time step.

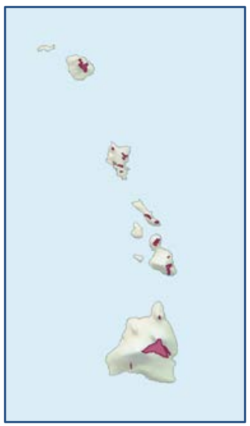
- **Disturbance index:** Considering 7 variables, including major density, reservoir storage, fresh water withdrawal, road density, landscape fragmentation, percentage of streamline coded as canals/ditches/pipelines, and distance to the nearest major National Pollutant Discharge Elimination System site.

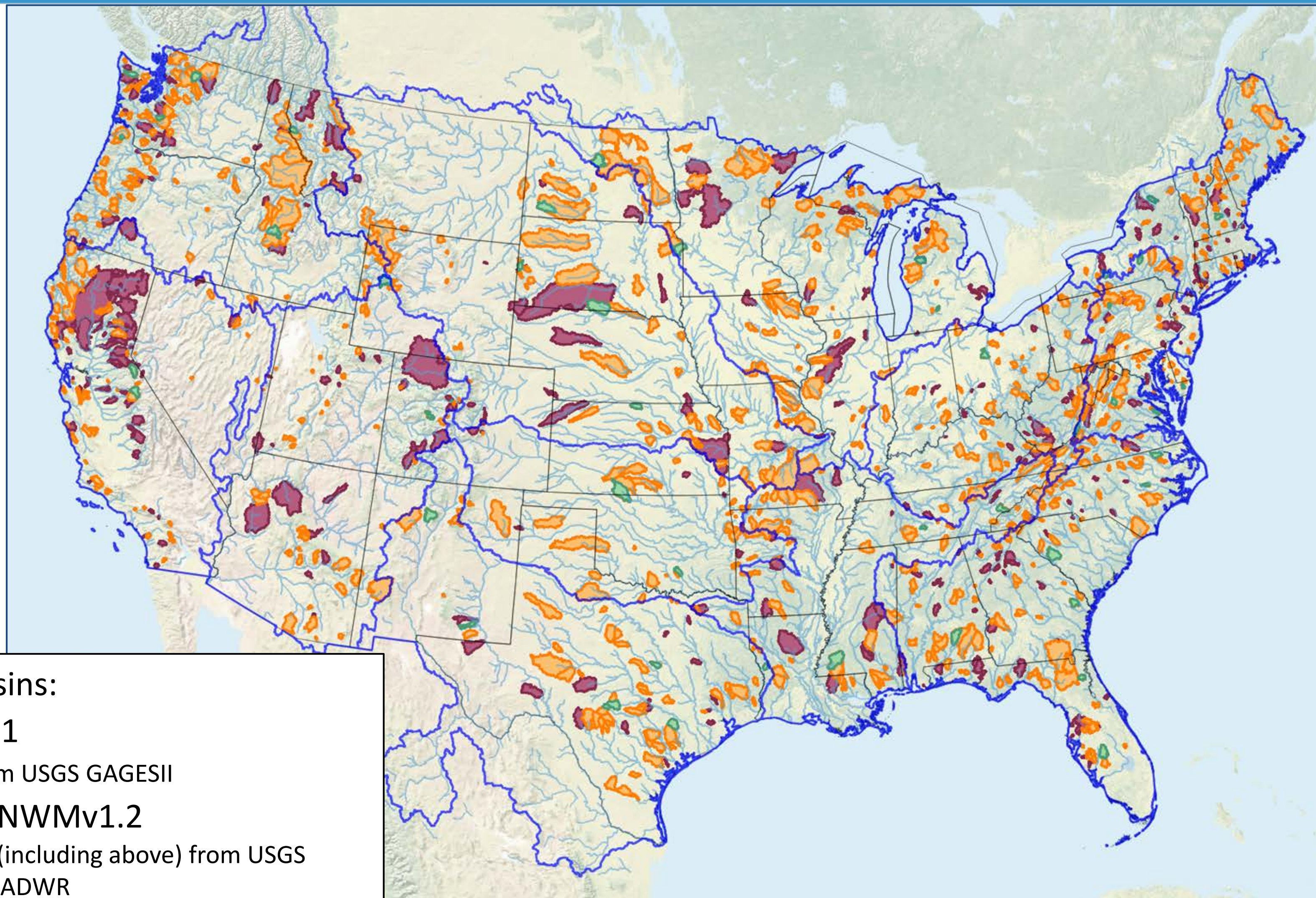
- **Basins containing lakes:** Even though the calibration basins were investigated to have minimal regulation through disturbance index, we further investigated the calibration basins containing water bodies.
  - Number of lakes in a basin
  - Distance of the lake outlet to the basin outlet
  - Percentage of the total lake drainage area to the basin drainage area
  - Percentage of the regulated flow (outflow from lakes in the basins) to basin outflow
  - Ratio of the lake storage volume to the basin mean annual flow volume

- Consider having enough basins available for regionalization

NWM Calibration: Version-to-Version Changes

Hawaii basins (28 total)





Calibrated basins:

- NWMv1.1
  48 total from USGS GAGESII
- New for NWMv1.2
  1,164 total (including above) from USGS GAGESII + CADWR
- New for NWMv2.0
  1,457 total (including above and Hawaii) from USGS GAGESII + CADWR + RFC

Calibration Methodology

Dynamically Dimensioned Search (DDS) algorithm

- search strategy in model parameter space is scaled to the maximum number of iterations specified by the user.
- In initial iteration the algorithm search globally and as the procedure approached the maximum user-defined number of iterations, the search transition from a global to a local search.

This transition from a global to local search is achieved by dynamically and probabilistically reducing the search dimension which is the subset of the calibration parameters that will be updated in a given iteration.

Dynamically dimensioned search algorithm for computationally efficient watershed model calibration

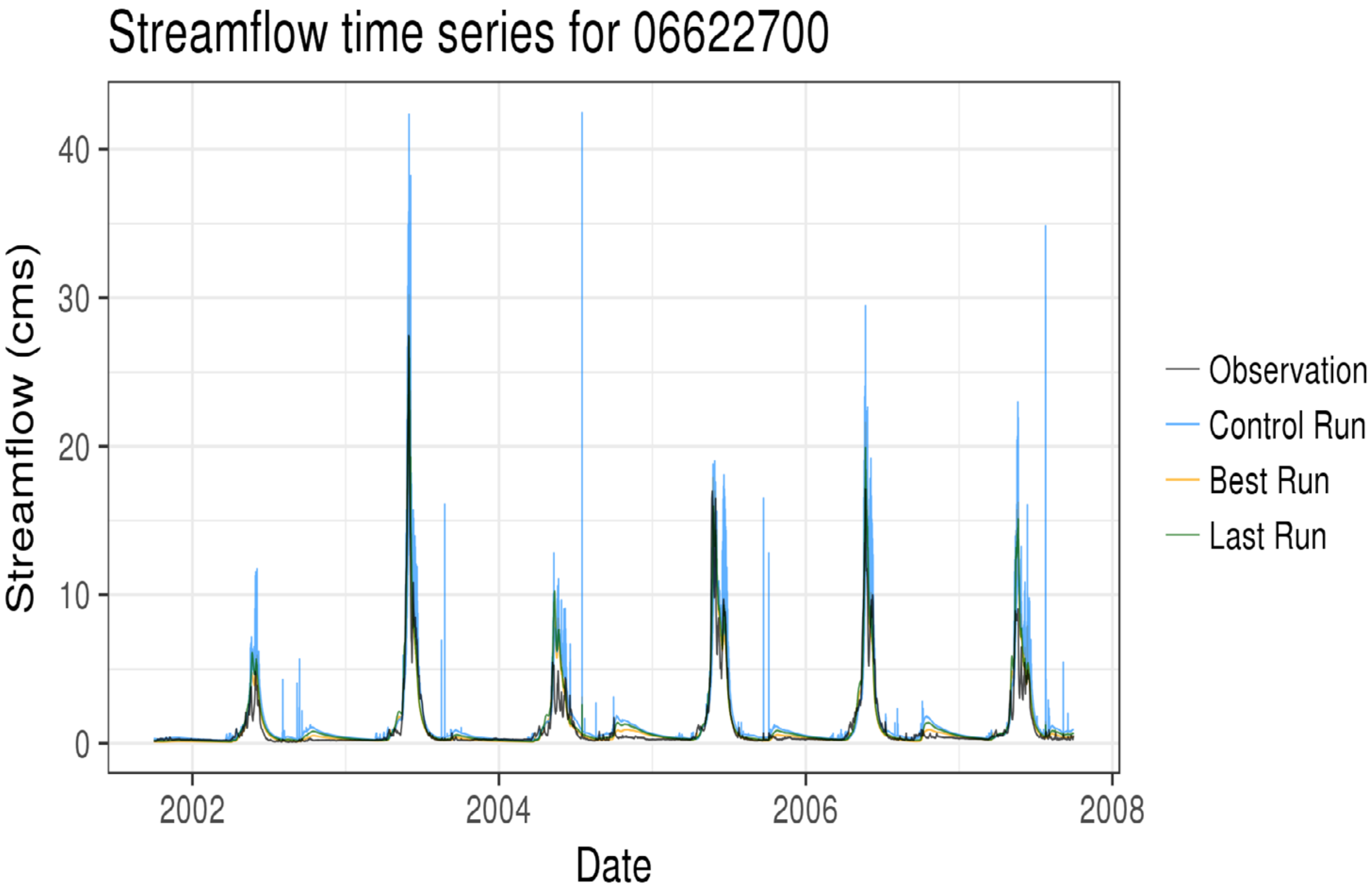
Bryan A. Tolson, Christine A. Shoemaker

First published: 17 January 2007 | https://doi.org/10.1029/2005WR004723 |

Calibration: Metrics

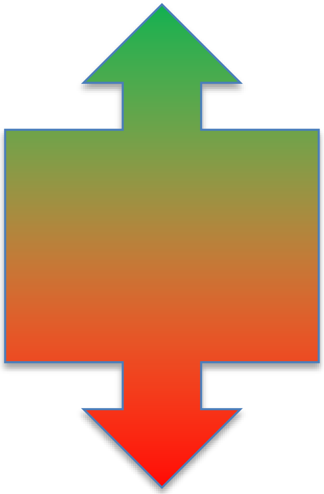
Metric	Equation	Optimal Value	Reference	Purpose
Objective Function	1-(NSE + NSELog)/2	0		Weighted NSE transformed so that minimal value is best (requirement of method obj fn)
Nash-Sutcliffe Efficiency (NSE)	NSE = 1 - (sum((obs - sim)^2) / sum((obs - mean(obs))^2)	1	See:Nash & Stucliffe 1970	Single metric combining timing and magnitude errors.
Log-transformed NSE (NSELog)	NSELog =1 - (sum((log10(obs) - log10(sim))^2) / sum((log10(obs) - mean(log10(obs)))^2)	1		Same as above but applied to log-transformed flowrates.
Weighted NSE (NSEWt)	(NSE + NSELog)/2	1		Capture flow timing and magnitude errors jointly via the NSE metric and somewhat reduce the peak flow emphasis of NSE by including the log-transformed metric.
Pearson correlation (Cor)		1		Flow timing
Root mean squared error (RMSE)	RMSE = sqrt(sum((sim - obs)^2)/n))	0		Flow magnitude
Percent bias (Bias)	Bias = sum(sim - obs) / sum(obs)	0		Flow magnitude
Kling-Gupta Efficiency (KGE)	KGE = sqrt((s.r*(1-r))^2 + (s.alpha*(1-alpha))^2 + (s.beta*(1-beta))^2); r = cor(sim, obs, use=use); alpha = sd(sim, na.rm=na.rm) / sd(obs, na.rm=na.rm); beta = mean(sim, na.rm=na.rm) / mean(obs, na.rm=na.rm)	1	See:Gupta et al 2009	Single metric combining timing and magnitude errors.
Multi-Scale Objective Function (MSOF)	MSOF=sqrt(sum((sd0/sd(k))^2*sum((obs-sim)^2))) where: sd0=standard deviation at native scale (e.g., hourly); sd(k)=standard deviation at the aggregated scale k (e.g., 6 hourly) obs, sim=aggregated observation or simulation at the kth aggregation scale first sum is over the n specified aggregation scales (k=1,n) second sum is over the m ordinates at the kth aggregation scale	0	See: Kuzmin et al. 2008	The MSOF was adopted as an optimization criterion for calibrating the HL-RDHM using the Stepwise Linear Search (SLS) algorithm. The rationale behind MSOF is to simultaneously consider contributions from a wide range of time scales of aggregation during the calibration process (i.e., mimicking manual calibration), and to reduce the likelihood of the search getting stuck in small ‘pits’, by smoothing the objective function surface

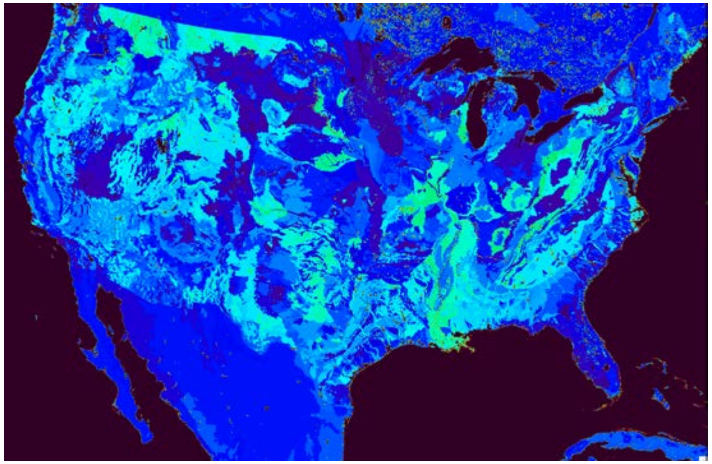
Calibration Strategy



Calibration: Parameters

- **Parameter adjustment:**
  - **Scalar adjustment**





  - **Replacement**
    - **Table values**
    - **Parameters with uniform values across domain**

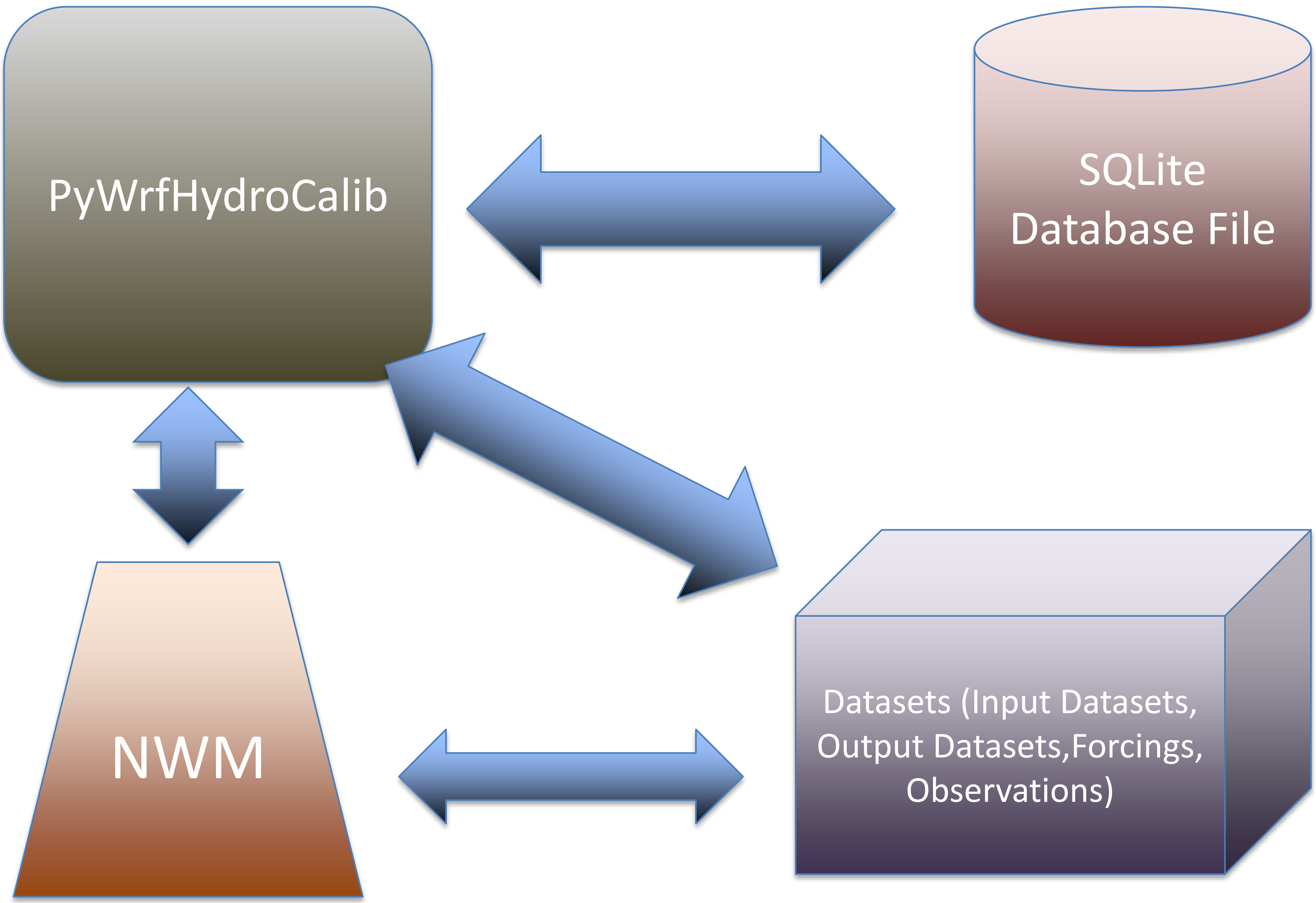
Calibration: Parameters

Name	Description	Units
SOIL PARAMS		
bexp	Pore size distribution index	dimensionless
smcmax	Saturation soil moisture content (i.e., porosity)	volumetric fraction
dksat	Saturated hydraulic conductivity	m/s
rsurfexp	Exponent in the resistance equation for soil evaporation	dimensionless
RUNOFF PARAMS		
refkdt	Surface runoff parameter; REFKDT is a tuneable parameter that significantly impacts surface infiltration and hence the partitioning of total runoff into surface and subsurface runoff. Increasing REFKDT decreases surface runoff	unitless
slope	Linear scaling of "openness" of bottom drainage boundary	0-1
RETDEPRTFAC	Multiplier on retention depth limit	unitless
LKSATFAC	Multiplier on lateral hydraulic conductivity (controls anisotropy between vertical and lateral conductivity)	unitless
GROUNDWATER PARAMS		
Zmax	Maximum groundwater bucket depth	mm
Expon	Exponent controlling rate of bucket drainage as a function of depth	dimensionless
VEG PARAMS		
CWPVT	Canopy wind parameter for canopy wind profile formulation	1/m
VCMX25	Maximum carboxylation at 25C	umol/m2/s
MP	Slope of Ball-Berry conductance relationship	unitless
SNOW PARAMS		
MFSNO	Melt factor for snow depletion curve; larger value yields a smaller snow cover fraction for the same snow height	Dimensionless
CHANNEL PARAMETERS		
Bw	Parameterized width of the bottom of the stream network	m
HLINK	Initial channel depth	m
ChSSlp	Channel side slope	m/m
MannN	Manning’s roughness coefficient	Dimension

Calibration Strategy (NWM v1.2)

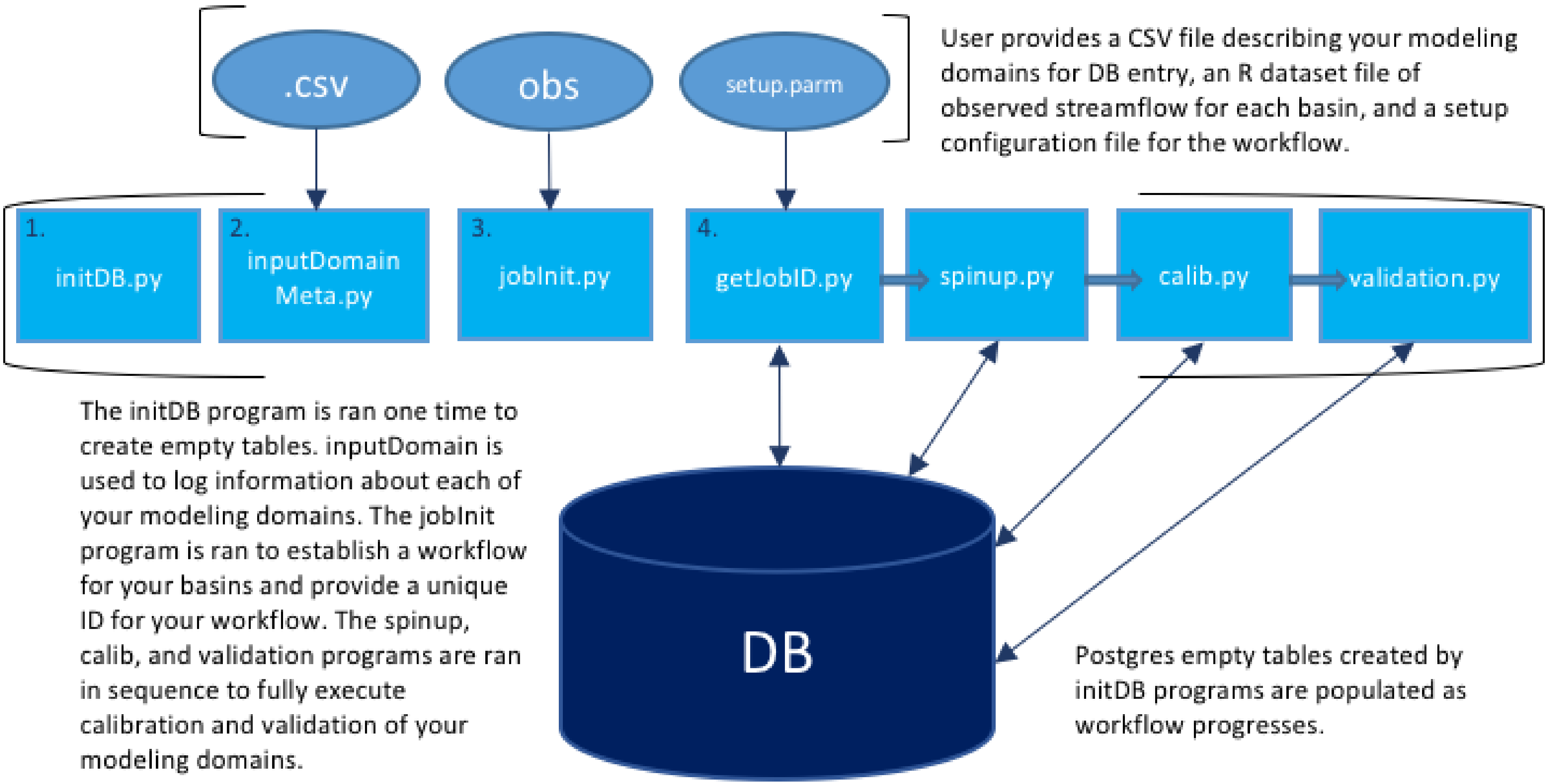
- Deliverables for >1100 basins demanded a more robust workflow to execute model simulations automatically on NCAR supercomputers.
- Ability to store model analysis statistics and workflow status on a database.
- Ability to restart calibrations when fatal system errors occurred.
- Proper error/message dissemination to the users running calibration.

NWM Calibration Procedure:



NWM Calibration Procedure:

Calibration Workflow



User provides a CSV file describing your modeling domains for DB entry, an R dataset file of observed streamflow for each basin, and a setup configuration file for the workflow.

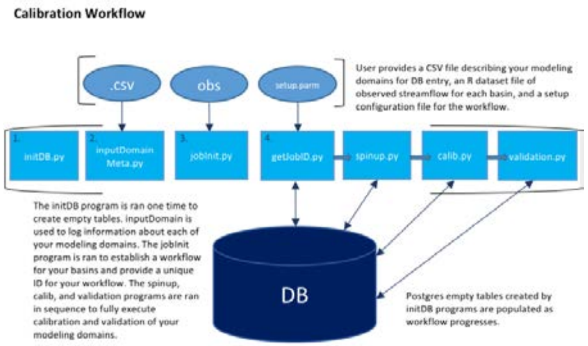
The initDB program is ran one time to create empty tables. inputDomain is used to log information about each of your modeling domains. The jobInit program is ran to establish a workflow for your basins and provide a unique ID for your workflow. The spinup, calib, and validation programs are ran in sequence to fully execute calibration and validation of your modeling domains.

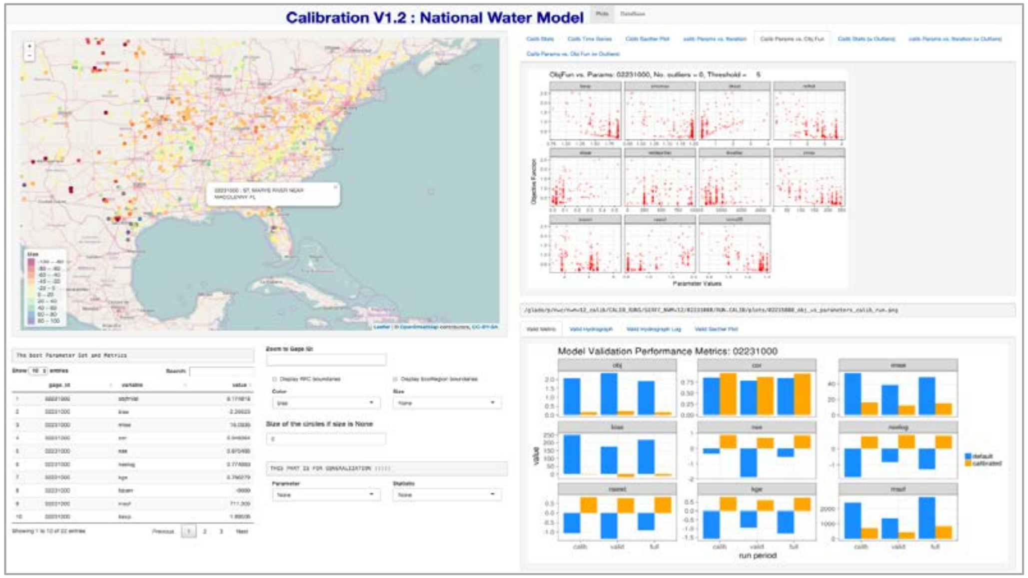
Postgres empty tables created by initDB programs are populated as workflow progresses.

PyWrfHydroCalib: Python + R package for model calibration

- **Domain subsetting tools**
- **Parameter sensitivity analysis**
  - **Distributed Evaluation of Local Sensitivity Analysis (DELSA) methodology (Rakovec et al. 2014)**
- **Calibration:**
  - **Dynamically Dimension Search (DDS) algorithm (Tolson, B. A., and C. A. Shoemaker: 2007)**
  - **Split sample calibration/validation**
  - **Multiple criteria monitoring (NSE, RMSE, % bias, correlation, KGE, MSOF)**
  - **Automated Rwrfhydro-NWM workflow**

Automated workflow using Python and R interacting with a MySQL database (PyNWMCalib)



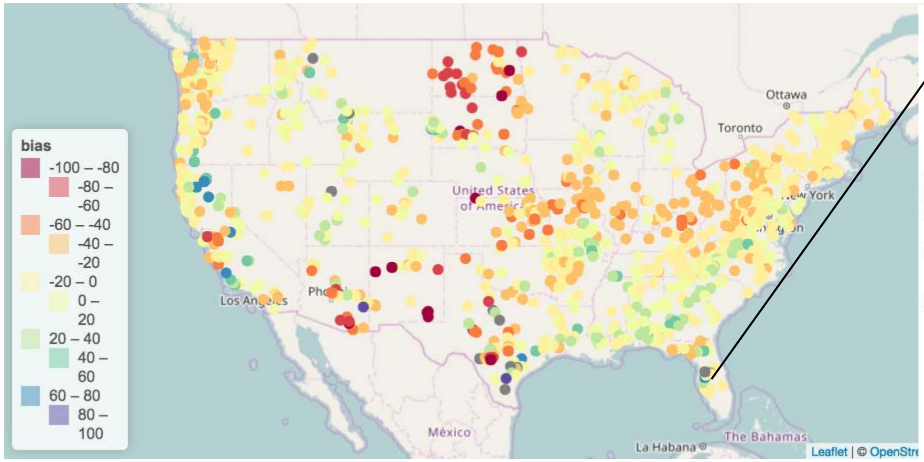


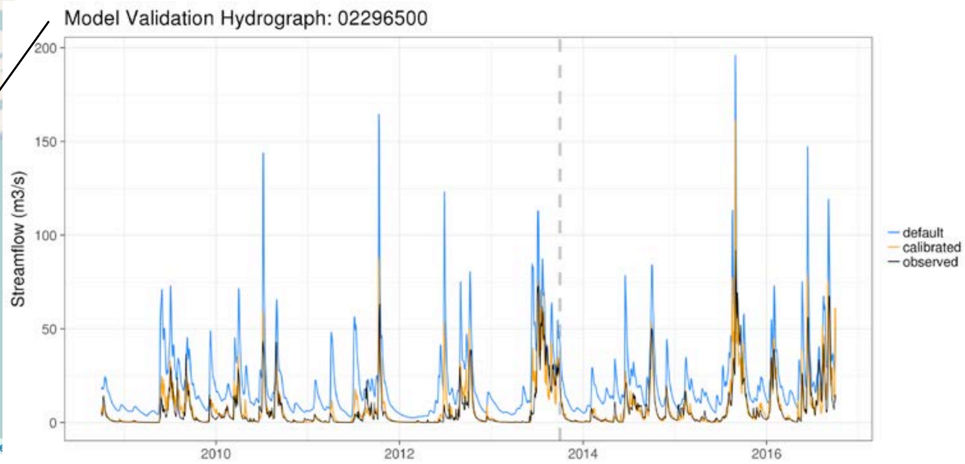
A. Dugger, L. Karsten, A. RafieeiNasab

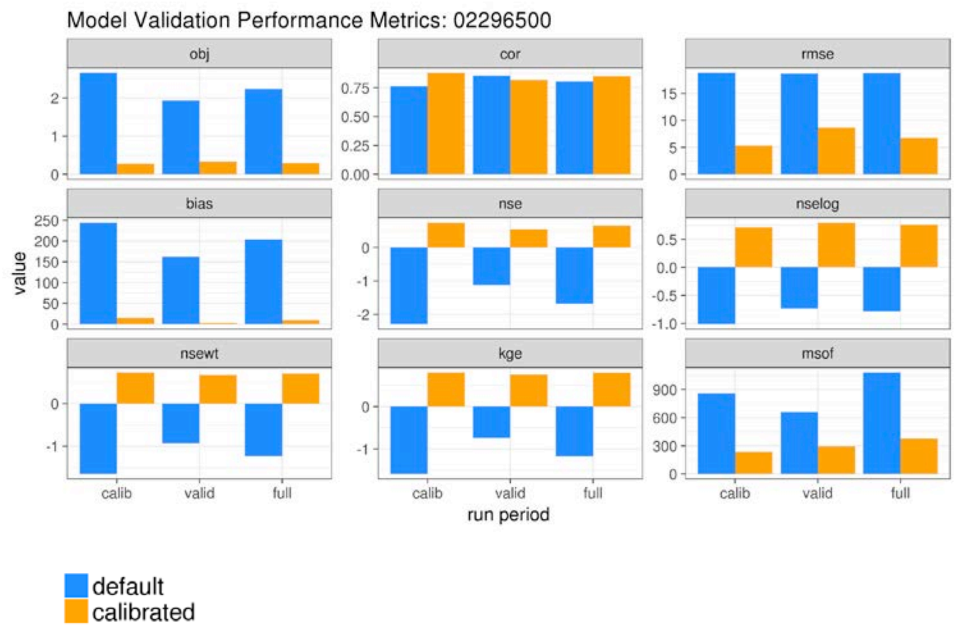
Necessary Packages

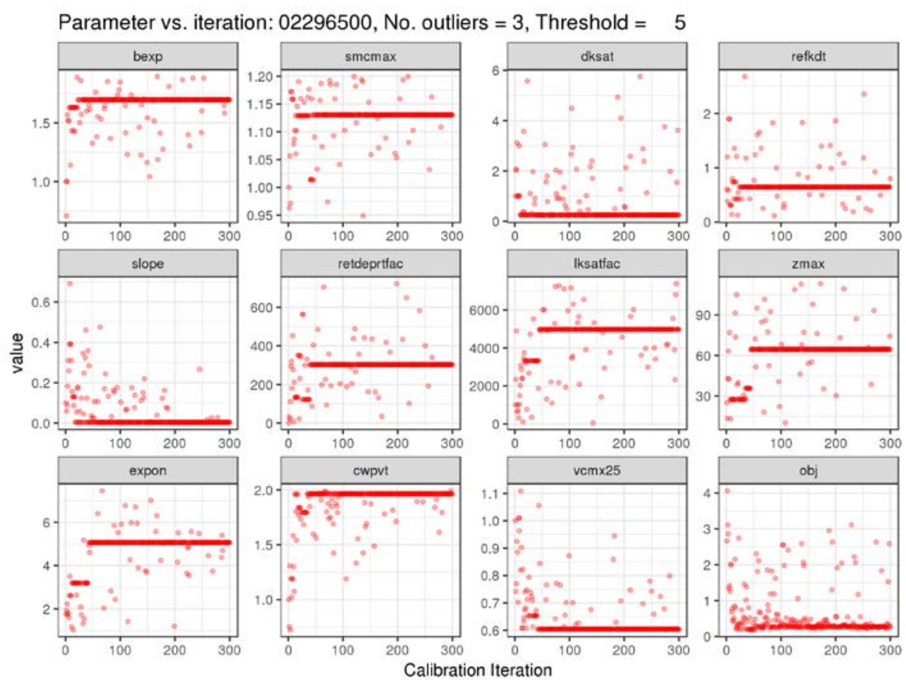
- **R**
  - ggplot2
  - data.table
  - gridExtra
  - sensitivity (if running sensitivity analysis)
  - randtoolbox (if running sensitivity analysis
  - boot
  - Ncdf4
  - Plyr
- **Python**
  - NetCDF4
  - Pandas
  - Numpy
  - psutil

Model Calibration









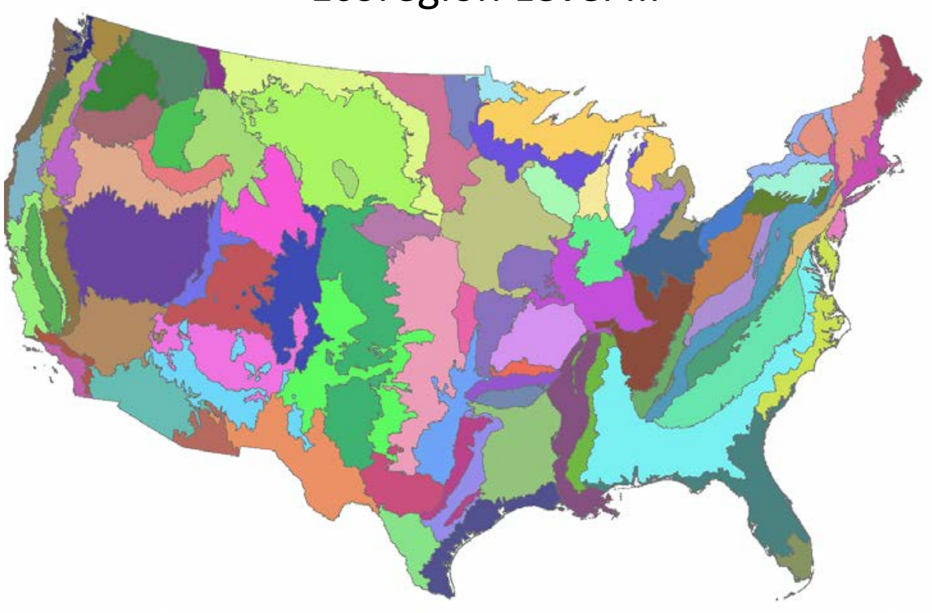
Calibration Strategy - Future

- **Improved retrospective forcing's.**
- **Multi-variate calibration**
  - **Snow**
  - **Soil Moisture**
- **Additional parameters for calibration**

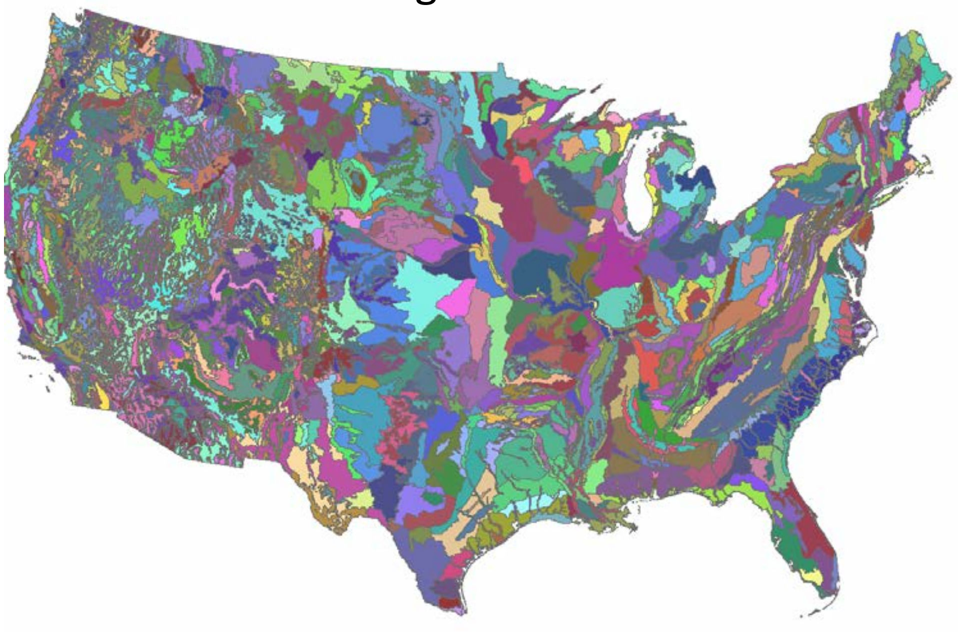
Regionalization

Ecoregions are based on perceived patterns of a combination of causal and integrative factors including land use, land surface form, potential natural vegetation, and soil (Omernik J.M., 1987) and are mapped into different levels based on the degree of classification details.

Ecoregion Level III

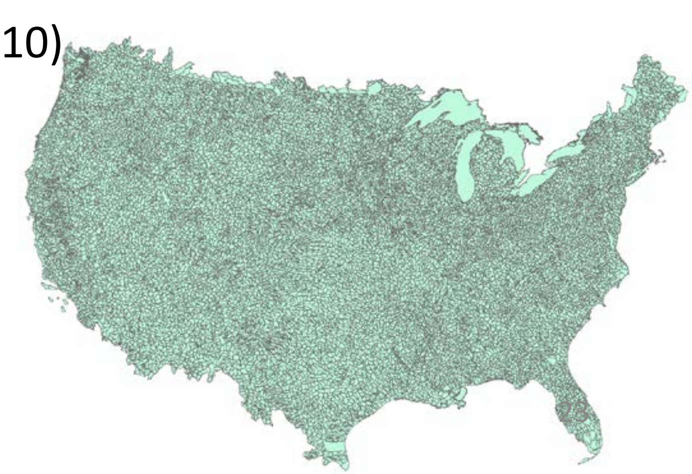


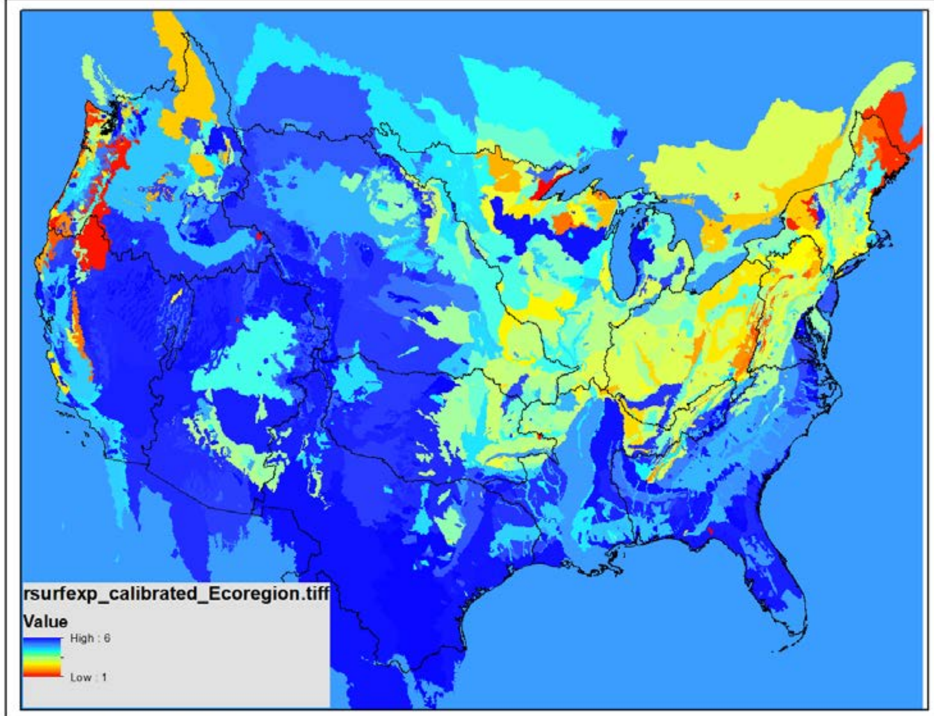
Ecoregion Level IV

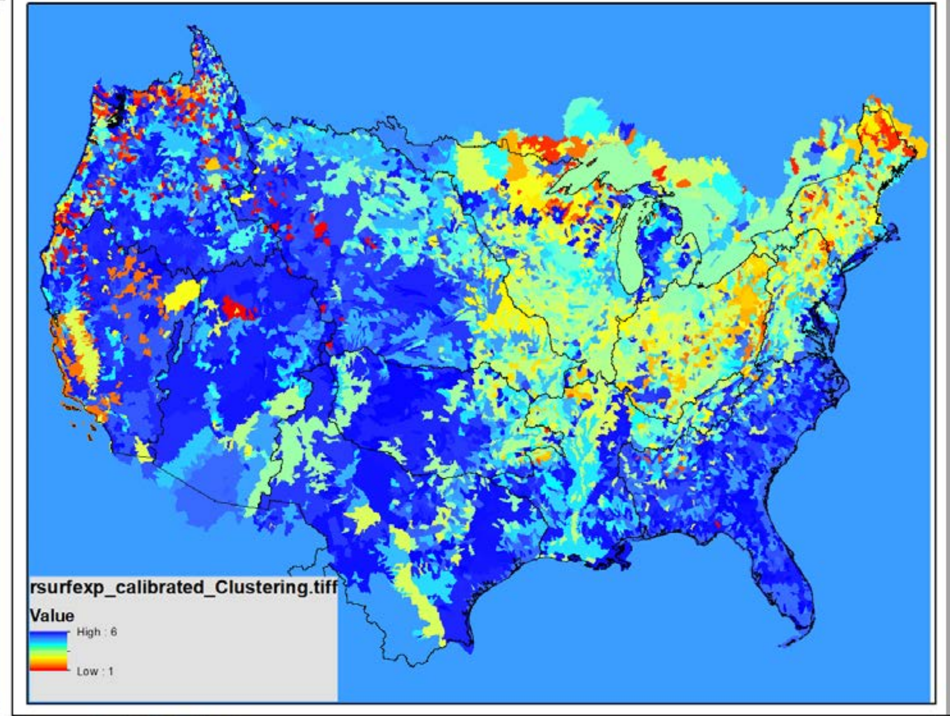


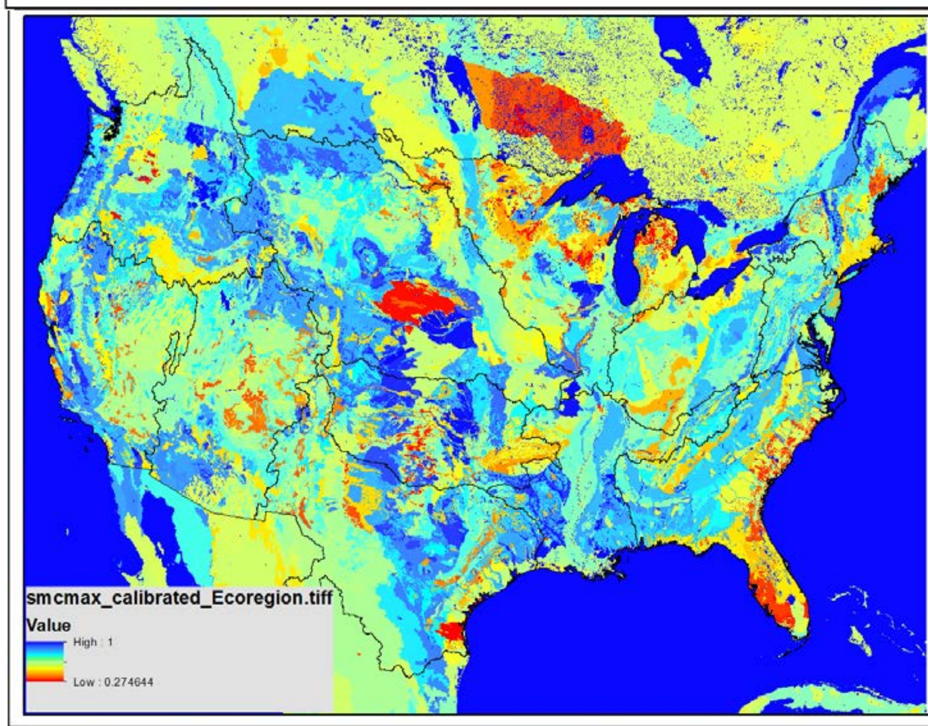
Hydrologic Landscape Regions (HLR) Clustering

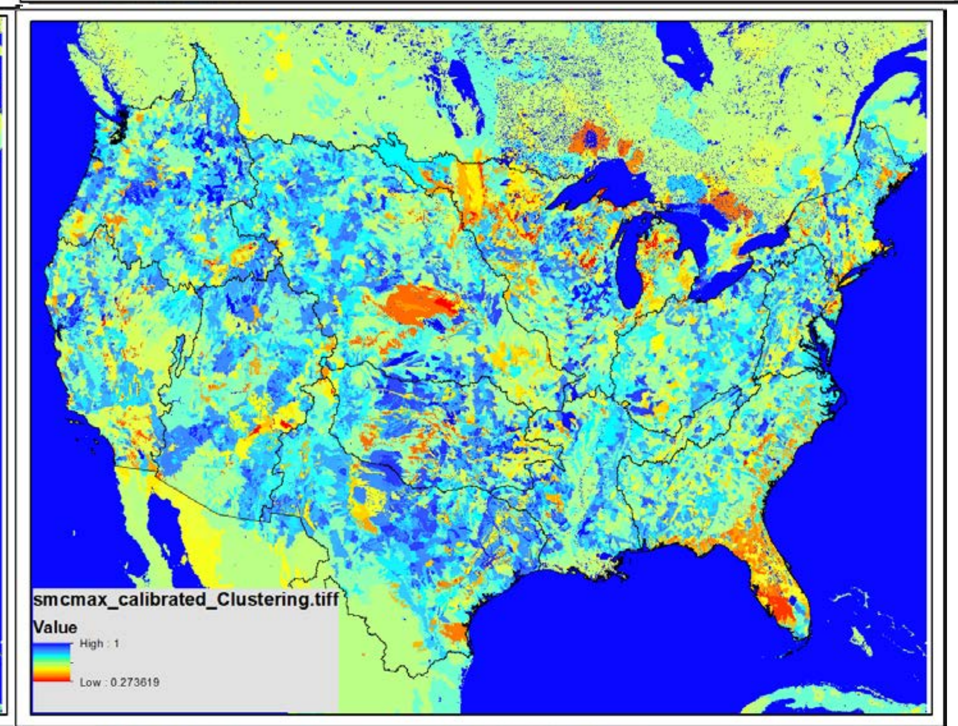
- **Collect/compute HLR parameters**
  - Climate (P-PET), land surface form (total %flatland, %flatland in upland, %flatland in lowland, relief)
  - Soil & geology (% sand, % clay, bedrock permeability), land cover (% forest cover)
- **Perform principal component analysis (PCA)**
  - Removes correlation among parameters
  - Identify principal components with each explaining at least 5% of the total variance
- **Perform clustering analysis**
  - Determine the number of clusters to use (tricky!)
  - Classify the HUC10 and calibration basins into clusters (K-means clustering)
- **Perform parameter regionalization**
  - Identify a donor calibration basin for each HLR (HUC10)
  - Map back to NWM grid




rsurfexp_calibrated_Ecoregion.tiff
Value
High : 6
Low : 1

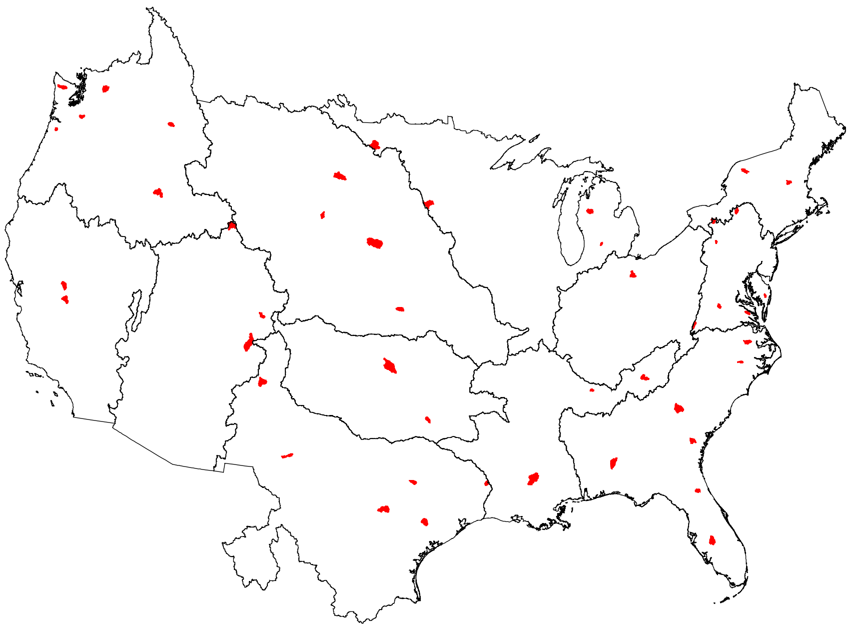

rsurfexp_calibrated_Clustering.tiff
Value
High : 6
Low : 1


smcmax_calibrated_Ecoregion.tiff
Value
High : 1
Low : 0.274644


smcmax_calibrated_Clustering.tiff
Value
High : 1
Low : 0.273619

Sensitivity Analysis

Distributed Evaluation of Local Sensitivity Analysis (DELSA), a hybrid local-global sensitivity analysis (SA) method, for extracting useful information on the importance of each parameter, with the added advantage of being relatively low computational cost compared to other common SA methods such as Sobol.



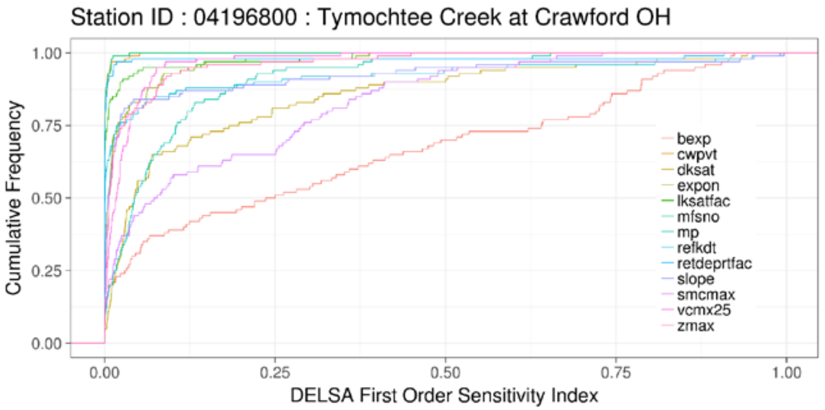
Name	Description	Units	value	Value	Value
SOIL PARAMS					
bexp	Pore size distribution index	dimensionless	x1	x0.4	x1.9
smcmax	Saturation soil moisture content (i.e., porosity)	volumetric fraction	x1	x0.8	x1.2
dksat	Saturated hydraulic conductivity	m/s	x1	x0.2	x10
RUNOFF PARAMS					
refkdt	Surface runoff parameter; REFKDT is a tuneable parameter that significantly impacts surface infiltration and hence the partitioning of total runoff into surface and subsurface runoff. Increasing REFKDT decreases surface runoff	unitless	0.6	0.1	4
slope	Linear scaling of "openness" of bottom drainage boundary	0-1	0.1	0	1
RETDEPRTFAC	Multiplier on retention depth limit	unitless	1	0.1	10
LKSATFAC	Multiplier on lateral hydraulic conductivity (controls anisotropy between vertical and lateral conductivity)	unitless	1000	10	10000
GROUNDWATER PARAMS					
Zmax	Maximum groundwater bucket depth	mm?	25	10	250
Expon	Exponent controlling rate of bucket drainage as a function of depth	dimensionless	1.75	1	8
VEG PARAMS					
CWPVT	Canopy wind parameter for canopy wind profile formulation	1/m	x1	x0.5	x2
VCMX25	Maximum carboxylation at 25C	umol/m2/s	x1	x0.6	x1.4
MP	Slope of Ball-Berry conductance relationship	unitless	x1	x0.6	x1.4
SNOW PARAMS					
MFSNO	Melt factor for snow depletion curve; larger value yields a smaller snow cover fraction for the same snow height	dimensionless	2	0.5	3

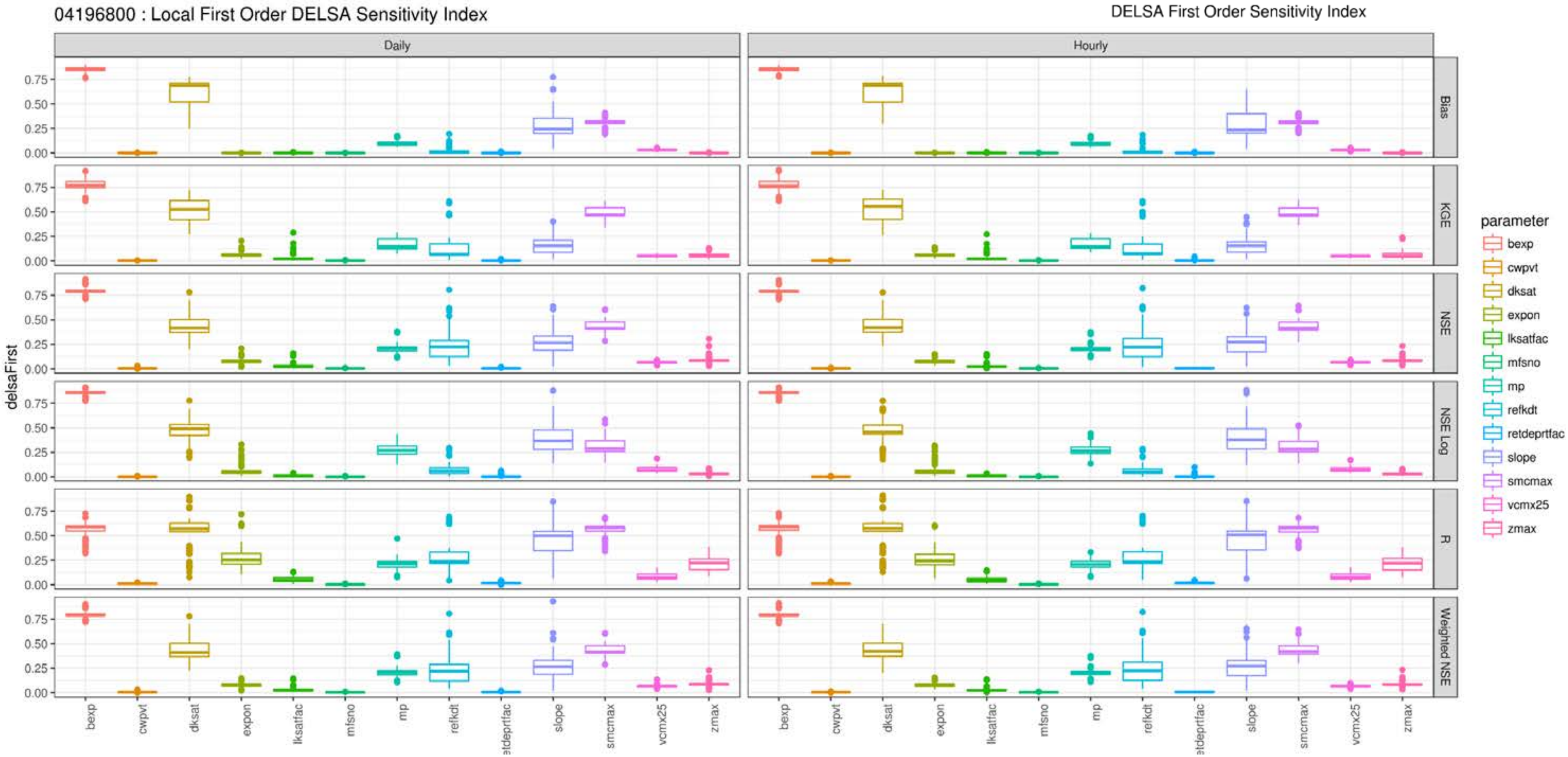
DELSA sensitivity index

Higher values DELSA sensitivity index indicates the model performance (for this example NSE) is more sensitive to the change in the parameter.

CDFs of the SA index for all the parameters are displayed for the NSE metric.

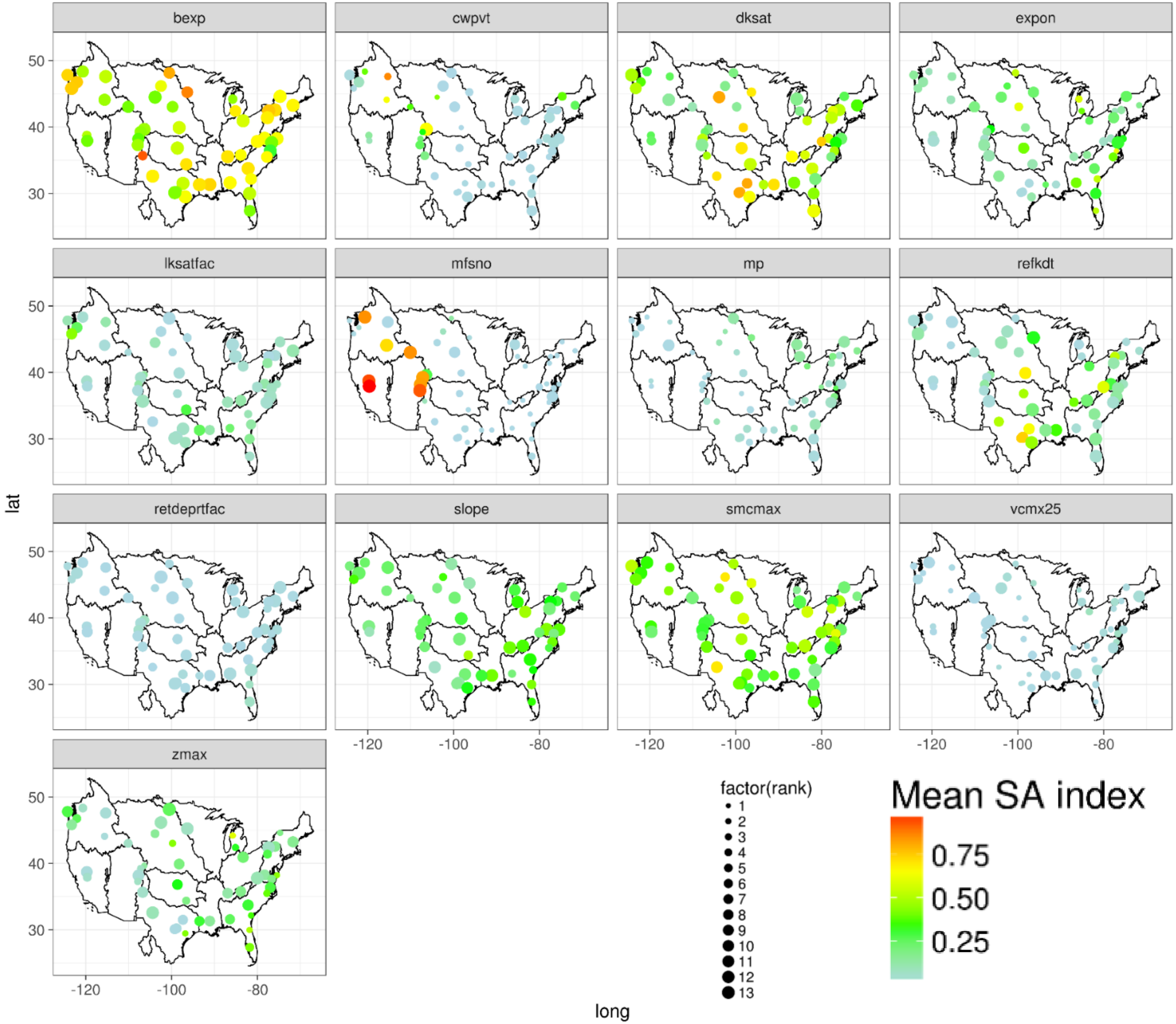
For the selected basin located in Idaho, **bexp** is the most sensitive parameter and the **mfsno** is the least sensitive parameter.



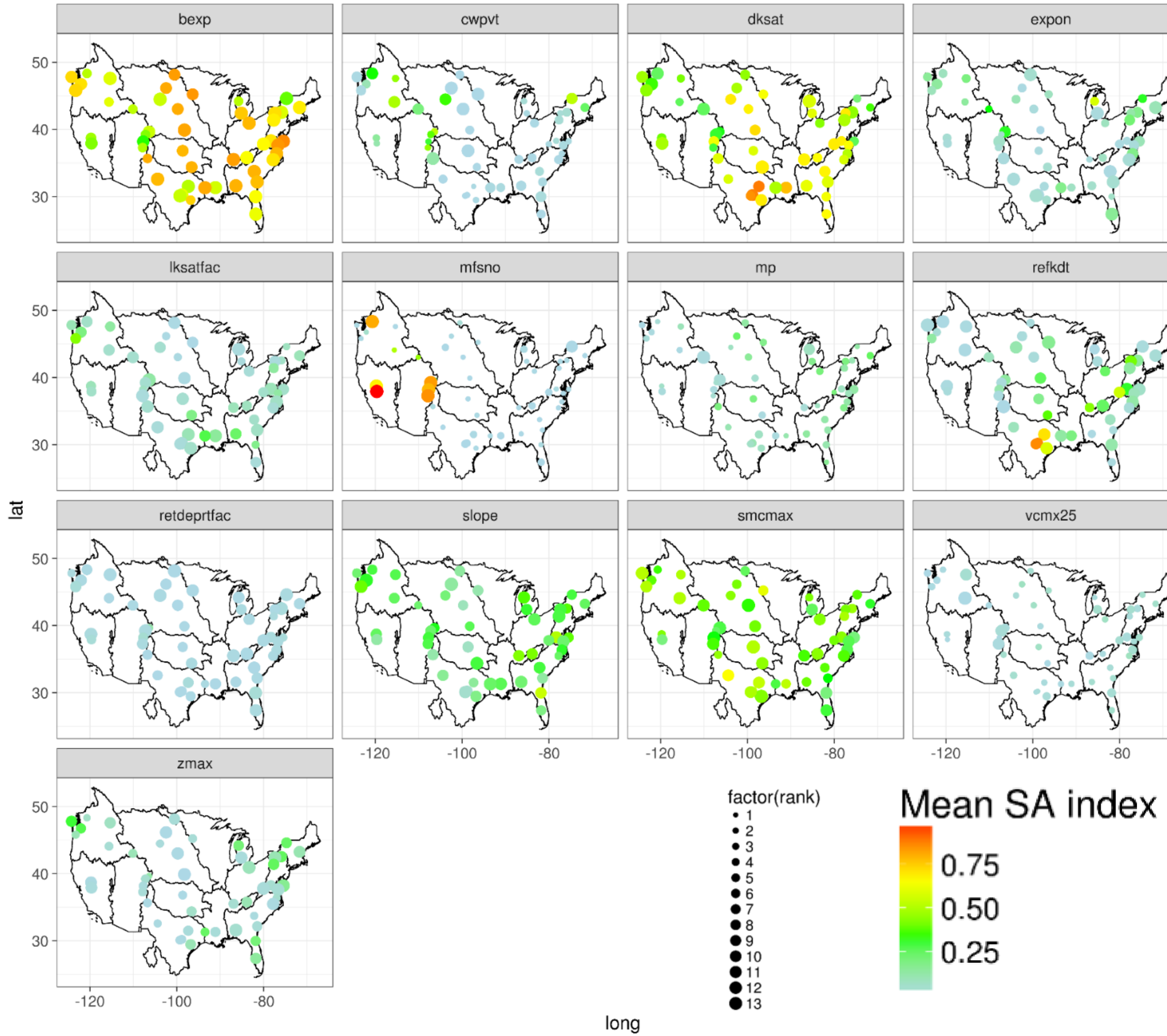


Mean of DELSA sensitivity index for streamflow bias

Mean of DELSA sensitivity index for streamflow Correlation Coefficient (hourly time step)



Mean of DELSA sensitivity index for streamflow NSE (hourly time step)



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THANK YOU!