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Bayesian calibration and evaluation of transferability of hydrologic parameters in CLM

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CESM joint LMWG-BGCWG-UQ meeting, Mesa Lab, Boulder, CO
21 February 2013

Outline

- An uncertainty quantification framework designed for CLM
  - Results at selected flux towers and MOPEX basins
- Bayesian inversion/calibration of the hydrologic parameters
  - MCMC inversion of CLM4
  - MCMC inversion using surrogates (Ray et al., this meeting)
- Toward understanding the parameter transferability
  - Classification of MOPEX basins
  - Future work plan

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An uncertainty quantification framework designed for CLM

Parameterization
- candidate parameters of interest

Prior information (mean, variance, bounds)

Entropy method
Minimum Relative Entropy (MRE)

$$f_{M|I}(m|I) = \prod_{j=1}^{p} \frac{\beta_j e^{-\beta_j m}}{e^{-\beta_j L_j} - e^{-\beta_j U_j}}$$

$$f_{M|I}(m|I) = \prod_{j=1}^{p} \frac{\sqrt{\frac{\gamma_j}{\pi}} \exp\left[-\gamma_j\left(m_j + \frac{\beta_j}{2\gamma_j}\right)^2\right]}{\Phi\left[\sqrt{2\gamma_j}\left(U_j + \frac{\beta_j}{2\gamma_j}\right)\right] - \Phi\left[\sqrt{2\gamma_j}\left(L_j + \frac{\beta_j}{2\gamma_j}\right)\right]}$$

Closed-form Prior probability density functions (pdfs)

Quasi Monte Carlo sampling

Realizations of parameter sets

CLM forward modeling

Symbol	Definition
f_{max}	Max fractional saturated area, from DEM
C_s	Shape parameter of the topographic index distribution
f_{over}	Decay factor (m^{-1}) for fsat
b	Clapp and Hornberger exponent
K_s	Hydraulic conductivity (mm s^{-1})
θ_s	porosity
Ψ_s	Saturated soil matrix potential (mm)
f_{drai}	Decay factor (m^{-1}) drainage
$q_{drai,max}$	Max drainage (kg m^{-2} s^{-1})
S_y	Average specific yield

Output responses:
Latent heat fluxes (LH)
Sensible heat fluxes (SH)
Total runoff

Output statistics:
1. Natural variability of LH/SH/runoff
2. Propagation of uncertainty of input parameters

Multi-variate generalized linear model analysis and significance statistical tests:
1. Rank of significance of input parameters
2. Relationships between LH/SH/runoff and inputs

Model reduction
and
adaptive sampling

Selected flux towers and MOPEX basins

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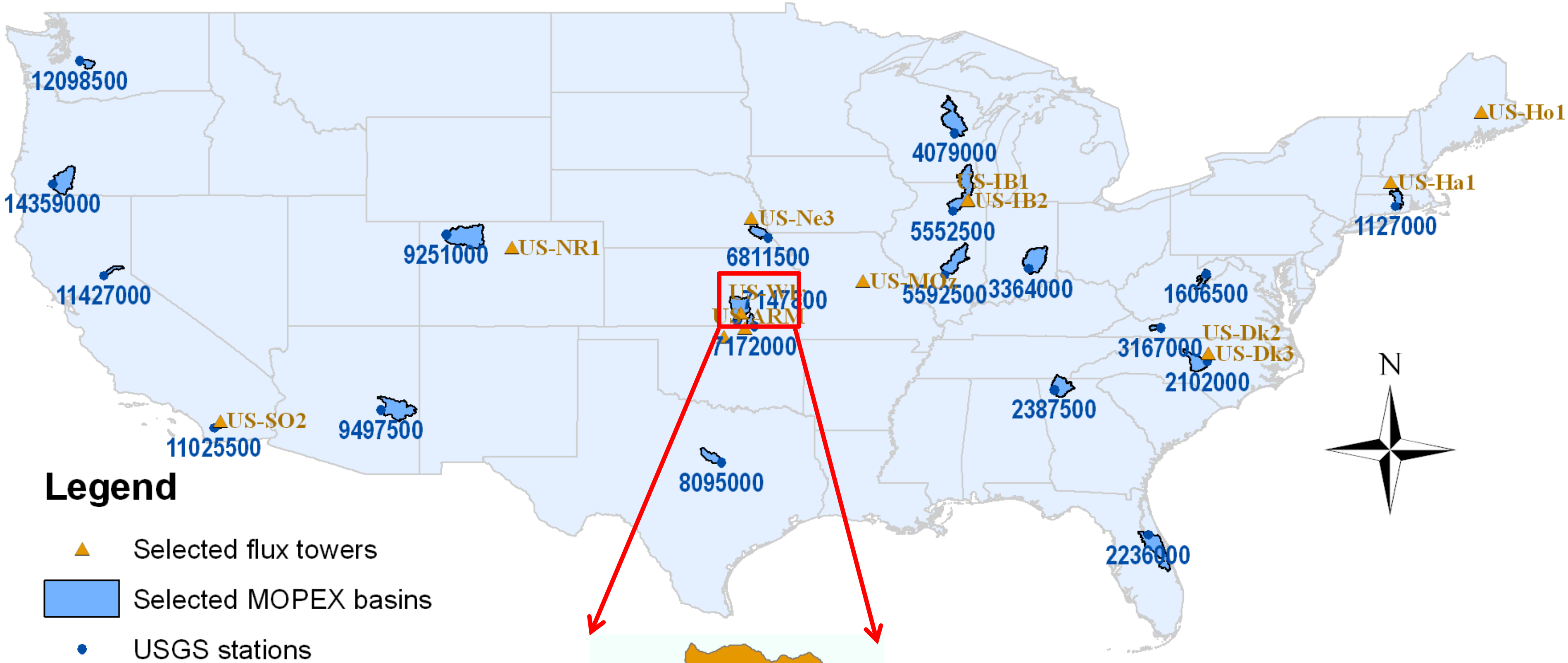

Hou et al. (2012), JGR
Huang et al. (in review), JHM

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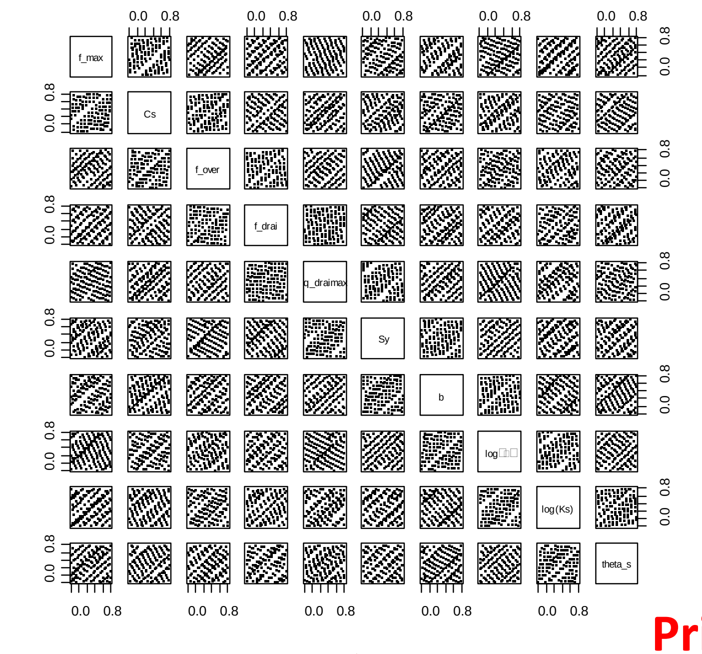
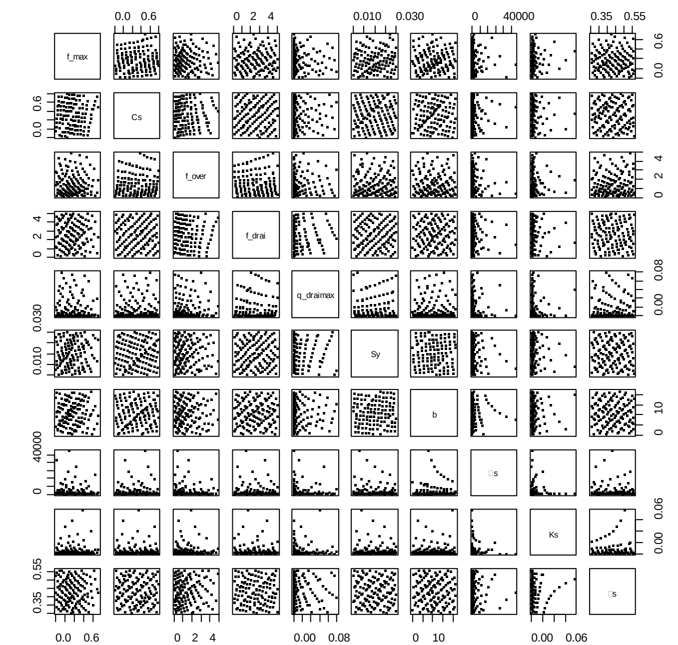
Efficient sampling of the parameter space

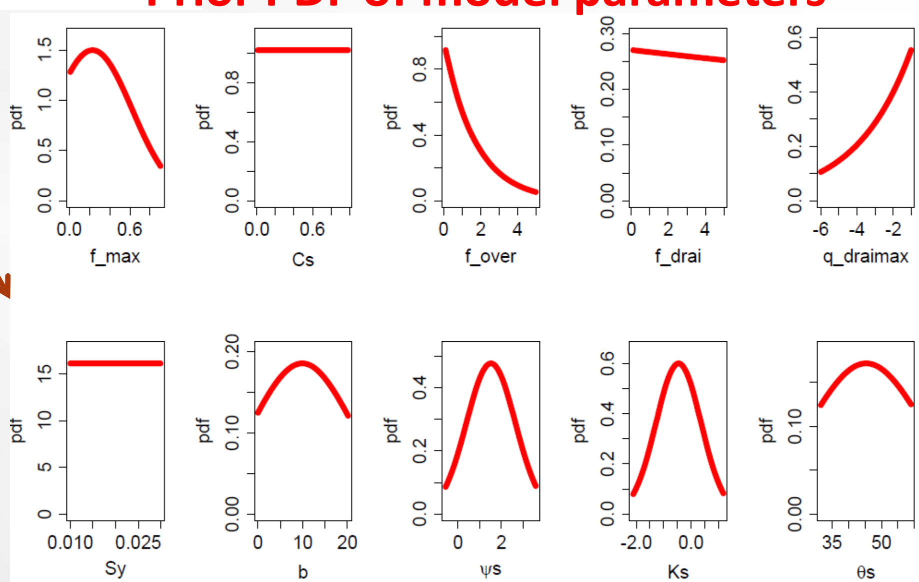
QMC samples in probability space



QMC samples in parameter space



Prior PDF of model parameters



Surface fluxes and runoff are very sensitive to model parameters

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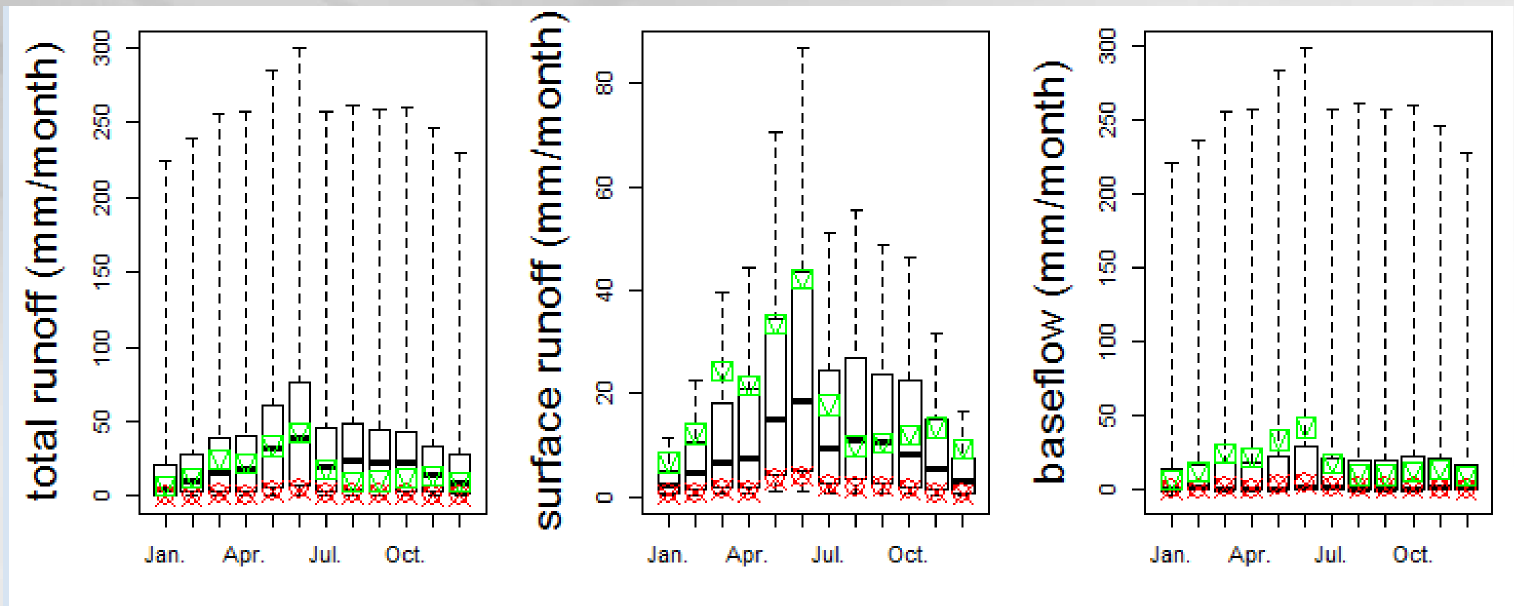

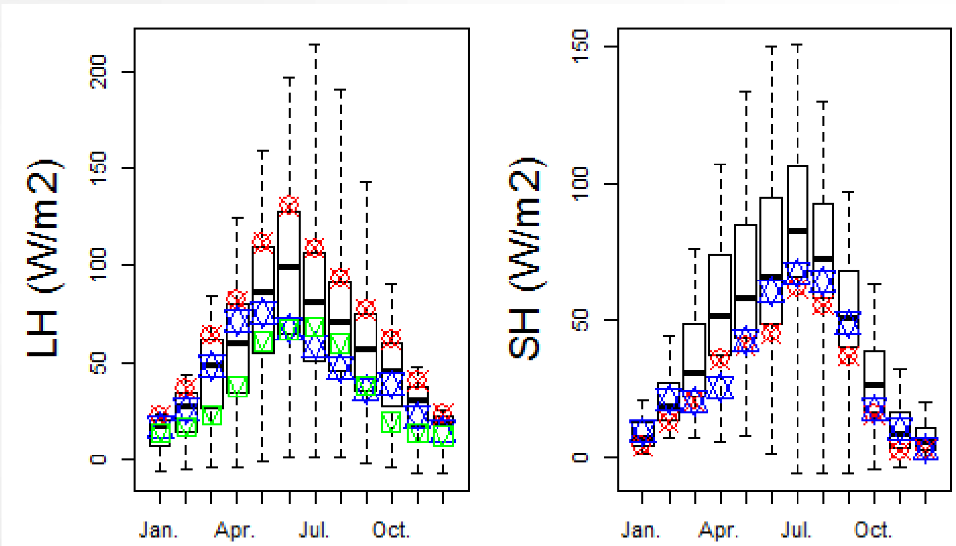

Ranks of significance of input parameters

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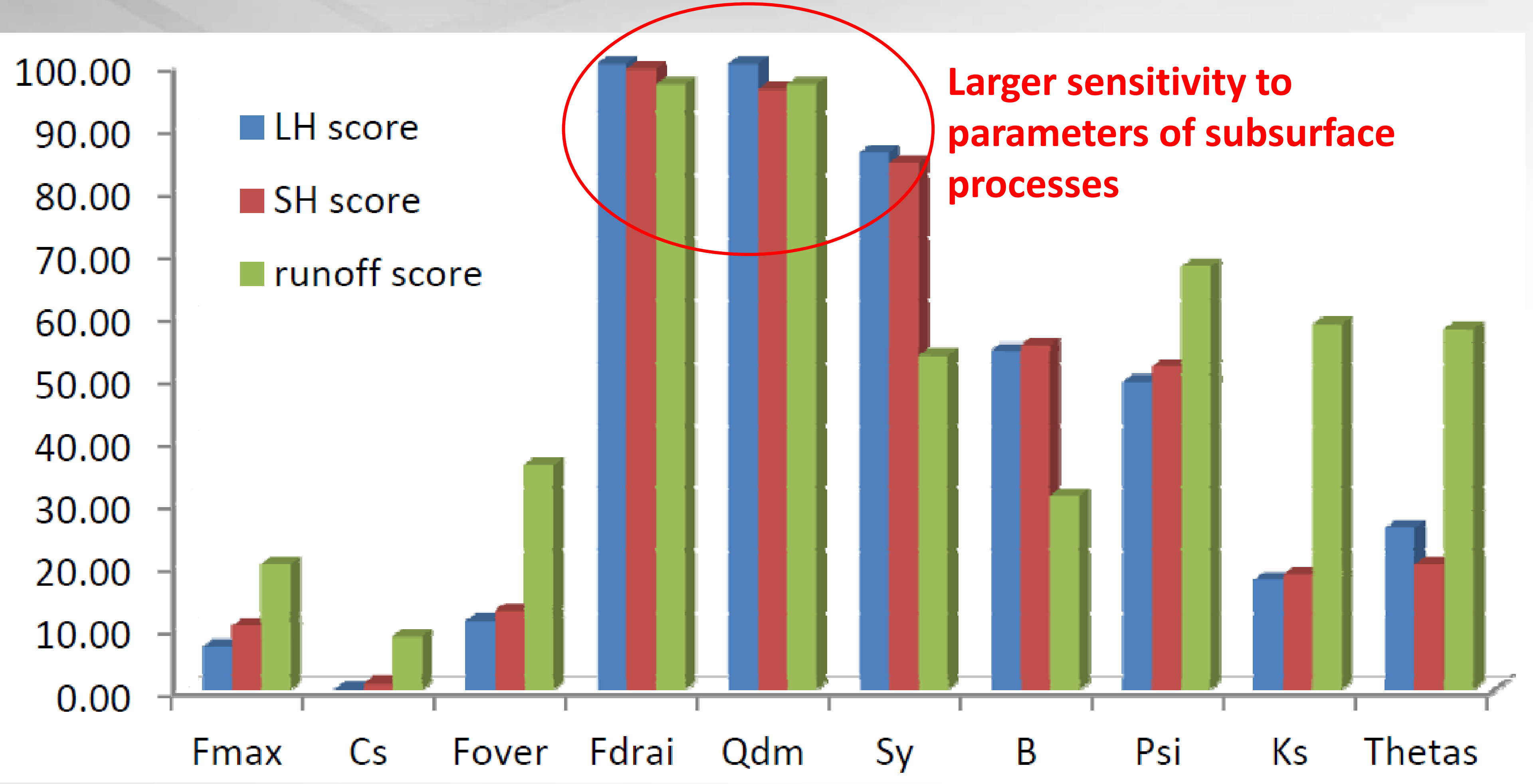

Inversion workflow for CLM4

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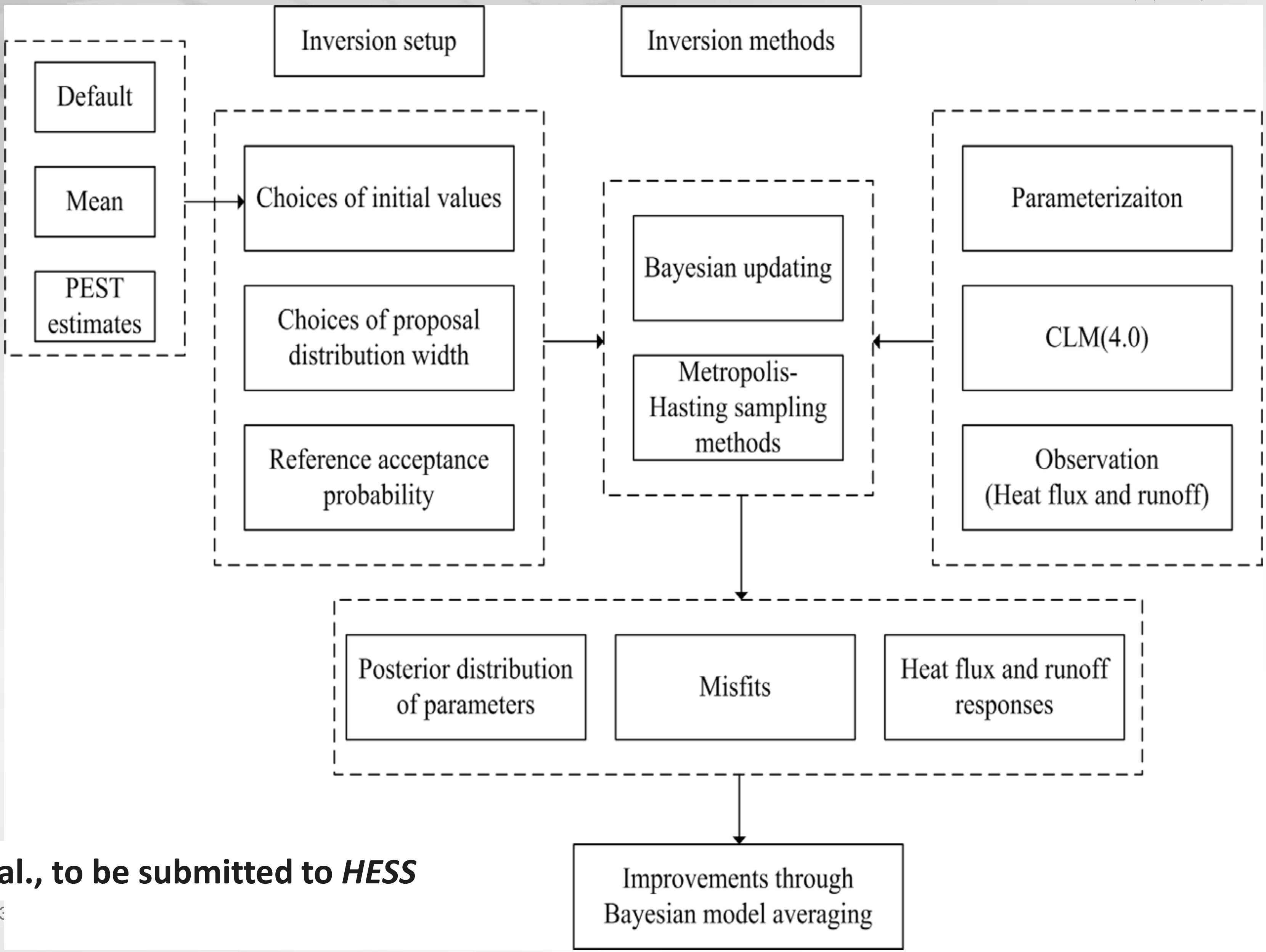
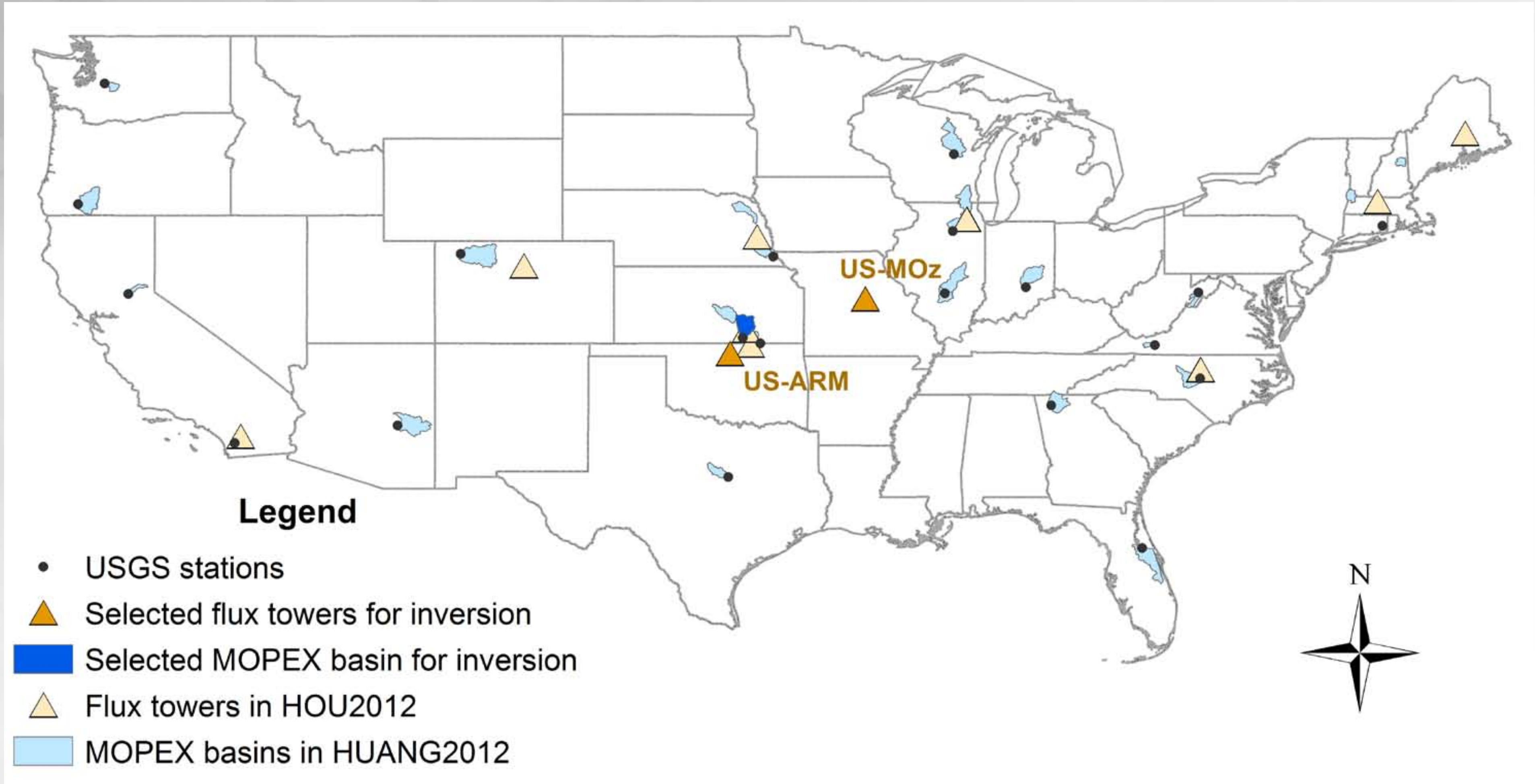


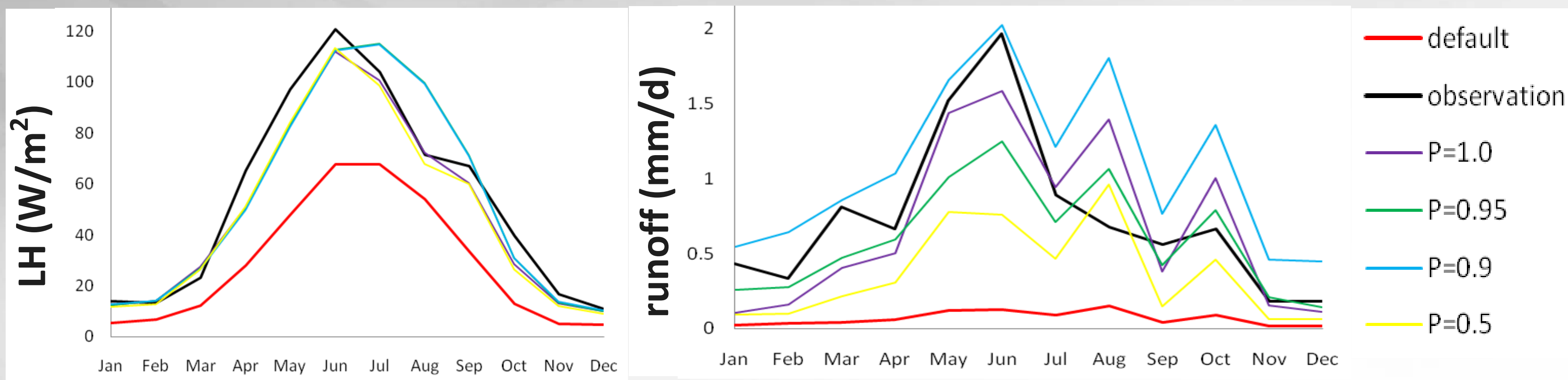
Sun et al., to be submitted to *HESS*

Selected sites for inversion

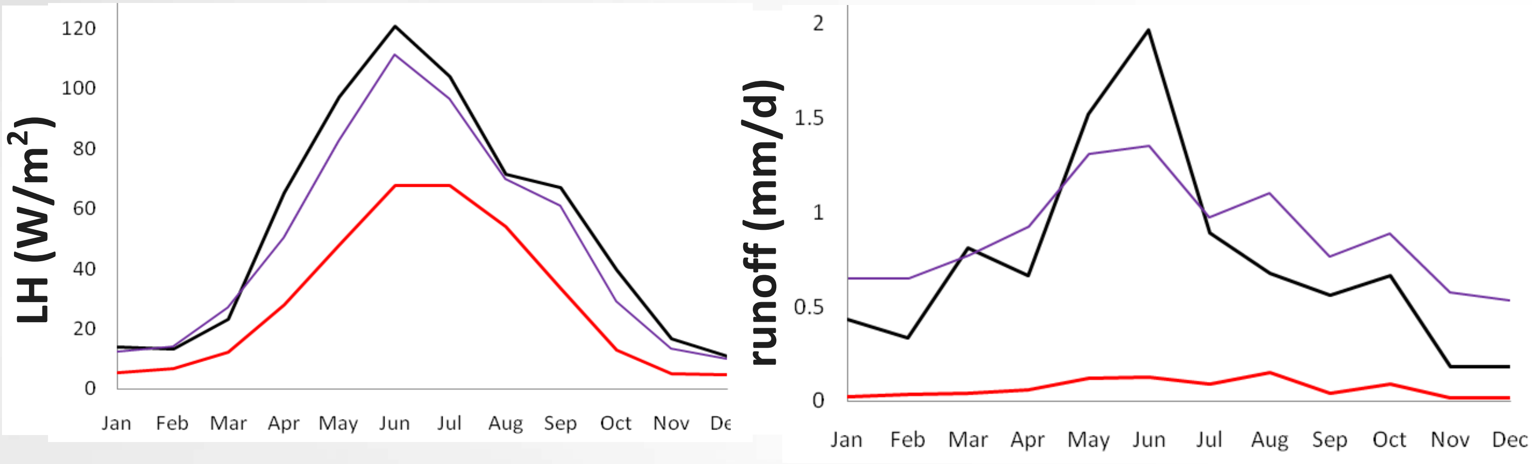


Inversion results

Inversion based on 10 parameters



Inversion based on 3 parameters



Model reduction and parameter transferability

- Although parameter calibration could be used to improve model simulations and quantify uncertainties, it suffers from issues associated with high-dimensionality in number of parameters or large spatial dimensions (e.g., a global domain);

- To reduce the dimensionality, we need to cluster sites/grid cells into classes that share similar characteristics;

- A PCA+MCLUST-based approach is used for classifications;

- Different classification systems were explored:
  - C-Class: Climate-based
  - S-Class: sensitivity-based;
  - H-Class: hydrologic indices-based

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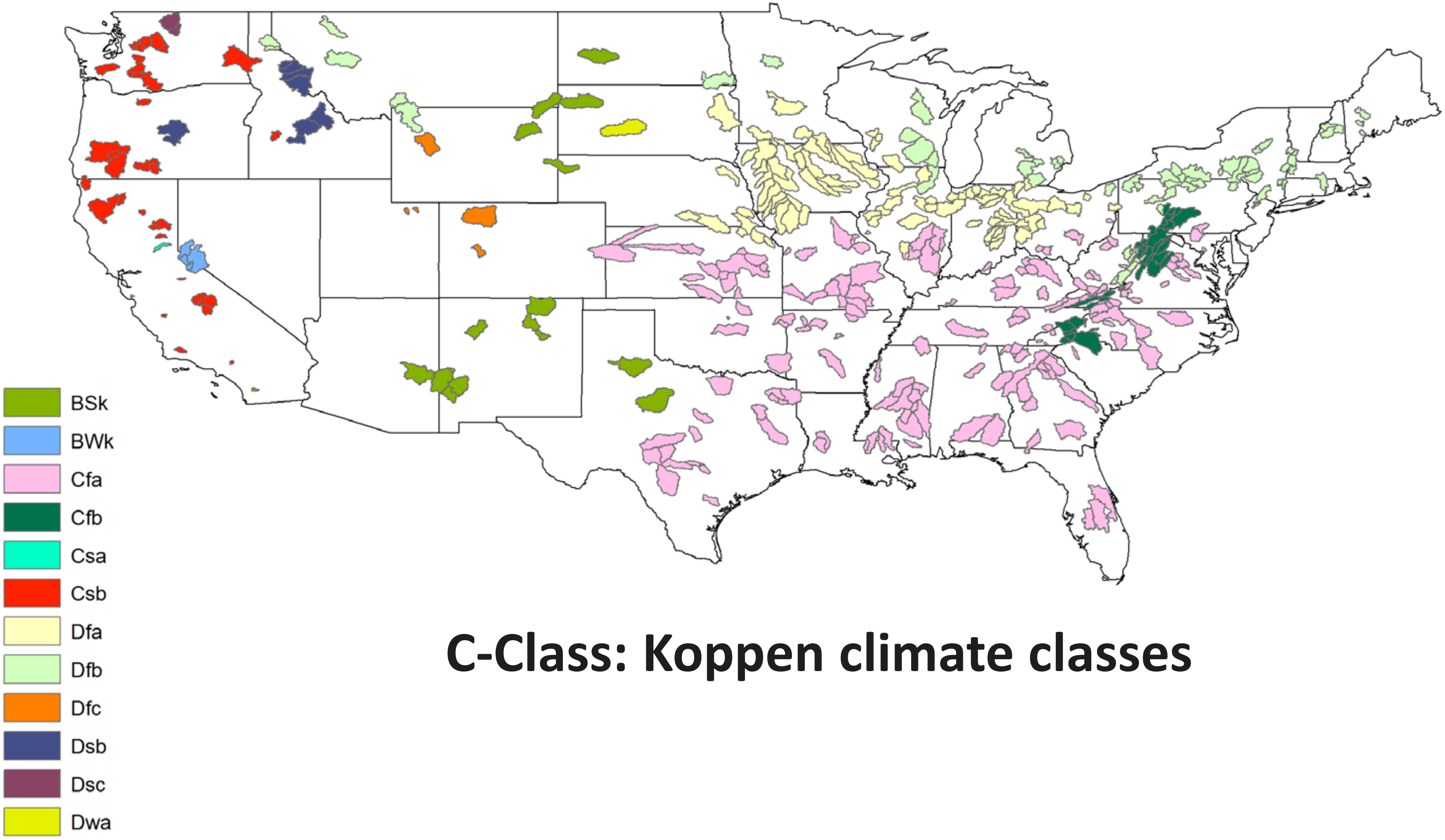
431 MOPEX basins over the US



C-Class: Koppen climate classes

Parameter sensitivity over 431 MOPEX basin

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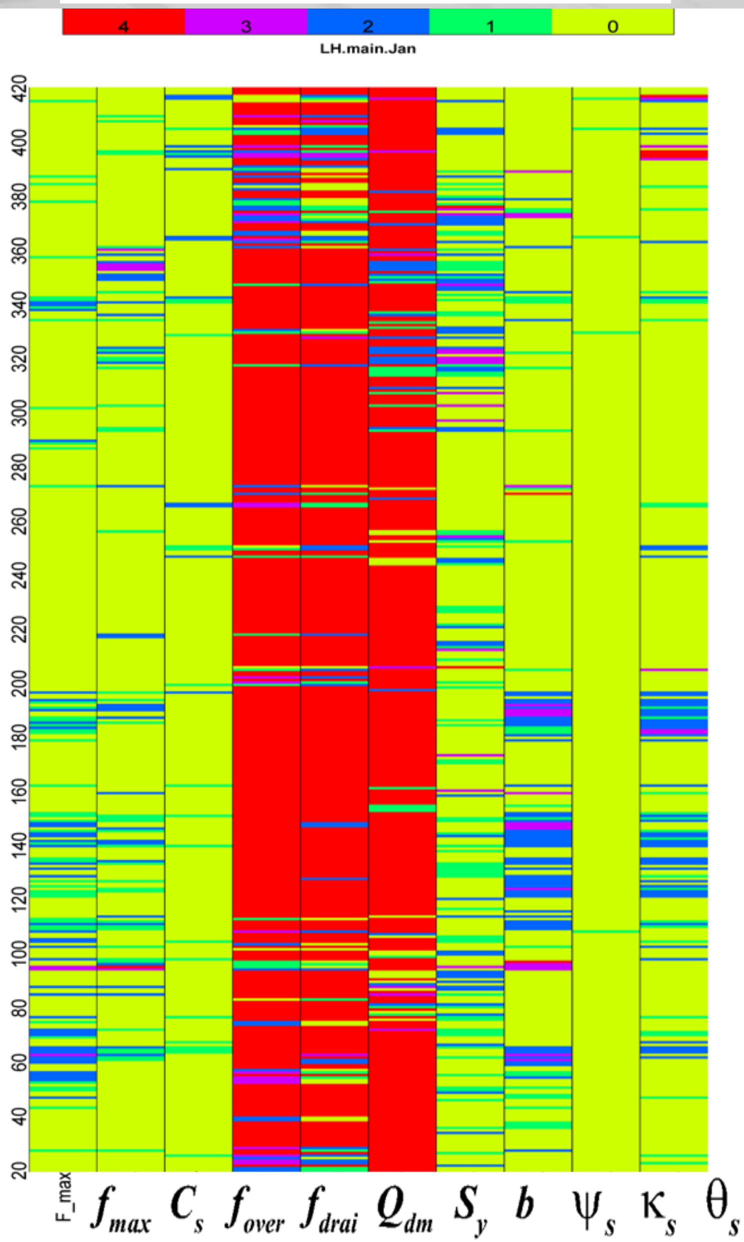
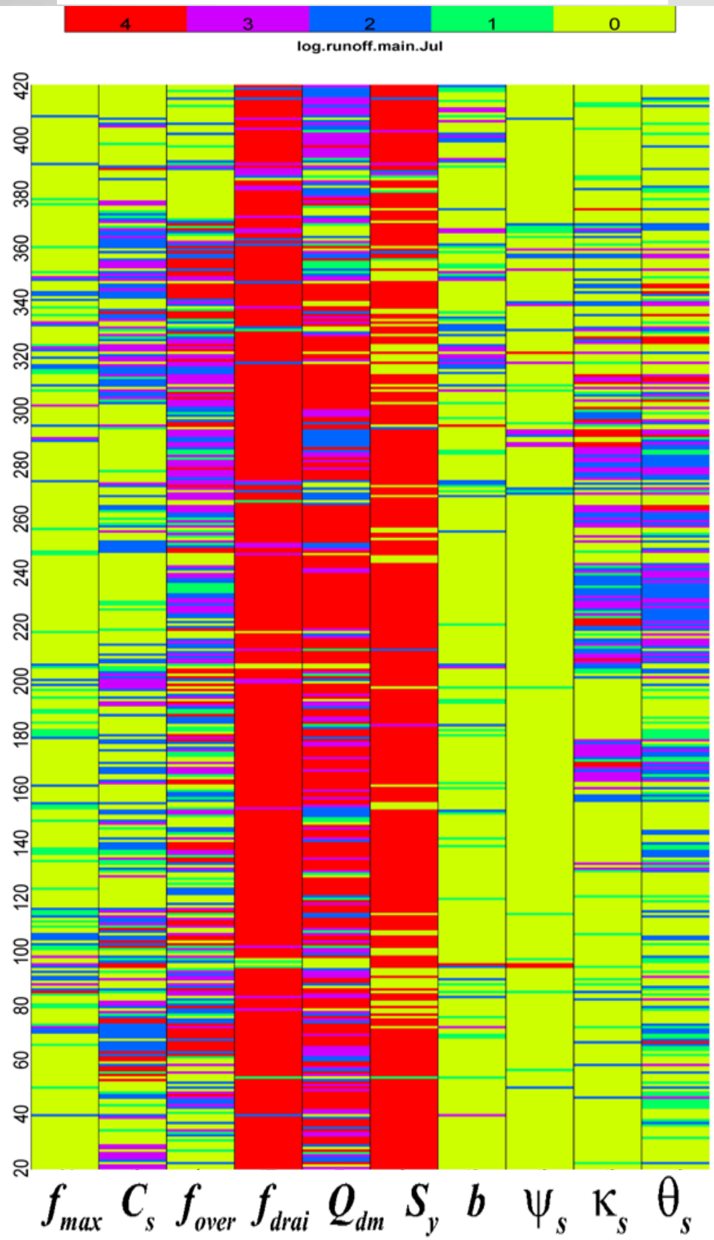
Sensitivity of LH



Sensitivity of runoff



Overall significance of the hydrologic parameters across the MOPEX basins

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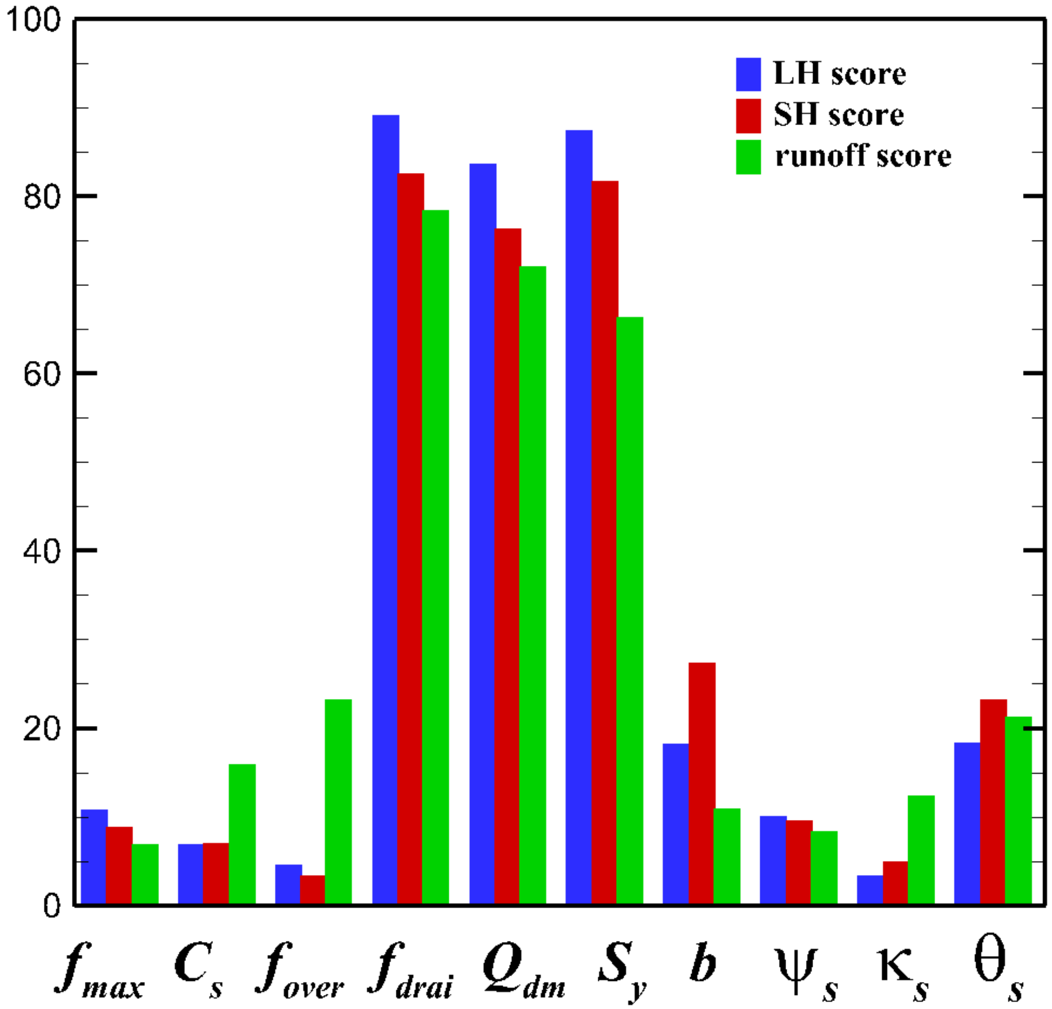
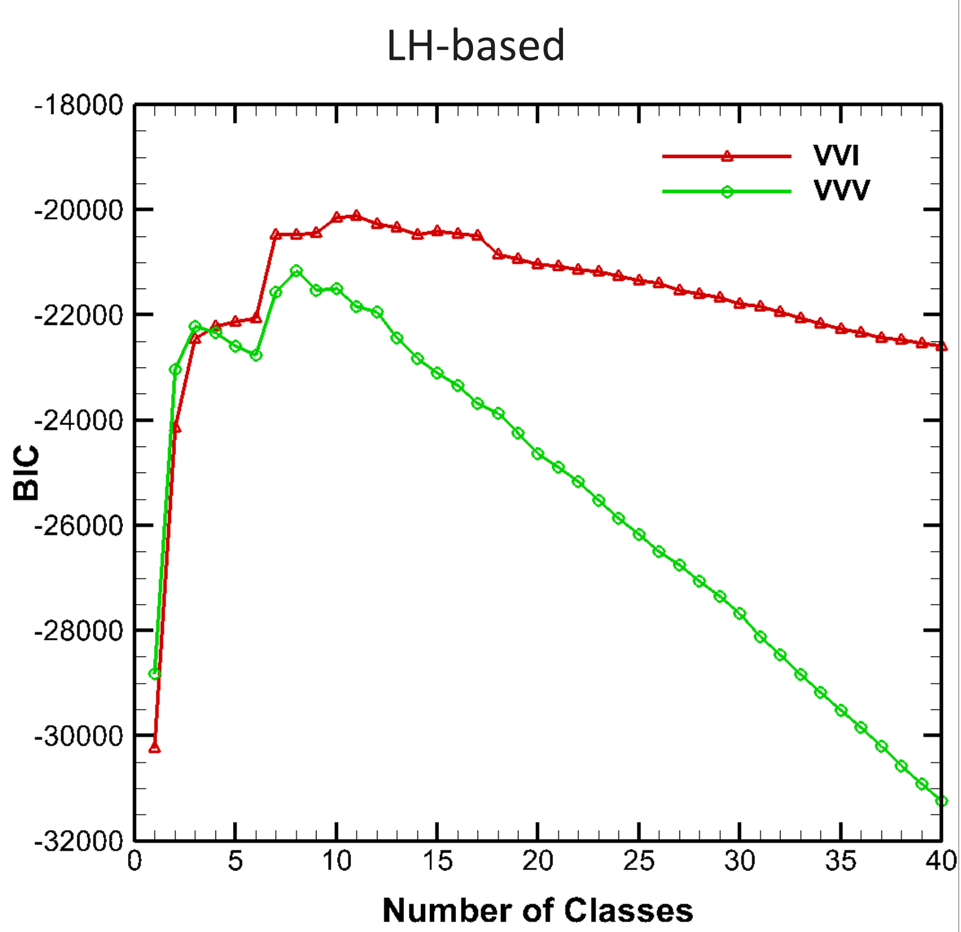
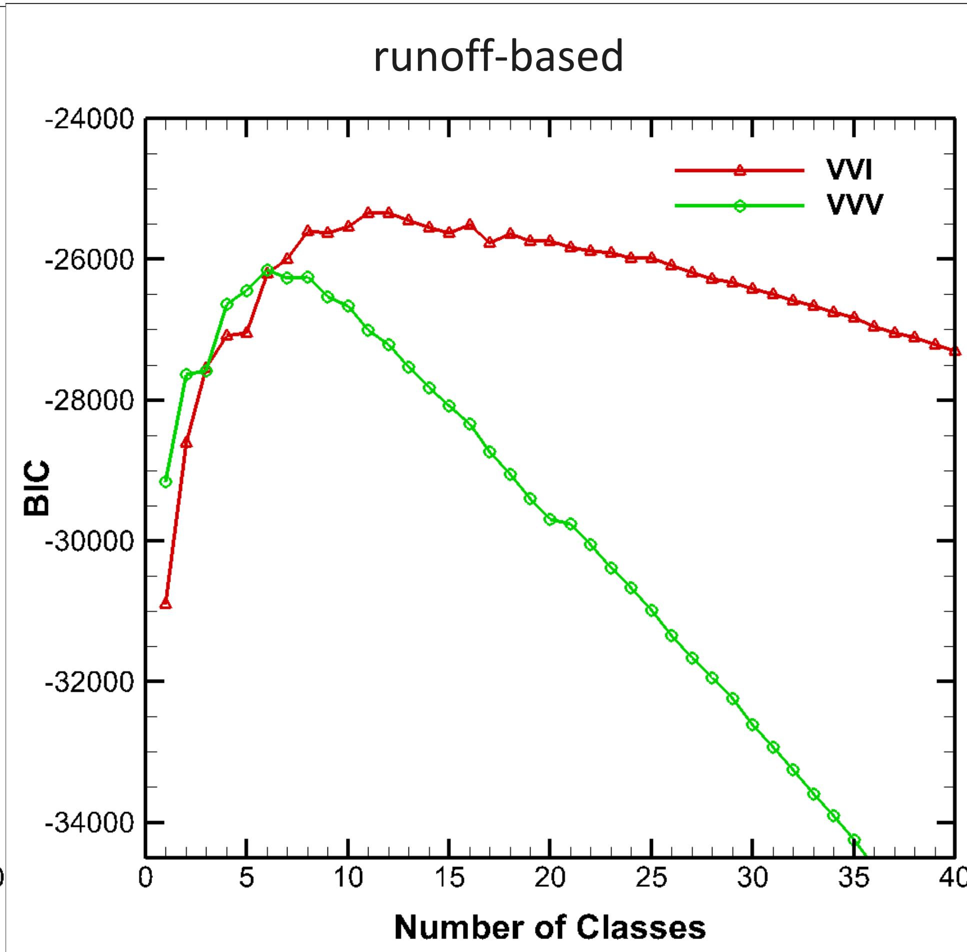


Determine number of classes

- Bayesian Information Criterion (BIC) for determining number of classes
- It is reasonable to choose 8 classes for the best compromise between class model complexity and likelihood of the model





S-Classes of the MOPEX basins

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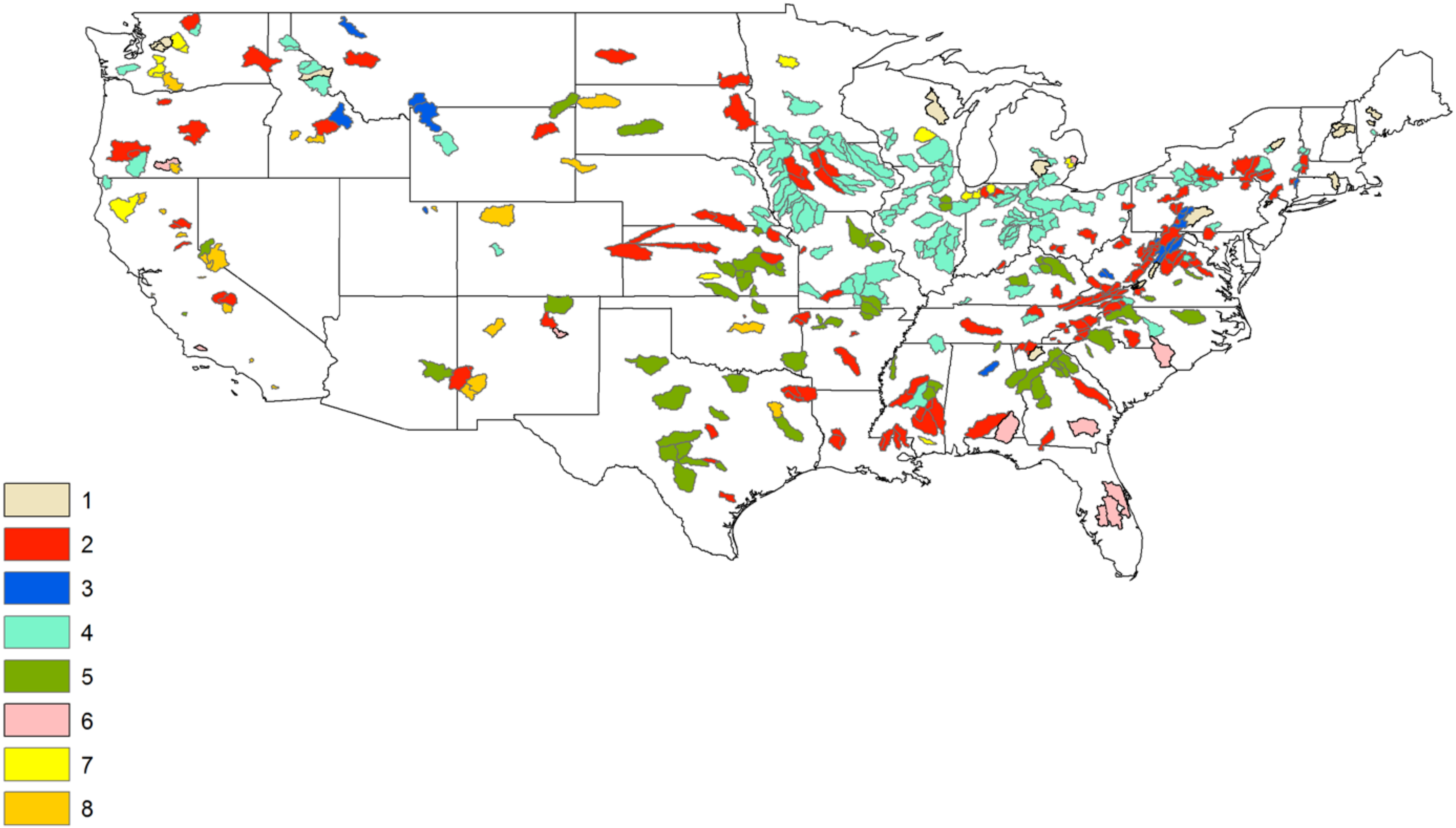

H-Classes of the MOPEX basins

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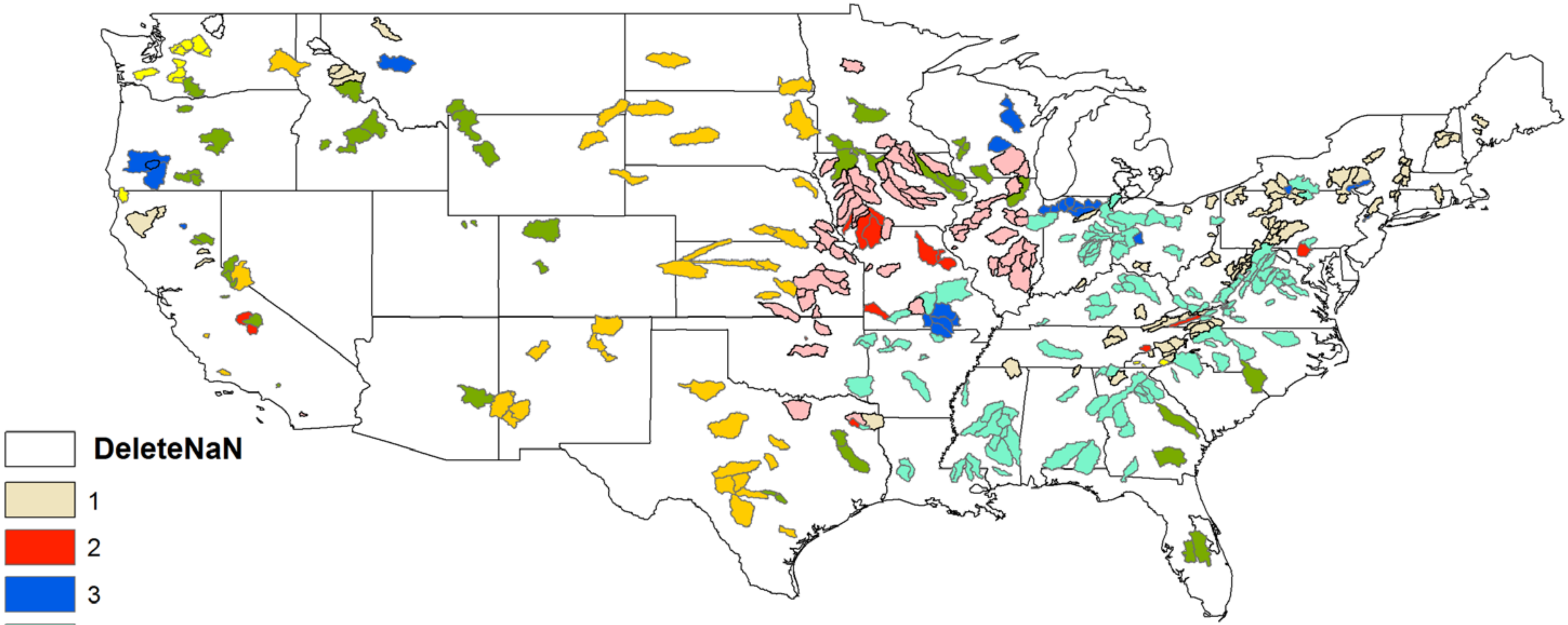

1. Runoff ratio
2. Humidity index
3. Baseflow index
4. Horton index
5. Drainage density

Summary and future work

- An uncertainty quantification framework has been implemented with CLM4; Application of the framework to selected sites suggests that CLM4 show the largest sensitivity to subsurface runoff generation parameters;
- The global sensitivity analyses provides guidance on reduction of parameter set dimensionality and parameter inversion framework design for CLM4;
- To reduce the dimensionality, we classify sites into classes that share similar characteristics;
- MCMC-Bayesian calibrations (using CLM or its surrogates) will be conducted at representative sites within each class to test/confirm the parameter transferability among all MOPEX basins.

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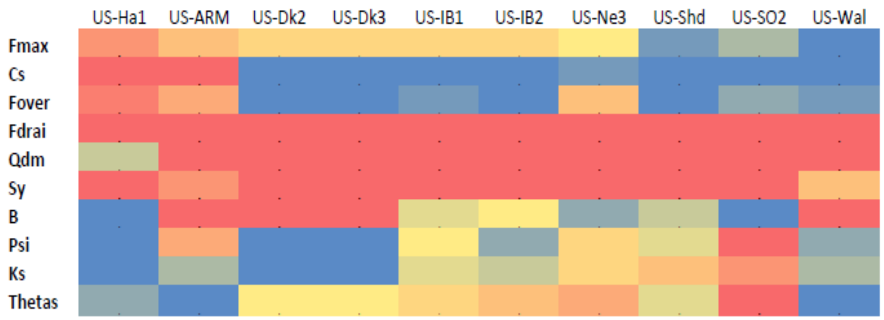
Acknowledgement

- DOE: Climate Science for a Sustainable Energy Future
- PNNL:Platform for Regional Integrated Modeling and Analysis (PRIMA) initiative

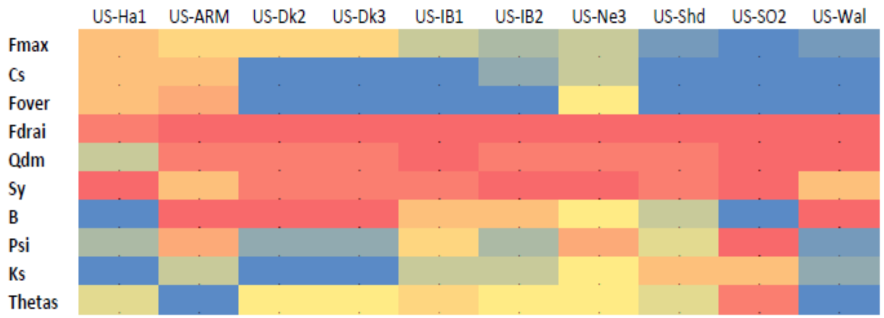
Summary of significance over flux towers

site-wise warmer = more significant **seasonal**

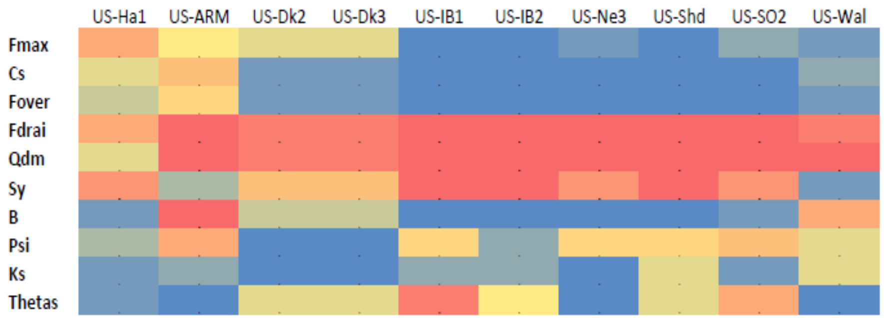
Latent heat flux



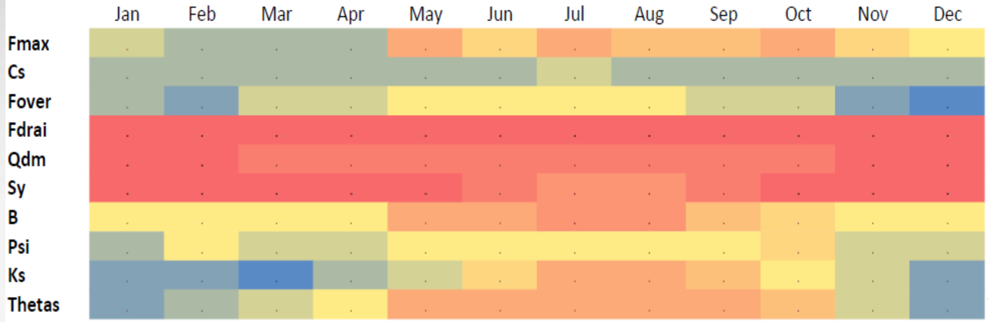
Sensible heat flux



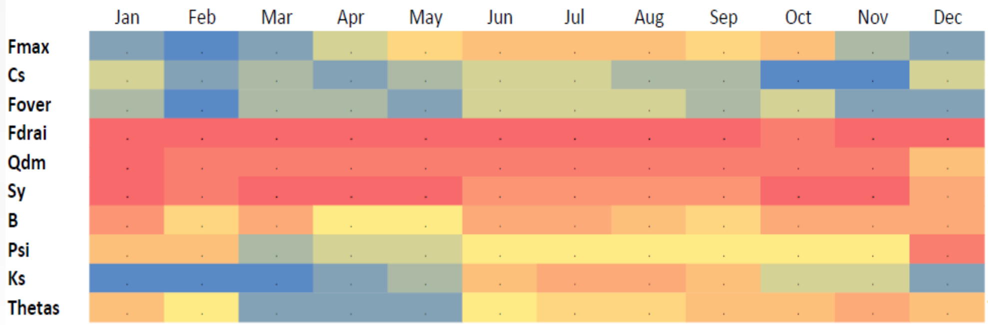
Total runoff



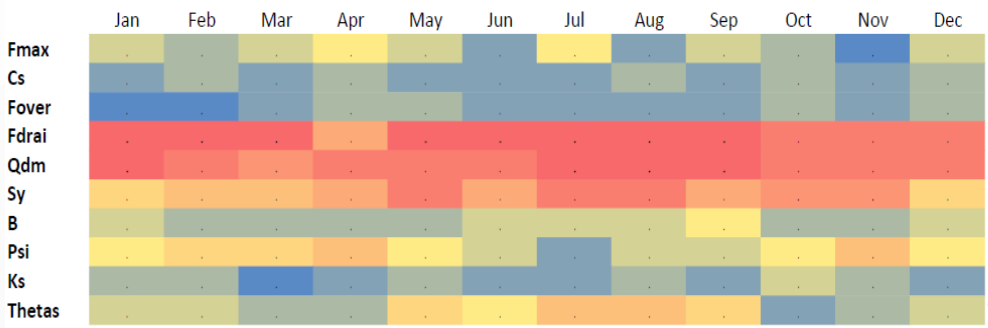
Latent heat flux



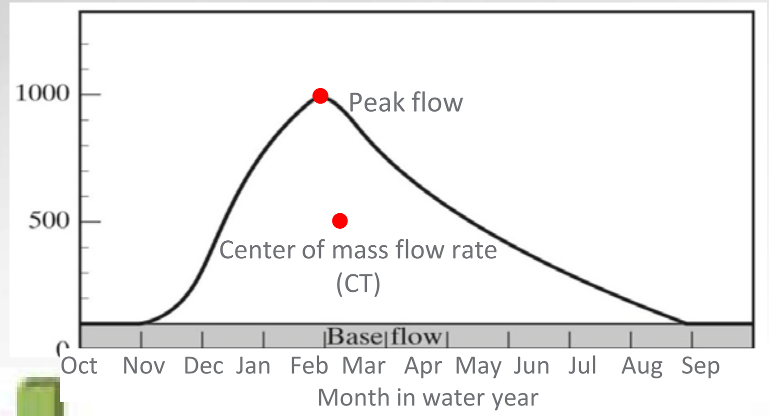
Sensible heat flux

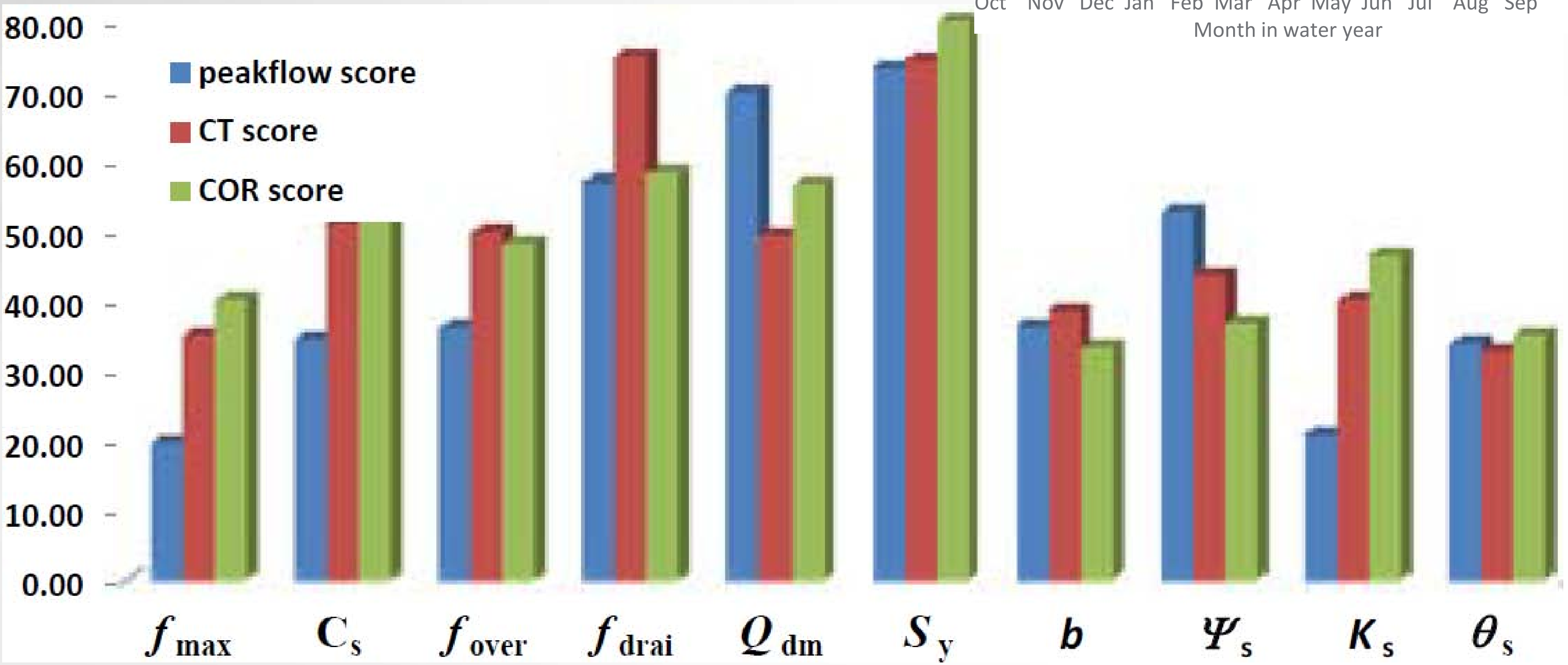


Total runoff

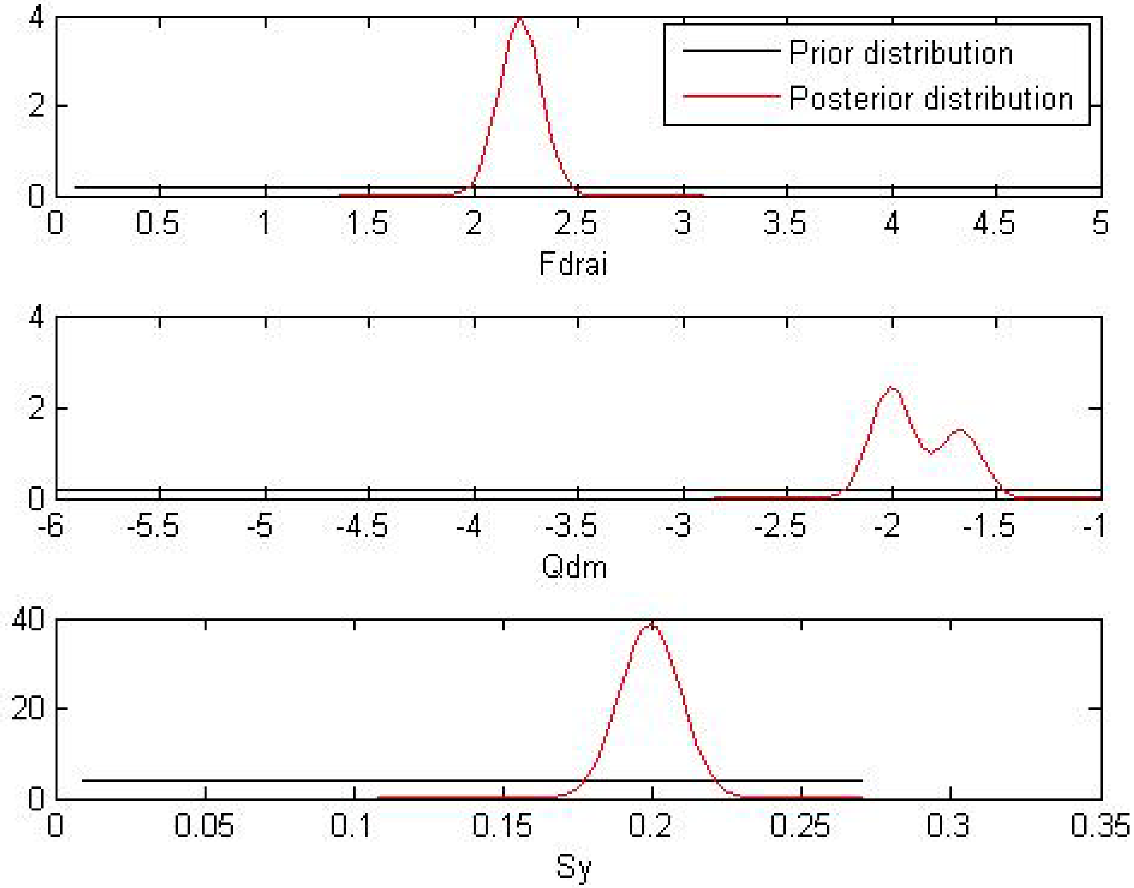


Potential of inversion: sensitivity of correlation with observed hydrographs over the MOPEX basins





Posterior distributions based on the 3-parameter inversion at US-MOz



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