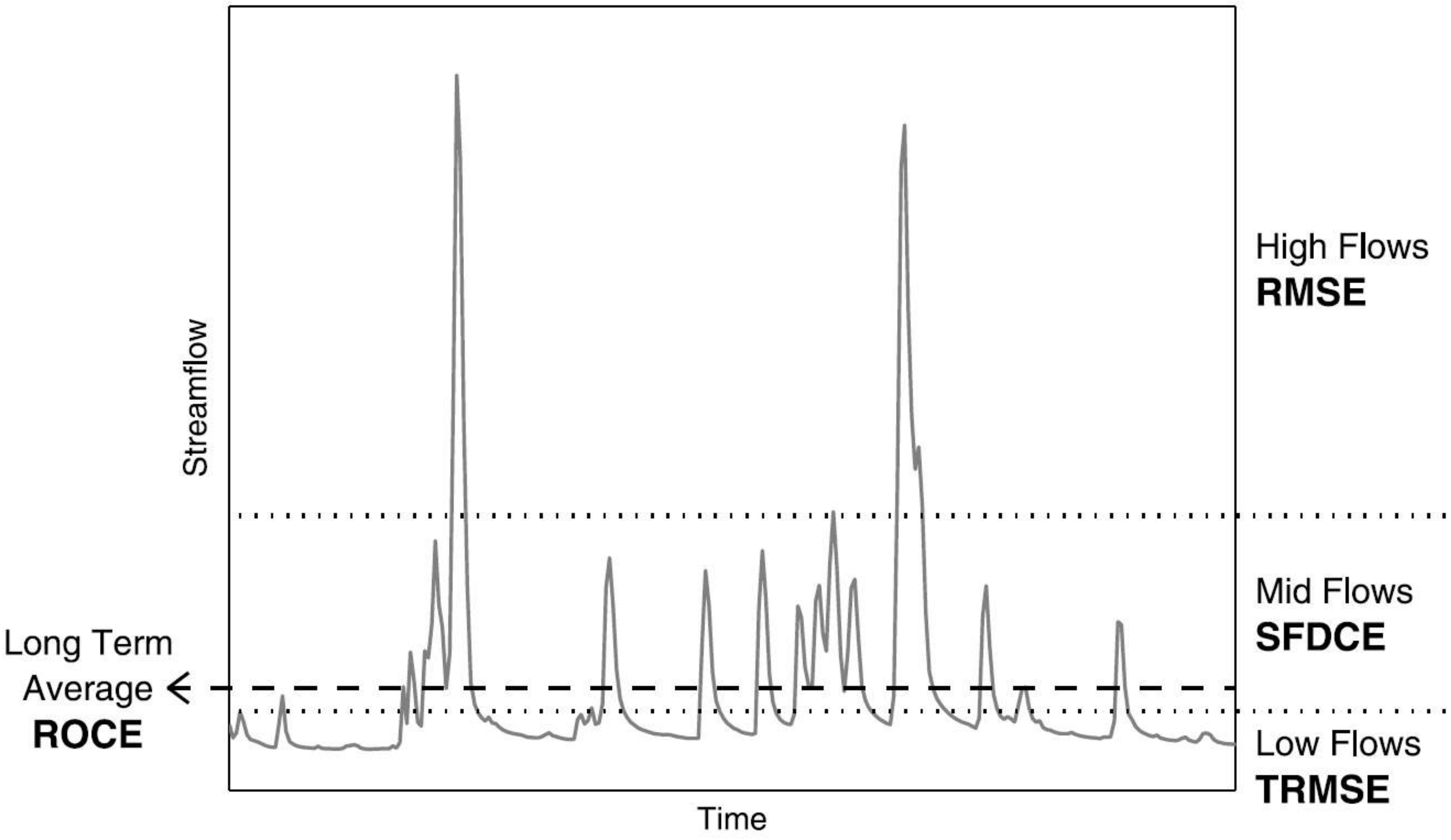
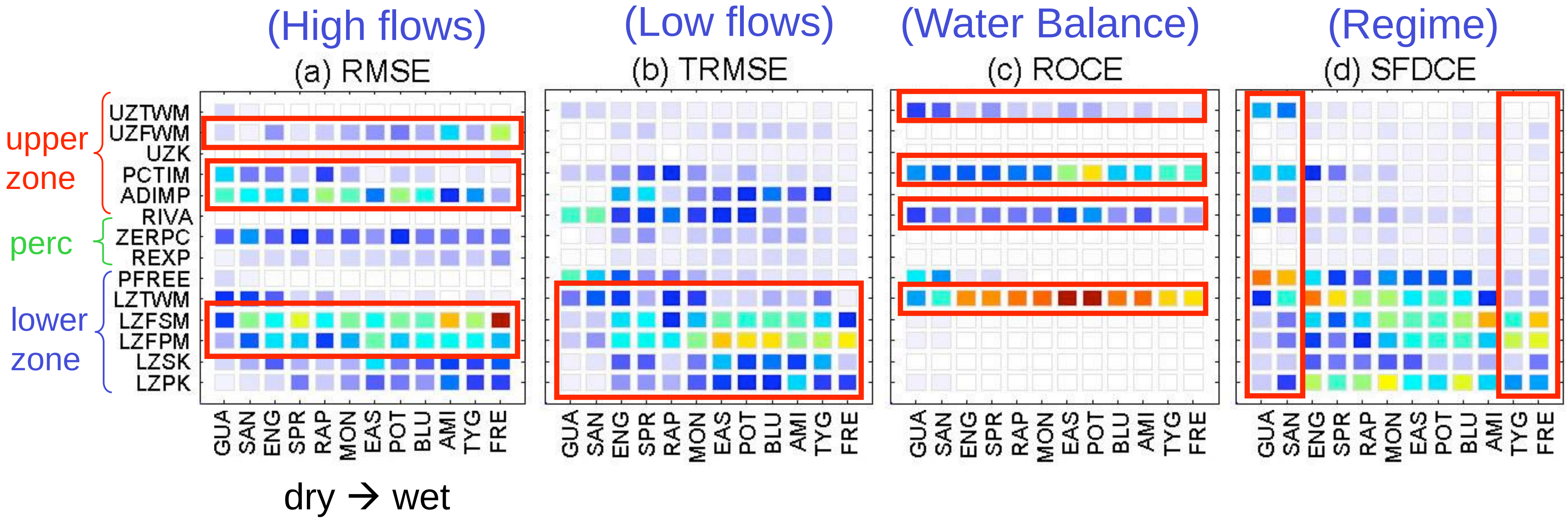
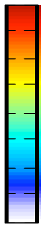
We utilize both statistical and 'hydrological' (signature) objective functions



[van Werkhoven et al. 2008 *WRR*]

We find significant variability in parameter sensitivity across the study region





- ✓ Patterns are correlated to hydroclimate, R up to 0.96
- ✓ Impervious area parameters important for peaks
- ✓ Lower zone impacts peaks through percolation
- ✓ Similar lower zone behavior for RMSE and TRMSE
- ✓ Importance of parameters that control ET losses
- ✓ Large differences between driest and wettest

[van Werkhoven et al. 2008 *WRR*]

PENNSTATE

These results have important consequences for model calibration and evaluation

⇨Parametric control varies significantly, though is traditionally assumed constant across watersheds and time periods

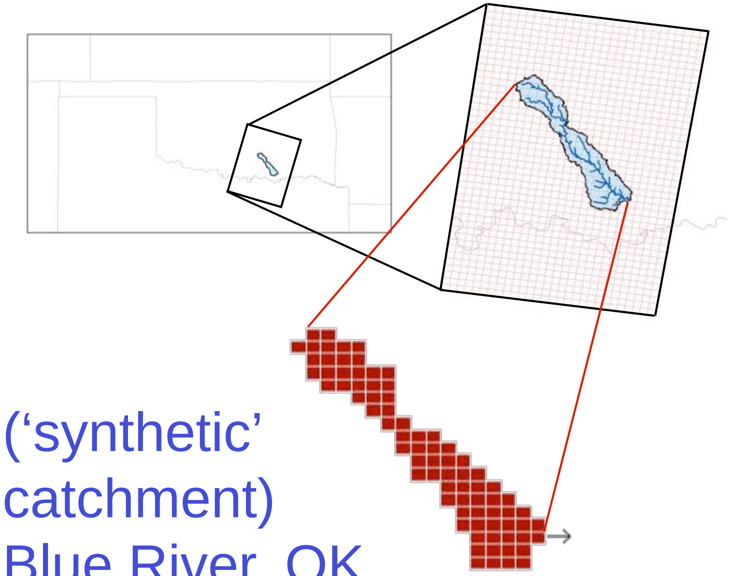
⇨ Greater model complexity might be justified for flexibility across watersheds, contrary to past assertions

⇨ Aggregation is evil!

Methods for evaluation and identification that ignore model behavior or assume static behavior are ill-formulated and might bias results!

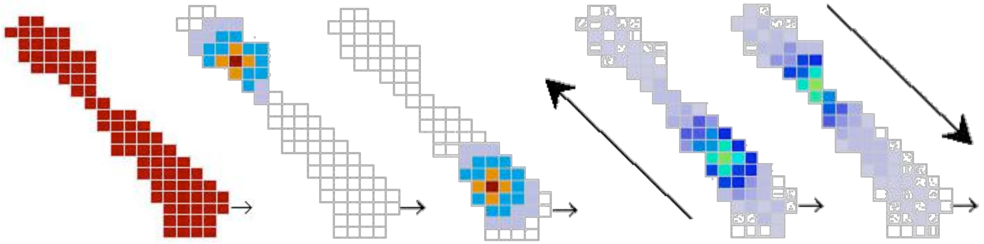
IDENTIFYING SPATIALLY DISTRIBUTED MODELS

We created a series of experiments to test the relationship between model forcing and its behavior

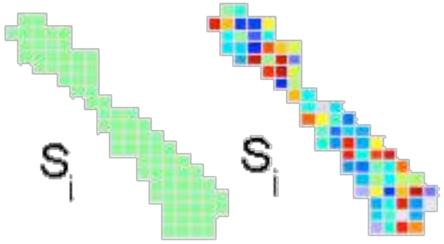


('synthetic' catchment)
Blue River, OK

5 rainfall events

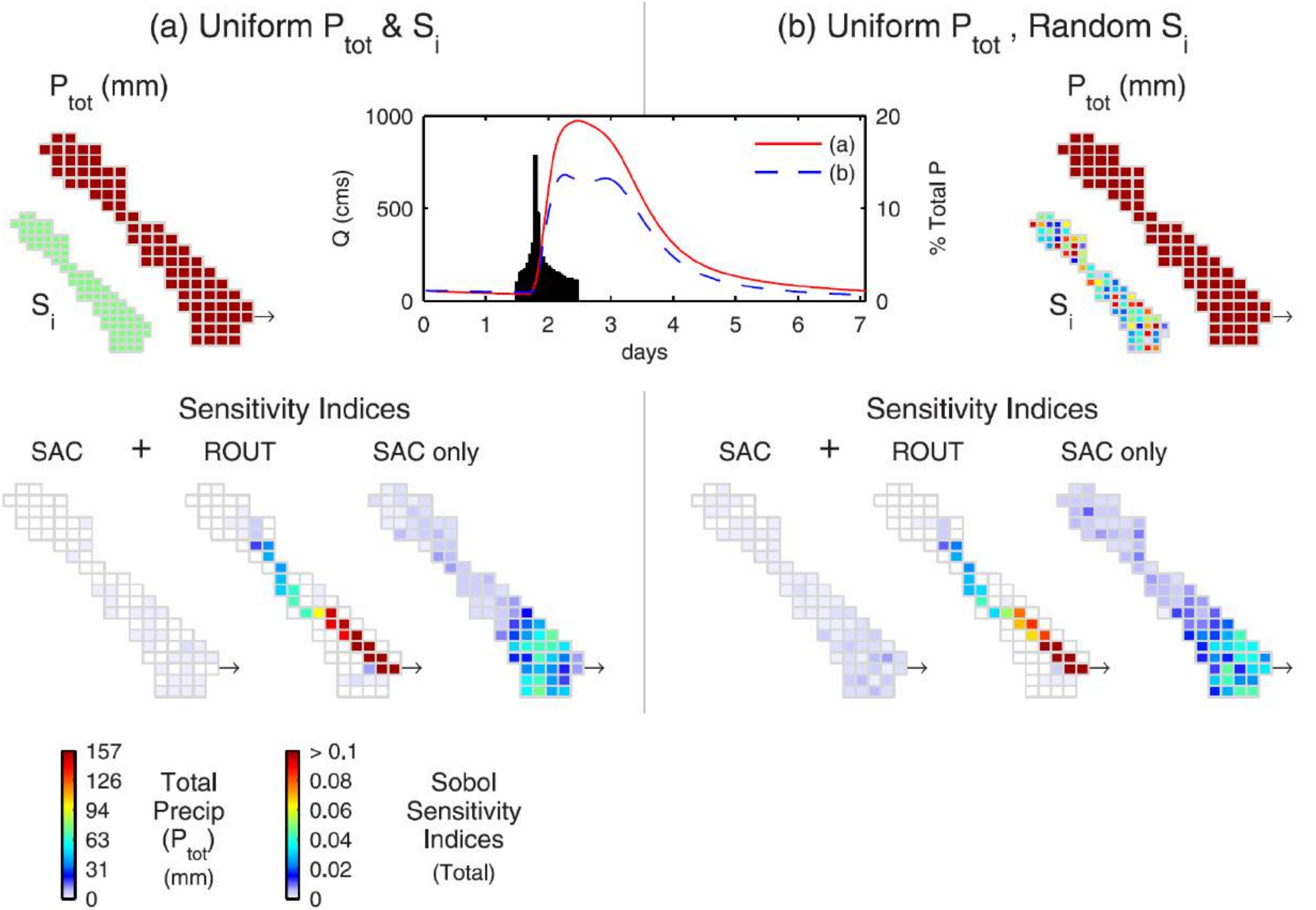


2 cases of initial states



[van Werkhoven et al. 2008 *GRL*]

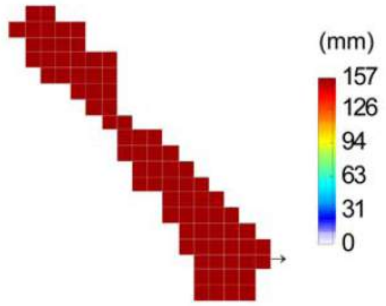
Uniform rainfall does not provide information about the upper part of the catchment

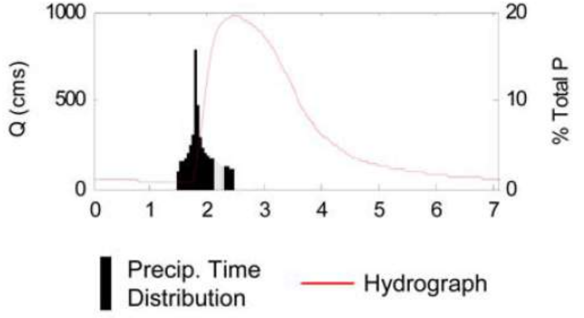


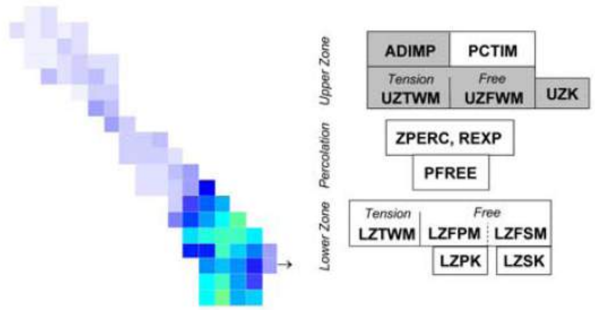
[van Werkhoven et al. 2008 *GRL*]

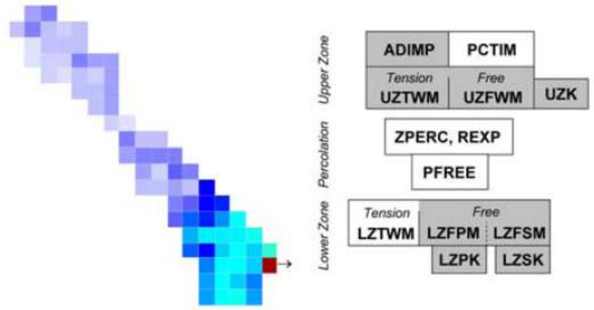
Vertical and horizontal sensitivity changes with objective function chosen

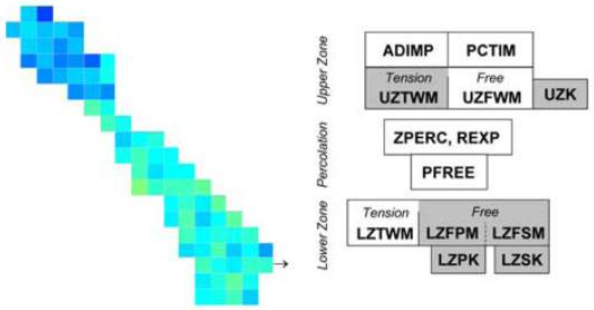
Experimental Setup:


(a) Uniform Precipitation Distribution


(b) Hyetograph and Hydrograph


(c) RMSE Sensitivity


(d) TRMSE Sensitivity


(e) ROCE Sensitivity

[Wagener et al. 2009 *WRR*]

Spatially distributed model identification strategies need to be dynamic to use information well!

⇨Information content of streamflow data is **dynamic** and mainly controlled by precipitation (near surface)

Existing calibration approaches (e.g. multipliers) do not account for dynamically varying information in streamflow data → thus add bias to parameters!

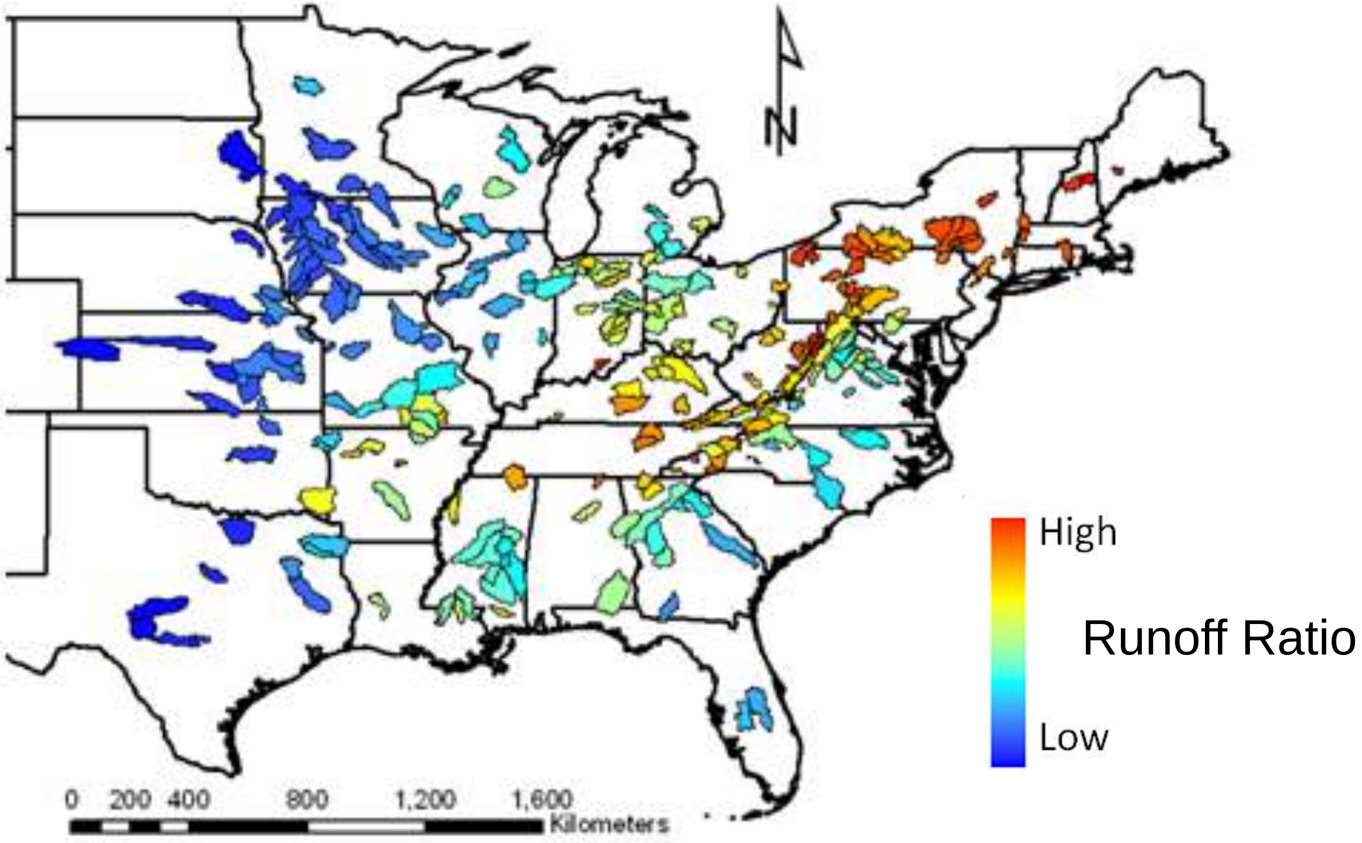
⇨The value of streamflow data extends only into portion of the watershed upstream from the gauge

This needs to be incorporated into observational network design to maximize the value of streamflow observations and to provide information everywhere!

How can we assess models without local historical observations of streamflow?

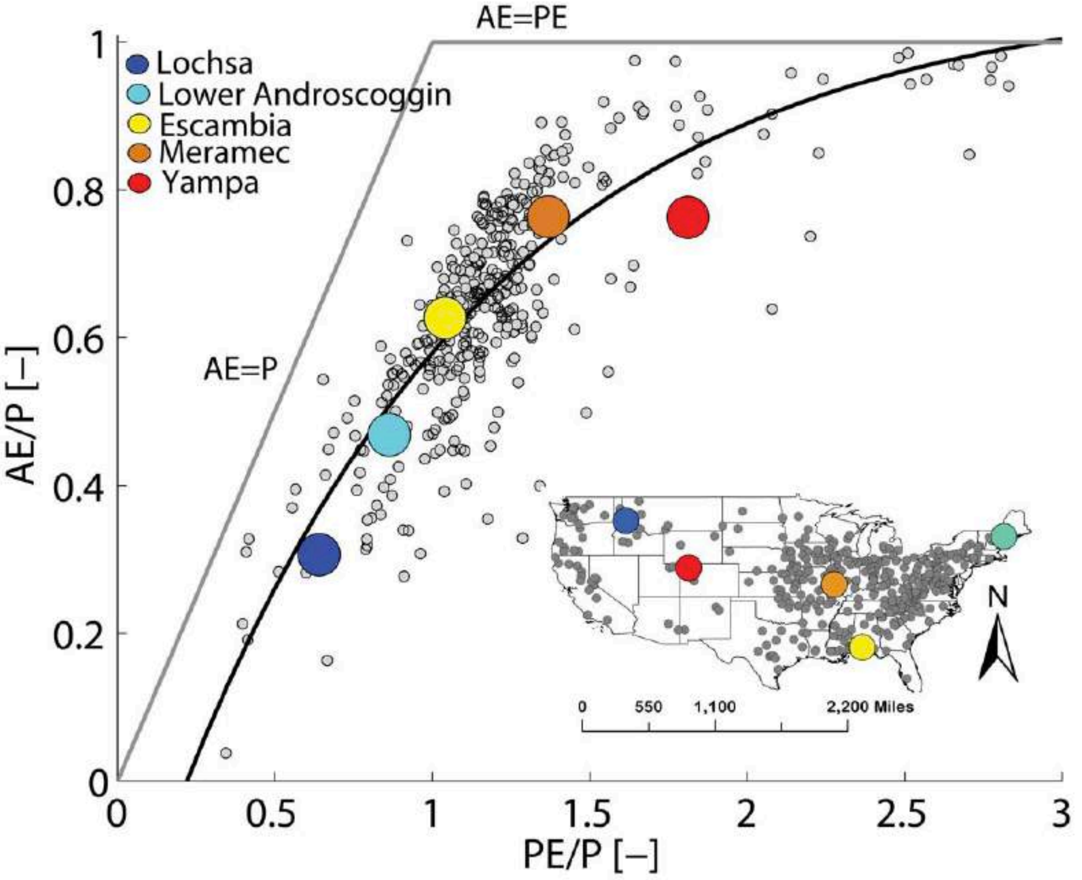
PREDICTION OF UNGAUGED LOCATIONS AND OF CHANGE IMPACTS

We can assess signatures for a large number of catchments, e.g. regarding how catchments partition rainfall into runoff and evapotranspiration



[Sawicz et al. 2011 *HESS-D*]

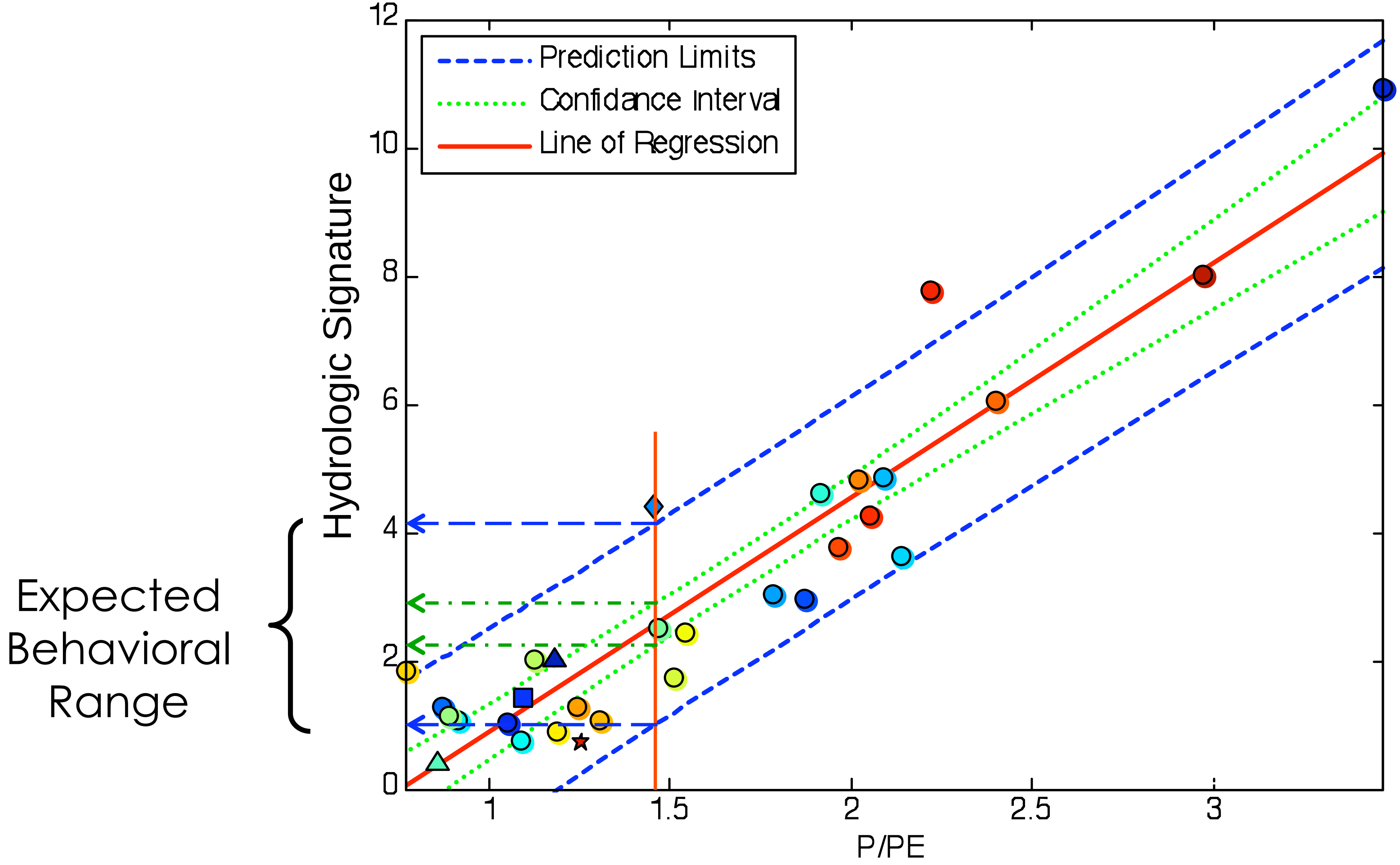
We can then build a model of this spatial variability



For example using the empirical model by Schreiber to estimate runoff ratio based on climate alone (PET and P).

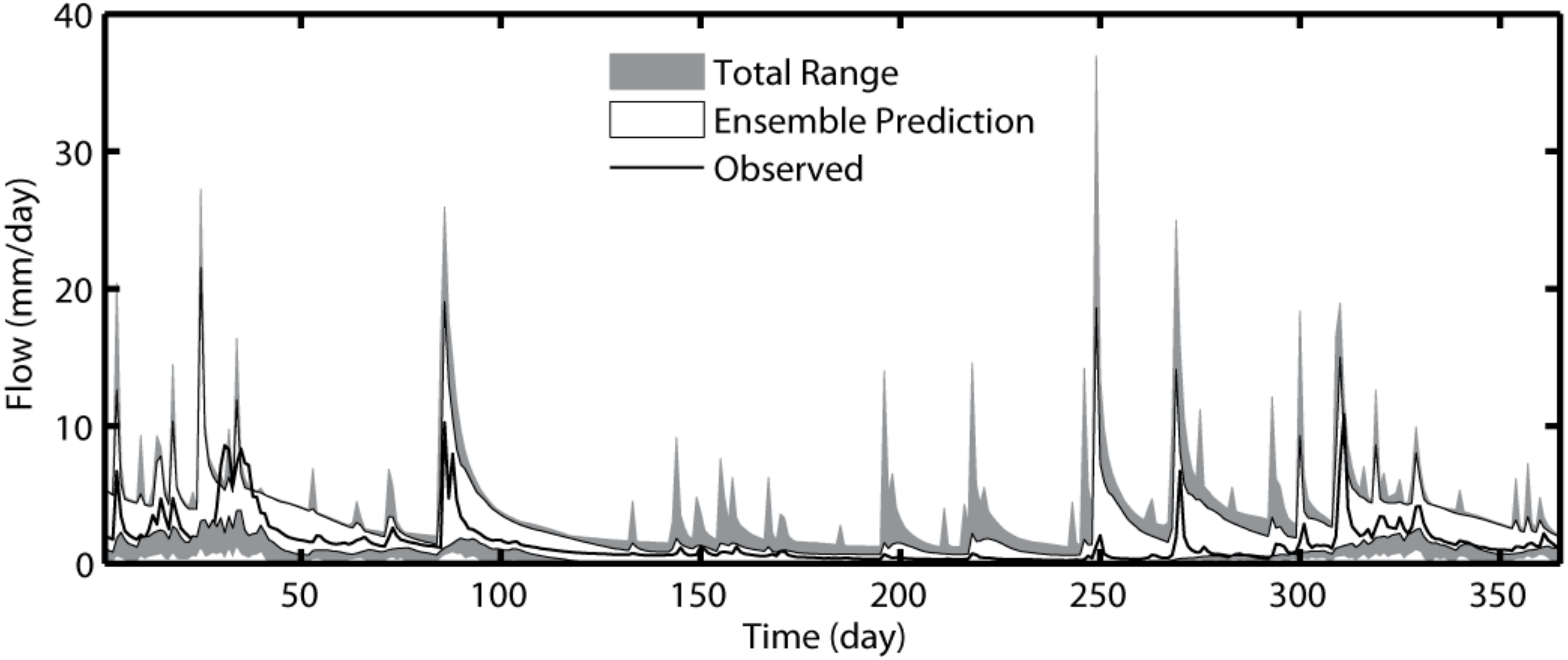
[Singh et al. 2011 *in Review*]

In the past we have used these spatial models to reduce the PUB problem by assimilating this information into a local catchment scale model



[Yadav et al. 2007 *Advances in Water Resources*]

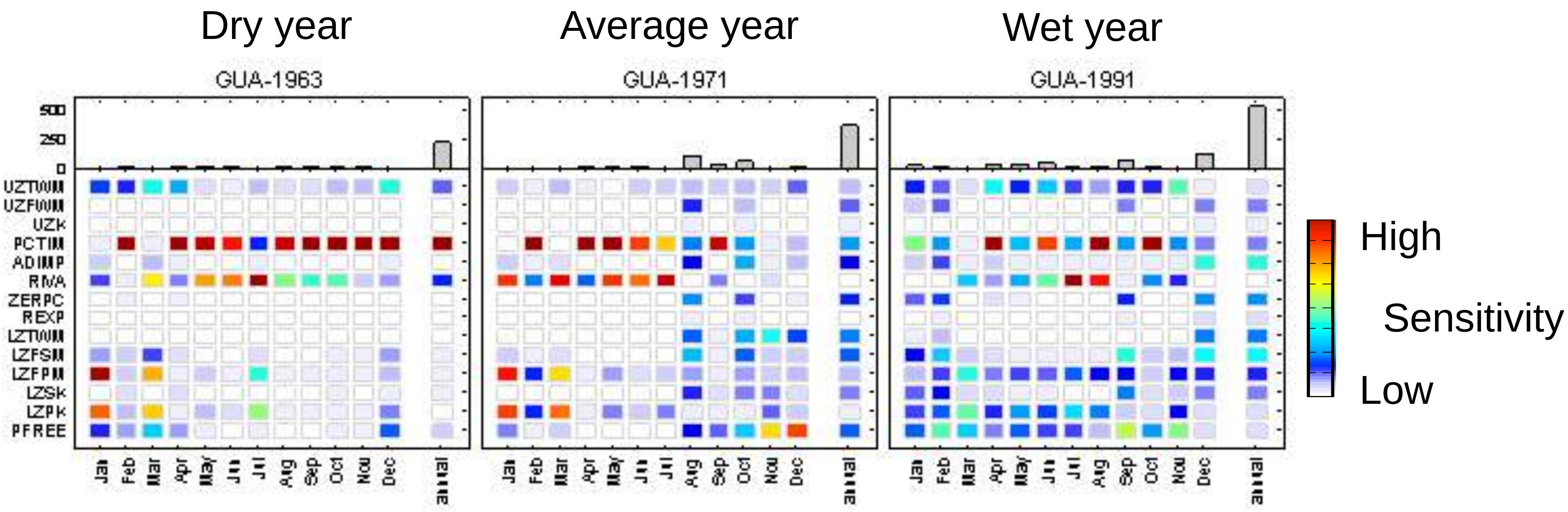
We can then use this knowledge to reduce the uncertainty in PUB (and change projections) by constraining/conditioning ensemble predictions of watershed models!!!



This approach is complementary to other strategies of deriving PUB!

[Yadav et al., 2007, *AWR*; Zhang et al. 2008, *WRR*;
Wagener and Montanari, In Press, WRR]

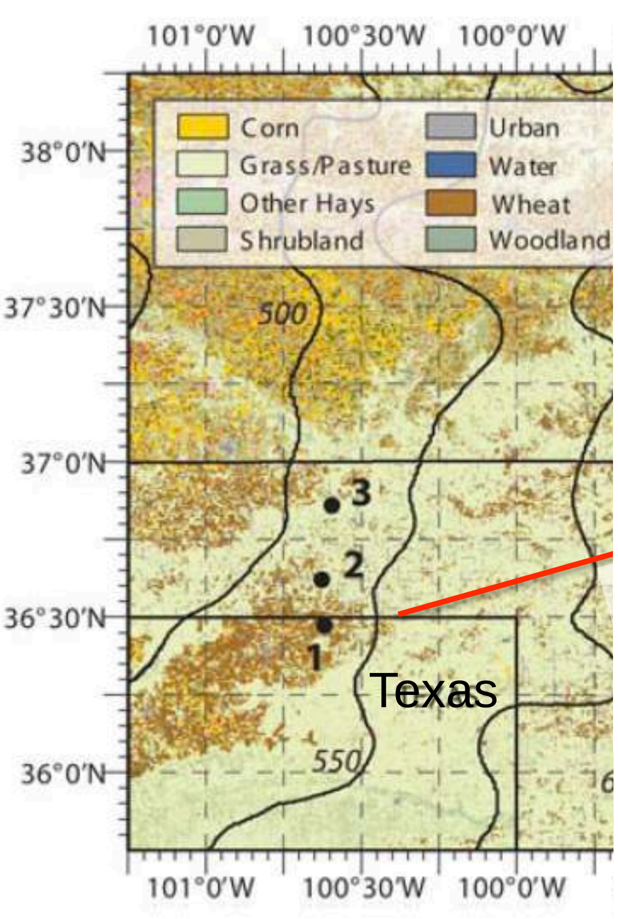
Sensitivity also varies in time within the same catchment

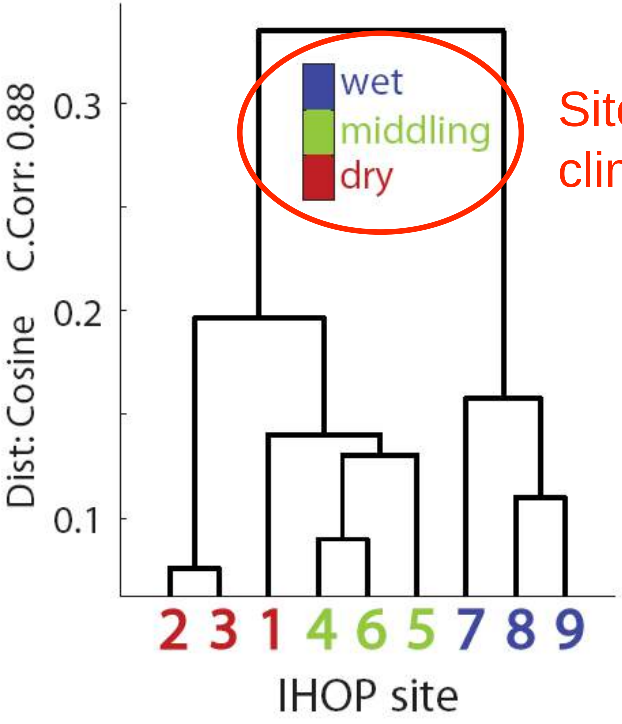


This suggests that model behavior and hence model parameters also vary in time!

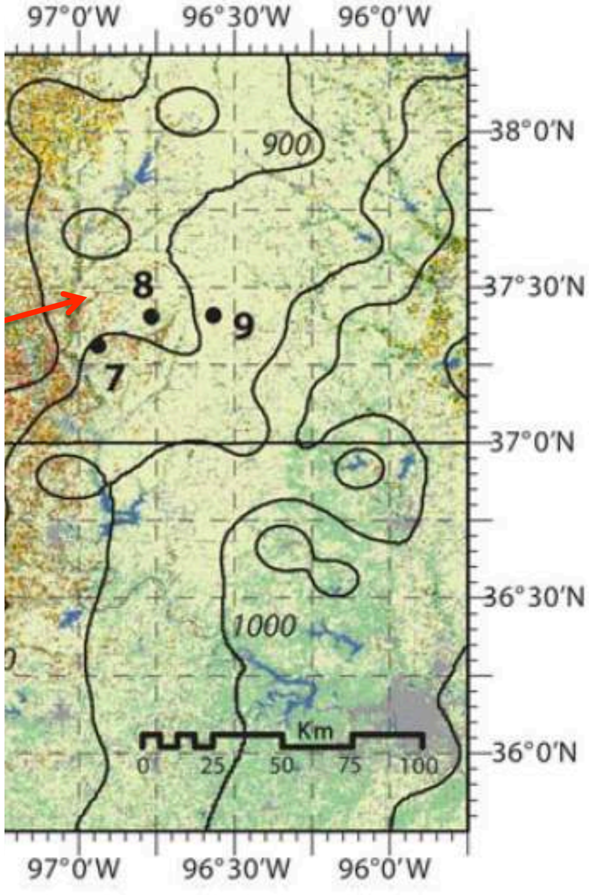
[Wagener et al. 2009 *Journal of Hydroinformatics*]

We found further evidence of this climatic control on parameters





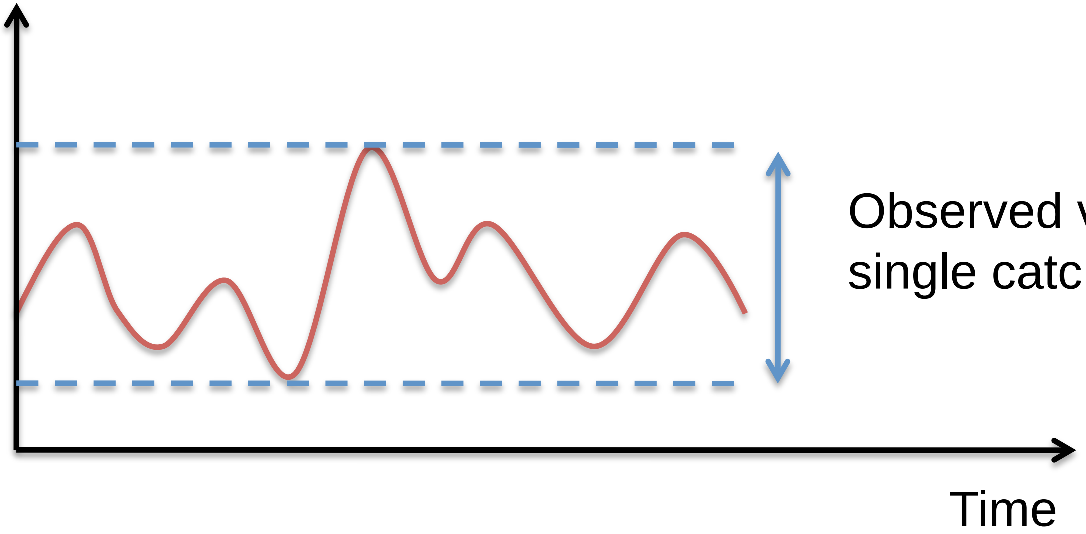
Site climate



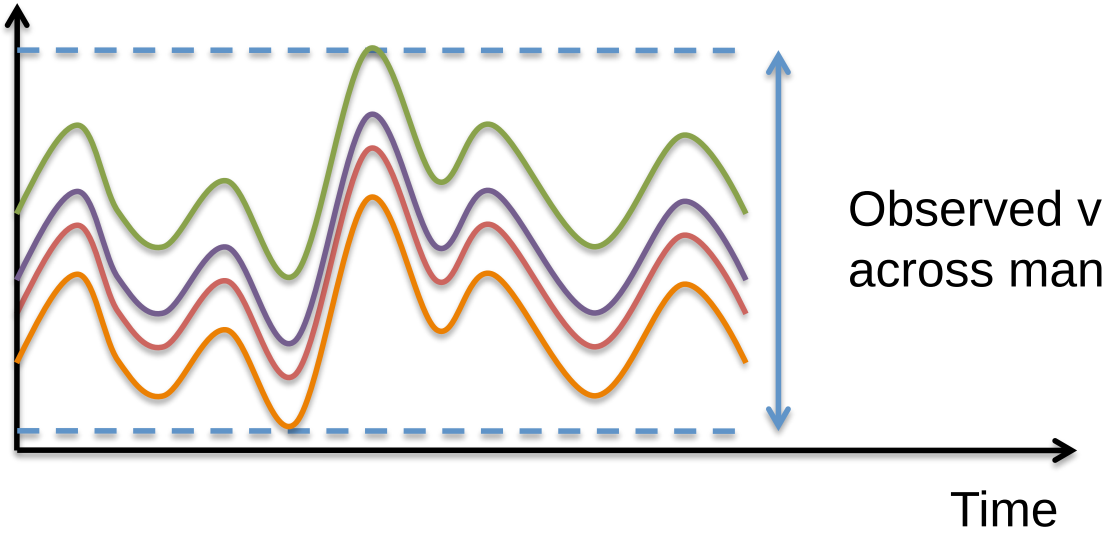
Behavioral parameters of a land surface model cluster with climate of site

[Rosero et al. 2010, *JGR*]

The observed historical variability in hydrologic variables at one place is often limited, and hence our ability to know a catchment's response



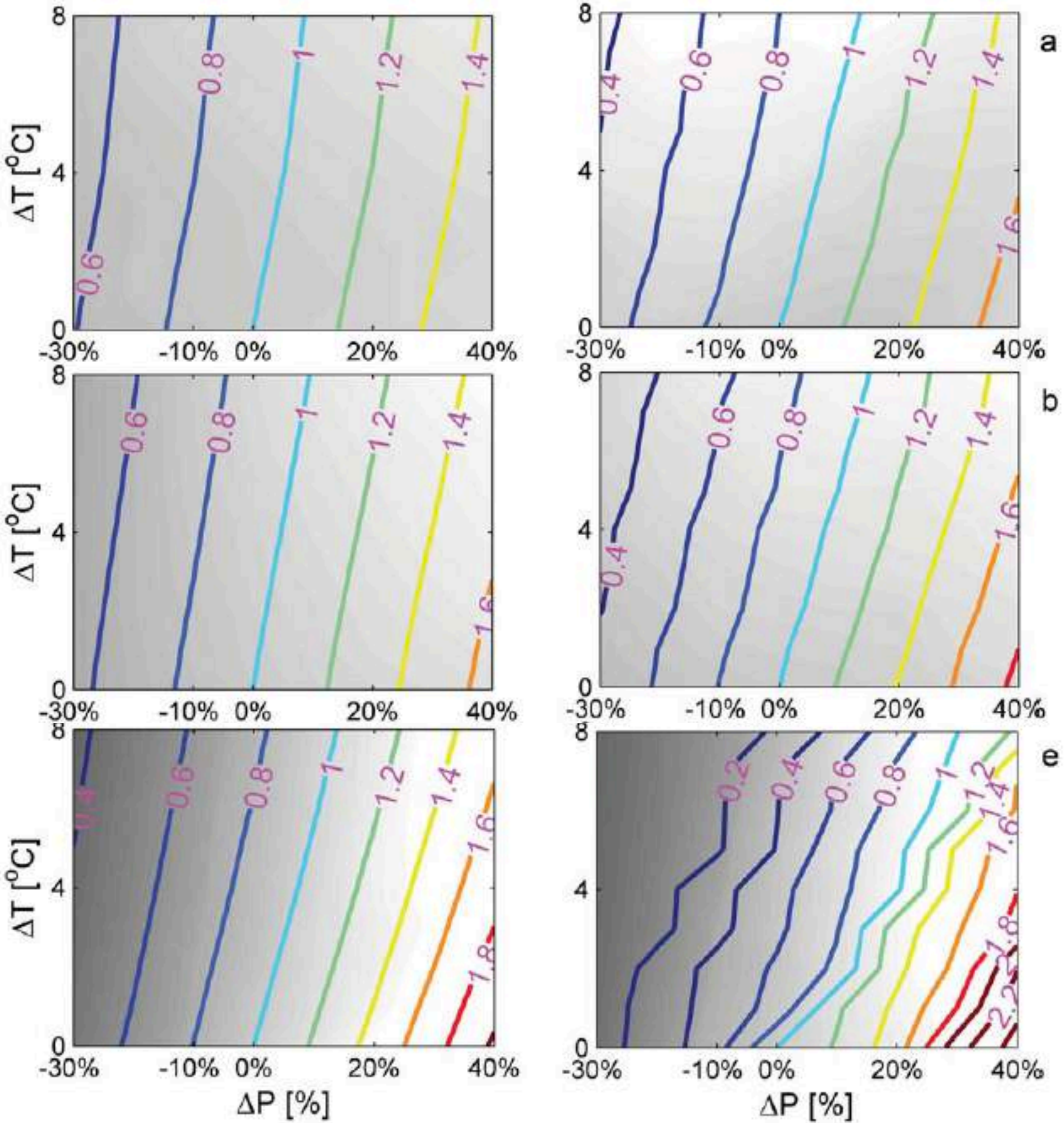
Observed variability in single catchment



Observed variability across many catchments!

We can also do this assuming a temporal gradient at the same location, i.e. we can trade space for time

Increasingly Drier



In summary, there is a need to re-assess how we identify and evaluate models for change impact projections/predictions

[Wagener et al. 2010 *Water Resources Research*]