A Probabilistic Framework for Projections of Watershed Services in US Headwaters under Climate Change Scenarios

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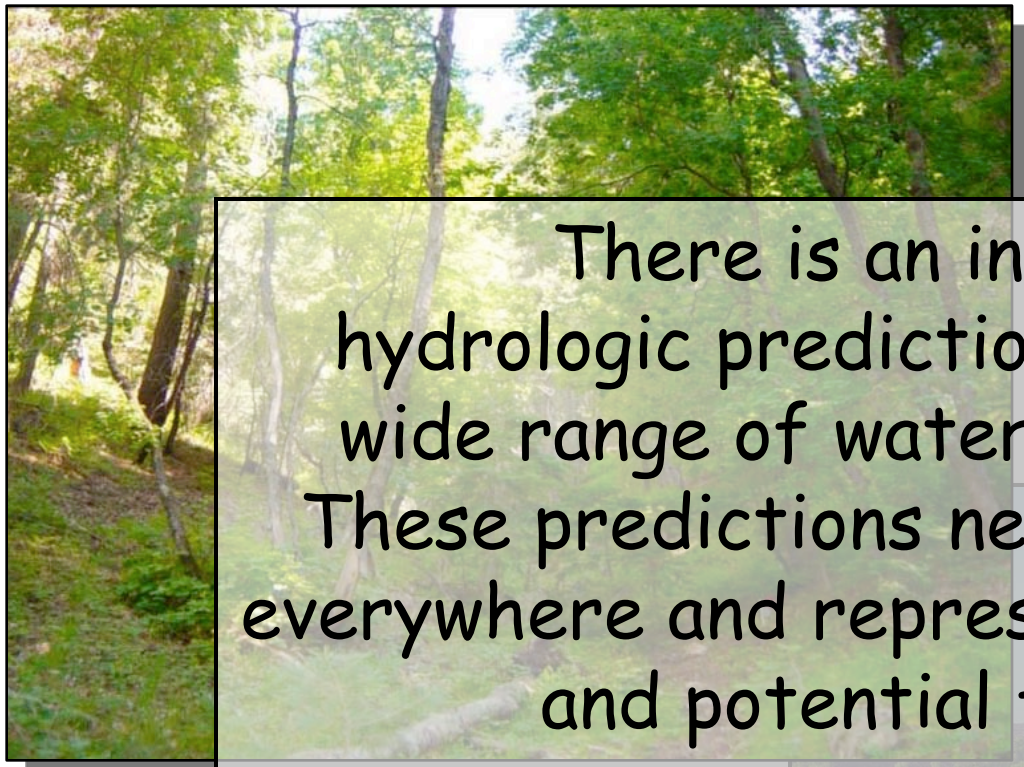
Many people contributed to the work I present

- Graduate students: Riddhi Singh, Keith Sawicz, Christa Kelleher, Liang Ning




- Collaborators: Patrick Reed, Murugesu Sivapalan, Peter Troch, Michael Mann, Robert Crane

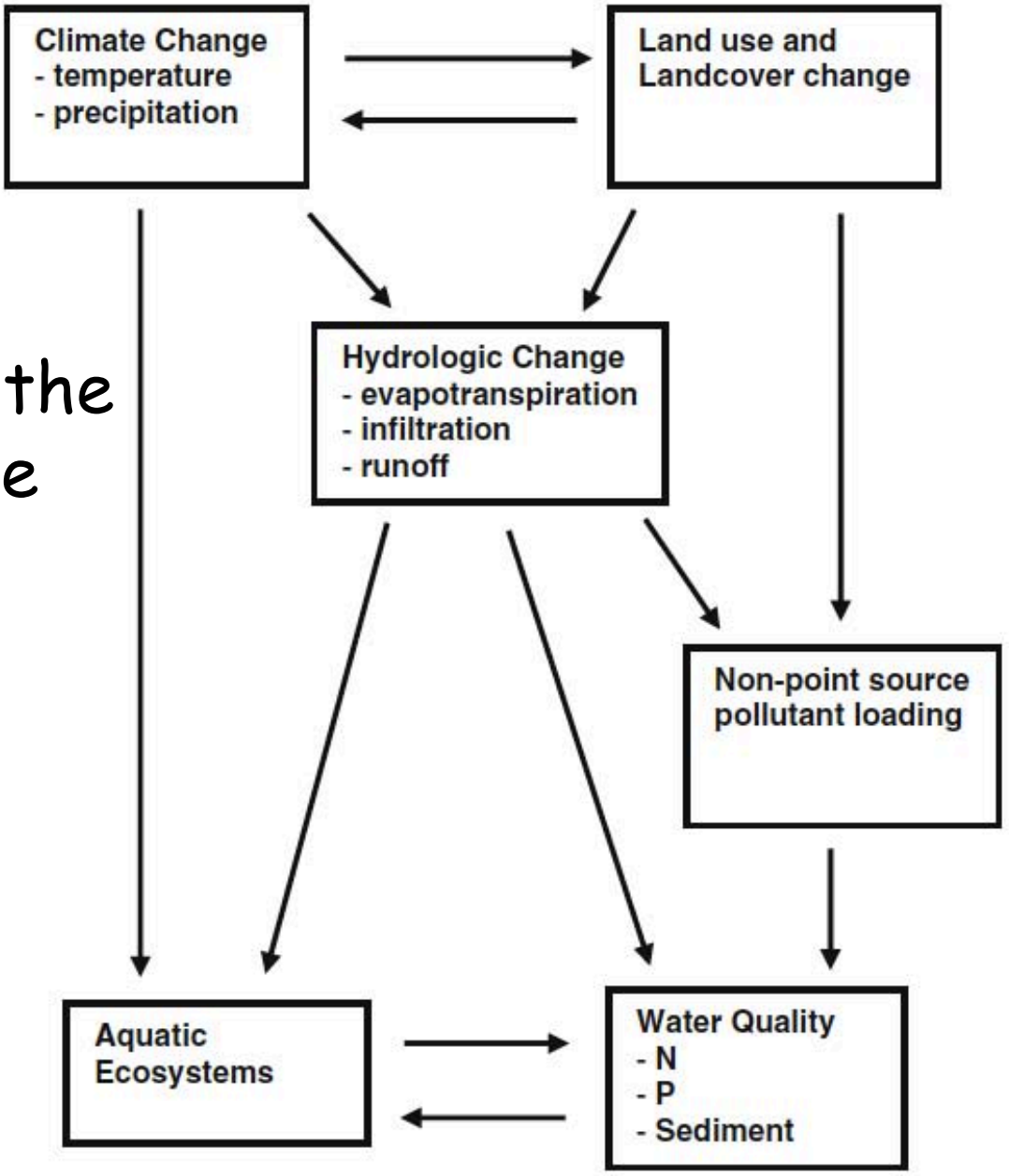


There is an increasing need for hydrologic predictions in support of a wide range of water services studies. These predictions need to be available everywhere and represent past, current and potential future conditions.

To achieve this, we need to ensure our models work for the right reasons, and use available data optimally.

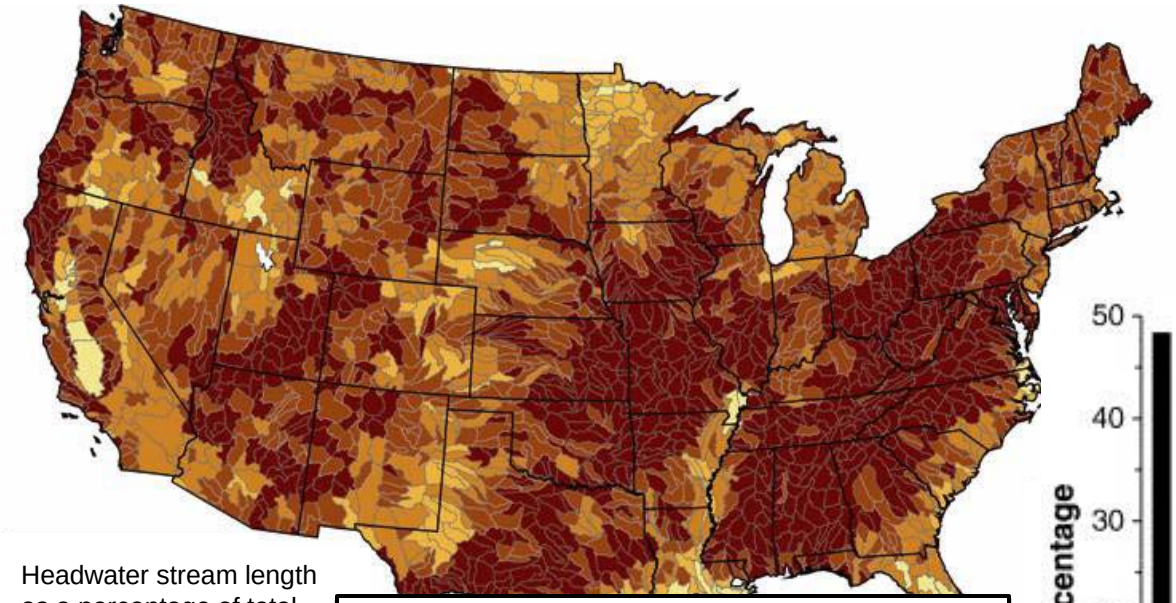
[Wagener et al. 2010 *Water Resources Research*]

Hydrology is often the link between climate and the ecosystem aspect we are concerned with



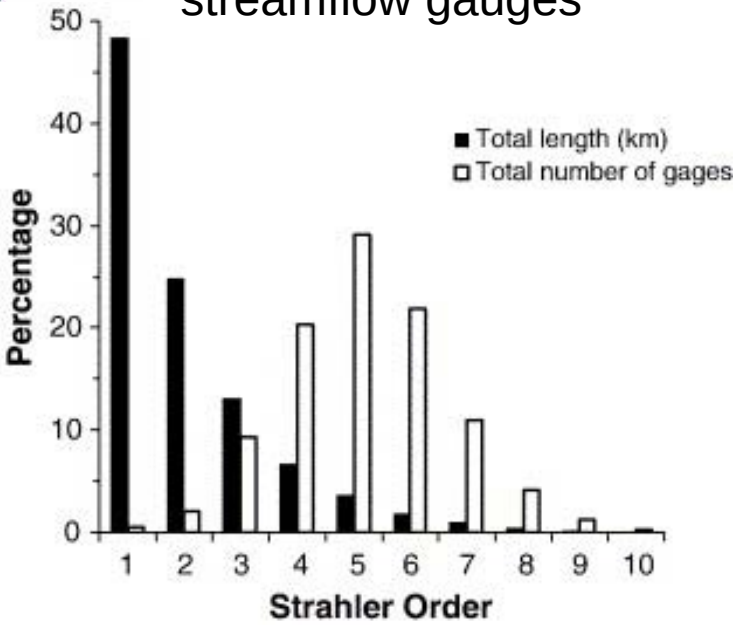
[Johnson and Weaver 2009 *Environmental Management*]

The limited extend of measurement points leaves significant gaps in our picture of the state of the environment, hence we rely on modeling



But we cannot calibrate if there is no streamflow data

US distribution of streamflow gauges



[Nadeau and Rains (2007) *AWRA*] & [Poff et al. (2006) *Geomorphology*] in [Wagener and Montanari (2011) *WRR*]

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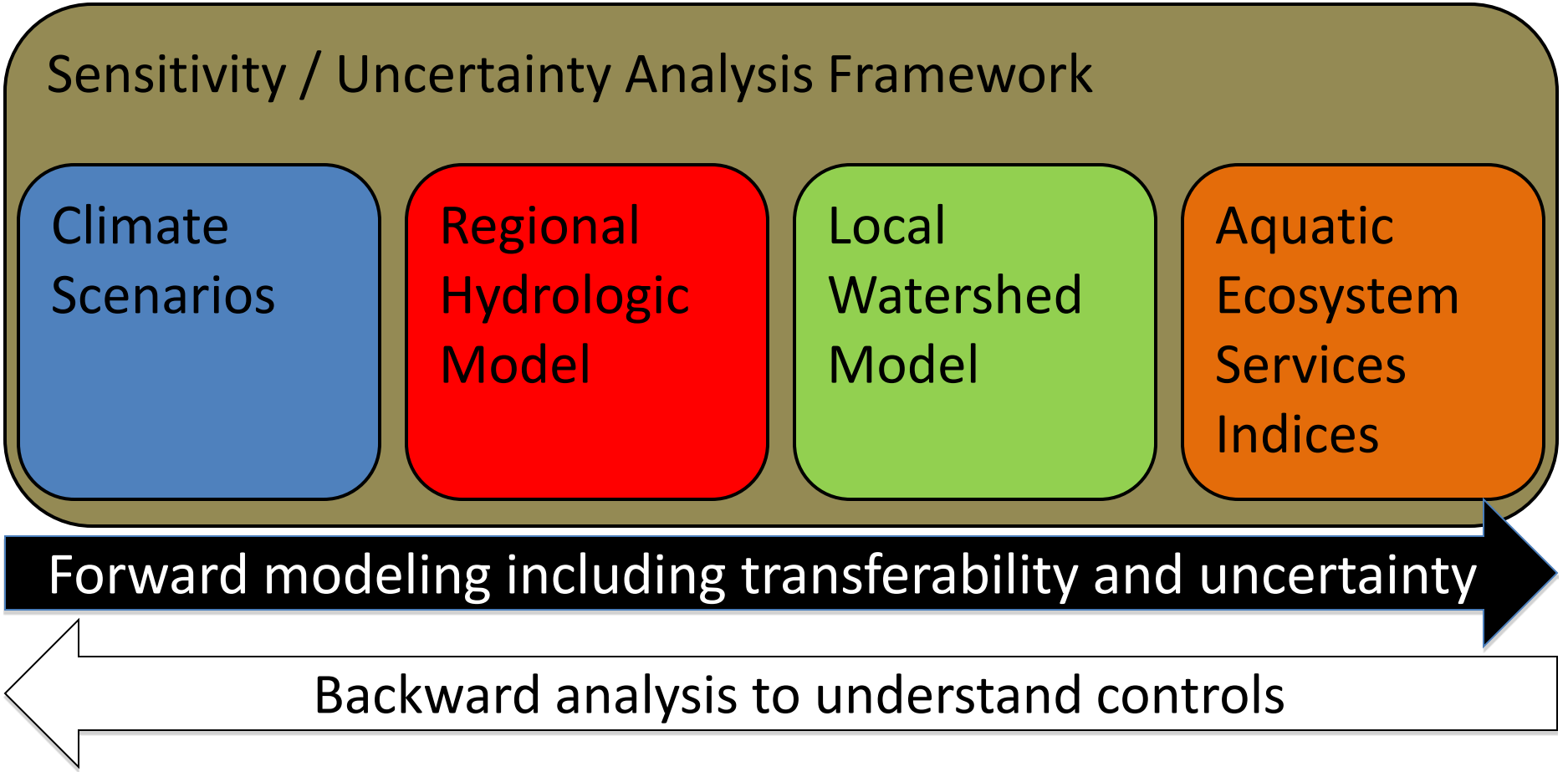
The need for predictions demands changes to how we perform hydrologic science

Current	Future
Assumption of stationarity: past is a guide to the future	Nonstationary world: past is no longer a sufficient guide to the future, expected variability could be outside the range of observed variability
Predicting response, assuming fixed system characteristics: boundary value problem with prescribed fixed topography, soils, vegetation, climate	Both system and response evolve: no longer a boundary value problem, boundary conditions and interfaces themselves evolve and are coupled. Becomes a complex adaptive system
Learning from studying individual places (often pristine experimental catchments) to extrapolate or upscale to other places	Comparative hydrology: learning from individual places embedded along gradients (e.g. changing climate, human imprint) and across spatial scales
Model predictions derive credibility by reproducing historical observations	Model predictions derive credibility via more in-depth diagnostic evaluation of model consistency with underlying system and testing of behavior outside of observed range

…

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

We need to address these questions for credible end-to-end modeling of ecosystem response to change



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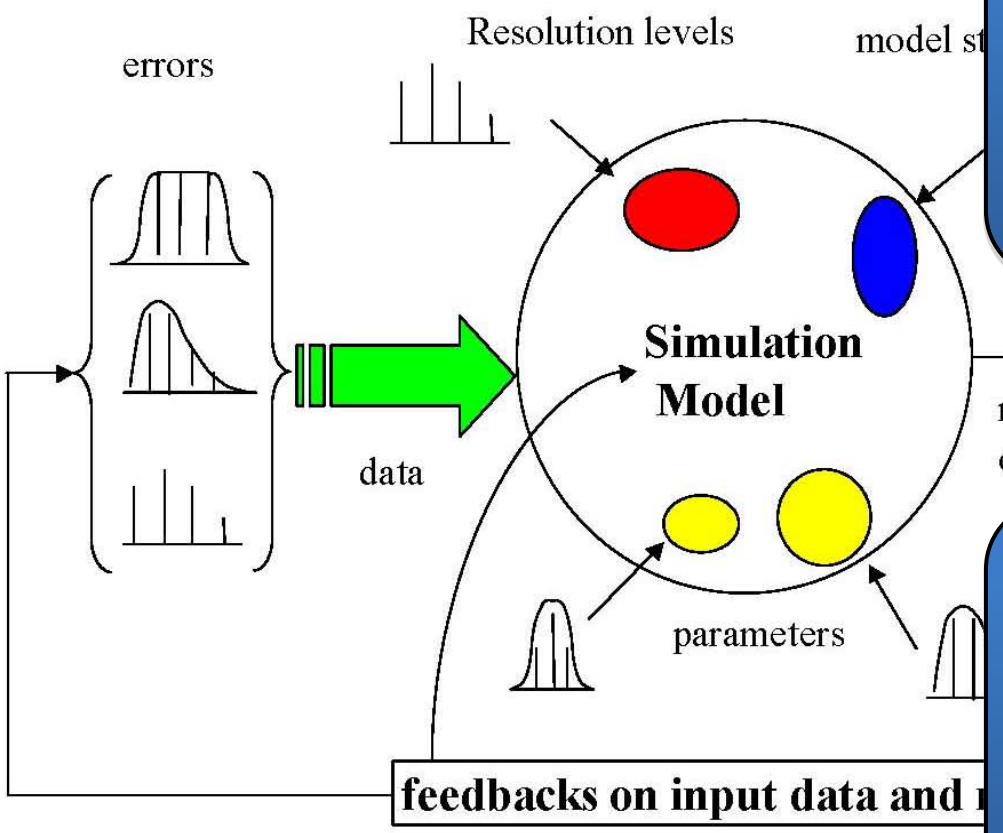
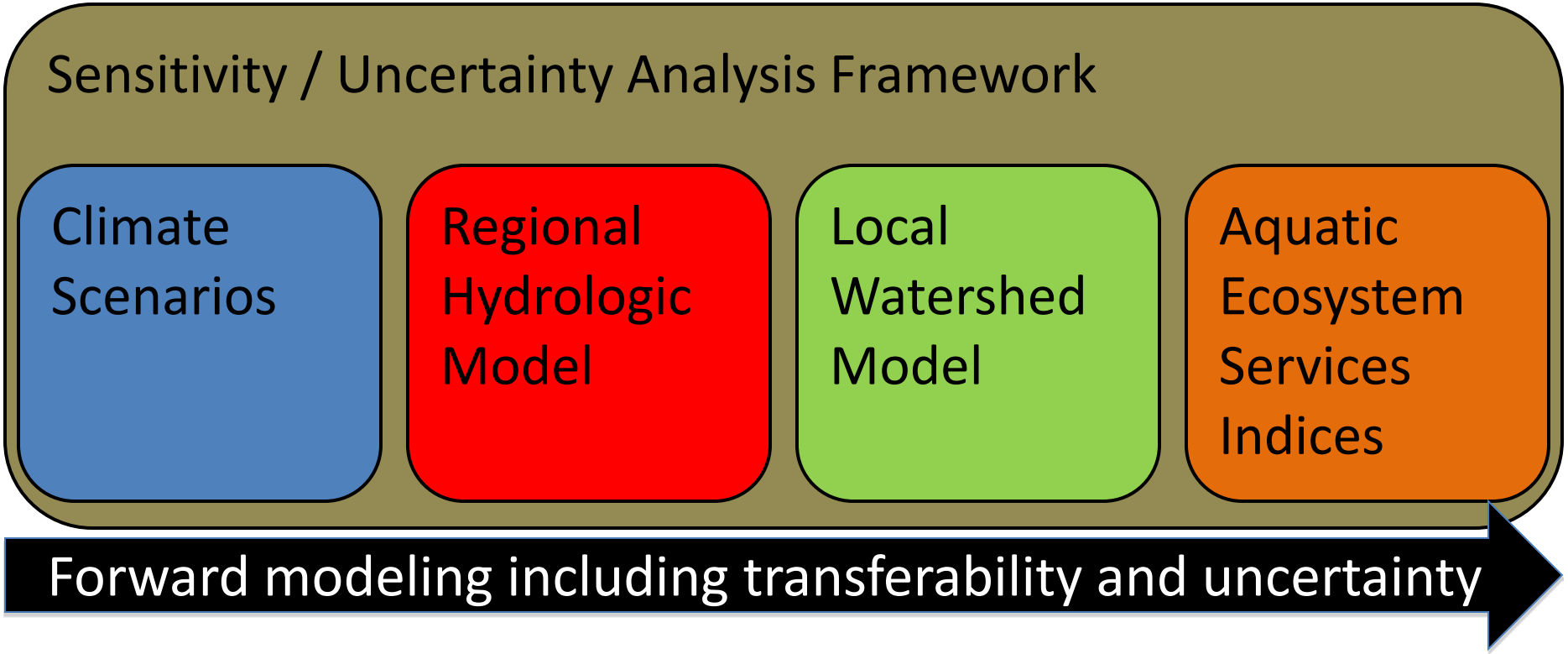
Combining uncertainty and sensitivity analysis allows us to address backward and forward analysis



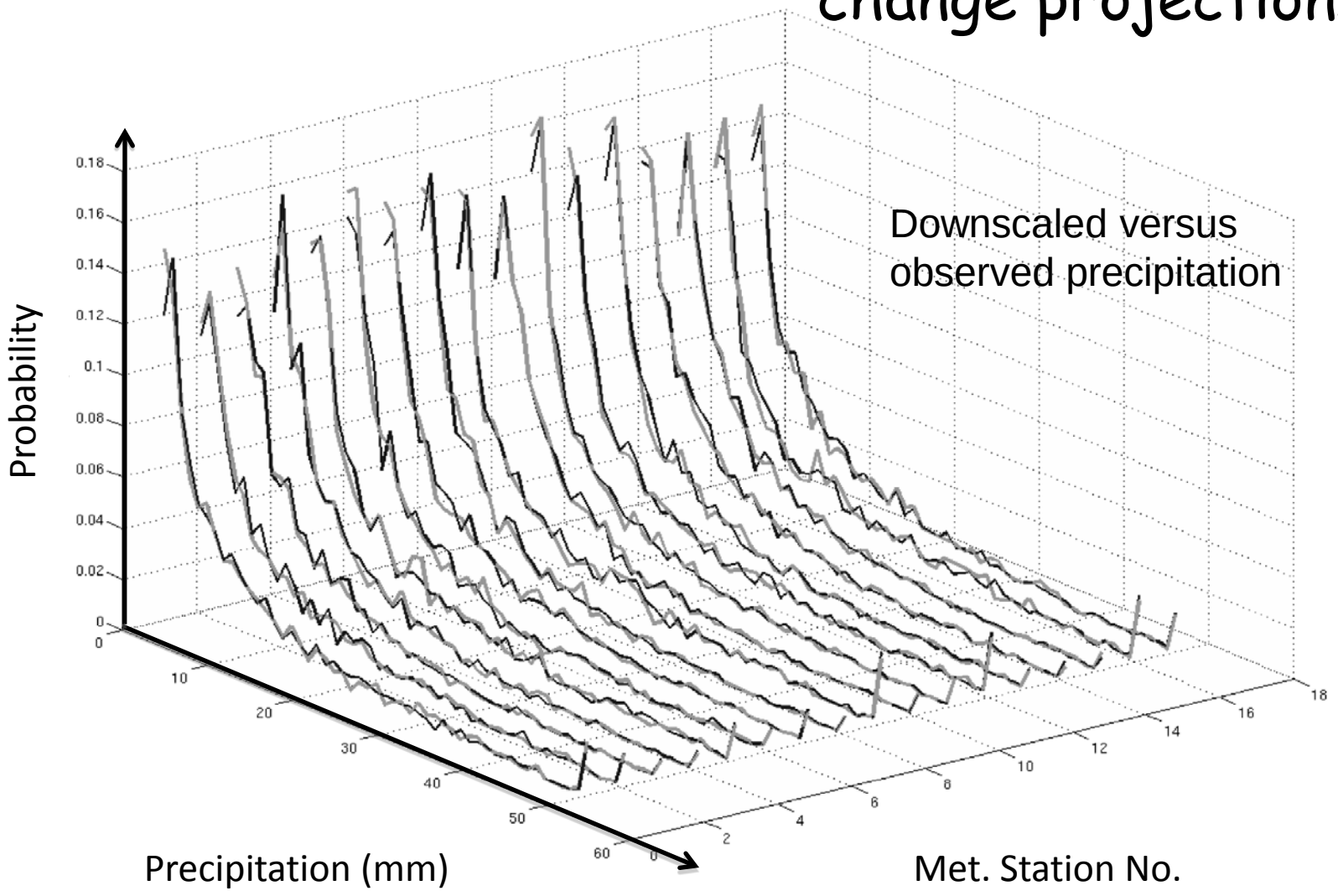
E.g. What is the probability that a critical temperature threshold is exceeded?

E.g. What controls the exceedance probability, and can it be changed?

[http://upload.wikimedia.org/wikipedia/en/0/01/Sensitivity_scheme.jpg]


Sensitivity / Uncertainty Analysis Framework
Climate Scenarios
Regional Hydrologic Model
Local Watershed Model
Aquatic Ecosystem Services Indices
Forward modeling including transferability and uncertainty

There is a lot of need to understand how we include uncertainty in (downscaled) climate change projections



[Ning et al. (In Press) *Journal of Climate*]

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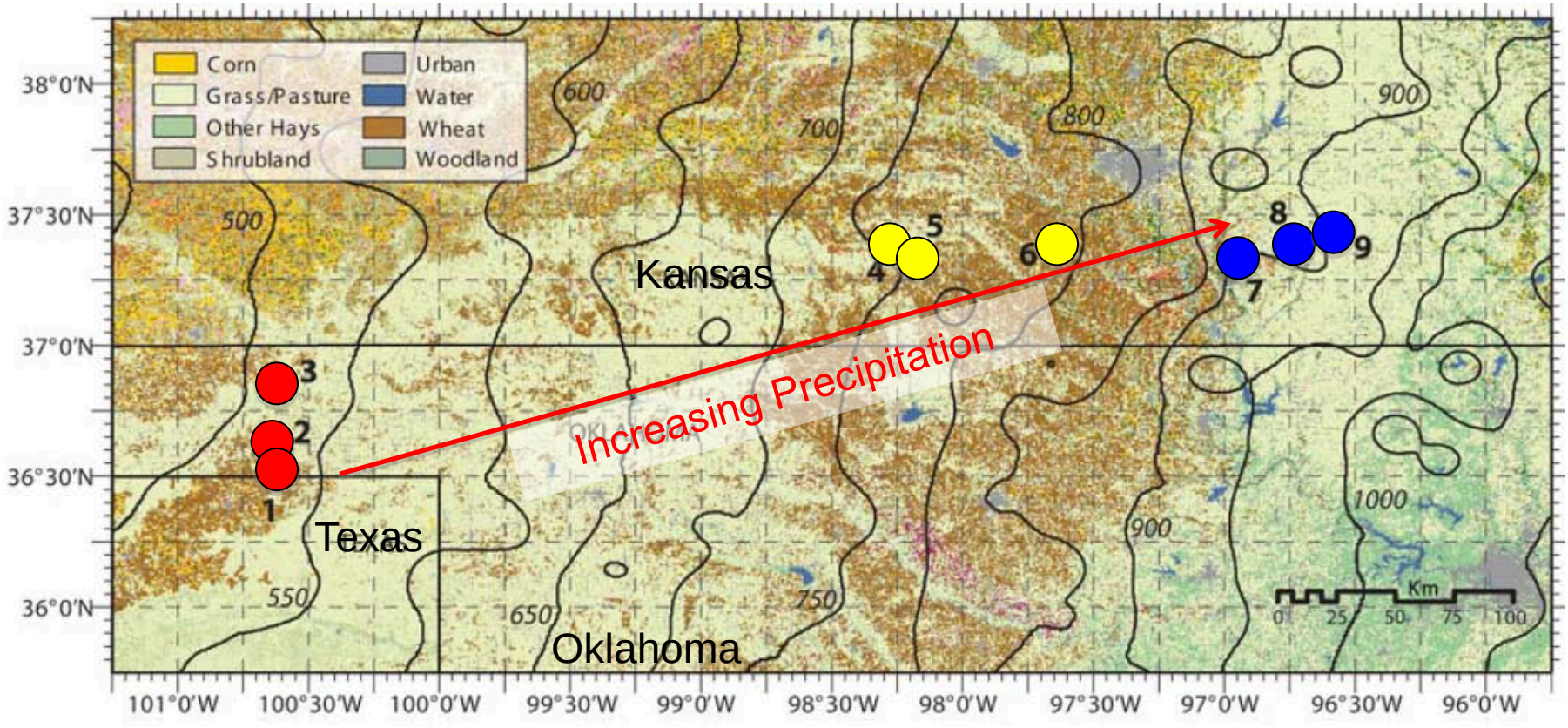
The need for calibration of watershed models poses a big problem for climate change impact studies



Behavioral NOAH parameters showed more dependence on precipitation gradient than on soils and vegetation characteristics

[Rosero et al. 2010, *Journal of Geophysical Research*]

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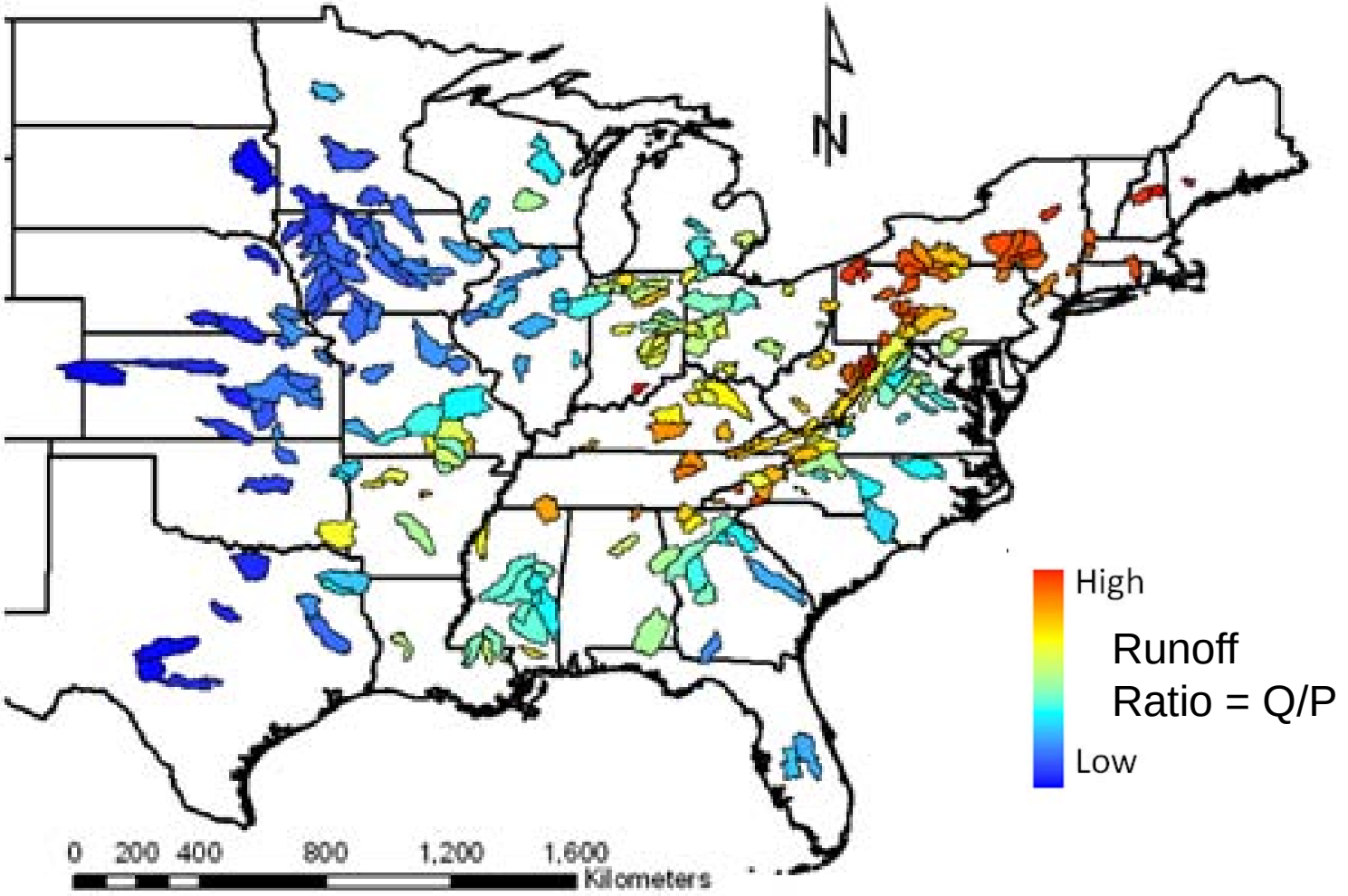
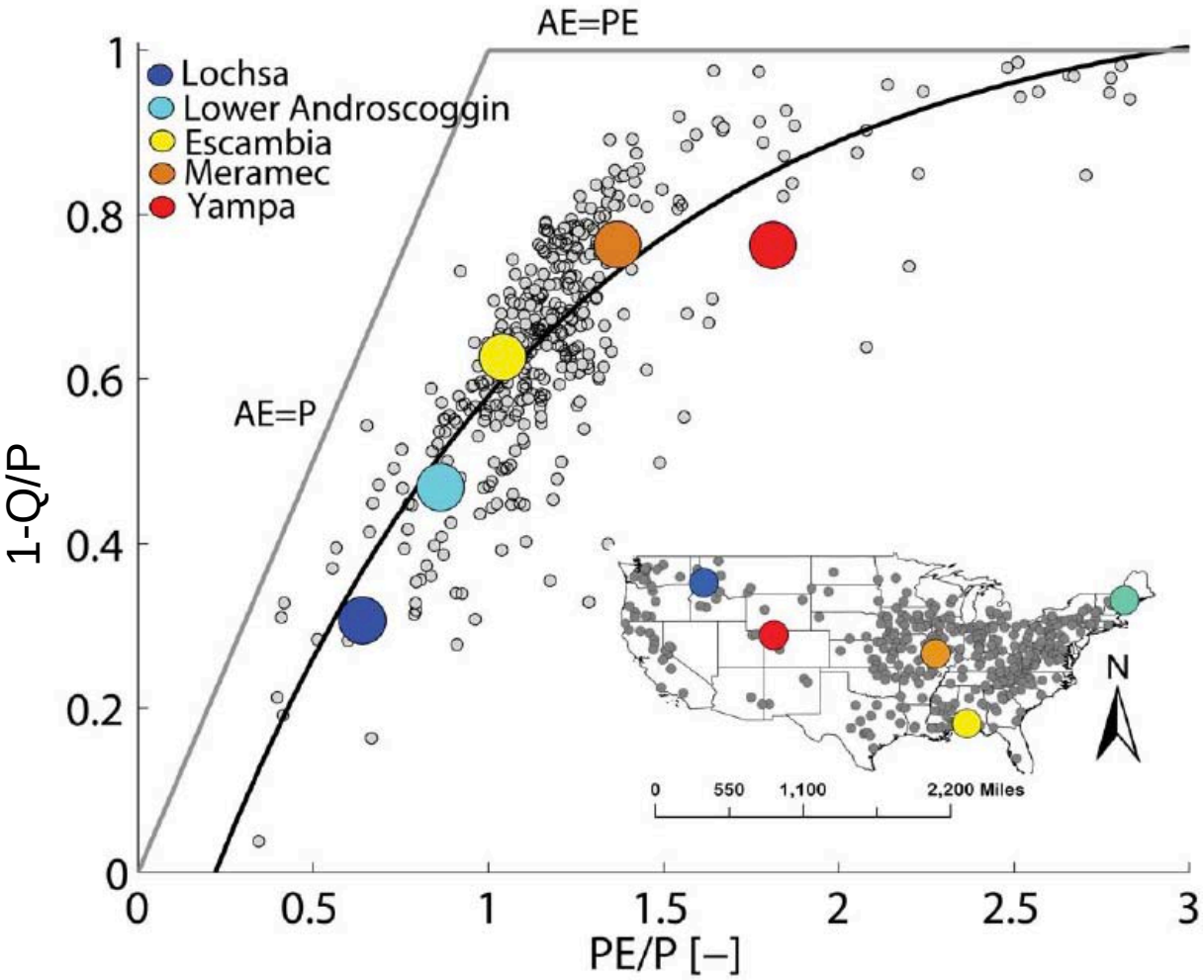
We need to understand how watersheds behave in different climates and how the landscape modulates this behavior



[Sawicz et al. (2011) *Hydrology and Earth System Sciences*]

We can then build a regional hydrologic model of this spatial variability



[Singh et al. (In Press) *Hydrology and Earth System Sciences*]

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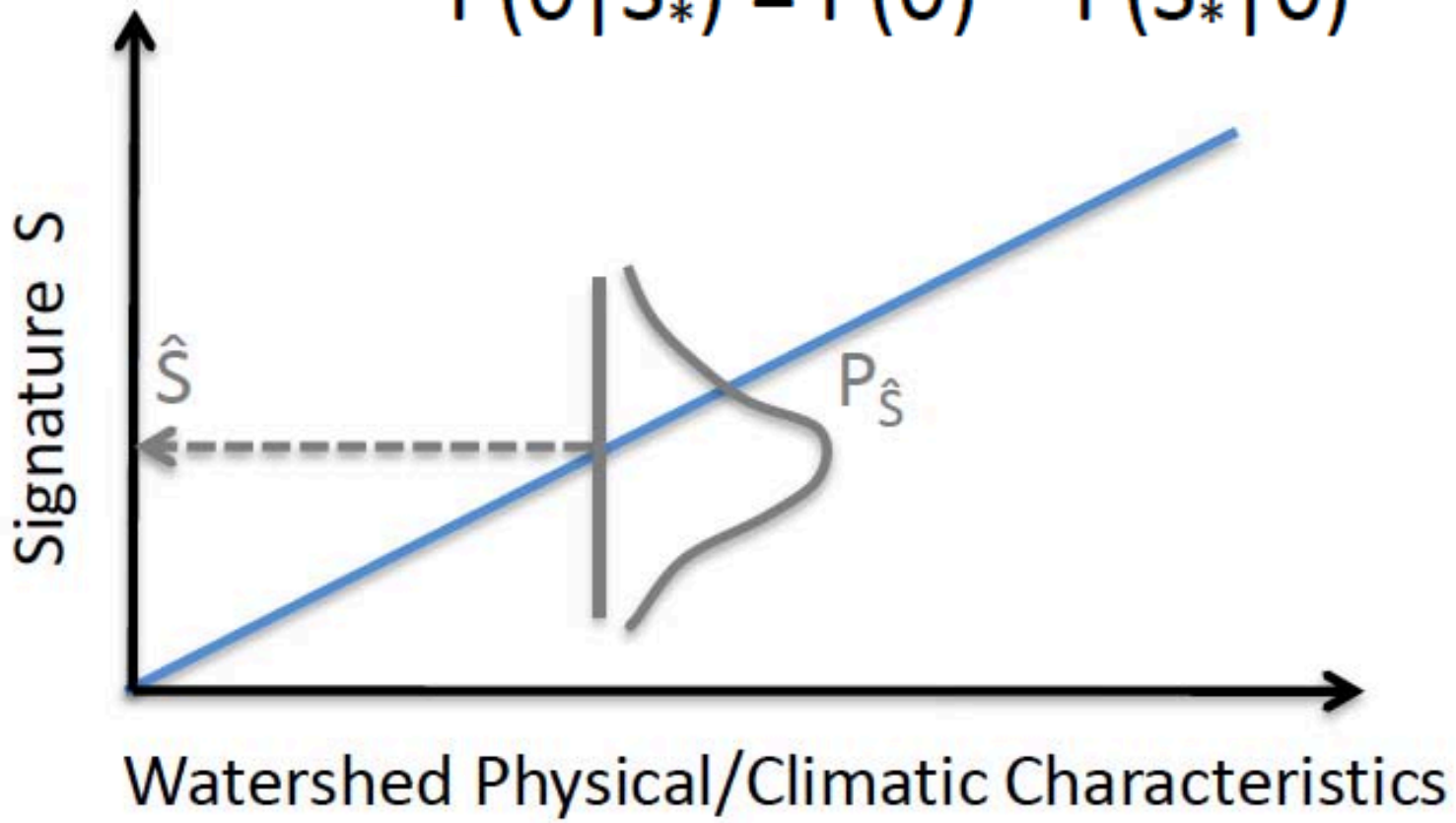
We can use this regional information to constrain (calibrate) any local watershed model

$$P(\theta|\hat{S}_*) = P(\theta) * P(\hat{S}_*|\theta)$$



[Singh et al. (In Press) *Hydrology and Earth System Sciences*]

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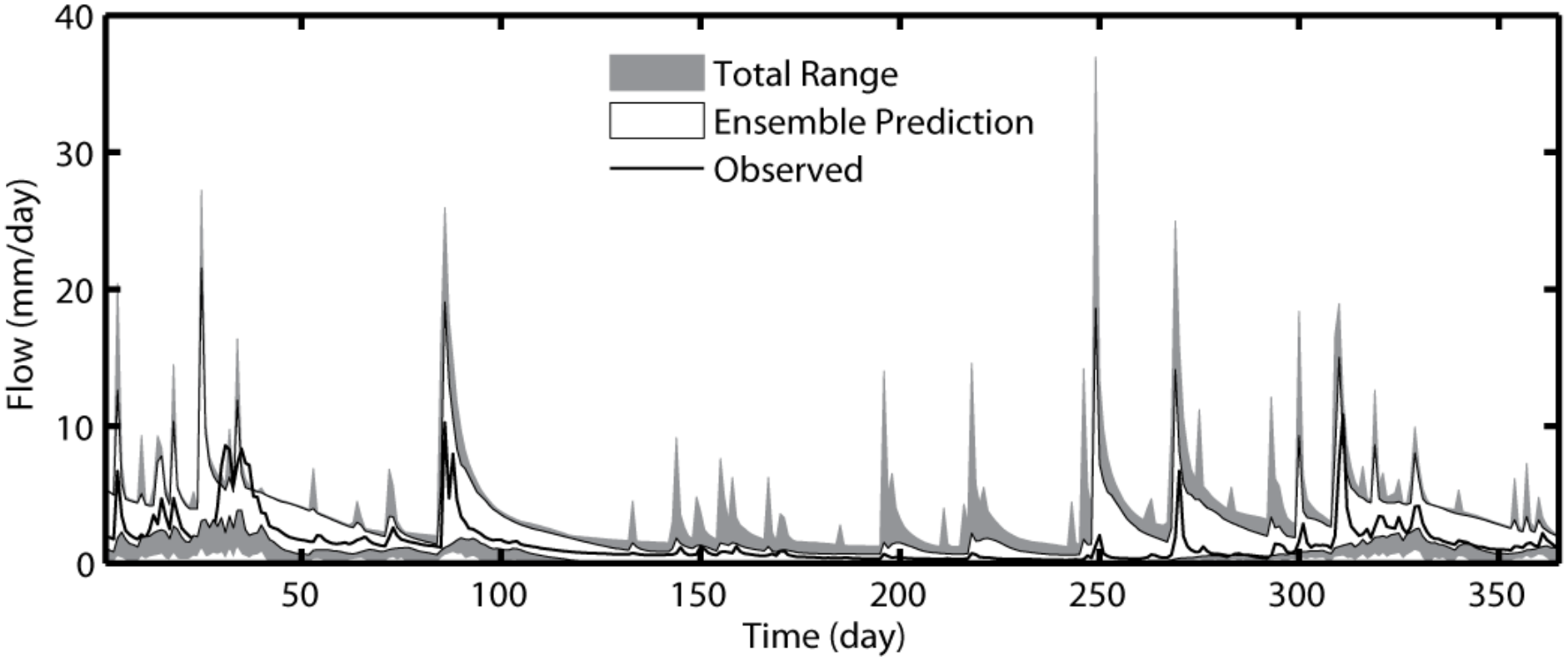
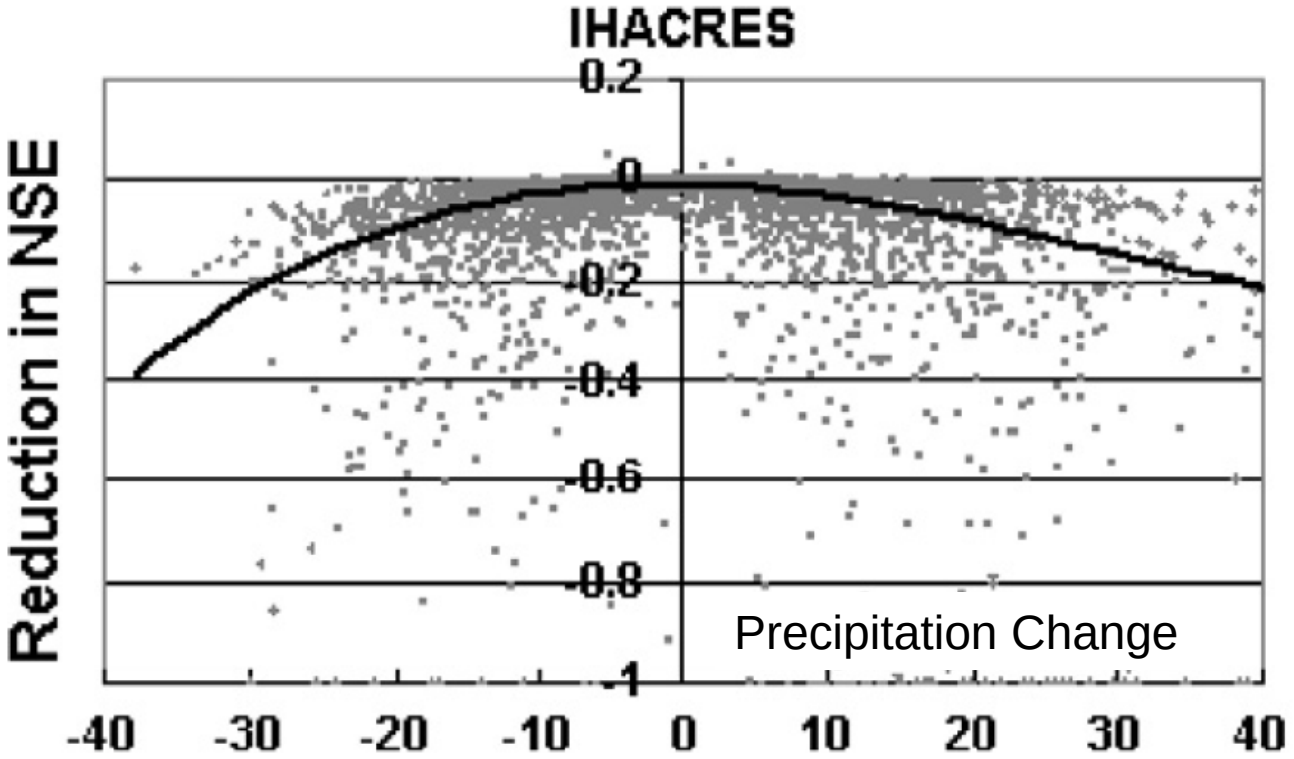
We can assimilate this information for better predictions in ungauged basins everywhere (within our study region)



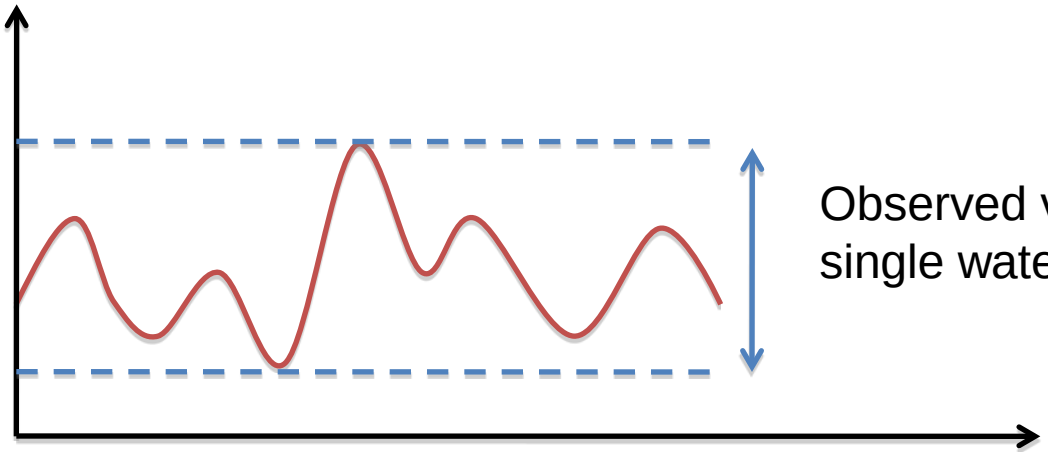
[Zhang et al. (2008) *WRR*; Wagener and Montanari (2011) *WRR*]

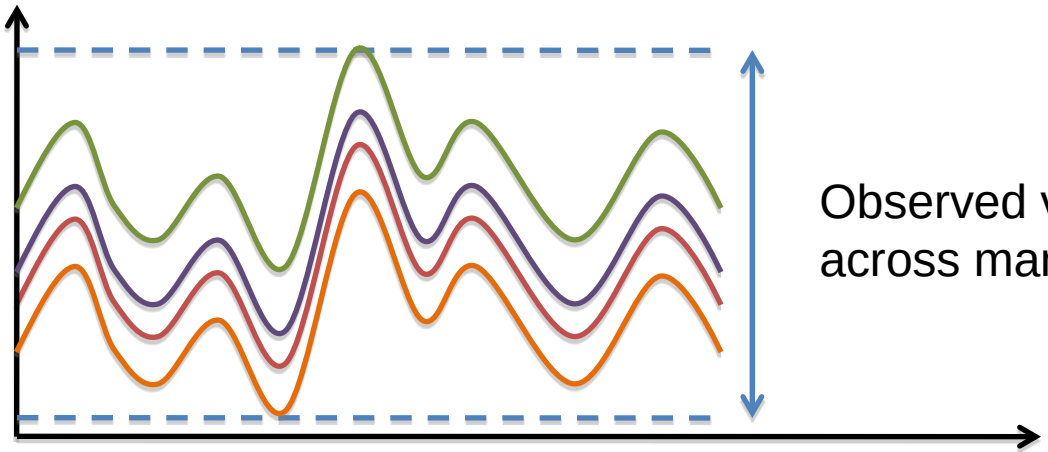
But climate and landcover are also changing in time!



Vaze et al. (2010, JoH) show how model performance declines with prediction periods being climatically different from calibration periods

We can also use it to expand the observed hydrologic variability in climate change assessments





[Singh et al. (In Press) *Hydrology and Earth System Sciences*]

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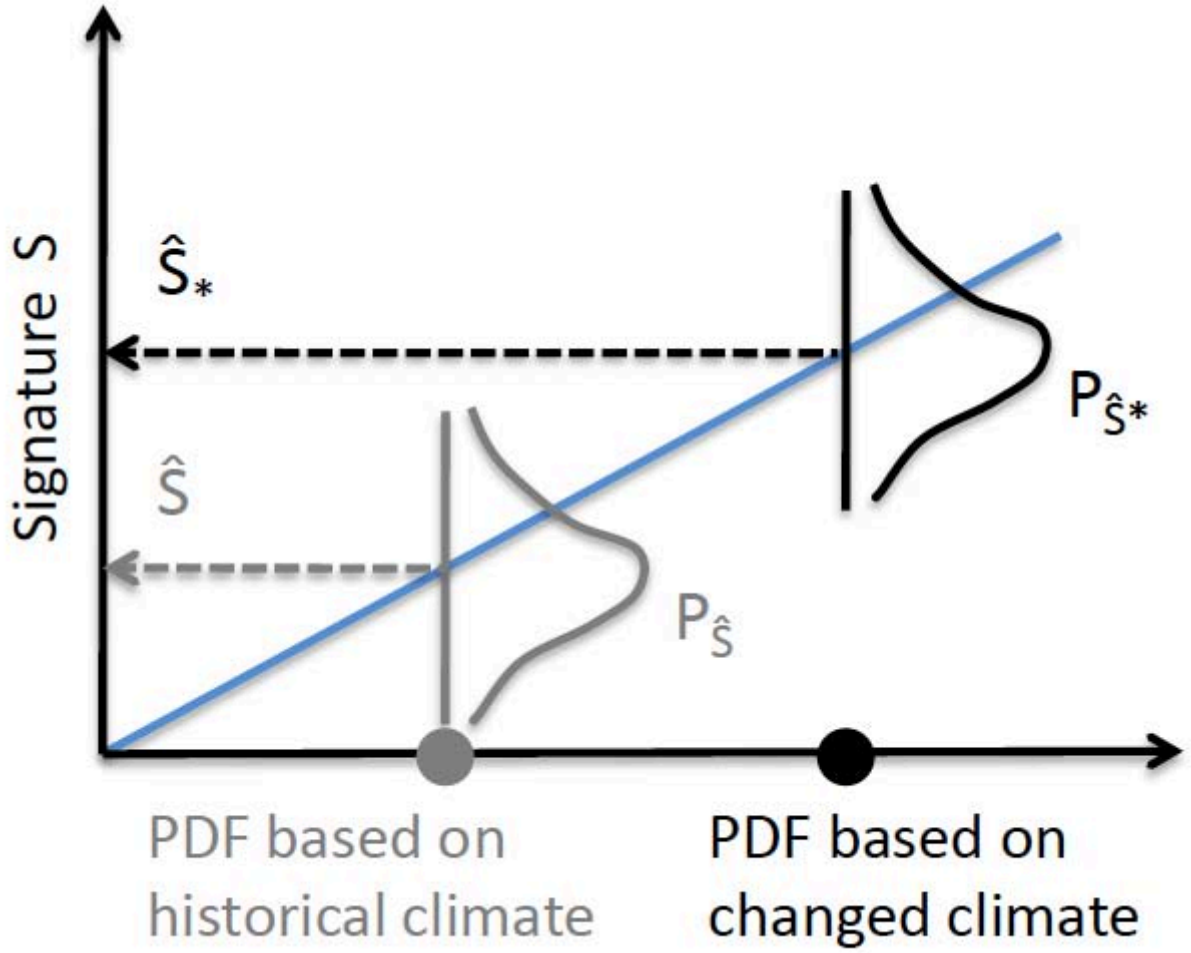

[Singh et al. (In Press) *Hydrology and Earth System Sciences*]

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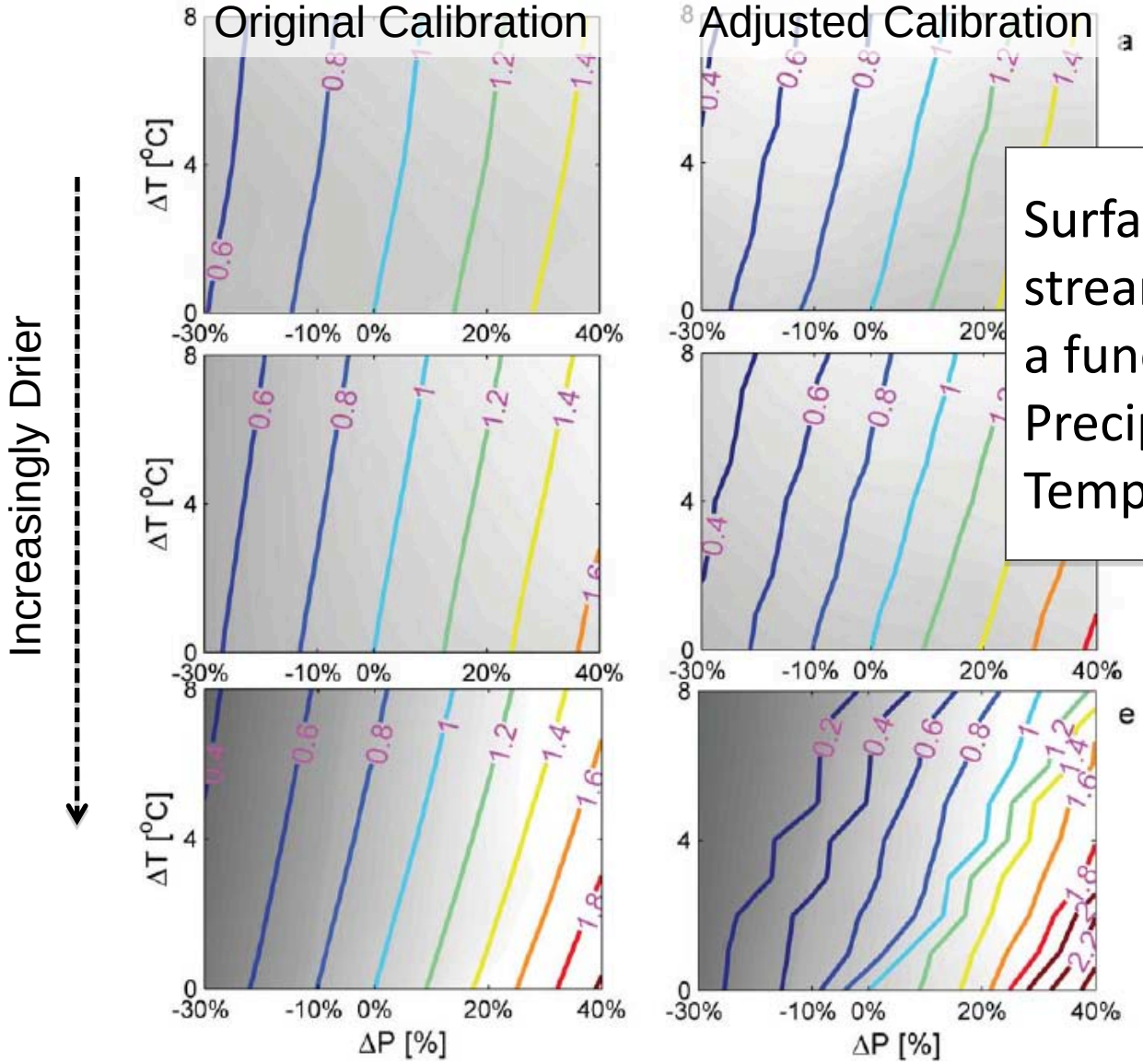
Adjusted parameters simulate a 'stronger' hydrologic response



Surface of streamflow as a function of Precip. and Temperature

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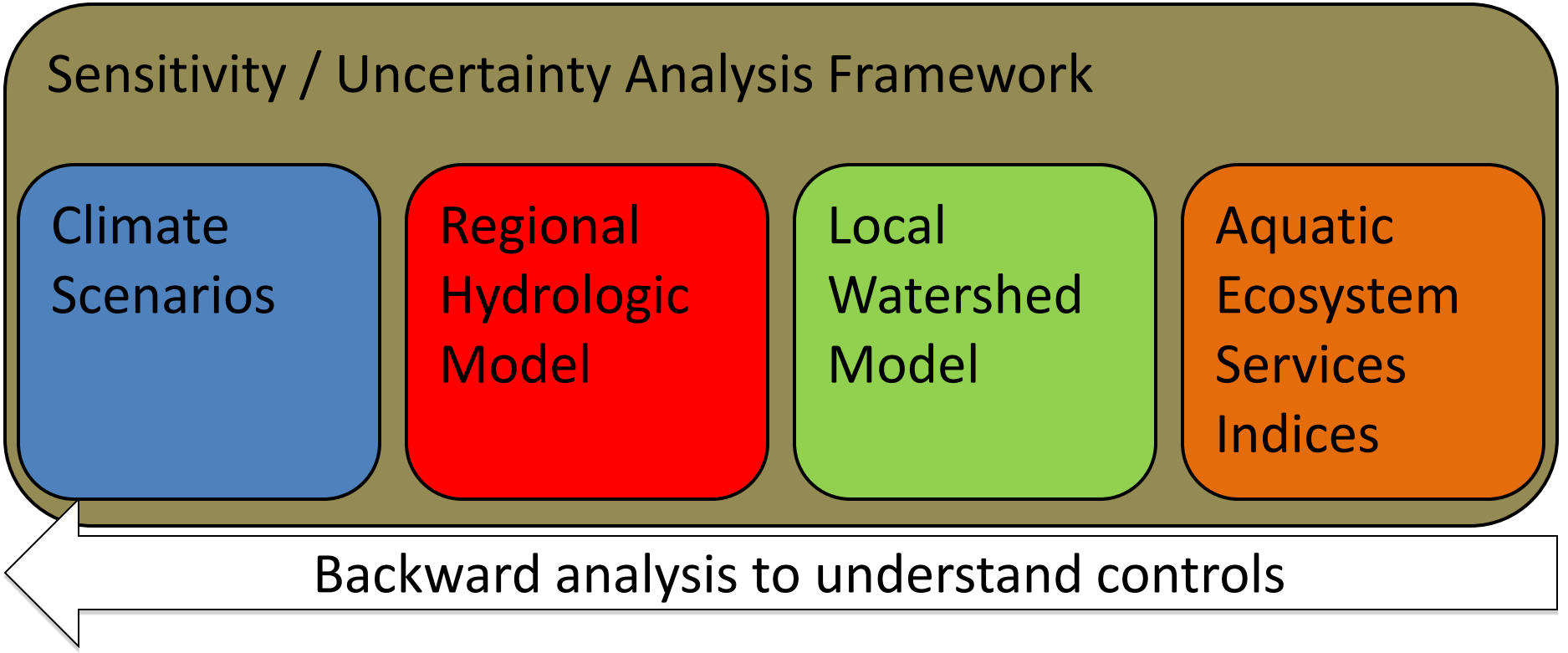
Sensitivity / Uncertainty Analysis Framework
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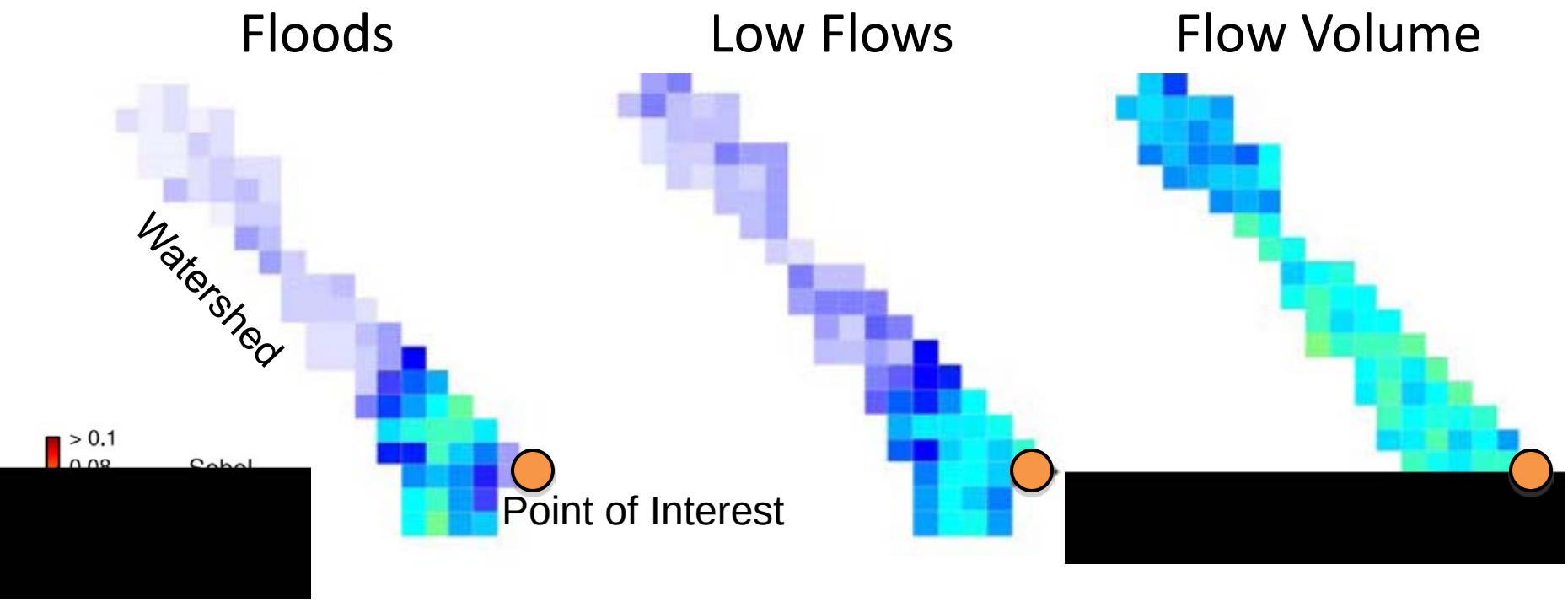
Backward analysis to understand controls

We use global variance-based sensitivity analysis to understand spatial controls on flow

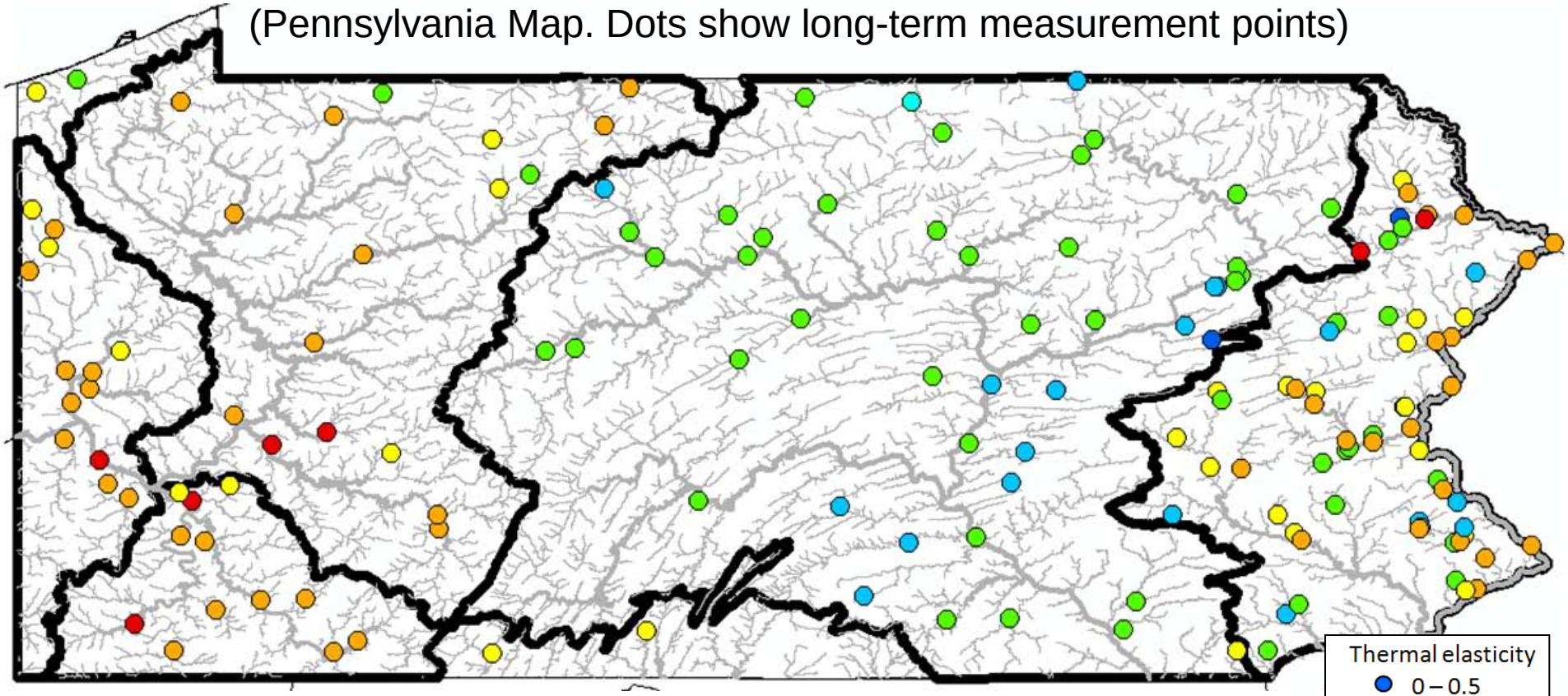


Differences in color of the grid show differences in spatial control on the flow characteristic at the point of interest

[Wagener et al. 2009 *Water Resources Research*]

Controls might change even at a smaller landscape level, e.g. with respect to stream temperature

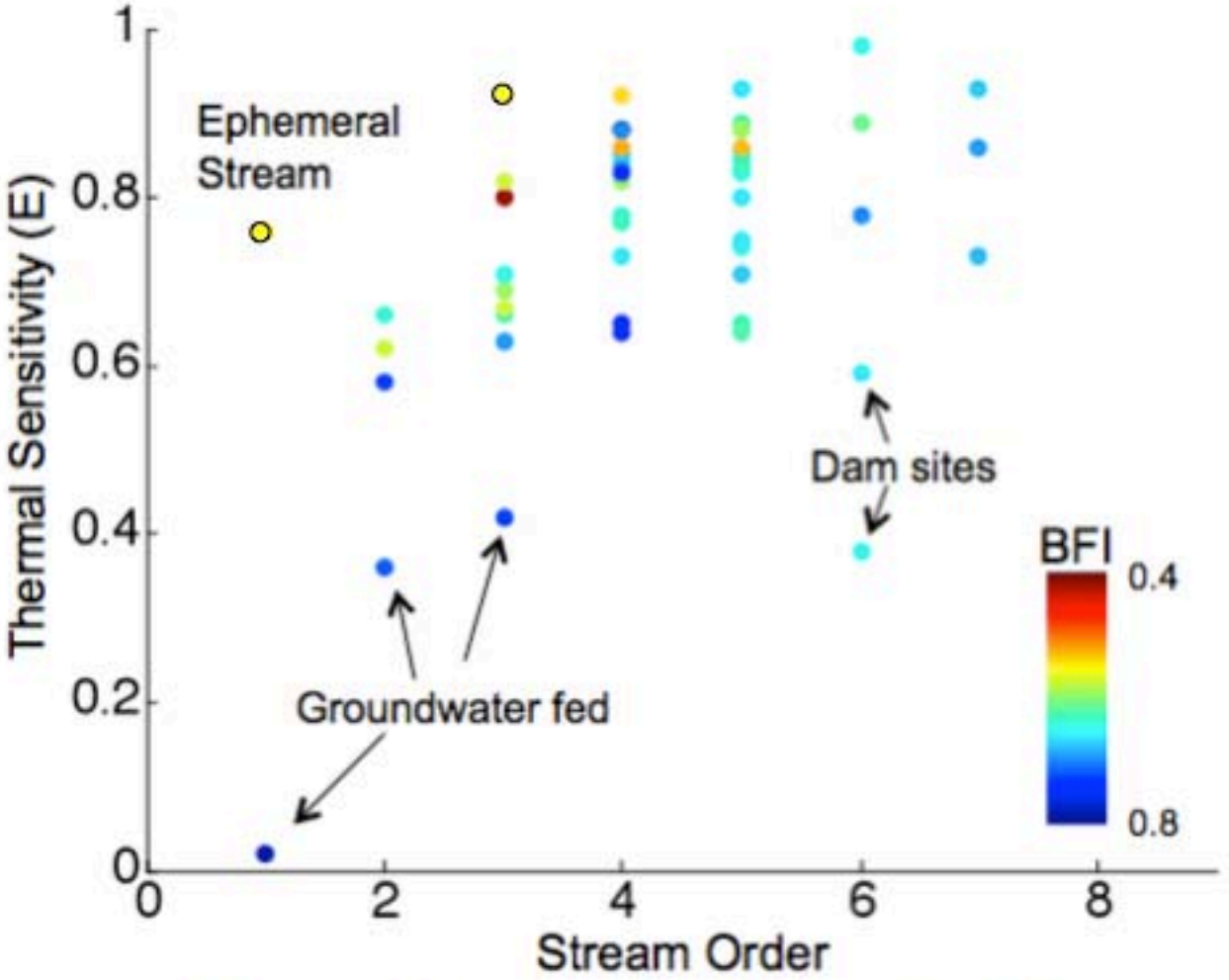
(Pennsylvania Map. Dots show long-term measurement points)



$$E = \frac{T_w}{T_a}$$

[Kelleher et al. (2011) *Hydrological Processes*]

$$E = \frac{T_w}{T_a}$$



Arrows indicate increasing importance relative to stream size as controls on thermal sensitivity:

Groundwater

Riparian shading

Variance in Air Temperature*

* A proxy for heat accumulation through the stream network

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We are developing a sensitivity/uncertainty analysis framework to assess watershed services everywhere and to understand their controls

- Understanding **confidence** in and **controls** on our predictions is necessary for **risk management**
- **A changing world** requires significant changes to how we use environmental models
- We combine statistical models and watershed models for **better use of available information**
- We use sensitivity analysis to **understand controls** on ecosystem indicators
- There is an urgent need to better assess **model limitations and epistemic uncertainty**

http://water.engr.psu.edu/wagener/