

Quantification of structural uncertainty in a land surface model

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► Motivations

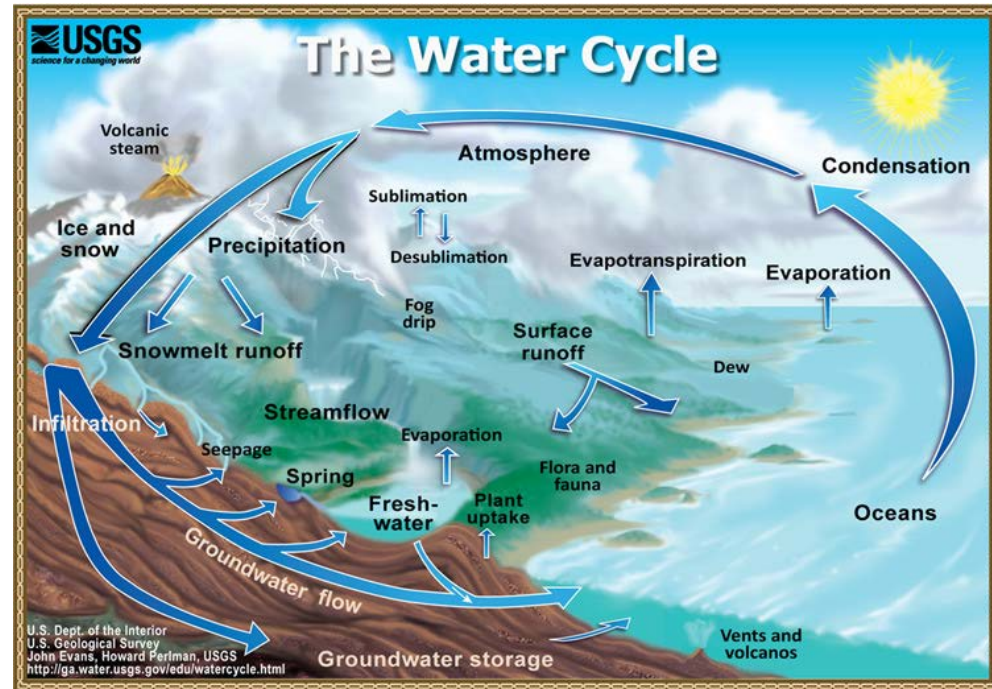
- To identify and quantify model structural uncertainty in the Community Land Model

► Approaches

- Efficient sampling–based sensitivity analysis
- Classification of complex climate system
- Time-frequency analysis of ensemble simulation errors
- Separation of model parametric uncertainty and structural uncertainty
 - MCMC-Bayesian using numerical forward models and/or surrogates
 - Time-frequency analysis of simulation errors from posterior samples

Motivations

- ▶ Climate system: multi-phase, multi-component, multiple biogeophysical/chemical processes
- ▶ Numerous model and coupling parameters; formidable high-dimensional parameter spaces
- ▶ Uncertain parameter values (parametric uncertainty)
- ▶ Model structural uncertainty (makes parameter inversion questionable)



► Sources of uncertainty

■ Model uncertainty

- Simplifications, structural model formulations/structures, extrapolations, resolution, model initial/boundary conditions

■ Parameter uncertainty

- Non-measurable, measurement errors, non-uniqueness, inaccurate calibration, misclassification due to under-sampling...

■ Data uncertainty

- Instrumental errors, consistency, gaps, resolution, scaling

■ Natural uncertainty/variability/heterogeneity

- Intrinsic quantities vary over time, over space, or across individuals in a population
- Physical processes/mechanisms/features vary over space, time, and individuals

► Assumptions

■ No systematic data measurement errors

■ Model prediction errors are mainly due to parametric and model structural uncertainty

■ The complex climate system can be divided into simpler subsets/groups, with each has common model structural errors

Step 1: Entropy concept and efficient sampling to fully represent parametric input uncertainty

Prior information

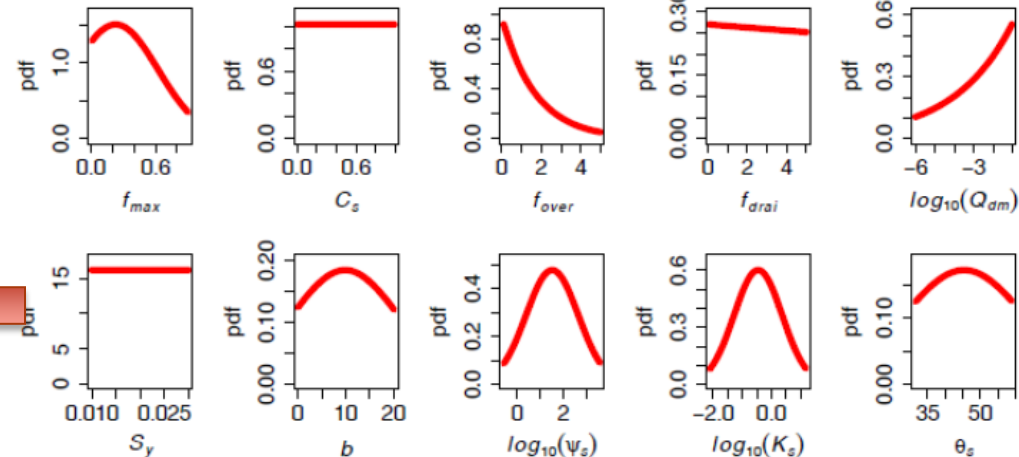
Symbol	Definition
f_{max}	Max fractional saturated area, from DEM
C_s	Shape parameter of the topographic index distribution
f_{over}	Decay factor (m ⁻¹) for fsat
b	Clapp and Homberger exponent
K_s	Hydraulic conductivity (mm s ⁻¹)
θ_s	porosity
Ψ_s	Saturated soil matrix potential (mm)
f_{drai}	Decay factor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

$$f(x) = \frac{\sqrt{\frac{\gamma}{\pi}} \exp\left[-\gamma\left(x + \frac{\beta}{2\gamma}\right)^2\right]}{\Phi\left[\sqrt{2\gamma}\left(U + \frac{\beta}{2\gamma}\right)\right] - \Phi\left[\sqrt{2\gamma}\left(L + \frac{\beta}{2\gamma}\right)\right]} \quad L \leq x \leq U$$

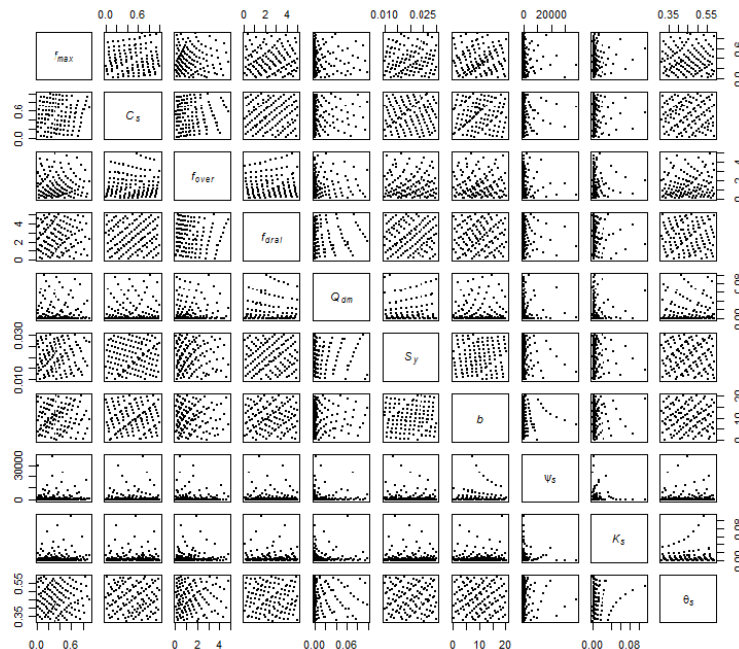
Entropy concept



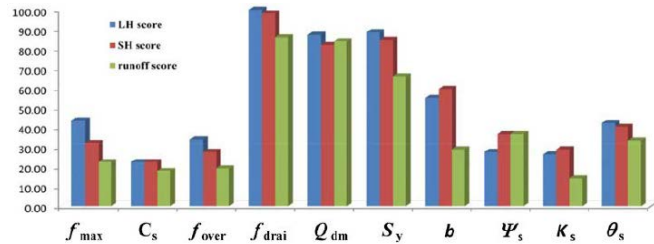
Prior pdfs



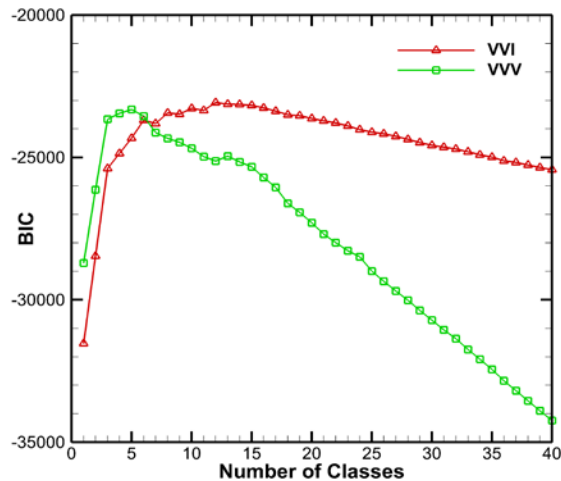
Efficient sampling



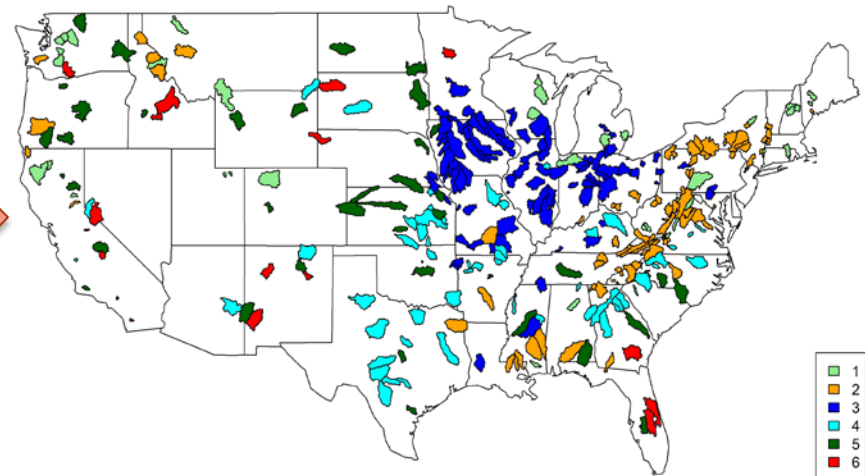
Step 2: Classify the complex system into subsets/groups



Parameter identifiability



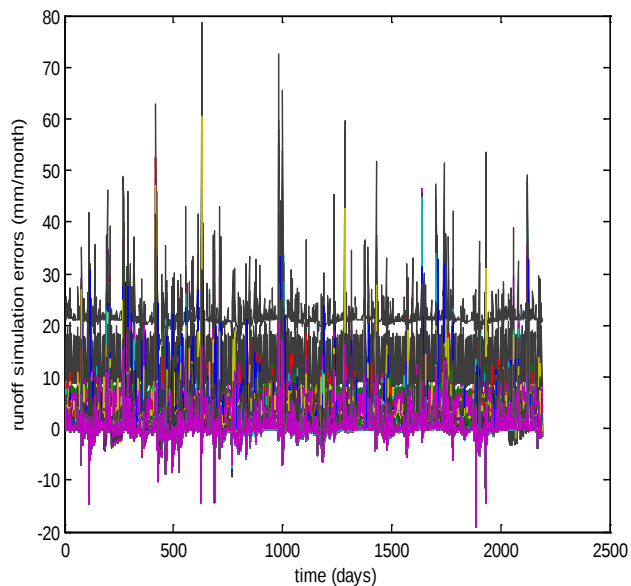
Expectation-maximization clustering



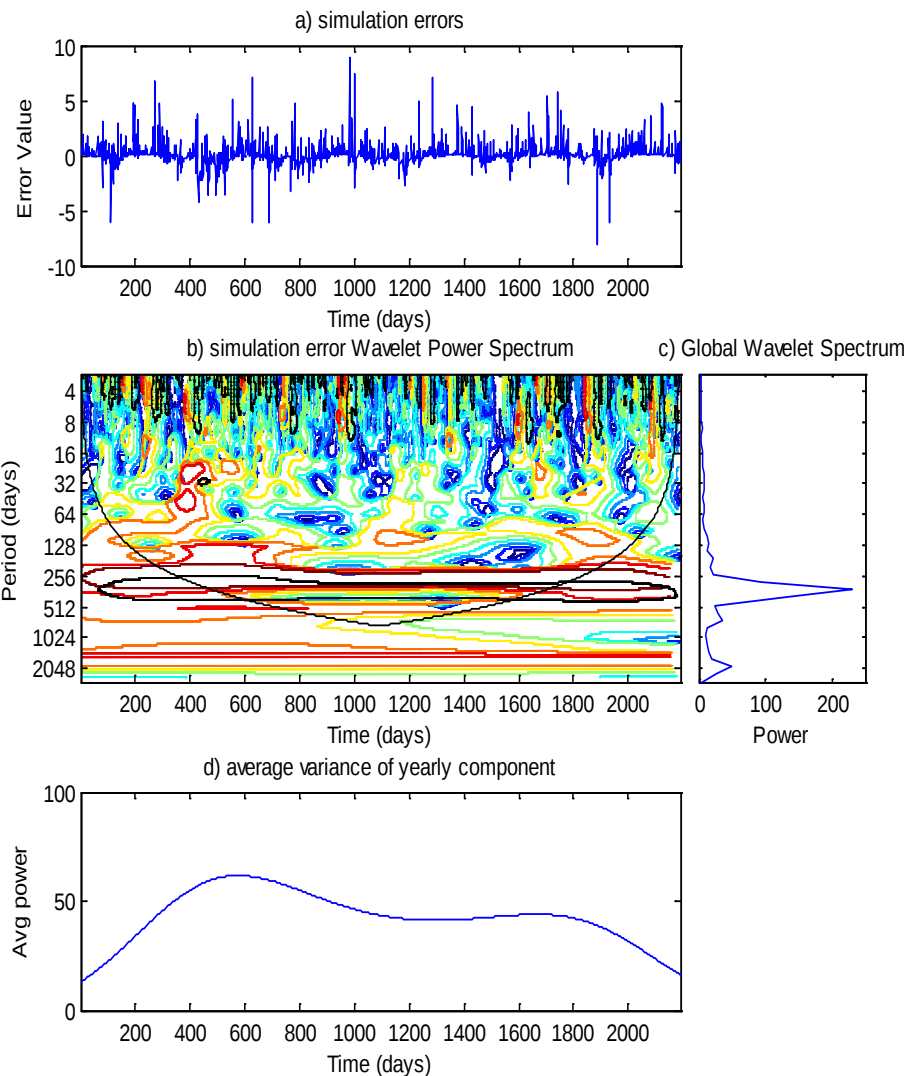
Clusters of US MOPEX basins

Step 3: Time-frequency decomposition of prior ensemble simulation errors

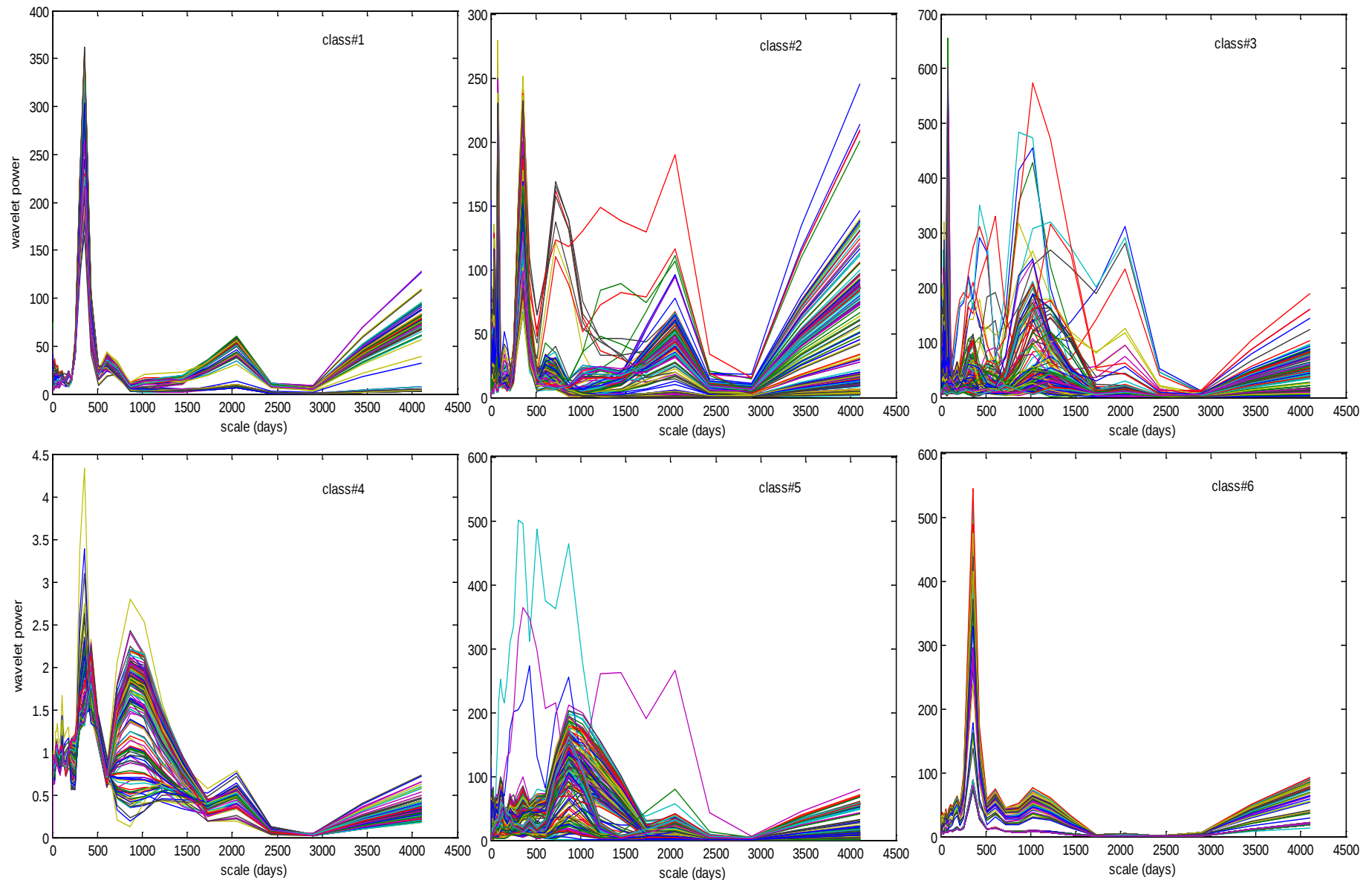
Model simulation errors



Wavelet analysis of simulation errors



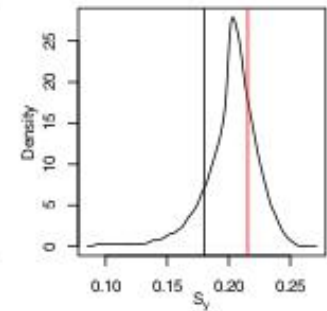
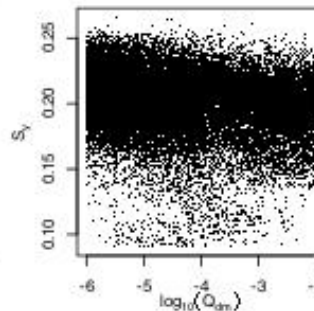
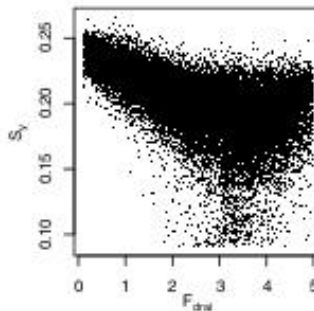
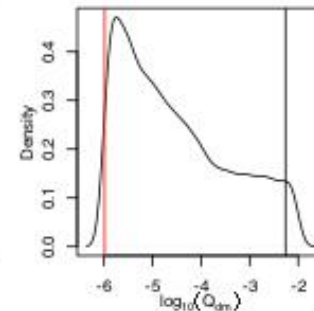
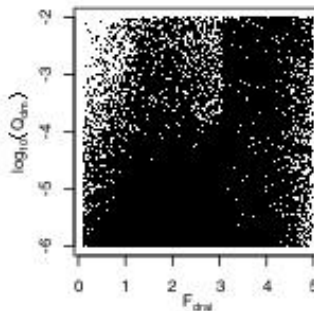
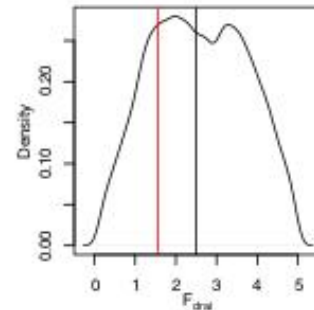
Step 3: Time-frequency decomposition of prior ensemble simulation errors



Step 4: Reduction of parametric uncertainty via MCMC-Bayesian inversion

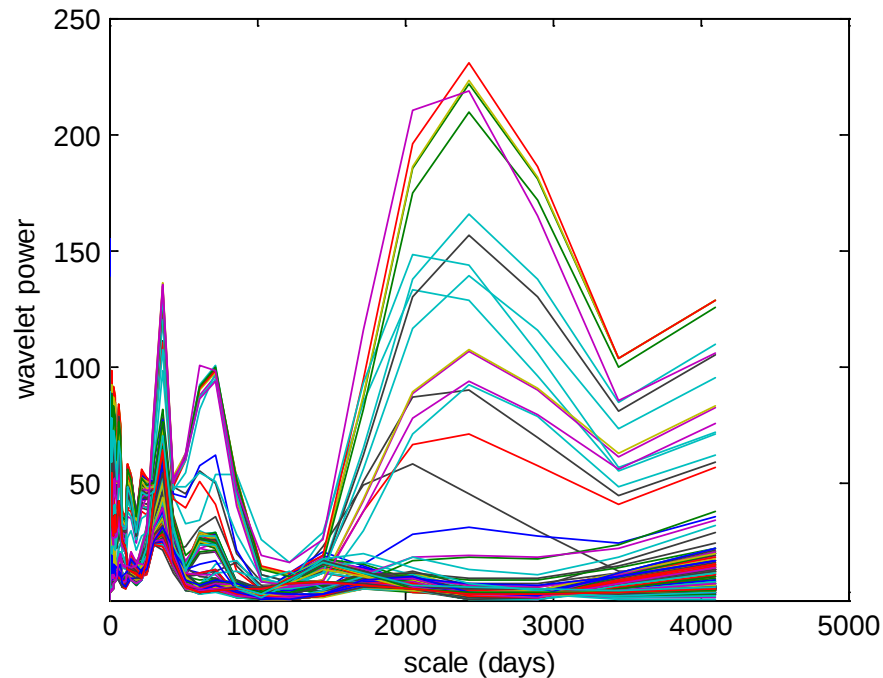
- ▶ MCMC-Bayesian inversion
- ▶ Surrogate development
- ▶ Parameter subspace selection
- ▶ Data refinement/classification

(Ray et al. 2015 and talks in sessions MS159/MS162)

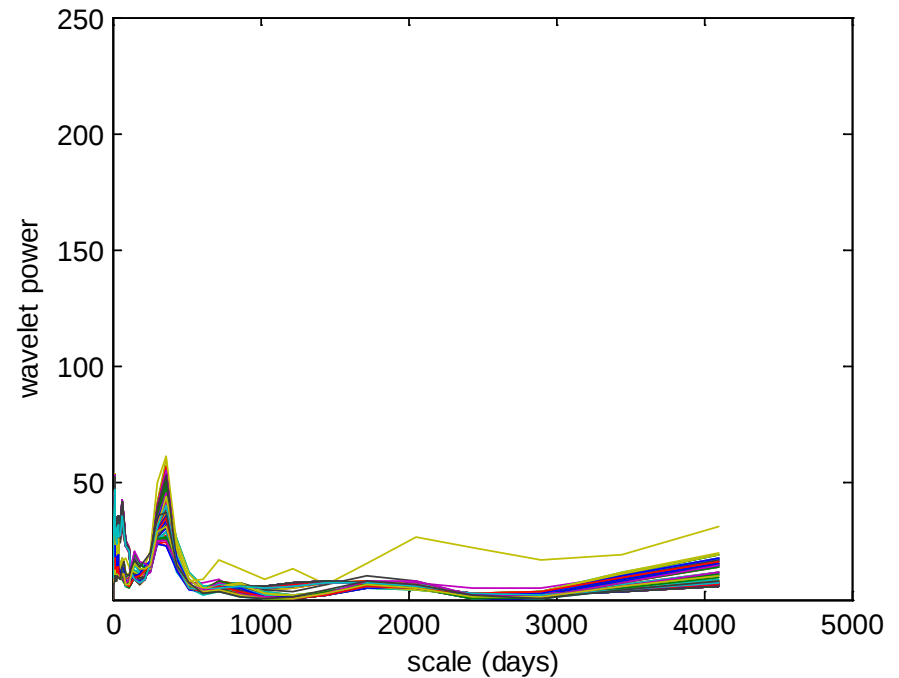


Step 5: Time-frequency decomposition of posterior ensemble simulation errors

Power spectrum of simulation errors
before parameter inversion



Power spectrum of simulation errors
after parameter inversion



- ▶ It is possible to identify model structural errors by quantifying input parameter uncertainty and fully exploring the input parameter space
- ▶ (Ensemble) model simulation errors provide information about the processes (and/or parameters) with major contributions to the errors
- ▶ Assuming no systematic errors in the conceptual models and observational data, the model structural errors can possibly be separated after parametric uncertainty is reduced.
- ▶ The remaining errors would provide guidance on further model improvement, e.g., by modifying the physical models or parameterizations that numerically affect the errors at the major spatial-temporal scales.