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Quantification of structural uncertainty in a land surface model

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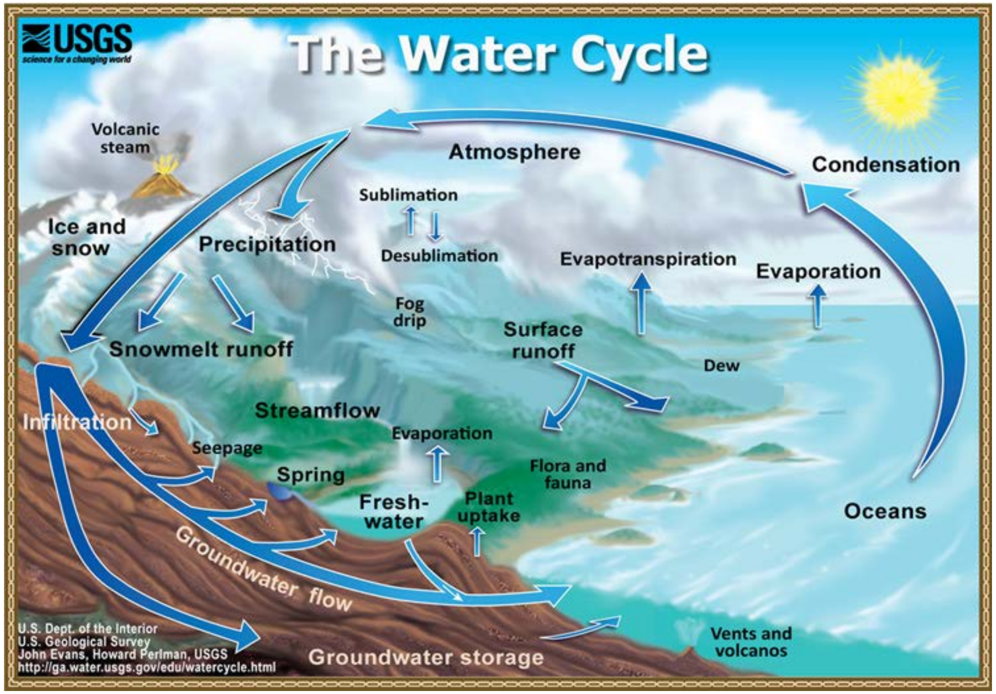
Outline

- 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)



Assumptions

- 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, mis-classification 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

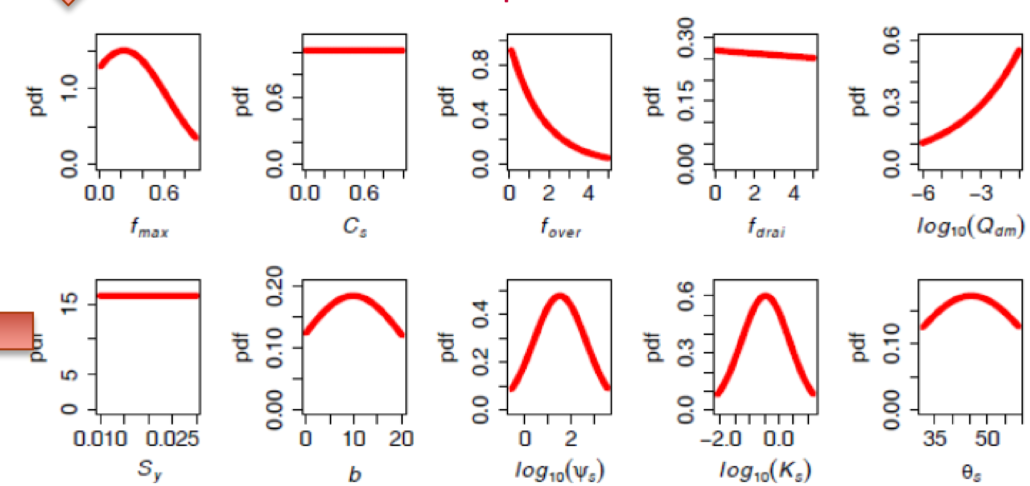
Prior information

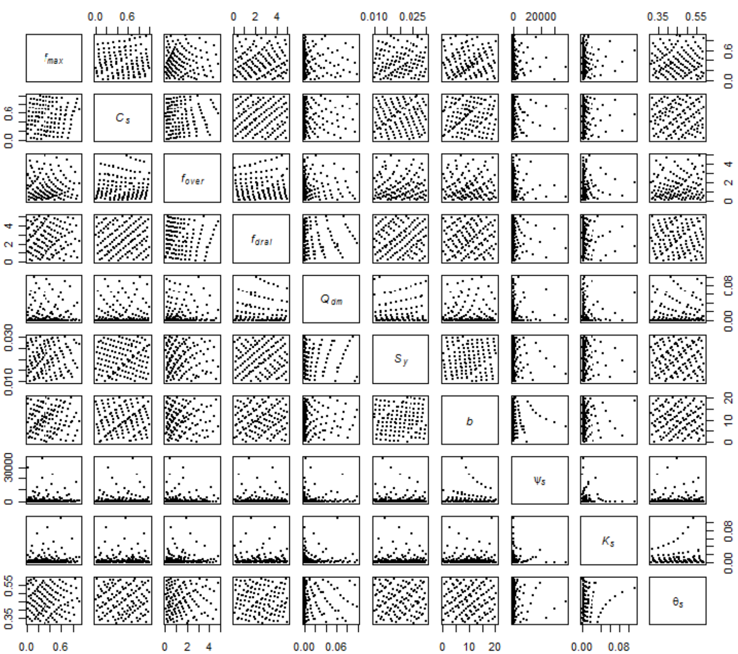
Symbol	Definition
f_{max}	Max fractional saturated area, from DEM
C_s	Shape parameter of the topographic index distribution
f_{over}	Decay factor (m^{-1}) for fsat
b	Clapp and Homberger exponent
K_s	Hydraulic conductivity ($mm\ s^{-1}$)
θ_s	porosity
Ψ_s	Saturated soil matrix potential (mm)
f_{drai}	Decay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

Entropy concept

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

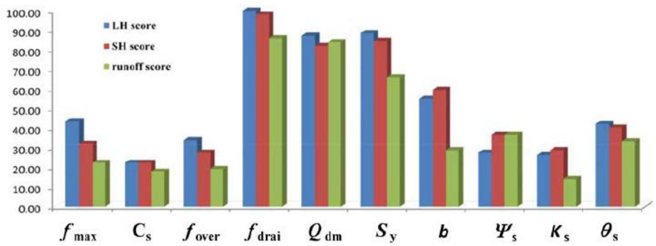
Prior pdfs



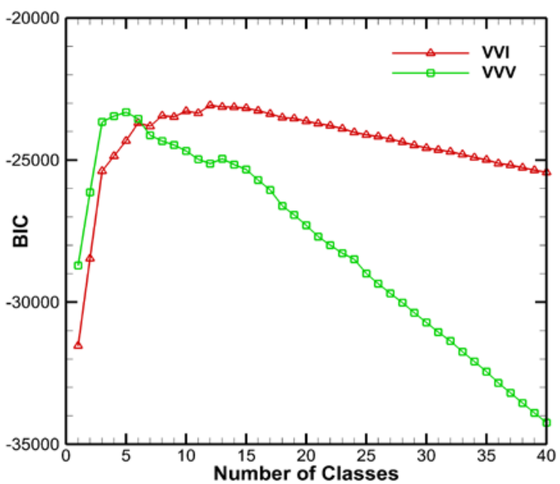


Efficient sampling

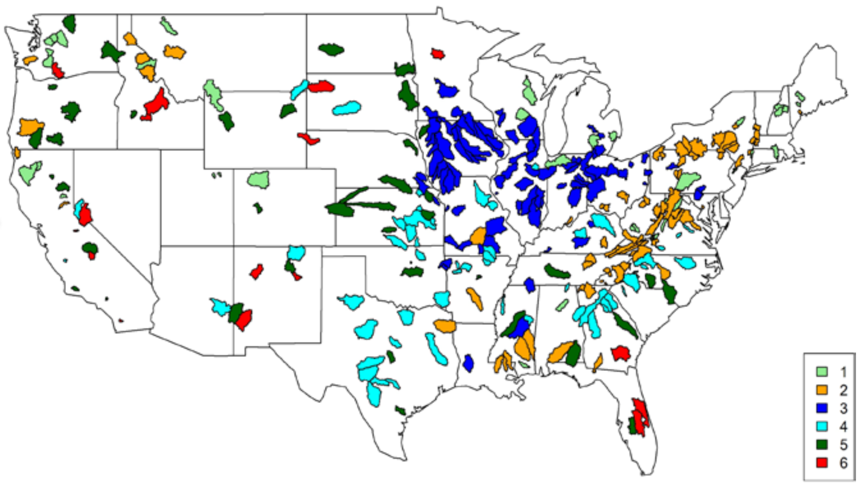
Step 2: Classify the complex system into subsets/groups



Parameter identifiability



Expectation-maximization clustering



Clusters of US MOPEX basins

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

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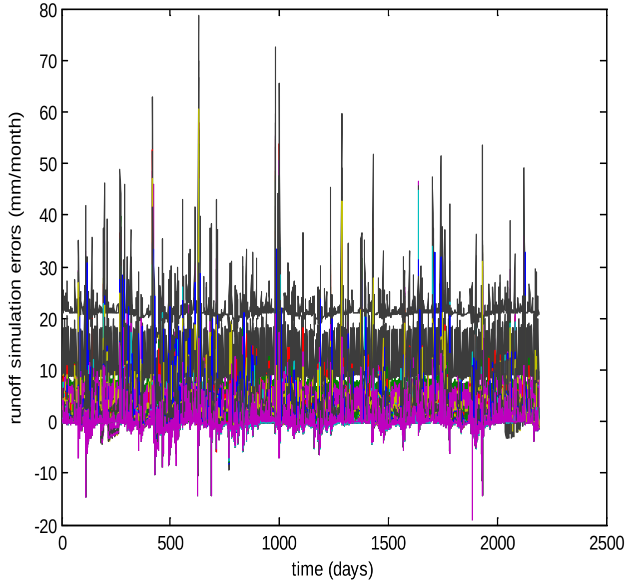
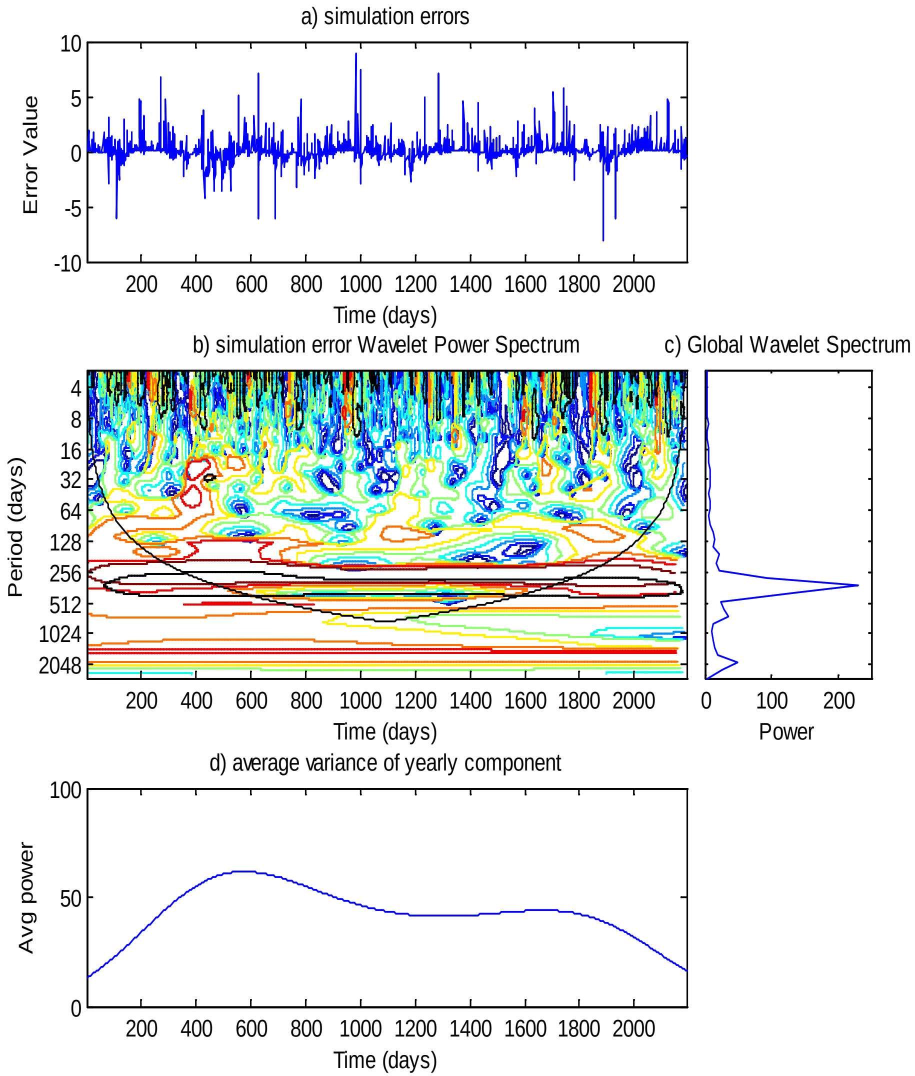
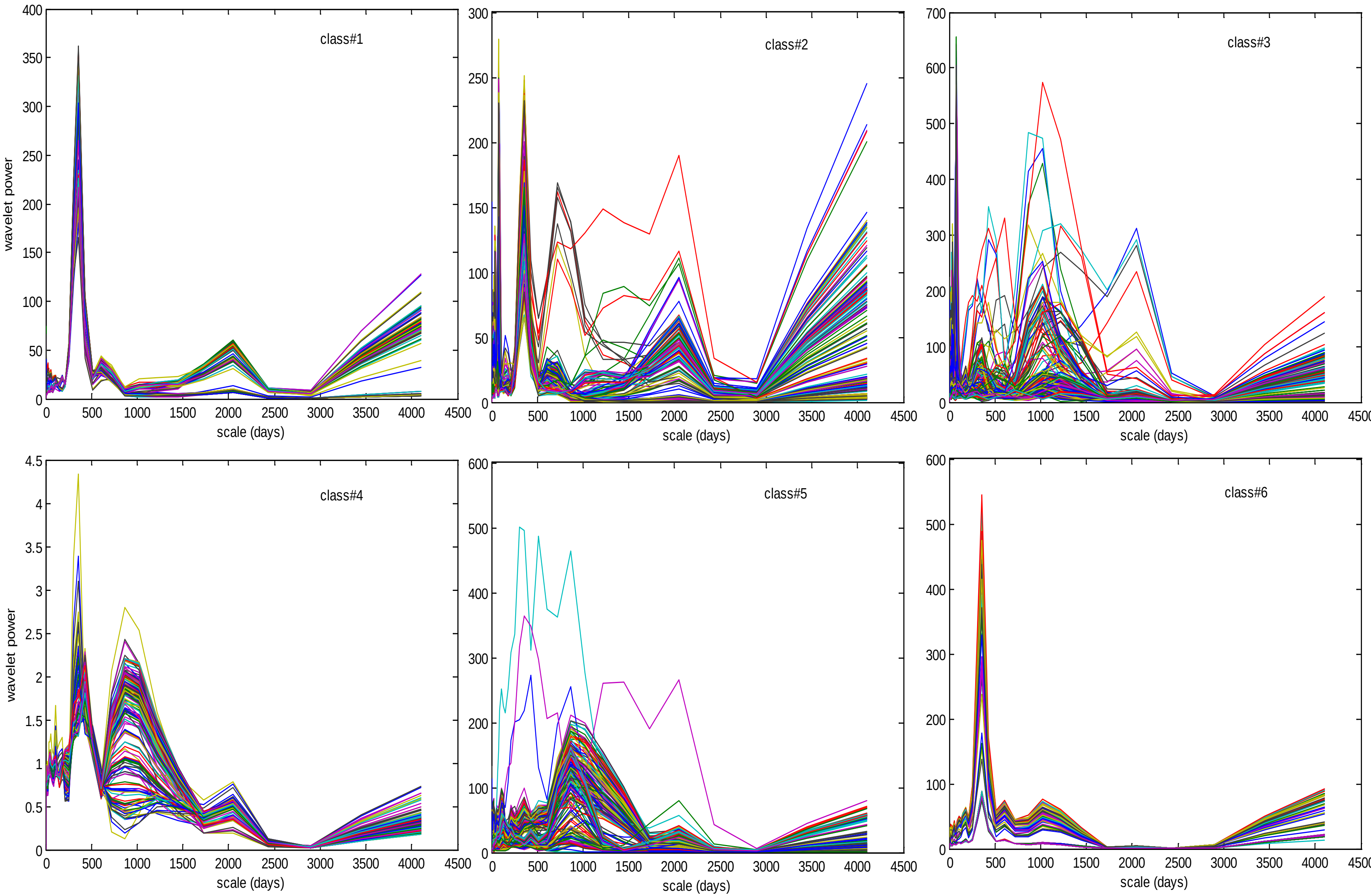
Model simulation errors



Wavelet analysis of simulation errors



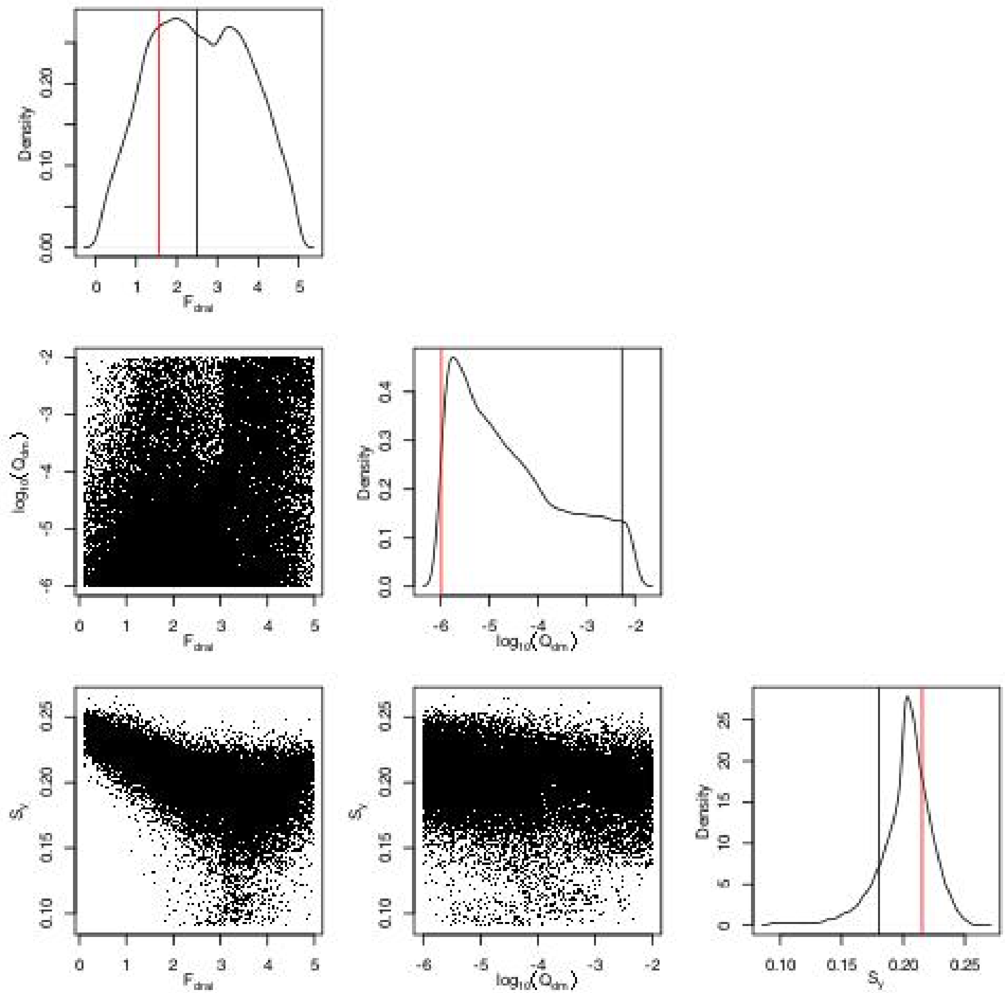
Step 3: Time-frequency decomposition of prior ensemble simulation errors



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

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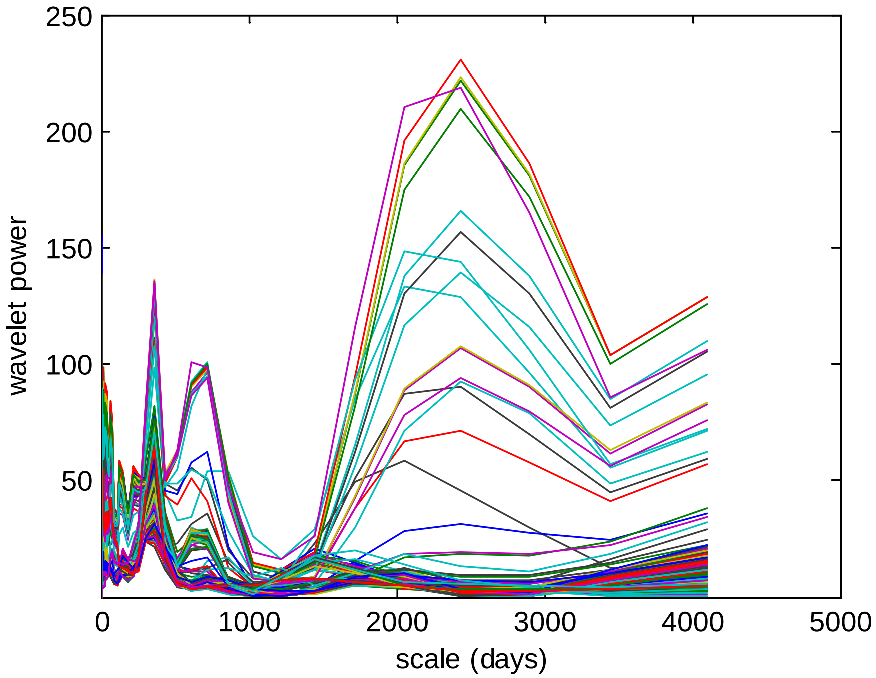
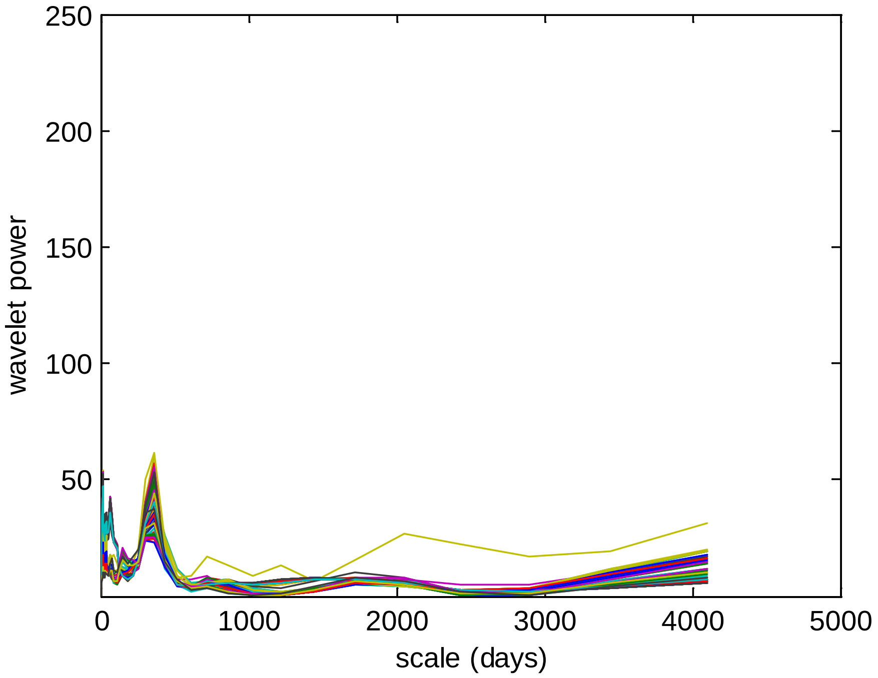
Power spectrum of simulation errors before parameter inversion



Power spectrum of simulation errors after parameter inversion



Summary

- 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.