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Potential and Challenges of Investigating Intrinsic Uncertainty of Hydrological Models with Stochastic, Time-Dependent Parameters

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Content

- Motivation
- Concept
- Numerical implementation
- Case study
- Conclusions

Motivation

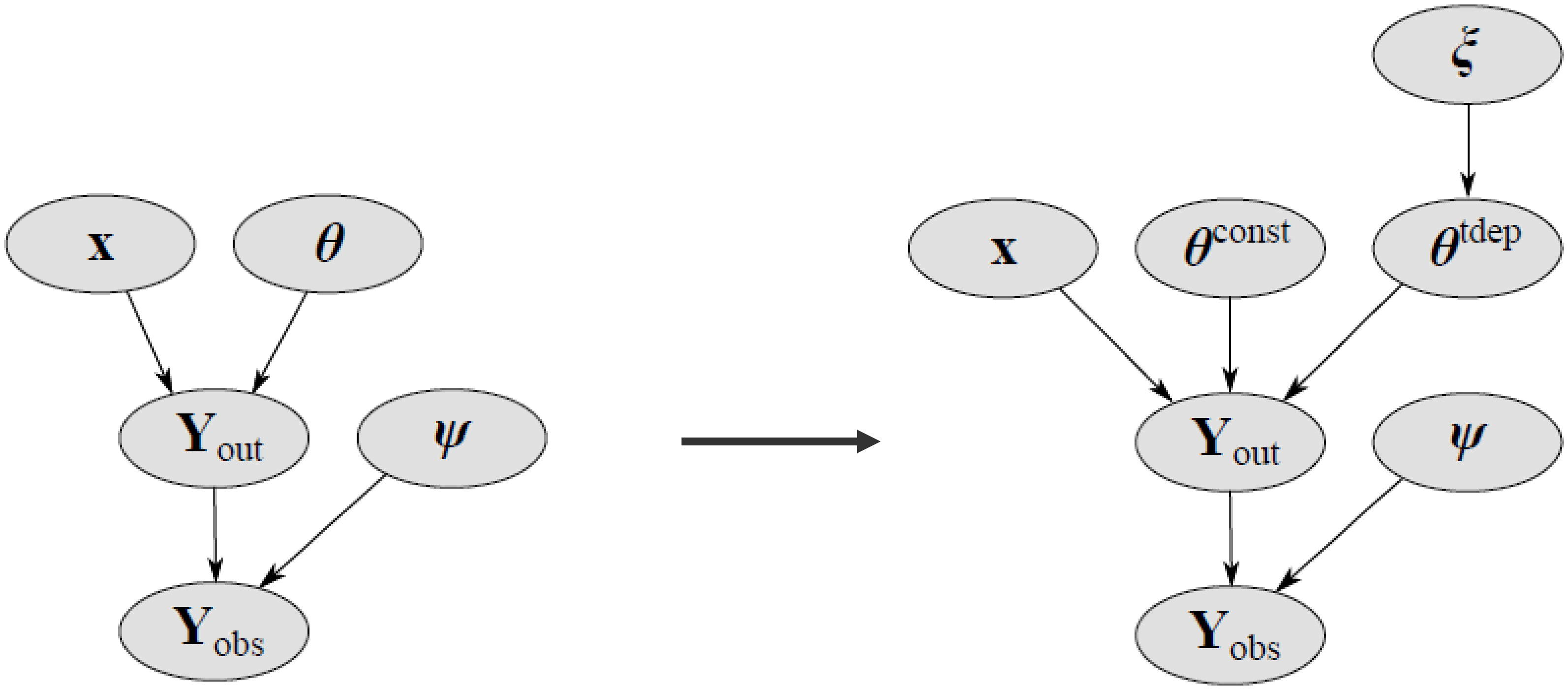
Hydrological process models should be stochastic, because

1. **At the resolution, we observe them, hydrological systems are not deterministic**: the same observed rainfall falling on a catchment with the same observed initial state will not lead to the same streamflow due to poor resolution of input, incomplete input, unobserved changes in state, etc.

2. **Stochastic process models can better cope with (un-avoidable) structural errors** as, even for given parameters, a state can develop into different future states with some probability rather than into a unique state.

Concept

Make parameters (fluxes) rather than state equations stochastic preserves mass balances.



Numerical implementation

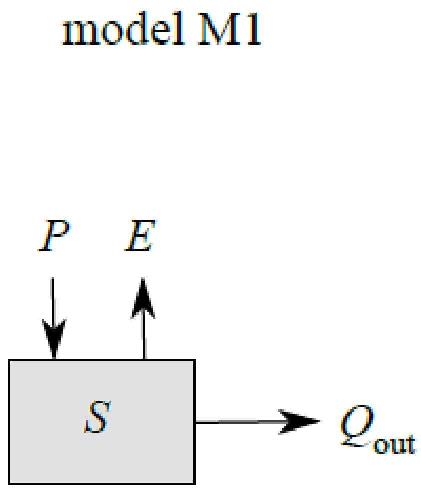
Several algorithms available

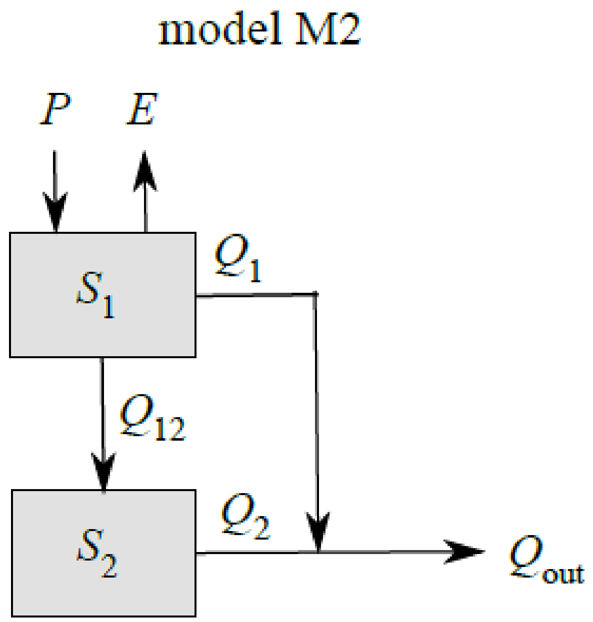
- **Particle Markov Chain Monte Carlo (PMCMC)**
  Combine particle filter/smoother for states with either marginal likelihood or Gibbs sampling for parameters
- **Hamiltonian Monte Carlo (HMC)**
  Requires analytical or automated differentiation of posterior
- **Approximate Bayesian Computation (ABC)**
  Very universal, but does not provide estimates of states
- **Conditional Ornstein-Uhlenbeck Sampling (COUS)**
  Simple interface to hydrological simulation program

Case Study Setting

4 models:

	M1a	1 linear reservoir
	M1b	1 nonlinear reservoir (exponent α)
	M2a	2 linear reservoirs
	M2b	2 reservoirs, fast res. nonlinear (exponent α_1)

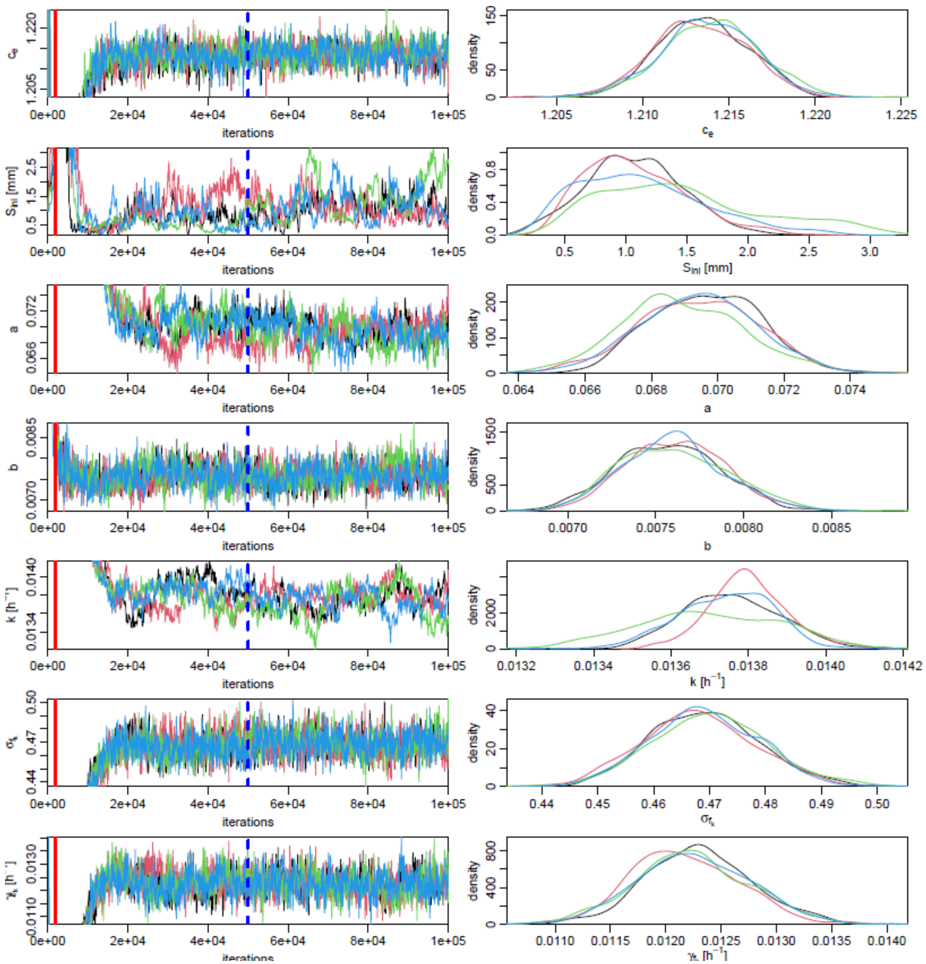


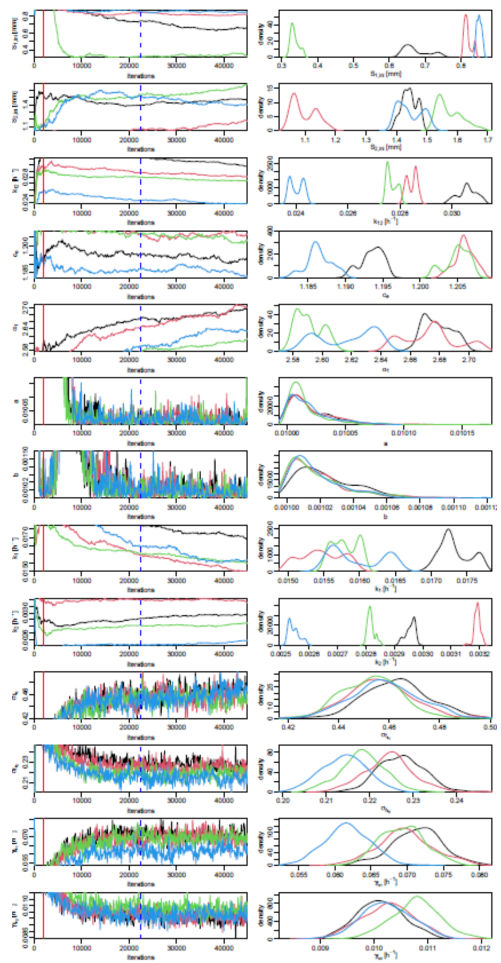


factors to outflow rate coefficients will be made time-dependent

Case Study

Issues with convergence



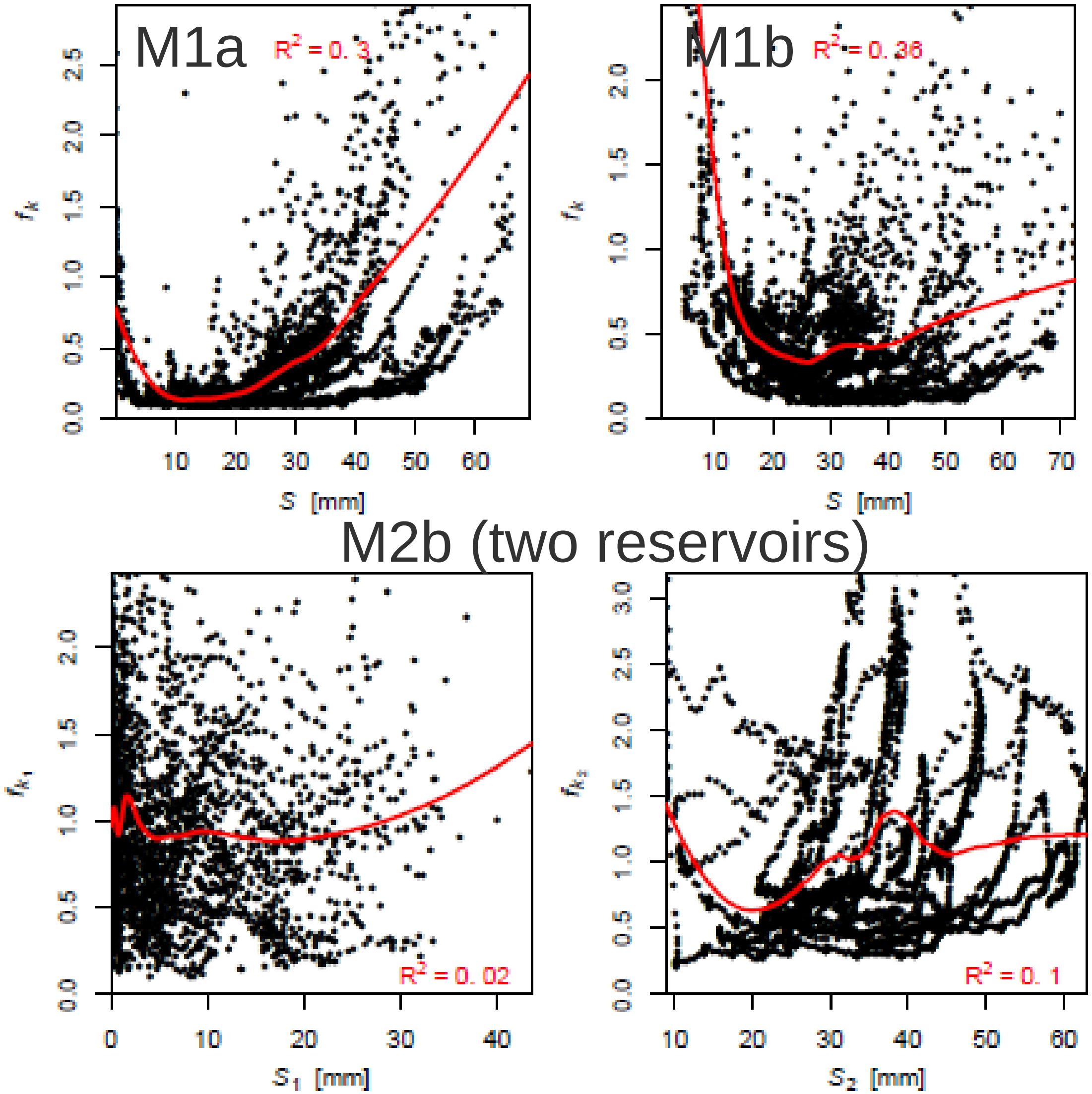


→ Good for M1a, bad for M2b; issue: nearly no noise in data

Case Study

Preliminary results

Outflow rate coefficient factor plotted as a function of reservoir level



→ Good identification of mod. deficits; reduction successful

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Case Study

Preliminary results

Overview

→ **Excellent calibration, good prediction, reasonable behaviour of variables and states**

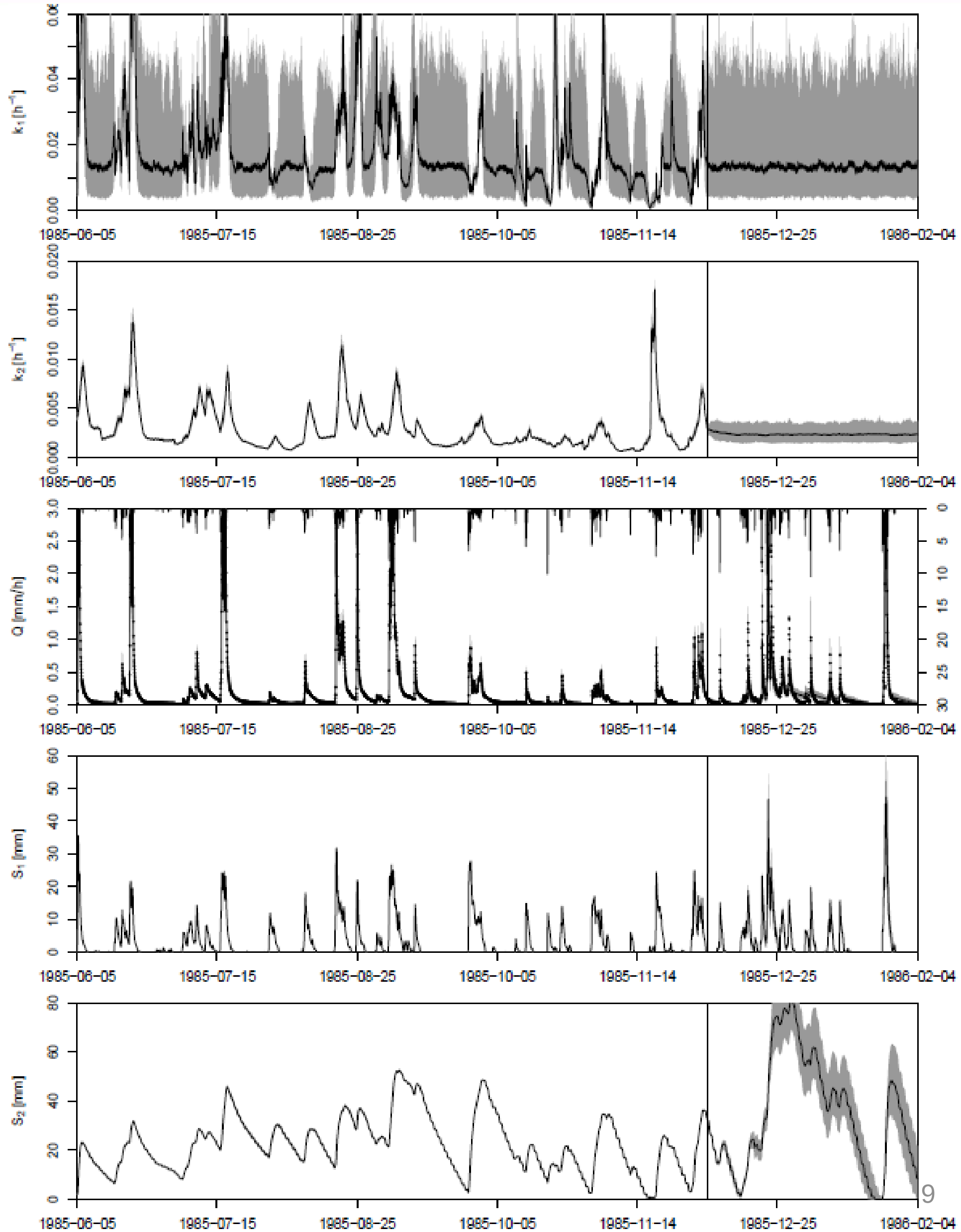
factor k_1

factor k_2

discharge

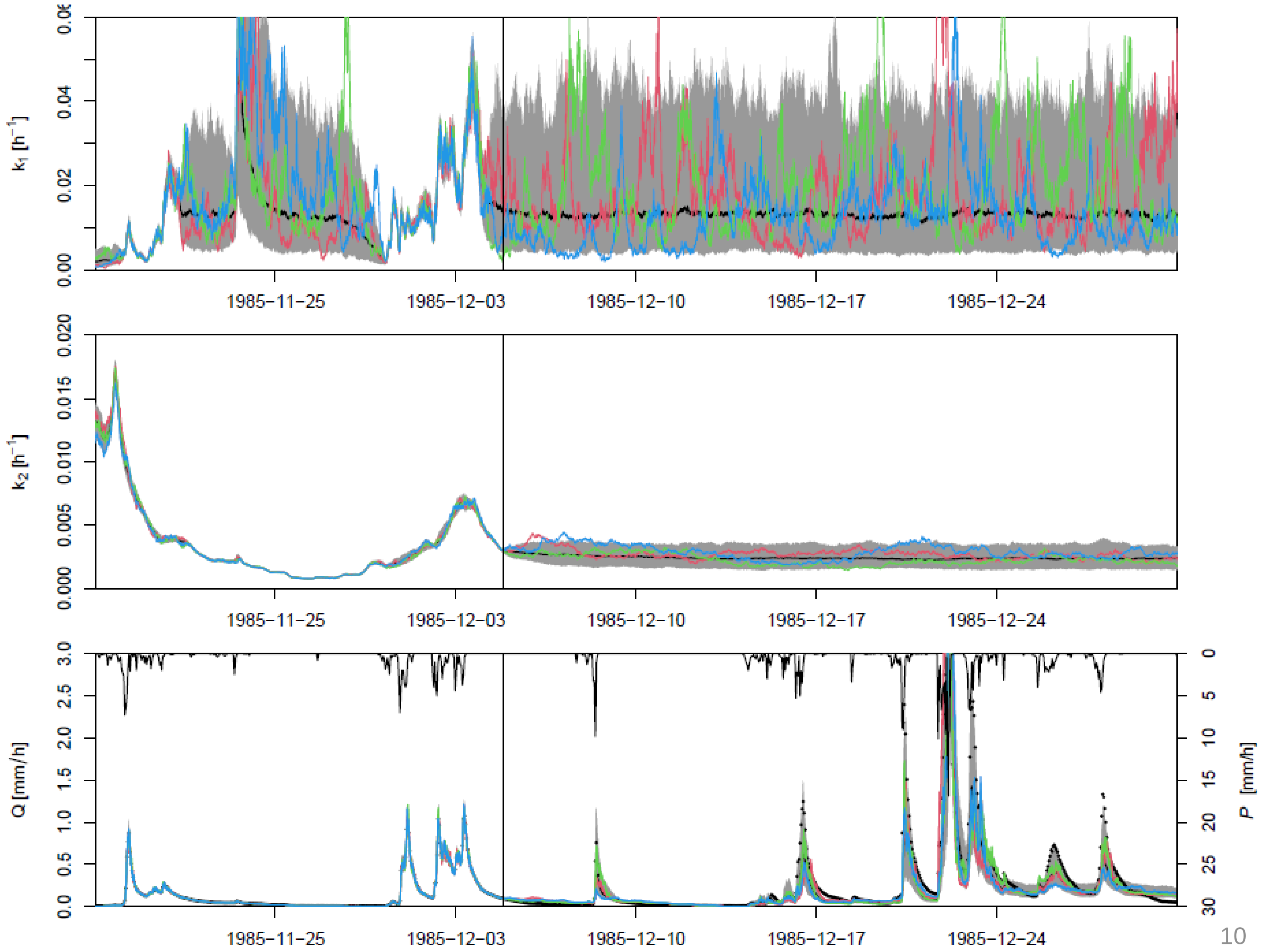
reservoir S_1

reservoir S_2

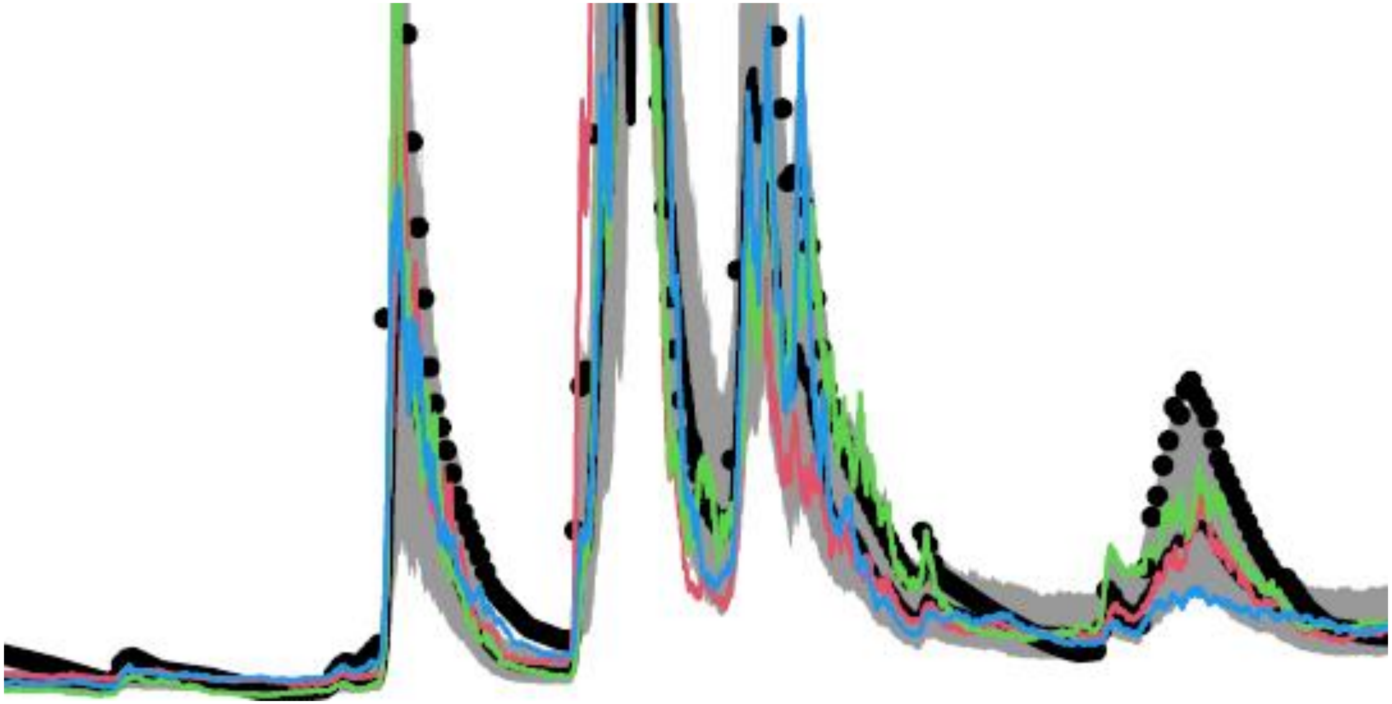


Case Study   Preliminary results, realizations

→ **Different fluctuation time scales for the two reservoirs**



Case Study Preliminary results



→ **Different fluctuation time scales for the outlets of the two reservoirs lead to different fluctuation time scales of dry and wet weather discharge** (see Ammann et al. 2019)

Conclusions

Opportunities

- Conceptually satisfying approach
- Correlated output errors naturally generated
- Uncertainty estimates in all model variables
- Output fluctuation time scale changes intrinsically

Challenges

- Identifiability – separate stochasticity from model deficits
- Convergence
- Computational demand

References

- Reichert, P., Amman, L and Fenicia, F.
  Potential and Challenges of Investigating Intrinsic Uncertainty of Hydrological Models with Stochastic, Time-Dependent Parameters.
  To be submitted in June 2020.
- Reichert, P., and Mieleitner, J.
  Analyzing input and structural uncertainty of nonlinear dynamic models with stochastic, time-dependent parameters.
  Water Resources Research, 45, W10402, 2009.
  https://doi.org/10.1029/2009WR007814
- Tomassini, L., Reichert, P., Künsch, H.-R. Buser, C., Knutti, R. and Borsuk, M.E.
  A smoothing algorithm for estimating stochastic, continuous-time model parameters and its application to a simple climate model.
  Journal of the Royal Statistical Society: Series C (Applied Statistics) 58, 679-704, 2009.
  https://doi.org/10.1111/j.1467-9876.2009.00678.x
- Ammann, L., Fenicia, F. and Reichert, P.
  A likelihood framework for deterministic hydrological models and the importance of non-stationary autocorrelation.
  Hydrology and Earth System Sciences, 23, 2147-2172, 2019.
  https://doi.org/10.5194/hess-23-2147-2019
- Reichert P., **R package `timedeppar`**, to be made available in June 2020