International Research Training Group „Integrated Hydrosystem Modelling“

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C2: Optimal Design of Monitoring in Coupled Hydrosystems

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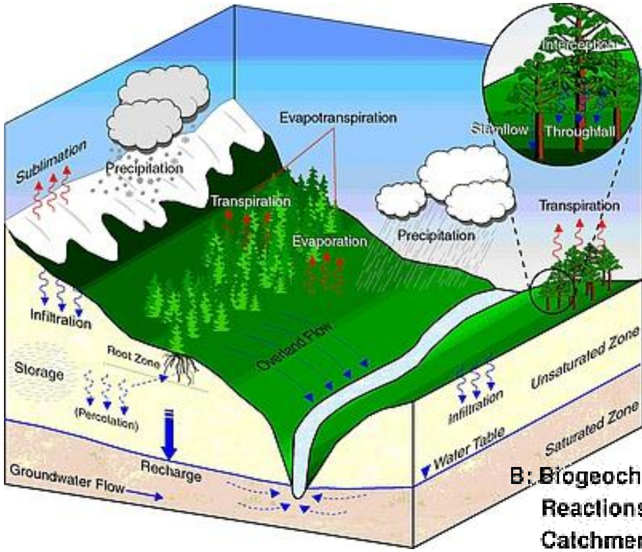
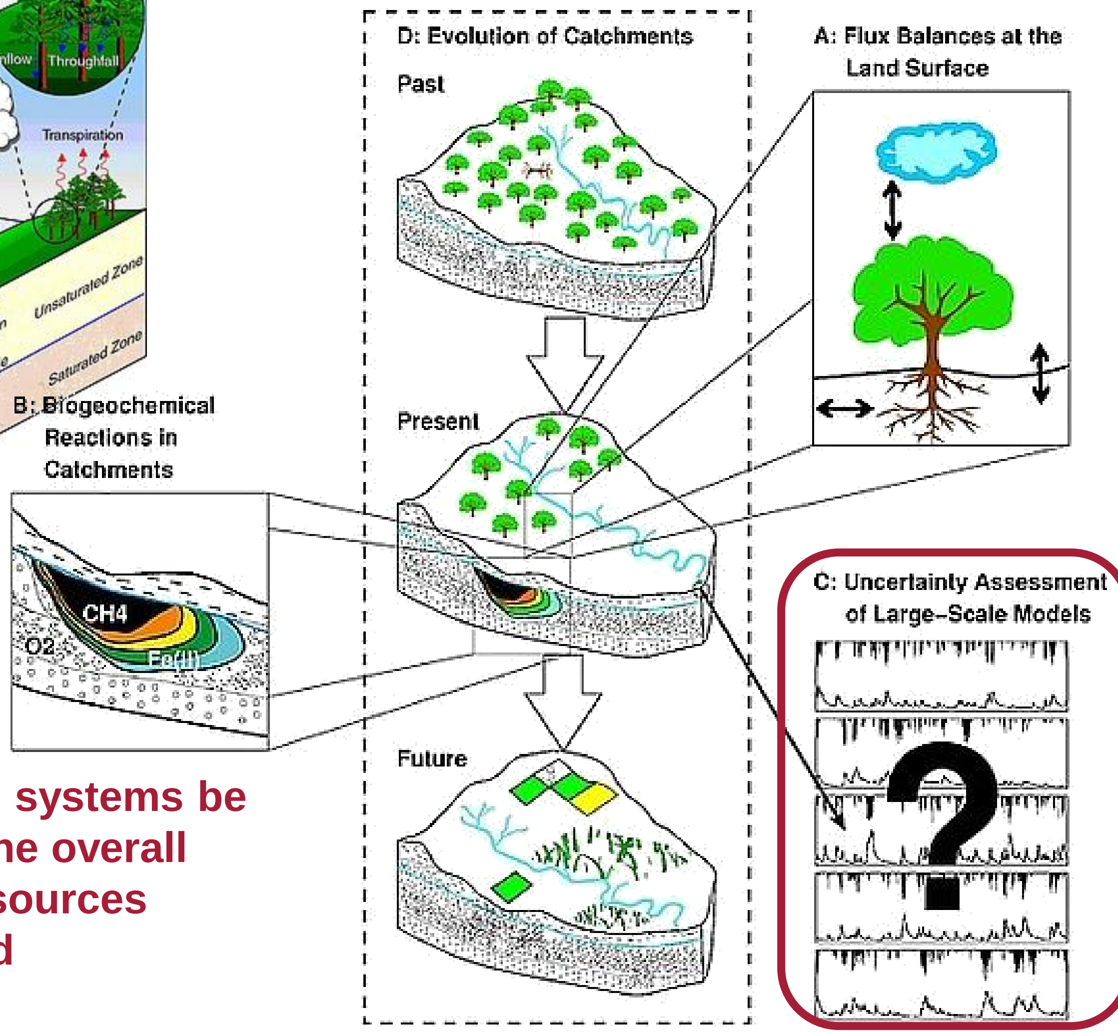
RESEARCH TOPIC WITHIN THE IRTG





How should monitoring systems be designed to minimise the overall uncertainty of water resources management in coupled hydrosystems?

Outline

- Previous work
- Uncertainty assessment in hydrogeological modelling
- Description of research topic
- Outlook

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- **Studies of environmental engineering**

  University of Stuttgart, supervisor: Wolfgang Nowak

  Focus on modelling of hydrosystems

  Diploma thesis „Parameter Estimation by Ensemble Kalman Filters with Transformed Data“

  Publication in WRR (A. Schöniger, W. Nowak, H.-J. Hendricks Franssen, 2012)

- **Internship**

  University of Calgary, supervisor: Edwin Cey

  Numerical modelling of macroporous flow

- **Work expericence at environmental consultancy**

  BoSS Consult GmbH, Stuttgart

  Numerical modelling of subsurface flow and transport processes

  Field investigations

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Sources of uncertainty

1) Model building

- Insufficient parameter identification (data scarcity, measurement error)
- Input/ output uncertainty (measurement error in forcings/ calibration data)
- Conceptual (structural) model uncertainty

Research Topic C1: Prioritizing uncertainty sources, quantification of parameter and input/ output uncertainty

→Remaining uncertainty due to choice of model structure

Sources of uncertainty

2) Model application (prediction)

- Parameter/ input/ output uncertainty
- Stochastic nature of future forcings (predictive uncertainty)
- Conceptual uncertainty

Research Topic C2: Accounting for conceptual uncertainty, usage of optimal design tools to reduce overall uncertainty

Choice of one “best” model is a strong assumption made by the modeller that leads to an underestimation of predictive uncertainty

→ Consider several plausible, competing conceptual models and select the best one on a more objective basis (**Model Selection**) or assign weights to all of them to obtain an averaged estimate (**Model Averaging**) and quantify structural uncertainty

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RESEARCH TOPIC

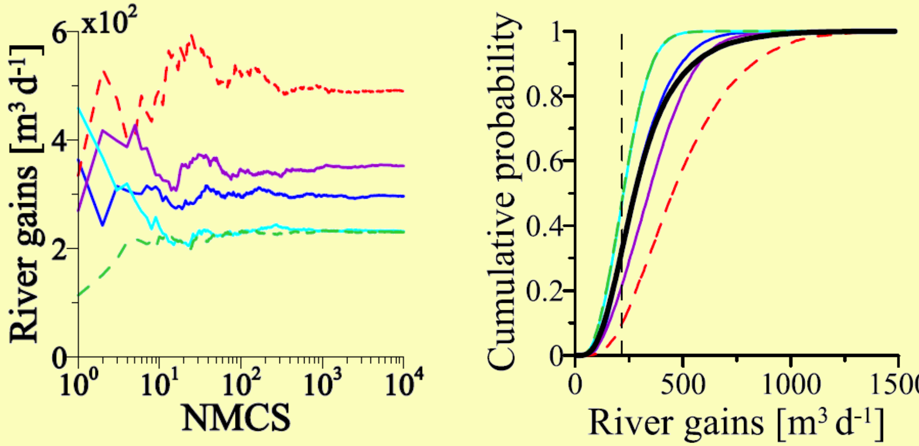
Bayesian Model Averaging (BMA)
Determine weighted pdf of predicted quantity and predictive uncertainty

Optimal Design of Monitoring (OD)
Develop sampling strategy for model selection that reduces overall uncertainty

Modelling of Large Coupled Hydrosystems

- Limited availability of measurements
- Multiple sources of uncertainty to be accounted for
- *Need for computationally efficient methods* → Use model selection techniques to cancel out unlikely models/ parameter realizations

Bayesian Model Averaging (BMA)



from Rojas et al., 2008

- Posterior distribution of quantity of interest Δ

$$p(\Delta|D) = \sum_{k=1}^{N_k} p(\Delta|D, M_k)p(M_k|D)$$

- Posterior probability for model M_k (model weights)

$$p(M_k|D) = \frac{p(D|M_k)p(M_k)}{\sum_{i=1}^{N_k} p(D|M_i)p(M_i)}$$

integrated likelihood

Bayesian Model Averaging (BMA)

- Posterior mean of Δ

$$E[\Delta|D] = \sum_{k=1}^{N_k} E[\Delta|D, M_k]\,p(M_k|D)$$

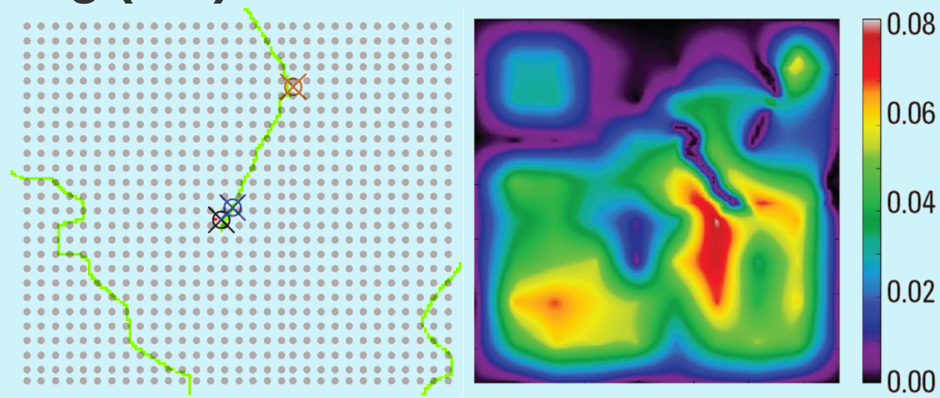
- Posterior variance of Δ

$$Var[\Delta|D] = \underbrace{\sum_{k=1}^{N_k} Var[\Delta|D, M_k]\,p(M_k|D)}_{\text{within-model variance}} + \underbrace{\sum_{k=1}^{N_k} \left(E[\Delta|D, M_k] - E[\Delta|D]\right)^2 p(M_k|D)}_{\text{between-model variance}}$$

within-model variance *between-model variance*

- *Evaluate significance of weights*

Optimal Design of Monitoring (OD)



Data worth, from USGS Scientific Investigations Report 2010–5159

Applications

- Evaluate existing monitoring networks
- Find optimal design to establish or extend a monitoring network (measurement locations, data types)

Objectives

- Determine the required complexity of the model(s)
- Reduce overall uncertainty of predictions to an acceptable/required level
- *Maximize confidence in the assigned weights*

Current work

- **Literature research and programming related to BMA**

“Which approach is suitable for which type of application?”
→ *Full BMA, Ensemble BMA, Maximum likelihood BMA, …*

“What are the differences in the assigned ranks/weights based on information criteria, what is their theoretical background, and what are the resulting implications for their use?”
→ *AIC(c), BIC, KIC, …*

“How can we evaluate the significance of the assigned weights?”
→ *Variance of weights under the influence of random measurement error, random parameter realizations, …*

Future work steps

- **Literature research and programming related to OD**

  "How should the objective function be formulated?"

  "How can we implement OD in an efficient but comprehensive manner?"

- **Application of the developed methods to test cases with increasing degree of complexity, performance assessment**

  Application-independent non-linear regression functions

  1D/2D synthetic or real-world examples for OD+BMA

  Full 3D coupled hydrosystem on catchment scale (Steinlach-Bogen test site near Tübingen)

References (Excerpt)

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Thank you – Do you have any questions?

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