HYACINTS Seminar, GEUS, 10 September 2009

Uncertainty in hydrological modelling – terminology, methodologies and HYACINTS' contribution

Jens Christian Refsgaard

Geological Survey of Denmark and Greenland (GEUS)

Coordinator of HYACINTS

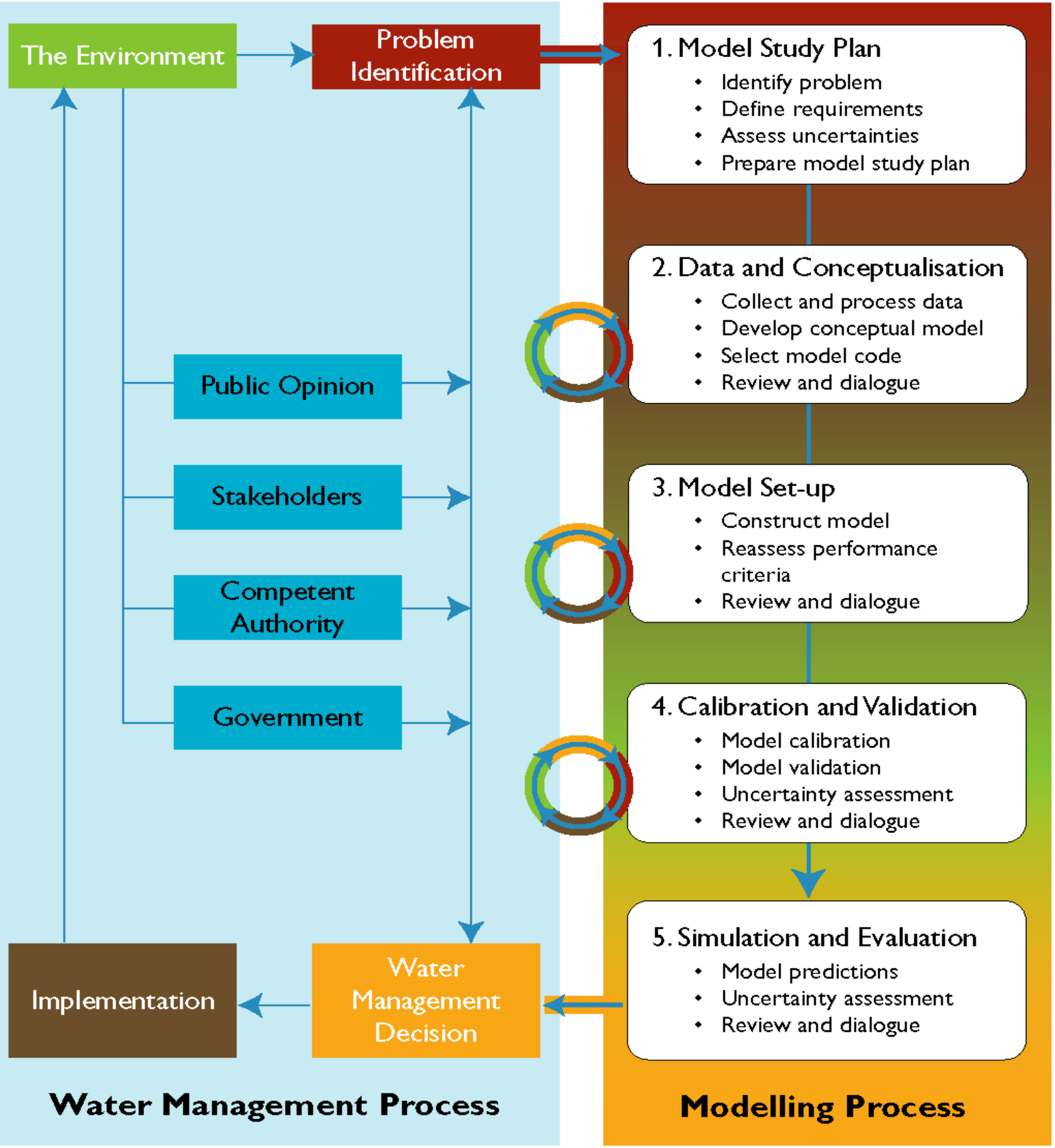
Outline

- **When** does uncertainty occur in the hydrological modelling process?
- **What** is uncertainty?
  - Definition
  - Characterisation of uncertainty
    - Type
    - Nature
    - Source
- **How** do we assess uncertainty - tools/methodologies?

- HYACINTS' contribution

The Water Management Process and the Hydrological Modelling Process

➔ **Uncertainty assessments influence throughout – not only in evaluating the final model simulations**



What is uncertainty – IPCC Glossary

(Bates et al., 2008, Climate change and Water. IPCC Technical Paper VI)

An expression of the degree to which a value (e.g., the future state of the *climate system*) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain *projections* of human behaviour. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgement of a team of experts.

- What is it?
- Where does it come from?
- How can it be characterised?

What is uncertainty?

- typical definition in water resources (Klauer and Brown, 2003)

Definition (Uncertainty): *A person is uncertain if s/he lacks confidence about the specific outcomes of an event. Reasons for this lack of confidence might include a judgement of the information as incomplete, blurred, inaccurate or potentially false.*

Uncertainty is a property (state of confidence) of the decision maker rather than a property (state of perfection) of the total body of available knowledge ➔ subjectivity is an important aspect of how we define uncertainty

Example: A person may be uncertain about the exact value of a river discharge value due to uncertainties related to instruments used for measurements, representativeness of measurements, method of transforming measurements (of often secondary variables) to discharge. Two different persons may have different perceptions of the magnitude of this uncertainty.

Types of uncertainty

Statistical uncertainty

- All outcomes known
- All probabilities known

Scenario uncertainty

- Range of outcomes of plausible futures (not all known)
- No probabilities known

Qualitative uncertainty

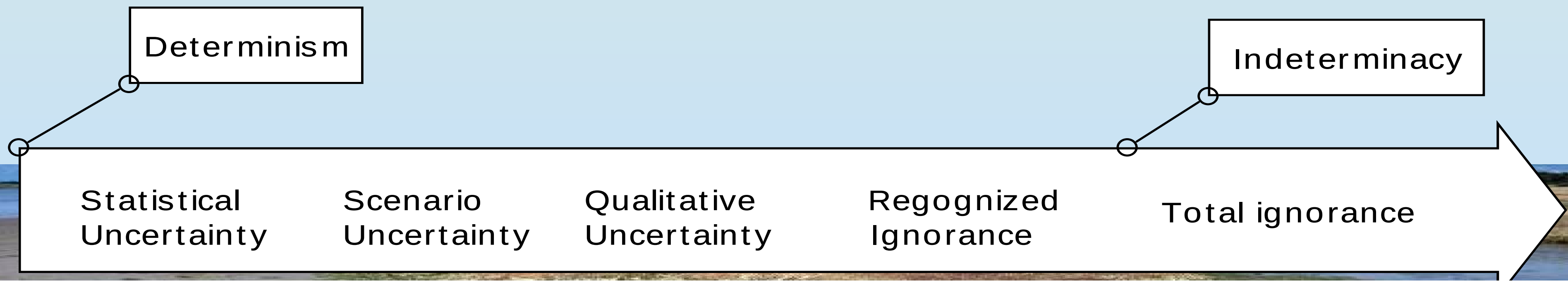
- Not all outcomes necessarily known
- Cannot be described statistically

Ignorance

- We are aware that there is something we do not know

Total ignorance

- We do not know that there is something we do not know



Nature of uncertainty

Epistemic uncertainty

- uncertainty due to imperfect knowledge

➔ *reducible by more data and knowledge*

Ontological uncertainty

(Other names: unpredictability, stochastic, variability uncertainty)

- uncertainty due to inherent variability, e.g. climate variability

➔ *non-reducible*

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Sources of uncertainty in Water Resources Management

Data
- physical, chemical, biological, etc.
- scale problems (temporal and spatial)

Model
- bugs in model code
- numerical solution (approximations)
- parameter values
- model structure (process equations, hydrogeological conceptual model)

Context – boundary conditions
- future climate
- legislation, regulatory conditions, etc.

Framing of problem
- ambiguity (multiple framing) among decision makers and stakeholders

Uncertainty Matrix
- Mapping of uncertainty characteristics

Source of uncertainty		Taxonomy (types of uncertainty)				Nature	
		Statistical uncertainty	Scenario uncertainty	Qualitative uncertainty	Ignorance	Epistemic uncertainty	Ontological uncertainty
Inputs	System data						
	Driving forces						
Model	Model structure						
	Technical						
	Parameters						
Context (boundary conditions)	Future climate						
	Regulatory conditions						
Framing	Ambiguity – multiple framing						

Adapted from Walker et al. (2003)

Uncertainty Matrix

- A dialogue platform for modeller, water manager and stakeholders to identify and characterise uncertainty as a basis for framing of the modelling study

Source of uncertainty	Type of uncertainty: Statistical uncertainty	Scenario uncertainty	Qualitative uncertainty	Recognised ignorance	Importance: Weight	(uncertainty x weight)
Problem context						
- future agritultural practise		medium	medium	medium	large	medium
- future climate		medium	medium	large	medium	medium
Input data						
- catchment data	medium			small	large	medium
- nitrate load from agriculture	small			small	large	small
Parameter uncertainty						
- water quantity	small			small	medium	small
- water quality	medium			medium	medium	small
Model structure (conceptual)						
- geology		large	large	medium	large	large
- nitrate reduction in underground		medium	medium	large	large	large
Model technical uncertainty						
- numerical approximation	small			small	medium	small
- bugs in software				medium	medium	small
					SUM:	

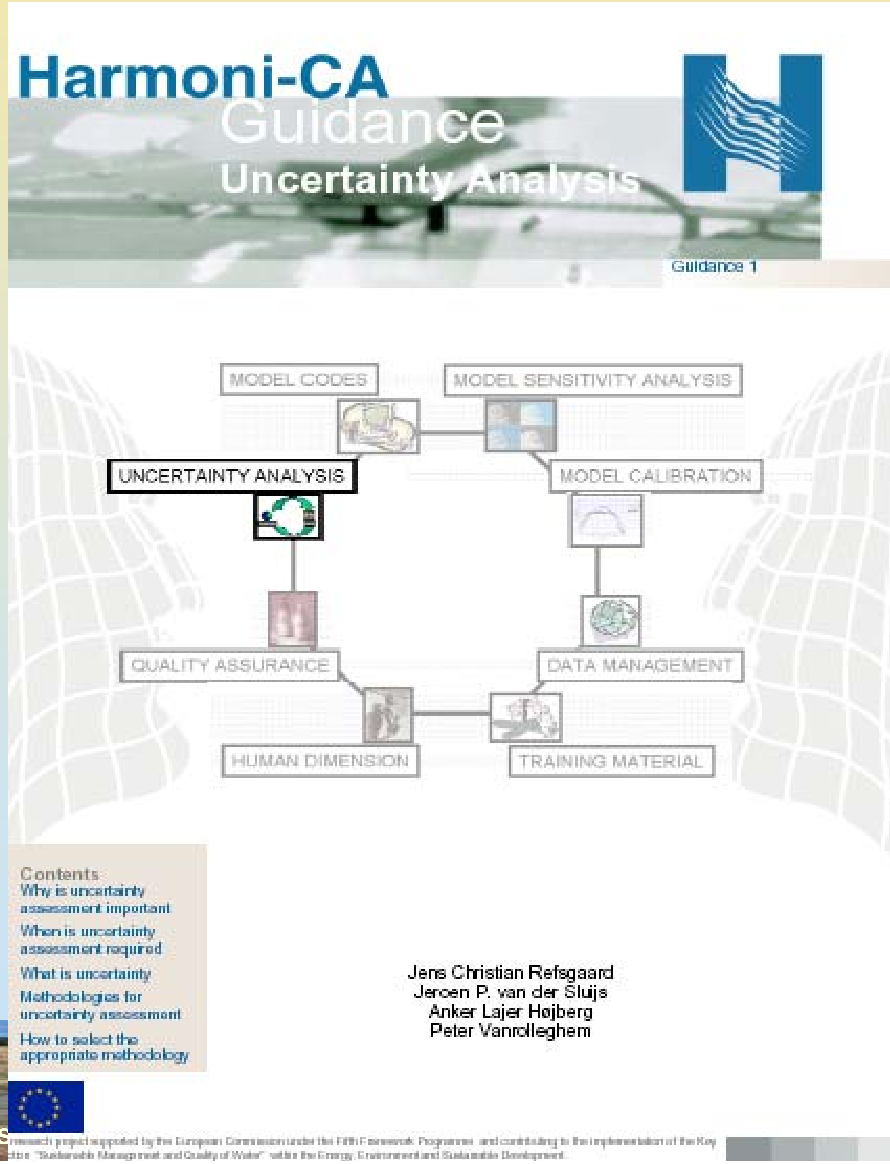
Methodologies for uncertainty assessment
- Numerous methods/tools and some guidances to identify appropriate tools

- Harmoni-CA Guidance 1 Uncertainty Analyses / Refsgaard et al. (2007) *Environmental Modelling and Software*
  - 14 groups of tools for quantitative, scenario and qualitative analyses.
- Matott et al. (2009) *Water Resources Research*
  - 65 tools for quantitative analyses
- Van der Keur et al. (submitted)
  - Overview over 22 different guidance documents providing guidance to select appropriate uncertainty assessment tools.

Methodologies for uncertainty assessment

- Selected methods described in Harmoni-CA Uncertainty Guidance Document

- Data Uncertainty
- Error Propagation Equations
- Expert Elicitation
- Extended Peer Review (review by stakeholders)
- Inverse modelling (parameter uncertainty)
- Inverse modelling (predictive uncertainty)
- Monte Carlo Analysis
- Multiple Model Simulation
- NUSAP
- Quality Assurance
- Scenario Analysis
- Sensitivity Analysis
- Stakeholder Involvement
- Uncertainty Matrix



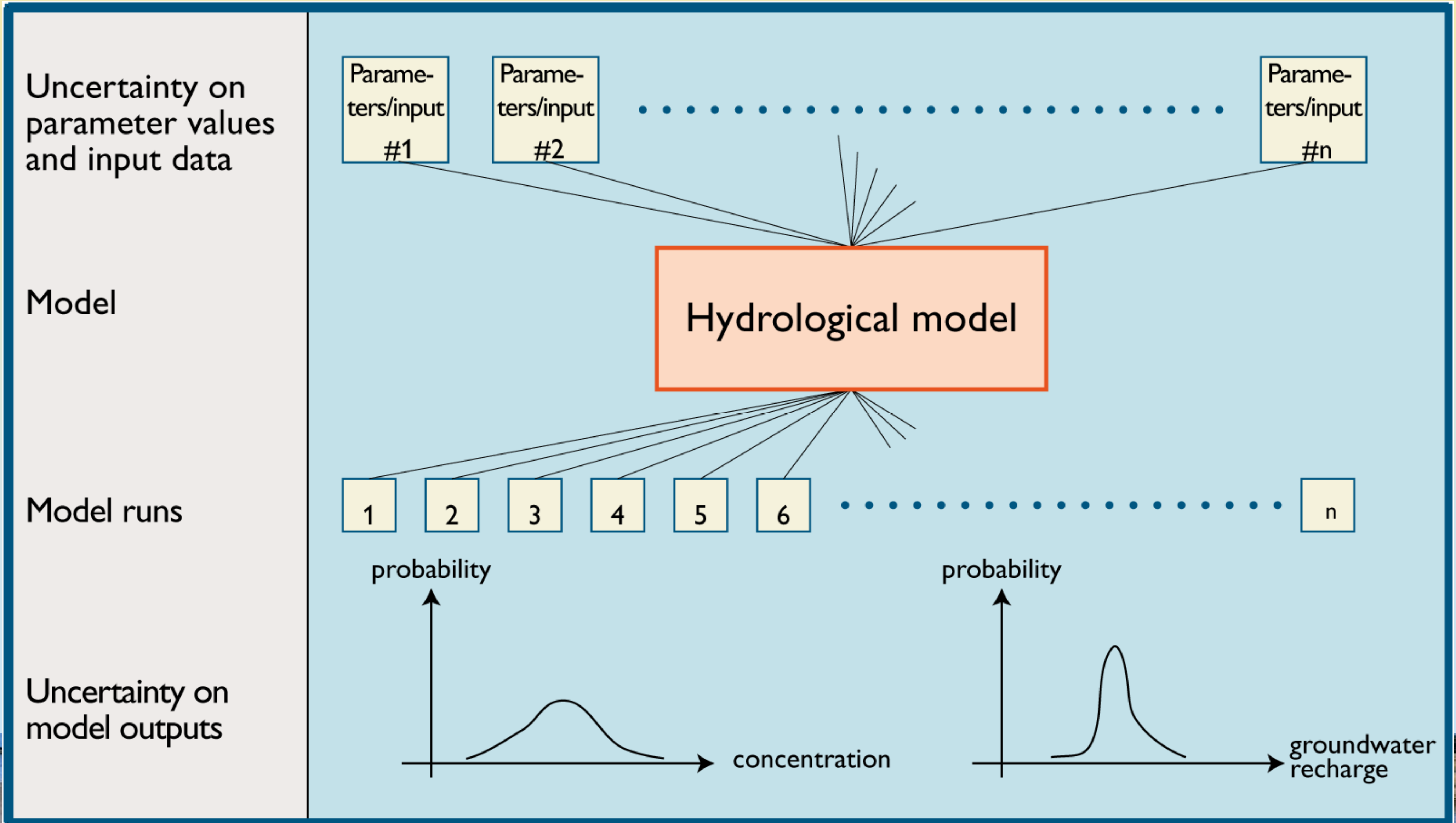
Suitable methods to deal with various types of uncertainty

Source of uncertainty		Taxonomy (types of uncertainty)			
		Statistical uncertainty	Scenario uncertainty	Qualitative uncertainty	Recognised ignorance
Context	Natural, technological, economic, social, political	EE	EE, SC, SI	EE, EPR, NUSAP, SI, UM	EE, EPR, NUSAP, SI, UM
Inputs	System data	DA, EPE, EE, QA	DA, EE, SC, QA	DA, EE	DA, EE
	Driving forces	DA, EPE, EE, QA	DA, EE, SC, QA	DA, EE, EPR	DA, EE, EPR
Model	Model structure	EE, MMS, QA	EE, MMS, SC, QA	EE, NUSAP, QA	EA, NUSAP, QA
	Technical				QA
	Parameters	IN-PA, QA	IN-PA, QA	QA	QA
Model outputs		EPE, EE, IN-UN, MCA, MMS, SA	EE, IN-UN, MMS, SA	EE, NUSAP	EE, NUSAP

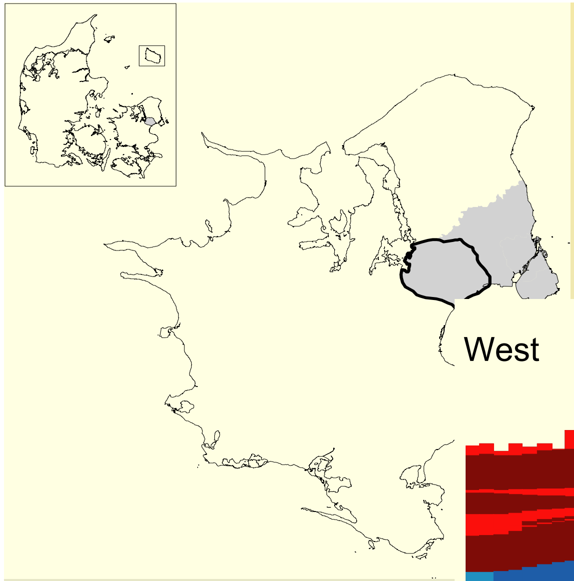
Abbreviations of methodologies:

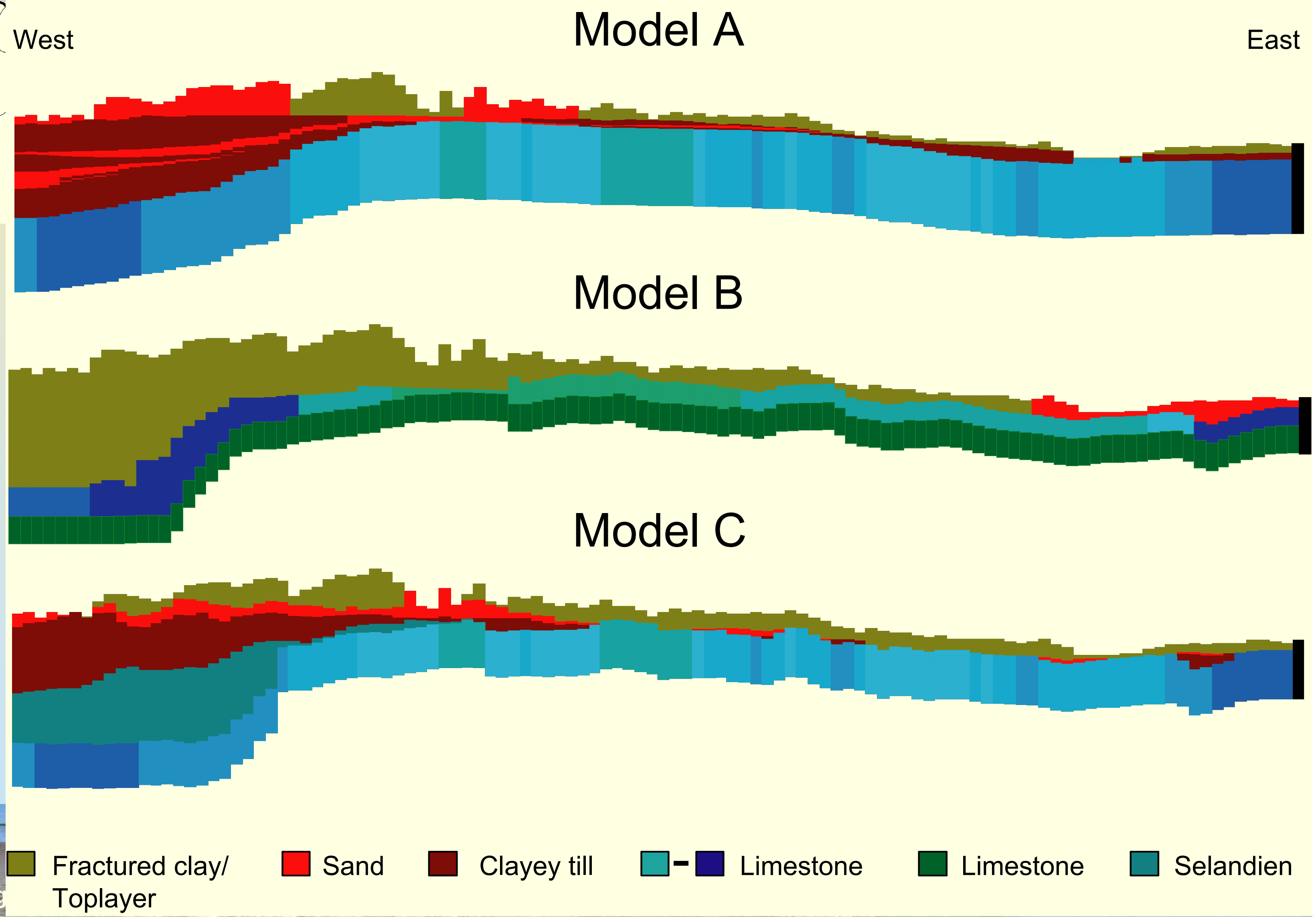
DA	Data Uncertainty	MMS	Multiple Model Simulation
EPE	Error Propagation Equations	NUSAP	NUSAP
EE	Expert Elicitation	QA	Quality Assurance
EPR	Extended Peer Review (review by stakeholders)	SC	Scenario Analysis
IN-PA	Inverse Modelling (parameter estimation)	SA	Sensitivity Analysis
IN-UN	Inverse Modelling (predictive uncertainty)	SI	Stakeholder Involvement
MCA	Monte Carlo Analysis	UM	Uncertainty Matrix

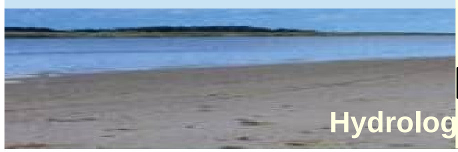
Monte Carlo Analysis



Multi-model simulation
(= Ensemble modelling)







NUSAP - Numerical, Unit, Spread, Assessment, Pedigree

- *Example for evaluating goodness of a conceptual model*

Score	Supporting empirical evidence		Theoretical understanding	Representation of understood underlying mechanisms	Plausibility	Colleague consensus
	Proxy	**Quality and quantity**				
4	Exact measures of the modelled quantities	Controlled experiments and large sample direct measurements	Well established theory	Model equations reflect high mechanistic process detail	Highly plausible	All but cranks
3	Good fits or measures of the modelled quantities	Historical/field data uncontrolled experiments small sample direct measurements	Accepted theory with partial nature (in view of the phenomenon it describes)	Model equations reflect acceptable mechanistic process detail	Reasonably plausible	All but rebels
2	Well correlated but not measuring the same thing	Modelled/derived data Indirect measurements	Accepted theory with partial nature and limited consensus on reliability	Aggregated parameterised meta model	Somewhat plausible	Competing schools
1	Weak correlation but commonalties in measure	Educated guesses indirect approx. rule of thumb estimate	Preliminary theory	Grey box model	Not very plausible	Embryonic field
0	Not correlated and not clearly related	Crude speculation	Crude speculation	Black box model	Not at all plausible	No opinion

Example from Refsgaard et al (2006)

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Hydrological Modelling for Assessing Climate Change Impacts at Different Scales

Coordinator: Jens Christian Refsgaard, GEUS

Objective

- To develop improved tools and methodologies for assessing the effect of climate change on water resources at both regional and local scales
  - Higher precision
  - Quantification of uncertainty

Funding

- The Strategic Research Council: 15 million DKK (2 M€)
- Self financing by partners: 10 million DKK

2008 – 2012

5 PhDs and 3 Post Docs

Partners

- Geological Survey of Denmark and Greenland (GEUS)
- Danish Meteorological Institute (DMI)
- Department of Geography and Geology, University of Copenhagen
- Geological Institute, University of Aarhus
- DHI
- Geographic Resource Analysis & Science A/S (GRAS)
- ALECTIA Aqua A/S
- Odense Water Ltd
- Copenhagen Energy
- Århus Water & Wastewater
- Environment Centre Odense
- Environment Centre Roskilde

- Associated SME project/partner: I-GIS

Work packages

WP1: Coupling of HIRHAM and MIKE SHE model codes

WP3: Hydrological change

WP2: Scaling of hydrological models

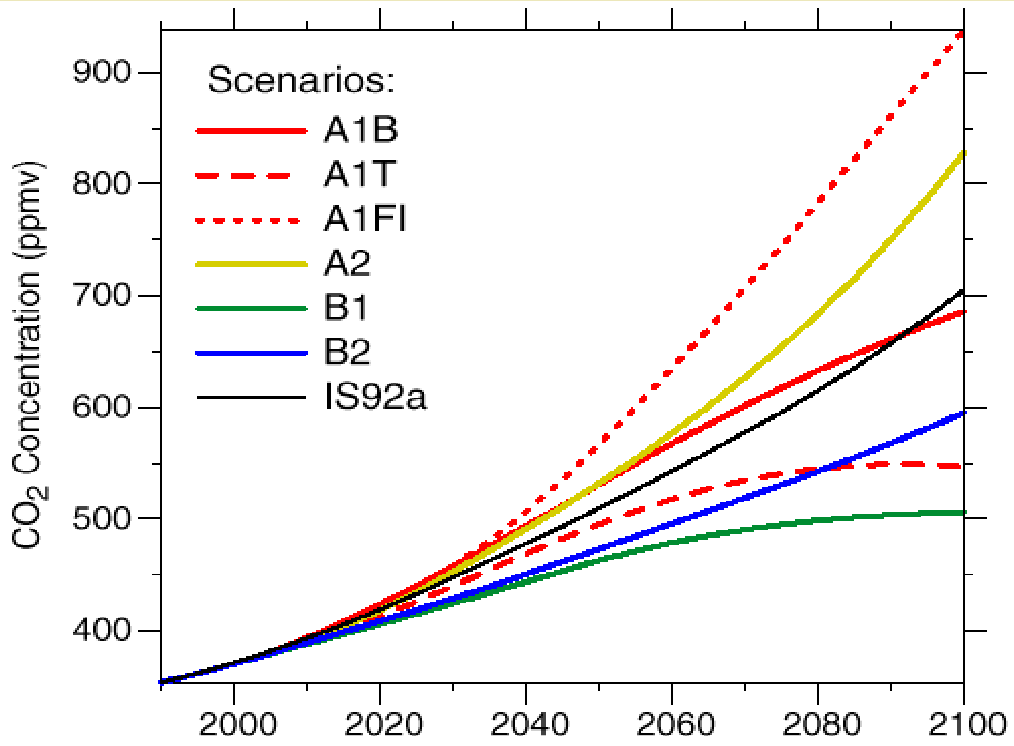
WP4: Uncertainty

- **Objective: To assess the uncertainties related to prediction of climate change impacts**

Assessment of uncertainty on hydrological change

- chain of uncertainties

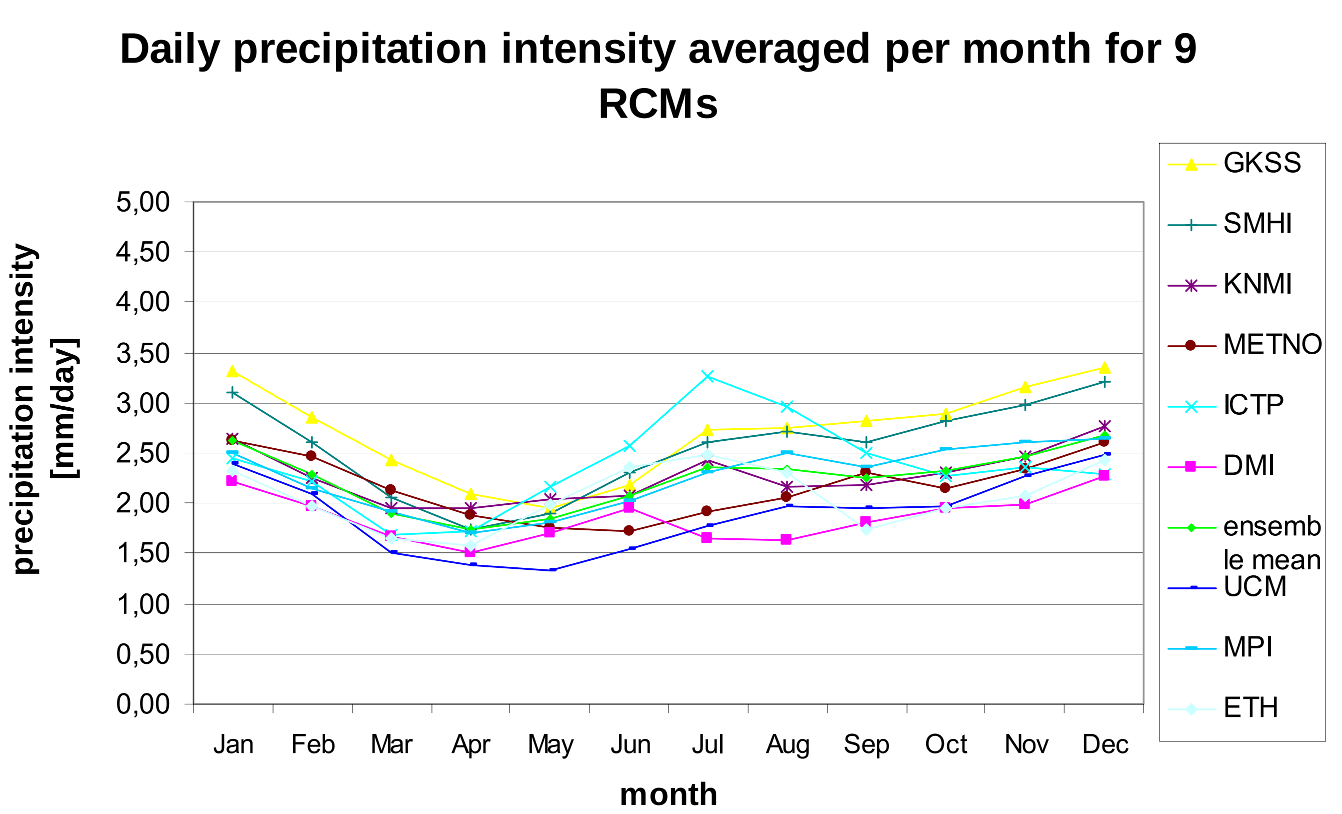
- Emission scenarios



Assessment of uncertainty on hydrological change

- chain of uncertainties

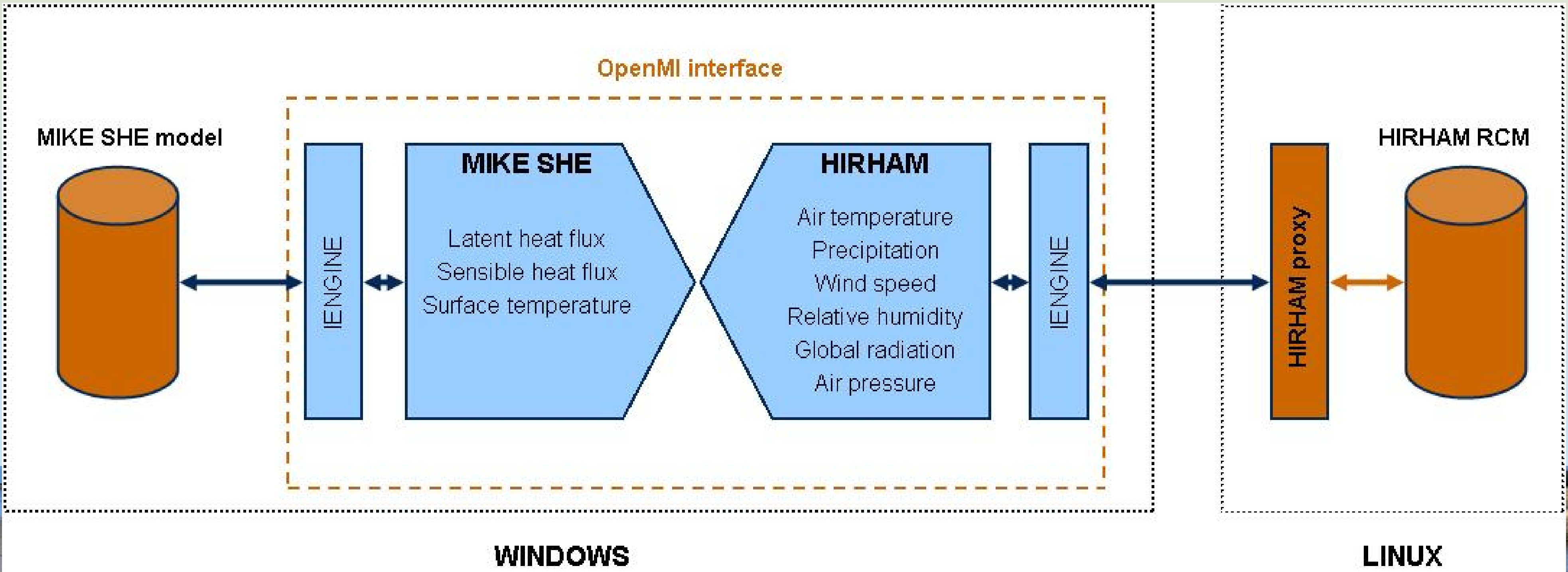
- Emission scenarios
- Climate modelling
  - GCM
  - RCM
  - Further downscaling/bias correction

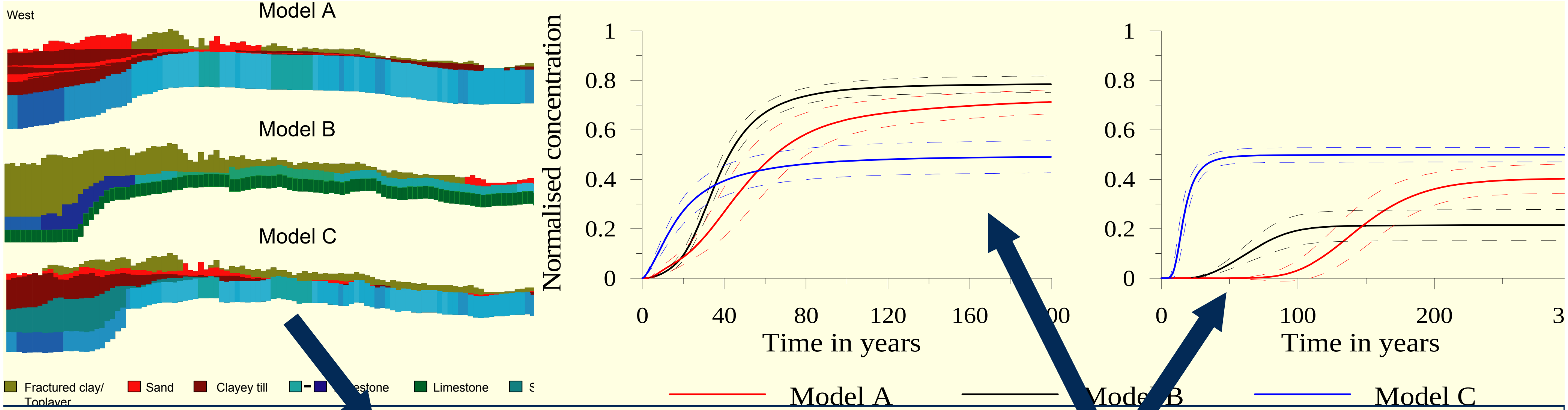


Assessment of uncertainty on hydrological change

- chain of uncertainties

- Emission scenarios
- Climate modelling
  - GCM
  - RCM
  - Further downscaling/bias correction
- Feedback atmosphere ↔ land surface processes





Three different geological interpretations

Three groundwater models' predictions of groundwater age at abstraction wells

- Hydrological model
  - Geological model
  - Hydrological process descriptions
  - Model parameter values
  - Downscaling/Local grid refinement
  - Local scale parameter variability
  - Model code
  - Input data (e.g. river geometry, water abstraction, land use)

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Assessment of uncertainty on hydrological change

- chain of uncertainties

- Emission scenarios
- Climate modelling
  - GCM
  - RCM
  - Further downscaling/bias correction
- Feedback atmosphere ↔ land surface processes
- Hydrological model
  - Geological model
  - Hydrological process descriptions
  - Model parameter values
  - Downscaling/Local grid refinement
  - Local scale parameter variability
  - Model code
  - Input data (e.g. river geometry, water abstraction, land use)
- Future water management (e.g. land use, water use)

Conclusions

Uncertainty in hydrological modelling

- Uncertainty assessment should influence the entire project approach right from the beginning – and not only after the modelling studies
- All sources and types of uncertainty should be considered in decision making – not only statistical uncertainty
- A large range of suitable methodologies exist

HYACINTS' contribution related to the chain of uncertainties on hydrological change

- Uncertainties due to climate models
- Land surface↔atmosphere feedback processes
- Downscaling of climate and hydrological models
- Geological uncertainty

Further information

www.hyacints.dk

Uncertainty guidance

- Harmoni-CA Guidance Uncertainty Analysis http://www.harmoni-ca.info/toolbox/docs/Harmoni-ca_Guidance_1_Uncertainty_Analysis.pdf

- Højberg AL, Refsgaard JC (2005) Metoder til usikkerhedsvurdering. Kapitel 19 i “Sonnenborg og Henriksen (red) Håndbog I grundvandsmodellering”, GEUS Rapport 80/2005. www.vandmodel.dk

- Refsgaard JC, van der Sluijs JP, Højberg AL, Vanrolleghem PA (2007) Uncertainty in the environmental modelling process – A framework and guidance. Environmental Modelling & Software, 22, 1543-1556. http://dx.doi.org/10.1016/j.envsoft.2007.02.004

- van der Keur P, Henriksen HJ, Refsgaard JC, Brugnach M, Pahl-Wostl C, DeWulf A, Buiteveld H (2008) Identification of major sources of uncertainty in current IWRM practice. Illustrated for the Rhine basin. Water Resources Management, 22, 1677-1708. http://dx.doi.org/10.1007/s11269-008-9248-6