Eawag –
Swiss Federal Institute of Aquatic
Science and Technology

Joint data assimilation and parameter calibration in real-time groundwater modelling using nested particle filters

Maximilian Ramgraber[1,2], Mario Schirmer[1,2]
[1] Department Water Resources & Drinking Water, Swiss Federal Institute of Aquatic Science and Technology (Eawag), Switzerland
[2] Centre d'hydrogéologie et de géothermie (CHYM), University of Neuchâtel, Switzerland

Inspiration

MARIE CURIE ACTIONS

A Introduction

Motivation:
- groundwater modelling is notoriously limited by availability of geological data

Classic approach:
- inverse parameter estimation with batch of available data

Problem:
- computational effort: with new data, lengthy recalibration is required

Alternative:
- sequential (real-time) calibration

B State of the Art: EnKF

The **ensemble Kalman filter** (EnKF) solves Bayesian inference in a special case. For calibration:

Required assumptions:
- Gaussian distributions
- linear model dynamic
- states and parameters are jointly Gaussian

Issue 1:
Hydrogeology: assumptions not met
→ stochastic significance lost

Issue 2:
Calibration is Gaussian
→ too simple to preserve geology

Issue 3:
Joint Gaussianity
→ parameters **implictly** time-varying

C Proposed approach

Employ **particle filters,** a general solution to Bayesian inference requiring fewer assumptions than the EnKF:

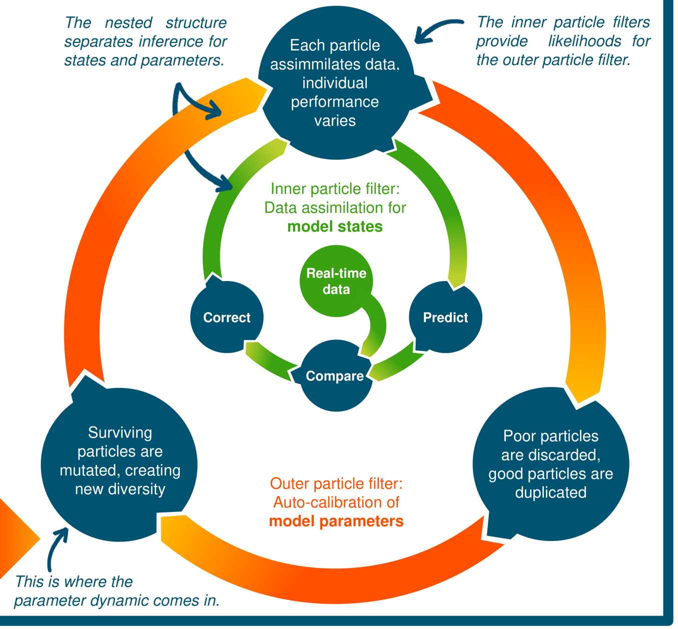
Issue partially persists
Curse of dimensionality
→ stochastic significance questionable

Introducing an ***artificial parameter dynamic*** *can preserve geology*

Issue persists
Artificial parameter dynamic (kernel)
→ parameters **explicitly** time-varying

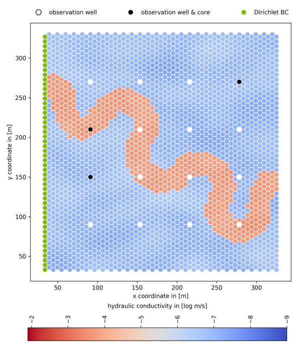
Assumption of time-varying parameters does not entail major errors in dissipative settings, which tend to 'forget' their history.

How do nested particle filters work?



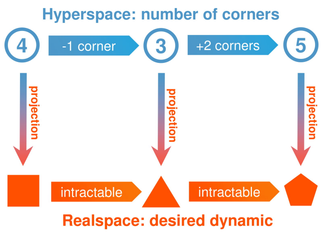
Model setup

Synthetic reality:
- 2-D aquifer
- 1 m fixed head western boundary
- sinusoidal recharge
- 16 observation wells (obs. error 2 cm)
- 2850 hexagonal cells
- implemented in MODFLOW USG
- geology: highly conductive meander
- facies type known at three wells
- boundary conditions assumed known

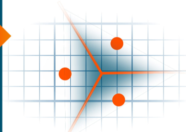


D Artificial parameter dynamic

Key ideas:
- **hyper(parameter)space**: describe desired geology via hyperparameters
- hyperspace can be projected into parameter space
- applying dynamic in hyperspace preserves geological patterns
- curse of dimensionality alleviated in lower-dimensional hyperspace

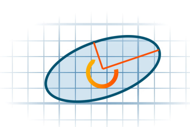


E Results from different hyperparameter kernels



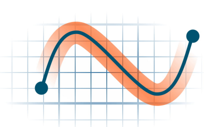
Node-based
- ~50 nodes
- projection via inverse distance weighting

Hyperparameters:
- number of nodes
- node positions and values



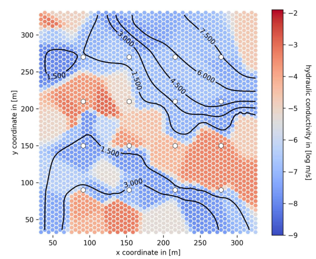
Lens-based
- ~12 elliptic lenses
- projection via structure mapping

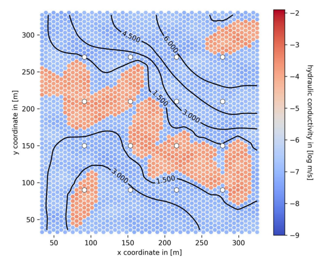
Hyperparameters:
- number of lenses
- lens geometries (rotation, size, aspect)
- facies maps (hydraulic conductivities. anisotropy misspecified)

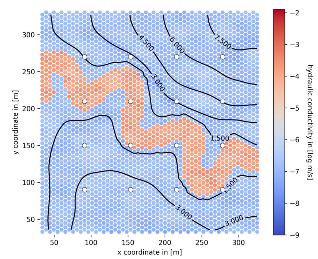


Meander-based
- one meander
- projection via structure mapping

Hyperparameters:
- meander geometry (number of turns, start & end, meander & channel width)
- facies maps (hydraulic conductivities. anisotropy misspecified)

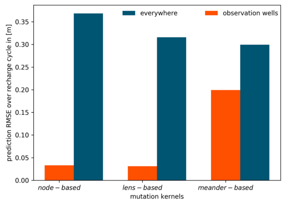






F Discussion

Discussion:
- **promising performance** of parameter estimation for **node-** and **lens-based** kernels
- **high RMSE** of **meander-based kernel:**
  - Facies map anisotropy was deliberately misspecified
  - lens-based kernel compensates via off-meander lens placement



Outlook:
- **model self-diagnosis:** Investigate parameter surrogacy to identify structural errors
- **complex hyperspace kernels:** Investigate possibility for calibrating more detailed geological structures

Augmented reality
Watch the algorithm in action

AR instructions
Scan any of the QR codes in section (E), allow camera access, focus this marker, tap screen to play video.

Contact:
Mail: max.ramgraber@eawag.ch
Phone: +41 78 692 83 99

vCard

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