Eawag –
Swiss Federal Institute of Aquatic
Science and Technology

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

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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:

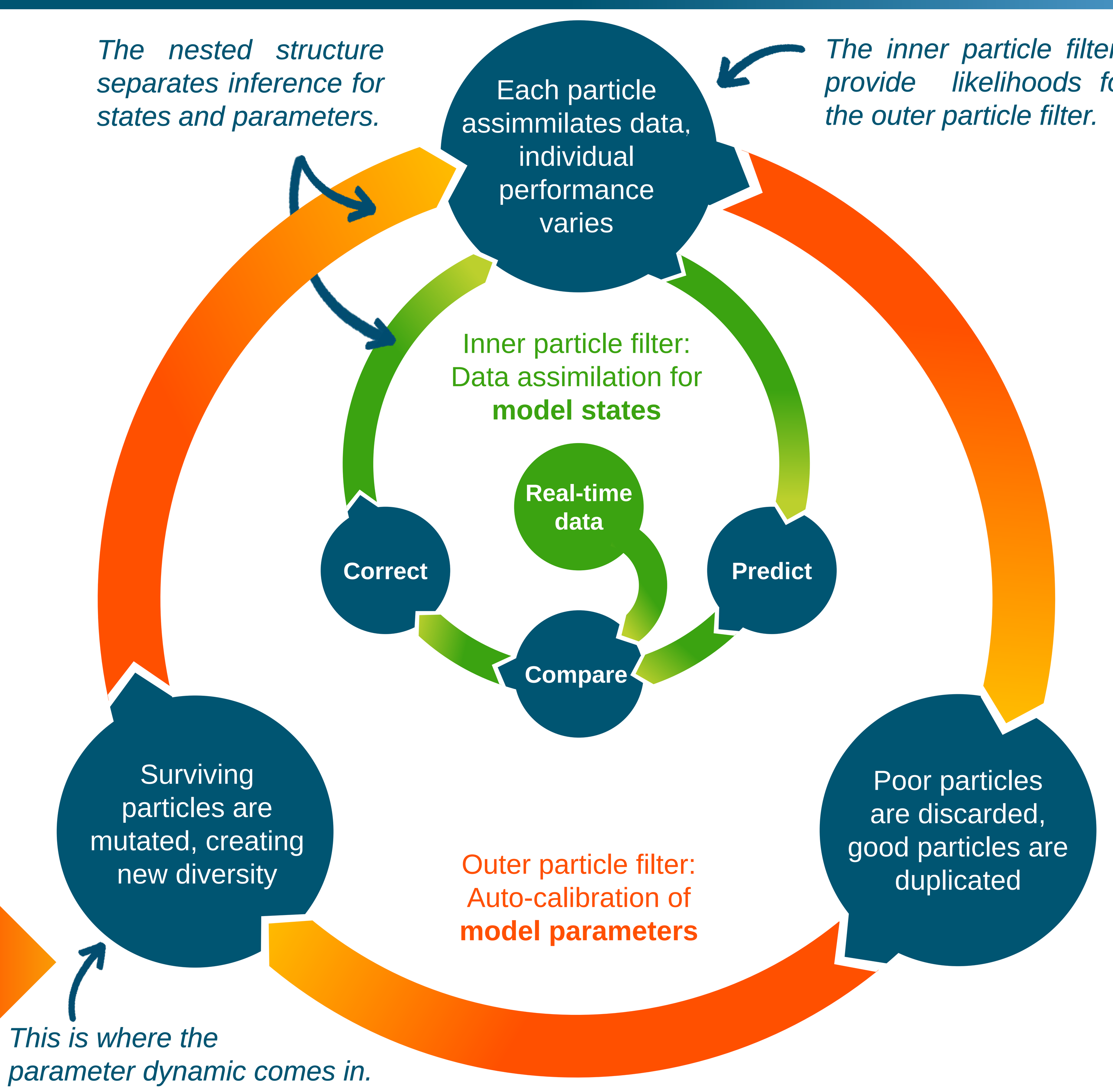
Issue partially persists
Curse of dimensionality
→ stochastic significance questionable

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

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

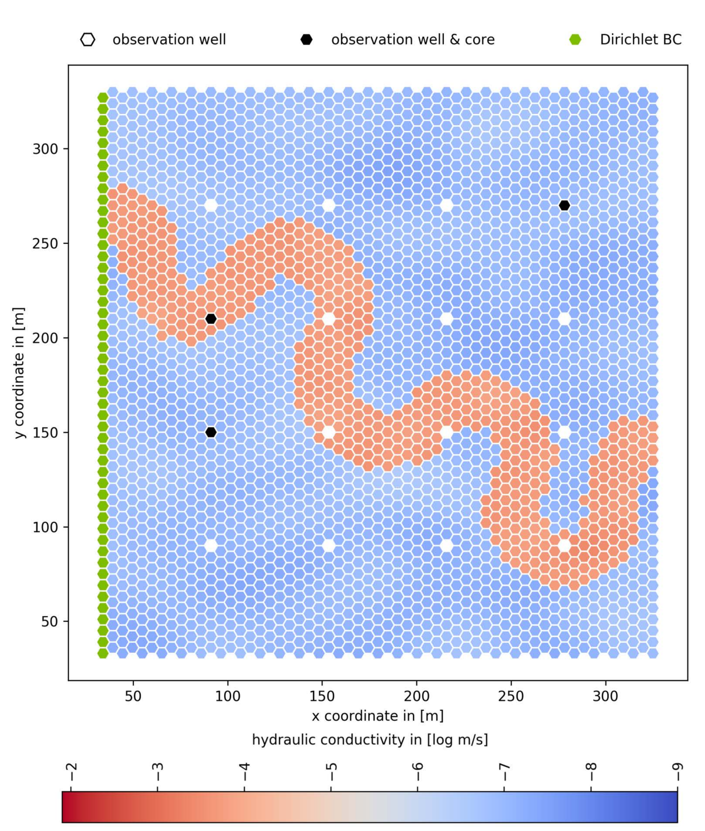
Assumption of time-varying parameters does not entail major errors in dissipative settings, which tend to 'forget' their history.

How do nested particle filters work?



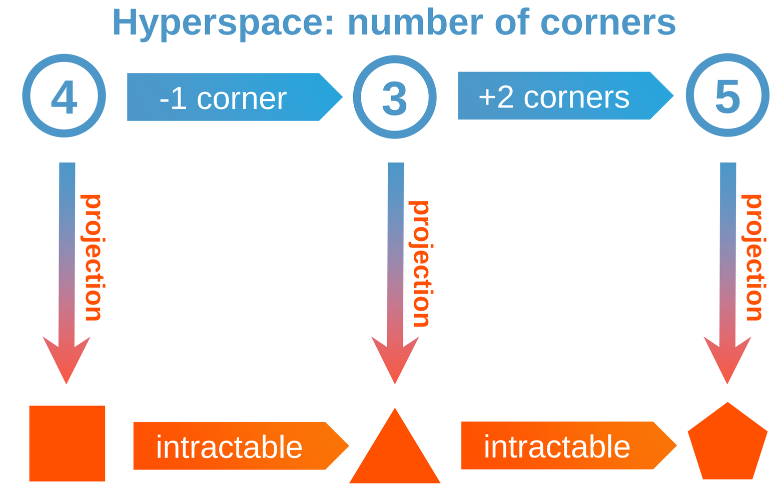
Model setup

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

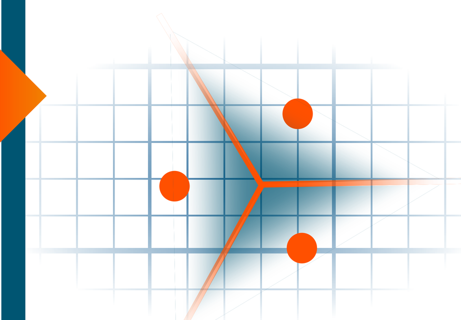


D Artificial parameter dynamic

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

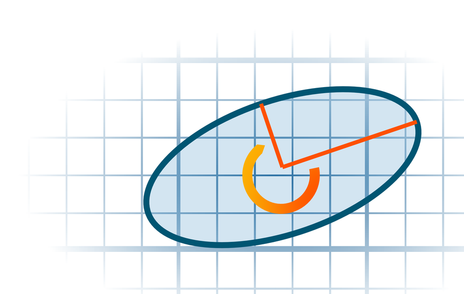


E Results from different hyperparameter kernels



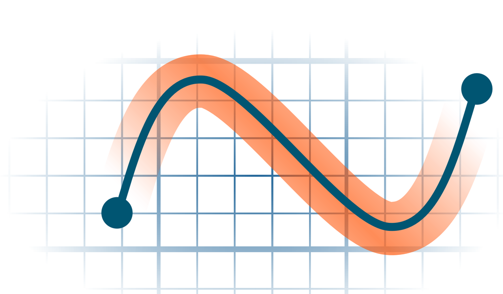
Node-based
- ~50 nodes
- projection via inverse distance weighting

Hyperparameters:
- number of nodes
- node positions and values



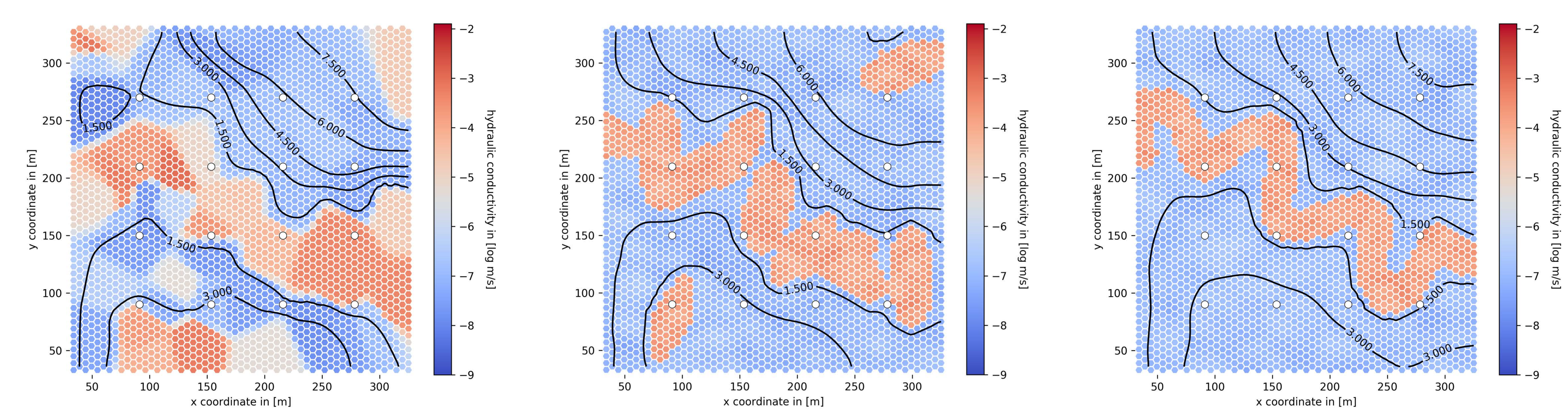
Lens-based
- ~12 elliptic lenses
- projection via structure mapping

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



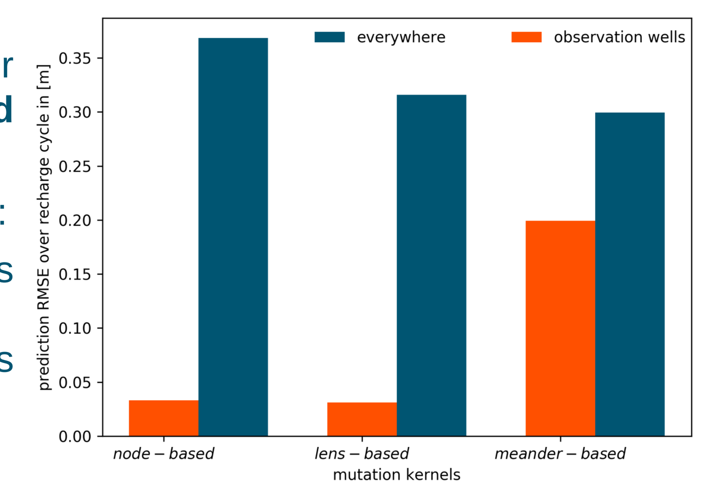
Meander-based
- one meander
- projection via structure mapping

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



Augmented reality
Watch the algorithm in action

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

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

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