

# 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 **implicitly** time-varying

## C Proposed approach

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

**Issue partially persists**

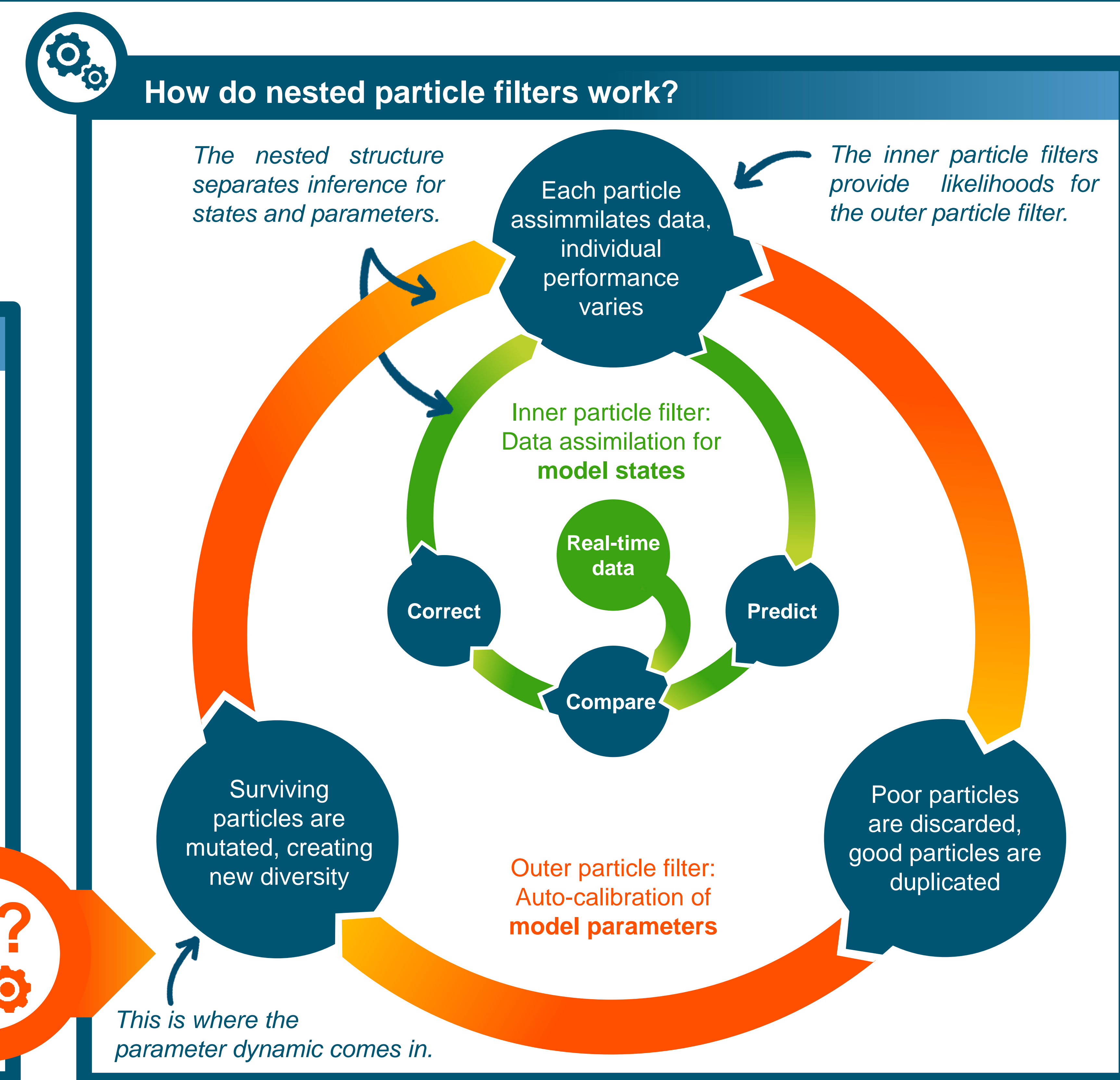
Curse of dimensionality → stochastic significance questionable

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

**Issue persists**

Artificial parameter dynamic → parameters **explicitly** time-varying

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



## D 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

## E 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

**Hyperspace: number of corners**

4 → -1 corner → 3 → +2 corners → 5

**projection**

**intractable**

**Realspace: desired dynamic**

## F Results: different hyperparametrizations

**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)

## G 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.

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