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

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Abstract:

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

- Gaussian distributions
- linear model dynamic
- states and parameters are jointly Gaussian

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

Issue 2: Calibration marker is Gaussian
- too simple to preserve geology

Issue 3: Joint Gaussianity
- parameters implicitly time-varying

Required assumptions:

- Curse of dimensionality alleviated
- applying dynamic in hyperspace
- hyperspace can be projected into hyper(parameter)space

Alternative inverse parameter estimation with:

Classic approach:

- groundwater modelling is notoriously limited by availability of geological data
- lengthy recalibration is required

Motivation:

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

Model setup:

- 2-D aquifer
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Artificial parameter dynamic:

- hyperparameters 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

Issue persists:

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

Issue partially persists:

- Curse of dimensionality
- stochastic significance questionable

Issue 1:

- too simple to preserve geology

Issue 2:

- stochastic significance lost

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

Node-based:
- ~50 nodes
- projection via inverse distance weighting
- number of nodes
- node positions and values

Lens-based:
- ~12 elliptic lenses
- projection via structure mapping
- number of lenses
- lens geometries (rotation, size, aspect)

Meander-based:
- one meander
- projection via structure mapping
- meander geometry (number of turns, start & end, meander & channel width)
- facies maps (hydrologic conductivities, anisotropy misspecified)

Results: different hyperparametrizations

Outlook:

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

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