History Matching Channelized Reservoirs Using the Ensemble Kalman Filter

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Outline

- Estimating facies using EnKF and distance functions
- Example 1
- Example 2
- Summary

Distance functions

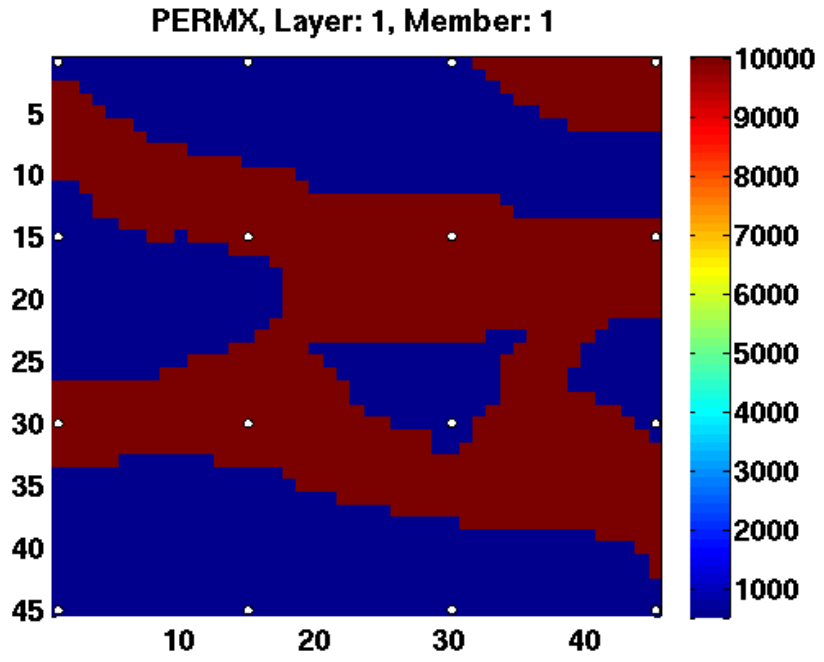
EnKF is applied to signed distances, defined by the shortest distance between a given position and the boundary separating facies types.

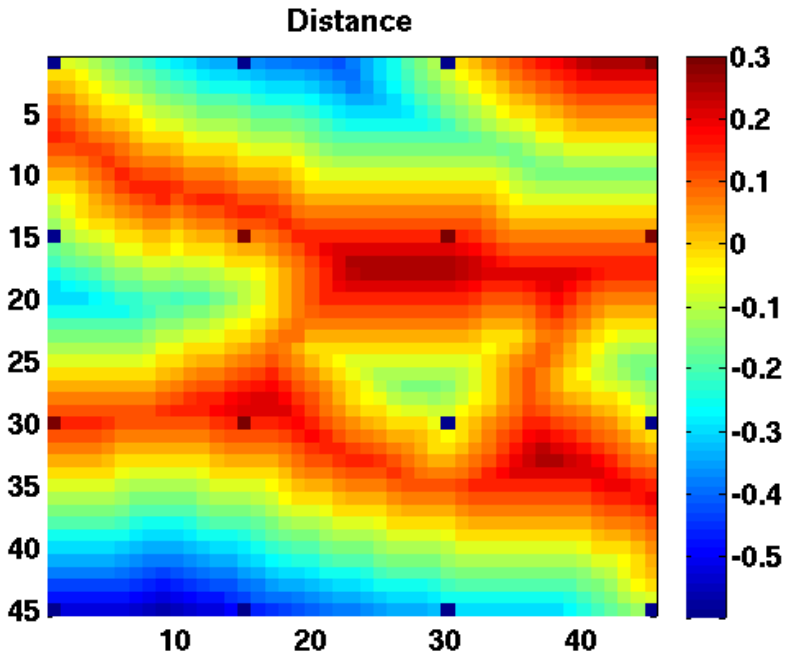
Motivated by the work by Moreno et al. [1].

Given an initial level set function, ϕ_0, distances are calculated by evolving the following PDE to steady state (reinitialization equation):

$$\phi_t + \text{sign}(\phi_0)(\|\nabla\phi\| - 1) = 0.$$

Distance field

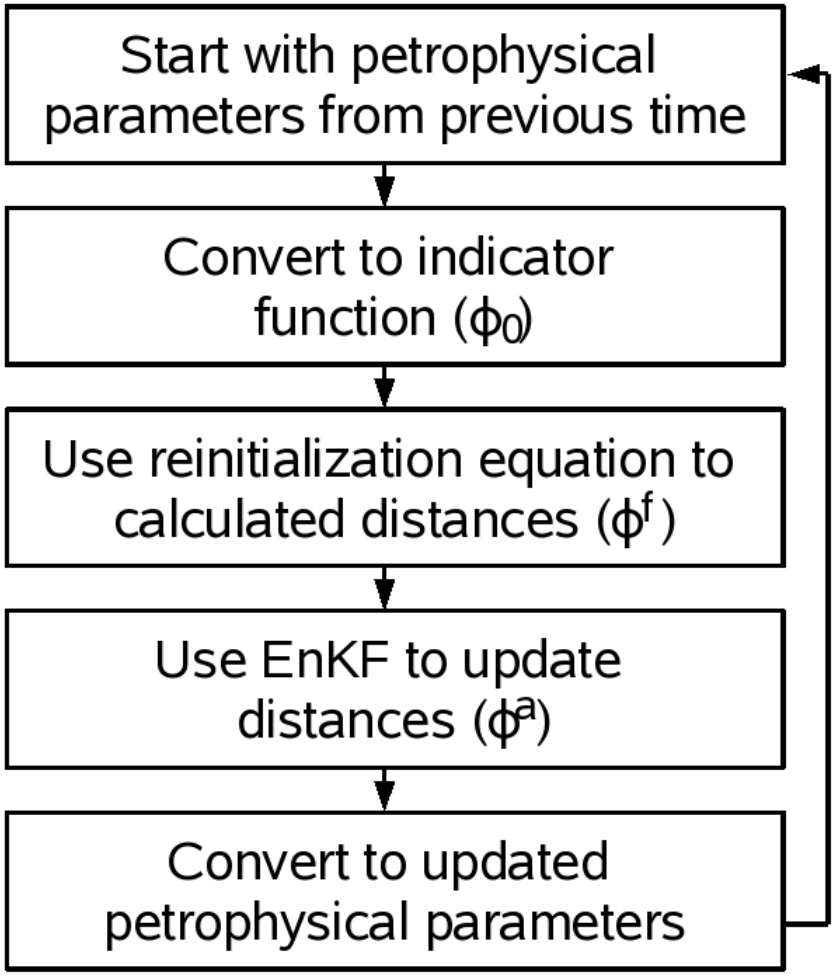




Features

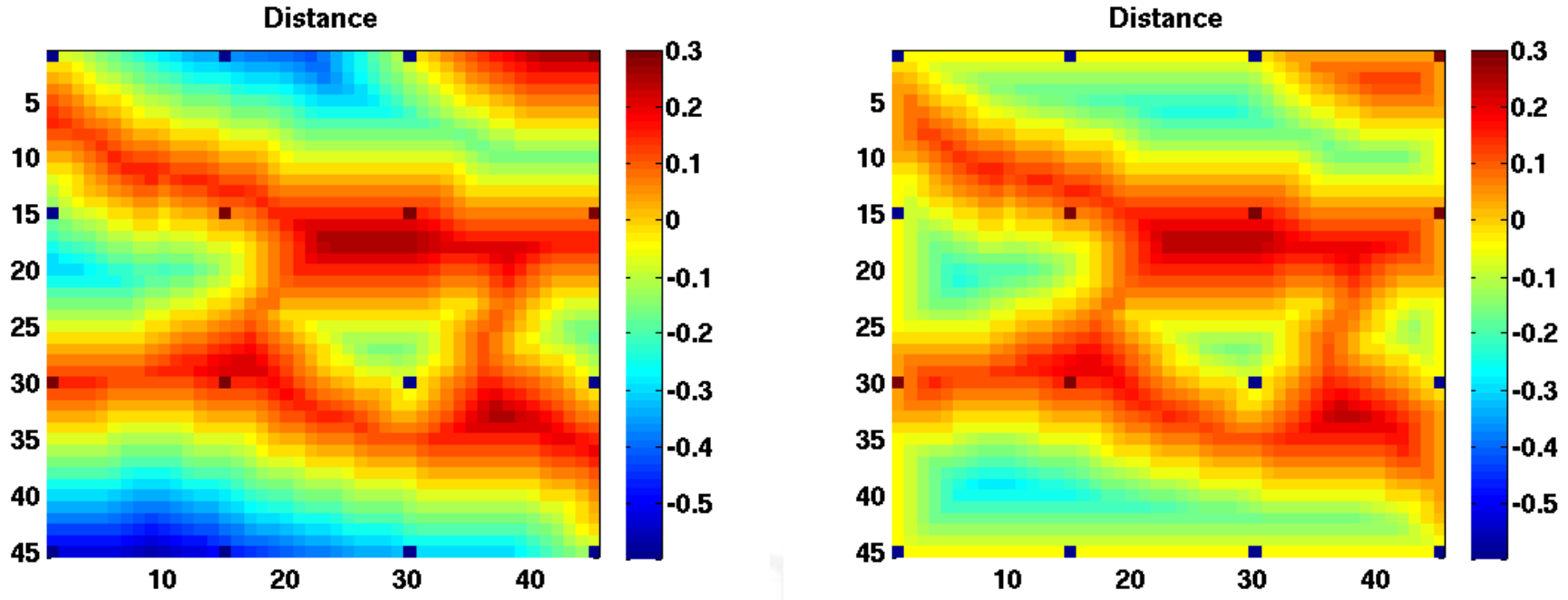
- The initial ensemble can be generated using any Geostatistical tool
- Possible to condition on facies types at well locations
- Conditioning is preserved by setting distances at well positions equal for all ensemble members
- Dynamic state variables are calculated after each assimilation step, by rerunning the simulator from time zero using the updated static parameters
- Distances recalculated after each assimilation step

Update procedure



Avoiding boundary effects

To avoid boundary effects, a frame of grid blocks with zero values have been added before (re)calculating the distances.



Left: Standard distances. Right: Distances with boundary treatment.

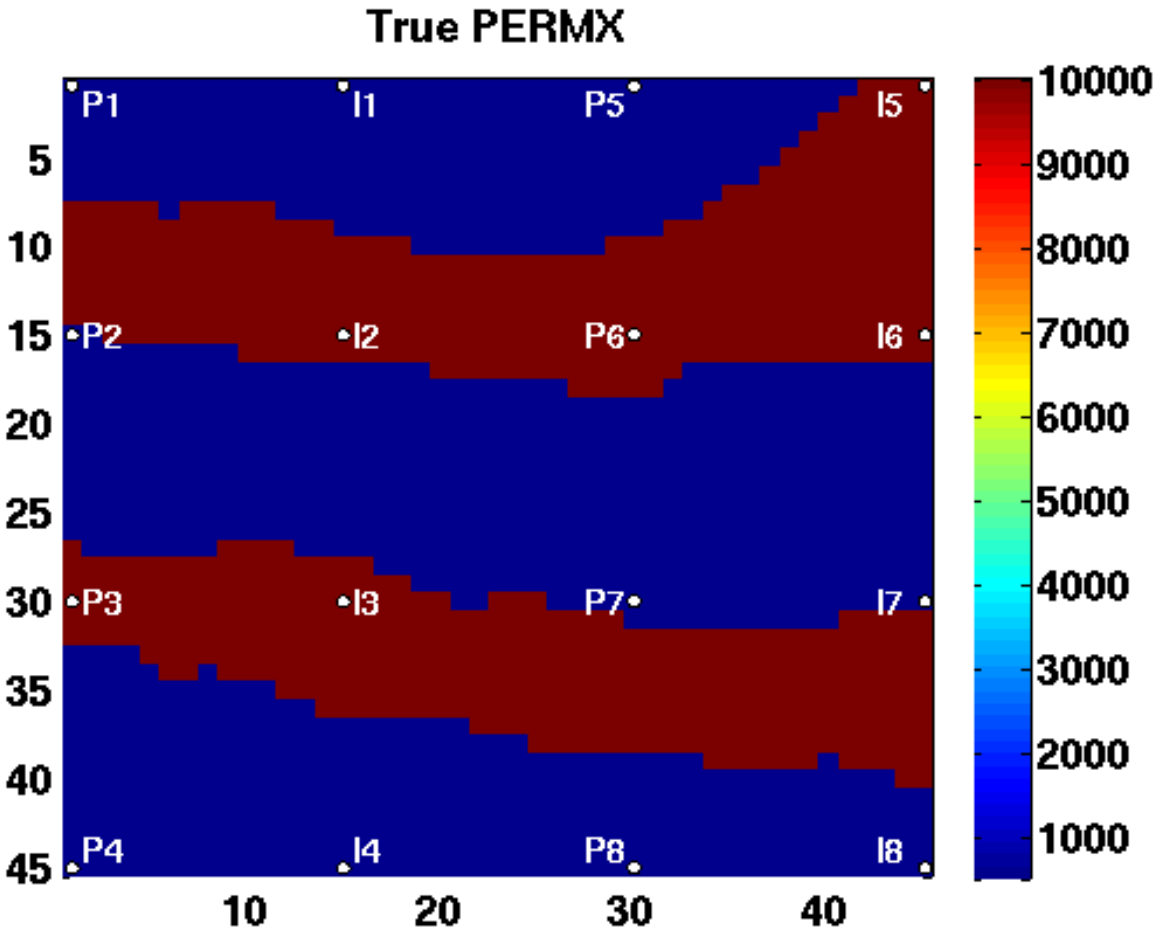
Conditioning on statistical measures

To preserve the channel properties, we condition the models on the following measures (Soleng et al. [3]), computed from the initial ensemble:

- Mean value of area to volume ratio of bodies ($\overline{\mathrm{A}/\mathrm{V}}$)
- Maximal body extension in X-direction (Max(X))
- Maximal body extension in Y-direction (Max(Y))
- Mean volume of bodies ($\overline{\mathrm{V}}$)
- Mean area of bodies ($\overline{\mathrm{A}}$)
- p75 quartile for the extensions in the X-direction (p75(X))
- Number of bodies (n)
- Global volume fraction (μ)

Example 1: reservoir overview

- Two dimensional channelized reservoir (Sarma and Chen [2])
- Initially saturated with oil (no gas)
- 45 $\times$ 45 gridblocks
- Eight water injectors and eight producers
- Steering strategy (true case):
  - water injection: 15.9 scm/day
  - target for pressure at producers: 400 bar

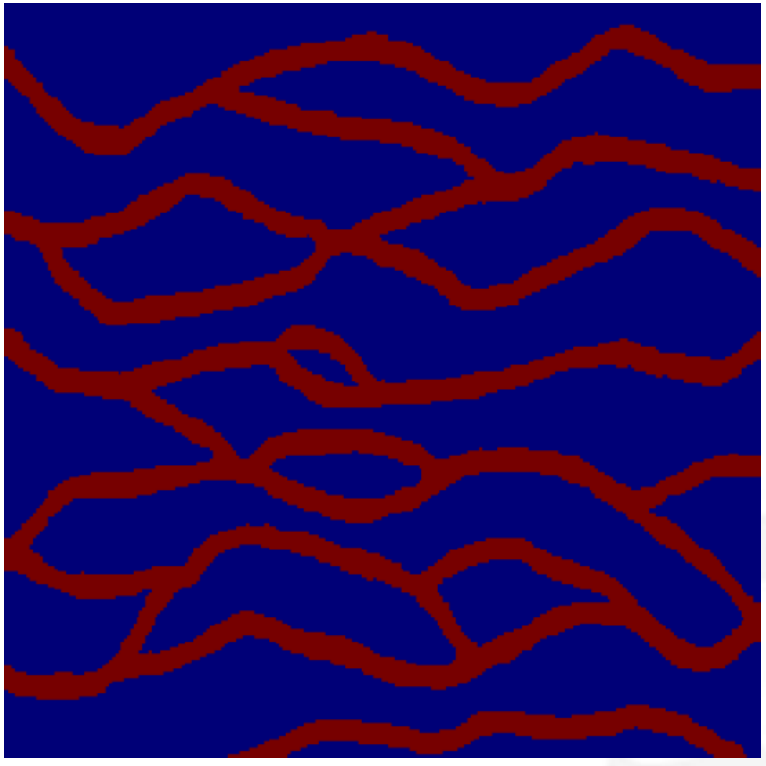


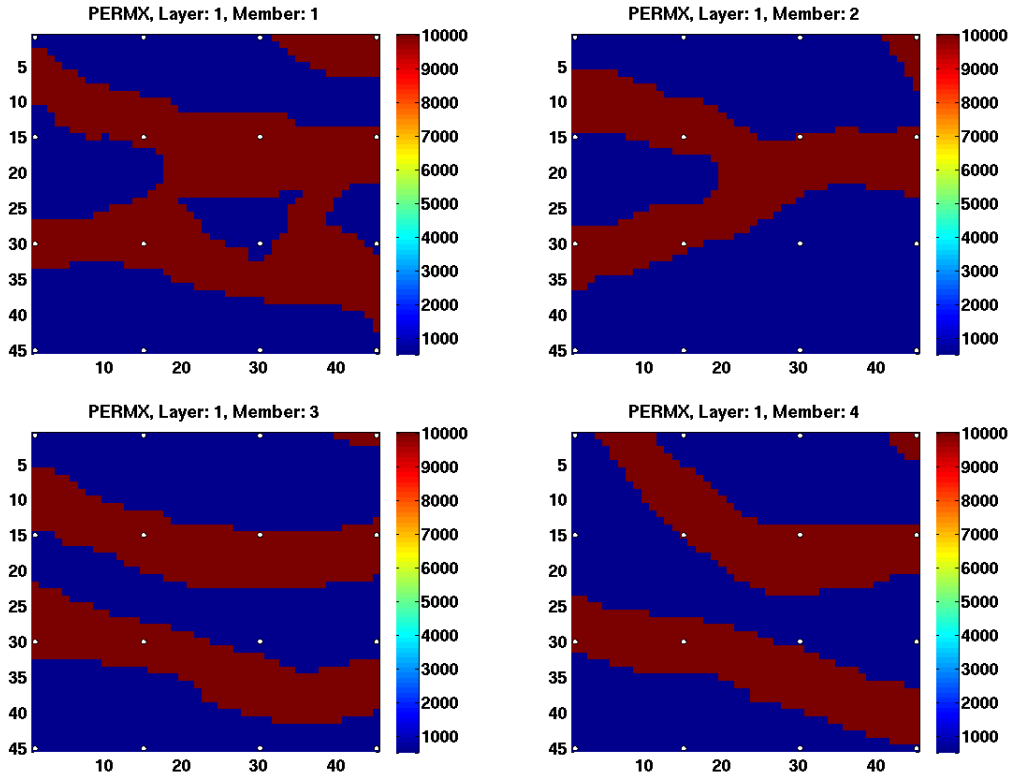
True field (K = 500 / 10000 mD, Φ = 0.1).

Assimilation overview

- Wells are controlled by reservoir volume rate
- Measurements are flow rates at producers ($\sigma^2 = 0.16$)
- Data assimilated 10 times with 190 days interval
- 100 ensemble members used

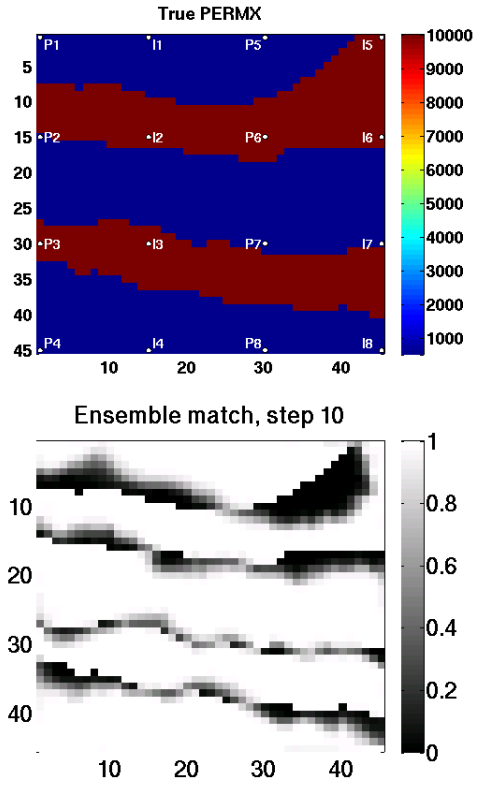
Initial ensemble using SNESIM

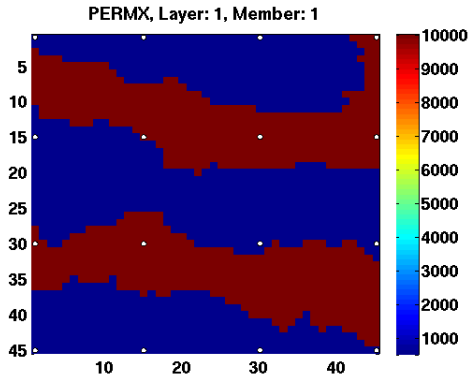


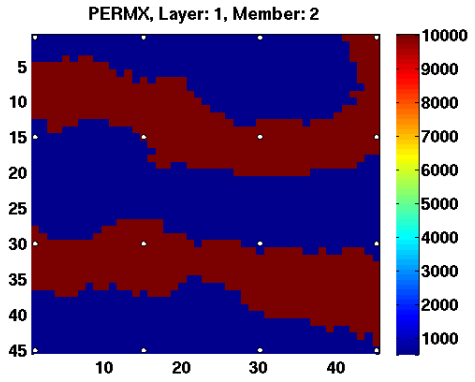


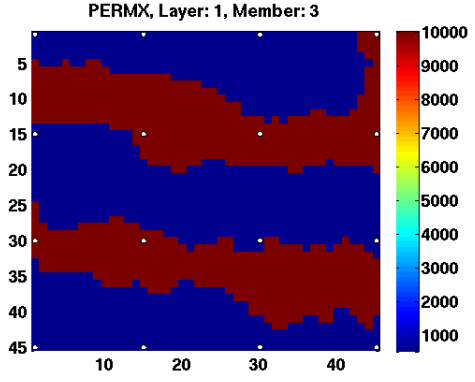
Left: Training image (250 $\times$ 250 gridblocks).
Right: Four (first) initial members conditioned at well locations.

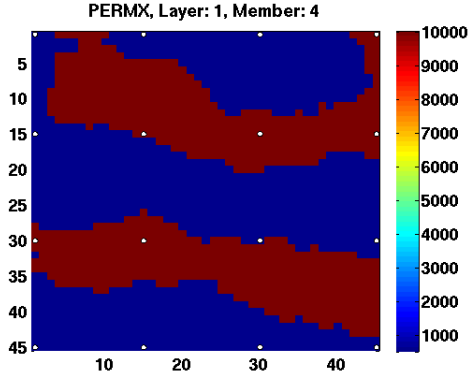
Final fields







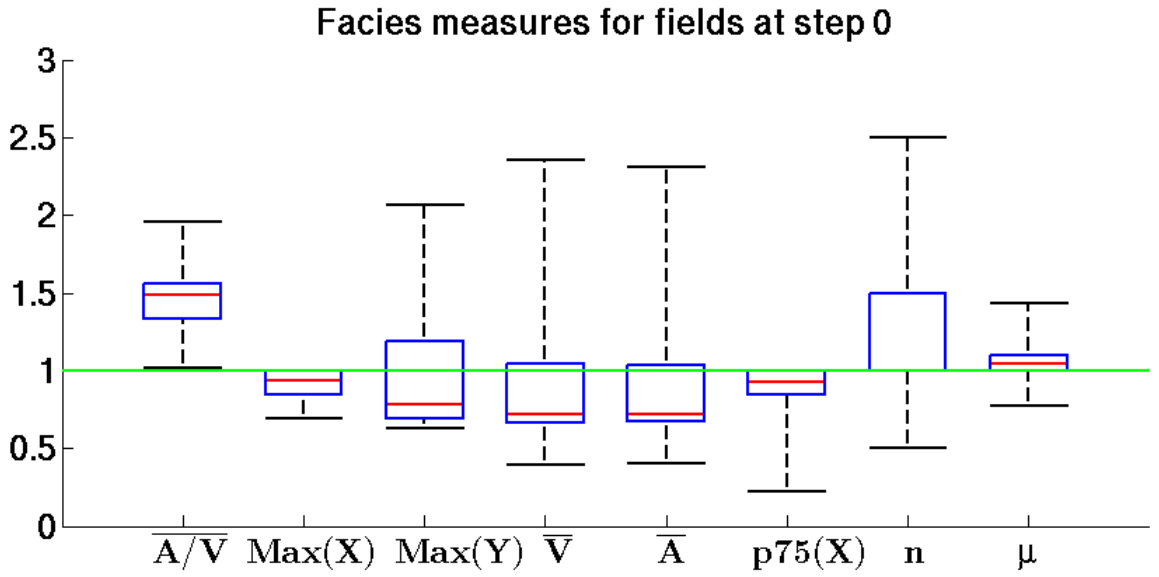




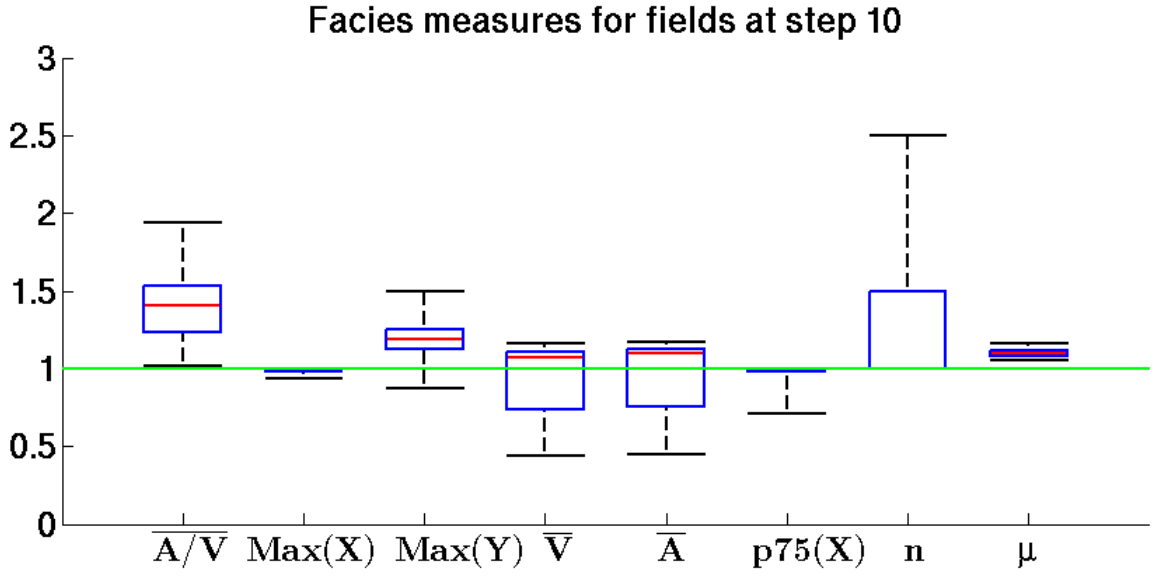
True field (top)
Ensemble match (bottom)

Four (first) final members

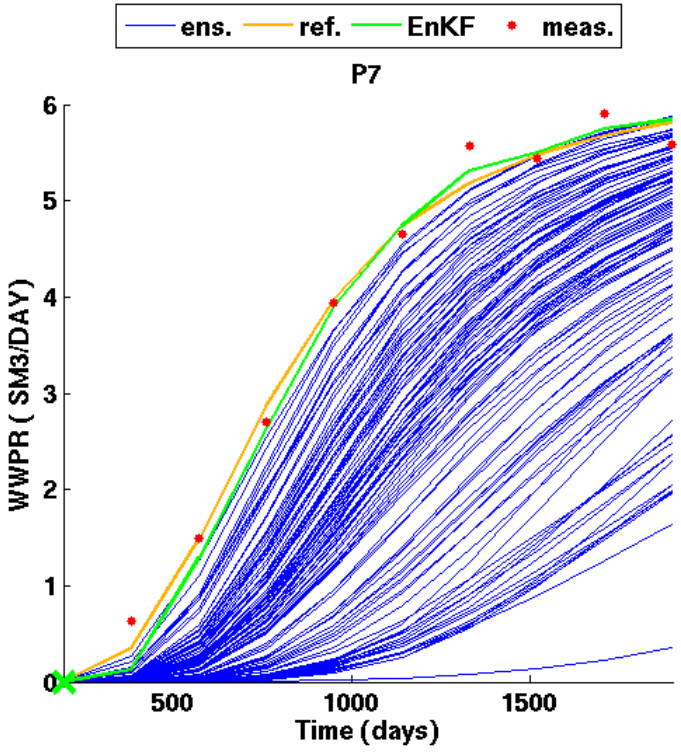
Initial

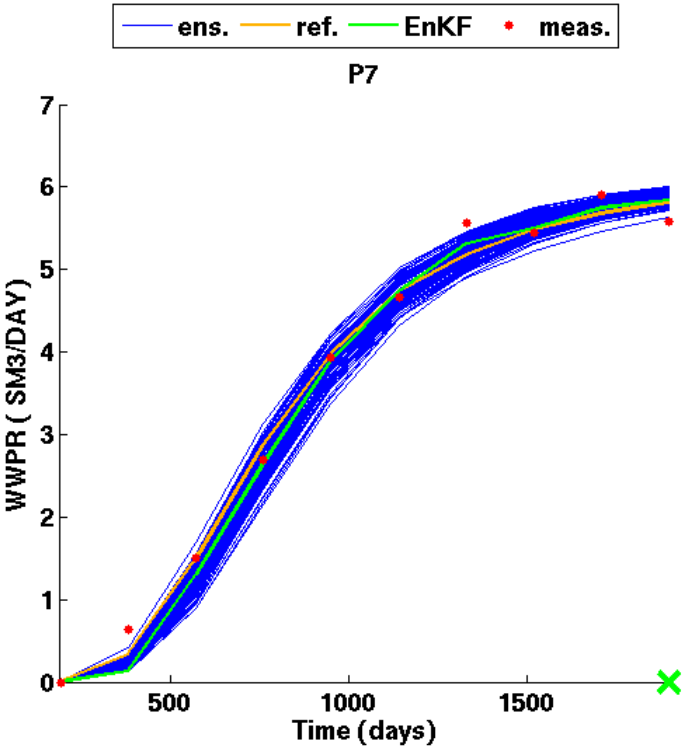


Final



Forecasts of water rate at well P7





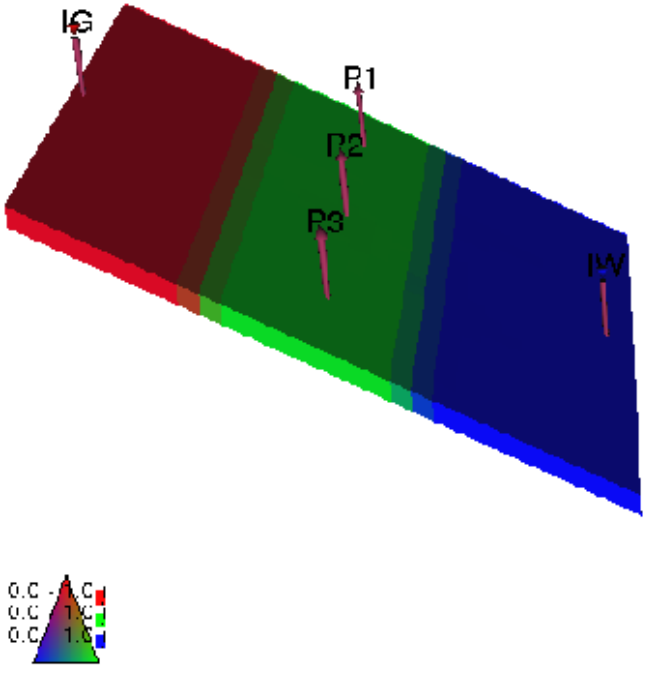
Forecasts from time zero using initial parameters (left) and using estimated parameters at final time (right).

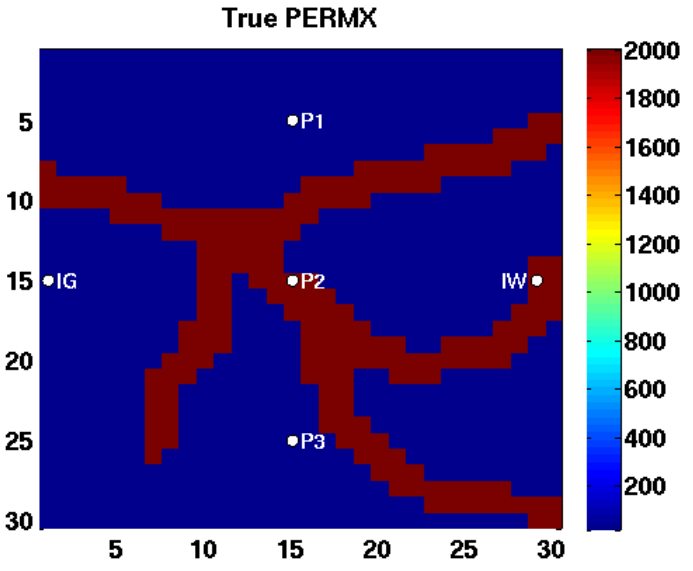
Example 2: reservoir overview

- 2D tilted (30°) reservoir
- Filled with water, oil and gas
- 30 × 30 gridblocks
- True permeability is a complex channel structure (2 facies)
- Steering strategy (true case):
  - reinjection of gas
  - water injection: 6000 scm/day
  - target for oil production: 10000 scm/day
  - upper limit for gas production: 2000000 scm/day
  - “most offending” connection (well) shut down if the limit is violated

Assimilation overview

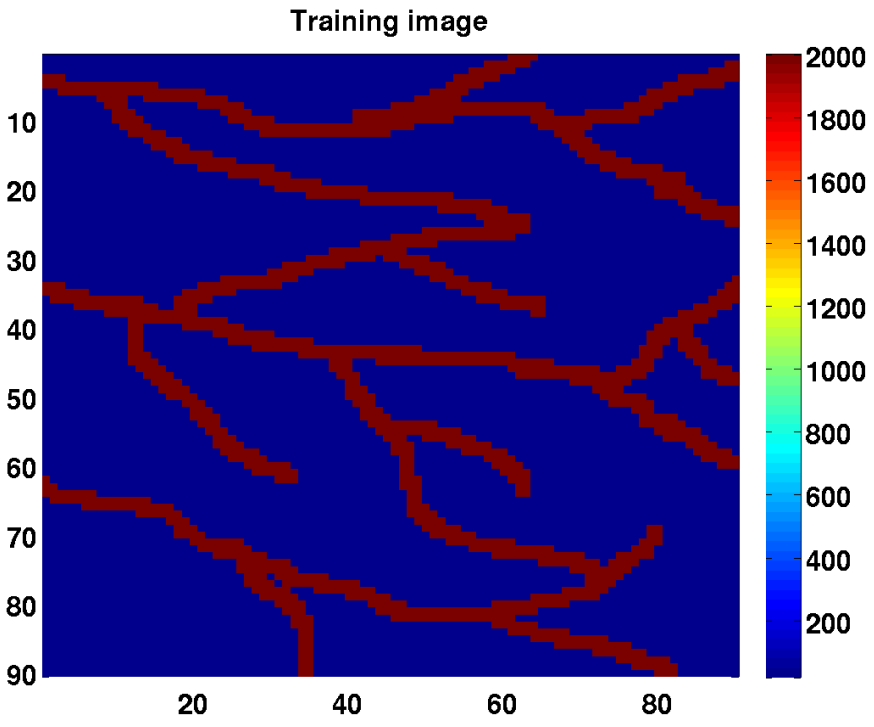
- Wells are controlled by reservoir volume rate
- Measurements are flow rates at producers ($\sigma = 5\%$)
- Data assimilated 51 times with 30 days interval
- 100 ensemble members used

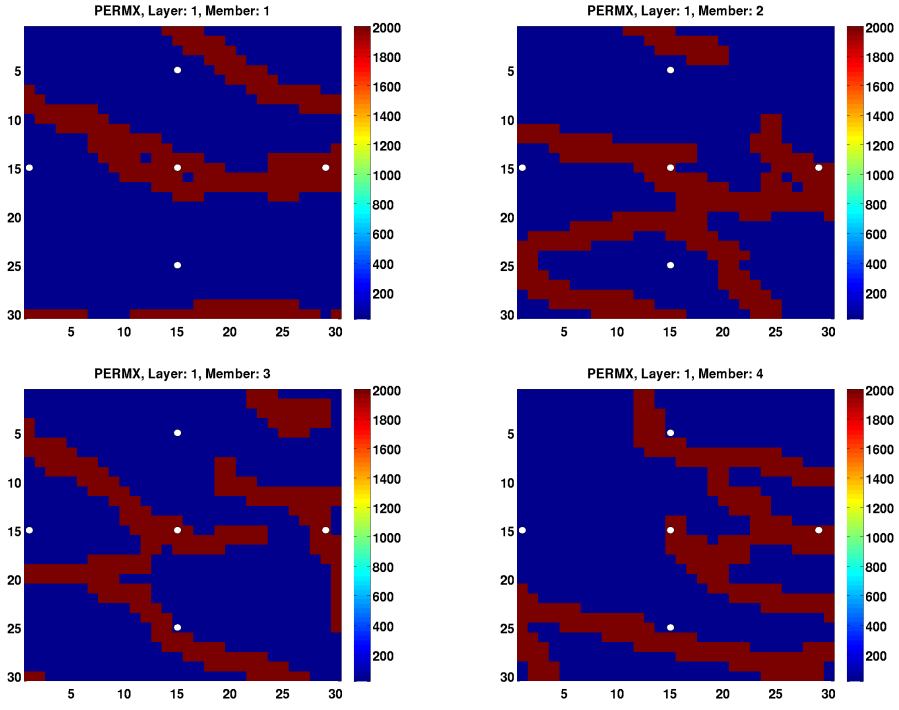




Left: Reservoir with initial saturations and well positions.
Right: True field (K = 20 / 2000 mD, Φ = 0.15 / 0.3).

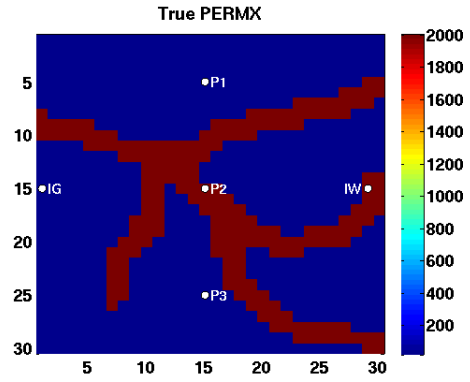
Initial ensemble using SNESIM

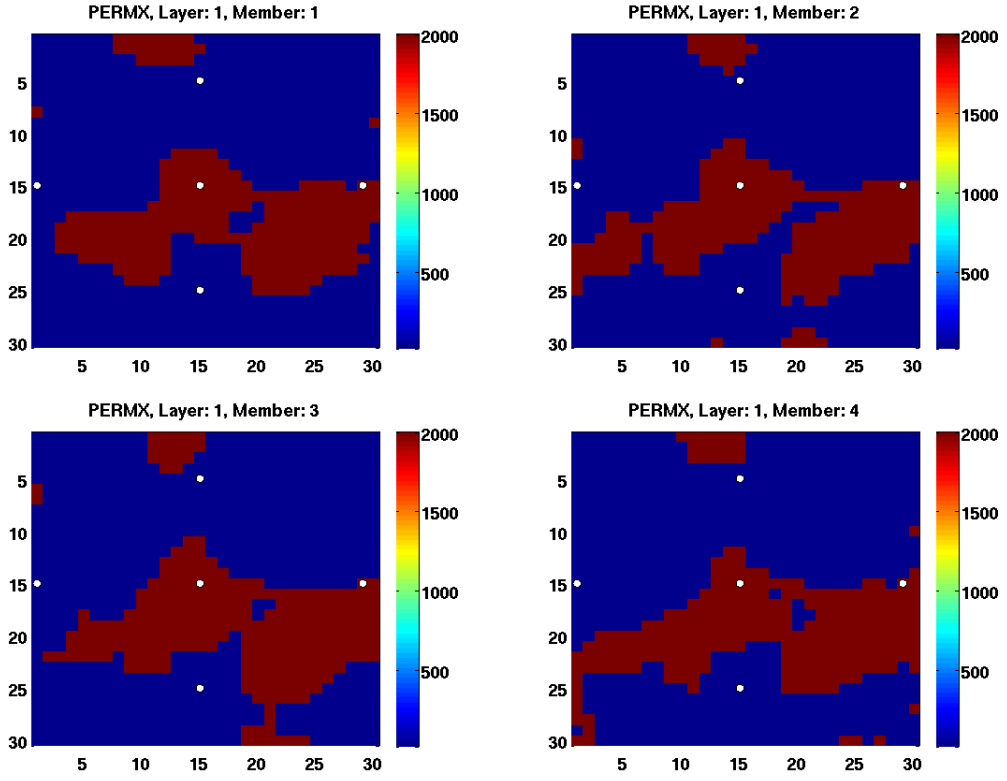




Left: Training image (90 $\times$ 90 gridblocks).
Right: Four (first) initial members conditioned at well locations.

Final fields

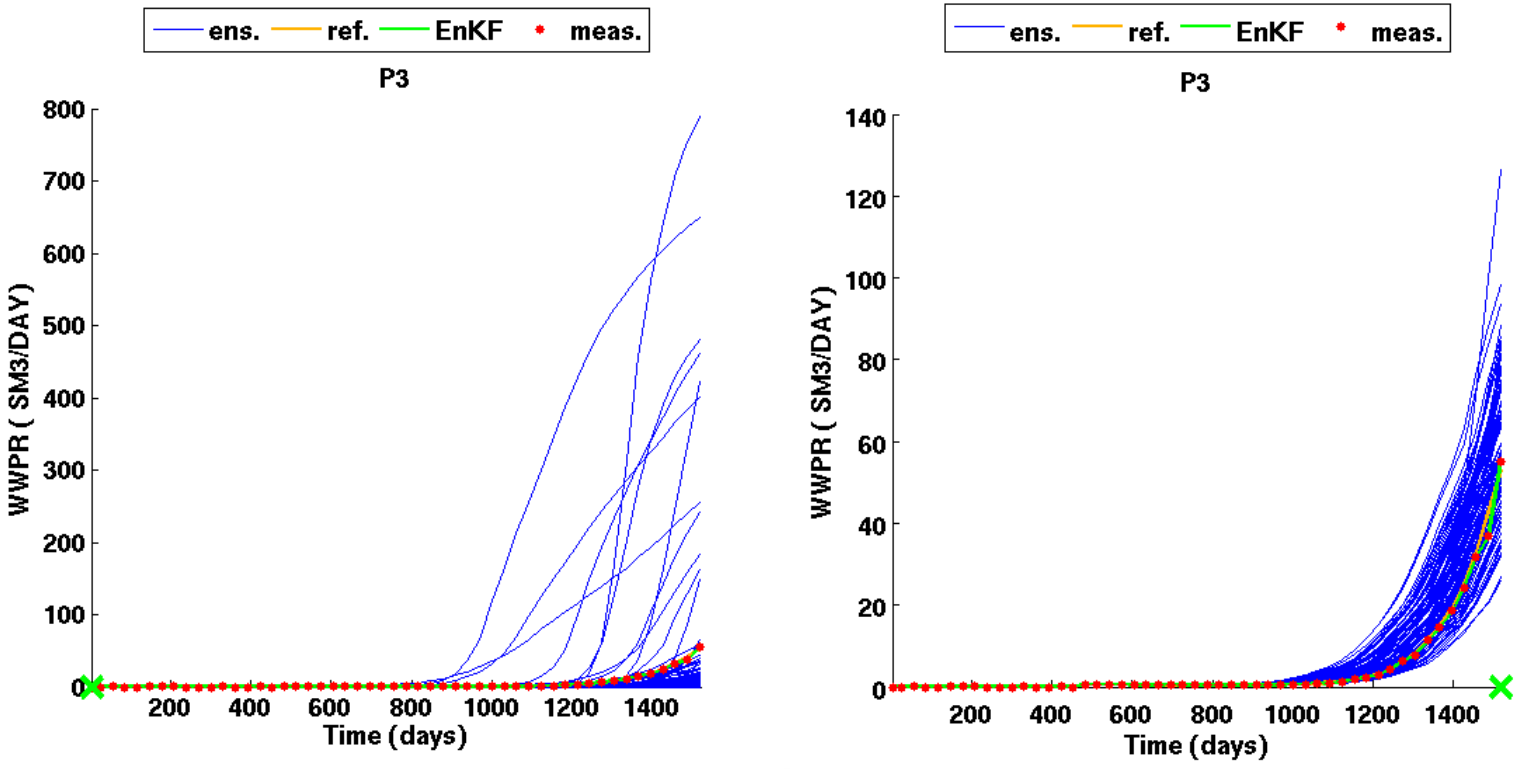




True field (top)
Ensemble match (bottom)

Four (first) final members

Forecasts of water rate at well P3



Forecasts from time zero using initial parameters (left) and using estimated parameters at final time (right).

Summary

- Use of EnKF for estimating facies fields introduced
- Updating distance functions
- Methodology tested on two examples
- Large history match improvements for both examples
- True permeability field recovered in Example 1
- Channels not completely recovered in Example 2

Acknowledgments

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D. Moreno, S. I. Aanonsen, G. Evensen, and J. A. Skjervehim.
Channel facies estimation based on Gausssian pertubations in the EnKF.
In *Proceedings of 11th European Conference on the Mathematics of Oil Recovery*, page Paper B08, Bergen, Norway, September 8-11 2008. EAGE.

P. Sarma and W. H. Chen.
Generalization of the ensemble kalman filter using kernels for non-gaussian random fields.
In *SPE Reservoir Simulation Symposium*, Huston, Texas, USA, 2 -4 February 2009.
SPE 119177.

H. H. Soleng, A. R. Syversveen, and O. Kolbjørnsen.
Comparing facies realizations - defining metrices on realization space.
In *Proceedings of 10th European Conference on the Mathematics of Oil Recovery*, Amsterdam, The Netherlands, 4 - 7 September 2006. European Association of Geoscientists & Engineers.