The importance of localization in the Assimilation of 4D seismic data with the Ensemble Kalman Filter

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Overview

• Introduction

• The EnKF and the need for localization

• Results from a 3D case

• Conclusions

• In Future...
Introduction

What is data assimilation?

Data Assimilation is that mathematical process which aims at the estimation and prediction of an unknown, true state by merging different observed information into a model.
The Ensemble Kalman Filter

Advantages

\[ \Psi^a = \Psi^f + P^f H^T \left( H P^f H^T + P_\varepsilon \right)^{-1} \left(D - H \Psi^f\right) \]

• Sequential updating
• Simple to use
• Versatility in estimating any parameter, through the cross-covariance matrix
The Ensemble Kalman Filter

Disadvantages

\[ \Psi^a = \Psi^f + P^f H^T \left( H P^f H^T + P_\epsilon \right)^{-1} \left( D - H \Psi^f \right) \]

- Based on Gaussian Parameter distribution and output honors a Gaussian distribution
- The update quality relies on the ensemble size
- Ensemble divergence

Introduction
- The EnKF and the local
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What is Ensemble divergence?

Frequent 4D seismics

All the ensemble members constrained to the observations.

The ensemble spread (covariance) becomes too narrow.

Weak influence of the measurements

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The benefit of localization

Localization: restriction of the EnKF update to only those gridblocks related to the measurement location.

Traditional EnKF: $N_{\text{ens}}$ to represent the state distribution
Localized EnKF: $N_{\text{ens}} \times N_{\text{reg}}$ to represent the state distribution

Advantage:
Increase the effective ens. size

Disadvantage:
Risk of geologically unrealistic updates
The EnKF and localization

Relationship between water rates at well nr 1 and permeability at two different locations for different realizations.

Localization eliminates spurious correlations by ruling out distant, unrelated gridblocks!
How do we select the update regions?

Drainage Areas

Cross-covariance between measurement and the permeability field

Distance

Cross-covariances with localization
The localization is applied with the Schur product between the matrix $T$ and the covariance matrix of the forecasted measurements.

\[
\Psi^a = \Psi^f + T \odot \left( P^f H^T \right) \left( HP^f H^T + P_\varepsilon \right)^{-1} (D - H \Psi^f)
\]
## Results from 3D model

- 6 runs
- 600 days history
- 600 days prediction
- 99 Ensemble members
- Liquid constraints

### Seismic measurements

<table>
<thead>
<tr>
<th>RUNS</th>
<th>Vertically averaged ΔS</th>
<th>Vertically averaged ΔP</th>
<th>Sat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uncertainty (%)</td>
<td>Frequency (days)</td>
<td>Localization</td>
</tr>
<tr>
<td>Prior</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
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<td>NA</td>
<td>NO</td>
</tr>
<tr>
<td>Prod + Drainage</td>
<td>NA</td>
<td>NA</td>
<td>NO</td>
</tr>
</tbody>
</table>

### Diagram

- PermX field

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**Introduction**

- The EnKF and the local
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**ISAPP**

*The Value of Smartness*
Production Data-BHP

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**Prior**

- Prod. Only
- Prod. + Seismic
- Prod. + Frequent Seismic
- Prod. + Distance
- Prod. + Drainage

**Truth**

**Ens. forecast**

**Mean forecast**

**Updates**

**Mean Update**
Production Data - Water Rates

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- Conclusions
- In future...

Prior

Prod. + Seismic

Prod. + Distance

Prod. Only

Prod. + Frequent Seismic

Prod. + Drainage

Water rate (bbl/day)

DAYS

Truth

Ens.forecast

Mean forecast

Updates

Mean Update
The more information is assimilated the narrower the ensemble, the better the history match. An excellent history match is not always followed by a good prediction: ENS. DIVERGENCE.
Permeability – Layer 8

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Prior Prod. Only
Prod. + Drainage
Prod. + Distance
Prod. + Freq. Seismic
Prod. + Seismic

True
Permeability – Layer 10

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True

Prior

Prod. Only

Prod. + Seismic

Prod. + Freq. Seismic

Prod. + Distance

Prod. + Drainage
Porosity – Layer 8

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Legend:
- Prior Prod. Only
- Prod. + Drainage
- Prod. + Frequency Seismic
- Prod. + Distance
- Prod. + Seismic
- True

Scale:
- 0.2
- 0.18
- 0.16
- 0.14
Porosity – Layer 10

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True  Prior  Prod. Only  Prod. + Seismic

Prod. + Freq. Seismic  Prod. + Distance  Prod. + Drainage

ISAPP  THE VALUE OF SMARTNESS
Conclusions

• The assimilation of 4D seismic data helps to improve the estimation of reservoir properties and the quality of the history match;

• Localization (drainage based, distance) seems to eliminate the problem of ensemble collapse leading to an improvement of the reservoir production forecast;

• First results indicate that with the use of distance based localization the estimation of porosity and permeability field appears to be better than with the use of the drainage area localization.
In Future…

• To test the traditional and localized EnKF on a more complicated, realistic field (SPE 119094-MS-submitted- Results Of The Brugge Benchmark Study For Flooding Optimisation And History Matching (2009) Peters, E, Arts, R.J., Brouwer, G.K., Geel, C.R., Cullick, S./Halliburton, Lorentzen R.J./IRIS, Chen, Y./University of Oklahoma, K.N.B. Dunlop/Roxar, Vossepoel, F.C. /Shell International Exploration and Production BV, Xu, R./Schlumberger, Sarma, P./Stanford University, Alhutali, A.H./Texas A&M University, Reynolds, A.C. /University of Tulsa. SPE Reservoir Evaluation & Engineering);
• To test the routine on a real dataset…
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Any Question?