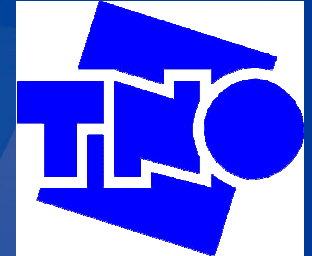


THE VALUE OF SMARTNESS



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

M. Trani ¹, R.J. Arts^{1,2}, O. Leeuwenburgh², J.H. Brouwer², S. Douma³

¹ TUDelft, ² TNO, ³ Shell International E&P B.V.

Fifth EBN-TNO Workshop , 14/01/2010

Overview

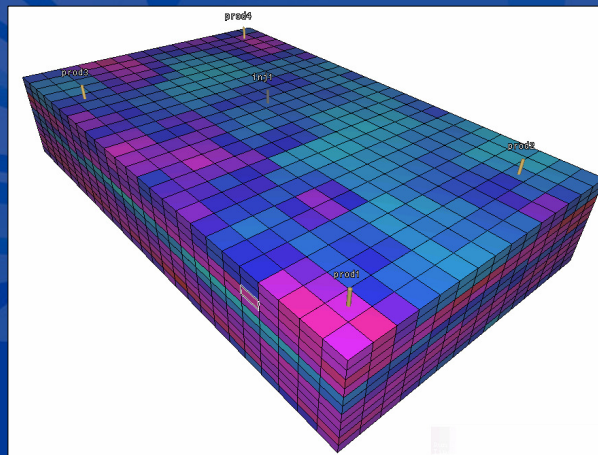
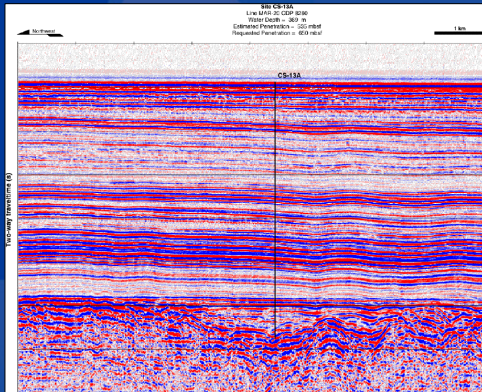
- Introduction
- The EnKF and the need for localization
- Results from a 3D case
- Conclusions
- In Future...

- Introduction
- The EnKF and the local
- Results 3D
- 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.



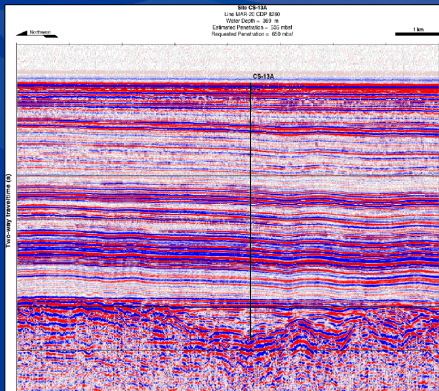
The Ensemble Kalman Filter

Advantages

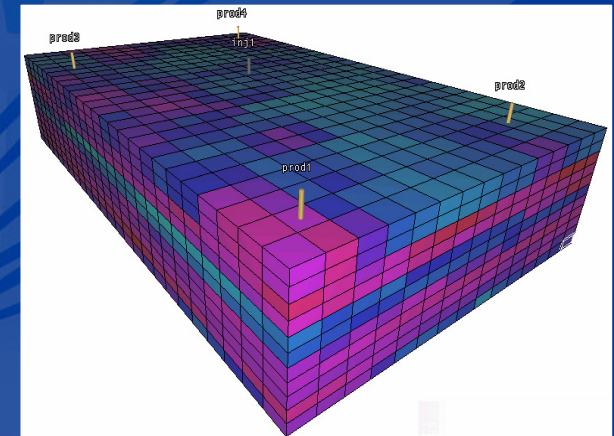
- Introduction
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$$\Psi^a = \Psi^f + P_{\Psi}^f H^T (H P_{\Psi}^f H^T + P_{\varepsilon})^{-1} (D - H \Psi^f)$$

- Sequential updating
- Simple to use
- Versatility in estimating any parameter, through the cross-covariance matrix



+



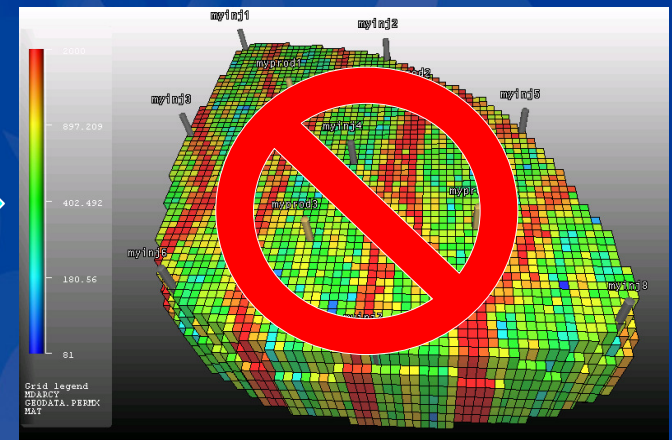
The Ensemble Kalman Filter

Disadvantages

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

$$\Psi^a = \Psi^f + P_{\Psi}^f H^T (H P_{\Psi}^f H^T + P_{\varepsilon})^{-1} (D - H \Psi^f)$$

- Based on Gaussian Parameter distribution and output honors a Gaussian distribution



- The update quality relies on the ensemble size
- Ensemble divergence

What is Ensemble divergence?

Frequent 4D seismics



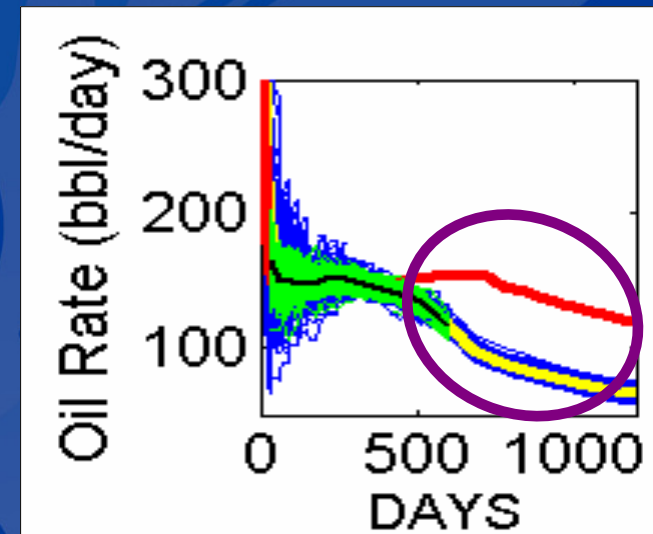
All the ensemble members constrained to the observations.



The ensemble spread (covariance) becomes too narrow.



Weak influence of the measurements



The benefit of localization

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

Traditional EnKF: N_{ens} to represent the state distribution

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



A diagram illustrating the concept of localization. It features two arrows originating from the text 'Localized EnKF: $N_{\text{ens}} * N_{\text{reg}}$ to represent the state distribution'. A green arrow points towards the 'Advantage' section, and a red arrow points towards the 'Disadvantage' section.

Advantage:

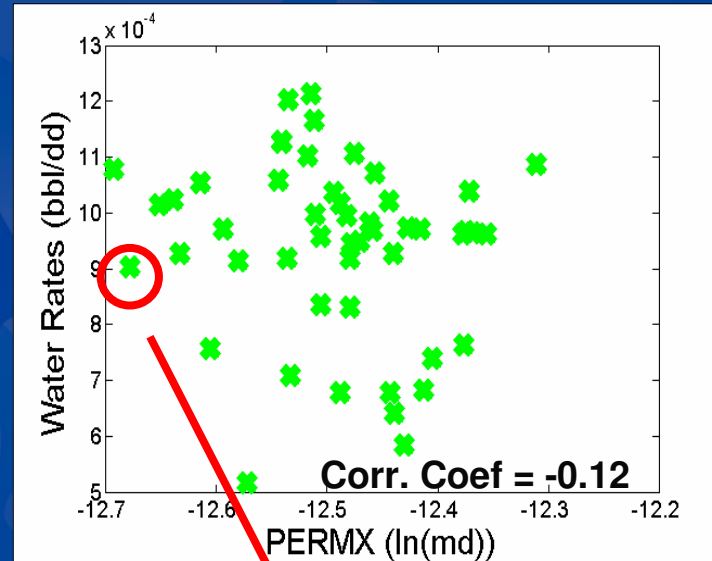
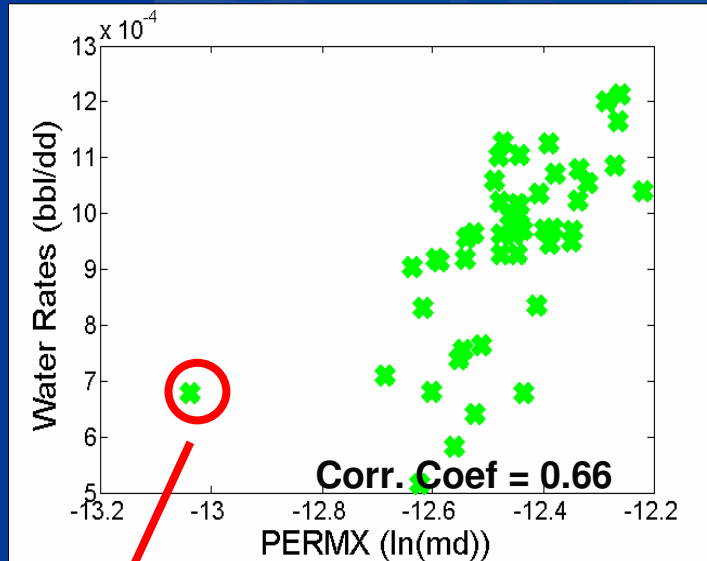
Increase the effective ens. size

Disadvantage:

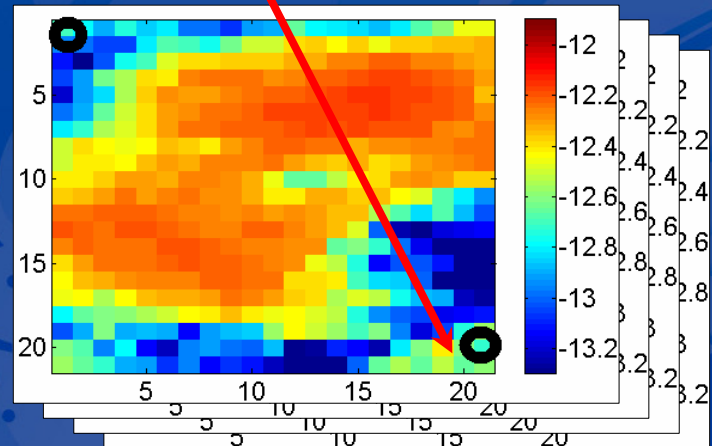
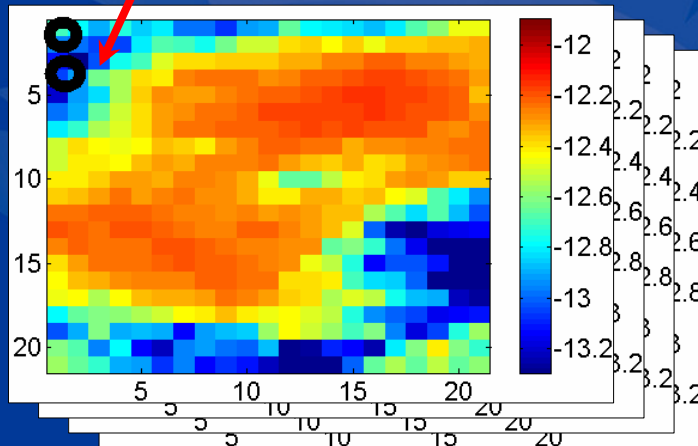
Risk of geologically unrealistic updates

The EnKF and localization

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...



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



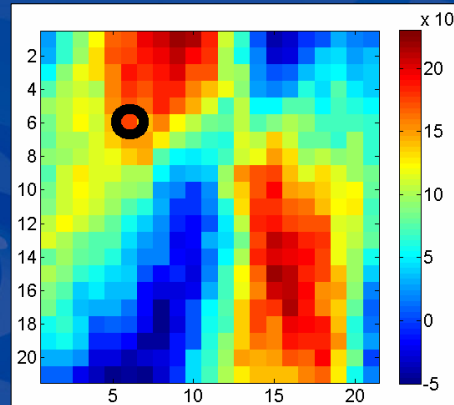
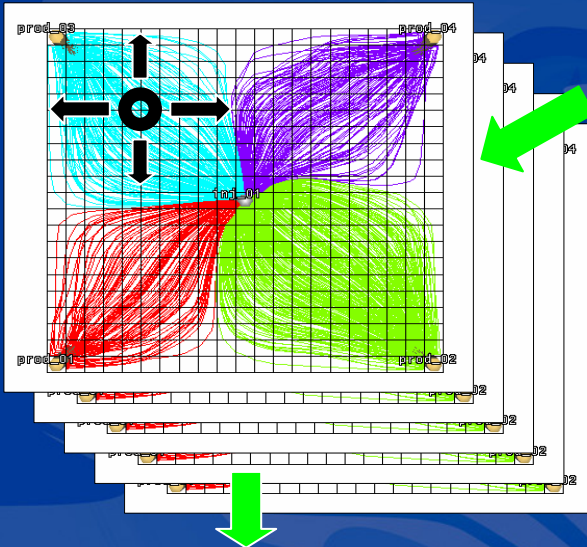
Permeability field for realization nr 1

Localization eliminates spurious correlations by ruling out distant, unrelated gridblocks!

How do we select the update regions?

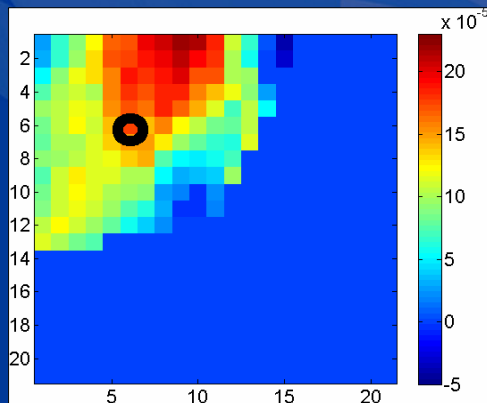
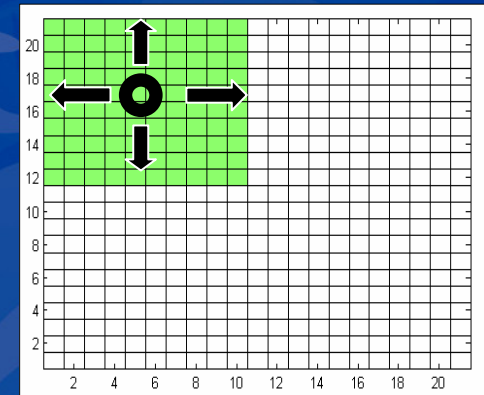
- Introduction
- The EnKF and the local
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Drainage Areas

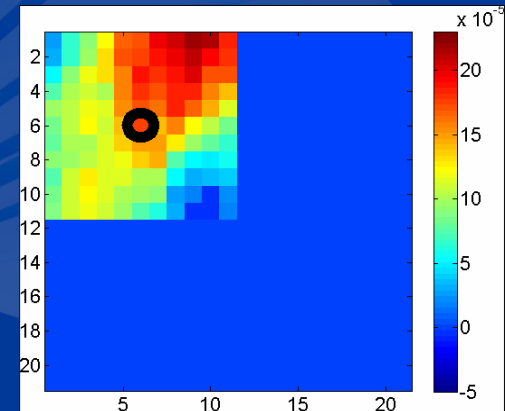


Cross-covariance
between
measurement and
the permeability
field

Distance



Cross-covariances with localization



Localized EnKF update

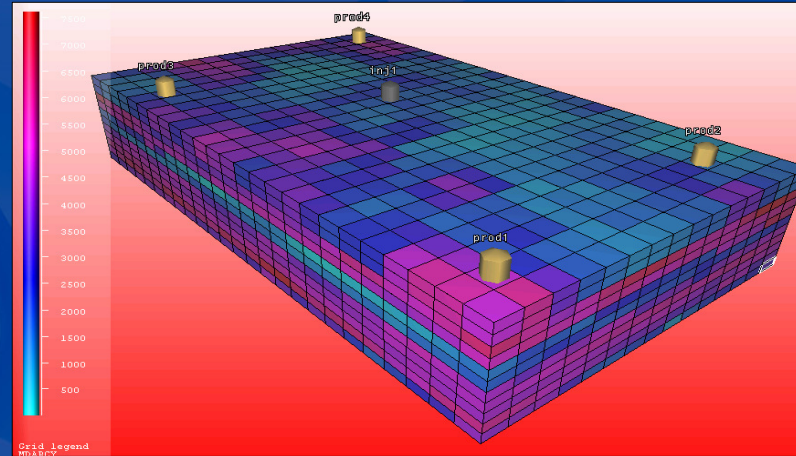
$$\Psi^a = \Psi^f + \textcolor{red}{T} \circ \left(P_{\Psi}^f H^T \right) \left(H P_{\Psi}^f H^T + P_{\varepsilon} \right)^{-1} \left(D - H \Psi^f \right)$$

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

Results from 3D model

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

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



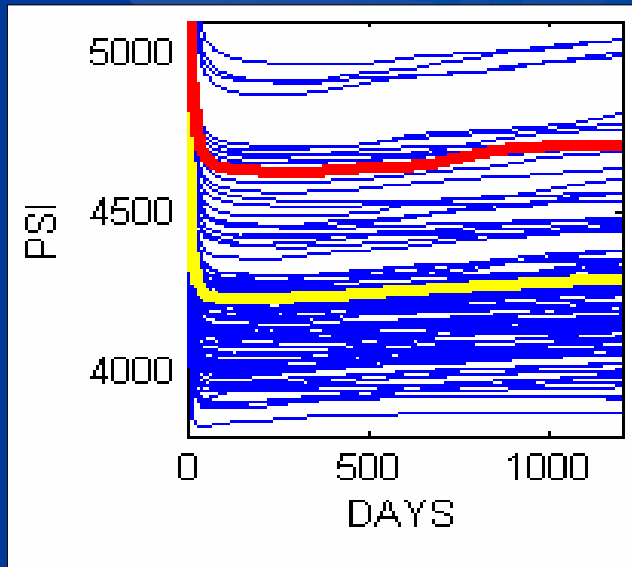
PermX field

RUNS	Seismic measurements								
	Vertically averaged ΔS			Vertically averaged ΔP			Sat		
	Uncertainty (%)	Frequency (days)	Localization	Uncertainty (PSI)	Frequency (days)	Localization	Uncertainty (%)	Frequency (days)	Localization
Prior	NA	NA	NA	NA	NA	NA	NA	NA	NA
Prod Only	NA	NA	NA	NA	NA	NA	NA	NA	NA
Prod + Seismic	0.1	150	NO	76	150	NO	NA	NA	NA
Prod + Frequent Seismic	0.1	30	NO	76	30	NO	NA	NA	NA
Prod + Distance	NA	NA	NO	NA	NA	NO	0.15	30	Distance
Prod + Drainage	NA	NA	NO	NA	NA	NO	0.15	30	Drainage

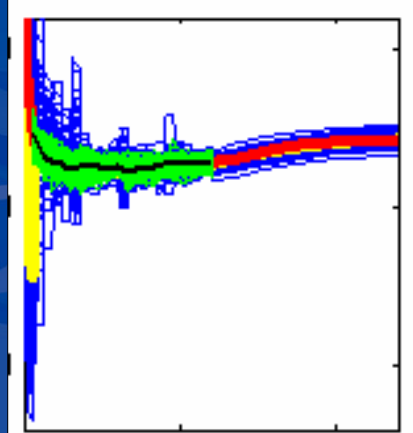
Production Data-BHP

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

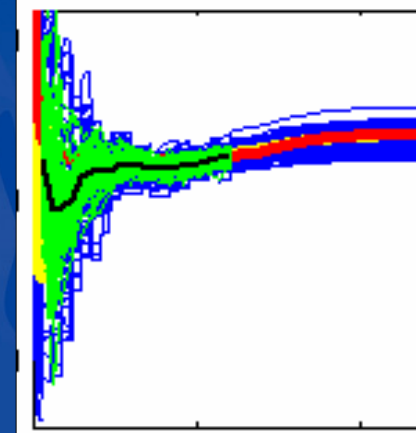
Prior



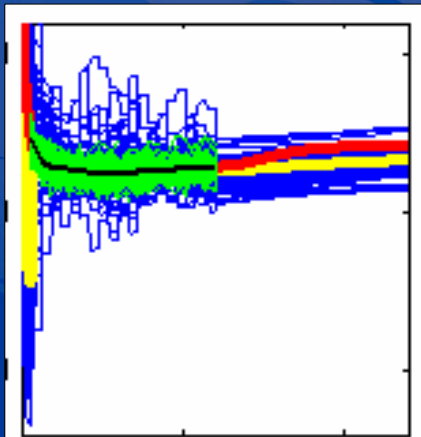
Prod. + Seismic



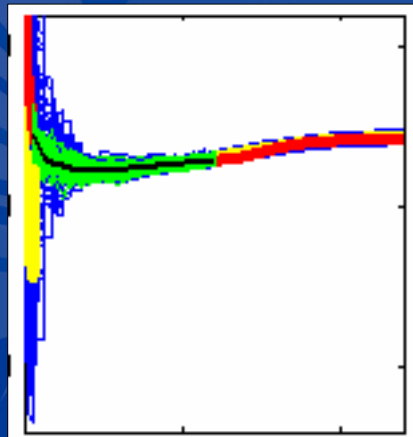
Prod. + Distance



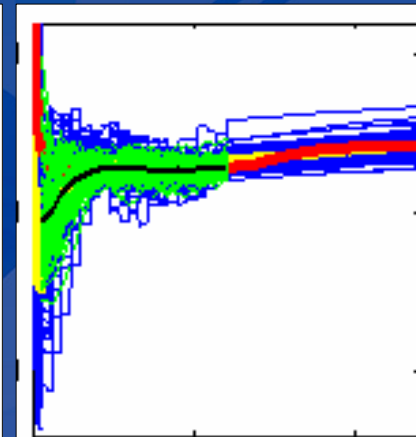
Prod. Only



Prod. + Frequent
Seismic



Prod.+ Drainage



Truth

Ens. forecast

Mean forecast

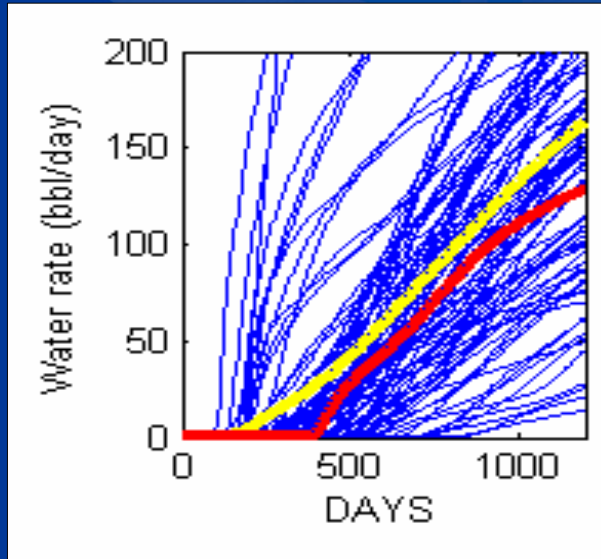
Updates

Mean Update

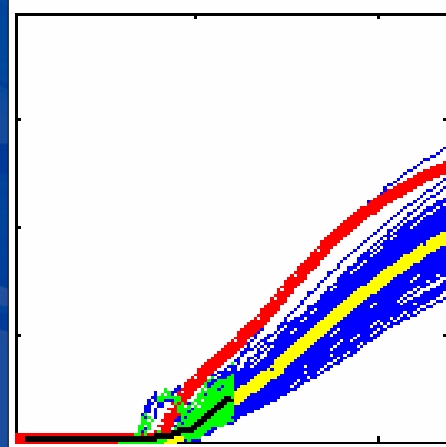
Production Data- Water Rates

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

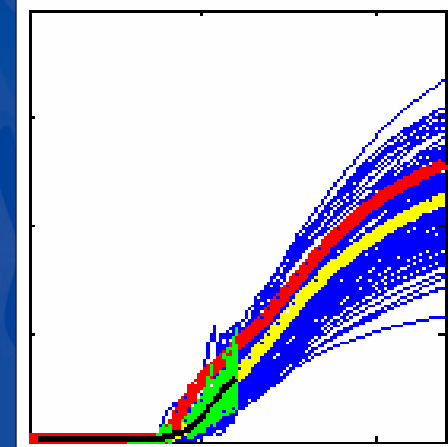
Prior



Prod. + Seismic



Prod. + Distance

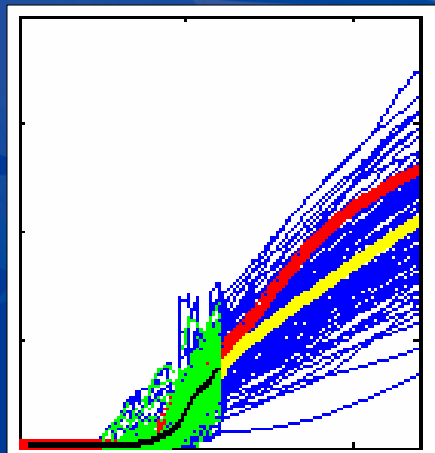


Truth

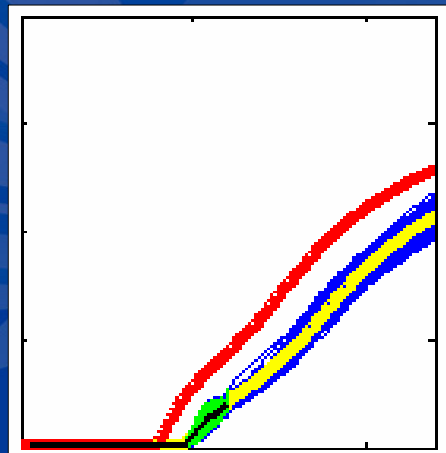
Ens. forecast

Mean forecast

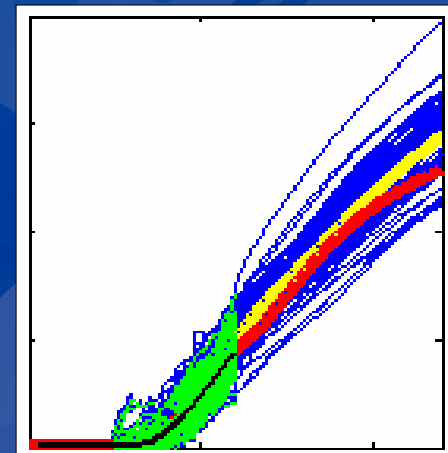
Prod. Only



Prod. + Frequent
Seismic



Prod.+ Drainage



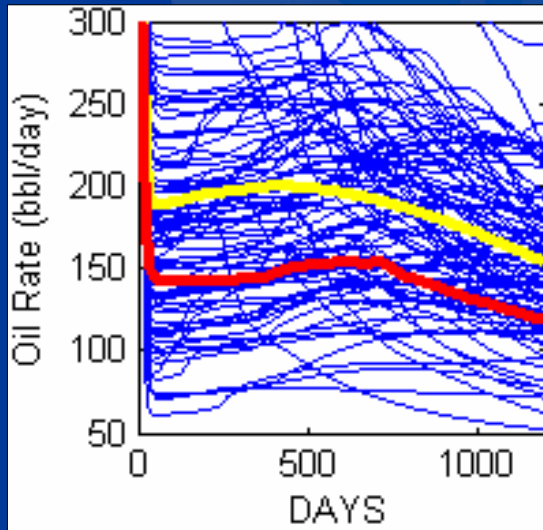
Updates

Mean Update

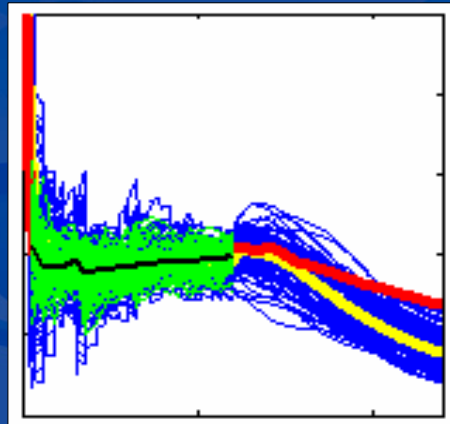
Production Rates-Oil Rates

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

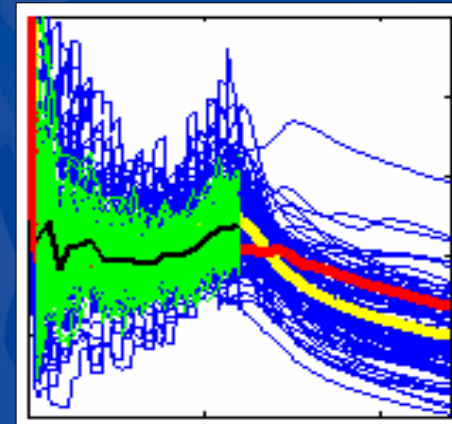
Prior



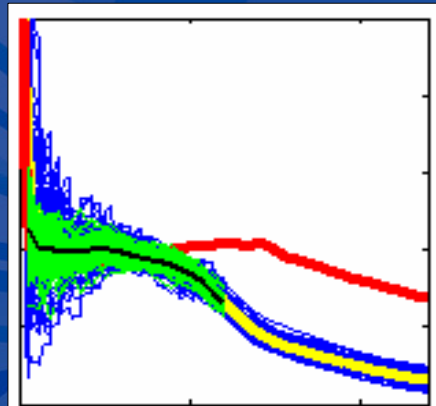
Prod. + Seismic



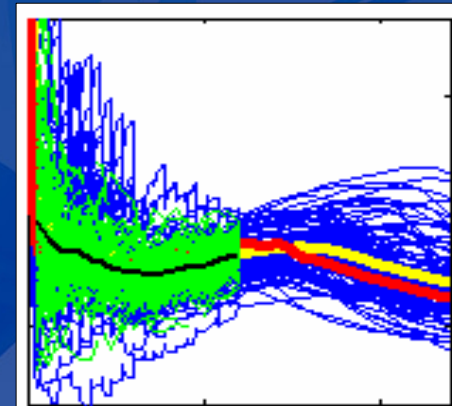
Prod. + Distance



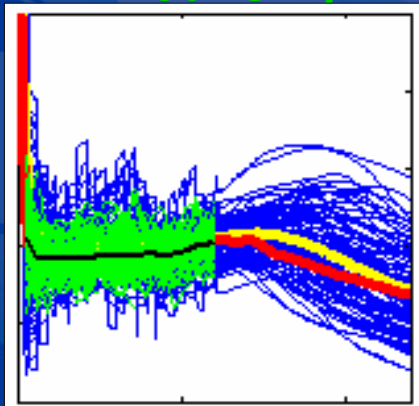
Prod. + Frequent
Seismic



Prod.+ Drainage



Prod. Only



Truth

Ens.forecast

Mean forecast

Updates

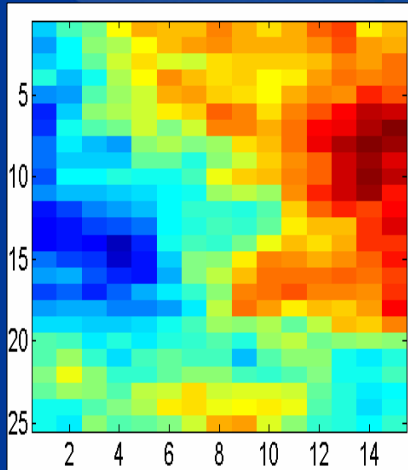
Mean Update

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,,

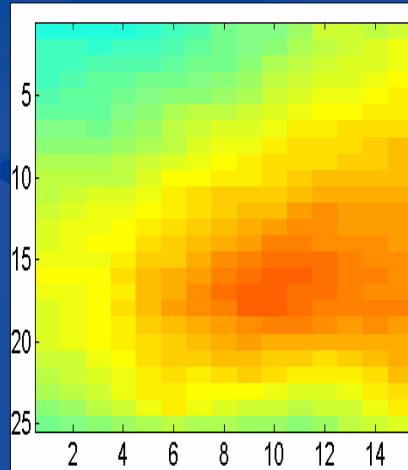
Permeability – Layer 8

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

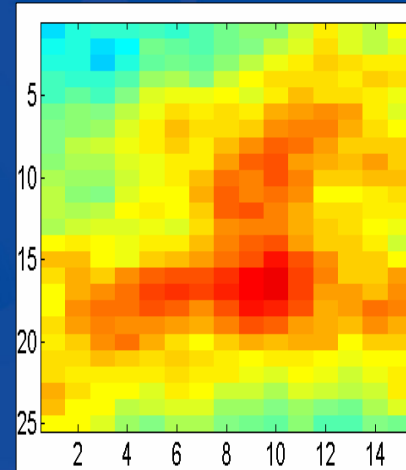
True



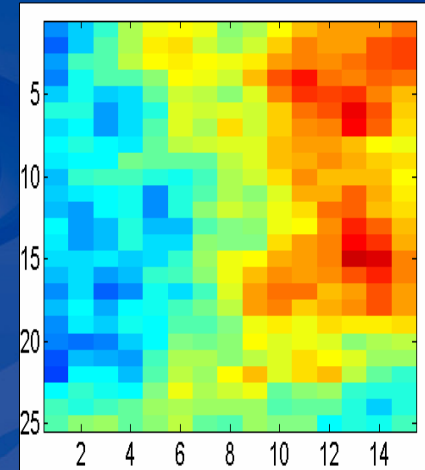
Prior



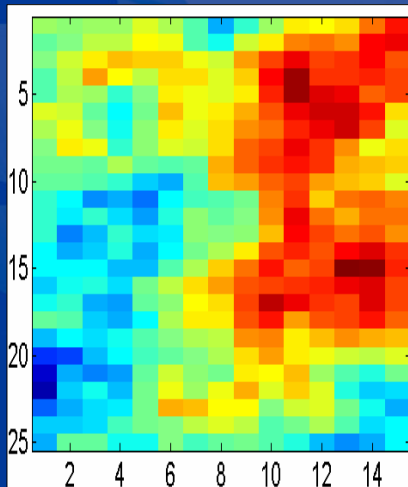
Prod. Only



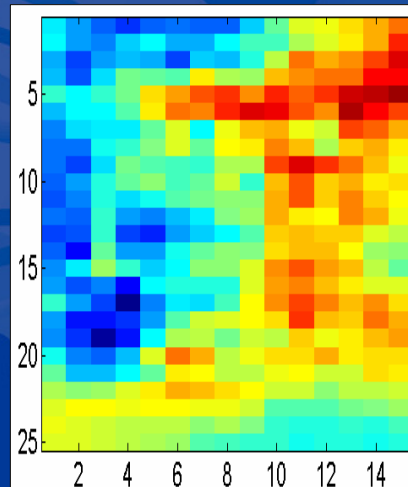
Prod. + Seismic



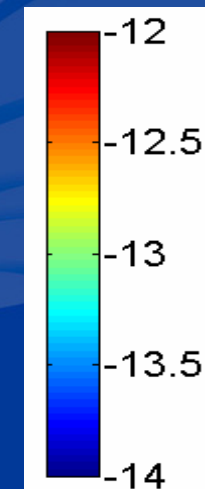
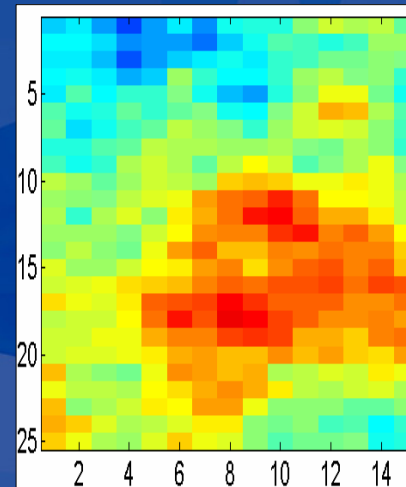
Prod. + Freq. Seismic



Prod. + Distance



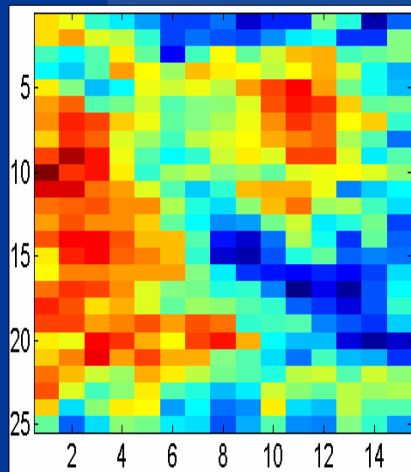
Prod.+ Drainage



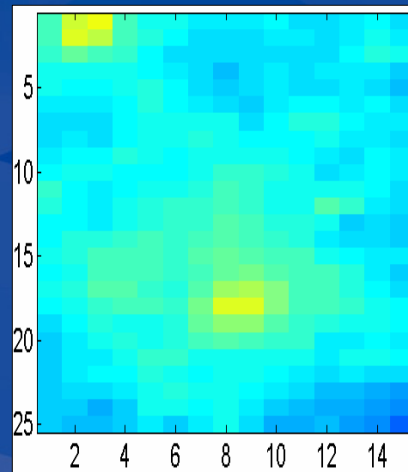
Permeability – Layer 10

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

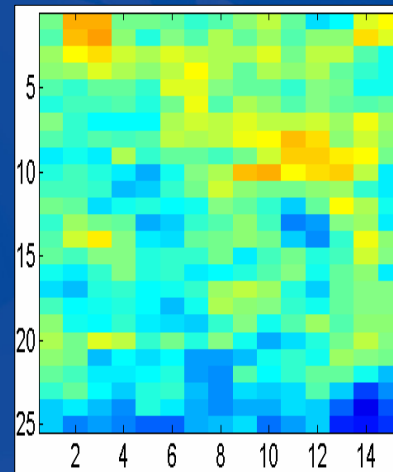
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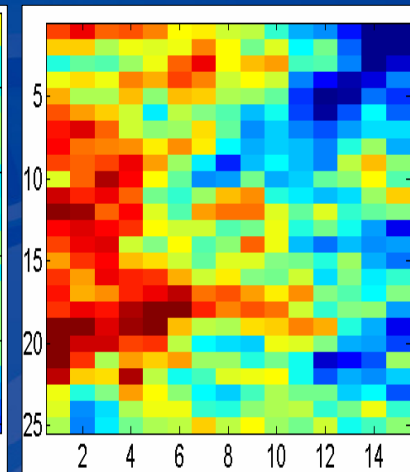
Prior



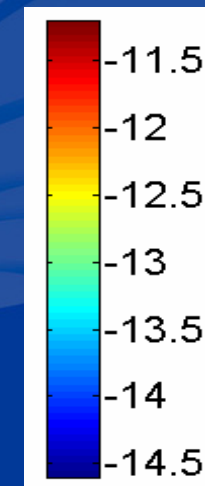
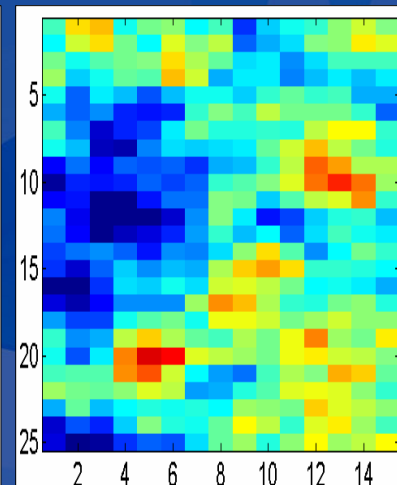
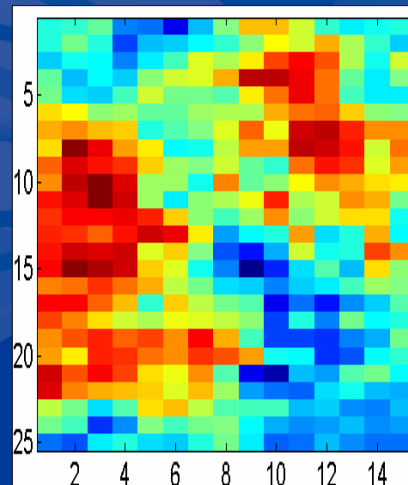
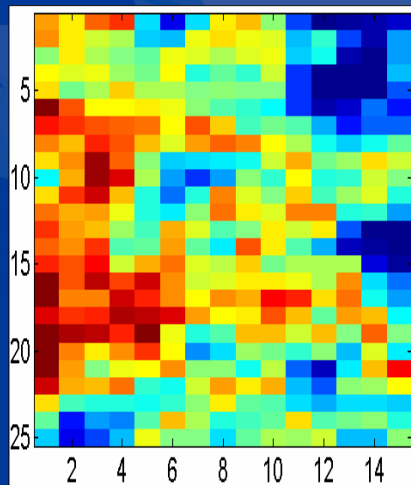
Prod. Only



Prod. + Seismic



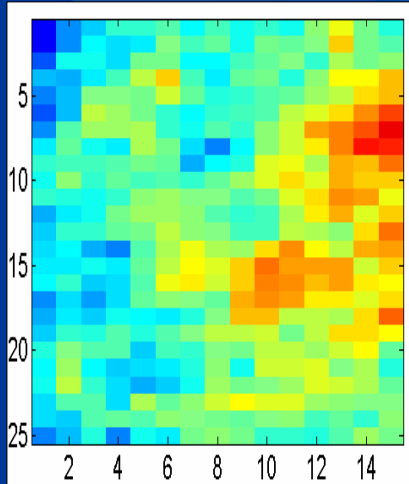
Prod. + Freq. Seismic Prod. + Distance Prod.+ Drainage



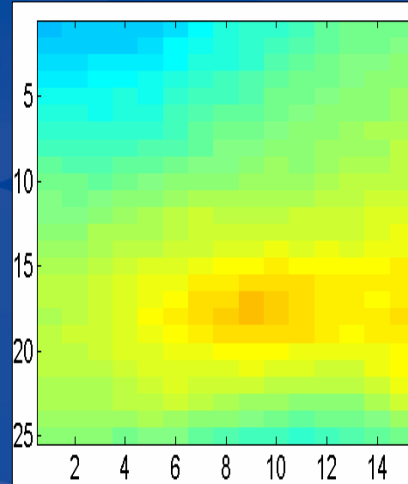
Porosity – Layer 8

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

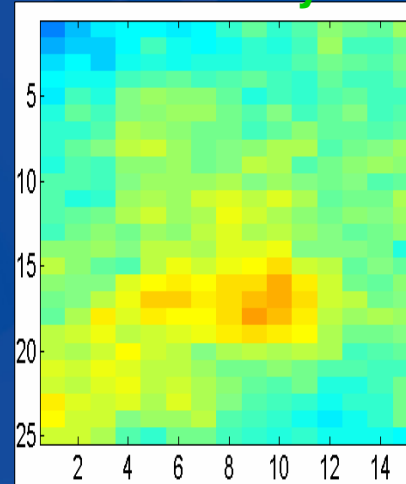
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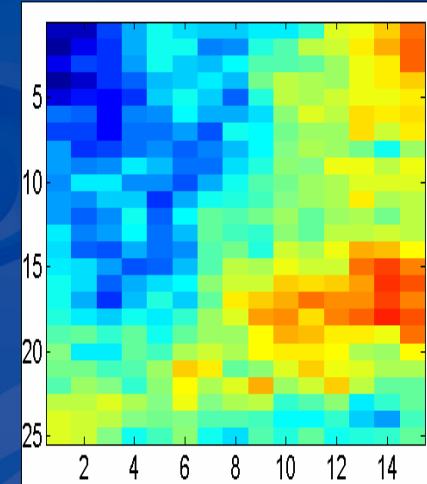
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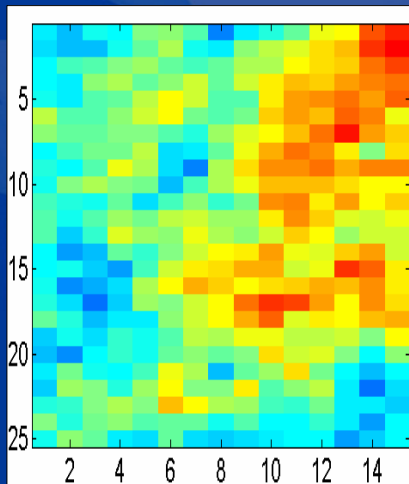
Prod. Only



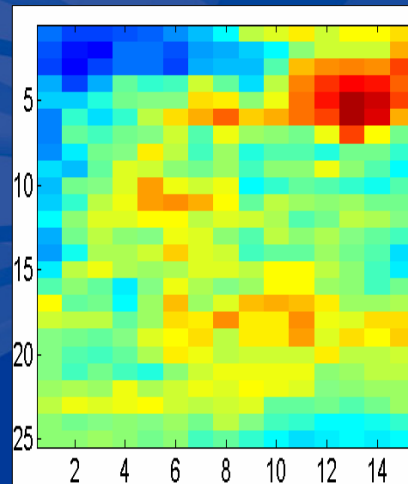
Prod. + Seismic



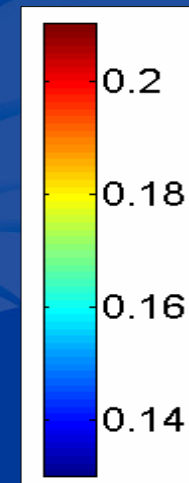
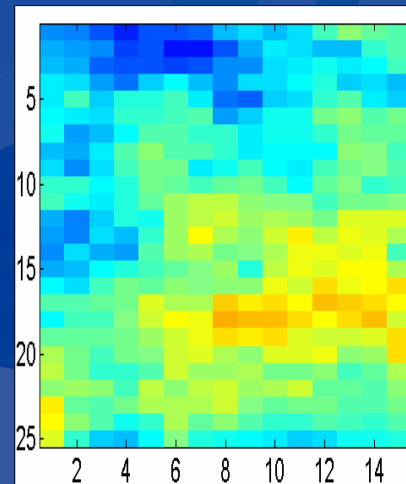
Prod. + Freq. Seismic



Prod. + Distance



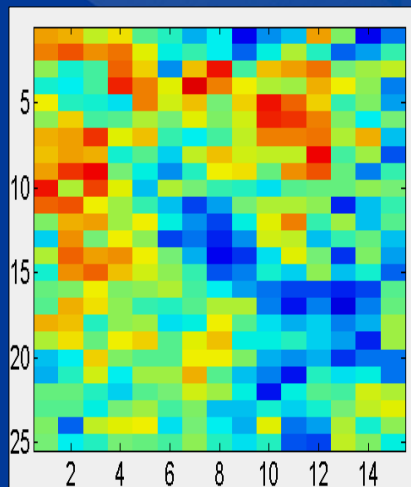
Prod.+ Drainage



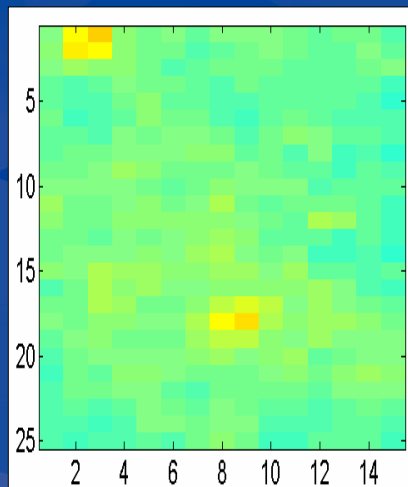
Porosity – Layer 10

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- In future...

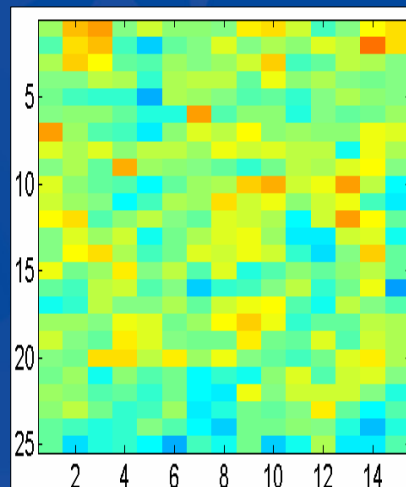
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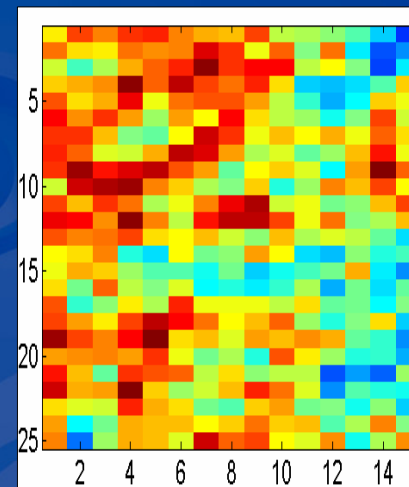
Prior



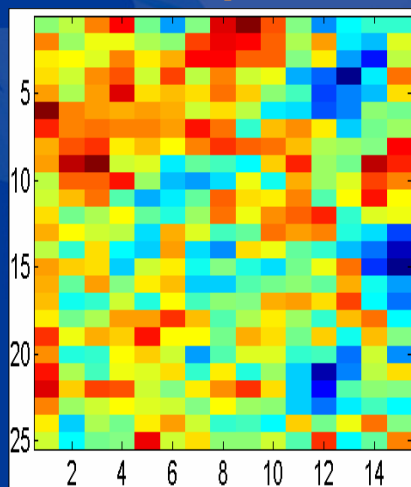
Prod. Only



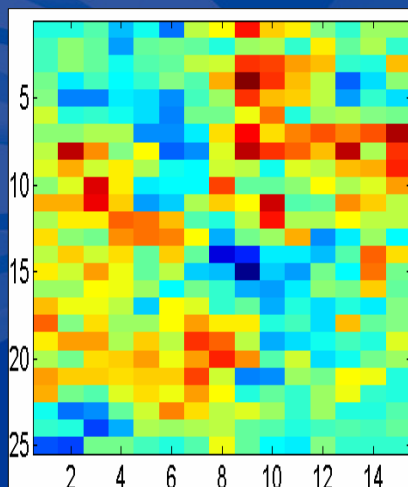
Prod. + Seismic



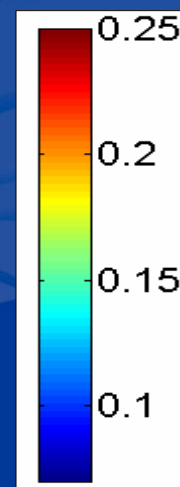
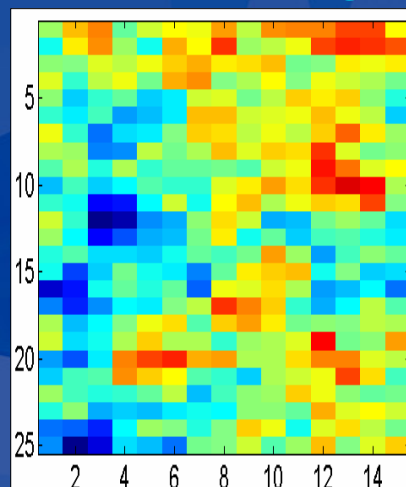
Prod. + Freq. Seismic



Prod. + Distance



Prod.+ Drainage



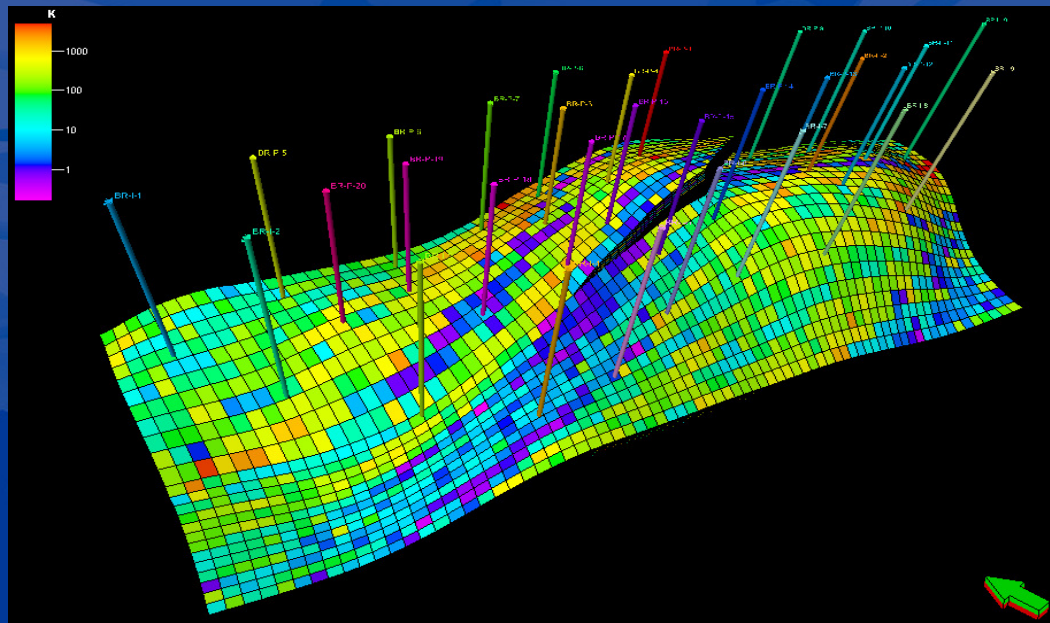
Conclusions

- 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...

- Introduction
- The EnKF and the local
- Results 3D
- Conclusions
- 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, Alhuthali, A.H./Texas A&M University, Reynolds, A.C. /University of Tulsa. SPE Reservoir Evaluation & Engineering);
- To test the routine on a real dataset...



Acknowledgements

This research was carried out within the context of the ISAPP Knowledge Centre. ISAPP – Integrated System Approach Petroleum Production – is a co-operation project of Shell International Exploration and Production BV, TU Delft, and Netherlands Organization for Applied Research TNO. The authors thank Shell International E&P for permission to use Shell's proprietary simulator suite Dynamo/MoReS, and the Shell Closed-loop Reservoir Management ("Clorem") toolbox in this study.

Any Question?

