History Matching Production and 4D Seismic Data and Application to the Norne Field

IOR Norway 2019

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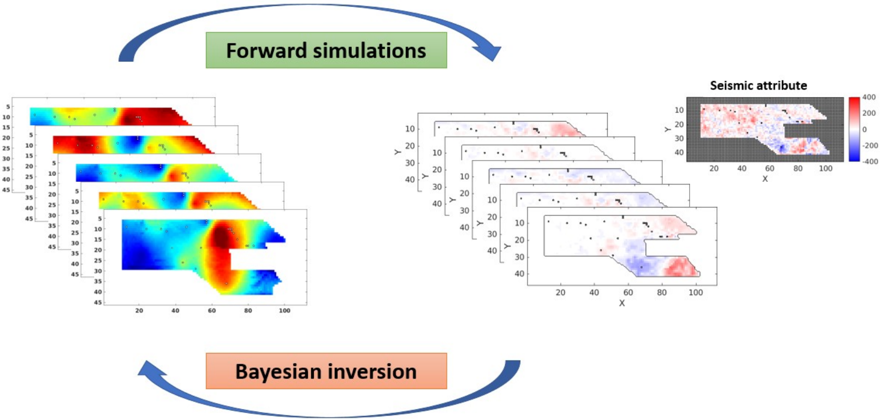
1: NORCE / The National IOR Centre, 2: University of Wyoming

Ensemble-based history matching



Ensemble-based history matching

- Provides uncertainty quantification for the reservoir model
  - Improved decision making
  - Better reservoir management
- Established for history matching of production data
  - First application to reservoir models: Nævdal et. al, 2002, SPE 75235
  - Methodology is applied world-wide, and is commercialized
  - Norne field: Evensen & Eikrem, 2018; Chen & Oliver, 2014, SPE-164902-PA
- Use of 4D seismic data is an important task for the IOR center
  - Problem with handling of large data sets (terabytes or petabytes)
  - Quantification of measurement noise is difficult

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Iterative ensemble smoother

$$m_j^{i+1} = m_j^i + K^i \cdot \Delta d_j^i,$$

$$K^i \in \mathbb{R}^{N_m \times N_d},\ \Delta d_j^i \in \mathbb{R}^{N_d \times 1}$$

Sunway Taihulight, China, 1.3 PB Mem (top500.org)

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$$\downarrow \text{SVD}$$

$$m_j^{i+1} = m_j^i + (A^i \cdot B^i) \cdot (C^i \cdot \Delta d_j^i),$$

$$A^i \in \mathbb{R}^{N_m \times N}, \ B^i \in \mathbb{R}^{N \times N}, C^i \in \mathbb{R}^{N \times N_d}$$

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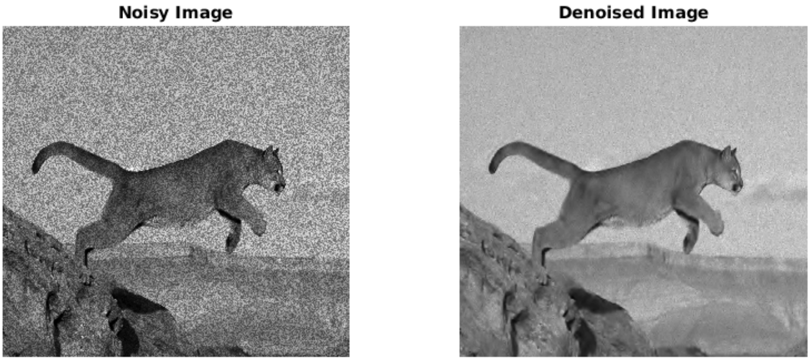
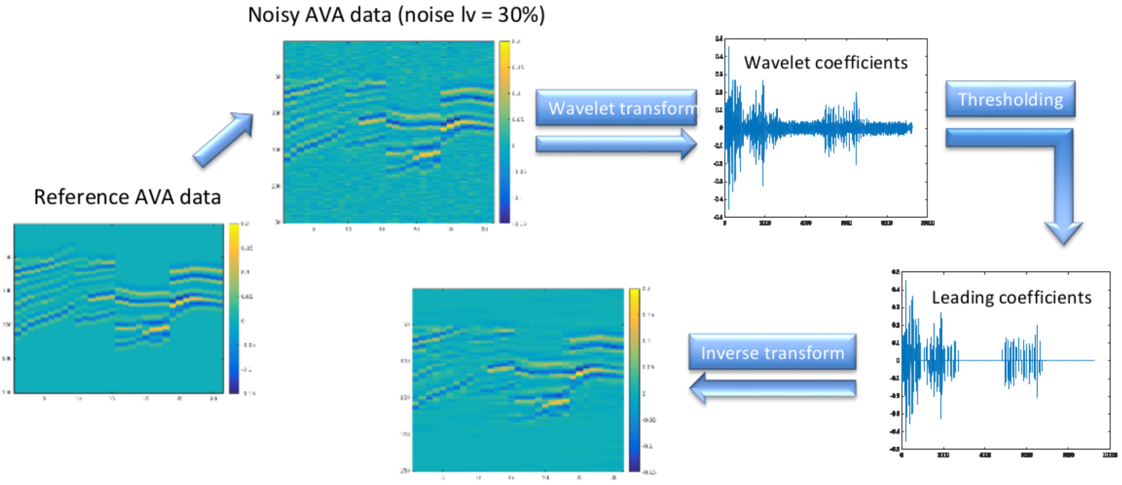
Image compression and denoising

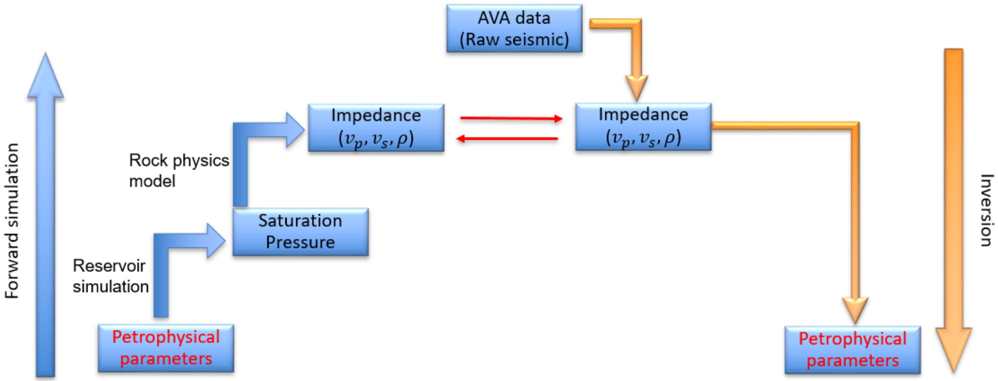


Ideas from image compression and denoising utilized for reduction of data size and measurement uncertainty quantification.
(Luo et. al, 2017, SPE-180025-PA)

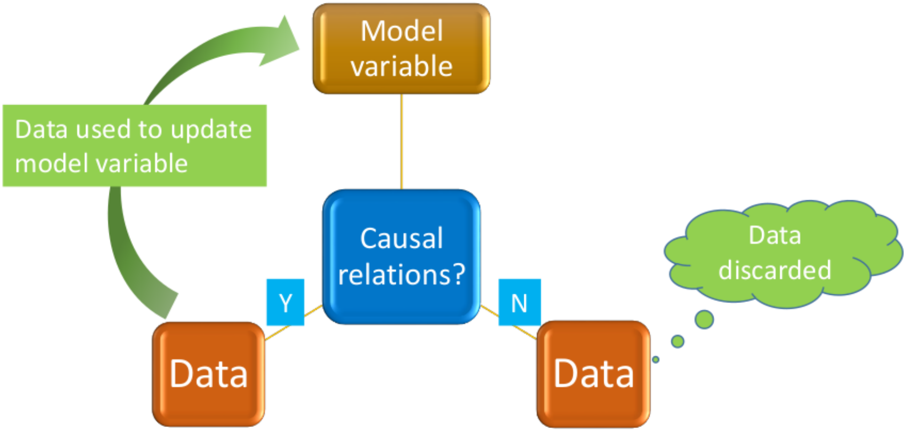
Image compression and denoising



Inclusion of 4D seismic data



Correlation-based adaptive localization

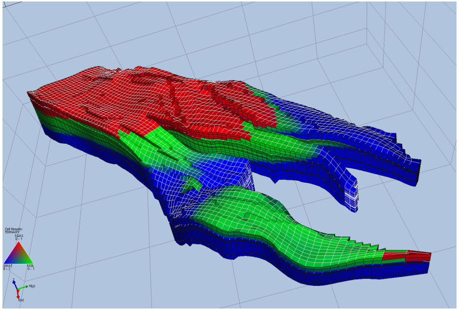


More information: Luo et. al, 2018, SPE-185936-PA.

Norne field

- Oil & gas field in Norwegian sector
- 5 formations
- Hydrocarbon column approx. 135 m
- Original oil-in-place: 160 million Sm^3
- Most of the sandstones are good reservoir rocks
- Wells: 9 injectors, 27 producers
- Production history: Nov. 1997–2006
- 4 seismic surveys (2001, 2003, 2004, 2006)
- 3×9 km

- Grid size: 46 x 112 x 22
- Active cells: 44927



History matching the Norne field

- Initial ensemble generated using Gaussian random fields
- Updates porosity, permeability, net-to-gross, transmissibility multipliers, relative permeability, initial oil-water contact,...
- Clay content defined as 1 minus "net-to-gross"
- Data scaled based on initial data match
- Seismic data inverted for acoustic impedance at four points in time
- Iterative ensemble smoother, RLM-MAC, used (Luo et. al, 2015, SPE-176023-PA)

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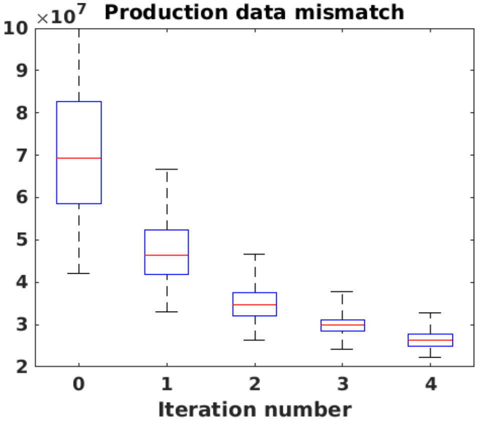
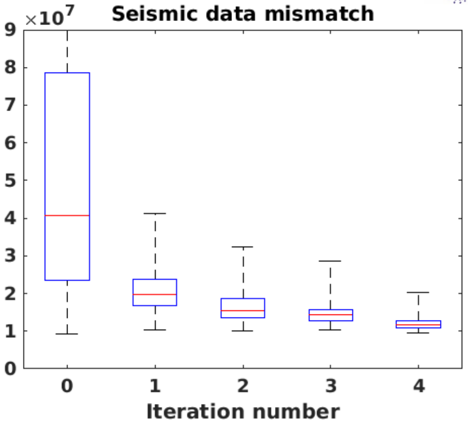


Production data mismatch
×10^7
10
9
8
7
6
5
4
3
2
0
1
2
3
4
Iteration number



Seismic data mismatch
×10^7
9
8
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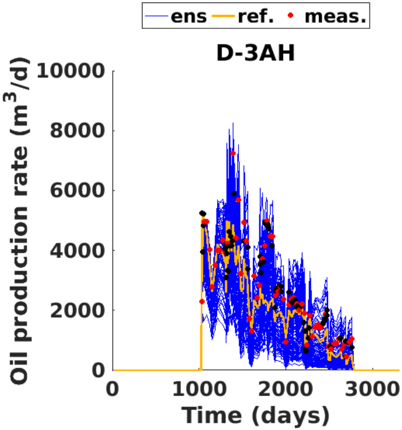

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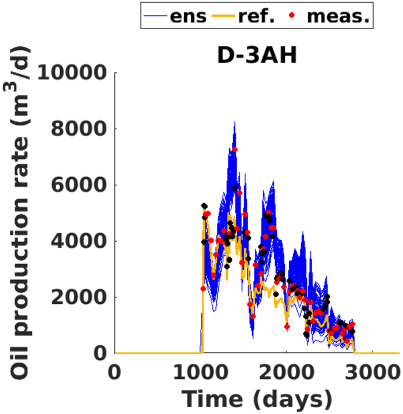
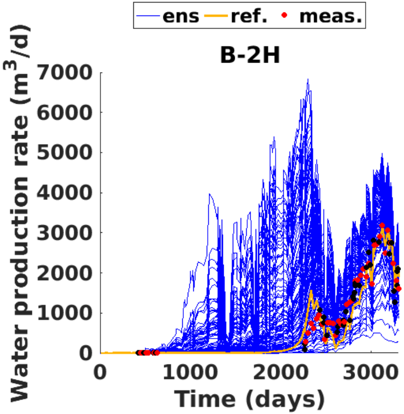


Final



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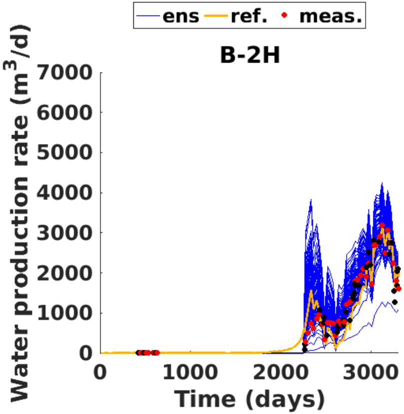

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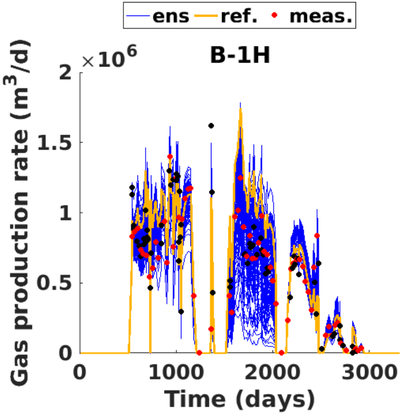

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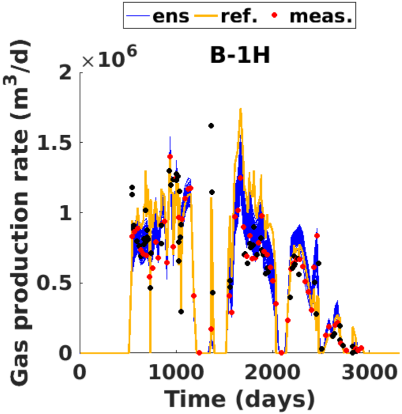
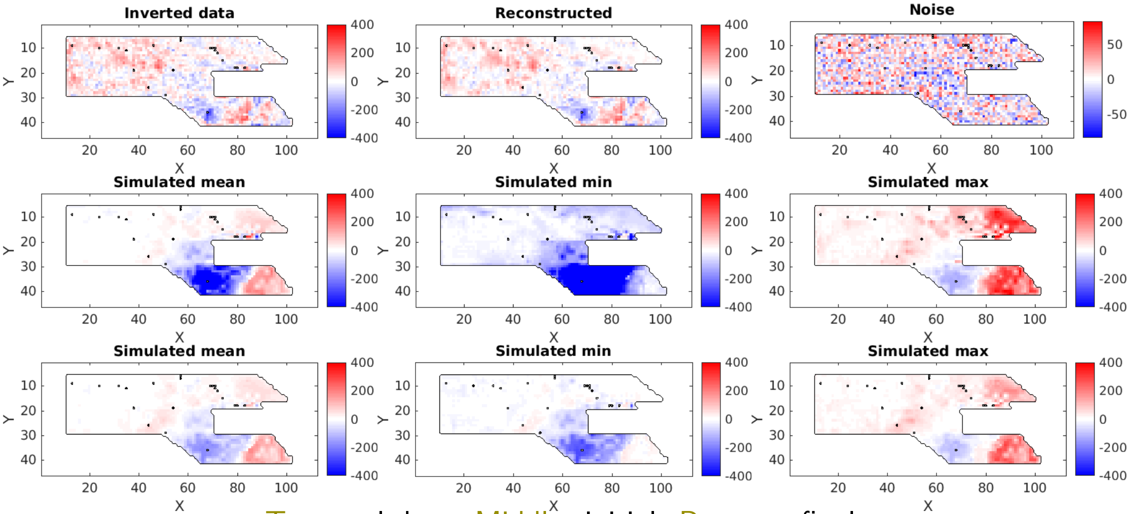
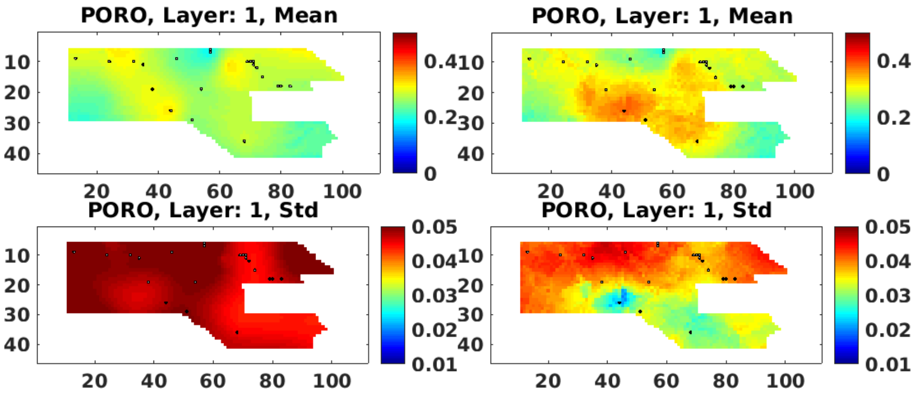


Final



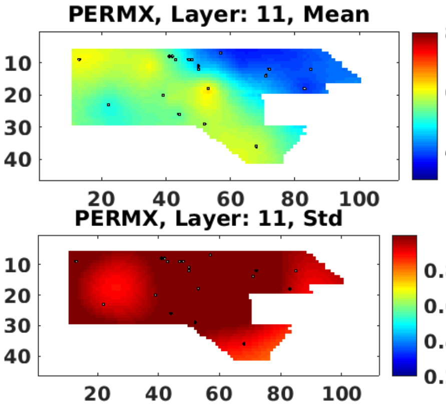
Top: real data. Middle: initial. Bottom: final.

Garn formation, Ip difference.

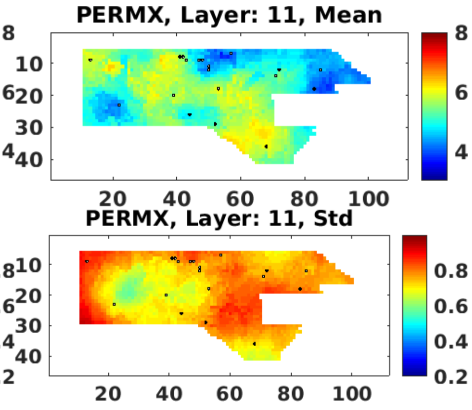


Initial

Final



PERMX, Layer: 11, Mean
PERMX, Layer: 11, Std
Initial



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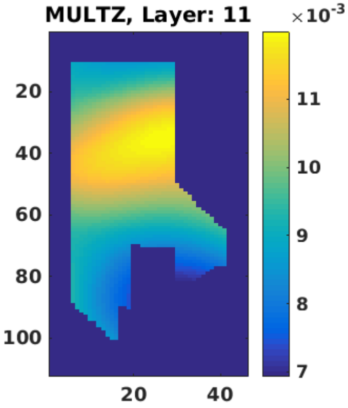

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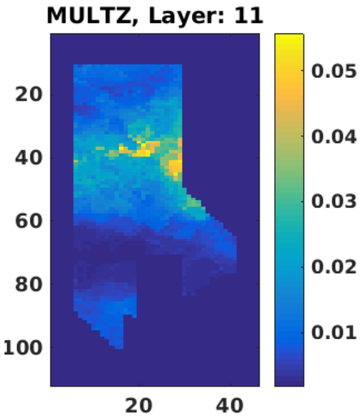

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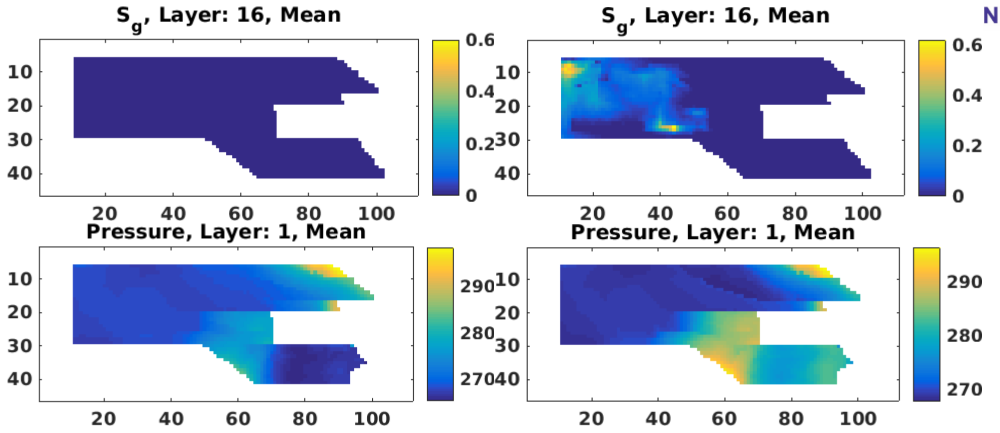

Mean gas saturation (*top*) and pressure (*bottom*) at year 1997 (*left*) and 2006 (*right*).

Summary / Conclusions

- A workflow for history matching real production and seismic data is presented
- Methodology demonstrated on the Norne field
- Clay content and other petrophysical parameters updated
- Data match improved for both production and seismic data
- Updated static fields are geologically credible
- Used for reservoir management and uncertainty quantification
- Simulation of infill wells, EOR strategies and monitoring of EOR operations

- Lorentzen et. al, 2018, ECMOR XVI, earthdoc.org; and submitted to Computational Geosciences (sequential updating)
- Lorentzen et. al, 2019, SPE Journal, DOI: https://doi.org/10.2118/194205-PA (synthetic data)
- https://github.com/rolfjl/Norne-Initial-Ensemble

The 2019 user partners and observers:

Acknowledgments

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- Equinor (operator of Norne field) and its license partners ENI and Petoro for the release of the Norne data.
- IOR Center for Integrated Operations at NTNU for cooperation and coordination of the Norne Cases.
- Schlumberger and CGG for providing academic software licenses to ECLIPSE and HampsonRussell, respectively.

Measurement operator

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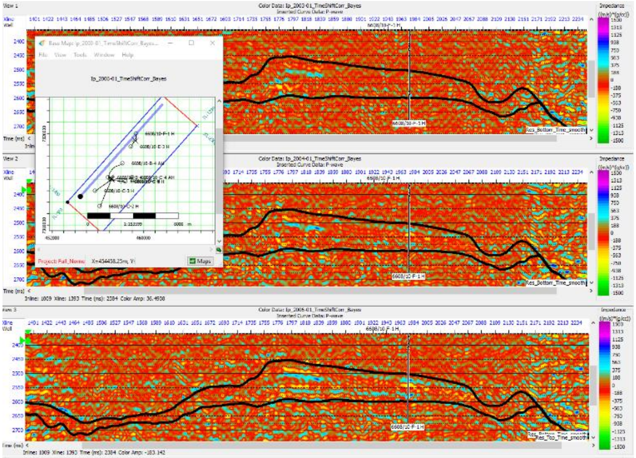
4. applying the discrete wavelet transform to get wavelet coefficients
5. using the leading indices $\mathcal{I}$ to get d_j

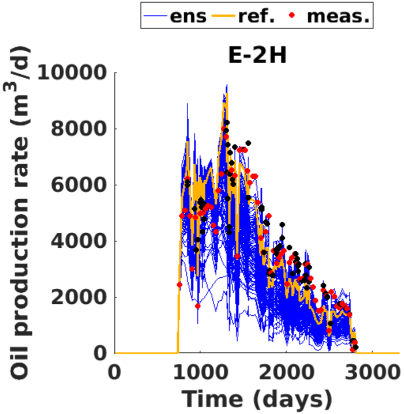
Seismic data inversion and transformation

- Time shift correction:
  Alfonzo et. al, 2017
- Linearized Bayesian approach:
  Buland and Omre, 2003
- Time to depth conversion:
  Provided Norne velocity model
- Upscaling:
  Petrel software
- Difference and averaging:
  $\overline{\Delta z}_p^o$



Petro-elastic model

- Estimate mineral bulk and shear moduli:
  $[K_s, G_s] \leftarrow \mathrm{Hashin - Shtrikman}(K_{\mathrm{quartz}}, G_{\mathrm{quartz}}, K_{\mathrm{clay}}, G_{\mathrm{clay}}, V_{\mathrm{clay}})$
- Dry rock bulk and shear moduli (empirical):
  $[K_{\mathrm{dry}}, G_{\mathrm{dry}}] \leftarrow f(p, p_{\mathrm{ini}}, \phi)$
- Fluid substitution:
  $[K_{\mathrm{sat}}, G_{\mathrm{sat}}] \leftarrow \mathrm{Gassmann}(K_{\mathrm{dry}}, G_{\mathrm{dry}}, K_s, s_o, s_g, s_w)$
- P-wave velocity and rock density:
  $[v_p, \rho_{\mathrm{sat}}] \leftarrow \mathrm{Mavko}(K_{\mathrm{sat}}, G_{\mathrm{sat}})$
  $z_p = v_p \times \rho_{\mathrm{sat}}$



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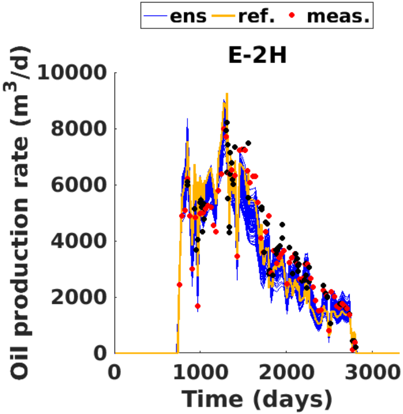

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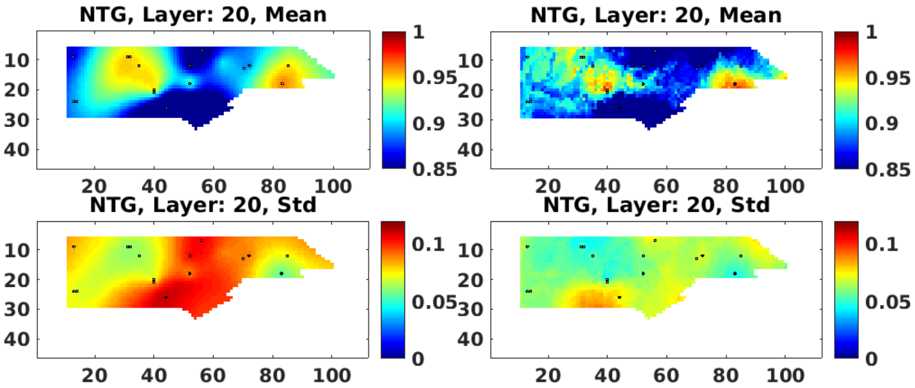

Initial

Final