Efficient big data assimilation through sparse representation: A case study in 4D seismic history matching

Xiaodong Luo, IRIS & The National IOR Centre of Norway; Tuhin Bhakta, IRIS & The National IOR Centre of Norway; Morten Jakobsen, UiB, IRIS & The National IOR Centre of Norway; and Geir Nævdal, IRIS & The National IOR Centre of Norway

Outline

- Background
- Proposed framework
- Numerical examples
- Conclusion and future works

Background

What is history matching about ?

Effect – observed data

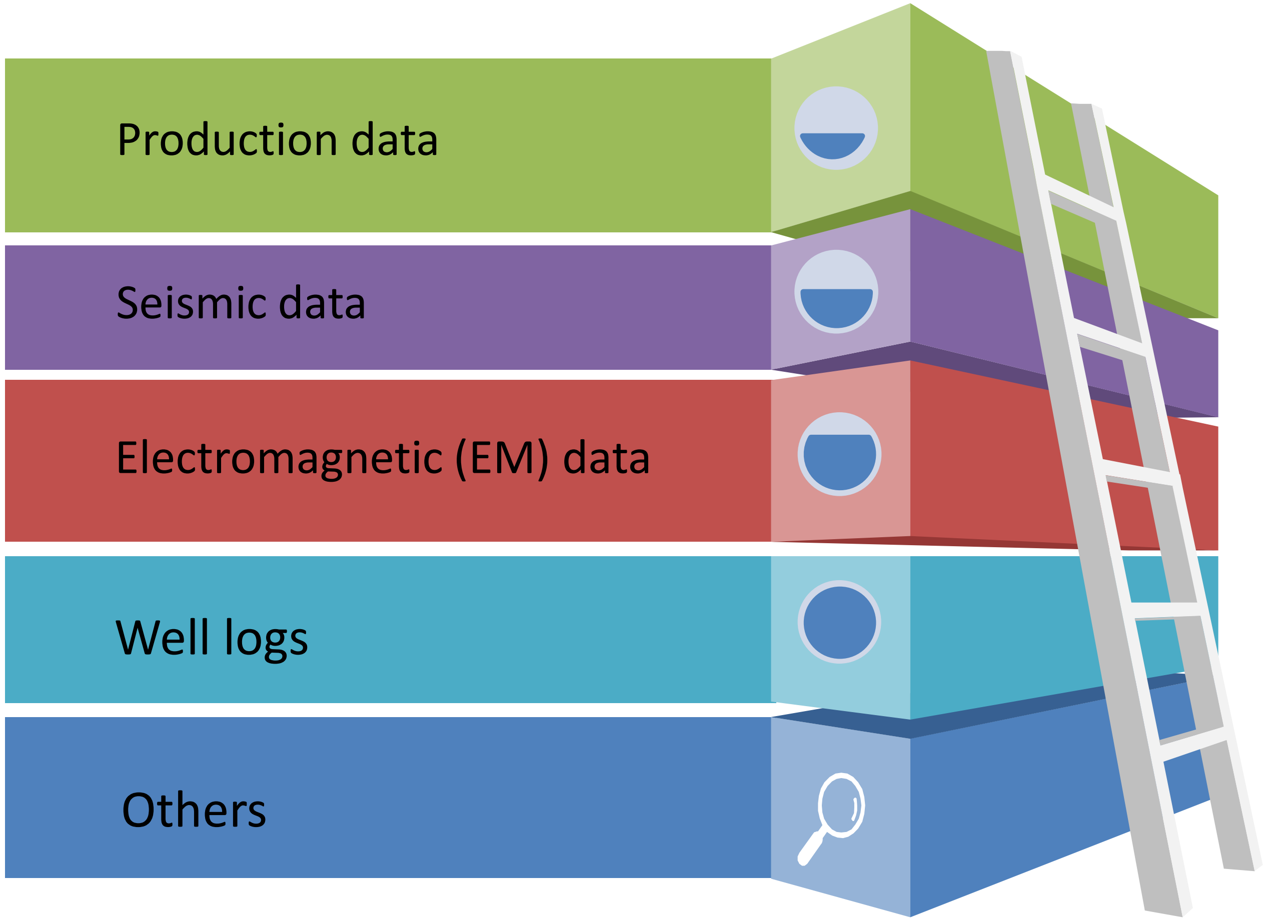
Cause – Petro-physical parameters (PERM,PORO)

Detectives – history matching algorithms

History matching aims to find proper values of petro-physical parameters to explain observed data

Background

Data in history matching



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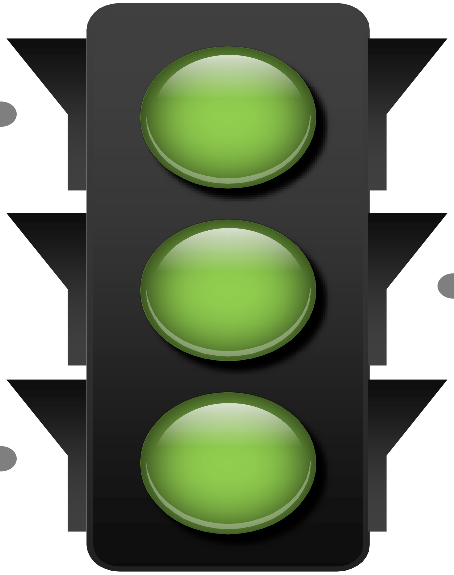
Background

Seismic data

- Amplitude versus angle (AVA);
- or raw seismic data



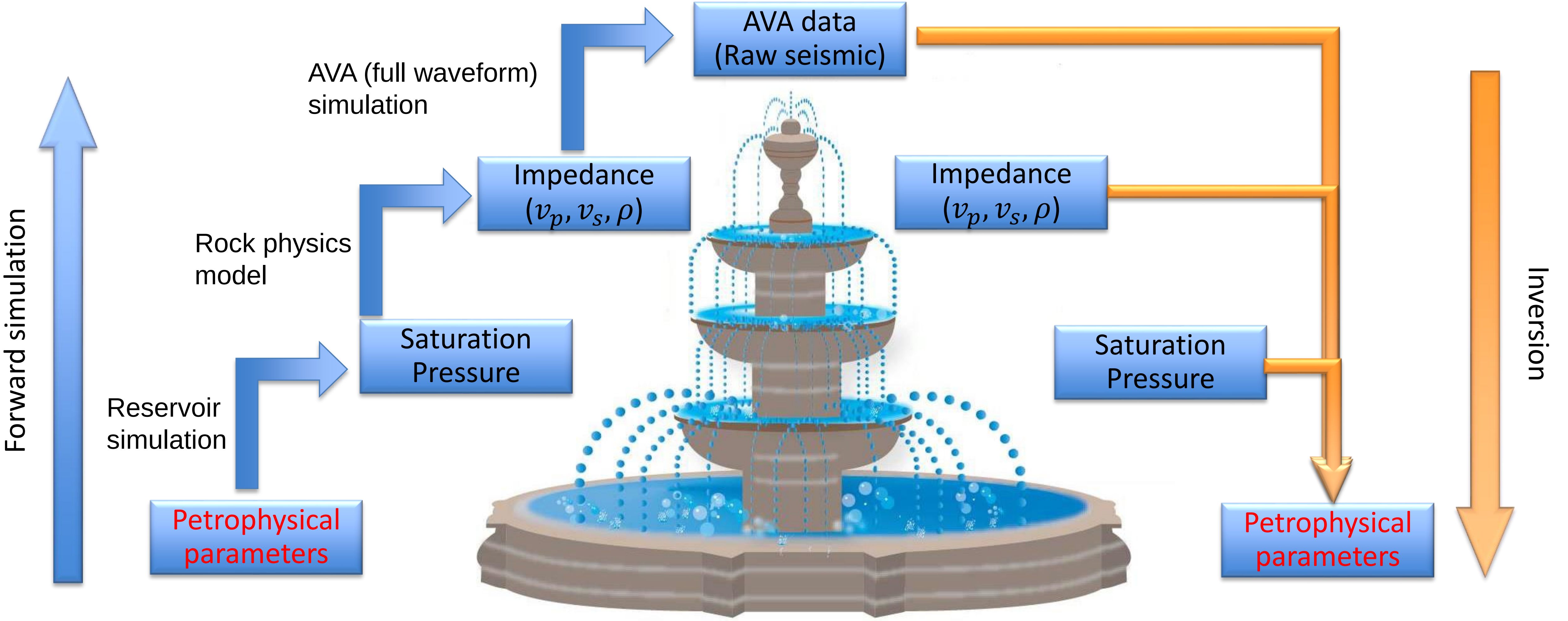
- Impedances (I_p, I_s);
- or velocities (v_p, v_s) and density

- Saturation and pressure maps

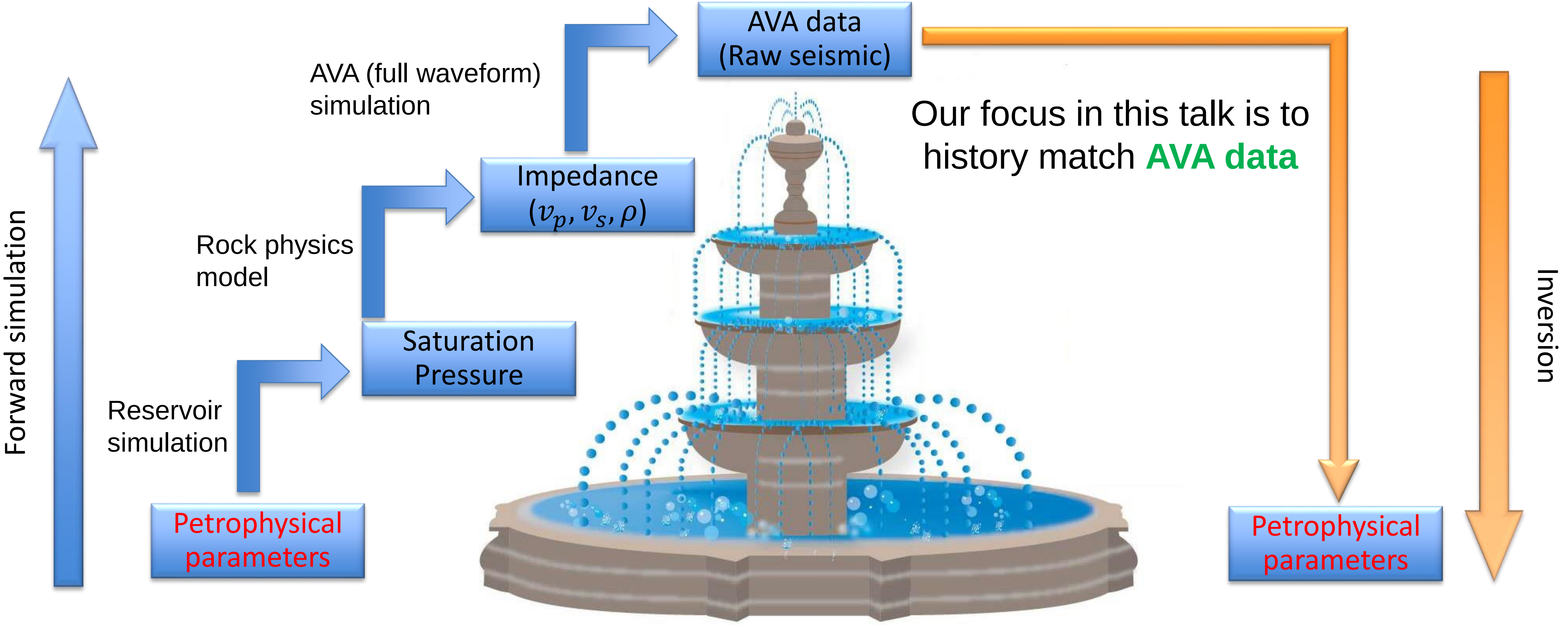
Seismic data at different “levels”

Background

Relation between reservoir petro-physical parameters and seismic data at different levels



Background


AVA data
(Raw seismic)
AVA (full waveform)
simulation
Impedance
(v_p, v_s, ρ)
Rock physics
model
Saturation
Pressure
Reservoir
simulation
Petrophysical
parameters
Forward simulation
Our focus in this talk is to
history match **AVA data**
Petrophysical
parameters
Inversion

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Background

Challenge in history-matching seismic data

Conventional history matching

- Small to moderate data
- Data size < model size
- Moderate demand of computing power and memory

Seismic history matching

- Big data
- Data size ≥ model size
- High demand of computing power and memory, if without an efficient method
- Extra computational issues

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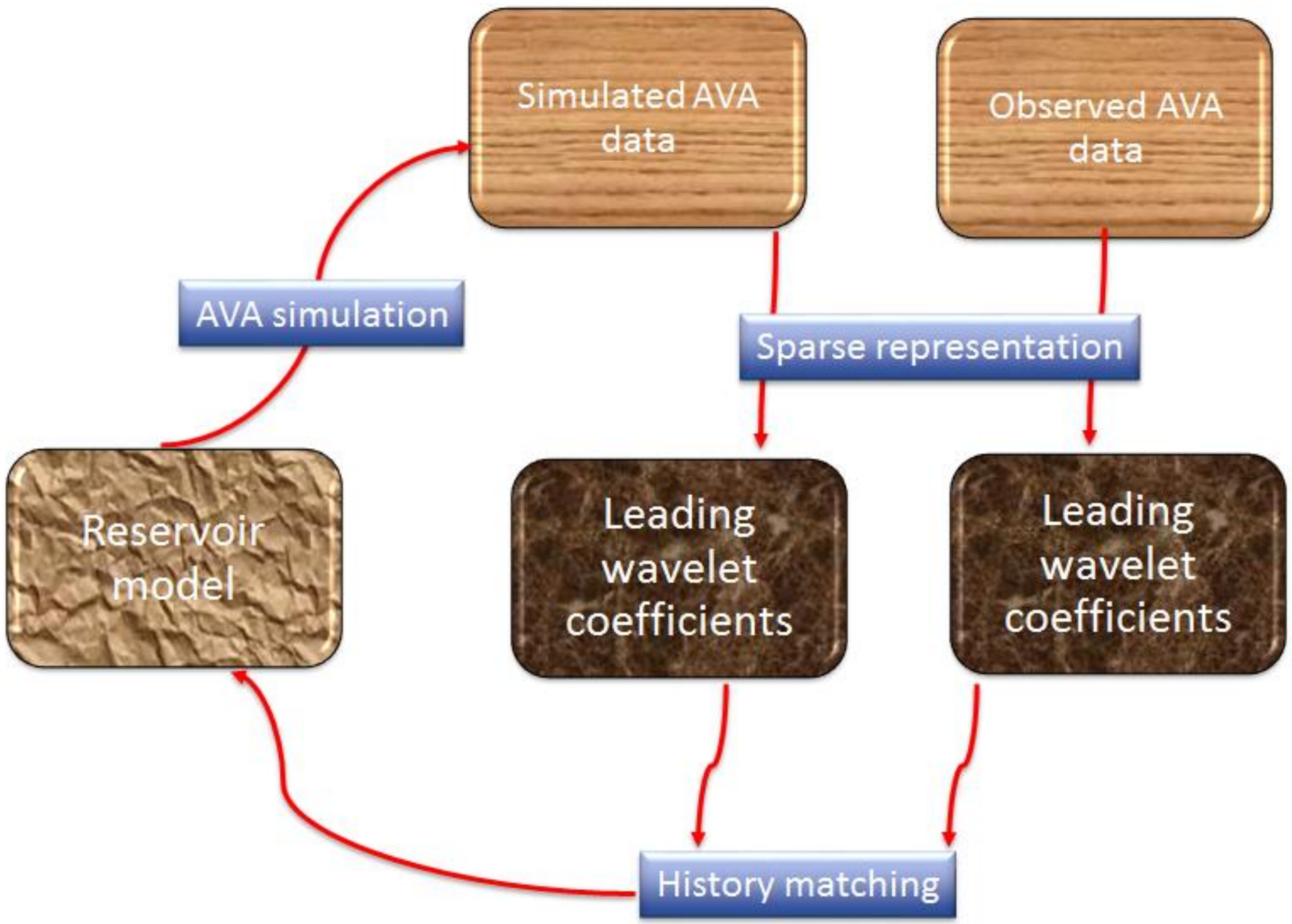
Proposed framework

Workflow



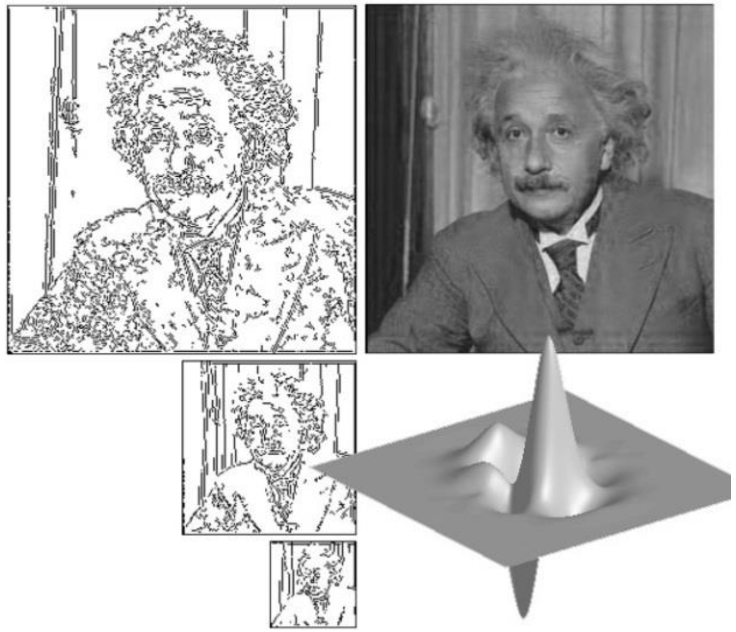
Proposed framework

Motivation

Use wavelet-based sparse representation to address the big data problem in seismic history matching.

Proposed framework

Wavelet-based sparse representation



Starck, Jean-Luc, Fionn Murtagh, and Jalal Fadili. Sparse Image and Signal Processing: Wavelets and Related Geometric Multiscale Analysis. Cambridge University Press, 2015

Seismic data

- Discrete wavelet transform (DWT)

Wavelet coefficients

- Estimate noise of wavelet coefficients
- Apply thresholding to remove small wavelet coefficients

Leading coefficients used for history matching

- Reduced data size
- Estimation of observation error covariance
- Applicability to various types of seismic data (AVA, impedance etc.)

Proposed framework

Illustration: 2D data

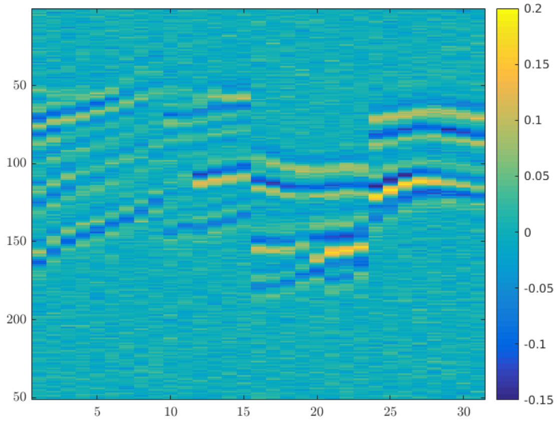
- Leading coefficients used in history matching
- Number of leading coefficients is about 6% of the original

Thresholding

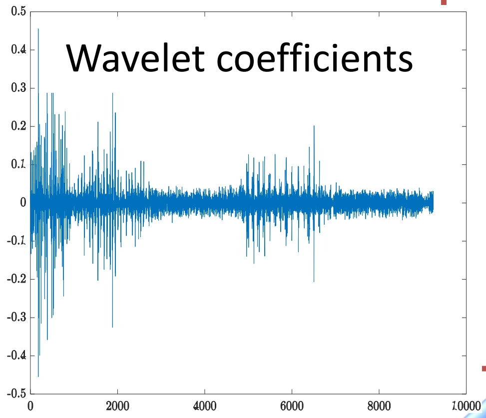
True noise STD = 0.0148;

...se STD = 0.0141

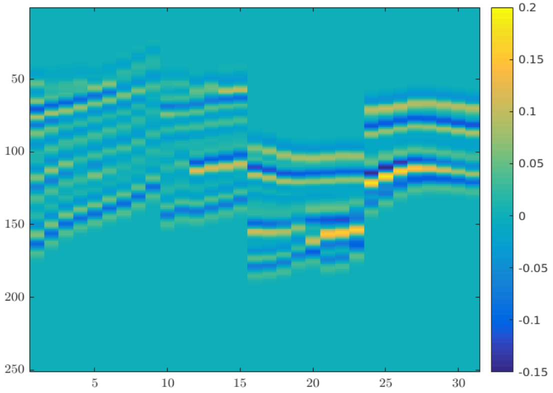
Noisy AVA data (noise lv = 30%)

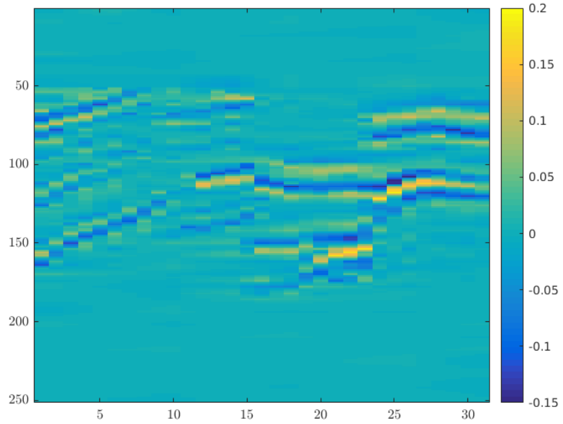


Wavelet transform

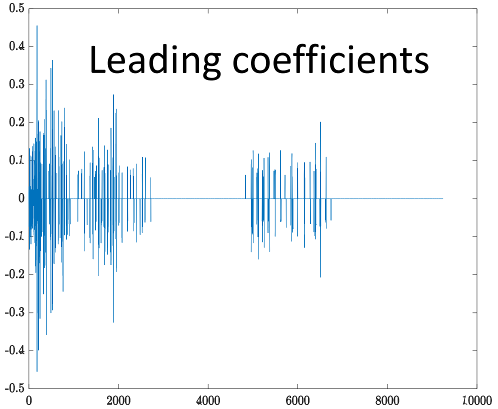


Reference AVA data





Inverse transform



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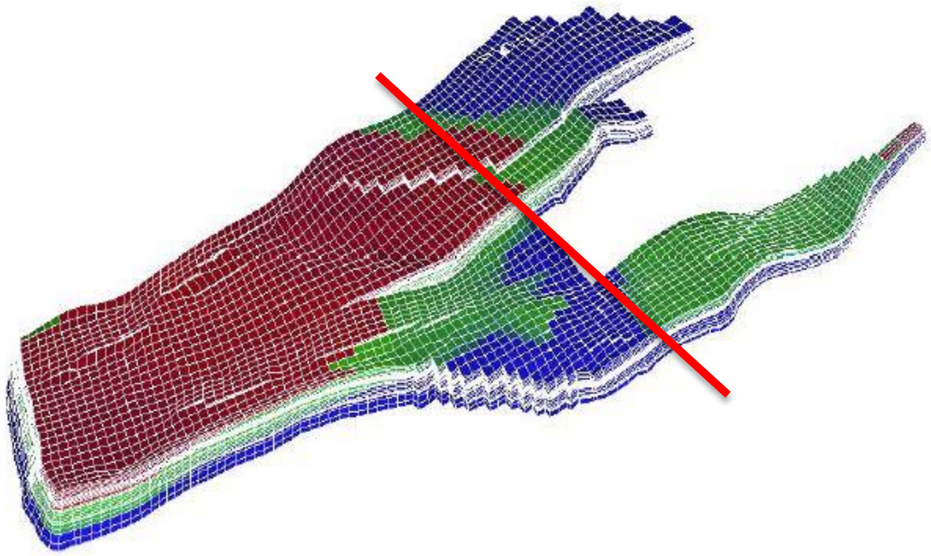
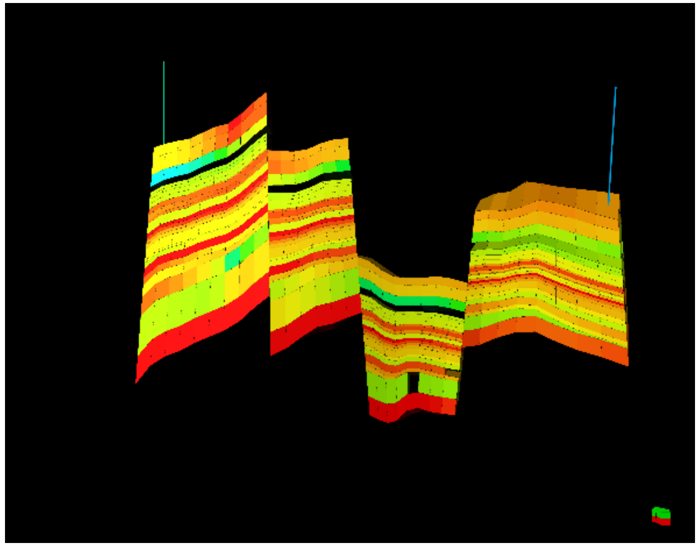
Numerical example I: A 2D Norne field model



3D Norne field model



PERMX filed of the 2D model

(The 2D model is kindly provided by Dr. Mohsen Dadashpour)

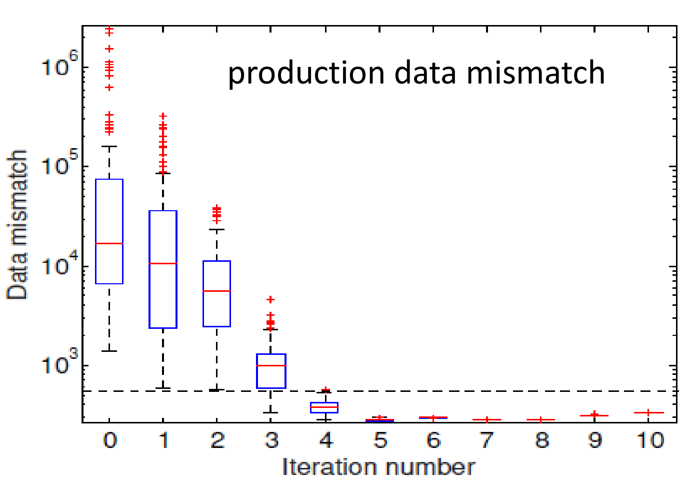
Numerical example I: A 2D Norne field model

Experimental settings	
Model size	39x1x26, with 739 out of 1014 being active gridcells
Parameters to estimate	PORO, PERMX. Total number is 2x739 = 1478
Production data (~10 yrs)	BHP, GOR, OPT, WCT. Total number is 135
4D seismic data (1 Base + 2 monitor surveys)	AVA intercept and gradient. Total number is 46686
Leading wavelet coefficients	Total number is 2746
History matching algorithm	Iterative ensemble smoother*

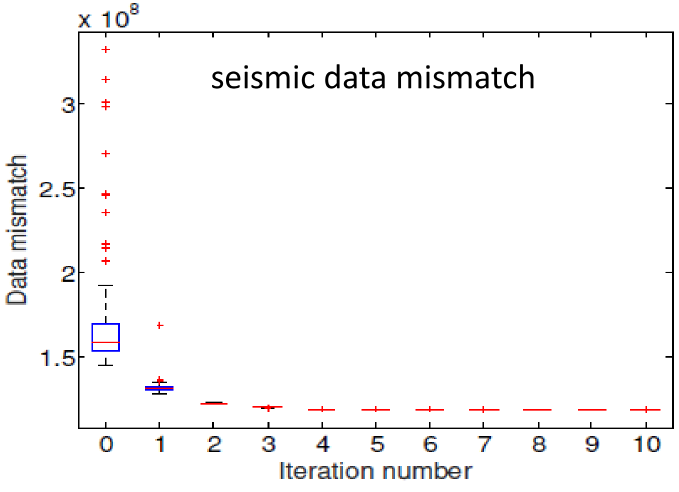
*Luo, X., et al. (2015). "Iterative ensemble smoother as an approximate solution to a regularized minimum-average-cost problem: theory and applications." SPE Journal, 20, 962 - 982, paper SPE-176023-PA.

Numerical example I: A 2D Norne field model

Results when both production and seismic data are used (more results in SPE-180025-MS*)



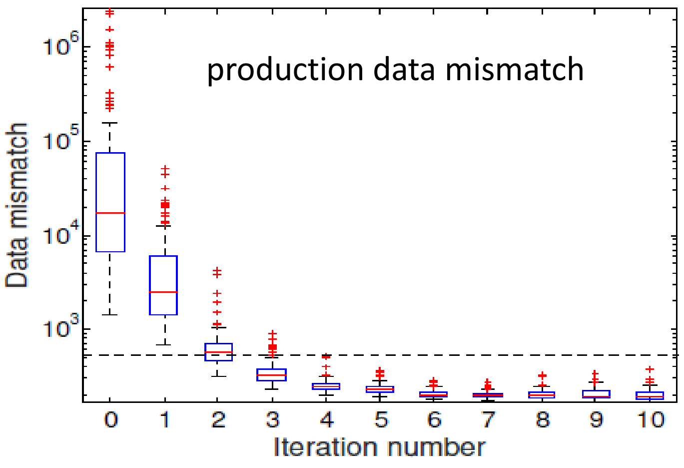
(a) Production data, full-data experiment



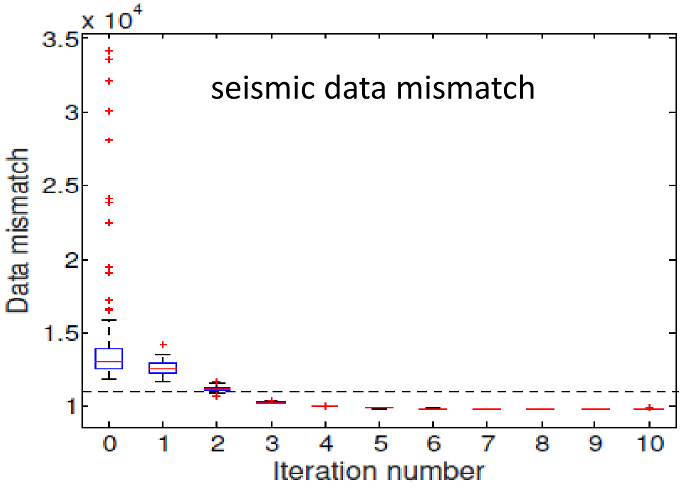
(b) Seismic data, full-data experiment

Production and seismic data mismatch

Results of history-matching original seismic data without wavelet-base sparse representation



(c) Production data, sparse-data experiment



(d) Seismic data, sparse-data experiment

Production and seismic data mismatch

Results of history-matching leading wavelet coefficients

*Luo, X., et al. (2016). An Ensemble 4D Seismic History Matching Framework with Sparse Representation Based on Wavelet Multiresolution Analysis. SPE Bergen One Day Seminar, Bergen, Norway, 20 April, 2016. Paper SPE-180025-MS.

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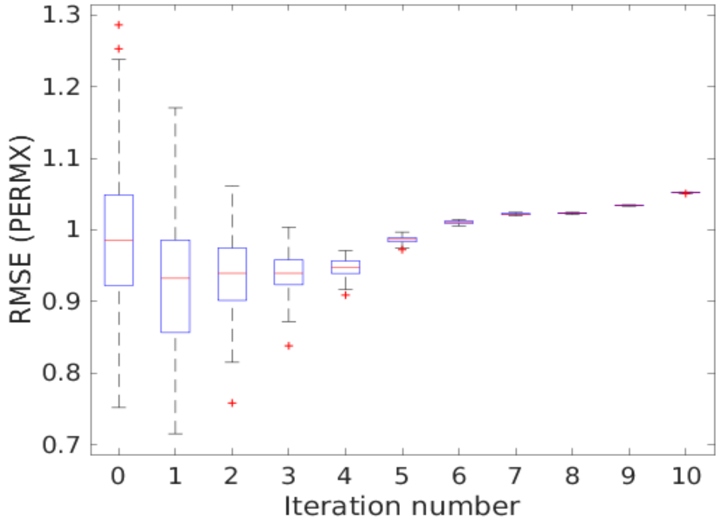
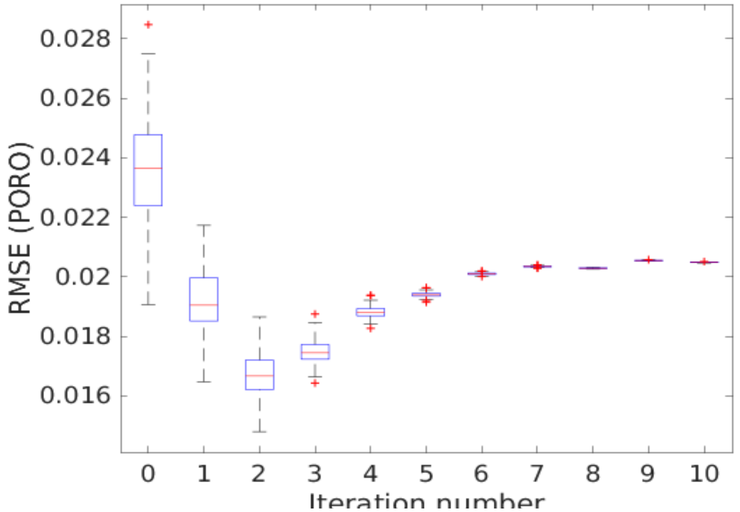
Numerical example I: A 2D Norne field model

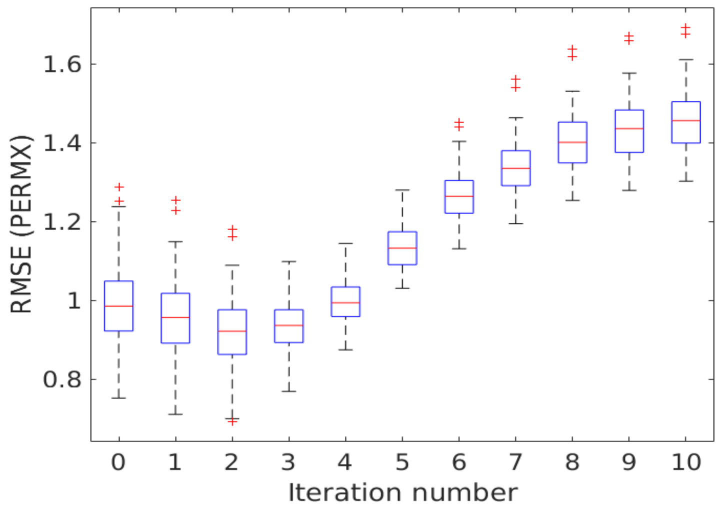
Results when both production and seismic data are used (more results in SPE-180025-MS*)

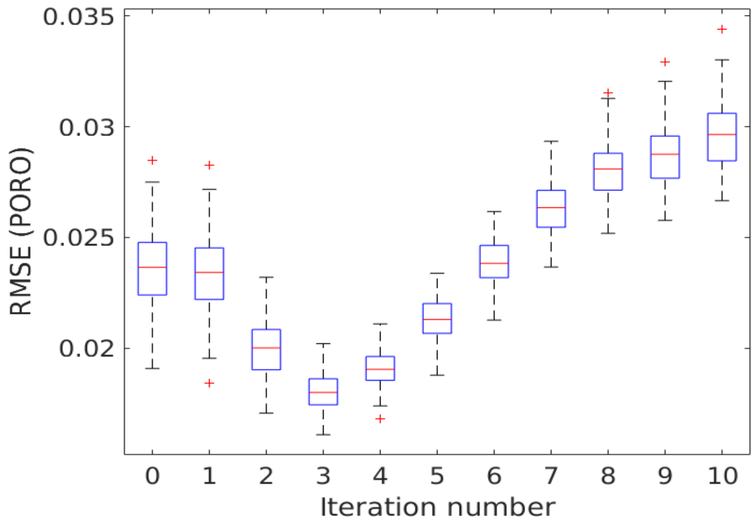




RMSE of PERMX (left) and PORO (right)

Results of history-matching original seismic data without wavelet-base sparse representation





RMSE of PERMX (left) and PORO (right)

Results of history-matching leading wavelet coefficients

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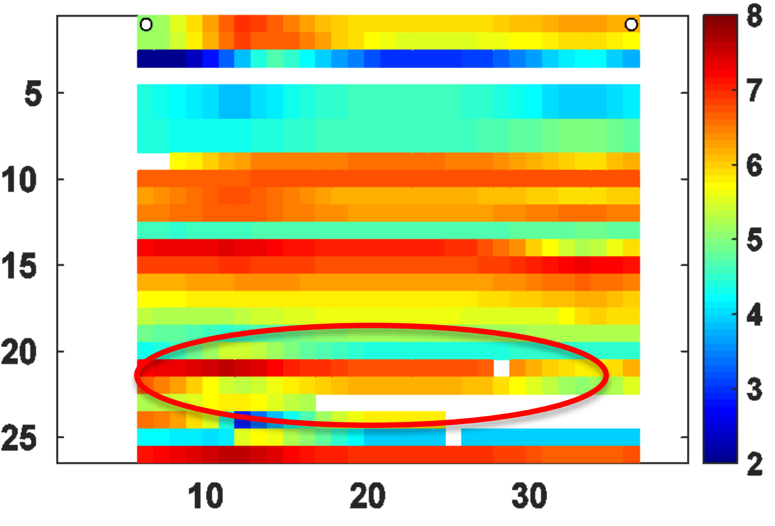
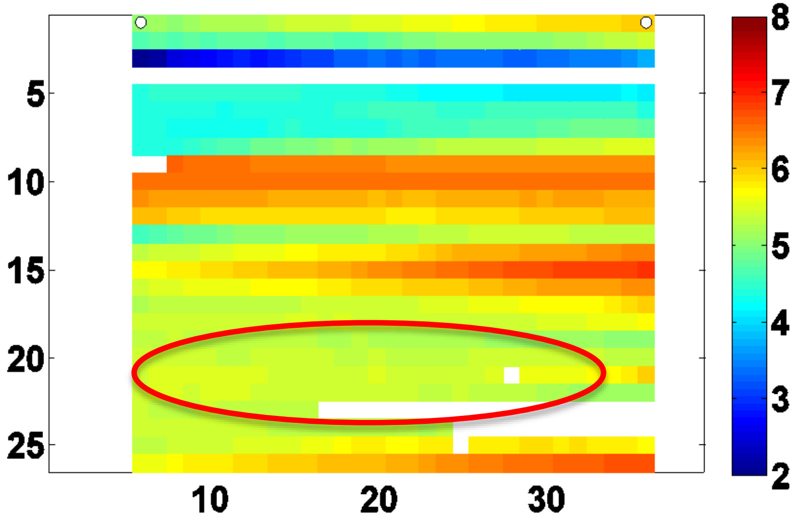
Numerical example I: A 2D Norne field model

Results when both production and seismic data are used (more results in SPE-180025-MS*)

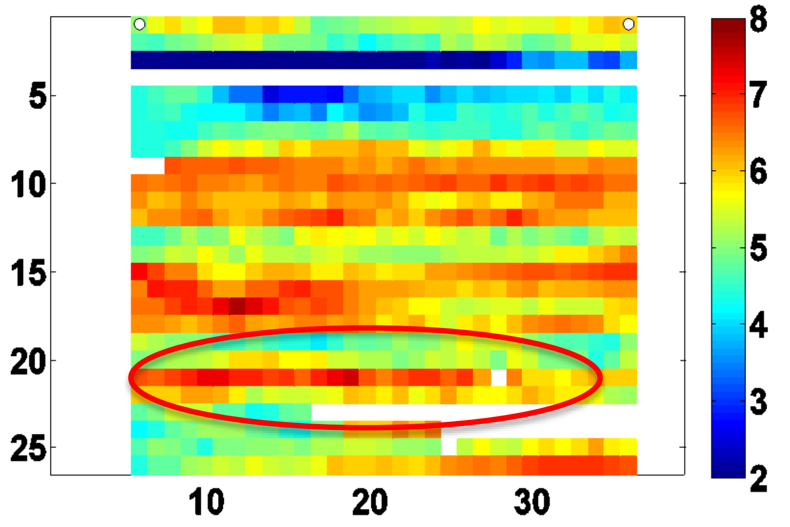
Reference log PERMX



Mean log PERMX of initial guess



Mean log PERMX after history matching



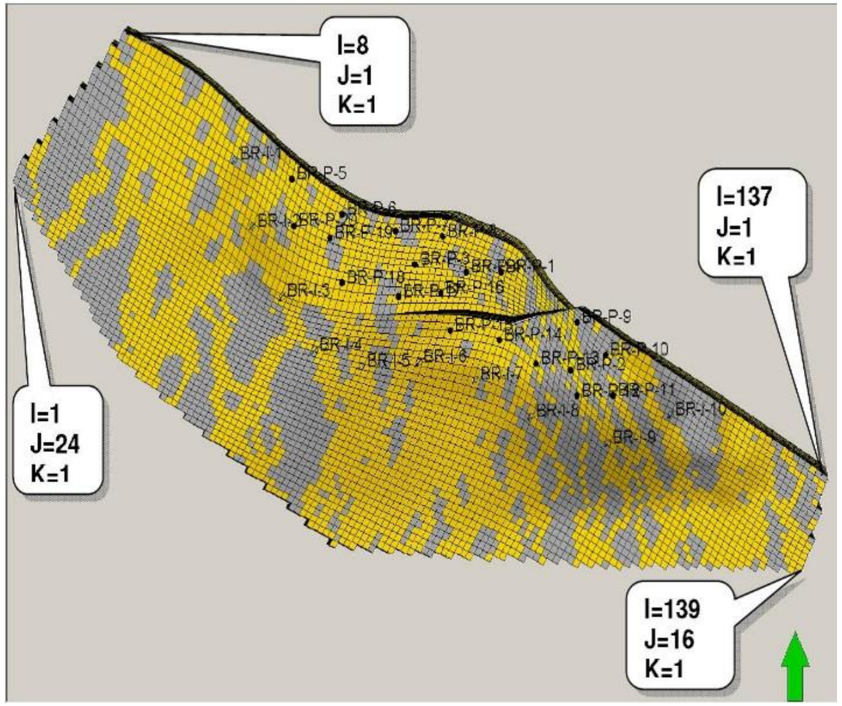
*Luo, X., et al. (2016). An Ensemble 4D Seismic History Matching Framework with Sparse Representation Based on Wavelet Multiresolution Analysis. SPE Bergen One Day Seminar, Bergen, Norway, 20 April, 2016. Paper SPE-180025-MS.

Numerical example I: A 2D Norne field model

Our finding in this particular case
(for more information see SPE-180025-MS)

Through sparse representation, better history matching results are obtained in comparison to the case of using the original AVA attribute data

Numerical example II: 3D Brugge field model



Grid geometry of Brugge field

Experimental settings

Model size	139x48x9, with 44550 out of 60048 being active gridcells
Parameters to estimate	PORO, PERMX, PERMY, PERMZ. Total number is 4x44550 = 178,200
Production data (~10 yrs)	BHP, OPR, WCT. Total number is 1400
4D seismic data (1 Base + 2 monitor surveys)	Near and far-offset AVA data. Total number is ~ 7 x 10^6 (needing too much computer memory to be used directly)
Leading wavelet coefficients	Two cases: 1. Total number is 178,332 (~2.5%); 100K case 2. Total number is 1665 (~0.02%). 1K case
History matching algorithm	Iterative ensemble smoother*

*Luo, X., et al. (2015). "Iterative ensemble smoother as an approximate solution to a regularized minimum-average-cost problem: theory and applications." SPE Journal, 20, 962 - 982, paper SPE-176023-PA.

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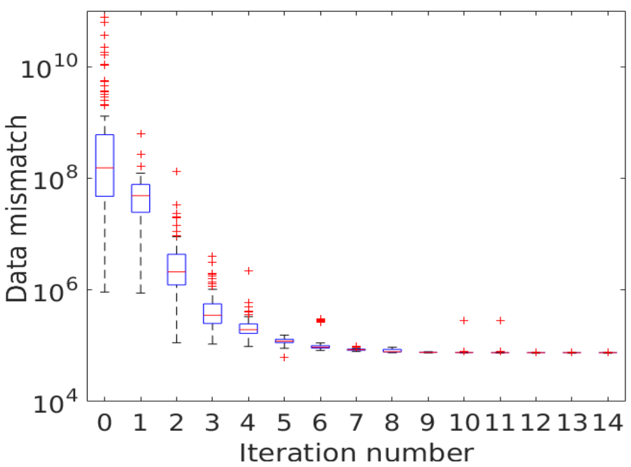
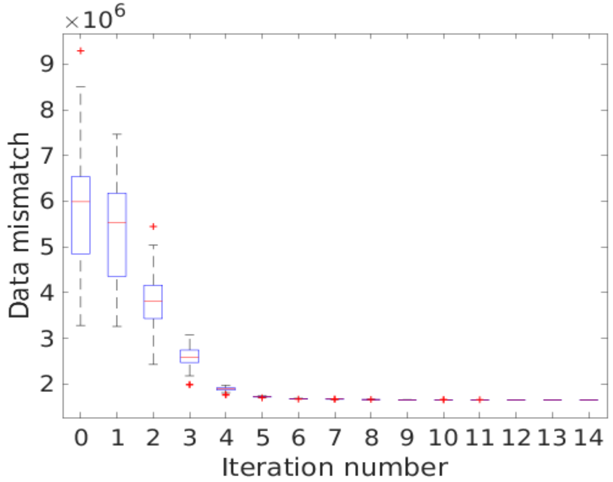
Numerical example II: 3D Brugge field model

Results when both production and seismic data are used (more results to be presented in ECMOR*)

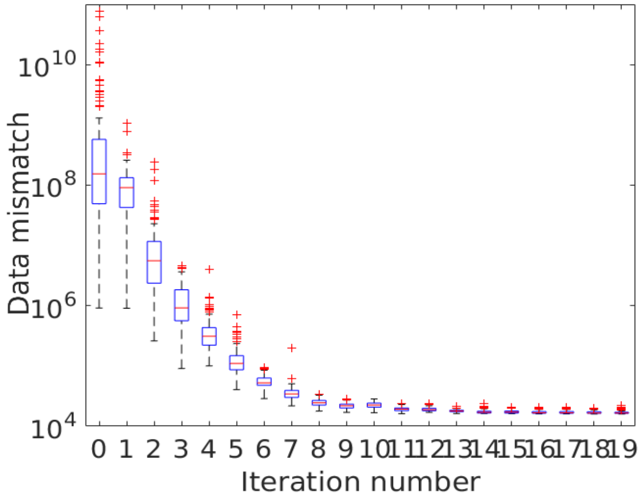
Production data mismatch

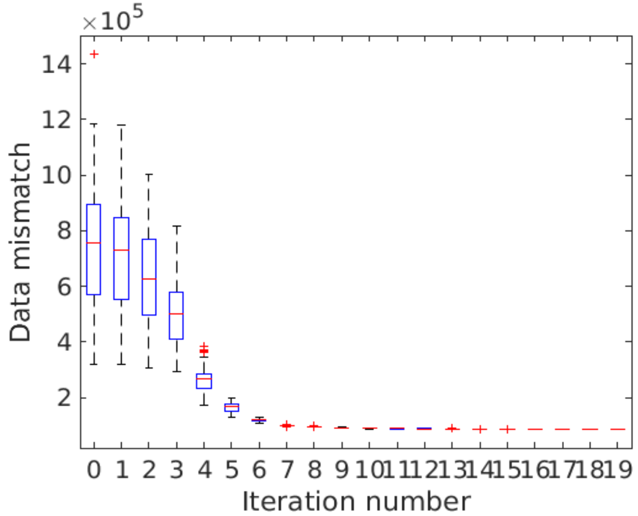


Seismic data mismatch



Production and seismic data mismatch in 100K case





Production and seismic data mismatch in 1K case

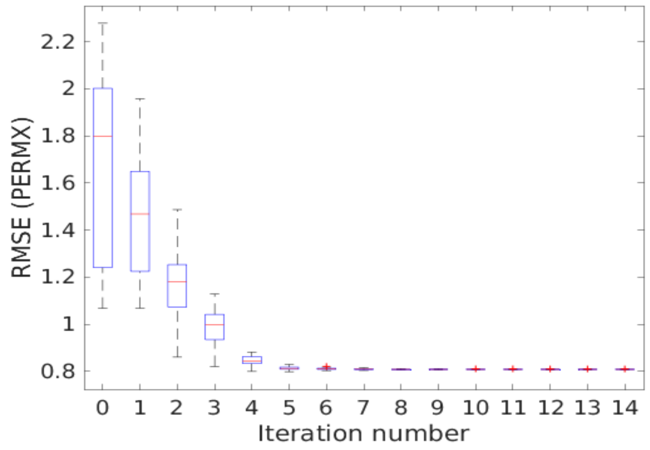
*Luo, X., et al. (2016). An Ensemble 4D Seismic History Matching Framework with Sparse Representation and Noise Estimation: A 3D Benchmark Case Study. 15th European Conference on the Mathematics of Oil Recovery (ECMOR), Amsterdam, Netherlands, 29 August - 01 September, 2016.

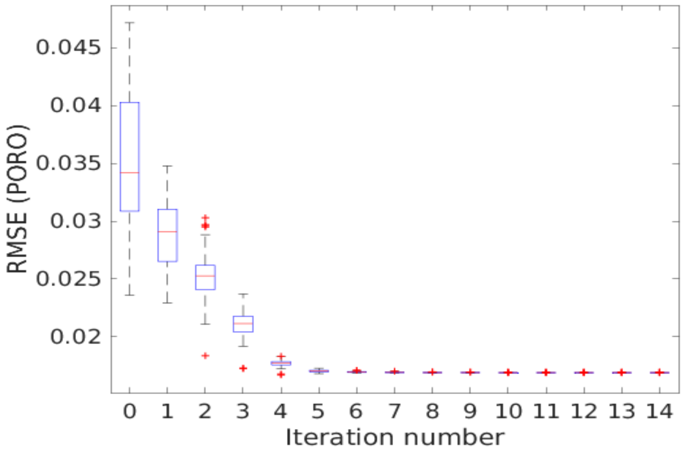
Numerical example II: 3D Brugge field model

Results when both production and seismic data are used (more results to be presented in ECMOR*)

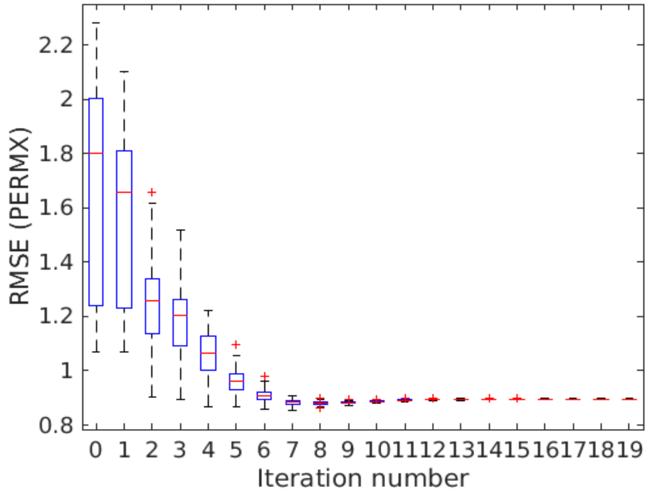
RMSE of PERMX

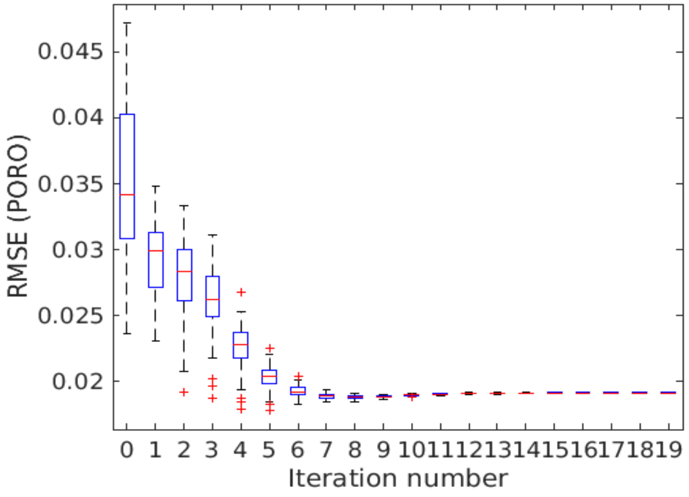
RMSE of PORO





RMSE of PERMX (left) and PORO (right) in
100K case





RMSE of PERMX (left) and PORO (right) in
1K case

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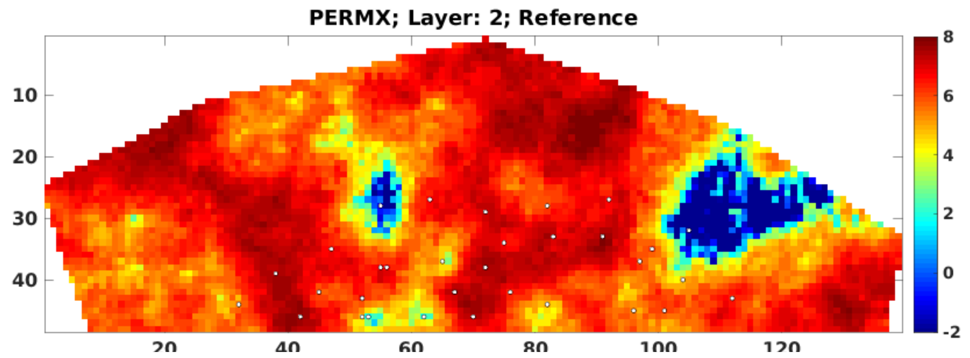
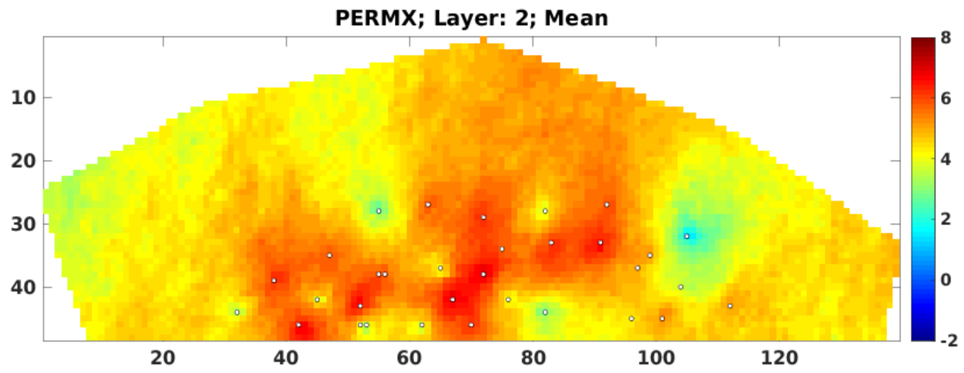
Numerical example II: 3D Brugge field model

Results when both production and seismic data are used (more results to be presented in ECMOR*)

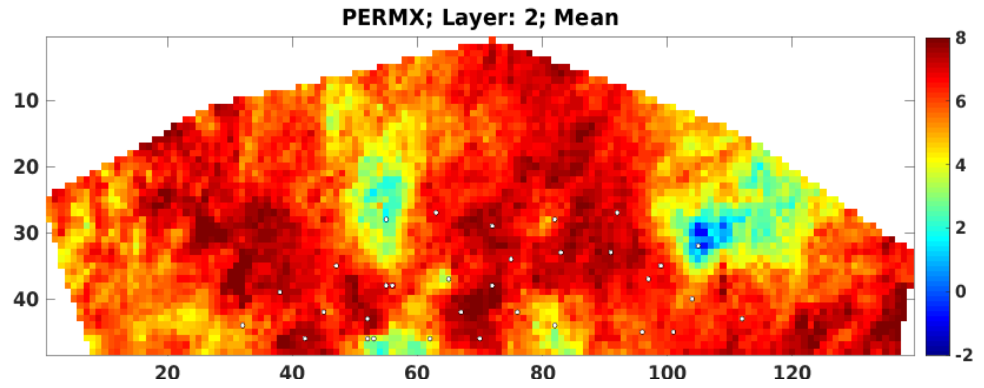
Reference log PERMX (at layer 2)



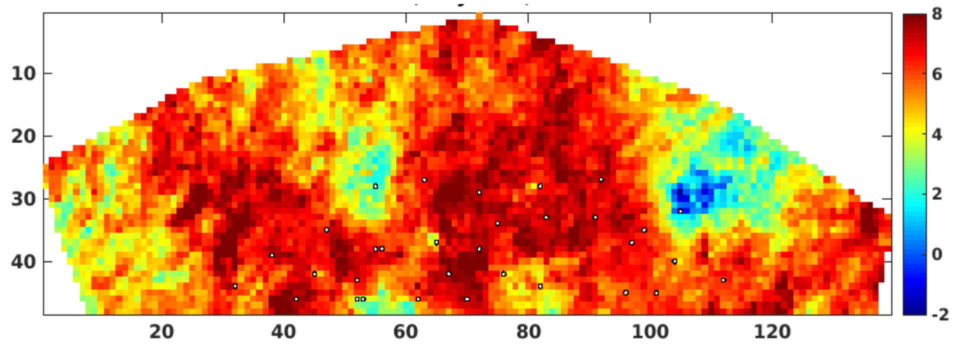
Mean log PERMX (at layer 2) of initial guess



Mean log PERMX (at layer 2) after history matching (100K)



Mean log PERMX (at layer 2) after history matching (1K)



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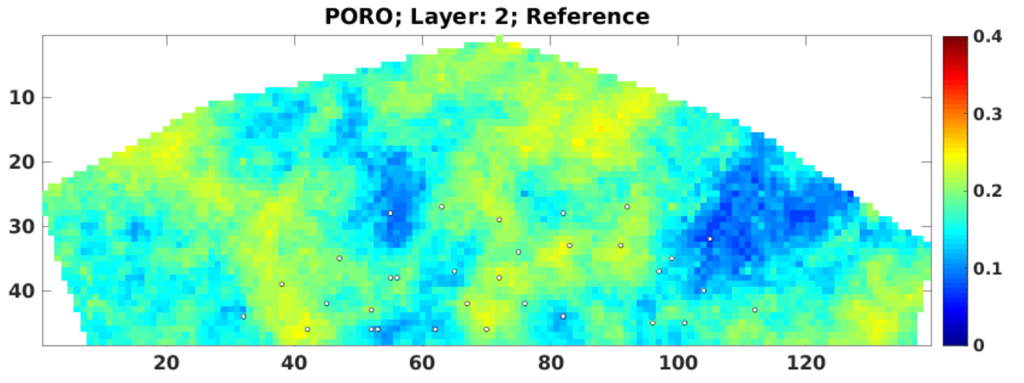
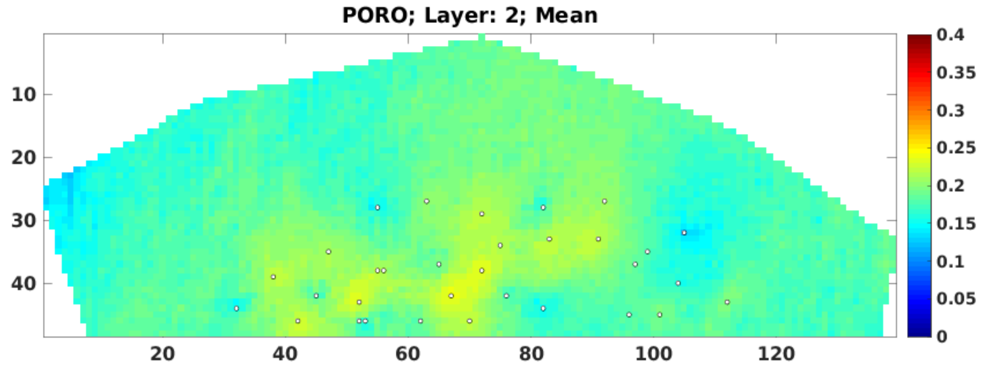
Numerical example II: 3D Brugge field model

Results when both production and seismic data are used (more results to be presented in ECMOR*)

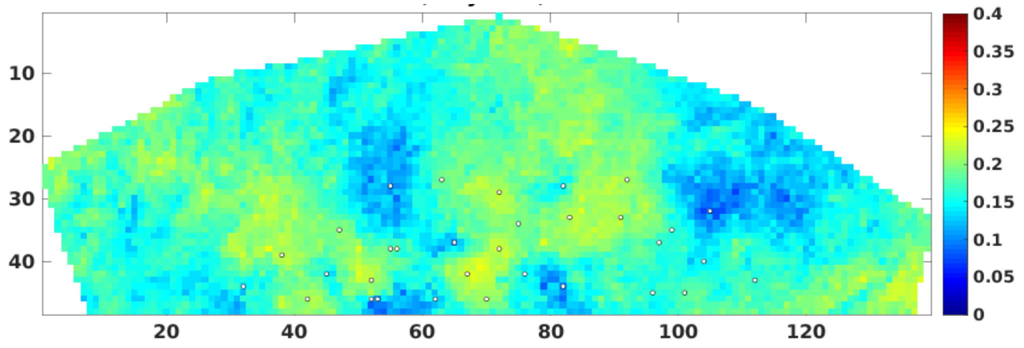
Reference PORO (at layer 2)



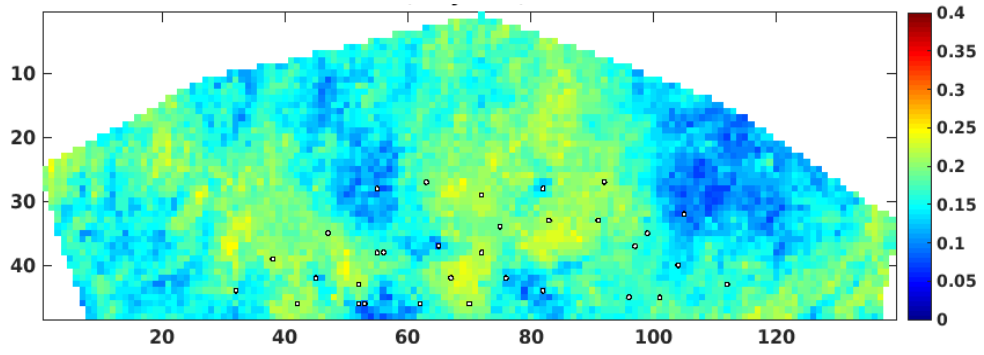
Mean PORO (at layer 2) of initial guess



Mean PORO (at layer 2) after history matching (100K)



Mean PORO (at layer 2) after history matching (1K)



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Conclusion and future works

Advantages in using wavelet-base sparse representation
In seismic history matching

- Efficient reduction of data size
- Intrinsic noise estimation in the data
- Applicability to various types of data (AVA, impedance, saturation map etc.)

Conclusion and future works

Possible future investigations

- Field case studies
- Various types of seismic data
- Covariance localization/local analysis

Acknowledgements / Questions

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