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
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

- Production data
- Seismic data
- Electromagnetic (EM) data
- Well logs
- Others
Background

Seismic data

- Amplitude versus angle (AVA);
- or raw seismic data
- Saturation and pressure maps
- Impedances ($I_p, I_s$);
- or velocities ($v_p, v_s$) and density

Seismic data at different “levels”
Background

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

AVA data (Raw seismic)

Impedance \((v_p, v_s, \rho)\)

Saturation Pressure

Reservoir simulation

Petrophysical parameters

AVA (full waveform) simulation

Rock physics model

Forward simulation

Inversion
Our focus in this talk is to history match AVA data.
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
Outline

• Background

• Proposed framework

• Numerical examples

• Conclusion and future works
Proposed framework

Workflow

- Simulated AVA data
- Observed AVA data
- Reservoir model
- Leading wavelet coefficients
- Leading wavelet coefficients
- History matching

AVA simulation

Sparse representation
Proposed framework

Motivation

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

Wavelet-based sparse representation

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
- True noise STD = 0.0148; Estimated noise STD = 0.0141

Noise AVA data (noise lv = 30%)

Reference AVA data

Wavelet transform

Thresholding

Wavelet coefficients

Leading coefficients

Inverse transform
Outline

• Background
• Proposed framework
• Numerical examples
• Conclusion and future works
Numerical example I: A 2D Norne field model

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

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

Numerical example I: A 2D Norne field model

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

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

Production and seismic data mismatch
Results of history-matching leading wavelet coefficients

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

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

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model size</td>
<td>139x48x9, with 44550 out of 60048 being active gridcells</td>
</tr>
<tr>
<td>Parameters to estimate</td>
<td>PORO, PERMX, PERMY, PERMZ. Total number is 4x44550 = 178,200</td>
</tr>
<tr>
<td>Production data (~10 yrs)</td>
<td>BHP, OPR, WCT. Total number is 1400</td>
</tr>
<tr>
<td>4D seismic data (1 Base + 2 monitor surveys)</td>
<td>Near and far-offset AVA data. Total number is ~ 7 x 10^6 (needing too much computer memory to be used directly)</td>
</tr>
<tr>
<td>Leading wavelet coefficients</td>
<td>Total number is 1665 (more than 4,000 times reduction)</td>
</tr>
<tr>
<td>History matching algorithm</td>
<td>Iterative ensemble smoother*</td>
</tr>
</tbody>
</table>

Preliminary results when both production and seismic data are used (more results to be presented elsewhere*)

Numerical example II: 3D Brugge field model

Preliminary results when both production and seismic data are used (more results to be presented elsewhere*)

Reference log PERMX (at layer 2)

Mean log PERMX (at layer 2) of initial guess

Mean log PERMX (at layer 2) after history matching

Outline

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

XL acknowledges partial financial supports from the CIPR/IRIS cooperative research project “4D Seismic History Matching” which is funded by industry partners Eni, Petrobras, and Total, as well as the Research Council of Norway (PETROMAKS).