Variance-based salt body reconstruction

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Outline

Motivation

Salt flooding technique

BP2004 model results
Motivation

- Hydrocarbons below salt bodies
- Seismic imaging challenged by high-velocity contrasts
- Complex geometries, steep flanks
- Multipulses
- Illumination issues

(Jones et al., 2014)
Motivation

“Top-to-bottom” manual approach

• Robust
• Interpreter-biased
• Time consuming

(Zhang et al., 2009)
Motivation

Constrained optimization

- Automatic
- A priori model assumptions
- Computationally expensive

(Esser et al., 2016)
Motivation

Gradient conditioning

• Less iterations

• Limited domain of convergence

(Alkhalifah, 2016)
Motivation

Many challenges in salt body imaging using FWI

We don’t have:
• Accurate starting model
• Low-frequency data
• Long-offset data
• …

How to overcome these difficulties?
Multiscale

Global-minimum

High

Low

(Bunks, 1995)
Multiscale strategy needs low-frequency data to find global minimum
Local minima at different frequencies
The proposed idea

Use variance between inversion results at different frequencies to build a better initial model for FWI
Outline

Motivation

Salt flooding technique

BP2004 model results
Variance-based salt flooding - Workflow

0. Updates from different frequencies
1. Average updates
2. Variance map and mask
3. Variance-based flooding

4. *FWI starting from “flooded” model
Variance-based salt flooding - Workflow

0. Updates from different frequencies

1. Average updates
2. Variance map and mask
3. Variance-based flooding

4. *FWI starting from “flooded” model
Model updates from different frequencies

0. Modeling
1. Averaging
2. Variance
3. Flooding

Crop from BP 2004 (Billette and Brandsberg-Dahl, 2005)
Model updates from different frequencies

0. Modeling
1. Averaging
2. Variance
3. Flooding

\[ f_1 \quad \text{Low} \]
\[ f_2 \]
\[ f_3 \]
\[ f_4 \quad \text{High frequency} \]
Selection of frequencies

Size of cycle-skipping artifacts proportional to wavelength $\lambda$

$$f_2 = \frac{\lambda_1}{\lambda_2} f_1$$

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Wavelength</th>
<th>Artifacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>$f_1$</td>
<td>$\lambda_1$</td>
</tr>
<tr>
<td></td>
<td>$f_2$</td>
<td>$\lambda_2$</td>
</tr>
<tr>
<td></td>
<td>$f_3$</td>
<td>$\lambda_3$</td>
</tr>
<tr>
<td>High</td>
<td>$f_4$</td>
<td>$\lambda_4$</td>
</tr>
</tbody>
</table>
Variance-based salt body reconstruction

Average model

Weighted average

\[ M_b = \frac{\sum_{k=1}^{N} M_k w_k}{\sum_{i=1}^{N} w_i} \]

using weights

\[ w_k = \frac{1}{f_k} \]

1. Averaging
2. Variance
3. Flooding
Variance between updates

0. Modeling
1. Averaging
2. Variance
3. Flooding
Variance between updates
Variance between updates
Variance

Weighted variance

\[ V = \frac{\sum_{k=1}^{N} w_k (M_k - M_b)^2}{\sum_{i=1}^{N} w_i} \]

using weights

\[ w_k = \frac{1}{f_k} \]
Variance-based salt body reconstruction

### 0. Modeling

- 1. Averaging
- 2. Variance
- 3. Flooding

### 2. Variance

Floating variance threshold

\[ \epsilon \sim \frac{V_{\text{max}}}{V_{\text{avg}}} \]

- \( \epsilon_0 \) Initial threshold
- \( V_{\text{max}} \) Maximum variance
- \( V_{\text{avg}} \) Average variance

![Variance mask diagram](image-url)
Variance mask and model overlap
Variance mask and model overlap
Variance mask and model overlap
Variance mask and model overlap

0. Modeling
1. Averaging
2. Variance
3. Flooding
Variance mask and model overlap

0. Modeling
1. Averaging
2. Variance
3. Flooding
Variance mask and model overlap

After flooding

Variance-based salt body reconstruction
Variance-based salt body reconstruction

0. Modeling
1. Averaging
2. Variance
3. Flooding

Variance mask and model overlap
Variance-based salt body reconstruction

Input

3 Hz

3.33 Hz

3.7 Hz

4.12 Hz

Masks

Result

Flooding 1
Var > 0.2
Max = 3.1
Mean = 0.17
Variance-based salt body reconstruction

Input

Masks

Result

Flooding 2
Var > 0.28
Max = 0.72
Mean = 0.029
Variance-based salt body reconstruction

Input

\[
\begin{array}{c}
3 \text{ Hz} \\
3.33 \text{ Hz} \\
3.7 \text{ Hz} \\
4.12 \text{ Hz}
\end{array}
\]

Masks

Result

Flooding 3
Var > 0.24
Max = 0.15
Mean = 0.0071
Input

3 Hz

Masks

Result

Flooding 4
Var  > 0.4
Max  = 0.17
Mean = 0.0046
Input

3 Hz

3.33 Hz

3.7 Hz

4.12 Hz

Masks

Result

Flooding 5
Var > 0.61
Max = 0.2
Mean = 0.0037
Input

3 Hz

3.33 Hz

3.7 Hz

4.12 Hz

Masks

Result

Flooding 6
Var > 0.73
Max = 0.22
Mean = 0.0033
Variance-based salt body reconstruction

Input

3 Hz

3.33 Hz

3.7 Hz

4.12 Hz

Masks

Result

Flooding 7
Var  > 0.76
Max  = 0.23
Mean = 0.0033
Input

3 Hz

3.33 Hz

3.7 Hz

4.12 Hz

Masks

Result

Flooding 8
Var > 0.71
Max = 0.21
Mean = 0.0033
“Flooded” model

True

Final
Outline

Motivation

Salt flooding technique

BP2004 model results
Central part of BP 2004

frequency range 3 -11 Hz
Initial

True

Initial

$z, \text{ km}$

$\text{x, km}$

$\text{km/s}$
FWI without flooding

**True**

**Without flooding**
Flooding result

**True**

![True flooding result](image)

**Flooding**

![Flooding result](image)
FWI with flooding

**True**

**With flooding**
Left part of BP 2004

frequency range 4 -11 Hz
Initial

True

Size: 107 x 550, dx = 20 m
FWI without flooding

---

**True**

---

**Without flooding**
Flooding result

True

Flooding
FWI with flooding

True

With flooding
Conclusions

• Updates at different frequencies can be analyzed to improve FWI

• Variance-based salt flooding
  Gives good initial model
  Easy to embed into an existing FWI
  Independent on forward solver
  Low computational costs

• Limitations
  Shifted artifacts
  Initial variance threshold
Acknowledgements

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Conclusions

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• Variance-based salt flooding
  Gives good initial model
  Easy to embed into an existing FWI
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  Low computational costs

• Requirements
  Shifted artifacts
  Initial variance threshold
Bibliography


Nick McArnie (2013), PES GB, London, Frequency Decomposition and colour blending of seismic data - “More than an image to me”