Extended images with surface-related multiples

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Why need image gathers?

- Effective velocity analysis tool
- Full-subsurface offset volumes allow us to conduct
  - AVA using information from all offset directions.
  - Geological dip corrections
Why need multiples?

illumination by primaries

illumination by multiples

subsurface reflector

surface
Least-squares imaging: 1 *primary-only* shot gather

Least-squares imaging: Imaging 1 *multiple-only* shot gather
Motivation

• *Leverage benefits of SRME*
  - highly accurate data-driven multiple prediction

• *All in one go method*
  - we combine SRME within the extended imaging condition
Extended imaging condition

\[ e(\omega, x, x') = \sum_i u_i(\omega, x)v_i(\omega, x')^* \]

- Organize wavefields in monochromatic data matrices
- Express extended image volume tensor as matrix

\[ E = UV^* \]
horizontal offset

horizontal + vertical offset

all offsets

[Biondo & Symes, '04; Sava & Vasconcelos, '11]
Extended images

sources

gridpoints

4D image volume as a matrix

\[ n_x \times n_z \]
Computation

- *Complete* image volume too *large* to form: \((n_x \times n_z)^2\)

- instead, *probe* volume for information via the action of a vector \(E_w\)

- \(w\) can be interpreted as subsurface (sim.) *source* function
Computation

- *mat-vec* with extended image:

\[ \tilde{E} = EW = H^{-1} P_s^T Q D^* P_r H^{-1} w \]

- \( \tilde{d} = P_r H^{-1} w \)  
  **(one subsurface source)**

- \( \tilde{y} = Q D^* \tilde{d} \)  
  **(surface source function)**

- \( \tilde{E} = H^{-1} P_s^T \tilde{y} \)  
  **(one surface source)**
Computation

computation of an *image point gather*

<table>
<thead>
<tr>
<th></th>
<th># of PDE solves</th>
<th>“flops for correlations”</th>
</tr>
</thead>
<tbody>
<tr>
<td>conventional</td>
<td>$2N_s$</td>
<td>$N_s \times N_h$</td>
</tr>
<tr>
<td>ours</td>
<td>$2N_x$</td>
<td>$N_s \times N_r$</td>
</tr>
</tbody>
</table>

$N_s$ - # of sources  
$N_r$ - # of receivers  
$N_h$ - # of subsurface offsets  
$N_x$ - # of sample points
Least-square extended imaging

\[
\text{minimize } \quad \frac{1}{2} \| D - \mathcal{F}(\tilde{E}) \|_F^2
\]

where

\[\mathcal{F}(\tilde{E}) = P_r H^{-1} \tilde{E}(Q^* P_s H^{-*} W)^*\]
How to incorporate the multiples
Linearized modeling with multiples

\[ P \triangleq \nabla F_i [m_0, Q_i - P_i] \]

\( \nabla F_i \) : linearized modelling

\( m_0 \) : background model

\( Q_i - P_i \) : areal sources
Extended imaging with multiples

\[ \tilde{E} = EW = H^{-1} P_s^T (Q - P) P^* P_r H^{-1} W \]

where

\((Q - P)\) : areal source

\(P\) : total upgoing wavefield
Experimental Results
Velocity model

True model

Initial model
Least-squares RTM images

Primary only  
Primary + multiples  
Primary + multiples

w/o areal sources  
with areal sources
Primary only

Primary + multiples
w/o areal sources

Primary + multiples
with areal sources
Conclusions

Multiples provide extra illumination that can complement primaries in least-squares seismic imaging.

Multiples can be used with primaries to form subsurface image gathers via least-squares inversion.
Future work

To find by case studies where the extra illumination from multiples can help extended imaging.

To incorporate the proposed method into migration velocity analysis.
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References


