Exact boundary conditions
for free-surface related multiple prediction

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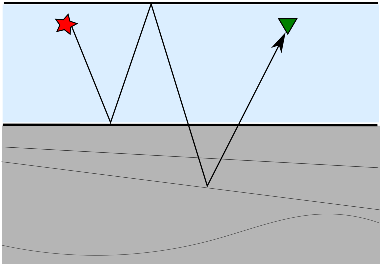
ROSE meeting, May 2014

Free-surface related multiples

In marine seismic experiments

- Sea surface reflects all upgoing energy
- Imaging and processing techniques require **primaries** only
- Successful multiple elimination is critical



Outline

- Introduction
- Exact boundary conditions (EBCs)
- Data pre-processing
- Numerical results
- Discussion and conclusions

Data-driven multiple elimination

Main strategies

- Predict multiples and adaptively subtract from recorded data
  - e.g., SRME (Dragoset et al., 2010)
- Transform data to new desired data from a hypothetical experiment without sea surface
  - e.g., MDD (Amundsen, 2001; Wapenaar et al., 2011)

Data-driven multiple elimination

Main strategies

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  - e.g., SRME (Dragoset et al., 2010)
- Transform data to new desired data from a hypothetical experiment without sea surface
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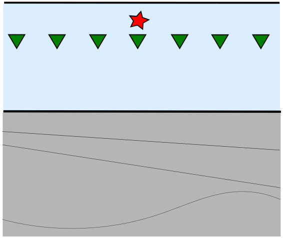
New method

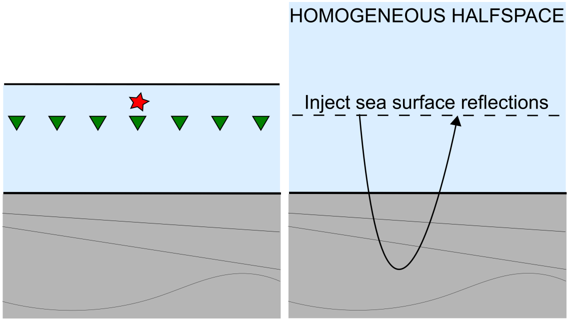
- Predicting all orders of multiples at once
- Relies on multicomponent seismic data
- Requires no subsurface knowledge
- Using conventional time-domain forward modeling
- Adaptive subtraction of predicted multiples

Concept



Actual experiment

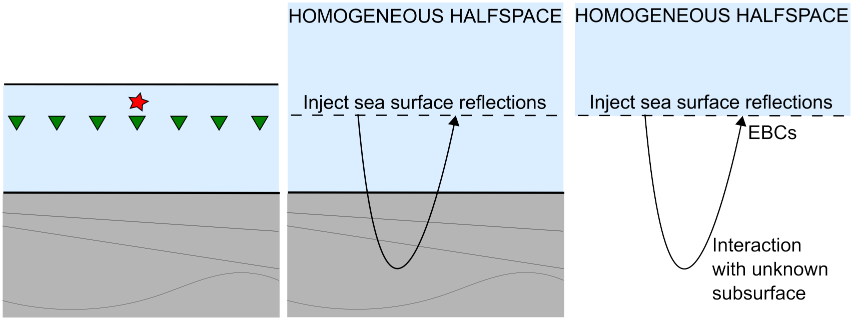
Concept



Actual experiment

Desired model for multiple prediction

Concept



Actual experiment

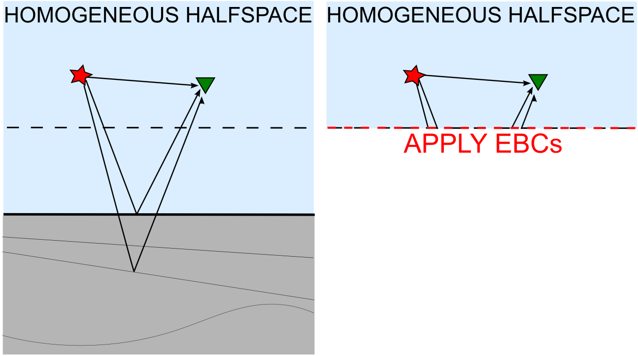
Desired model for multiple prediction

Model for multiple prediction using EBCs

Exact boundary conditions

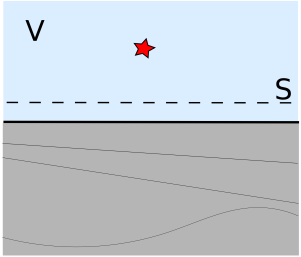
Enable **local** wavefield computation on a truncated domain (van Manen et al., 2007)

- Two domains dynamically linked
- All interactions correctly modeled



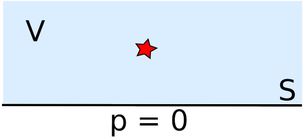
Exact boundary conditions

Full domain



$$p^{full}(\boldsymbol{x}') =$$
$$\int_V s(\boldsymbol{x}) * G^{p,q}(\boldsymbol{x}', \boldsymbol{x}) d^3\boldsymbol{x}$$
$$+ \int_S [G_i^{p,f}(\boldsymbol{x}', \boldsymbol{x}) * p^{full}(\boldsymbol{x})] n_i d^2\boldsymbol{x}$$

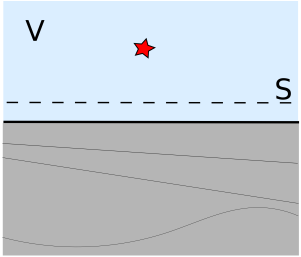
Truncated domain



$$p^{trunc}(\boldsymbol{x}') =$$
$$\int_V s(\boldsymbol{x}) * G^{p,q}(\boldsymbol{x}', \boldsymbol{x}) d^3\boldsymbol{x}$$

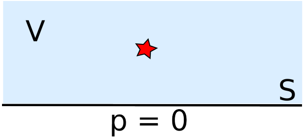
Exact boundary conditions

Full domain



$$p^{full}(\boldsymbol{x}') = \int_V s(\boldsymbol{x}) * G^{p,q}(\boldsymbol{x}', \boldsymbol{x}) d^3\boldsymbol{x} + \int_S [G_i^{p,f}(\boldsymbol{x}', \boldsymbol{x}) * p^{full}(\boldsymbol{x})] n_i d^2\boldsymbol{x}$$

Truncated domain



$$p^{trunc}(\boldsymbol{x}') = \int_V s(\boldsymbol{x}) * G^{p,q}(\boldsymbol{x}', \boldsymbol{x}) d^3\boldsymbol{x} + \int_S [G_i^{p,f}(\boldsymbol{x}', \boldsymbol{x}) * p^{full}(\boldsymbol{x})] n_i d^2\boldsymbol{x}$$

Exact boundary conditions

Recorded multicomponent data to predict $p^{full}(\boldsymbol{x}, t)$ on boundary:

$$p^{full}(\boldsymbol{x}, t) = \int_0^t \int_{S'} [G_i^{p,f}(\boldsymbol{x}, \boldsymbol{x}', t - t')p^{full}(\boldsymbol{x}', t') + G^{p,q}(\boldsymbol{x}, \boldsymbol{x}', t - t')v_i^{full}(\boldsymbol{x}', t')]n_i d^2\boldsymbol{x}' dt'$$

Recursive time-discrete version (van Manen et al., 2007):

- Contributions to extrapolation integral evaluated at each timestep
- Recorded data predict interaction with unknown subsurface: $G^{p,q}(\boldsymbol{x}, \boldsymbol{x}')$ and $G_i^{p,f}(\boldsymbol{x}, \boldsymbol{x}')$

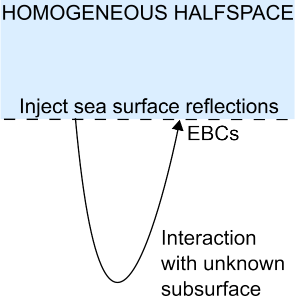
Data pre-processing

Multicomponent data: finite-difference injection to prepare data (Robertsson and Chapman, 2000; Amundsen and Robertsson, 2014)

- Redatumning and reciprocity
  - $G^{p,q}(\boldsymbol{x}^r, \boldsymbol{x}) \rightarrow G^{p,q}(\boldsymbol{x}, \boldsymbol{x}')$
  - $G_i^{v,q}(\boldsymbol{x}^r, \boldsymbol{x}) \rightarrow G_i^{p,f}(\boldsymbol{x}, \boldsymbol{x}')$
- Remove source signature

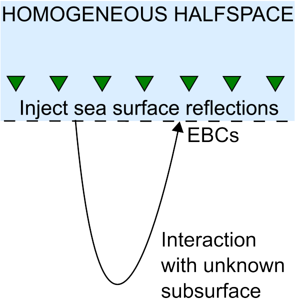
Modeling engine for multiple prediction

- Inject sea surface reflections
- Model interaction with unknown subsurface



Modeling engine for multiple prediction

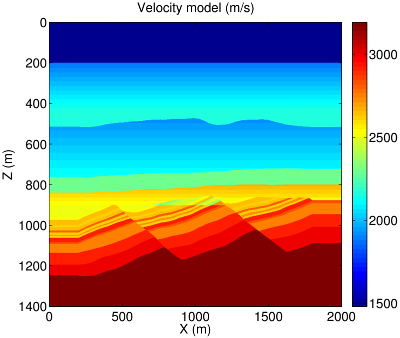
- Inject sea surface reflections
- Model interaction with unknown subsurface
- Predicts **all orders** of of free-surface related multiples



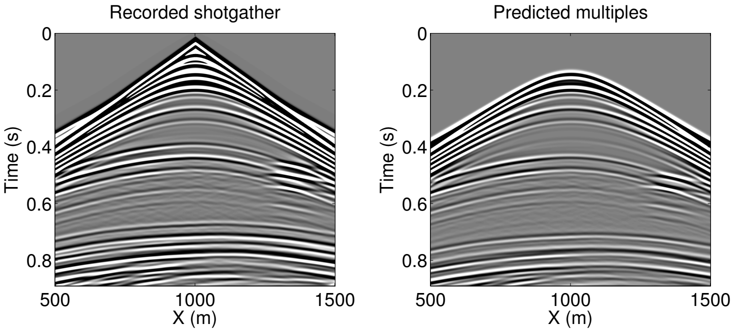
Numerical results

Demonstration of the method

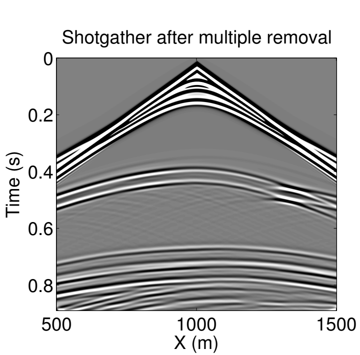
- Acoustic FDTD modeling
- Record multicomponent data
- FD injection for redatumning and source signature removal
- Inject into modeling engine with EBCs



Numerical results



Numerical results



Discussion of results

- Exact implementation for densely sampled data at all offsets
- Resemblance with SRME, but essential differences:
  - Predict all orders of multiples at once
  - Exploit benefits of multicomponent data
  - Source signature removal through FD injection
  - Receiver ghosts naturally accounted for
- Similar interpolation requirements for field data

Conclusions

- Method to predict all orders of multiples in marine multicomponent data
- Problem solved in time-domain by applying EBCs to conventional FD propagator
- Avoid issues related to inverse problems

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Acknowledgments

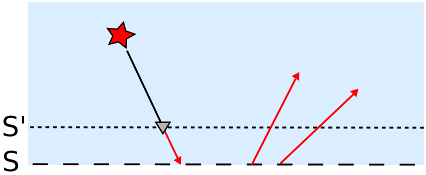
- Statoil
- SNF grant 2-77532-12

Thank you

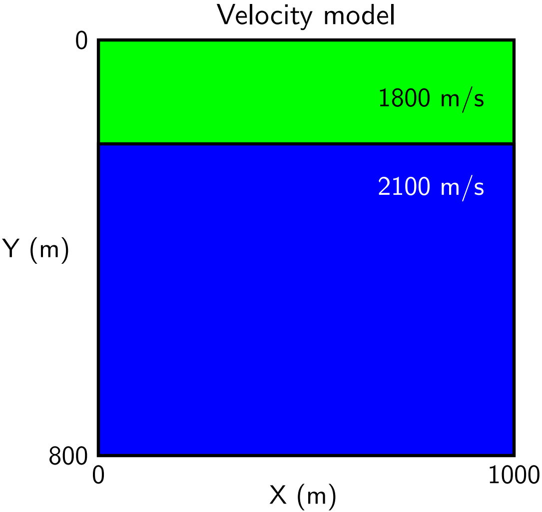
Back up slides

Time discrete wavefield extrapolation

$$p^{full}(\boldsymbol{x}, l, n) = p^{full}(\boldsymbol{x}, l, n-1)$$
$$+ \int_S [G_i^{p,f}(\boldsymbol{x}, \boldsymbol{x}', l-n) p^{full}(\boldsymbol{x}', n) + G^{p,q}(\boldsymbol{x}, \boldsymbol{x}', l-n) v_i^{full}(\boldsymbol{x}', n)] n_i d^2\boldsymbol{x}'$$



EBCs in numerical modeling



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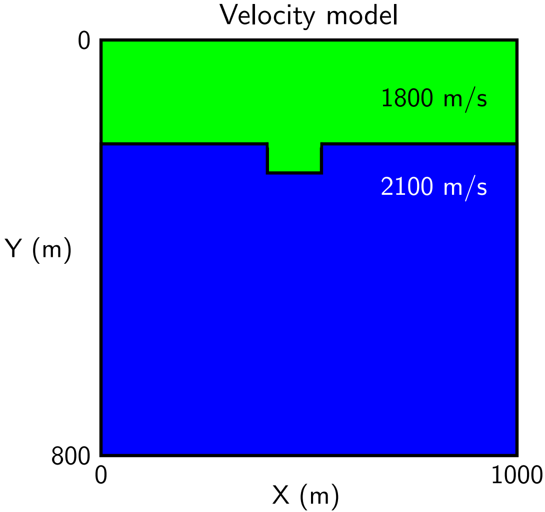

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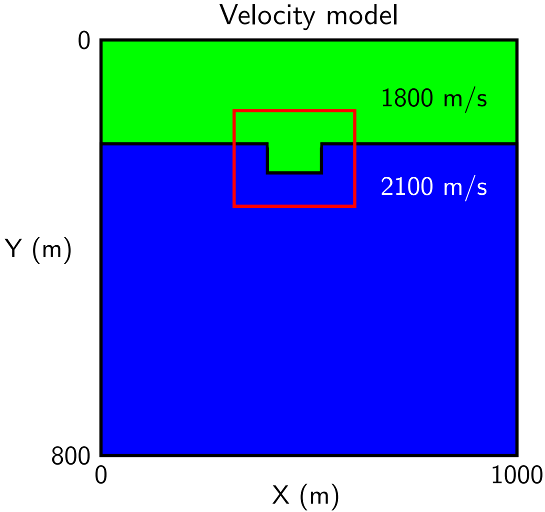

EBCs in numerical modeling

(Loading local wavefield recomputation movie..)