MODELING AND MIGRATION OF MARINE SEISMIC DATA WITH GENERAL SOURCE CONFIGURATIONS

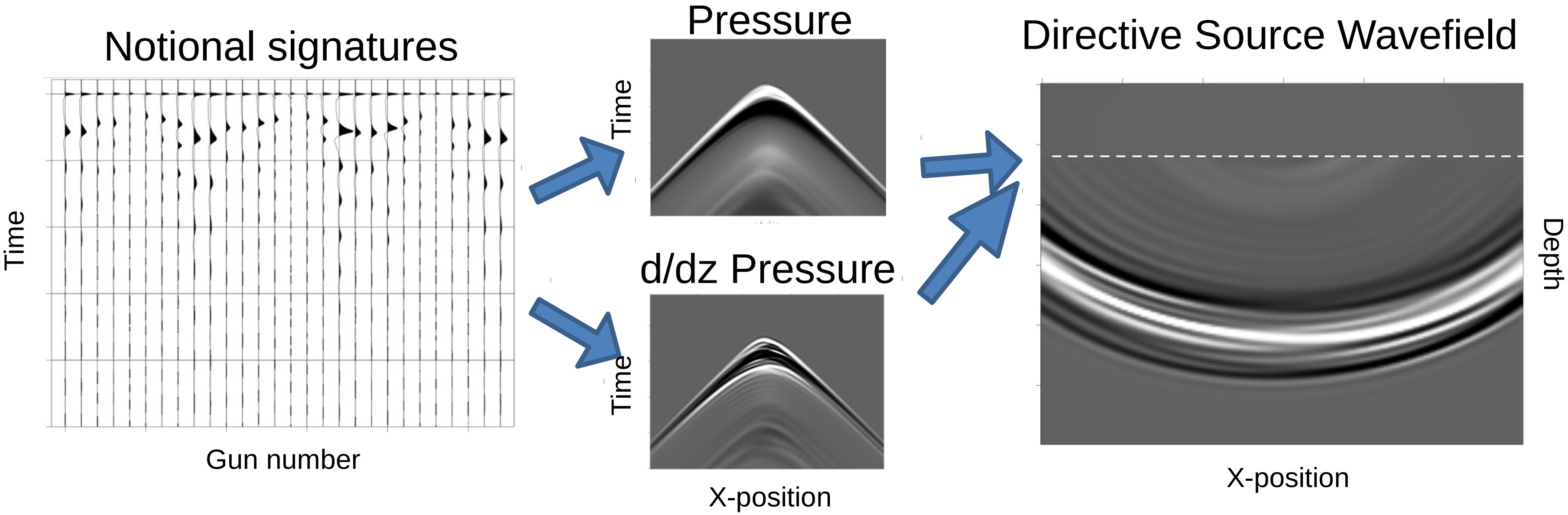
ROSE Meeting 2015

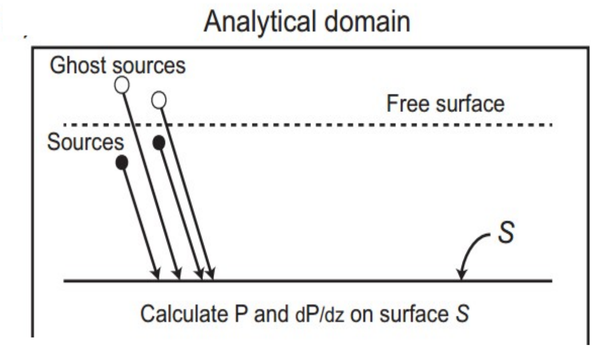
Kjetil Eik Haavik*

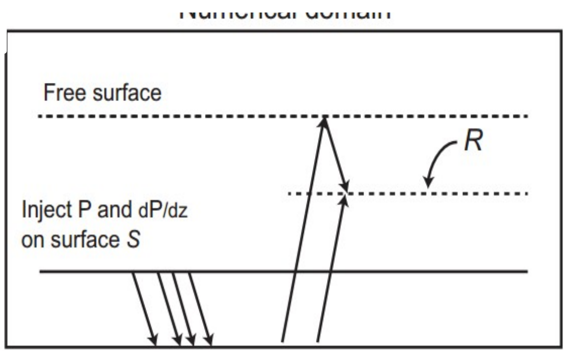
NTNU
Norwegian University of
Science and Technology

* kjetil.haavik@ntnu.no

Summary

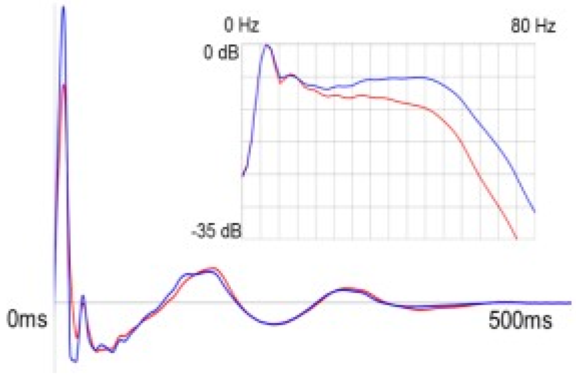

Notional signatures
Time
Gun number
Pressure
Time
d/dz Pressure
Time
X-position
Directive Source Wavefield
Depth
X-position


Analytical domain
Ghost sources
Free surface
Sources
S
Calculate P and dP/dz on surface S

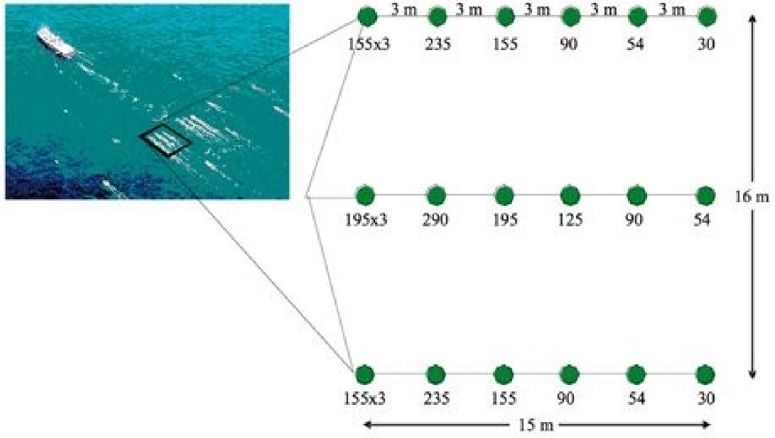

Numerical domain
Free surface
R
Inject P and dP/dz
on surface S

Introduction

- The marine source usually consist of many air-guns and emmits a directive wavefield.
- Knowledge of this source wavefield is important for many processing steps.
- Our goal in the future must be to image seismic data without too much pre-processing.
- Aim of this work: To implement directive source wavefields in FD-modeling, migration and, in the future, FWI.



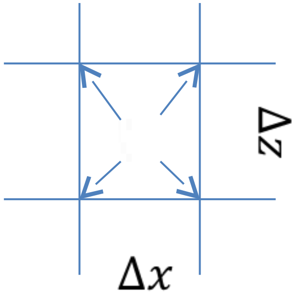
Vertical, 50 deg

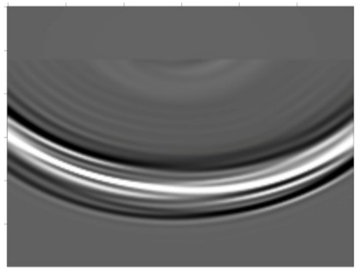


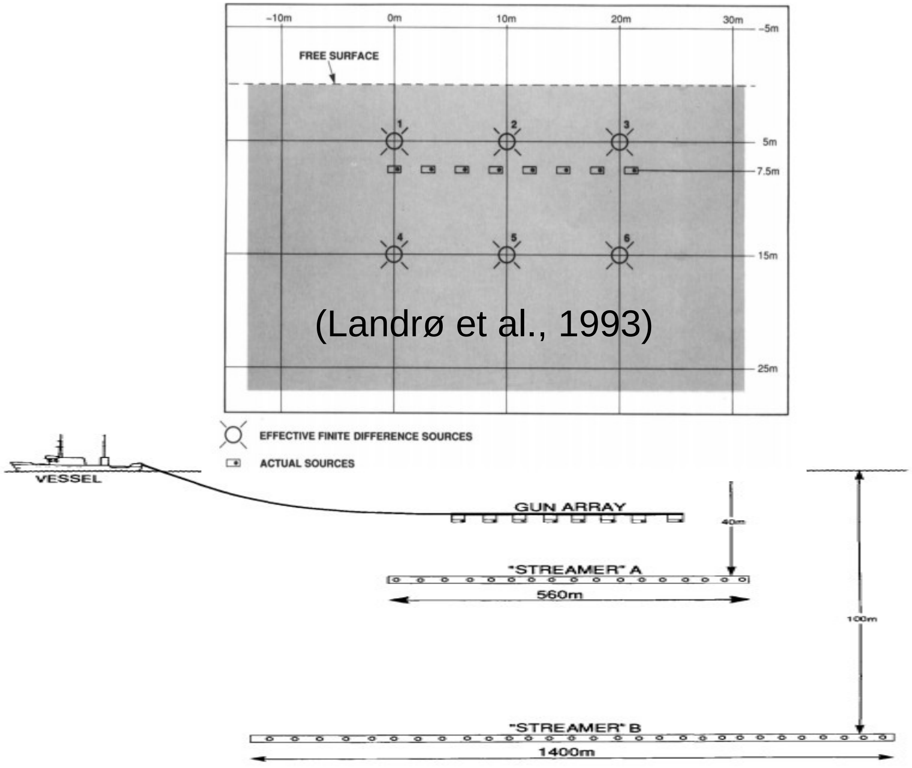
(Upper picture from Lee et al, 2014. Bottom: Landrø & Amundsen, 2010)

Sources in FD-methods: Previous work

- Hybrid approaches can be used to implement known wavefields in to FD schemes (e.g. Alterman and karal, 1968)
- Methods for injecting point sources that does not coincide with grid cells have been developed (Mittet and Arntsen, 1999, Hicks, 2002).
- A method for implementing measured source wavefields from a directive air-gun array was proposed by Landrø et al. (1993).
- A known wavefield can be introduces in FD-methods by using wavefield injection (e.g Mittet, 1994, Robertsson and Chapman, 2000).

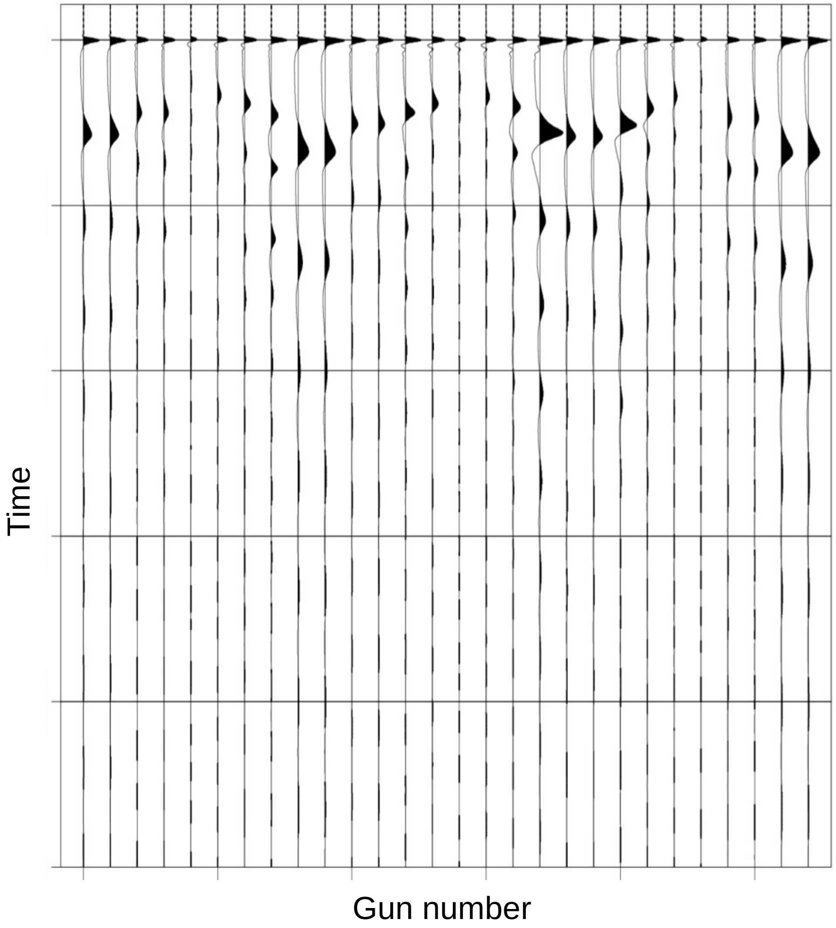


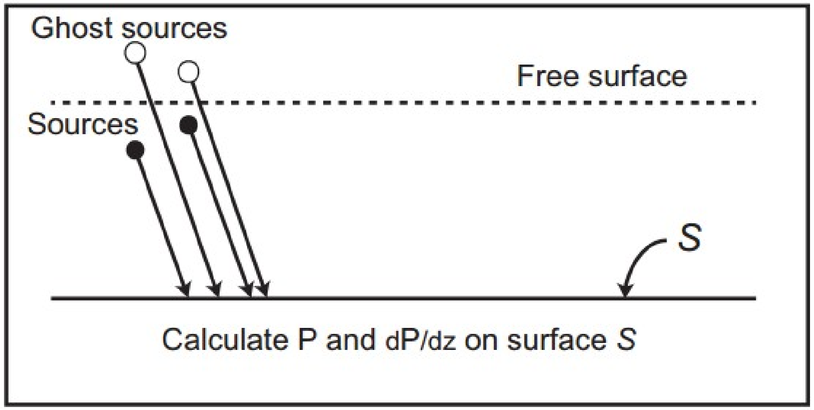


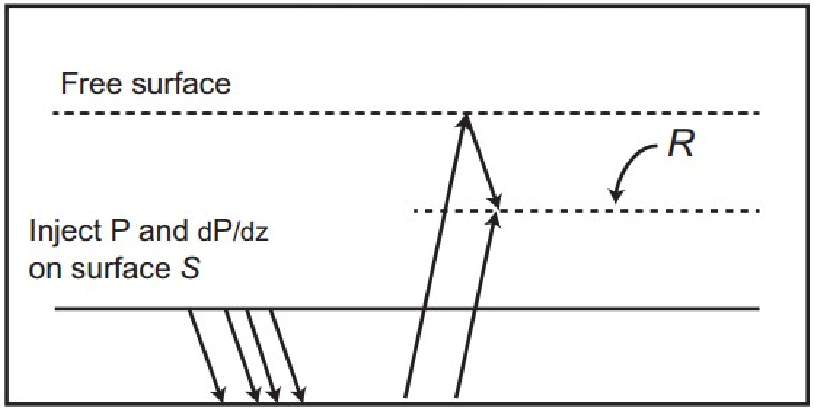


(Landrø et al., 1993)

Method


Notional signatures


Analytical domain


Numerical domain

Analytical Extrapolation

$$P(\mathbf{x},t) = \sum_{i=1}^{N} \int g_t(\hat{\mathbf{x}}, t, \mathbf{x}_i) * W(t)_i \mathrm{d}V(\hat{\mathbf{x}})$$

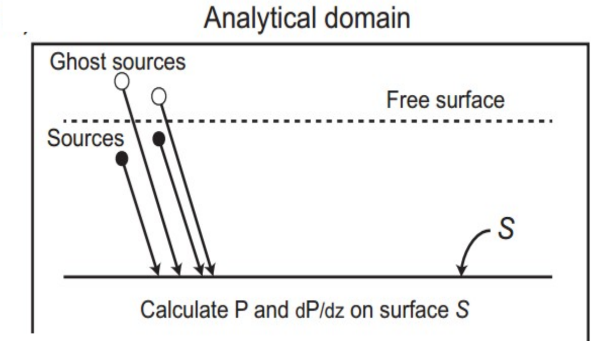
The Pressure field at **x** from N sources

$$g_t(\mathbf{x}, t; \hat{\mathbf{x}}) = \frac{1}{4\pi}\left[\frac{\delta(t-\tau)}{|\mathbf{x}-\hat{\mathbf{x}}|} + R(t) * \frac{\delta(t-\tau')}{|\mathbf{x}-\hat{\mathbf{x}}'|}\right]$$

The Greens function with mirror source

$$\frac{\partial P}{\partial z} = -\frac{1}{c}\frac{z}{R}\frac{\partial P}{\partial t}$$

How to calculate the vertical derivative of pressure



1. Calculate the pressure and its vertical derivative at all points on the line *S*
2. Store them for later use

Wavefield Injection

$$\frac{1}{c^2}\frac{\partial^2}{\partial t^2}P\left(\mathbf{x},t\right)-\nabla^2 P\left(\mathbf{x},t\right)=\sum_{i=1}^{N}\delta\left(\mathbf{x}-\mathbf{x}_i\right)W_i(t)$$

Wave equation for N sources

$$\frac{1}{c^2}\frac{\partial^2}{\partial t^2}P\left(\mathbf{x},t\right)-\nabla^2 P\left(\mathbf{x},t\right)=s^m+s^d$$

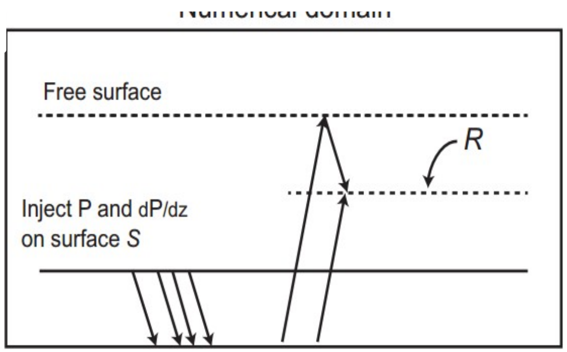
Wave equation with equivalent source terms

$$s^{(m)}(\mathbf{x},t;\mathbf{x}_s)=\int\frac{1}{\rho}\frac{\partial P(\zeta,t;\mathbf{x}_s)}{\partial n}\delta(\mathbf{x}-\zeta)\mathrm{d}S(\zeta)$$

Monopole terms

$$s^{(d)}(\mathbf{x},t\ \mathbf{x}_s)=\int\frac{1}{\rho}\boxed{P(\zeta,t;\mathbf{x}_s)\frac{\partial\delta(\mathbf{x}-\zeta)}{\partial n}}\mathrm{d}S(\zeta)$$

dipole terms



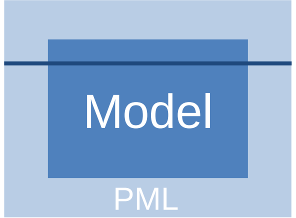
Approximation of derivative in the implementation

$$\boxed{\frac{\partial\delta(z)}{\partial z}P(z)\approx\sum_{i=1}^{M}P(z)\alpha_i\frac{\delta(z+i\Delta z)-\delta(z-i\Delta z)}{\Delta z}}$$

(Amundsen and Robertsson, 2014, Vaaland, 2014)

Implementation on a staggered grid

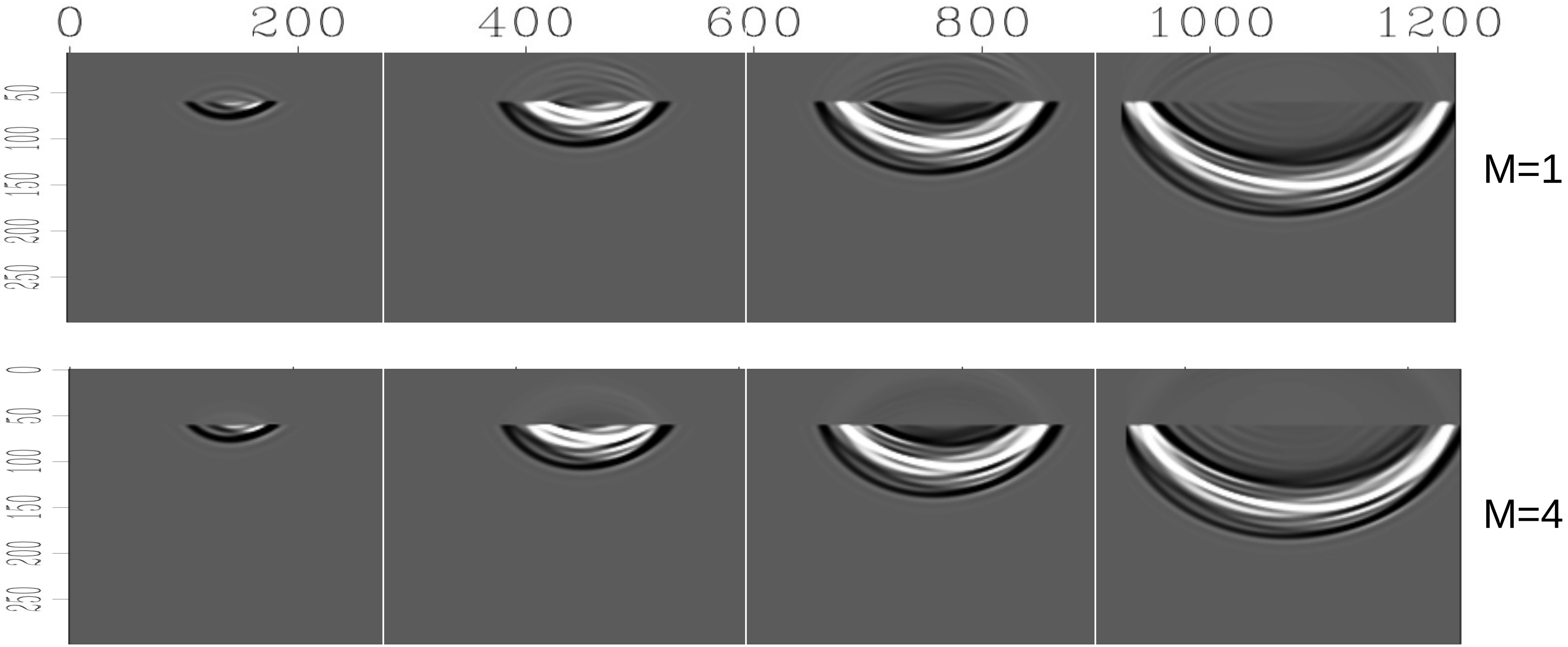
$$\frac{\partial \delta(z)}{\partial z} P(z) \approx \sum_{i=1}^{M} P(z)\alpha_i \frac{\delta(z+i\Delta z)-\delta(z-i\Delta z)}{\Delta z}$$



Model

PML

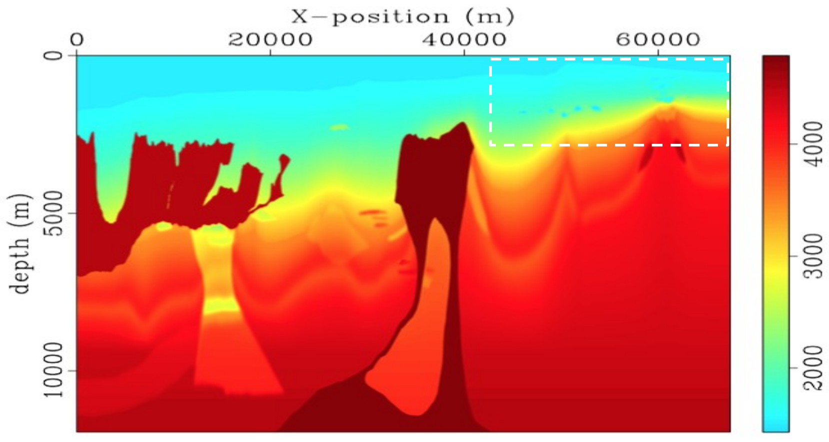
Injection surface extends out in PML boundary to avoid edge diffractions.

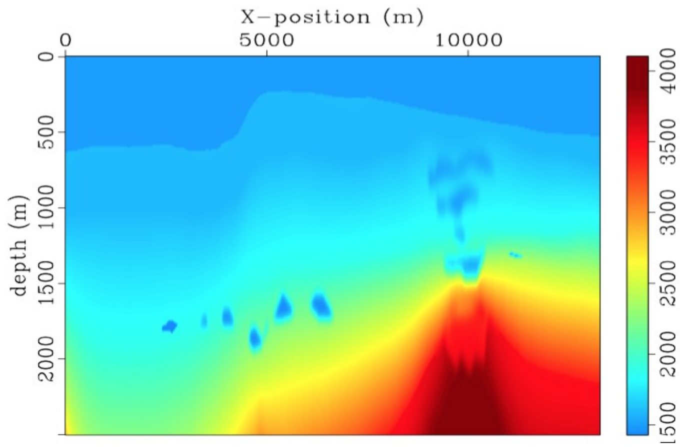


t = 0.03 t = 0.05 t = 0.07 t = 0.1

Modeling and Migration

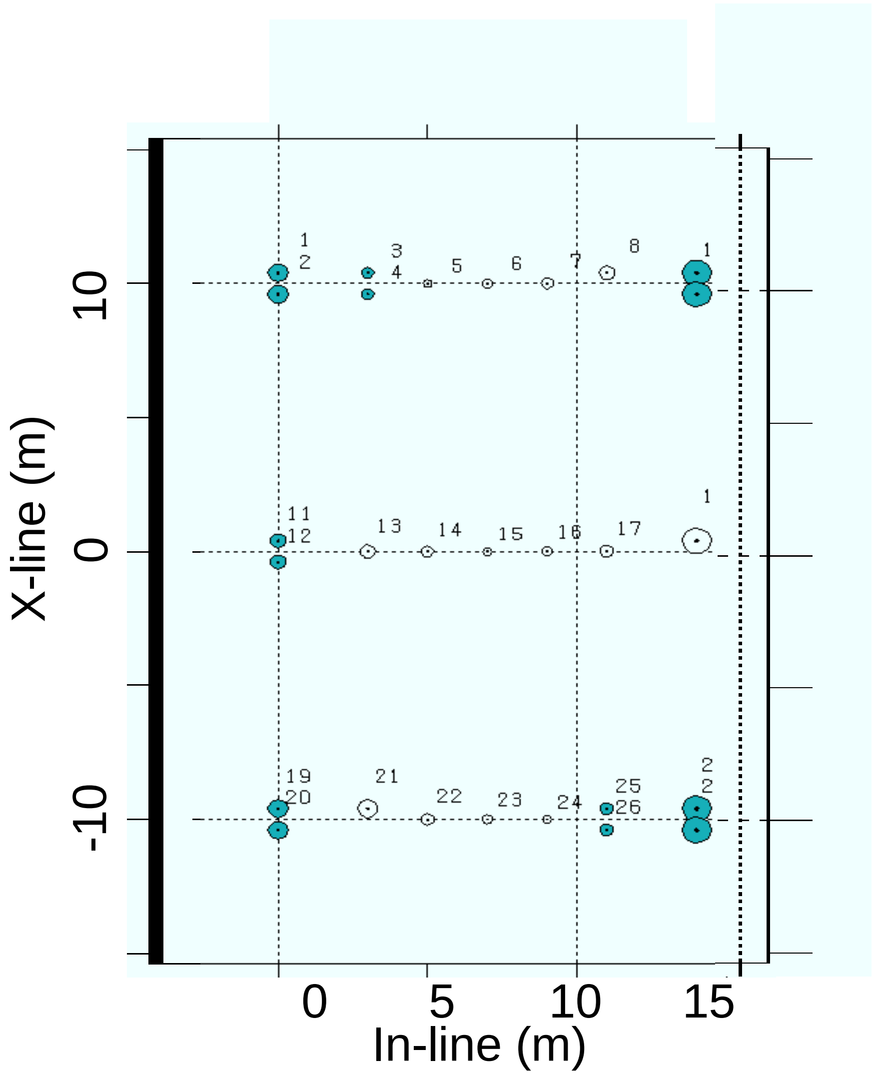
- Source: Air gun array consisting 28 air guns in three subarrays, notional signatures from Nucleus air-gun modeling software.
- Model: Part of the BP benchmark model
- Forward modeling: 2D Acoustic FD scheme
- RTM: Convential zero time-lag cross-correlation between forward and backward propagated fields

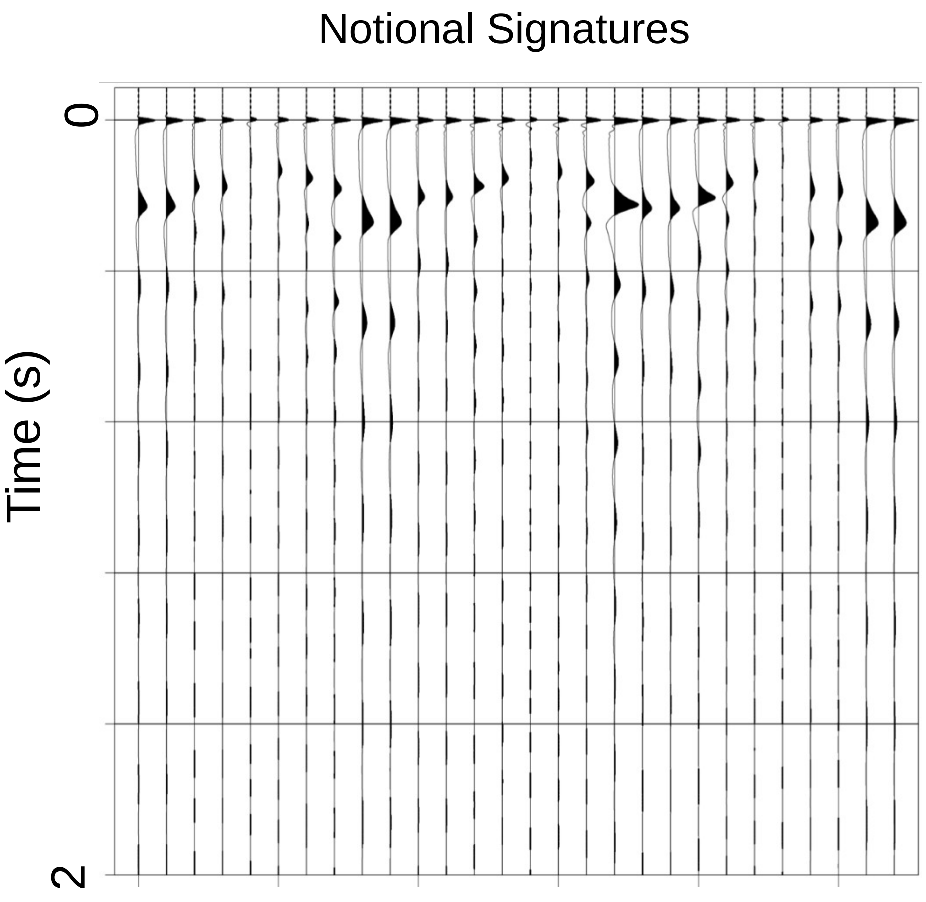




(BP benchmark model: courtesy of BP, Billette and Brandsberg-Dahl, 2005, Modeling and migration code developed by Espen B. Raknes)

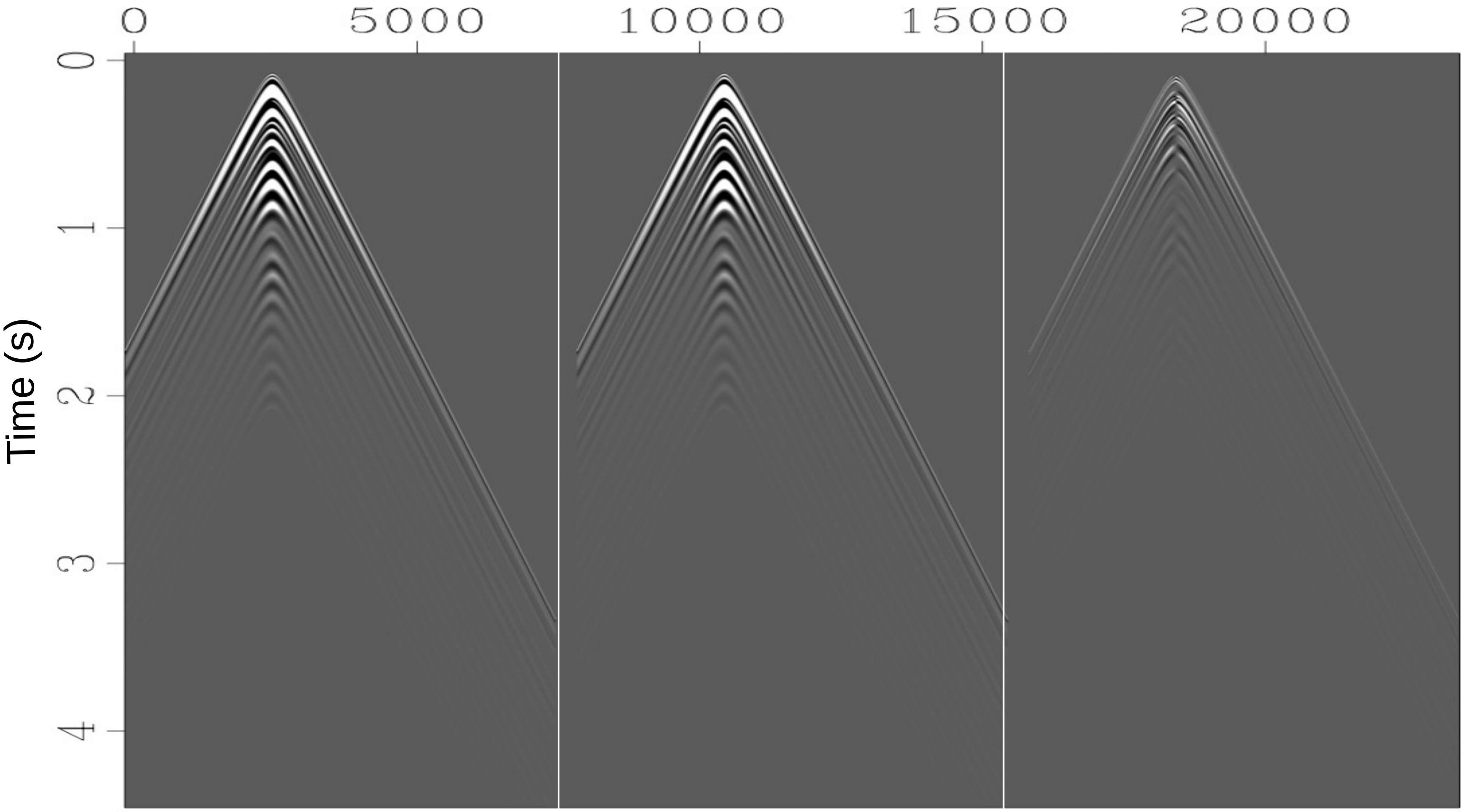
Source Array





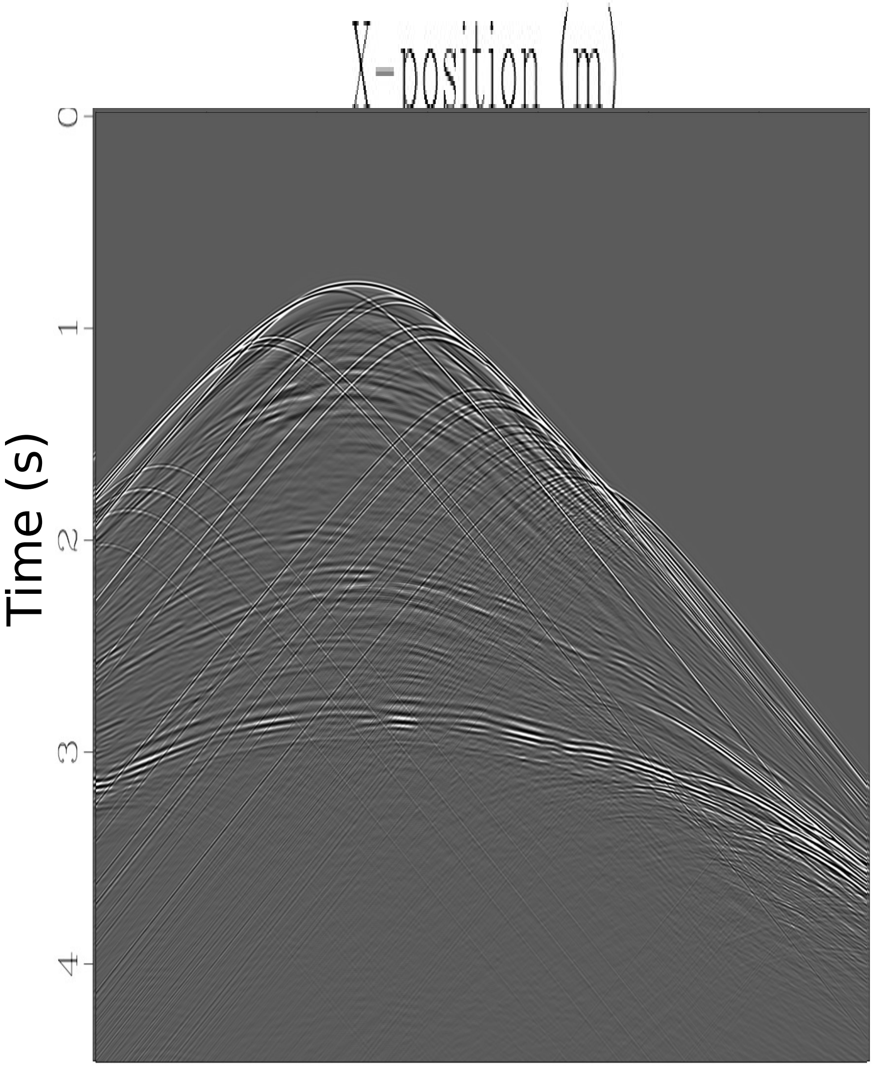
High-cut filter @ 60 Hz

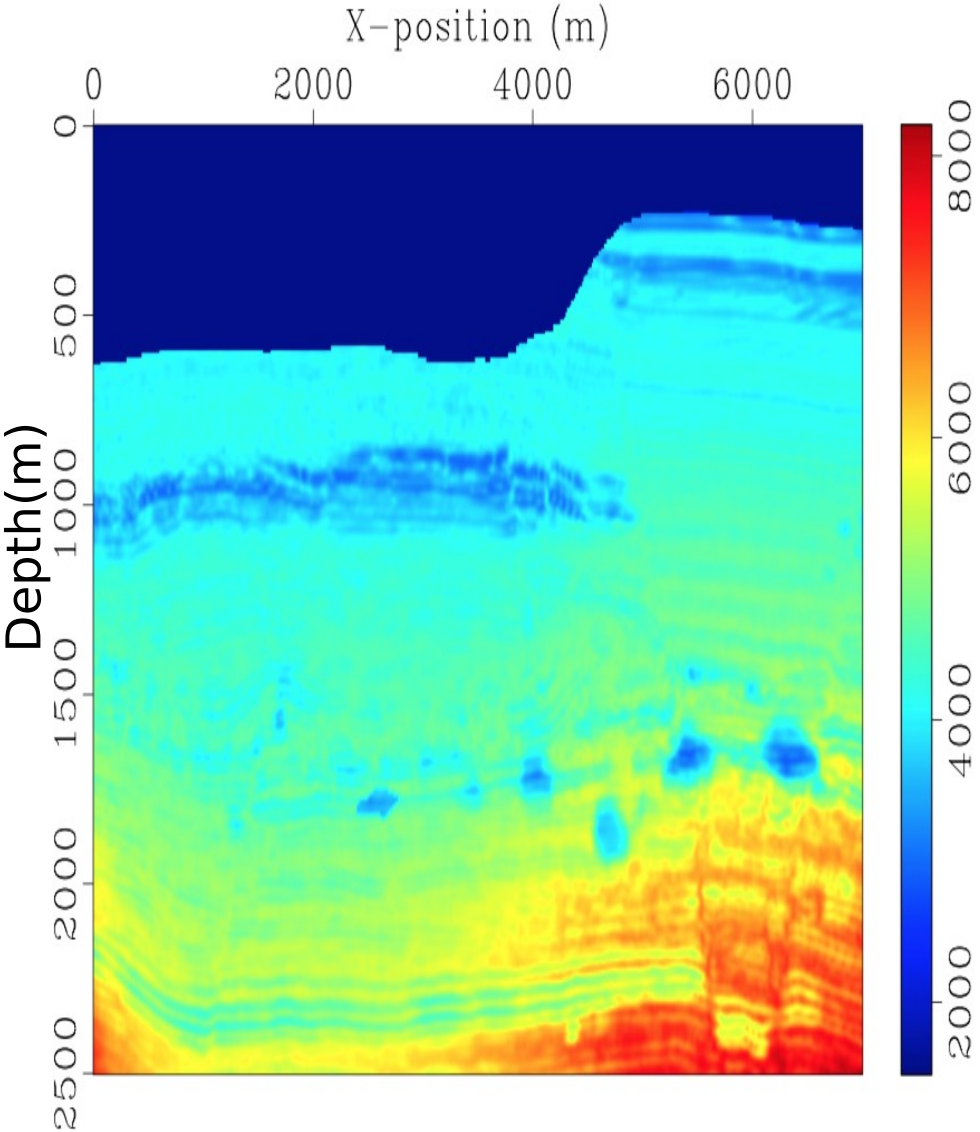
Source wavefields at injection surface



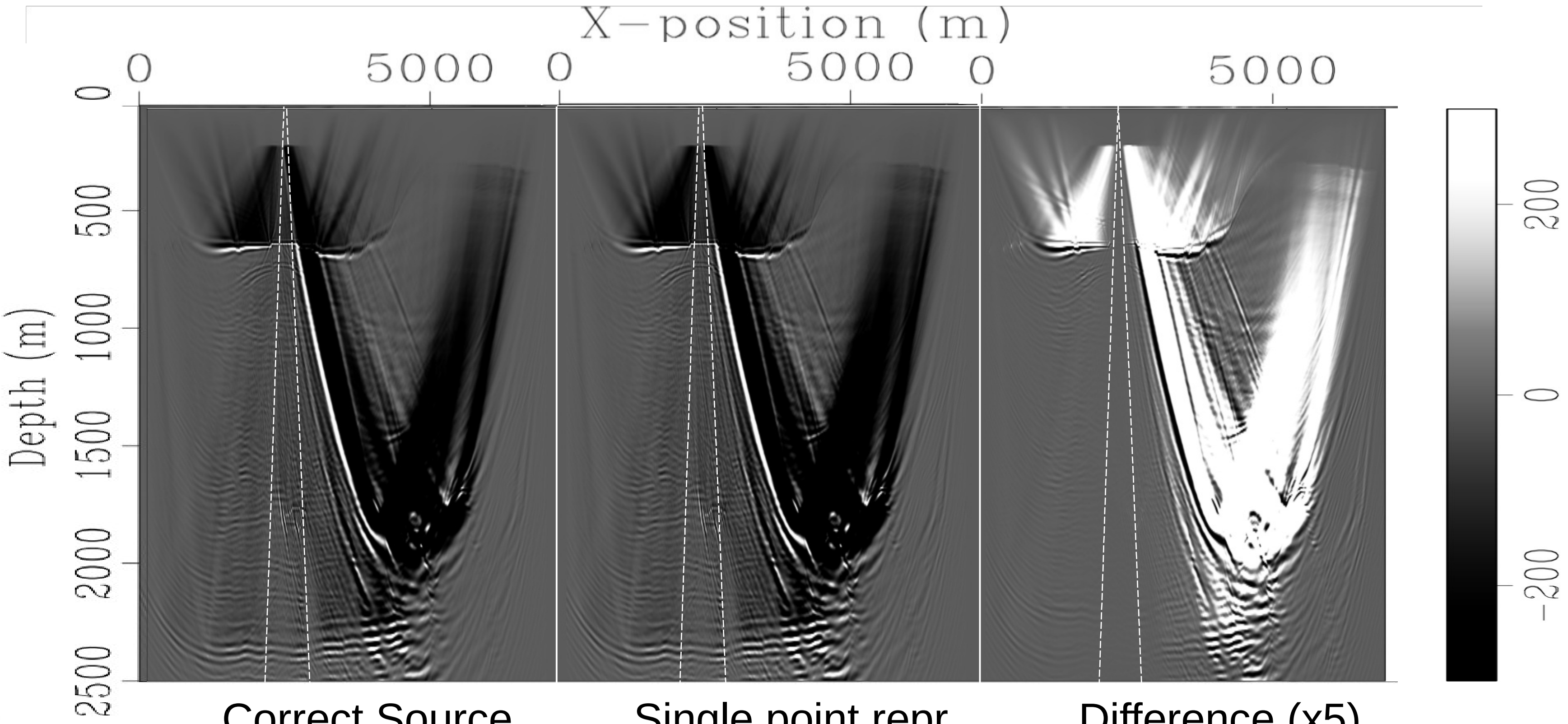
Correct Source Single point repr. Difference

Modeling of one shot





Modeling and RTM of a single shot

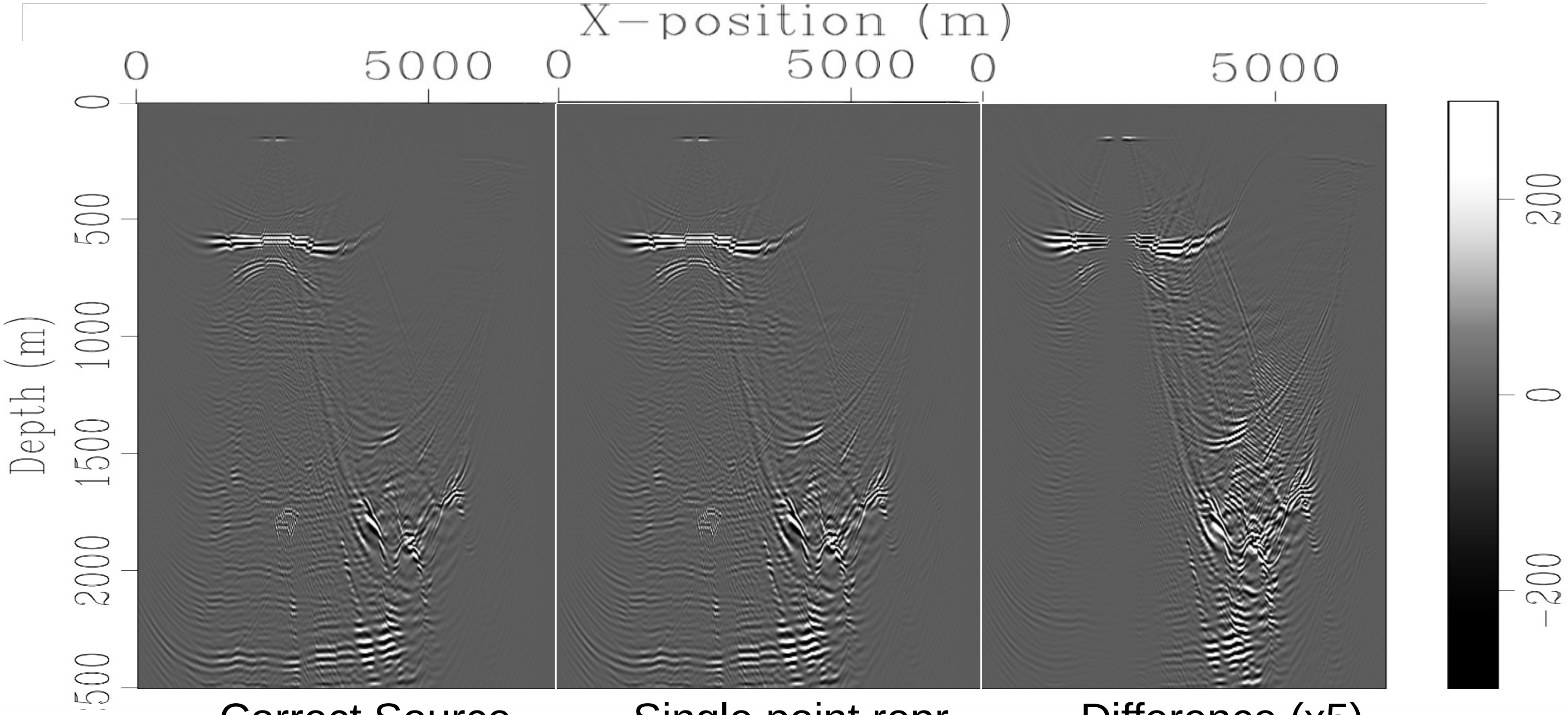


Correct Source Single point repr. Difference (x5)

Source array at (x,z) = (2350,6) m. No filter.

For small offsets there are almost no differences!

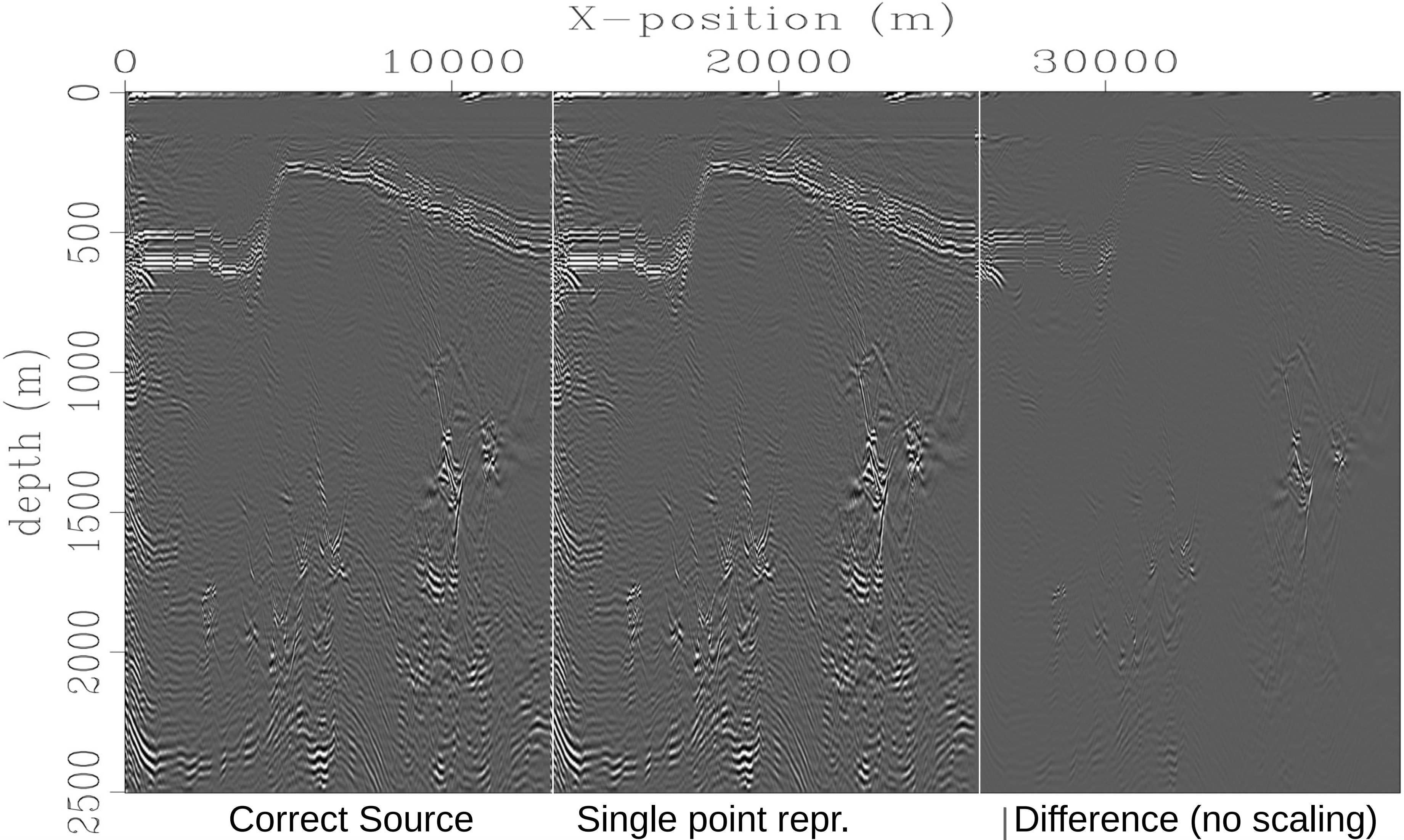
Modeling and RTM of a single shot



Correct Source Single point repr. Difference (x5)

Source array at (x,z) = (2350,6) m. Double z derivative filter.
For small offsets there are almost no differences!

Preliminary Full Stack Image



Correct Source

Single point repr.

Difference (no scaling)

Discussion and remarks (1)

- If we can handle directivity, then we can use longer/wider source arrays that focus energy downwards. This would also be beneficial for the environment: less energy in the water layer and less high frequency energy.
- For longe/wide arrays we can expect that the difference will increase.
- Directional designature can be performed in the tau-p domain. A more recent approach is to use a ”boot-strap” method (Lee et al. 2014).
- Ideal for FWI because the whole wavefield is considered.
- We can specify the free surface reflection coefficient, and make it frequency dependent.
- What about multiples?
  - We often need source signature for Multiple Elimination.
  - New RTM algorithms may migrate Multiples in multi-component data (Amundsen and Roberstsson, 2014)

Discussion and remarks (2)

- This approach can be used with any shot profile imaging technique, and for other imaging conditions (e.g. inverse scattering IC, Op't Root et al., 2012)
- In this approach, designature is done in the imaging step. In the examples shown here we use a X-correlation IC, so it is more like a directional zero phasing.
- This approach can be used for all source types (di- or quad-pole etc.) as long as the analytical extrapolation is carried out correct and the radiation pattern is known.
- As long as the position of each source element and its notional signature is known, we can have different acquisition parameters every shot. Statics will be corrected for in the imaging.

Future Work

- Refine method - Find a better way to implement wavefield injection.
- Use the developed tools and compare different source configurations (multi-level source, slanted source, variable source depth acquisition).
- Try out different approaches: e.g. deconvolve data and source wavefield with zero-offset signature (without ghost) and migrate with the directivity only.
- Process real seismic data.
- Perform FWI on synthetic data and real data.
- Try to find more applications.

Conclusions

- A method for implementing general source wavefields in FD modeling is proposed.
- The method require the knowledge of the notional source signature and the position of each source element.
- In migration, there is a ‘’chicken and the egg’’ issue related to multiples. New promising RTM algorithms may resolve this issue.
- The proposed method will perform the ‘’designature’’ in the imaging step.
- The results presented here shows that the difference between imaging with the true source wavefield and a single point representation is large for shallow geology and complex wavepaths.

Acknowledgements

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