3D free-surface multiple elimination

and summation in the cross-line conjugate domain

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Key Points

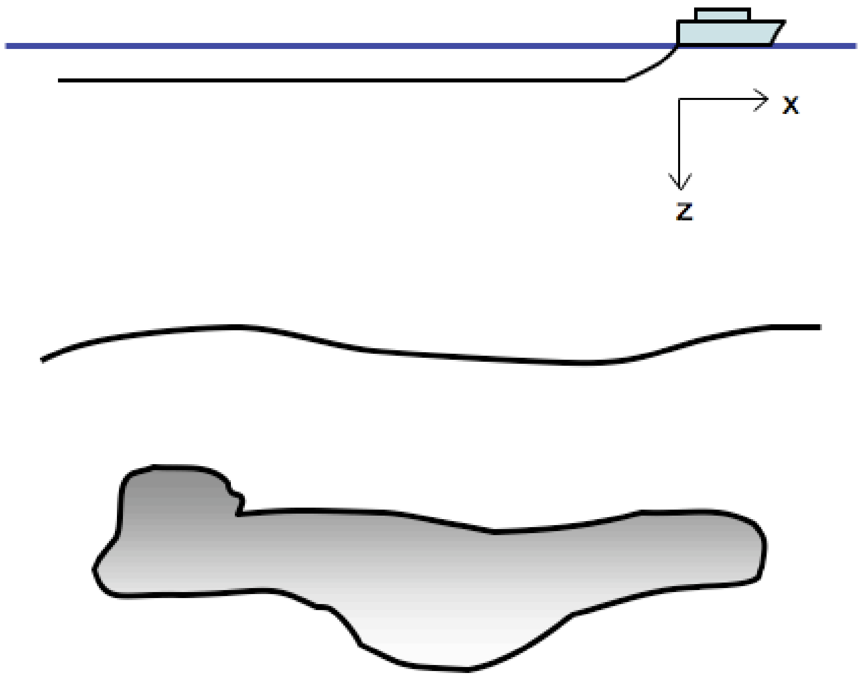
Free-surface multiple elimination (Carvalho, 1992; Weglein et al., 1997) is a wave-theoretically complete method calculated in the frequency-wavenumber domain. Incorporates the obliquity factor.

It is also common to perform a 3D prediction in the space-frequency domain, absent of the obliquity factor. Less complete, however strategies exist for managing acquisition issues (e.g., cross-line sampling/aperture) in this domain.

Similar strategies would be useful for 3D FSME. Two possibilities: (1) transform the algorithm to space, apply the O.F. as a filter, (Dragoset) or (2) seek out strategies specific to the FK domain. We begin a research effort aimed at the second of these.

3D FSME data requirements

Choose a coordinate system with x as the in-line direction and y as the cross-line direction.



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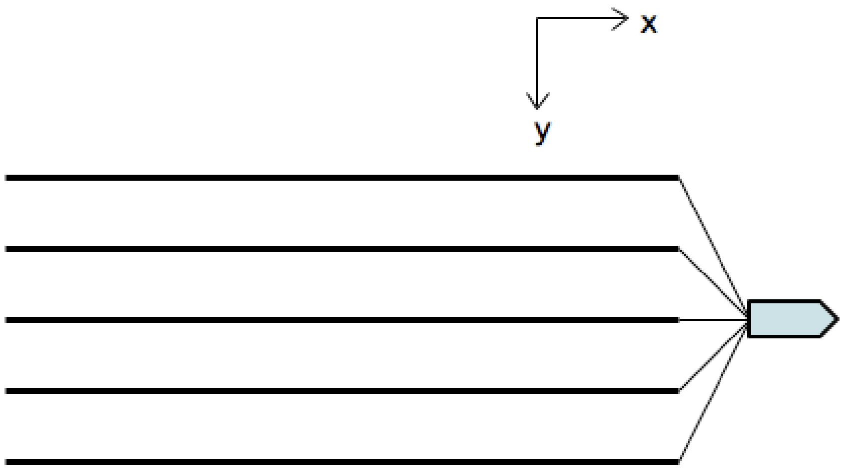

plan

3D FSME data requirements

The algorithm asks for wide aperture and dense sampling in 5 dimensions:

$$D(x_g, y_g, x_s, y_s, t)$$

x_g	y_g	x_s	y_s	t
in-line receiver	cross-line receiver	in-line source	cross-line source	time

The algorithm requires a Fourier transform over each of these coordinates.

The time, and in-line coordinates tend to be acquired with sufficient aperture and sampling to permit such transforms. The cross-line dimension is less likely to be sufficient in either respect.

3D FSME data requirements

We will find ourselves therefore paying particular attention to

$$D(k_{xg}, k_{yg}, k_{xs}, k_{ys}, \omega)$$

in-line receiver	cross-line receiver	in-line source	cross-line source	frequency

Question: what is required to manage a specific anticipated sampling/aperture deficiency?

Begin to answer this by considering what other approaches have required...

Space-frequency strategies

van Dedem & Verschuur (2005)
Matson & Abma (2005)
Hokstad & Sollie (2006)

Some themes:

Separate the influence of cross-line acquisition on the 3D prediction from the influence of the more complete in-line component.

Study the cross-line behaviour in isolation.

Devise coping/compensation strategies based on regularities in the observed behaviour

Isolation of 3D FSME cross-line behavior

Assuming the wavelet S known, deghosted data, we compute first term in 3D FSME series

$$M_{3D}(k_{xg}, k_{yg}, z_g, k_{xs}, k_{ys}, z_s, \omega) = \frac{A}{S(\omega)} \int \int dk'_x dk'_y q' e^{iq'(z_g+z_s)} D(k_{xg}, k_{yg}, z_g, k'_x, k'_y, z_s, \omega)$$

$$\times D(k'_x, k'_y, z_g, k_{xs}, k_{ys}, z_s, \omega)$$

where $q' = \frac{\omega}{c_0}\sqrt{1 - \frac{k_x'^2 c_0^2}{\omega^2} - \frac{k_y'^2 c_0^2}{\omega^2}}$ is the obliquity factor.

Isolation of 3D FSME cross-line behavior

Compare the 3D case with the 2D case...

$$\frac{A}{S(\omega)}\int\int dk'_x dk'_y q' e^{iq'(z_g+z_s)} D(k_{xg},k_{yg},z_g,k'_x,k'_y,z_s,\omega) D(k'_x,k'_y,z_g,k_{xs},k_{ys},z_s,\omega)$$

$$\frac{A'}{S(\omega)}\int dk'_x \tilde{q}' e^{i\tilde{q}'(z_g+z_s)} D(k_{xg},z_g,k'_x,z_s,\omega) D(k'_x,z_g,k_{xs},z_s,\omega)$$

$$M_{2D}(k_{xg},z_g,k_{xs},z_s,\omega) = \frac{A'}{S(\omega)}\int dk'_x \tilde{q}' e^{i\tilde{q}'(z_g+z_s)} D(k_{xg},z_g,k'_x,z_s,\omega) D(k'_x,z_g,k_{xs},z_s,\omega)$$

where $\tilde{q}' = \frac{\omega}{c_0}\sqrt{1-\frac{k_x'^2 c_0^2}{\omega^2}}$

Isolation of 3D FSME cross-line behavior

3D FSME can be seen as a sequence of 2D FSME runs, integrated, or stacked, together as a final step:

$$M_{3D}(k_{xg}, k_{yg}, z_g, k_{xs}, k_{ys}, z_s, \omega) = \int dk'_y M^*_{2D}(k_{xg}, k_{yg}, z_g, k_{xs}, k_{ys}, z_s, \omega | k'_y)$$

where

$$M^*_{2D}(k_{xg}, k_{yg}, k_{xs}, k_{ys}, \omega | k'_y) = \frac{A}{S(\omega)} \int dk'_x q' e^{iq'(z_g+z_s)} D(k_{xg}, k_{yg}, k'_x, k'_y, \omega) D(k'_x, k'_y, k_{xs}, k_{ys}, \omega)$$

This essentially isolates the cross-line behavior of the prediction step from the inline behavior.

A cross-line conjugate gather

The final summation over the cross-line conjugate dimension k_y' is where 3D aspects of the multiples are incorporated into the prediction.

Gathers produced by fixing all coordinates except for ky' and frequency, prior to the summation, suggest themselves as means to study the cross-line behavior

$$M^*_{2D}(k'_y, \omega)|_{k_{xg}, k_{yg}, k_{xs}, k_{ys}}$$

Plan

Kaplan et al. (2006) have implemented 3D FSME code that is in the process of testing and validation.

This will involve generating 3D synthetic data sets for simple, and then increasingly complicated subsurface structure and multiples

Initially wide-aperture, densely sampled test data will be used.

Concurrent testing of the response of the prediction to compromised sampling/aperture (particularly) in the cross-line dimension. Determine behaviour in terms of these gathers. Compensation strategies?

Compensation strategies

Treat the problem as:

- Aperture- or sampling-limited FT problem
  (e.g., Sacchi and Ulrych)

- Data reconstruction problem
  (e.g., Stolt, Ramirez et al., Zwartjes, Herrmann etc.)

- A "new" problem posed in terms of 3D FSME.

In either case, we require insight into cross-line prediction response.

Summary

Free-surface multiple elimination (Carvalho, 1992; Weglein et al., 1997) is a wave-theoretically complete method calculated in the frequency-wavenumber domain. Incorporates the obliquity factor.

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