# A decomposition and multiple removal strategy for multicomponent OBC data

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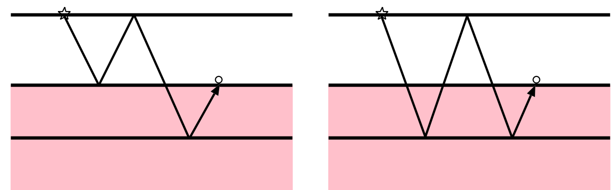
**Summary**

By performing a wavefield decomposition on multicomponent seismic ocean-bottom data, the upgoing P- and S-waves just below the ocean-bottom can be obtained. After this step, surface-related multiples that arrive at the receiver from above will have been removed from the data. However, all surface-related multiples that end with a reflection from a reflector below the ocean-bottom will still be present in the decomposed upgoing data. To remove these remaining multiples, the multiple elimination method described by (Verschuur, 1991; Verschuur et al., 1992) is used. To apply the multiple removal method to the decomposed dataset, the method is extended to accomodate ocean-bottom acquisition geometry (Verschuur and Neumann, 1999; Soellner and Widmaier, 2000). The multiple removal method can be used on any ocean-bottom receiver type (i.e. pressure, velocity, P-waves, S-waves). The relative importance of additional multiple elimination will be illustrated with examples on a field dataset.

**Introduction**

One approach to the processing of multicomponent measurements of the total elastic wave field is to first decompose the wavefield into one-way P- and S-wave fields (Wapenaar et al., 1990; Amundsen and Reitan, 1995). Application of wavefield decomposition to field data was shown by a.o. Osen et al. (1999) and Schalkwijk et al. (1999). Because in field data issues of imperfect measurements and unknown medium parameters just below the ocean-bottom have to be dealt with, in Schalkwijk et al. (1998) an adaptive decomposition procedure was proposed, where any unknown quantities are estimated from the data itself. This adaptive decomposition procedure was successfully tested on several field datasets with ocean-bottom depths ranging from 120 meters to 1300 meters.

After wavefield decomposition, most surface-related multiples will have been removed from the upgoing wavefields just below the ocean-bottom. As the upgoing wavefield consists of all events with the last propagation path coming up from below, there are still surface-related multiples left which have reflected at the surface before reflecting from below (Figure 1). The events in Figure 1a are also called source-side peg-legs. To remove these remaining surface-related multiples from the data, the multiple elimination method developed by Verschuur et al. (1992) is used. As this method is designed for data acquisition with both sources and receivers at the water surface (streamer data), it has to be adapted to accomodate ocean-bottom acquisition geometry. Multiple elimination for ocean-bottom data has also been discussed in Ikelle (1999) and Verschuur and Neumann (1999) for the situation where streamer data are available alongside OBC data. The procedure discussed here is similar, except that in this case the streamer data are simulated from the OBC data. Field data examples of multiple elimination on ”undecomposed” OBC data have been shown in Soellner and Widmaier (2000). In this work, the importance of additional multiple elimination on a field data example (after wavefield decomposition of the data into upgoing P- and S-waves just below the bottom) will be investigated.



*a)* *b)*

***Fig. 1:*** *Examples of events that are “upgoing” at the receiver, but still contain a surface reflection, (a) source-side peg-leg multiple, and (b) double reflected event.*

**Wavefield decomposition on ocean-bottom data**

The adaptive decomposition scheme, as described by Schalkwijk et al. (1999), consists of five stages and is repeated below for convenience (decomposition equations are written in the rayparameter-frequency domain for the 2-D situation):

**Stage 1. ‘Rotation’ of the velocity components** In this first stage the $V_z$ measurement is corrected for an imperfection in the acquisition that is not addressed in the preprocessing nor in the decomposition: ‘mechanical cross-coupling’, visible as converted waves recorded on the $V_z$ component that cannot be found on the $P$ component.

**Stage 2. Acoustic decomposition just above the bottom** The acoustic decomposition is used to resolve the calibration filter $A(\omega)$ between the pressure and vertical velocity component, caused by imperfect coupling of the geophone to the ocean-bottom:

$$\tilde{P}^{\pm} = \frac{1}{2}\tilde{P} \pm A(\omega)\frac{\varrho_0}{2q_0}\tilde{V}_z, \tag{1}$$

where $\varrho_0$ and $q_0 = \sqrt{c_0^{-2} - p^2}$ are the density and vertical slowness in the water-layer, and $p$ is the horizontal rayparameter. To resolve $A(\omega)$, the criterion that there should be no primary reflections present in the decomposed downgoing wavefield *above* the bottom ($P^+$) is applied.

**Stage 3. Elastic decomposition into $\tau_{zz}^{\pm}$ just below the bottom** The next stage is an elastic decomposition *below* the bottom, into up- and downgoing normal stressfields:

$$-\tilde{T}_{zz}^{\pm} = \frac{1}{2}\tilde{P} \pm A(\omega)\frac{\varrho_1\beta_1}{2q_{P,1}}\tilde{V}_z, \quad (2)$$

where $\varrho_1$ and $q_{P,1} = \sqrt{c_{P,1}^{-2} - p^2}$ are the density and vertical P-wave slowness of the medium just below the bottom, and $\beta_1 = c_{S,1}^4[4p^2 q_{P,1} q_{S,1} + (c_{S,1}^{-2} - 2p^2)^2]$. This time the unknown factor is the operator in front of $\tilde{V}_z$, as it depends on the medium parameters just below the bottom. To find the operator, the expression is replaced by a general rayparameter dependent filter $\tilde{F}(p)$:

$$-\tilde{T}_{zz}^{\pm} = \frac{1}{2}\tilde{P} \pm A(\omega)\tilde{F}(p)\tilde{V}_z. \quad (3)$$

The condition imposed on the decomposition result is that there should be no direct wave and water bottom multiples in the upgoing normal stressfield *below* the bottom.

**Stage 4. Elastic decomposition into $\tau_{xz}^{\pm}$ just below the bottom** The fourth decomposition stage involves the $P$ and $V_x$ components, making it possible to resolve the calibration filter $B(\omega)$ between them:

$$-\tilde{T}_{xz}^{\pm} = \pm\frac{\gamma_1 p}{2q_{S,1}}\tilde{P} \pm b(\omega)\frac{\varrho_1\beta_1}{2q_{S,1}}\tilde{V}_x. \quad (4)$$

where $q_{S,1} = \sqrt{c_{S,1}^{-2} - p^2}$, $\gamma_1 = c_{S,1}^2[2q_{P,1}q_{S,1} - (c_{S,1}^{-2} - 2p^2)]$ and $\beta_1$ as above. First the decomposition operators are calculated with the medium parameters just below the ocean-bottom, before $B(\omega)$ can be obtained. An estimate of the medium parameters was obtained by inverting the filter $\tilde{F}(p)$ found in the previous stage. The condition imposed on the decomposition result is that there should be no direct wave in the up- or downgoing shear stressfield *below* the bottom.

**Stage 5. Elastic decomposition into $\varphi^{\pm}$ and $\psi^{\pm}$** In the last stage the estimated parameters just below the ocean-bottom and the results of the elastic decomposition into up- and downgoing stressfields are simply combined to obtain the up- and downgoing P- and S-waves:

$$\tilde{\Phi}^{\pm} = \frac{c_{S,1}^2}{\beta_1}\{\mp 2pq_{S,1}\tilde{T}_{xz}^{\pm} - (c_{S,1}^{-2} - 2p^2)\tilde{T}_{zz}^{\pm}\}, \quad (5)$$

$$\tilde{\Psi}^{\pm} = \frac{c_{S,1}^2}{\beta_1}\{(c_{S,1}^{-2} - 2p^2)\tilde{T}_{xz}^{\pm} \mp 2pq_{P,1}\tilde{T}_{zz}^{\pm}\}. \quad (6)$$

The first three stages of the adaptive decomposition scheme are readily applicable to multicomponent ocean-bottom data. When the water depth is not too shallow, the windows in which the energy minimization is performed are easier to determine. To apply stages 4 and 5, an inversion for the medium paramers just below the ocean-bottom is necessary. The medium parameters are inverted from the least-squares filter $\tilde{F}(p)$ obtained in stage 3 (Schalkwijk et al., 2000). The result of the decomposition procedure for the Mahogany dataset for common-receiver gather 1323 is displayed in Figure 3 (the middle gather).

**Theory of multiple elimination for OBS data**

After wavefield decomposition the OBS data consist of upgoing P- and S-wavefields. A lot of surface-related multiples have been removed by the decomposition, but events as in Figure 1 remain. The iterative version of the multiple elimination procedure consists of a repeated application of the following two steps (Berkhout and Verschuur, 1997):

- Prediction of the "unscaled" multiples by auto-convolution of the data:

$$\mathbf{M}(z_0) = \mathbf{P}_0^-(z_0)\mathbf{P}^-(z_0), \quad (7)$$

  where $z_0$ denotes the water surface.

- Adaptive subtraction of the predicted multiples from the input data:

$$\mathbf{P}_0^-(z_0) = \mathbf{P}^-(z_0) - \mathcal{A}(\omega)\mathbf{M}(z_0). \quad (8)$$

The function $\mathcal{A}(\omega)$ contains the average free-surface reflection coefficient $r_0$ and the inverse source signature $S^{-1}(\omega)$ :

$$\mathcal{A}(\omega) = r_0 S^{-1}(\omega), \quad (9)$$

The matrix $\mathbf{P}^-(z_0)$ is the multiple prediction operator and contains the upgoing pressure wavefield at the free surface (deghosted data) for one frequency and all sources. The matrix $\mathbf{P}_0^-(z_0)$ is the input data. In the first iteration $\mathbf{P}_0^-(z_0)$ is the deghosted data itself ($\mathbf{P}^-(z_0)$).

In Berkhout and Verschuur (1997) it is also shown that the same multiple elimation procedure can be applied to a CFP gather (on the source or receiver side), using the original surface shot records as the multiple prediction operator. As the decomposed OBC data can be considered as a CFP gather, using focusing in detection with the focus point at the ocean-bottom, application of multiple elimination when streamer data is available is straightforward. When streamer data are not available, they can be simulated from the OBC data. Using the output of the acoustic decomposition of stage 2 of the adaptive decomposition scheme (*upgoing* pressure wavefield just *above* the ocean-bottom) and extrapolating this to the surface, simulated "receiver-ghost free" streamer data are obtained. The propagation operator is easily constructed using the water depth and velocity. Equation (7) modifies to

$$\vec{\mathbf{M}}^{-\dagger}(z_1^+, z_0) = \vec{\mathbf{P}}_0^{-\dagger}(z_1^+, z_0)\mathbf{W}^-(z_0, z_1)\mathbf{P}^-(z_1^-, z_0), \quad (10)$$

where $z_1$ is the depth of the ocean-bottom, $z_1^-$ is just above the ocean-bottom and $z_1^+$ is just below the ocean-bottom.

The multiple prediction operator is $\mathbf{W}^{-}(z_0, z_1)\mathbf{P}^{-}(z_1^{-}, z_0)$, $\vec{\mathbf{P}}_0^{-\dagger}(z_1^{+}, z_0)$ contains the input data for one frequency and all shots, i.e. it corresponds to one (decomposed) common-receiver gather just below the bottom. The multiple elimination procedure as it is applied to OBC data is illustrated by Figure 2. The upgoing pressure wavefield just above the ocean-bottom is resorted from common-receiver gathers to common-shot gathers and then extrapolated to the surface. One-common shot gather of the simulated streamer data is shown in Figure 2. To predict the multiples this shot gather is convolved with a decomposed common-receiver gather. This can either be the upgoing P-waves or the upgoing S-waves just below the ocean-bottom. The convolution results in curved events, with the apex at the spatial position of the reflection point at the surface. These multiple contribution events are summed in the horizontal direction to obtain the multiples for one source-receiver pair. If this procedure is repeated for all common-shot records of the simulated streamer data, the multiple prediction for one complete common-receiver gather is obtained.

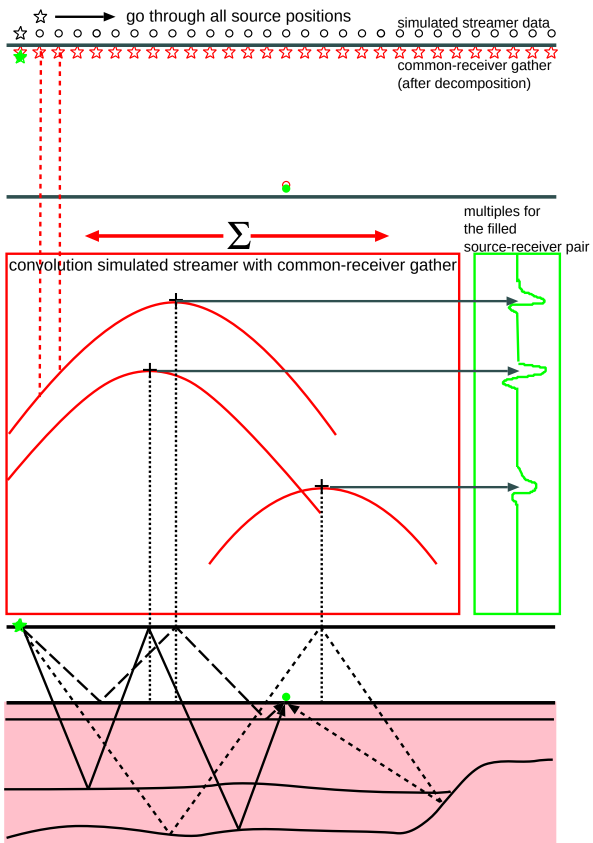



*Fig. 2: Multiple elimination for OBS data: the decomposed common-receiver gather is convolved with the acoustic decomposition result after extrapolation to the water surface to simulate streamer data.*

## Field data example

The data example shown here to illustrate the multiple elimination procedure comes from the Mahogany dataset which was acquired in the Gulf of Mexico. The water depth at this particular location is around 120 meters. A wavefield decomposition was performed on one OBC receiver line consisting of 59 four component receivers. The shot line overlapped the receiver line on the surface and consisted of 401 shots. Both receiver and shot interval was 25 meters. The wavefield decomposition was done per common-receiver gather. To simulate streamer data the acoustic decomposition result had to be sorted into common-shot gathers. Because of the limited number of receivers, the covered aperture was limited.

In Figure 3 the pressure data for common-receiver gather 1323 is displayed on the left, the upgoing P-wave potential after wavefield decomposition just below the bottom is displayed in the middle, and the predicted multiples for the upgoing P-waves are displayed on the right. A strong primary reflection can be seen at about 1.2 s zero-offset, from which at least two peg-leg mul-

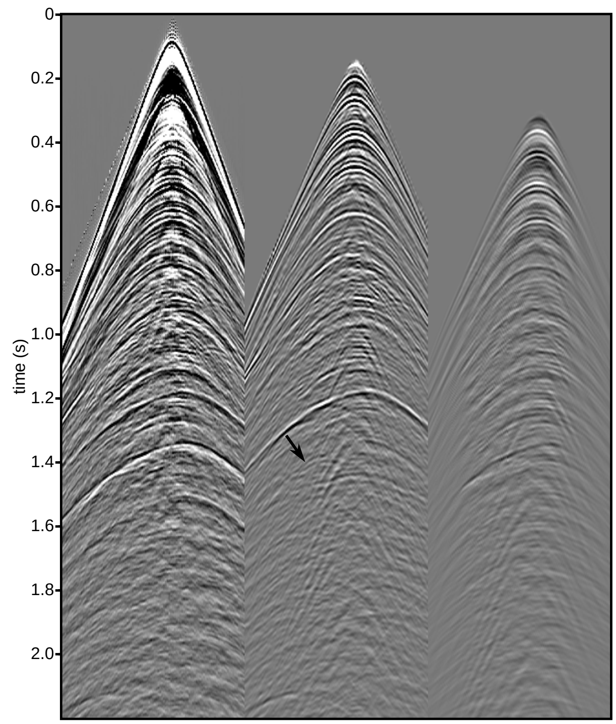



*Fig. 3: The first gather is the pressure component after deconvolution, the second gather is the upoing P-wave potential just below the ocean-bottom obtained after elastic decomposition, and the third gather contains the predicted multiples for the decomposed P-wave gather. The arrow points at a remaining source-side pegleg multiple.*

tiples can be identified. After decomposition the multiples arising from this strong primary are already strongly attenuated, but the source-side peg-leg multiple can still be seen. This peg-leg multiple is also predicted in the right gather. Due to the limited aperture the multiple cannot be predicted correctly over the whole offset range. Especially on the right-hand side there is almost no energy present in the predicted multiples. To improve these results more OBC lines need to be taken into account in the prediction process.

In Figure 4 the predicted multiples have been subtracted from the decomposed upgoing P-wave gather. In the first gather the data is displayed after decomposition only, the middle gather displays the decomposed data after additional multiple elimination. The gather on the right contains the predicted multiples. Some attenuation of the peg-leg multiple at about 1.35 s zero-offset can be seen, though the strongest part of the peg-leg is out of range of the aperture. At 0.8 s zero-offset is another multiple that has been removed.

## Conclusions

Multiple removal can be applied to OBC data in combination with wavefield decomposition. Decomposition in its own needs less data and removes the major part of surface-related multiple energy already. The extra value of performing a wavefield decomposition lies in the separation of P- and S-waves.

As source-side pegleg multiples are left in the decomposition result that can have the same strength as weaker primaries, multiple removal in combination with wavefield decomposition can have additional value for further processing.When the S-velocity just below the ocean-bottom is very low (P and S already separated on the vertical resp. horizontal velocity components) and there is enough source and receiver coverage, a multiple elimination in its own would be sufficient.

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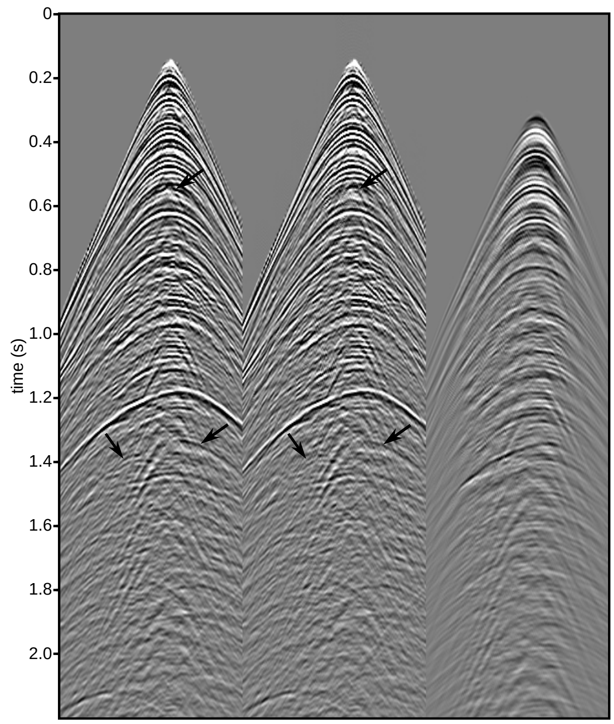


***Fig. 4:*** *The first gather is the upoing P-wave potential just below the ocean-bottom obtained after elastic decomposition, the second gather is the upgoing P-wave potential after additional surface related multiple elimination, and the third gather contains the predicted multiples again, that were subtracted from the first gather. The arrows point at multiple events that were removed.*