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Nearfield Hydrophone Driven 3D Source Designature and Deghosting for Multi-Level Source Data

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SUMMARY

Combined with recent receiver deghosting strategies, the use of multi-level sources can provide further uplift to the ever broadening bandwidth of seismic data. While multi-level sources help mitigate source notches in the output spectrum, the resulting emitted wavelet still exhibits residual ghosts, directivity, and bubble energy which must be handled in processing. We highlight the compatibility of Ziolkowski's notional source method with multi-level source acquisition. We continue by showing how the directional signatures may be used for 3D directional designature and deghosting on shallow water towed streamer data. The results show a significant improvement in the level of ringing relating to source wavelet directivity effects.

Introduction

Technology to provide broadband marine data began mainly on the receiver side with a range of approaches to remove the receiver-side free surface ghost based on over-under streamers (Posthumus, 1993), dual-sensor streamers (Carlson et al., 2007), variable depth streamers (Soubaras, 2010), or processing only solutions based on horizontal streamers. Although these technologies began to unlock the broadband nature of the Earth response, results were still limited by the source-side free surface ghost. Initially source-ghost compensation was combined with source designature, attempting to remove the source ghost with spectral shaping, where the signal to noise ratio allowed. This was limited at high frequencies by the first source ghost notch, which was often too deep (with extremely low signal amplitudes) to be effectively corrected by spectral shaping.

More recently the geometry of airgun source arrays has been modified to alleviate the source-ghost problem, positioning airguns at more than one depth. One such strategy places airguns at two different depths as shown in Figure 1a, fired with synchronised timing in order to time align the down-going energy (Siliqi et al., 2013). The different gun depths give rise to different ghost timings, providing signal within the ghost notches of individual gun depths as shown in Figures 1e and 1f. The source signature relating to the shallow airguns, deep airguns, and all guns are given in Figures 1b, 1c, and 1d, respectively. While the ghost energy is observed to be the same amplitude as the primary for the shallow and deep gun vertical farfields, the vertical farfield relating to all guns exhibits weaker ghost energy relative to the primary. While this results in a farfield signature without a strong ghost notch, the spectrum still exhibits amplitude fluctuations which require a processing correction.

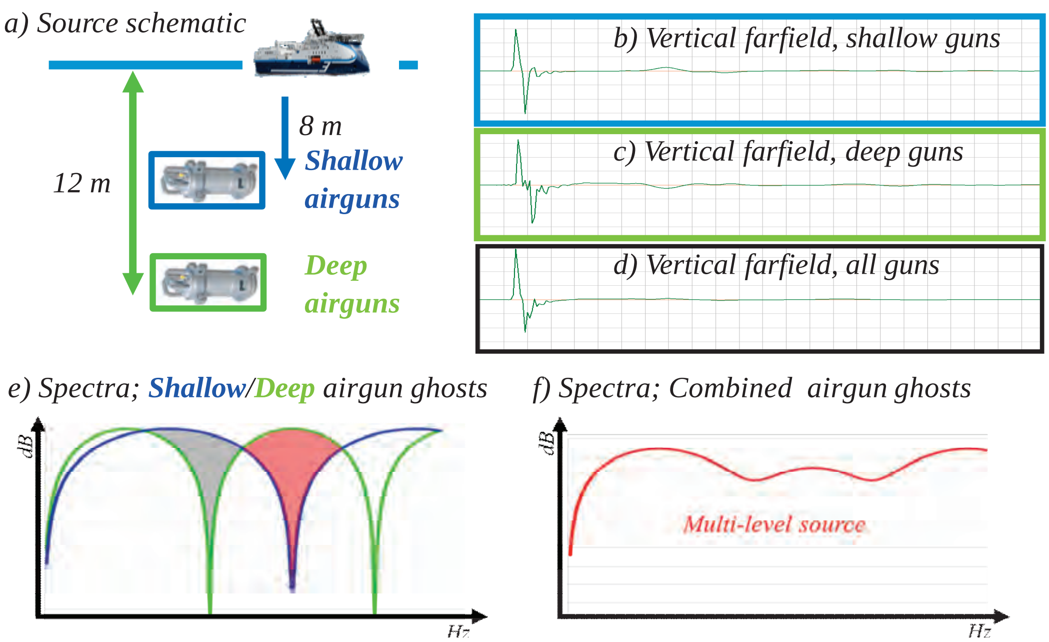

Figure 1 *Multi-level airgun source array layout, wavelets and spectra for shallow airguns at 8 m depth (blue), deep airguns at 12 m depth (green), and all airguns (red).*

In this paper we apply the method of Ziolkowski et al. (1982) to estimate directional farfield signatures for a multi-level airgun source array. We use the directional signatures as a resignature operator combined with a sparse 3D tau-p solver to estimate a towed streamer shot gather free of the source ghost and the bubble. The resulting model is used to estimate the ghost and bubble energy which is subtracted from the data. The approach assumes source-receiver raypath symmetry as described by Poole et al. (2015). A similar approach has also been given by Wang et al. (2015).

Method

Farfield signatures used in seismic data processing are often modelled as a global source signature that depends on the source-array configuration. However, the use of nearfield hydrophone measurements (Ziolkowski et al., 1982) to derive farfield signatures has recently been gaining popularity as an alternative approach able to measure variations in the actual source signature with time. Ziolkowski's method consists of two stages. In the first stage, an inversion problem is solved to estimate hypothetical notional sources for positions close to each airgun or airgun cluster. In the second stage, the notional sources are beam-formed to compute farfield signatures at different take-off angles and azimuths. More recently Ni et al. (2014) extended the first stage to include farfield hydrophone measurements to further constrain the process, especially for source-geometry estimation. The method may be used to compute one set of farfields to use for all shots, different farfields for different source configurations (for example, gun switches) or for every shotpoint.

Once a set of notional source signatures have been found, they may be used in a modified tau-px-py transform as outlined by Poole et al. (2015) or Wang et al. (2015). These methods derive a tau-px-py model representative of a point source with no ghost, so that when convolved with the source signature and ghost and reverse transformed describe the input data in a least-squares sense. Once the model has been found, it may be used to output the modelled primary energy either at the free surface or at some other datum. Alternatively, it may be used to output an estimate of the ghost and bubble energy which is subsequently subtracted from the input data. This approach can be attractive when sparse inversion has been used to derive the tau-p model in the presence of aliasing. In the same way high resolution Radon demultiple subtracts undesired multiples from an input CMP (Herrmann et al., 2000), we estimate the undesired ghost and bubble energy to subtract from the shot gather. This has the benefit of modifying the input data as little as possible, thereby leaving the character of the input data intact. Due to aliasing across a coarse array of cables, the tau-px-py model may be derived using iteratively reweighted least squares to guide the inversion to higher frequencies (Herrmann et al., 2000).

Ideally the method should be applied in the common receiver domain, for example relating to an ocean bottom node with dense shotpoint spacing. As described by Poole et al. (2015), we may also apply the approach in the common-shot domain assuming source-receiver raypath symmetry. Although this approximation is not suited to all geological settings, in the case that the Earth is approximately one dimensional locally, the approach may still offer benefits relating to strong source directivity compared with use of a designature operator based on vertical take-off angles.

Data example

The data example, Figure 2, comes from a North Sea acquisition deploying two multi-level airgun sources and towing 10 variable-depth streamers with a lateral spacing of 100 m. Due to the coarse sampling of shots, it is necessary to apply the approach in the shot domain and assume source-receiver raypath symmetry. For comparison, the data is also processed using 1D source designature methods, including ghost compensation. After 3D directional designature (and deghosting), receiver deghosting is applied in the common-shot domain following Poole (2013). Figure 2b shows the results of applying a 1D designature, which suffers from significant ringing in the shallow section as highlighted by the red arrows. This is due to the incorrect assumption of vertical take-off angles for events travelling to the outer streamers at small two-way times. The waterbottom reflection relates to a y-direction take-off angle of approximately 50 degrees. 3D designature as shown in Figure 2c does not create these ringing artefacts as it properly honours the directional variation of the source wavelet. Finally we see that the image after receiver deghosting, Figure 2d, has simplified the wavelet further revealing the broadband nature of the data.

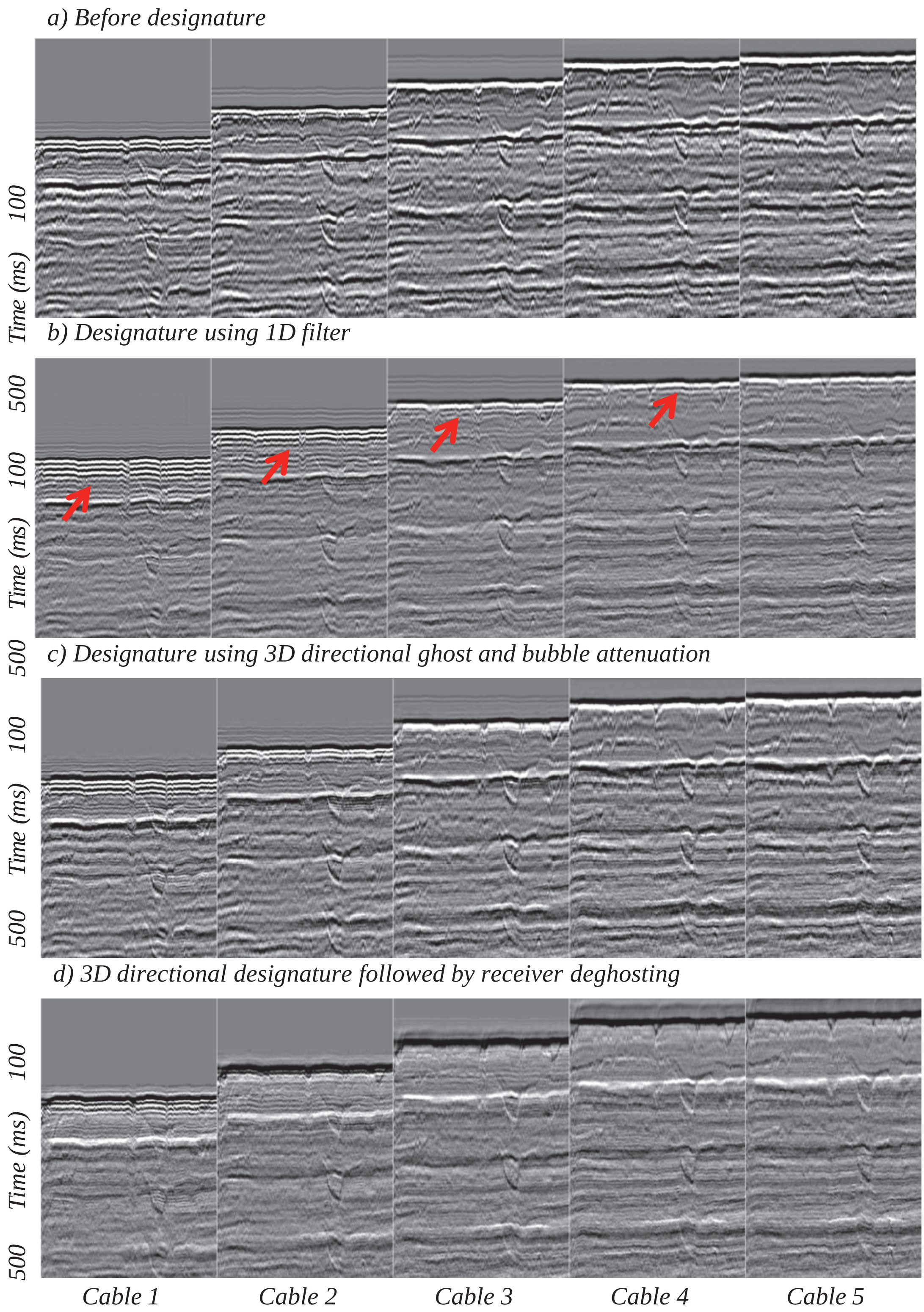

Figure 2 *Common channel displays for cable 1 (outer) to cable 5 (inner). Examples given for a) input, b) after 1D designature, c) after the proposed 3D directional designature, and d) 3D directional designature followed by receiver deghosting.*

Conclusions

We have demonstrated the use of nearfield hydrophone data for 3D directional designature in the case of multi-level sources. The amplitude spectrum of the multi-level source is free of the sharp ghost notch observed in the single level case, and provides directional farfield signatures for input to 3D directional designature. The directional designature benefits from the spectral in-fill of the source-ghost notches, recovering a flat spectrum without over-boosting noise. Use of 3D directional designature with multi-level sources helps produce broadband images of the Earth's subsurface when combined with receiver deghosting methods. The approach may also be used for multi-vessel acquisitions.

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