A closer look at hydrophone-only versus two-component deghosting in deep-tow streamer data
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Summary

Learnings drawn from a large body of prior work should leave little doubt that broadband acquisition/processing add value to the seismic end product. However, there is still a lack of true 1-to-1 comparisons between processing-only versus acquisition-assisted methods. Here, we compare two-component (2C) deghosting with hydrophone-only (1C) deghosting, using seismic data acquired with a multi-component streamer system. We find that 2C deghosting provides a measurable uplift over 1C deghosting on migrated full-angle stacks, for both internally and externally processed data. This result validates multi-component streamers with regard to the method discussed here, i.e. 2C deghosting; however since the overall uplift is modest it may not translate into added value in the final product depending on survey objectives and target depth, amongst others. This needs to be evaluated on a case-by-case basis.

Introduction

Three multi-component streamer systems are currently in production or pre-production testing: GeoStreamer® (PGS) which was launched in 2007, followed by IsoMetrix® (WesternGeco) in 2012 and most recently Sentinel® MS (Sercel) in 2013 (Carlson et al., 2007; Robertsson et al., 2008; Mellier et al., 2014). In addition to hydrophones measuring pressure, all three systems have vertical motion sensors recording velocity or acceleration; these record complementary ghost responses facilitating wavefield separation into up- and downgoing wavefields, a process also referred to as two-component (2C) deghosting. Some systems also have horizontal components enabling additional applications; however, these are not considered here.

Why use a multi-component streamer? The main motivation has been to enable a deeper streamer tow. It is well established that deeper tow improves low-frequency signal-to-noise by reducing destructive interference from the receiver ghost and swell noise due to larger distance from the sea surface. Figure 1 illustrates the impact of sea state and tow depth on hydrophone/pressure data. Lower sea state and/or deeper tow lead to lower noise at low frequencies (below ~10Hz) while increasing signal in the low to mid frequency band.1 Towing streamers deep, however, introduces a problem in that receiver ghost notches may creep into the signal bandwidth, requiring a “deghosting” operation to recover the information in and around the ghost notches. Multi-component streamers are an acquisition solution to this problem by recording two physical measurements with complementary ghost notches. Hence, in theory, multi-component streamers enable elimination of the ghost notches which is especially important for deep tow acquisition since ghost notches may be located within the signal band at typical reservoir depths. In addition to this acquisition solution, there is an increasing set of processing methodologies that attempt to retrieve usable signal in the ghost notches from the hydrophone recording only; such methods are here referred to as 1C deghosting (see for example Kemal et al., 2008; Ryanti et al., 2008; Poole et al., 2013; Wang et al., 2014). Towing streamers at variable depth can assist 1C deghosting methods by providing data with greater ghost notch “diversity”.

Figure 1: Effect of tow depth and sea state on hydrophone data: Deep tow data (red) have lower noise (=less swell) below and higher amplitude (=more signal) >7Hz. The two shallow tow examples (green / black) had different sea state: Both have similar signal content (curves align >12Hz) but different amount of swell. Extrapolating the signal curves illustrates differential signal uplift at the low end by towing deep.

1 Towing streamers deep can also have operational benefits by widening the acceptable weather window and thus shortening the survey duration.

Theory and Method

The ghost function and the 1C deghosting method used here are described in Jovanovich et al (1983). For 2C deghosting, pressure (P) and vertical velocity (Vz) data are summed after the following pre-conditioning steps:

- Vz data is first converted to pressure-equivalent units and matched to the hydrophone instrument and potentially array response. Acceleration measurements require an additional integration step.
- An obliquity correction is applied to Vz data to recover signal at non-vertical incidence (panel e) in Figure 2) and a weight function (panel f) is applied to filter out
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data below the first Vz ghost notch. This last step is due to motion sensor noise, see next section.
- For P data, 1C deghosting is applied to recover signal below the first Vz ghost notch and a complementary weight function is applied.

In the data examples, 2D operators were used for both 1C and 2C deghosting which is adequate for a single streamer towed approximately centrally behind the source array. See Day et al (2013) for more details on 2C deghosting including an extensive list of additional references.

Motion sensor noise and streamer tow depth

If noise was not a significant issue, 2C data acquired at almost any streamer depth could be separated into perfect up- and down-going wavefields over the full signal bandwidth, including at ultra-low frequencies. However, in practice noise on motion sensor data increases rapidly towards low frequencies, limiting its use below a certain frequency. Figure 4 displays spectral estimates of the noise content on raw P (red) and Vz (blue) data from the shallow water survey introduced in the next section. Vz has higher average noise than P below ~40Hz, however a large amount of this noise is effectively removed as part of the Vz pre-conditioning flow for 2C deghosting detailed above (black line in Figure 4). Note that in this and other typical shallow water data sets, the high noise level on P above ~20Hz is caused by water-trapped energy which Vz records to a lesser extent due to the high angle of incidence. In deep water, on the other hand, ambient noise levels on P are often lower than Vz over the full bandwidth both before and after Vz pre-conditioning.

In our experience, the usable low-frequency limit for Vz data is somewhere above 15Hz (depending on factors such as sea state and cable tension). Currently, below this limit, Vz data does not add value to 2C deghosting due to the comparatively high level of noise (note this may change in the future with improved acquisition and/or processing techniques). Hence, we need to rely on P data alone below 15Hz (or higher). This has the side-effect of limiting streamer tow depths to a maximum of ~25m since towing deeper would move the first Vz ghost notch below 15Hz requiring good quality Vz data below 15Hz for effective 2C deghosting. The trade-off between streamer tow depth and motion sensor noise is thus:

a) Deeper tow depth (usually) improves low-frequency information recorded on pressure data.

b) Motion sensor noise limits the practical tow depth to 25m or shallower.

Combining the above arguments with experience from a number of surveys, we believe the current optimum tow depth for multi-component streamers to be around 20m; operational aspects can further influence this choice, usually towards shallower tow depths.

Real data example

As a case study we will use a multi-component data set from offshore Norway. The survey was acquired in approximately 120m of water at 15m streamer and 6m source depth, respectively. Figure 3 shows a comparison between pressure (P) and vertical velocity (Vz) data. While input Vz data shows a large amount of non-seismic noise, it appears visually cleaned after the pre-conditioning step for 2C deghosting described earlier. Comparing the x-t displays with the noise estimates in Figure 4, Vz data after pre-conditioning has comparable, if not better, signal-to-noise than P data over the bandwidth required for 2C deghosting. Obviously, noise levels are survey dependent so we cannot generalize from this observation. However, experience from a number of surveys gives us confidence that motion sensor data adds information without adding

Figure 2: 2D FK plots for illustrating a) P and b) Vz ghost operators, c) Regions between sequential P ghost peaks (stars), d) Incidence angle, e) Vz obliquity correction factor [dB], f) Filter following 1st notch (cyan area in (c)) which can be used to precondition Vz data prior to P+Vz summation.
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undue noise in the process, provided an appropriate streamer tow depth was chosen and an adequate processing flow is applied.

We apply a 1C and 2C deghosting flow to this data set, including source designature, zero-phasing and wavelet shaping. No dedicated noise attenuation is applied except shallow water demultiple. Figure 5 is a shallow window display of 2D migrated sections with their corresponding amplitude spectra shown in figure 6. The 1C and 2C deghosted results are visually very similar, but the 1C deghosted result has some residual receiver ghost energy most easily identifiable just below the water bottom (red arrow). Also, the 1C result has overall higher background noise which affects weaker events (blue arrow), while stronger events are equally resolved (yellow arrow). A coherence based signal-to-noise spectrum (figure 7) demonstrates the uplift around the ghost notches from 2C deghosting. Note that 1C deghosting alone does not improve underlying signal-to-noise compared to the input P data. We have also estimated signal-to-noise on two other data sets processed with multiple vendors as well as in-house deghosting technologies (figure 8). In all cases the fundamental issue is the same: 1C deghosted data has lower signal-to-noise around the notch areas regardless of the deghosting methodology (however we have also seen variations in the magnitude of the difference in other data sets not presented here).

In summary:
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1) Shallow stacked sections show modest uplift in data quality when comparing 1C and 2C deghosting.
2) The quantity of the signal-to-noise uplift is estimated to be up to 6dB around the ghost notches.

The uplift of 2C versus 1C can be expected to decrease with depth due to greater angle coverage (i.e. more notch diversity) and a narrower signal bandwidth; on the other hand it may be greater for pre-stack data for the same reason. For 1C deghosting, one could argue that with improved noise attenuation or deghosting method the difference could be reduced. However, low or missing signal likely limits what additional noise processing can achieve: Figure 9 displays narrow band limited, migrated stacked sections. While noise is visibly higher in the 1C compared to the 2C deghosted section, signal also appears weaker or missing entirely (circled areas). It seems unlikely that signal can be generated by 1C deghosting where it is not recorded in the hydrophone data.

Conclusions

We have shown that there is a measurable uplift in signal-to-noise by using two-component (2C) versus hydrophone-only (1C) deghosting. The uplift is confined to a narrow band around the ghost notches with an overall modest impact on stacked migrated sections while being more significant for weak events. We believe the potential impact on final interpretation products needs to be evaluated on a case-by-case basis depending on the environment, water depth and project objectives.

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EDITED REFERENCES
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