Increased streamer depth for dual-sensor acquisition – Challenges and solutions

Marina Lesnes, Anthony Day, Martin Widmaier, PGS*

Summary

The towing depth applicable to dual-sensor streamer acquisition has hitherto been limited by operational challenges associated with maintaining the fronts of the streamers at deeper tow positions, which creates additional drag, and noise recorded by the particle velocity sensor. These restrictions have limited 3-D acquisition to a maximum tow depth of 20m whilst 25m towing depth is routinely used for 2-D acquisition. In July 2013, a field trial was performed with streamers towed at 15m at the front increasing to 30m depth at mid- and large- offsets. Since the front of the streamer is deployed at a depth routinely used for dual-sensor acquisition, such a streamer profile is no more difficult to achieve and has comparable noise performance to a horizontal streamer. Wavefield separation can be performed for arbitrary streamer profiles and the up-going wavefield output at a horizontal datum, thereby presenting no additional difficulties for subsequent processing steps. The benefit of deploying the streamer at a greater average depth is increased low frequency signal-to-noise ratio (frequencies below 16 Hz). This uplift was demonstrated by comparing the deep tow data to that obtained using a horizontal streamer at 15m depth.

Introduction

During seismic data acquisition, a well-known way to improve signal-to-noise ratio at low frequencies is to tow the streamer deeper. A deeper streamer records more low frequency signal energy. By increasing the streamer depth from 15m to 30m, a signal improvement is expected below 16 Hz. By recording further away from the sea surface, we also anticipate less noise related to weather and sea surface roughness. For dual-sensor acquisition, towing the streamer deeper implies using more of the particle velocity data at the lower end of the frequency spectrum for wavefield separation. This part of the spectrum is likely to be the most contaminated by mechanical noise. On the operational side, towing the streamers deeper requires a substantial increase in the downward force applied to the front ends.

A way to limit these difficulties is to keep the front ends of the streamers at the usual tow depth for dual-sensor acquisition and gradually increase the towing depth to a pre-defined maximum. This acquisition geometry is easy to maintain during 3-D seismic acquisition since the fronts of the streamers are towed at the same depth as for most of the 3-D dual-sensor surveys that have been acquired to date. The noise on the particle velocity sensor is well understood: since the streamer is at the usual dual-sensor streamer tow depth in the front, the particle velocity signal that contributes to the wavefield separation remains the same. The mechanical noise recorded by the particle velocity sensor decreases with tension, so the noise content is less at mid- and large offsets where the streamer is deeper and the wavefield separation requires more use of the particle velocity data. By having a substantial part of the streamer deeper, the signal-to-noise ratio at the low end the spectrum – where only the pressure sensor contributes - is improved.

Test description and processing

A field test was conducted offshore Brazil by Ramform Viking in July 2013. She is equipped with dual-sensor streamers that record pressure and particle velocity datasets using collocated sensors. A reference line was acquired using a production configuration comprising 10 streamers at 15m constant depth. A deep tow line was acquired with the front ends of the streamers at 15m while the middle- and far-ends of the streamers were towed deeper at a pre-defined depth. The increase in streamer depth is a constant slope of 2m per 300m horizontal distance until 30m depth is reached at an inline offset of 2625m. The 10 streamers of the spread followed the same depth profile with a constant cross-line separation of 100m retained for both lines.

The main objectives of the field trial were to assess the operational feasibility of increased tow depth and quantify the benefits in the low frequency part of the spectrum. In the ultra-low frequency range a pressure sensor on a streamer at 30m depth is expected to record more low frequency signal than on a streamer at 15m depth - see Figures 1 and 2. At higher frequencies, the ghost notches for the pressure and particle velocity sensors are complementary and are filled equally well in the wavefield separation for 15 and 30m streamer depth.

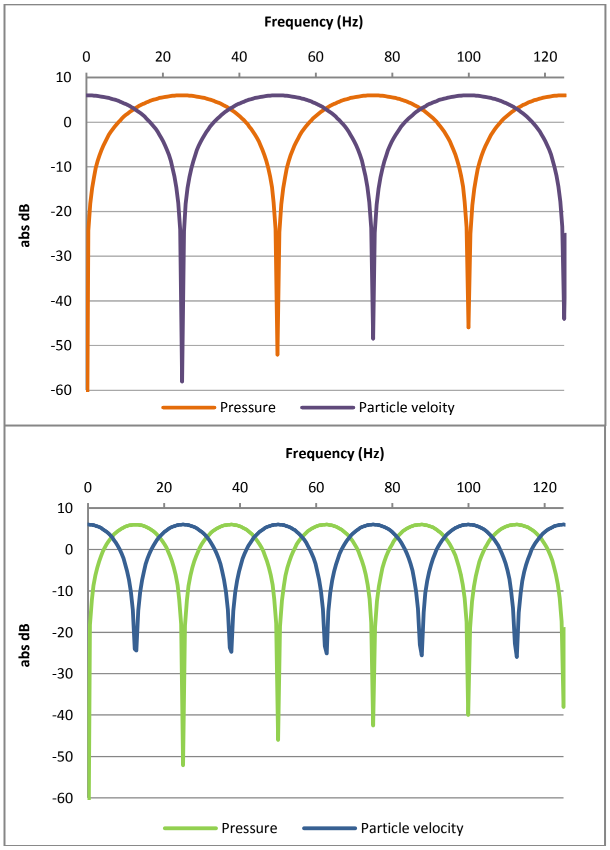
Both lines acquired by Ramford Viking were processed in an identical way based on standard production flows. The wavefield separation was performed using standard dual-sensor processing techniques that output the up-going pressure field (P^{up}) at a constant horizontal datum. A scaled version of the vertical particle velocity record (V_z) is combined with the pressure record (P) according to the following formulae for horizontal streamers:

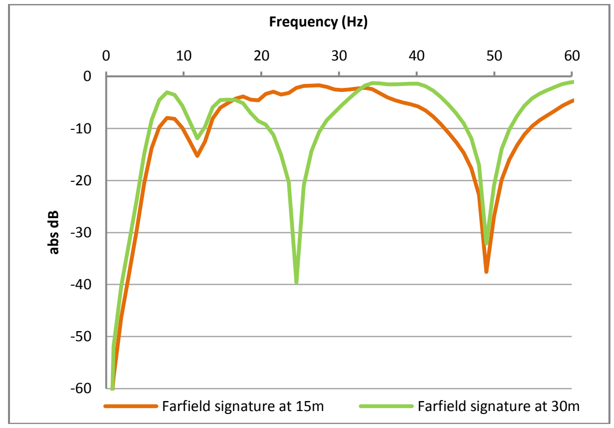
$$P^{up} = \frac{1}{2}(P - FV_Z) \quad \text{and} \quad P^{down} = \frac{1}{2}(P + FV_Z)$$

In the frequency-wavenumber domain the scaling filter F is

$$F(\omega, k_x, k_y) = \frac{\rho\omega}{k_z}, \text{ with } \; k_z = \sqrt{(\frac{\omega}{v_w})^2 - {k_x}^2 - {k_y}^2}$$

DOI http://dx.doi.org/10.1190/segam2014-0729.1





←Figure 1 (left): Pressure and particle velocity ghost functions for a recording depth of 15m (top) and 30m (bottom)

↑ Figure 2 (above): Far-field signatures for a pressure sensor at 15m (orange) and 30m (green) sensor depth showing the signal difference at low frequencies. By towing at 30m depth, an uplift in signal is expected below16 Hz.

This scaling filter includes the corrections for acoustic impedance and the obliquity factor necessary when a particle velocity record is transformed to a pressure record (Amundsen, 1993). In the above formulae k_x, k_y and k_z denote the three components of the angular wavenumber vector, w denotes angular frequencies, and ρ and v_w are the density and the acoustic wave propagation velocity of water respectively. For the deep tow data, where the streamers were not horizontal, the data can be processed using a generalisation of the above method to arbitrary streamer profiles described by Söllner et al. (2008). In practice we approximate this procedure by discretizing the cable depth profile in locally horizontal streamer segments. This approximation is valid due to the smooth and gentle variation in depth with offset.

The low frequency portion of the vertical particle velocity records tends to be relatively noisy. Consequently, the lowest frequencies of the vertical particle velocity are rebuilt from the pressure record, a procedure referred to as low frequency compensation (LFC) and described by Carlson et al. (2007). The LFC procedure can only be applied up to frequencies a little less than the first non-zero notch in the pressure ghost function for reason of stability. Since the notch frequency is depth dependent, the frequency up to which LFC is applied can be varied for each depth slice. This frequency limit was gradually decreased from 22.5 Hz at 15m to 17.5 Hz at 30m depth in 2m depth increments. For the longer offsets, we can use more of the particle velocity data; sensors are closer to the rear where tension, and consequently mechanical noise, is lowest.

After wavefield separation, the up-going wavefield may be extrapolated to a more convenient horizontal datum. This extrapolation process has no effect on the frequency content of the data. In this example, the output depth for P^{up} for both sequences was chosen to be 23m at all offsets. Consequently, dual sensor streamer acquisition using a slanted profile does not present any fundamental processing difficulties for wavefield separation or any subsequent processing steps (e.g. demultiple) since these can be performed as though the data were acquired with horizontal streamers.

DOI http://dx.doi.org/10.1190/segam2014-0729.1

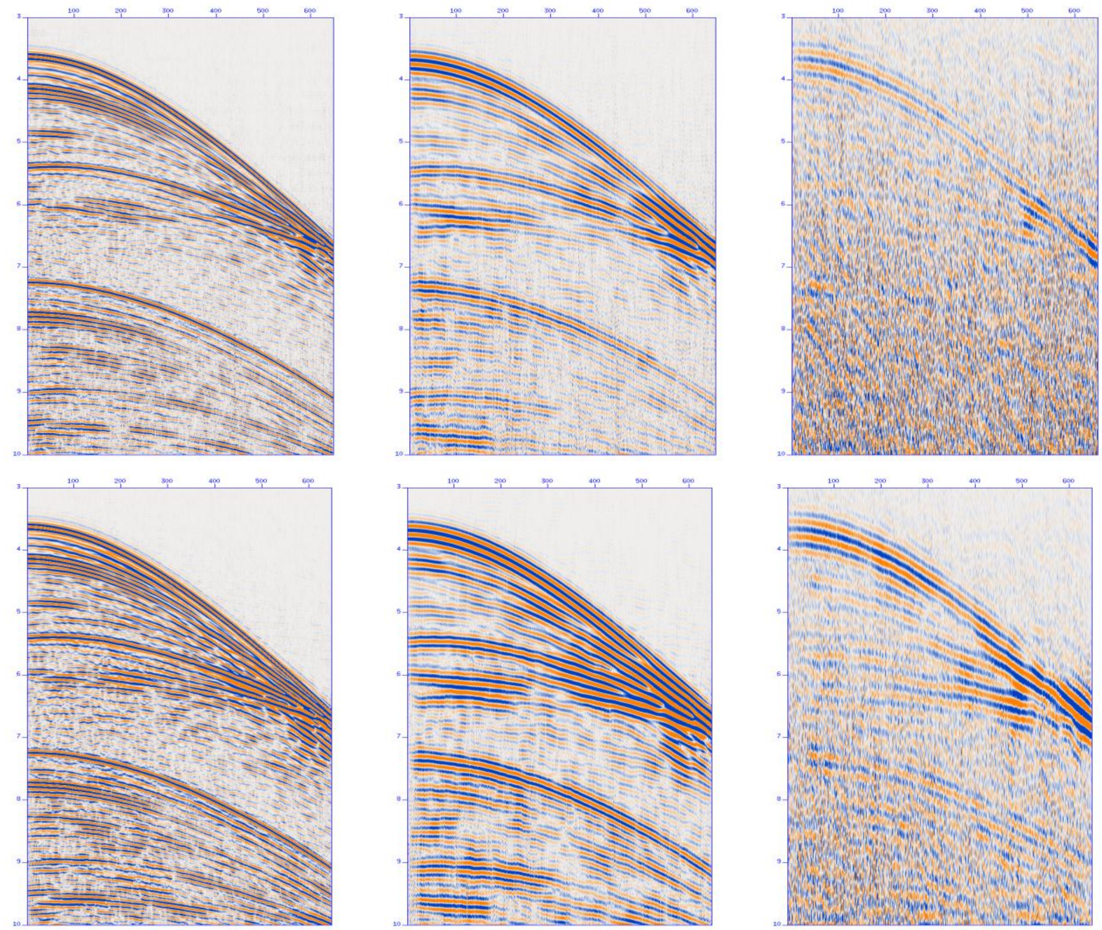


Figure 3: Shot records from the pressure sensor after swell noise attenuation in the frequency range 8-16 Hz (left column), 4-8 Hz (middle column) and 2-4 Hz (right column) for flat streamer acquisition at 15m depth (top row) and deep tow geometry streamer (bottom row). The low frequency signal enhancement at mid- and far offsets arising from increased tow depth is clearly visible .

Results

Shot gathers from the pressure sensor after swell noise attenuation from both acquired lines are presented in Figure 3. Comparing the deep tow line with the reference line acquired with 15m constant depth profile, the water bottom reflection and deeper reflectors are more continuous and have higher amplitudes for the deep tow line. The gain in signal is ~4 dB and benefits the mid- and large- offsets from 2 to 16 Hz. This observation is consistent with the predictions from modelling in Figure 2. At near offsets, the noise content is similar for the two acquired lines. The depth variation at the front of the deep tow streamer profile does not introduce additional noise. This observation is as expected since the streamers are close to horizontal (the depth changes by 2m vertically for every 300m horizontally).

For the particle velocity sensors, the noise content is independent of streamer depth so is substantially the same for both lines. At mid- and far-offset, where the streamer is towed at 30m, particle velocity data contribute to P^{up} from 17.5 Hz. At these offsets, the particle velocity sensors provide good signal-to-noise ratio also at lower frequencies due to lower tension.

For the up-going pressure field, the signal for both configurations should be identical. Hence, any improvement in signal-to-noise ratio in the raw data will appear as decreased noise. Figure 4 presents up-going pressure shot gathers for both lines. For the deep tow line, the random noise is reduced at low frequencies and an uplift is clearly visible, especially between 2 and 8 Hz. This improvement in signal-to-noise ratio leads to cleaner stacked sections and better images. Reflectors are better defined, especially in the deeper part and at low frequencies

DOI http://dx.doi.org/10.1190/segam2014-0729.1

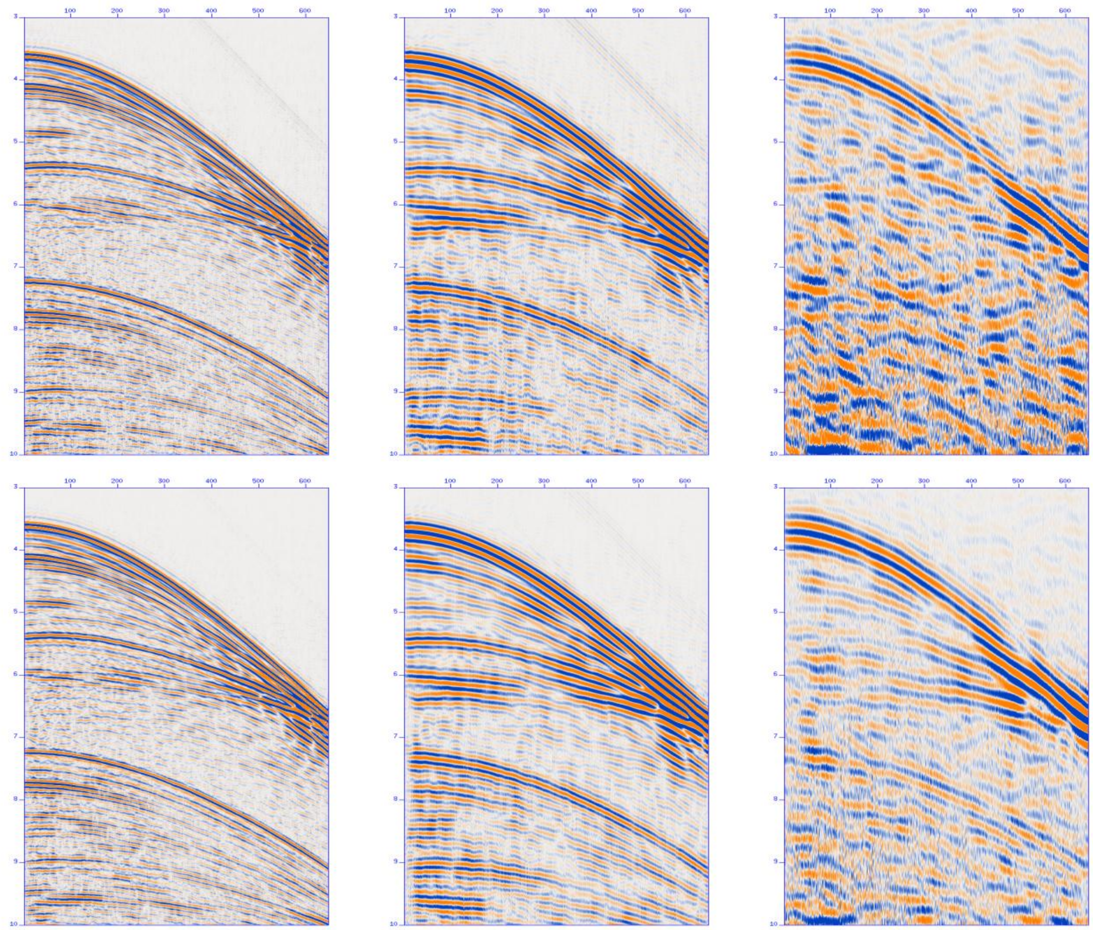


Figure 4: P^{up} shots 8-16 Hz (left column), 4-8 Hz (middle column) and 2-4 Hz (right column) for flat streamer acquisition at 15m (top row) and deep tow streamer (bottom row). Note the clear improvement in signal to-noise ratio for the deep tow geometry.

Conclusions

This field trial demonstrates the feasibility and advantages of 3-D acquisition of dual-sensor streamers with increased tow depth. No major technical difficulties were encountered. The modified dual-sensor streamer depth profile removes any operational challenges and benefits the signal at low frequencies. The control of the streamers both laterally and in depth was retained throughout the entire test without problems. The noise performance of this geometry is comparable to a horizontal streamer, so no extra swell noise attenuation is required during the processing of the data. The signal uplift below 16 Hz predicted by modelling was successfully observed in the raw data and led to clear improvement in the low frequency signal-to-noise ratio of the up-going pressure wavefield. The complementary signals recorded by the collocated pressure and particle velocity sensors in a dual-sensor streamer mean there is no drawback at higher frequencies.

The output from the wavefield separation is the up-going pressure field at a horizontal datum: hence all subsequent processing steps (multiple removal for example) can be applied as usual. Furthermore, it is anticipated that the improved signal-to-noise ratio at the lowest frequencies will be particularly beneficial for procedures such as full waveform inversion and acoustic impedance inversion.

Acknowledgements

PGS acknowledges the kind permission granted by Repsol Sinopec Brazil S. A. to acquire the GeoStreamer deep tow test lines in their licensed area Offshore Brazil. We would like to thank the crew of the Ramform Viking and everyone involved in this test.

http://dx.doi.org/10.1190/segam2014-0729.1

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2014 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Amundsen, L., 1993, Wavenumber-based filtering of marine point-source data: Geophysics, **58**, 1335–1348, http://dx.doi.org/10.1190/1.1443516.

Carlson, D., A. Long, W. Söllner, H. Tabti, R. Tenghamn, and N. Lunde, 2007, Increased resolution and penetration from towed dual-sensor streamer: First Break, **25**, no. 12, 71–77.

Söllner, W., A. Day, and H. Tabti, 2008, Space-frequency domain processing of irregular dual-sensor towed streamer data: 78th Annual International Meeting, SEG, Expanded Abstracts, 1078–1082.