Increased Streamer Depth for Dual-sensor Acquisition - Challenges and Solutions

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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 a deeper tow position, which creates additional drag, and noise recorded by the vertical particle velocity sensor. These restrictions have limited 3-D acquisition to a maximum towing depth of 20 m whilst 25 m towing depth is routinely used for 2-D acquisition. In July 2013, a field trial was performed with a slanted streamer, from 15m depth at the front to 30m at larger offsets. Since the front of the streamer is deployed at a depth routinely used for dual sensor streamer acquisition, such a slanted streamer profile is no more operationally 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 a substantial proportion of the streamer at greater depth is increased low frequency signal-to-noise ratio (less than 16 Hz). This uplift was demonstrated by comparing the data acquired using a slanted streamer profile to that obtained using a horizontal streamer.

Introduction

It is well known that the low frequency signal-to-noise ratio can be improved by increasing the streamer depth in seismic data acquisition. In practice, there are two main limiting factors that have hitherto prevented 3-D dual sensor streamer acquisition at constant depths greater than 20 m. On the operational side, increasing the streamer depth requires a substantial increase in the downward force that must be applied to the front of the streamers. Another limiting factor is the mechanical noise recorded by the particle velocity sensor, which is strongest near the front of the streamers where the tension is greatest. Increasing the streamer depth would require using more of the particle velocity data at the lower end of the frequency spectrum for the purpose of wavefield separation; however this part of the signal spectrum is expected to be most affected by the mechanical noise.

In order to mitigate these limitations, it was proposed to adopt a slanted profile streamer geometry whereby the front of the streamers are towed at the most commonly used dual sensor streamer 2D acquisition depth of 25 m with the streamer depth gradually increasing to a pre-determined maximum, 30 m in this case. This acquisition geometry removes the operational difficulty outlined above. Furthermore, since the fronts of the streamers are towed at conventional dual sensor streamer depths, the mechanical noise recorded by the particle velocity sensor is less problematic. By towing deeper, we expect to record more low frequency signal energy. Signal improvement is expected below 16 Hz. We also anticipate less noise related to sea surface roughness and weather.

Test description and processing

By having part of the streamer towed at 30 m depth , we expect to record more low frequency signal energy due to the spectral slope near 0 Hz (see Figures 1 and 2). At higher frequencies, ghost notches on hydrophone and particle velocity sensors are complementary and filled equally well for 15 m and 30 m streamer depth. To assess the uplift for the low frequency part of the frequency spectrum and the operational feasibility, a field test was conducted using the Ramform Viking offshore Brazil in July 2013. A test line was acquired using a slanted streamer profile, whereby the front ends of the streamers were towed at 15m depth with a subsequent constant slope of 2 meters depth increase for every 300 meters horizontal distance until 30 m depth was reached at an inline offset of 2625 m. In total a 10 streamer spread was towed with an identical depth profile for all streamers and a constant cross-line streamer separation of 100m. In addition, a reference line was acquired using a production configuration with flat streamers at 15 m depth.

The two datasets were processed in parallel through the same standard production-based processing sequence. The wavefield separation was performed using standard dual-sensor data processing techniques and the up-going pressure field (P^{up}) output at a selected constant horizontal datum. For horizontal cables, the separation of the total wavefield into up- and down-going parts was performed by combining a scaled version of the vertical particle velocity record (V_z) with the pressure record (P)

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

In the frequency-wavenumber domain, the scaling filter F is given as:

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

This scaling filter includes the corrections for acoustic impedance and the obliquity factor necessary when a vertical particle velocity record is transformed to a pressure record (Amundsen, 1993). k_x, k_y and k_z denote the three components of the angular wavenumber vector, ω denotes angular frequency, and ρ and v_w are the density of water and the acoustic wave propagation velocity in water, respectively. The slanted profile streamer 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 applying horizontal streamer processing for depths between 15 and 30 m with a 0.2 m increment and combining the results based on the actual depth of each receiver. This approximation is valid due to the smooth and gentle variation in recording depth with offset.

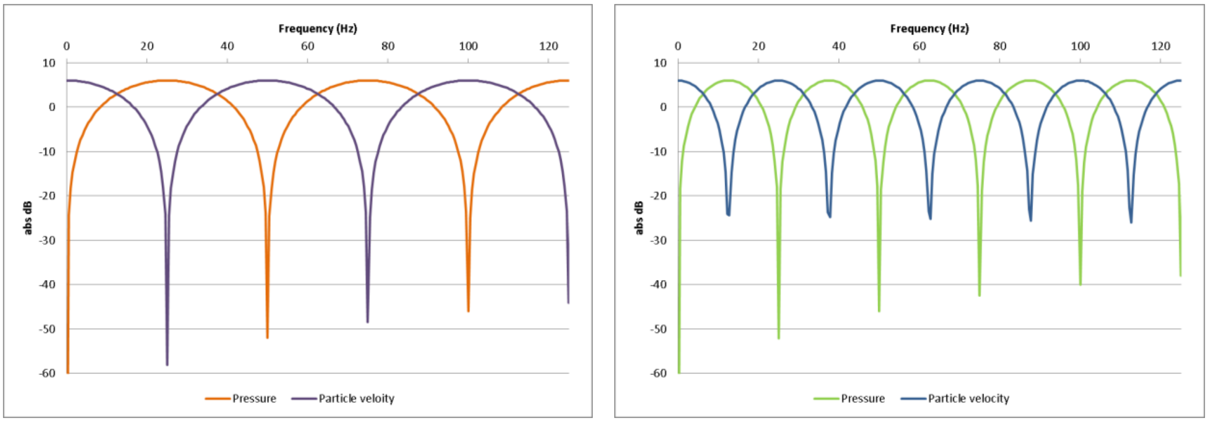

Figure 1 (above): Hydrophone and particle velocity ghost functions for a recording depth of 15m (left) and 30m (right)

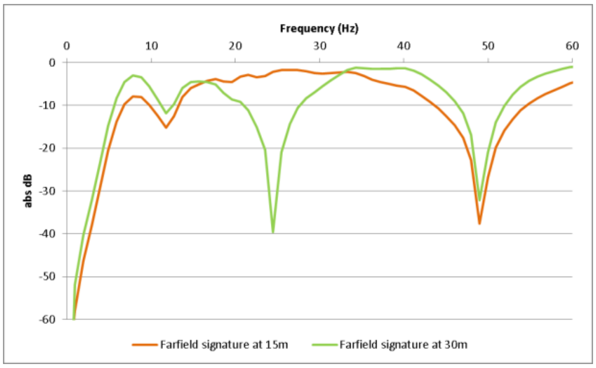

Figure 2 (right): Far-field signatures for a hydrophone at 15m (red) and 30m (green) sensor depth showing the signal difference at low frequencies. By towing at 30m depth, an uplift in signal is expected below16 Hz.

The low frequency portion of the vertical particle velocity record 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 reasons of stability. Since this notch frequency is depth dependent, the frequency up to which LFC is applied will likely vary for each depth slice. The LFC limits were gradually decreased from 22.5 Hz at 15m to 17.5 Hz at 30m depth in 2 meter increments. The particle velocity data is used at the lowest frequencies (17.5 Hz) only for the deepest parts of the streamers which are closest to the tail end of the streamer where tension, and consequently mechanical noise, is lowest.

After wavefield separation, the up-going wavefield may be extrapolated independently 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} of both datasets has been chosen to be 23m at all offsets. Consequently, dual sensor streamer acquisition using slanted cables 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.

Results

A clear signal improvement (4 dB) is visible on the raw hydrophone data acquired with a slanted streamer profile between 2 and 16 Hz (see Figure 3). This improvement is most obvious at mid- and large- offsets where the streamer is towed at 30 m depth. The water bottom reflection and deeper reflectors have higher amplitude and are more continuous. This observation is consistent with the predictions from modelling in Figure 2. On the near offsets, no additional noise is introduced by the slanted streamer profile. Since the slant was very modest (2 m vertically for every 300 m horizontally) such that the streamers are close to horizontal, this observation is entirely as expected.

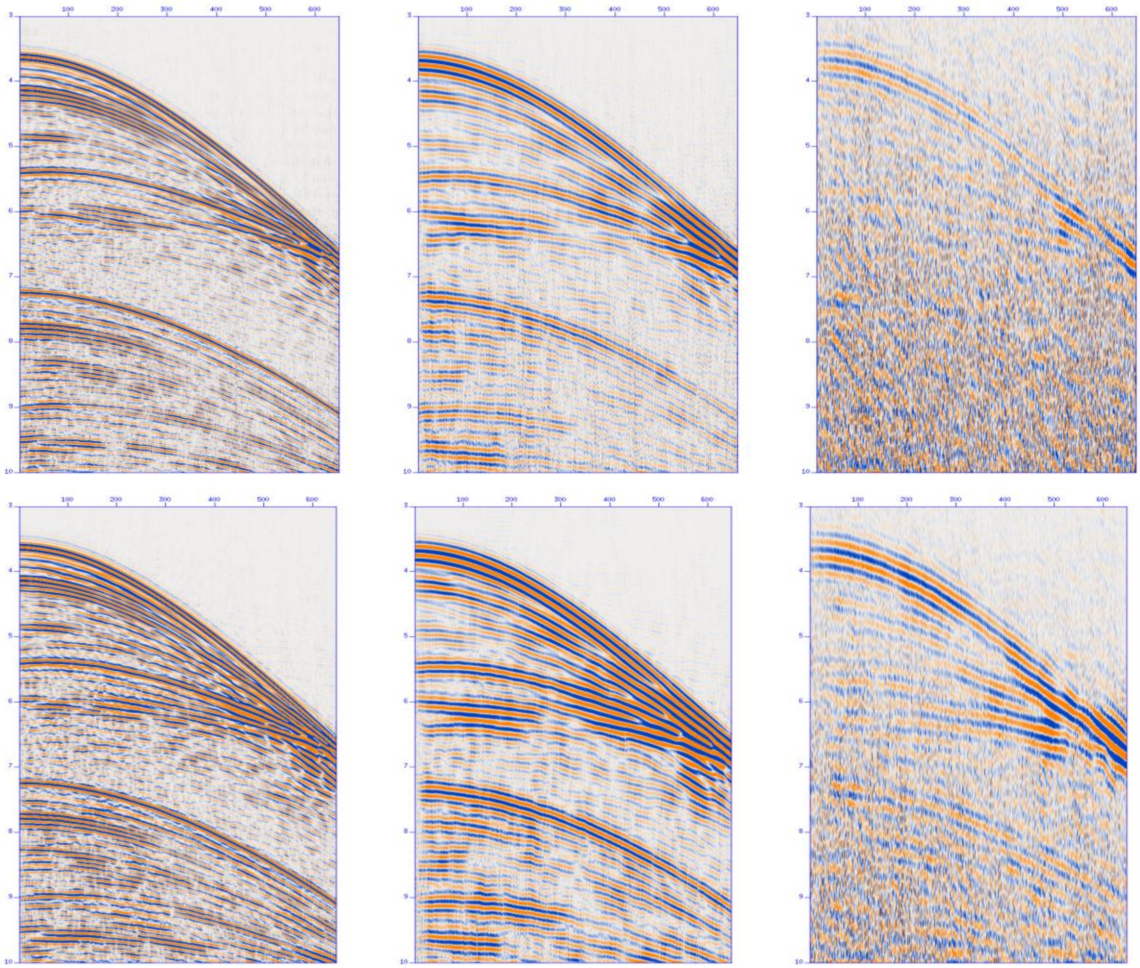

Figure 3: Hydrophone shots after swell noise attenuation in the frequency range 8-16 Hz (left column), 4-8Hz (middle column) and 2-4 Hz (right column) for flat streamer acquisition at 15m depth (top row) and slant profile geometry streamer (bottom row). The low frequency signal enhancement at mid- and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

The noise on the particle velocity sensor is not dependant on the streamer depth and is not affected by the very modest slant of the streamer. At mid- and far- offsets and above 15/20 Hz the noise is within reasonable limits and can be easily removed; consequently the data quality of P^{up} is not compromised.

After wavefield separation to create P^{up}, the signal for both acquisition profiles should be identical. Hence, the improved signal-to-noise ratio observed in the raw data will manifest as decreased noise in P^{up}. The random noise at low frequencies (0 – 8 Hz) is reduced with the variable depth configuration. An uplift in signal-to-noise is clearly visible on shots in Figure 4, especially between 2 and 8 Hz. This improvement leads to cleaner stacked sections and better defined reflectors, especially in the deeper part and at low frequencies.

Conclusions

A 3-D acquisition of dual sensor streamers with a slanted depth profile was successfully conducted in July 2013. No major technical difficulties were encountered during the test. The control of the streamers (lateral and depth) was retained throughout the entire test without problems. The slanted depth profile of the streamer did not introduce any additional noise and the general noise level was as expected. No extra swell noise attenuation was 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 a clear improvement in the low frequency signal-to-noise ratio of the P^{up} wavefield. There was no observed drawback at higher frequencies. The complementary signals recorded by the collocated pressure and particle velocity sensors were used to perform wavefield separation and the up-going pressure field generated for a horizontal datum; hence all subsequent processing steps (multiple prediction 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.

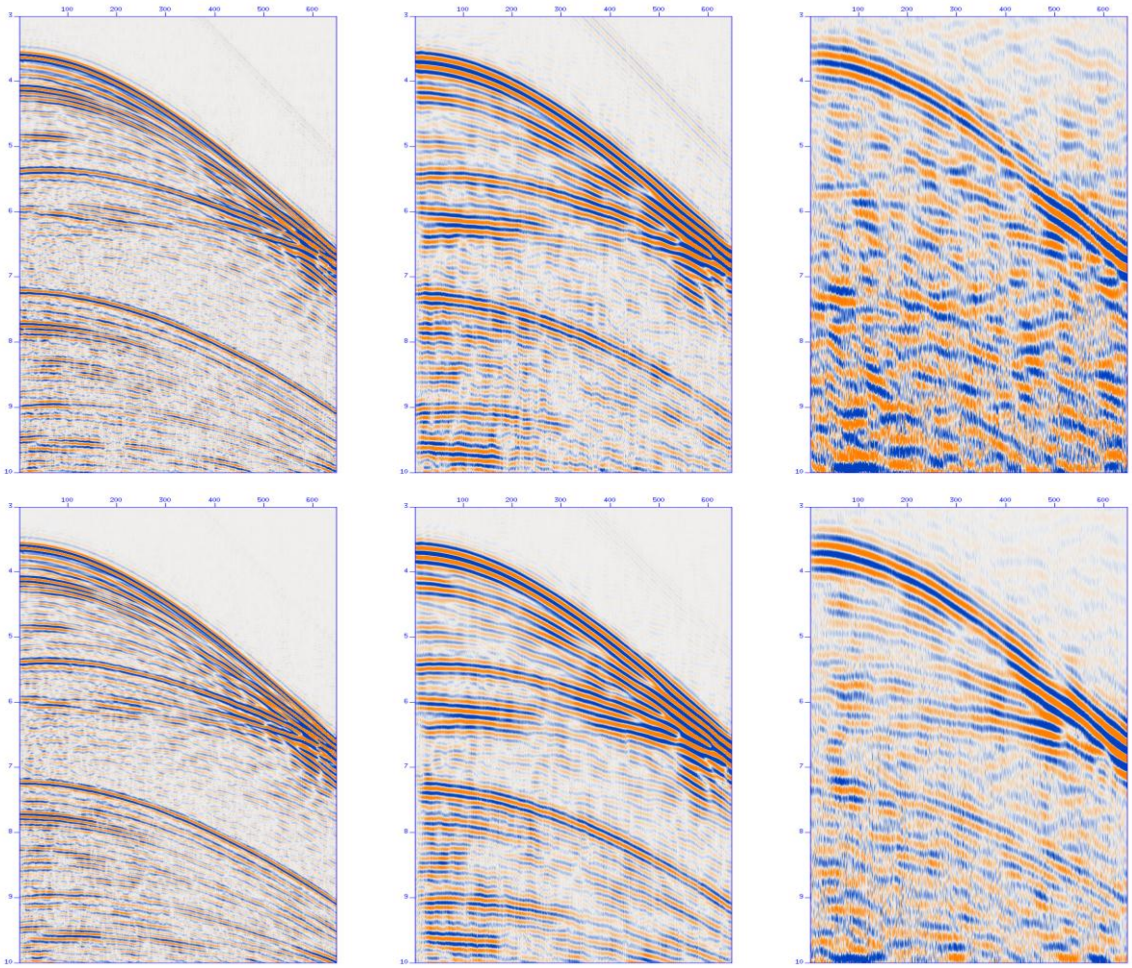

Figure 4: P^{up} shots 8-16 Hz (left column), 4-8 Hz (middle column) and 2-4Hz (right column) for flat streamer acquisition at 15m (top row) and variable depth streamer (bottom row). Note the clear improvement in signal to-noise ratio for the slant profile streamer geometry.

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