Integration geoConvention 2013 geoscience engineering partnership

A Step Change in Seismic Imaging – Using a Unique Ghost Free Source and Receiver System

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Summary

Until the invention of the dual-sensor streamer in 2007, towed streamer seismic acquisition and processing projects where hampered by the imposed sea-surface ghost reflections. There was always a trade off in terms of towing depth and frequency content as they are inherently linked to each other. Deeper tow meant more low frequency signal at the expense of the high frequencies. Since 2007 the seismic industry has taken on the challenge of delivering broadband signal – uncompromised by the sea-surface ghost reflections. This paper describes the unique ghost free acquisition system based on the dual-sensor streamer combined with a ghost free time and depth distributed source. The new system allows for true removal of the surface ghosts, leading to an acquisition platform that can be towed deeper for increased low frequency content and increased signal to noise ratio (S/N) without compromising the high frequency S/N.

Source and receiver ghosts

Because towed marine streamer seismic always operates beneath the sea-surface, any seismic wavefield traveling in the water column will see the water surface acting as a reflection surface with reflection coefficient close to -1. This means that when the source emits its primary energy, this pulse is also reflected up to the sea surface and an almost identical source wavefield trails its original one with opposite polarity but later in time, depending on the source depth. This is illustrated in Figure 1 where the direct source wavefield is annotated with (1) and the source ghost reflection is annotated with (2). This similar physical behavior will also happen on the receiver side, such that the two source events now become four. In an ideal world of seismic – we would want to eliminate both the sea-surface mirror effect on the source- and on the receiver- side.

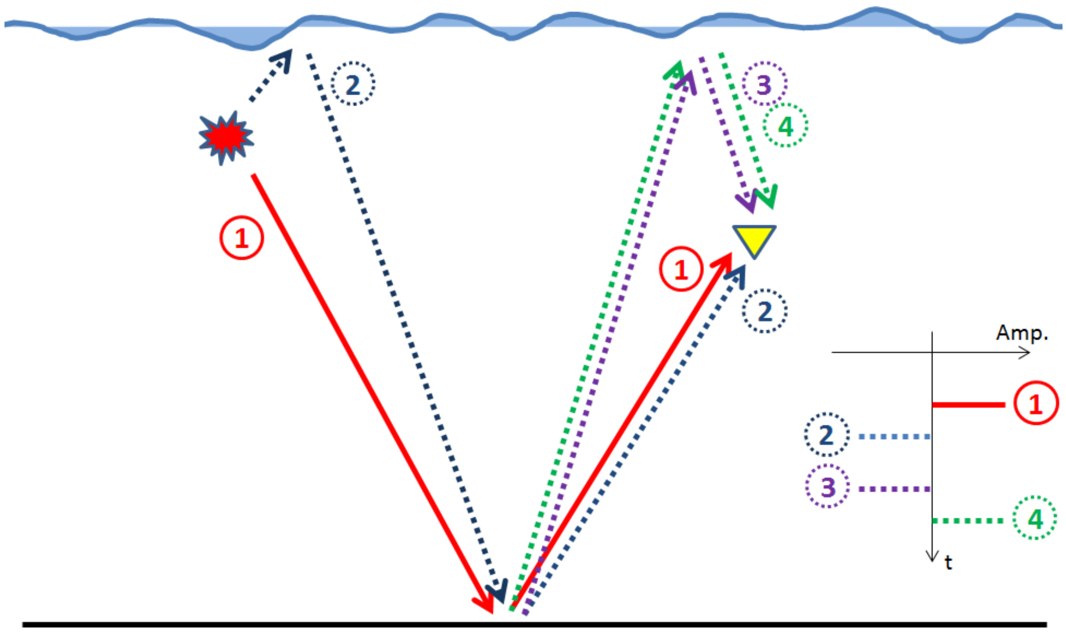

Figure 1: *Diagram of the wavefield emitted from a source and how one single pulse is effectively recorded as 4 individual events on the receiver side. Event number 3 and 4 are caused by the receiver side ghost, and event number 2 is caused by the source side ghost. This paper explains how a new ghost free acquisition system has been designed and is able to eliminate all the 3 ghost events and only image the single original emitted source wavefield.*

Removing the receiver side ghost

A key component of the ghost free acquisition system was introduced in the seismic exploration industry in 2007, through the dual-sensor seismic streamer. This utilizes co-located pressure and complementary vertical velocity sensors such that a combination of the two will eliminate the receiver side ghost. For further details see e.g. Carlson et al. (2007) or Tenghamn et al. (2007). However, it is worth mentioning that the streamer can be towed much deeper than any conventional streamer, thereby reducing the noise levels, and at the same time increasing the low frequency signal levels. Because the dual-sensor streamer can be towed much deeper, in a quieter environment, acquisition can continue in conditions where conventional recording would have to be interrupted.

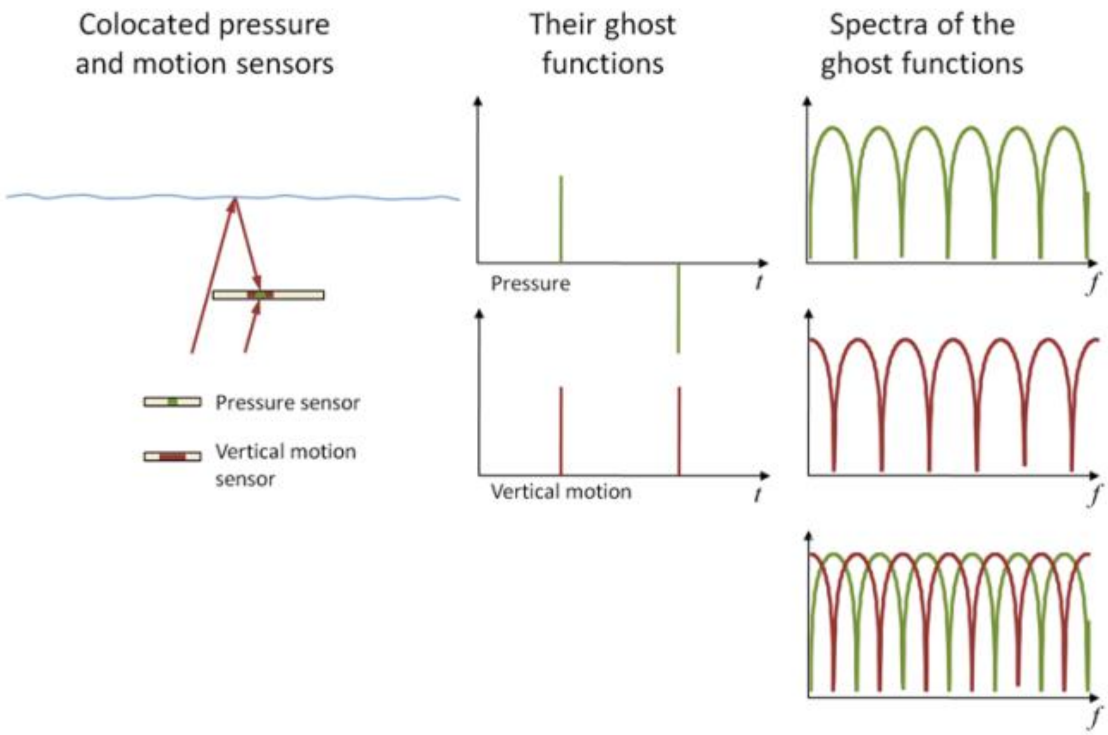

Figure 2: *Receiver deghosting using co-located pressure and velocity sensors in the dual-sensor seismic streamer. The ghost functions (pressure and vertical motion) are completely complementary to each other so by combining the two sensors – a full elimination of the receiver ghost is possible.*

Removing the source side ghost

The new ghost free source is a time and depth distributed source. The depths are chosen such that the independent depths exhibit complementary ghost functions – so where one source depth has a notch, the other has strong signal and vice versa. There are many alternative depths that work together. One example is 5 m and 9 m, and another pair can be 10 m and 14 m. The new source is not limited to only two depths, but can be composed of several more independent depths if needed. Since the new source is ghost free – you can essentially tow at any depth operationally feasible as long as they exhibit complementary ghost functions. The time distribution is chosen such that the independent sources can be separated from each other. Typical randomization schemes can be 1-1000 ms, or any other randomization that is deemed appropriate. Since there can be several source depths, one can choose to randomize all variable depths, or only one. Compared to earlier versions of over-/under sources in marine seismic, the new time and depth distributed source preserves the same shot efficiency and density as a conventional source, so there is no compromise in fold or data quality. See Parkes and Hegna (2011) for further details about the time and depth distributed source.

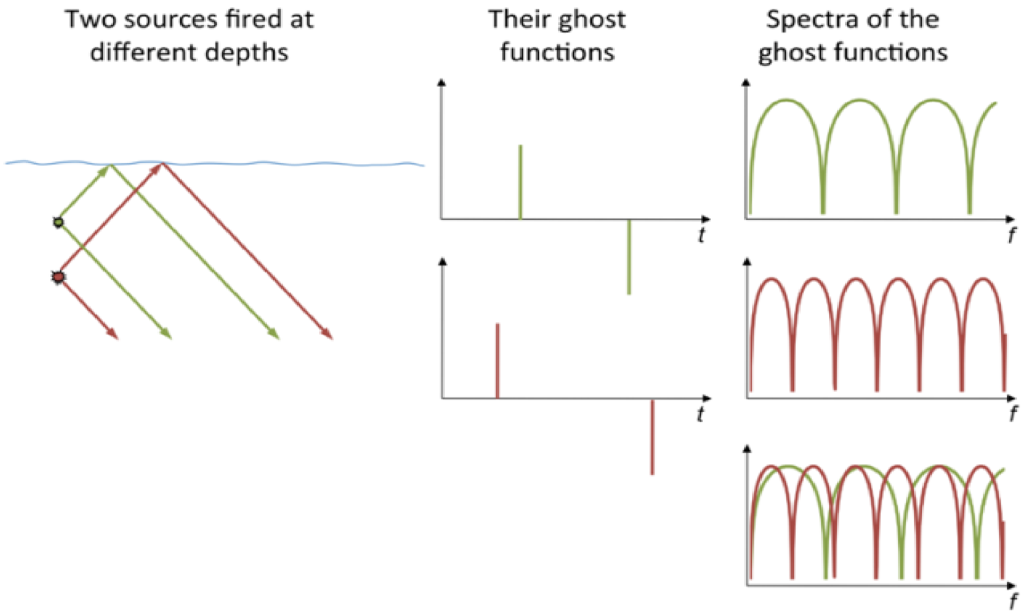

Figure 3: *Illustration of the time and depth distributed source. The depths are chosen such that the independent depths exhibit complementary ghost functions – so where one source depth has a notch, the other has strong signal and vice versa.*

After the data has been acquired using the new time and depth distributed source in combination with the dual-sensor streamer, the data can be deghosted both on the receiver and on the source side very early in the processing flow. The resultant output is a fully deghosted raw shot gather dataset with a complete spectrum over the whole frequency bandwidth of the recording system, typically 2.5 – 220Hz.

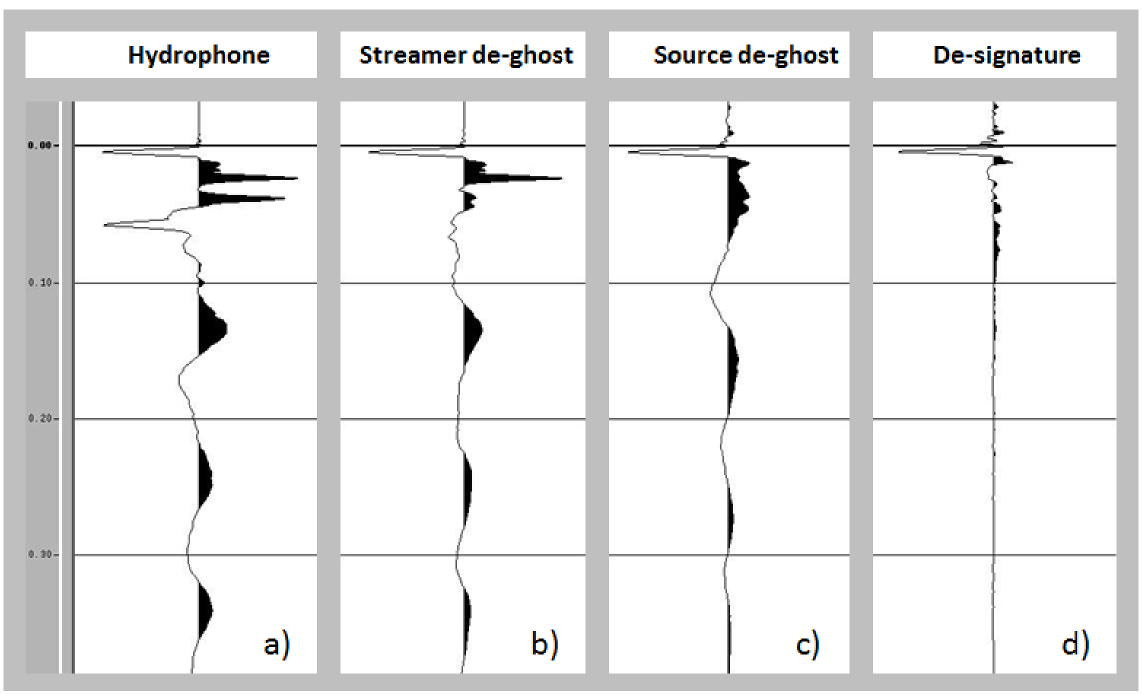

Figure 4: *Image showing the summed wavelet from over 3000 shots of near-traces – illustrating how the deghosting process effectively eliminates the 2 ghosts and collapses the long wavelet in image a) into an almost single spike in image d).*

Processing and imaging with unprecedented bandwidth – 2.5 - 220Hz

The full deghosting method presented in this paper is based on an acquisition solution for broadband imaging. The 1st steps in processing include the receiver wavefield separation, then the source separation and finally the source deghosting and application of the ghost free designature filter. After the ghost-free shot gathers have been produced the processing and imaging can be more or less similar to conventional processing – but care must be taken to avoid limiting the bandwidth unintentionally. Most processing flows and procedures have over the years been optimized to fit a conventional frequency bandwidth and would not necessarily work well with deghosted broadband data.

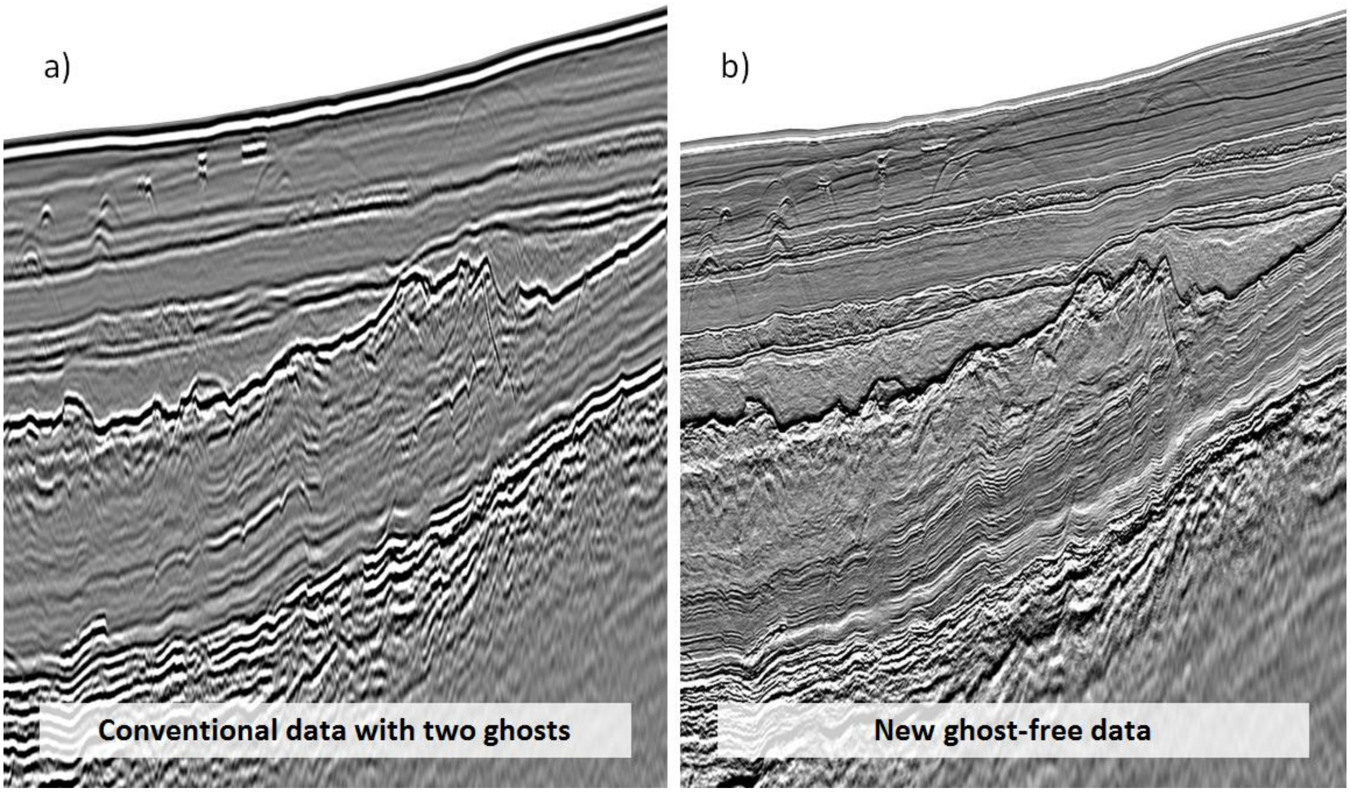

Figure 5: *Comparison of conventional data with two ghosts (a) and new ghost free data (b). Special care for retaining the bandwidth is important when processing and imaging ghost free broadband data.*

Inversion of ghost free broadband data

The simultaneous extension of both high and low frequencies achievable with the new deghosted acquisition system has a major positive impact on the interpretability of the seismic data (Reiser et al, 2012) .In Figure 6 both the conventional data and the deghosted data have been inverted to generate a P-impedance section of both. The benefits of the improved low frequency signal content lie mainly in the ability to perform an inversion with a limited a-priori model or well log calibration. This significantly increases our ability to predict reservoir properties (lithology and fluid) away from the well control. The broadband high resolution seismic data experience significant detuning (compare figure 6b to 6a) which in turn will allow extraction of reliable attributes for very thin layers. This will in turn allow proper characterization of downlapping, onlapping and truncating pinch outs events.abstract presents technically correct ideas with a fresh and enlightening perspective.

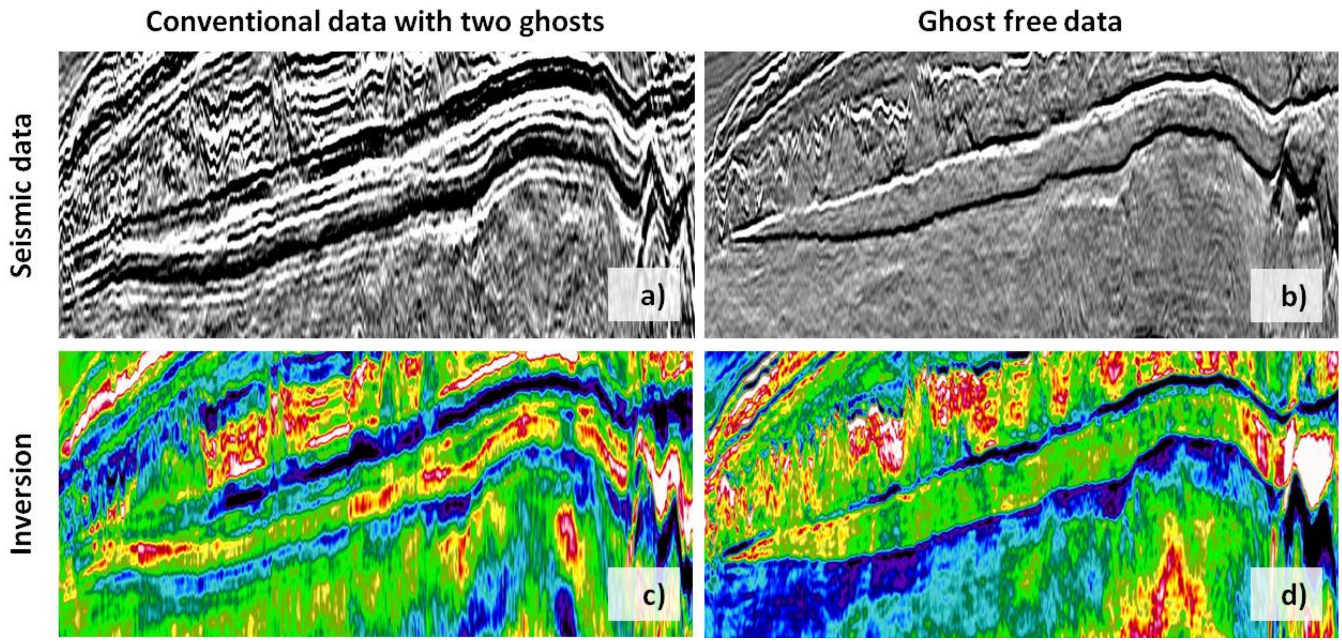

Figure 6: *Comparison of a conventional dataset (a) with a ghost free dataset (b). The two datasets have been inverted below and simple comparison between c) and d) reveals how much better the broadband ghost free data is. Extremely thin layers can now be characterized using the new ghost free broadband data.*

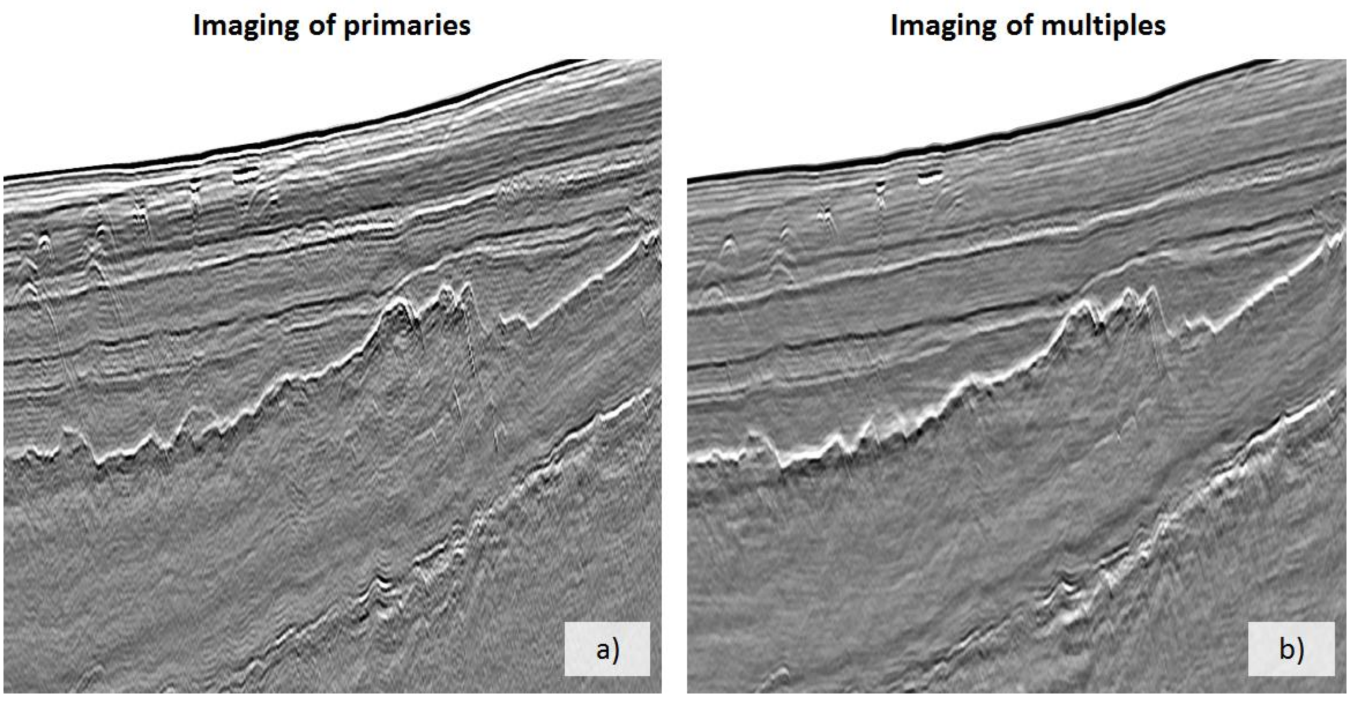

Figure 7: *Depth imaging using separated wavefields. The left image a) is derived from the primaries and the right image b) is imaging using the multiples.*

Imaging with separated wavefields

The new ghost free data lends itself to another benefit through imaging with separated wavefields, *P-up* and *P-down*. Because the deghosting happens at a very early stage in the processing, unique ghost free shot gathers are available both as upgoing- and downgoing- wavefields. These can be imaged separately and combined to produce even better images of the sub-surface (Lameloise et al, 2012). Figure 7 shows an example of depth imaging using separated wavefields where imaging using the primaries are shown in a) and imaging using the multiples are shown in b).

Conclusions

A unique ghost free source and receiver system has been demonstrated through processing to deliver broadband seismic data with a frequency content of 2.5-220Hz. The new system is based on a time and depth variable source combined with a dual-sensor streamer. In combination they deliver true ghost free raw shot records at a very early stage in the pre-processing sequence – allowing the subsequent demultiple and imaging sequence to benefit from the broad frequency range and high signal to noise level. The added benefit of the new system is shown to give a range of possibilities when it comes to reservoir characterization, pre-stack inversion and imaging with separated wave fields. The new data is unrivalled in detail, resolution and low frequency content.

Acknowledgements

The authors would like to thank PGS for permission to publish this paper. We would also like to thank the various vessels and field crews for all their support in acquiring these unique new ghost free datasets. Finally we would like to thank a number of talented data processing people, both in Oslo, London and Houston for their efforts in processing and imaging the datasets.

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