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Broad-band seismic data from the ocean floor – Ocean bottom nodes

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Summary

Ocean bottom nodes (OBN) are able to capture the full frequency band of the seismic signal generated by current marine air gun sources. First, data recorded by nodes at the ocean floor – with appropriate processing applied – are free of the receiver ghost. Second, nodes are ideal for recording very low frequency signal not usually attainable with conventional marine acquisition systems: Nodes can achieve this due to the low ambient noise environment at the seafloor, especially in deep water, and the possibility to use sensors with high sensitivity and a low noise floor.

Keywords: *Multi-component, broad band, ocean bottom nodes*

Introduction

OBN surveys are arguably the most efficient marine acquisition technique to acquire wide or full azimuth seismic data, and to obtain effective coverage underneath surface obstructions. Commercial nodes are usually equipped with a hydrophone and three component velocity sensors, recording the full elastic seismic wave field, including shear waves. Recording with both pressure and vertical velocity sensors enables receiver de-ghosting using wave field separation techniques, due to the two sensor's complementary receiver ghosts (figure 1), relevant for P-wave processing. Receiver de-ghosting can in principle also be achieved with streamer acquisition techniques, but for these, the receiver ghost notch at 0Hz remains. Data recorded by the vertical sensor lacks the ghost notch at 0Hz, and is not affected by surface swell or flow noise such as towed streamers (Elboth et al, 2009). Hence, selection of a suitably low natural frequency geophone with a low system noise floor should enable high fidelity recording of the lowest frequency information generated by current marine seismic air gun sources, while also giving the full response at high frequencies. Broad band signal content leads to a sharper seismic wavelet, which obviously improves interpretability of the seismic data. Rock physics inversion, in particular, benefits from lower frequencies.

How to boost low frequency recording

The hydrophone channel in Seabird's CASE Abyss node is recorded with an analogue 1.5Hz low cut filter required for high impedance sensors. In comparison, data recorded on hydrophone channels in towed streamers used to have a digital 3Hz low cut filter applied before even arriving on the vessel, in addition to any analogue filter in the electronics. Nowadays the digital filter is usually (or should be) turned off, but analogue filters are still at or above 2Hz.

Pressure sensors in marine acquisition are subject to a notch at 0Hz caused by the receiver surface ghost (left figure 2). The deeper the sensor can be placed, the better.

For velocity measurement, the CASE Abyss node uses 8Hz geophones. These are sensitive to tilt and have to be planted with care. In comparison, standard omnidirectional geophones used in ocean bottom cables have a natural frequency of around 14.5Hz. Hence, in comparison to other systems, the CASE Abyss node gives a wider dynamic range at low frequencies (right figure 2).

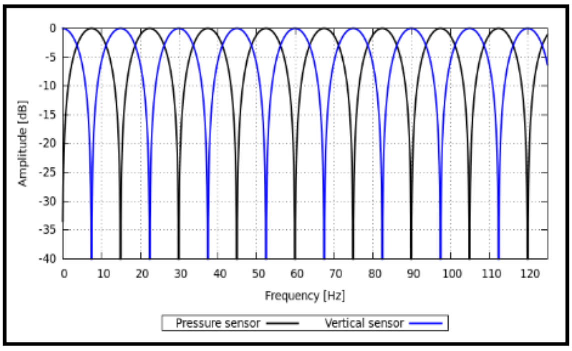

Figure 1: Vertical receiver ghost for hydrophone (black) and geophone (blue) at a depth of 50m.

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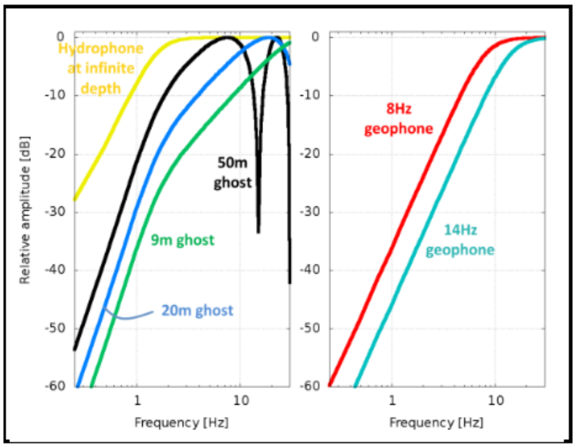

Figure 2: (Left) Hydrophone amplitude response including receiver ghost effect at different depths, and with 1.5Hz low cut filter. (Right) Geophone amplitude response for two different types of geophones.

It is often claimed that MEMS sensors (accelerometers) should give improved low frequency response compared to geophones due to their flat response down to DC. Such comments appear for example in Tessman et al (2002) and Gibson et al (2011). Hons et al (2007) perform an actual field experiment which was unfortunately not designed to give clarity with regard to the different sensors' noise floor. There is however work providing evidence that MEMS sensors have a lower effective dynamic range at low frequencies than standard geophones (figure 3, from Meunier and Menard, 2004). They measured the ambient background noise with co-located MEMS and 10Hz geophones buried at 200m depth in a very quiet environment, and conclude that below 50Hz, the MEMS' noise floor is above the geophones', while above 50Hz the opposite is true.

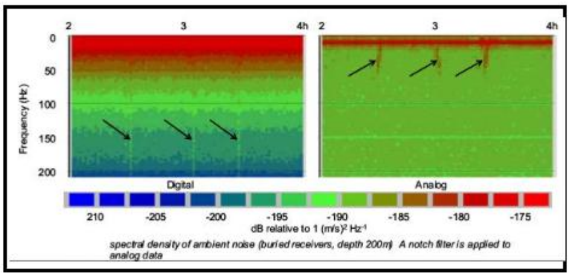

Figure 3: …from Meunier and Menard (2004). (Left) MEMS, (right) geophone. Black arrows indicate the same transient noise source recorded by the MEMS above ~50Hz, and on the geophones below ~50Hz.

Other so-called broad-band seismometers can achieve even higher sensitivity and lower noise floors at low frequencies than standard geophones and hydrophones. However, such sensors are bigger, heavier, and limited at the high frequency end. I argue that the sensors used in this study are already optimal for recording the full seismic signal band generated by current marine seismic sources. Equipped with what appears in theory to be adequate sensors, let's see how they perform in reality.

Real data analysis

Figure 4 shows the mean spectrum over a 35 day recording, for the hydrophone and the 3-component geophone sensors. Each spectral estimate is taken over consecutive 8 minute traces which are then averaged for all data. Note that the recording window contains both active and passive seismic periods, thus averaging between both. The linear frequency plot in panel (a) shows mainly the active shot energy acquired with a standard 5220cuin air gun array with its characteristic bubble reverberations, and the high end roll off due to a 200Hz anti-alias filter. On the linear plot, rich information at the low end is masked, while the logarithmic plot unveils matching spectral peaks on all four components around 0.3Hz.

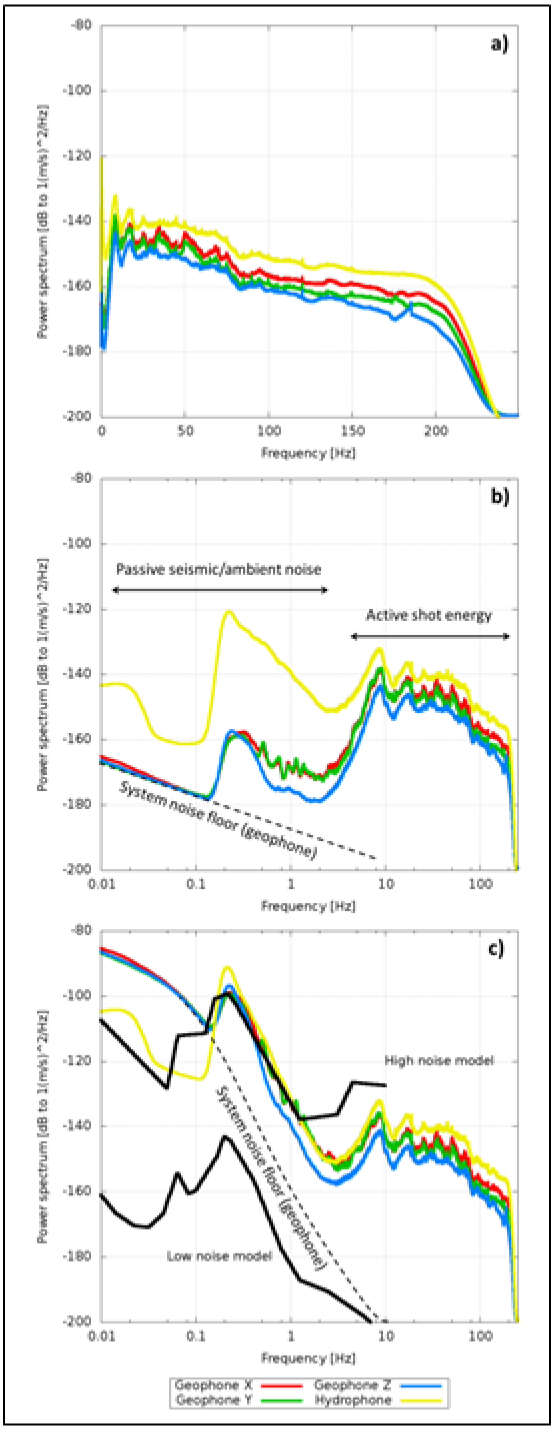

Figure 4: Mean frequency spectra, four components, over a 35 day recording period. (a) Linear plot, (b) logarithmic plot, (c) same as (b) but after inverse sensor response filter.

The spectral peaks can be better compared after applying an inverse sensor response filter (panel c). Above ~2Hz, active seismic energy generated by the air guns dominates, while below 2Hz, the dominant energy is ambient noise. In this particular data set, the geophone's noise floor surpasses the ambient noise level at around 0.1Hz. The hydrophone data, on the other hand, do not show any apparent noise floor, at least not down to 0.01Hz. Overlaid thick black lines indicate the USGS high/low noise models (Peterson, 1993) which were derived from land-based recordings from all over the world.

Figure 5 shows FX spectra from all continuous recorded/consecutive 8-minute traces, for three of the four components (the two horizontal components are very similar so only one is shown here), with a selected\ frequency window of 0.012Hz to 12Hz. In this spectral view, active seismic energy can be followed down to 1.5Hz, at which point the ambient noise starts to dominate. Passive periods with no active shooting are characterized by low energy above 1.5Hz. However, there seems to be some activity in the passive periods (dark blue events) that may relate to other, distant seismic surveys/seismic interference. The ambient noise dominating the spectrum below 1.5Hz in quiet periods, and 2Hz in more noisy periods, originates indirectly from ocean waves. The characteristic shape/peak of the spectrum around 0.3Hz is called the microseism peak. Microseisms are the result of nonlinear wave-wave interaction of wind generated ocean gravity waves travelling in opposite directions (Olofsson, 2010, and references therein). Microseism energy is generated at any water depth but most strongly in vicinity of coastal areas, and travels as Rayleigh-type modes to the most distant places on earth. Microseisms are observed in seismic recordings world-wide, whether in marine environment or on land. Hence, microseism noise can be considered unavoidable, since it is recorded with the same strength both at the sea surface as well as at the seabed. Note that this is different from direct swell noise which decays exponentially with water depth and is hardly noticeable at most seabed depths.

Raw data gathers (figure 6), filtered with a 4th order Butterworth band-pass filter to narrow bands of 1-2Hz, 2-3Hz, and 3-4Hz, confirm that even below 2Hz there is coherent energy generated by active shots which still stands out above the ambient noise.

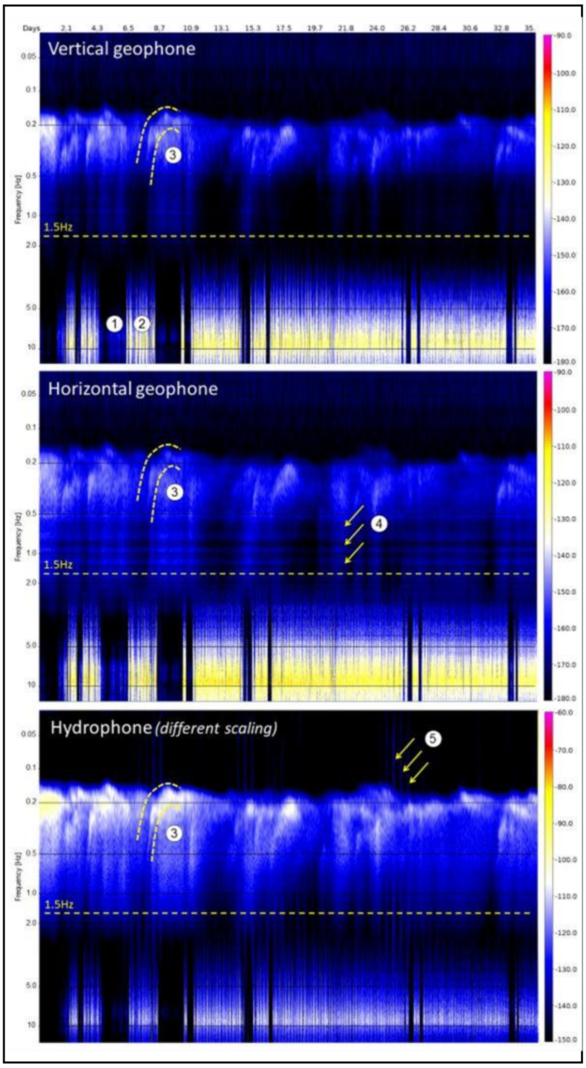

Figure 5: FX spectra of continuous recorded data over 35 day period. Events indicated by numbers: (1) Period of passive recording, (2) period of active shooting, (3) ocean wave noise generated by local storm system, (4) horizontal striping due to shear wave resonances in shallow sediments, (5) vertical striping caused by tidal related water currents.

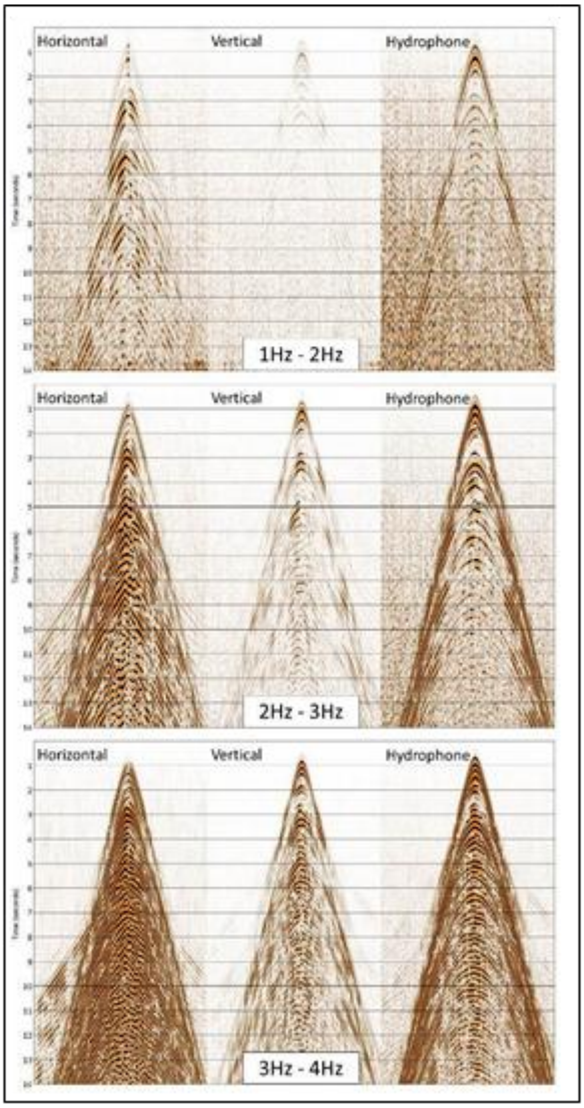

Figure 6: Raw receiver gathers with T1 gain and narrow band pass filter applied. All panels are relative amplitude scaled.

Conclusions

a) Judging from their sensors' specifications, ocean bottom nodes are capable of recording the full wave field generated by a standard marine seismic source, including the very low end.

b) Real data analysis in the spectral domain supports this claim. Data examples presented here show apparent signal down to ~0.1Hz for the 8Hz geophone, and down to 0.01Hz for the hydrophone (and possibly lower).

c) Raw data gathers further confirm that a standard air gun array produces visible signal down to at least 1.5Hz which is recorded by the sensors while still sitting comfortably above both the ambient and system noise floor. This means that ocean bottom nodes are capable of capturing the full seismic band width generated by marine air guns with a high signal/noise ratio.

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