CONTINUOUS WAVEFIELDS METHOD – THE ACOUSTIC WAVEFIELD GENERATED BY THE SEISMIC VESSEL

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Summary

The acoustic wavefield originating from the seismic vessel itself is generally not treated as acoustic signals in the imaging of marine seismic data, and is typically categorized as ambient noise. If this acoustic wavefield could be characterized, the noise could be attenuated. Also, this ambient noise may be used to image the subsurface, alternatively as a complement to images based on active sources. During a field test of the continuous wavefields method acquired offshore Malaysia late 2019, also more than one hour of “passive” seismic data were acquired without triggering any airguns. In this paper, estimation of the acoustic wavefield generated by the seismic vessel itself using these data is discussed. The continuous wavefields method has been used to create a seismic image of the subsurface from these data. This image is compared with an image produced from data acquired by triggering individual airguns with short random time intervals.

Continuous Wavefields Method – The Acoustic Wavefield Generated by the Seismic Vessel

Introduction

Marine seismic vessels are designed to generate as little noise and vibrations in the hull as possible. However, such vessels are not silent when towing seismic equipment. Seismic vessels generate an acoustic wavefield that responds to the local geology, and these signals are received by the sensors in the streamers. This acoustic wavefield originating from the seismic vessel itself is generally not treated as acoustic signals in the imaging of marine seismic data, and is typically categorized as ambient noise. If this acoustic wavefield could be characterized, the noise could be attenuated. Also, this ambient noise may be used to image the subsurface, alternatively as a complement to images based on active sources.

Imaging the subsurface using ambient noise is well known. Seismic interferometry techniques, based on cross-correlating traces recorded in different positions, are used to retrieve information about the subsurface without knowledge of the source wavefield. Different seismic interferometry approaches are discussed in Wapenaar et al. (2004). Another possible method is up-down deconvolution described by Amundsen (2001). This is a method for eliminating the effect of the free surface from marine seismic data. The source wavefield is deconvolved as part of the process. A third possible method is imaging with separated wavefields, discussed in Whitmore et al. (2010). In common with up-down deconvolution, this method requires separated up- and down- going wavefields as input. To image the primary reflections without knowledge of the source wavefield, the direct wavefield needs to be recorded and be a part of the down-going wavefield after wavefield separation.

There are, however, challenges to applying these methods to data acquired with towed streamers. The fact that acoustic signals are generated continuously by the seismic vessel in combination with moving sources and receivers means that seismic data recorded continuously cannot be split into natural common ‘shot’ or receiver gathers. Another challenge is that the receivers are mounted in streamers and typically towed at relatively shallow depths and a long distance behind the seismic vessel. This means that the near-vertical part of the source wavefield that goes into the ground is essentially not recorded.

During a field test of the continuous wavefields method acquired offshore Malaysia late 2019, discussed in Hegna et al. (2020), also more than one hour of “passive” seismic data were acquired without triggering any airguns. In this paper, estimation of the acoustic wavefield generated by the seismic vessel using these data (i.e., ship noise) will be discussed. In addition, the continuous wavefields method, first introduced in Hegna et al. (2018), has been used to retrieve information about the subsurface. This method is designed to handle continuous wavefields on both the source and the receiver side in combination with moving sources and receivers. Hence, it is well suited to seismic data acquired without an active source, provided that the wavefield emitted from the passive source is known.

Method

In the case of towed streamer acquisition, the only measurements that can be used to estimate the acoustic signals generated by the seismic vessel are the data recorded by the streamers. The propagation of a wavefield from a source to receivers in a group located in a streamer can be expressed as

$$P(\omega) = \frac{1}{N}\sum_{n=1}^{N}\left[\frac{e^{-i\omega r_n/c}}{r_n} + R\,\frac{e^{-i\omega r'_n/c}}{r'_n}\right] \quad (1)$$

where ω is the angular frequency, N is the number of receivers in the receiver array, r_n is the distance from the source to receiver n in the receiver array, c is the velocity of sound in water, R is the reflection coefficient at the sea surface (close to -1), and r'_n is the distance from the source to receiver n in the receiver array via the sea surface.

The direct wave D(ω) can be expressed as

$$D(\omega) = S(\omega)P(\omega)R_{sens}(\omega) \quad (2)$$

where S(ω) is the emitted source wavefield at an angular frequency ω, and $R_{sens}(\omega)$ is the response of the receiver array and its sensors at the same angular frequency. An estimate of the wavefield emitted from the source $\tilde{S}(\omega)$ can be derived using the following equation,

$$\tilde{S}(\omega) = \widetilde{D}(\omega)[P(\omega)R_{sens}(\omega)]^{-1} \tag{3}$$

where $\widetilde{D}(\omega)$ is the seismic data measured by a receiver array after having isolated the signals coming from the direction of the source. Since there are many receiver arrays in each streamer, and several streamers towed behind the vessel, data from many receiver arrays can be used to estimate the wavefield emitted from the source (in this case ship noise). These estimates can be stacked to obtain one estimate of the source wavefield. The distances between the source and the receivers tend to vary slightly during seismic acquisition. The source wavefield may therefore be estimated in overlapping time windows, e.g. in the order of 10-20 seconds long, to take these variations into account.

Examples

During the field test of the continuous wavefields method offshore Malaysia in late 2019, some seismic data were recorded without triggering any airguns. These data were acquired along the same line trajectories used for the acquisition of seismic data with individual airguns triggered with short random time intervals. Figure 1 shows examples of a two seconds time window for seismic data recorded when triggering airguns, and when recording without triggering airguns for comparison.

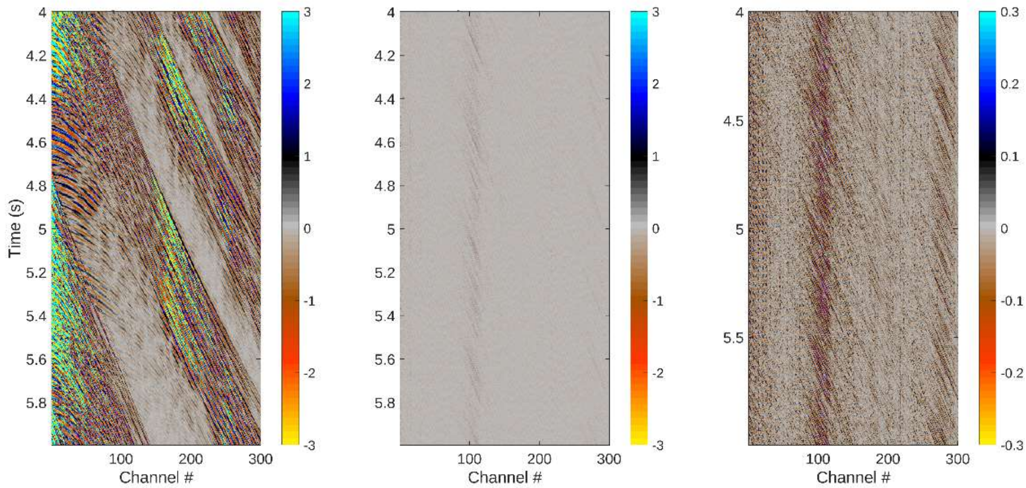

Figure 1 *Examples of raw recorded hydrophone data when triggering airguns (left panel), and when recording data without triggering any airguns (middle and right panels). In the panel on the right the limits of the color scale have been compressed by a factor of 10 so that the recorded signals are more visible.*

The amplitude increase around channel 105 visible in the middle and right panels of Figure 1 is related to signals reflected at an angle close to the critical angle. These reflected signals are most likely associated with the acoustic wavefield generated by the seismic vessel itself, since the ship noise is the main source of acoustic signals during the recording of these data.

Figure 2 shows the same data in the frequency-wavenumber domain. The acoustic signals associated with the emitted source wavefield and the response of the earth is clearly visible within the signal cone in both the data acquired with airgun sources and the data acquired without an active source. In the data acquired without an active source, i.e. the signals associated with the seismic vessel and its response from the earth, are not visible below 25-30 Hz due to high levels of non-acoustic noise. Therefore, it is difficult to estimate the acoustic wavefield generated by the vessel below ~30 Hz from the recorded hydrophone data.

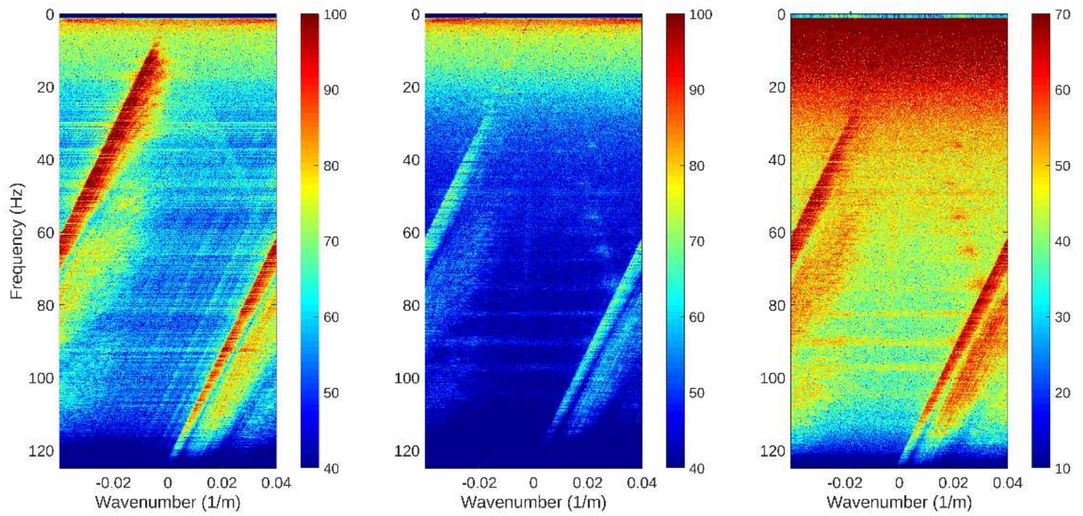

***Figure 2** Frequency – wavenumber spectra of the same data as shown in Figure 1. The temporal length of the data input to the Fourier transform is more than 40 minutes.*

When estimating the acoustic wavefield generated by the seismic vessel, the signals coming from the direction of the seismic sources, i.e. close to 90 degrees emergent angle in the frequency – wavenumber spectra shown in the middle and right panels of Figure 2, have been isolated. The estimation has been performed using Equation 3 for time windows of 20 seconds with 10 seconds of overlap between them. Figure 3 shows the estimated acoustic signals generated by the seismic vessel.

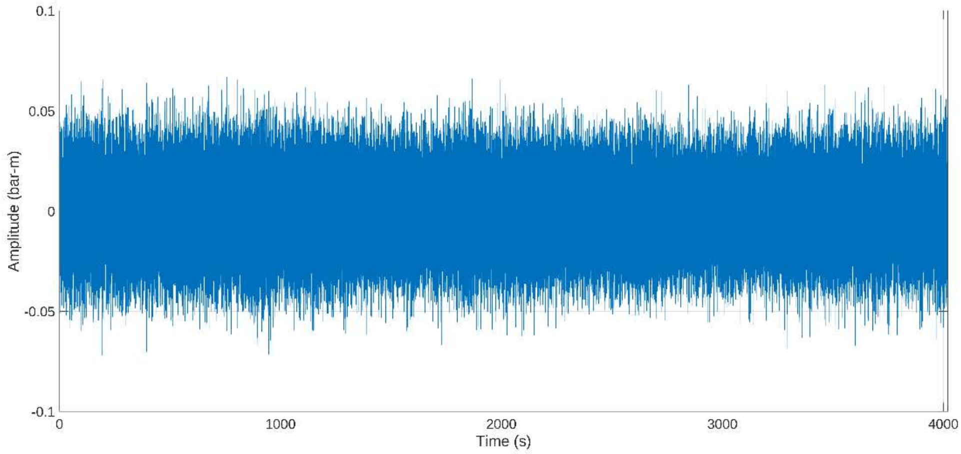

***Figure 3** Estimated acoustic signals (pressure in bar at 1 m from the source) generated by the seismic vessel as a function of time, emitted in the direction towards the streamers.*

It is assumed that the acoustic signals emitted in the direction directly towards the streamers are similar to the emitted signals going into the subsurface. However, in reality it is likely that the acoustic wavefield generated by the seismic vessel is directional, and that this assumption will cause some errors.

The estimated acoustic signals generated by the seismic vessel were deconvolved from the received wavefield using the iterative multidimensional deconvolution described in Hegna et al. (2018). The resulting gathers were migrated and stacked to obtain a seismic image of the subsurface. During the field test, seismic data were acquired along the same line trajectory by triggering airguns with short random time intervals. These data have been processed using a similar workflow as for the data acquired without an active source for comparison. Since the vessel was approximately 825 m in front of the active sources, an offset range similar to the offset range available in the data acquired without an active source was selected before stacking. In addition, signals below 30 Hz were filtered out since it was difficult to estimate the acoustic signals generated by the seismic vessel below this frequency. A comparison between the results is shown in Figure 4.

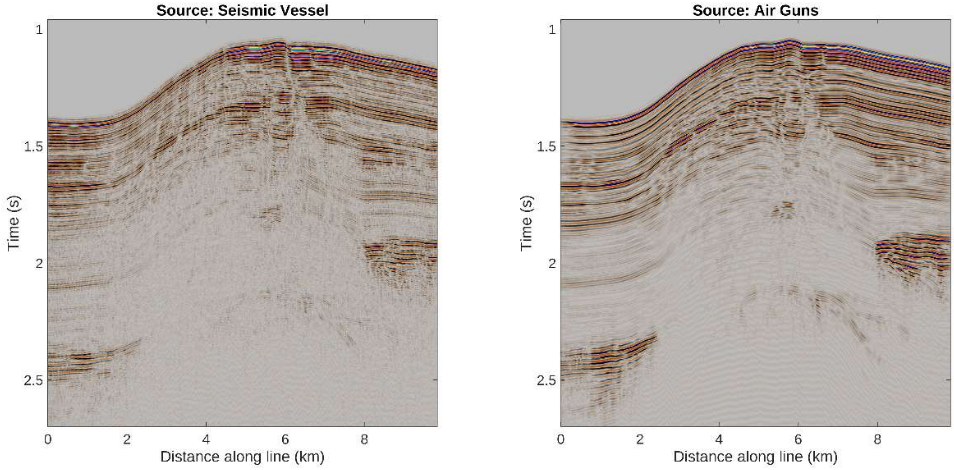

Figure 4 *Comparison between a seismic image derived from data recorded without an active source using the acoustic signals generated by the seismic vessel as the source (left), and an image produced from data acquired by triggering individual airguns with short random time intervals (right).*

Conclusions

The acoustic signals generated by the seismic vessel have been estimated for frequencies above 30 Hz, using hydrophone data recorded by towed streamers. The estimation is based on isolating the signals coming from the direction of the seismic vessel, and back-propagation of the resulting signals from the receiver locations to the location of the seismic vessel. The continuous wavefields method has been used to pre-process the recorded hydrophone data together with the estimated source wavefield, and then migrated and stacked to obtain an image of the subsurface. These results have been compared with an image produced based on data acquired by triggering individual airguns with short and random time intervals. There are clear similarities between these images; however, there are obvious differences too. These differences are likely to be related to errors in the estimated acoustic signals generated by the seismic vessel. Further work is needed to improve the estimation of the wavefield generated by the seismic vessel. Nevertheless, these results serve to demonstrate the feasibility of using streamer data to derive an unknown source wavefield with sufficient accuracy to image the subsurface.

Acknowledgements

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