# The acoustic wavefield generated by a vessel

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This paper was prepared for presentation during the 18th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, 16-19 October 2023.




## Abstract

There are areas around the world where the use of traditional marine seismic sources is not permitted throughout the year, or only permitted in short time periods. Therefore, an alternative to traditional sources has been considered. Acquiring seismic data without active sources, estimating the acoustic wavefield generated by the vessel from the recorded direct arrivals, and using this wavefield for imaging the subsurface has been worked on and tested over the last couple of years. These tests have been carried out with different acquisition configurations, and in a variety of different geological settings. An overview of these tests and how the method performed is discussed in this paper and illustrated with data examples.


## Introduction

Acoustic signals generated by vessels have several characteristics that makes them interesting as an alternative to traditional marine seismic sources. Firstly, the emitted signals are completely continuous. This means that the peak Sound Pressure Levels (SPL) and the sound levels integrated over time, typically referred to as Sound Exposure Levels (SEL), are significantly lower than conventional sources. This also means that high spatial resolution along the vessel path can be achieved. Secondly, and as will be shown in this paper, the signals generated by vessels are broadband. Therefore, as will be shown in some data examples, both high temporal and spatial resolution can be achieved. The high resolution relies on an accurate estimation of the acoustic wavefield generated by the vessel. How accurately this wavefield can be estimated depends on the acquisition configuration.

## Method

A variety of different methods and techniques for imaging the subsurface from recorded ambient noise have been suggested over the years. Seismic interferometry techniques, based on cross-correlating traces recorded in different positions, have been used to retrieve information about the subsurface without knowledge of the source wavefield. Different seismic interferometry approaches are discussed in Wapenaar et al. (2004). More specifically related to vessels, hydrophones protruded through the hull of a vessel just above the propeller was tested to investigate whether noise generated by propellers could be used as a seismic source in Davies et al. (1992).

The method developed in this work is based on estimating the acoustic wavefield generated by a vessel from the recorded direct arrivals. The method, which relies on continuous recording of seismic data, involves the following:

1) Isolating the direct arrivals.
2) Determining the positions from where the signals were emitted.
3) Estimating the signals emitted from these positions by backpropagating the wavefield from the receiver positions to the source position, done via a least squares inversion.

Since a vessel is not a point source, the wavefield need to be characterized on a grid of multiple locations. An iterative method, starting with the location from where the strongest signals were emitted, has been developed to determine both these locations as well as the signals emitted from each of them. This iterative scheme is illustrated in Figure 1.

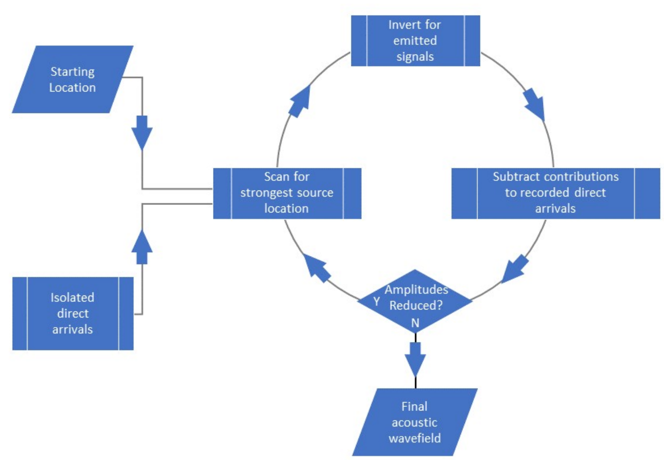


***Figure 1*** *- Iterative method for estimation of the acoustic wavefield generated by a vessel.*

Once the origin of the strongest signals has been identified, the signals emitted from this grid point are estimated, the contributions of these signals to the recorded direct arrivals are determined and subtracted from the input data. In the following iteration the location where the strongest signals in the residual data are emitted from is identified, and the contribution of the signals from this point to the recorded direct arrivals are estimated and subtracted from the residual data from the previous iteration. The iteration loop continues until any new point source locations can no longer be identified, or the amplitudes of the residuals are not further reduced by additional iterations. This method was described in Hegna (2022a) and in Hegna (2022b).

## Examples

The method was first tested on a dataset acquired offshore Malaysia. The test was carried out during the acquisition of an exploration survey with a large streamer spread consisting of 16 multisensor streamers with 100m separation. The streamers are towed far behind the seismic vessel with such a large streamer spread. This limits the ability to estimate the acoustic wavefield generated by the seismic vessel over a large frequency band. Figure 2 shows a comparison between a seismic image derived from the data acquired without triggering the airguns, and an equivalent image derived from data acquired with airguns.

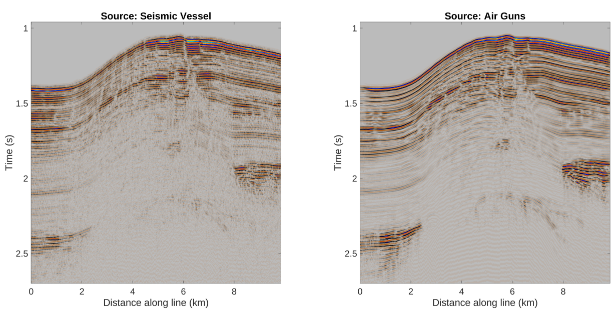


***Figure 2** - Comparison between a seismic image derived from data without an active source (left), and an image produced from data acquired using airguns (right). From Hegna (2021).*

The estimation of the wavefield generated by the vessel was limited to between 30Hz and 100Hz due to the long distance between the vessel and the front of the streamers. Therefore, the images shown in Figure 2 are limited to this frequency range. This test gave a first indication that using the acoustic wavefield generated by a vessel may provide useful information from the subsurface.

In conjunction with testing a short streamer in a Norwegian fjord, data were acquired without any active source. A small 15m long vessel was sailing back and forth within the fjord while towing a 500m long test streamer. The streamer was towed approximately 110m behind the vessel. Some of these recorded data have been used to see if it would be possible to image the subsurface in this fjord using the signals generated by the small vessel towing the test streamer. Figure 3 shows a migrated stack. It is difficult to judge the quality of this result since it is not allowed to acquire seismic data using airguns or any type of active source in this area. However, it does look like a plausible seismic image. This shows that the method may be used with a very small acquisition set-up, and in areas where it is not allowed to use active sources.

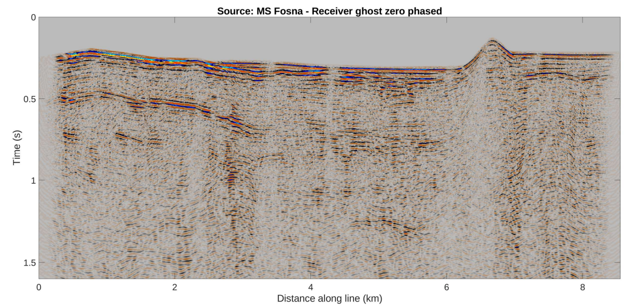


***Figure 3** – Seismic image derived from data acquired in a Norwegian fjord without any active source and using the acoustic wavefield generated by a small vessel towing a short streamer.*

Acquisition with a configuration where the vessel is sailing over the top of a streamer spread was discussed in Hegna (2022a). During the acquisition of such a survey in the Barents Sea, part of one sail line was repeated without triggering the airgun arrays. The acoustic signals associated with the vessel sailing on top of the streamer spread were recorded continuously by the streamers. The streamer spread consisted of 16 multisensor streamers with 75m separation towed at a depth of 30m, making it possible to sail a vessel over the streamers. This acquisition configuration gives a nearly complete measurement of the acoustic wavefield emitted by the vessel sailing over the streamers covering a large range of emission angles and frequencies. Figure 4 shows directivity plots of the estimated wavefield.

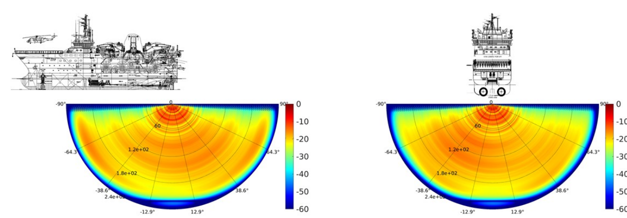

***Figure 4** - The inline (left) and crossline (right) directivity of the emitted acoustic wavefield from the vessel sailing on top of the streamer spread. The emission angles range from -90 to 90 degrees and the displayed frequency range is from 0 to 240 Hz (the wavefield has been estimated up to 250 Hz).*

The figure shows that the wavefield appears to be mostly omnidirectional; it does not contain any deep notches in any particular direction and exhibits only minor variations with emission angle. It also shows that the wavefield is very broadband covering the entire recorded frequency range. Figure 5 shows a comparison between NMO stacks derived from data using the vessel as the source and by triggering airgun arrays. The NMO stack of the data acquired with an active source is a QC stack from an early pre-processing step and does not show the full potential of the data. However, the comparison shows that the main features observed in the data acquired when using an active source can also be recognized in the data acquired when using the vessel as a source. This figure also illustrates the resolution that can be achieved in the shallow section when using acoustic signals generated by a vessel, and with this acquisition configuration.

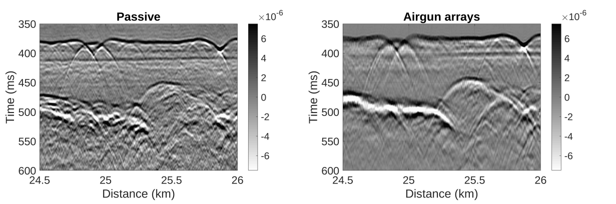


***Figure 5*** *- NMO stack from data acquired without an active source (left) and with airgun arrays (right).*

The use of a continuous source wavefield, rather than discrete shot points, is likely a significant contributory factor to the high spatial resolution. The broadband acoustic signals generated by the vessel in combination with the robust removal of the receiver ghost with multisensor streamers are likely to be the main contributory factors to the high temporal resolution. The high resolution is visible throughout the entire length of the line. Figure 6 shows an example from a different part of the line with lots of diffractions, steeply dipping events, and details immediately below the seafloor.

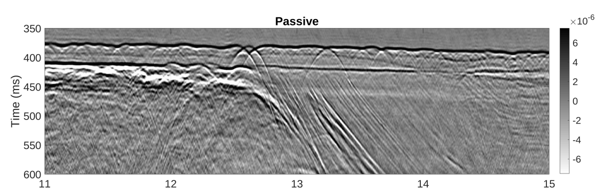


***Figure 6*** *- The NMO stack of the data acquired without an active source from a different part of the line.*

Figure 7 shows octave panels from the same line, that the bandwidth of the resulting NMO stack covers seven octaves in the shallow section with coherent signals demonstrated from the 2-4 Hz octave all the way up to 250 Hz. This large bandwidth could be achieved because of the acquisition configuration enabled a very accurate estimation of the acoustic wavefield generated by the vessel sailing over the streamers, in combination with the bandwidth of this acoustic wavefield.

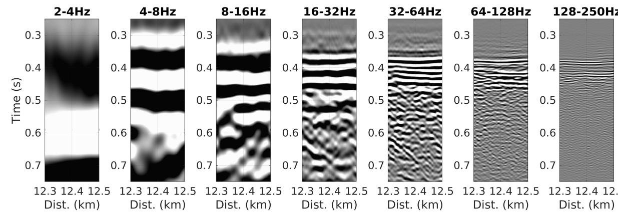


***Figure 7*** *– Octave panels of the NMO stack from data acquired without an active source.*

The method has also been tested on data acquired by sailing a vessel over receivers located on the seafloor. A small test has been performed, indicating that the method should also work with ocean bottom cables or nodes (OBC/N) as discussed in Hegna et al. (2023).

## Conclusions

A method for acquiring marine seismic data without the use of active sources, and instead use the acoustic wavefield generated by a vessel to image the subsurface has been discussed. This acoustic wavefield can be estimated from the recorded direct arrivals. The method has been tested with several different acquisition configurations in very different geological settings. Useful images have been produced in all these tests.

The accuracy of the estimated wavefield generated by the vessel depends on the acquisition configuration. Streamer spreads normally used for large exploration surveys have limited near offset information due to the large distance between the stern of the seismic vessel and the front of the streamers. This limits the frequency range it is possible to estimate the wavefield, as well as the directional characteristics of the wavefield. Such configurations are most suitable in relatively large water depths. Despite of these limitations, a seismic image has been produced that compares very well with an equivalent image from data acquired with airguns.

A small-scale test in a Norwegian fjord shows that it is possible to use the method with a small vessel towing a short streamer, that may be of interest in areas where it is not possible to acquire seismic data with large vessels and streamer spreads, and where it is not allowed to use active sources.

A test carried out in the Barents Sea with a vessel sailing over a streamer spread shows that with such an acquisition configuration it is possible to characterize the wavefield generated by the vessel sailing over the streamers in detail. The entire wavefield including its directional characteristics can be determined, resulting in high resolution images after processing the data.

The method has also been tested on OBC/N data, indicating that it should work also with seismic sensors located on the seafloor.

**Acknowledgments**

The author would like to thank to AkerBP and its partners DNO Norge AS and Petoro AS in PL1083 for permission to show the results from the test with a vessel sailing on top of the streamer spread.

The author would also like to thank PGS for supporting this work and for permission to publish the results.

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