EAGE ANNUAL 2018
80TH CONFERENCE + EXHIBITION
COPENHAGEN | DENMARK

We A10 04

# Making the Transition from Discrete Shot Records to Continuous Wavefields – Real Data Application

T. Klüver* (PGS), S. Hegna (PGS), J. Lima (PGS)

## Summary

In this paper, we present real data applications of the acquisition and processing method outlined in the companion paper (Hegna, S., Klüver, T., and Lima J., 2018, Making the transition from discrete shot records to continuous wavefields – Methodology: Expanded abstract submitted to the EAGE annual meeting). We discuss the design of sources that emit continuous wavefields approaching the properties of white noise using air-guns. The design minimizes correlation between sources and allows a six-source configuration with a vessel towing six strings of air-guns, thereby increasing efficiency or cross-line sampling. The environmental benefit of spreading source energy in time will be demonstrated. We illustrate the processing method based on continuous source and receiver wavefields on seismic data acquired on top of data acquired previously based on discrete shot records. Both data sets will be compared at image level.

## Introduction

A method that can retrieve the response of the earth from continuous source and receiver wavefields has been developed (Hegna et al., 2018). In that paper it is shown on synthetic data that a common receiver gather with the response of the earth can be extracted from a continuous receiver trace in a stationary position calculated based on a source continuously emitting white noise while moving. In reality however it is not possible to generate white noise. Therefore, ways of generating a source wavefield which approaches the properties of white noise using existing equipment will be discussed in this paper including real data examples. Seismic data acquired by triggering individual air-guns with short randomized time intervals in a near continuous fashion will be compared to seismic data acquired with large source arrays triggered every 25m. The continuous source wavefield improves the sampling of common-receiver gathers compared to conventional acquisition methods. Spreading the source energy out in time results in reduced peak sound pressure levels with the new method.

## Generating a wavefield approaching white noise

Typically, seismic vessels tow six strings with air guns that are most commonly divided in two sources consisting of three strings each. Usually, all air-guns within a source are triggered simultaneously with a pre-defined lateral interval generating each time a wavefield that is close to a spike. In order to generate a continuous source wavefield that is approaching the properties of white noise using similar equipment, individual air-guns are triggered with short randomized time intervals in a near-continuous fashion.

The order the air-guns are triggered in is optimized to minimize the trigger time interval. This order will have to be repeated at some point. However, the trigger times can be randomized all the time, so not repeated in any particular interval. Air-guns triggered in such a sequence generate a continuous source wavefield approaching the properties of white noise both in a spatial and temporal sense.

In order to facilitate a stable deconvolution of the source wavefield, complementary bubble periods are necessary to mitigate the deep notches in the spectrum of the wavefield emitted from a single air-gun. Complementary bubble periods can be achieved by using air-guns of different volumes, or by deploying the air-guns at different depths. If there is a need to correct for the effects of the source ghost beyond crossing the notch frequencies, it is beneficial to deploy the air-guns at different depths. Complementary bubble periods can in such cases be achieved by the differences in depth even if all air-guns are of the same volume. If the differences in depth are not sufficiently large to obtain complementary bubble periods, air-guns of different volumes can be used. By using air-guns of different volumes, each source can be configured differently to obtain further encoding of the wavefield emitted from each of them.

By emitting unique wavefields from each string of air guns with low correlation between the wavefields, and with the method described utilizing continuous source and receiver wavefields, it is possible to output as many common receiver gathers as there are strings with air-guns. An example of data acquired with continuous recording and emitting near-continuous wavefields from six strings with air-guns is illustrated in Figure 1. When triggering individual air-guns with very short time intervals emitting a continuous source wavefield, the continuously recorded seismic data contains signals that are interfering with each other all the time, as shown in Figure 1. Because of the low correlation between the wavefields emitted from each string of air-guns, it is possible to extract the response of the earth associated with the six strings as illustrated in Figure 2. This means that each string of air-guns represents a source, so effectively a six-source configuration. This ability combined with the near continuous wavefield emitted from each source means that the spatial sampling can be improved both in-line as well as cross-line compared to conventional methods.

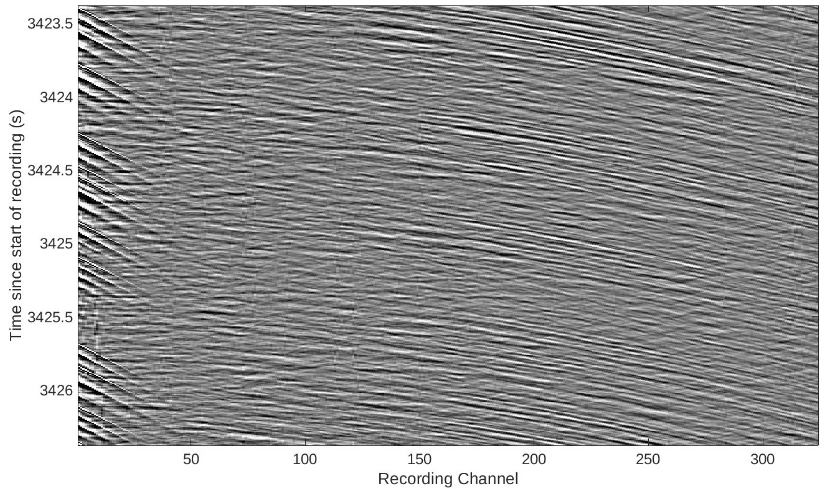


***Figure 1*** *Raw hydrophone data recorded continuously. The vertical axis is time since the start of the continuous recording. The horizontal axis is channel number along the streamer. The direct wavefield is visible in the front of the streamer on the left hand side of the image, illustrating the density of the trigger times. In this data example air-guns were triggered with a mean interval of 290 milliseconds.*

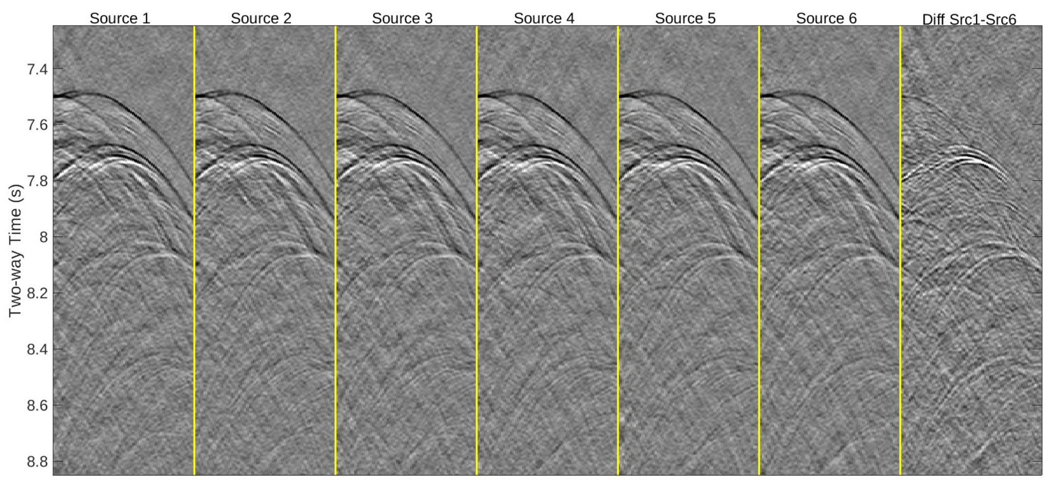


***Figure 2*** *Result of deconvolving the source wavefield into six common receiver gathers with earth responses extracted from one stationary receiver location based on data shown in Figure 1. The spacing between the strings of air-guns was 12.5m. The difference between the common receiver gather associated with source 1 and with source 6 is shown on the right hand side of the image.*

**Data comparisons**

In order to illustrate how the seismic method utilizing continuous source and receiver wavefields compares to other methods, a ~60km 2D line acquired south-east of the Faroe Island will be shown. The line was acquired with a 6km two-component streamer, the seismic data were recorded continuously, and the source consisted of six strings with two 150 cubic-inch air-guns on each string. These twelve air-guns were triggered individually with a mean interval of 1 second, i.e., it took about twelve seconds until the same air-gun was triggered again. The strings of air-guns were deployed at 6, 10 and 14m depths resulting in complementary bubble periods and ghost functions. The 2D line was acquired in a position where a line had been acquired previously with a time and depth distributed source (Parkes and Hegna, 2011). That source consisted of 66 air-guns in two sub-sources: one 4800 cubic-inch sub-source at 14m depth, and one 2400 cubic-inch sub-source at 10m depth. The shot spacing was 25m. Significantly less energy was emitted from the source generating a continuous wavefield compared to the time and depth distributed source. The difference in emitted pressure levels is illustrated in Figure 3 clearly demonstrating the environmental benefit in form of reduced sound pressure levels gained by spreading the source energy out in time. The main challenge in the area where these 2D lines have been acquired is penetration through basalt layer(s). Therefore, traditionally very powerful sources have been used to try to improve the seismic images below the basalt layer(s). The data acquired by triggering individual air-guns with a mean interval of 1 second is a very different approach, as can be seen in Figure 3.

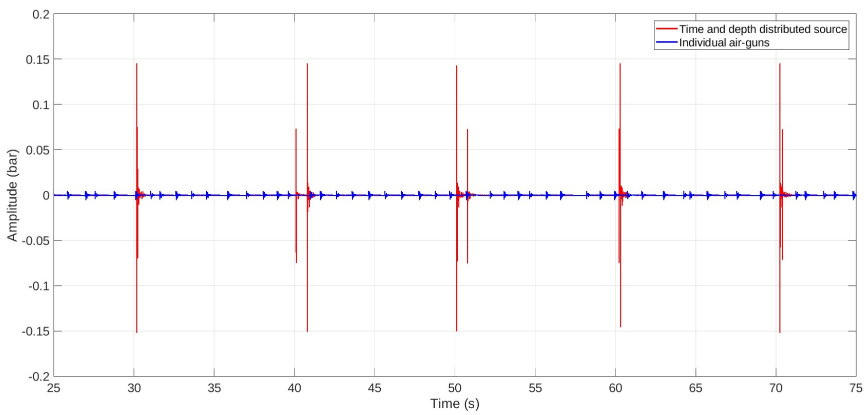


***Figure 3*** *Comparison of sound pressure levels at a distance of 750m from a time and depth distributed source consisting of 66 air-guns in total triggered with a mean interval of 10 seconds (red curve), and when triggering 12 individual air-guns each with a mean interval of 12 seconds corresponding to 12 triggerings per 12 seconds (blue curve).*

As described in Hegna et al. (2018), the pre-processing of seismic data based on continuous source and receiver wavefields consists of correcting for the sensor responses and any analogue filtering effects, noise attenuation, receiver motion correction, and wavefield separation on the receiver side before deconvolving the emitted source wavefield. The steps before the deconvolution of the source wavefield are applied to the continuously recorded data. Especially the low frequencies benefit from the large time length of the continuous record. Figure 4 shows f-k spectra before and after noise attenuation of particle velocity data.

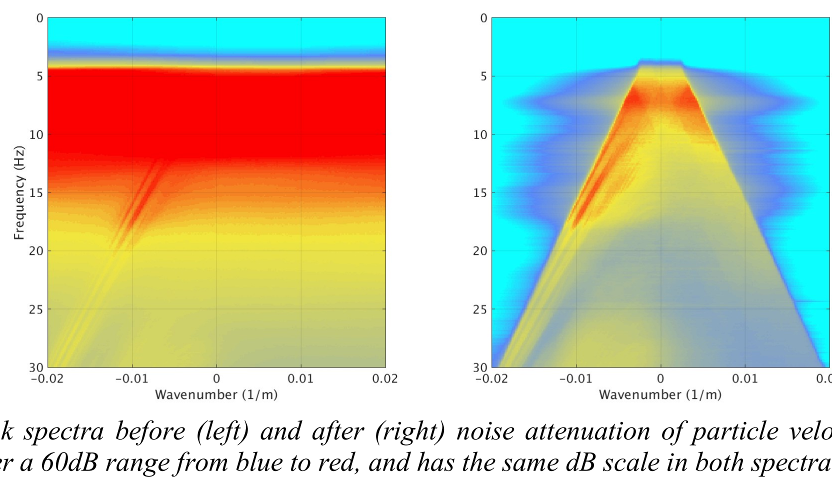


***Figure 4*** *F-k spectra before (left) and after (right) noise attenuation of particle velocity data. The colours cover a 60dB range from blue to red, and has the same dB scale in both spectra.*

As illustrated in Figure 4, a significant amount of noise is attenuated towards lower frequencies. After the noise attenuation, particle velocity signals can be seen below 10Hz, which are completely obscured before noise attenuation. After the receiver side pre-processing steps, and the deconvolution of the source wavefield, the data are processed further using conventional methods. The final migrated stack of the 2D line is shown in Figure 5 together with a migrated stack of the line acquired with a time and depth distributed source.

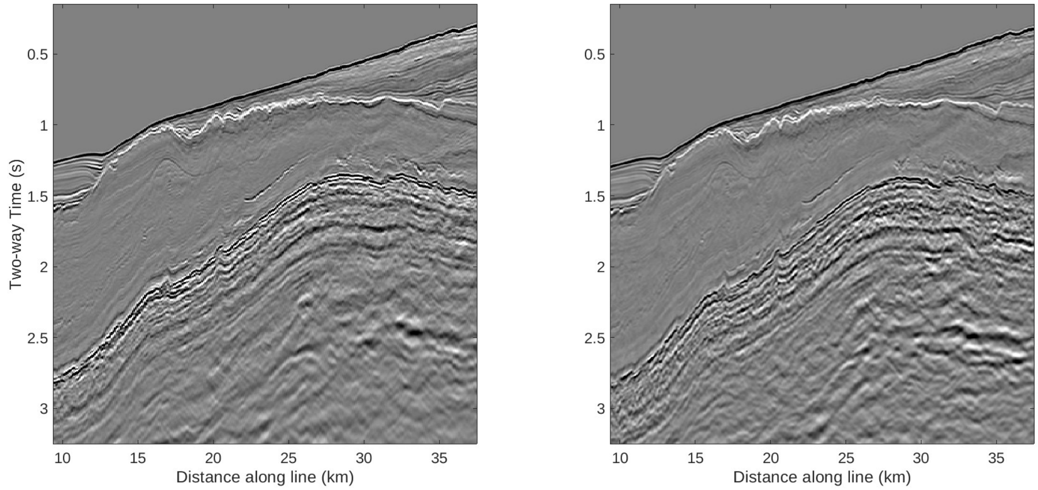


***Figure 5*** *Final migrated stack of data acquired with a time and depth distributed source (left), and of data acquired by triggering individual air-guns with a mean interval of 1 second (right).*

Despite the fact that the two data sets shown in Figure 5 were acquired in completely different ways with significant differences in the wavefields emitted from the sources, the resulting final images are fairly similar. Also the penetration below the strong top basalt reflector appearing at ~2.75 seconds on the left hand side and at ~1.5 seconds on the right hand side appears to be comparable between the two methods.

**Conclusions**

We have shown with real data that by acquiring data in a continuous fashion and emitting a continuous wavefield from sources by triggering individual air-guns with short randomized time intervals it is possible to deconvolve seismic data in stationary receiver positions to extract the response of the earth associated with multiple sources. Because of the continuous wavefield that is emitted, the trace spacing in the common receiver gathers after the deconvolution of the source wavefield can be denser compared to conventional acquisition. Also the cross-line sampling can be improved by extracting earth responses associated with multiple sources. We have also shown that, when triggering individual air-guns in a near-continuous fashion emitting significantly less energy, it is possible to achieve results that are comparable to data acquired with a much more powerful time and depth distributed source. Reduced peak sound pressure levels by spreading the source energy out in time is an environmental benefit with the new method.

**Acknowledgements**

We thank PGS for permission to publish this paper, and Statoil and The Research Council of Norway for funding the project together with PGS.

**References**

Hegna, S., Klüver, T., and Lima J. [2018] Making the transition from discrete shot records to continuous wavefields – Methodology. Extended abstract submitted to the EAGE annual meeting.

Parkes, G., and Hegna, S. [2011] An acquisition system that extracts the earth response from seismic data. *First Break,* **29**, 81-87.