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A Seismic Interference Noise Experiment in the Central North Sea

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SUMMARY

During the 2014 North Sea summer season a 2-D line with seismic interference (SI) noise from varying separations and azimuths was recorded. This line was then used to synthetically evaluate new navigation system functionality and procedures that aim to help randomize the arrival time of SI during a line acquisition. Good randomization of SI is important for many denoising algorithms.

For this experiment, with appropriate acquisition planning, execution and denoising, we were able to successfully attenuate nearly all SI from all azimuths. However, broadside SI that comes in at the same time on consecutive shots is difficult to attenuate, and should be avoided. The SI attenuation algorithms were not influenced by the amplitude of the SI. This implies that the current industry practice with regards to accepting SI during acquisition might be too conservative, and that the amount of downtime from time-sharing currently done by contractors could be reduced.

Introduction

Seismic interference (SI) noise is observed when seismic vessels operate in close proximity, and acoustic energy from one vessel is picked up by sensors on another vessel. For reflection times greater than a few seconds below the water bottom time, SI noise is often stronger than the reflections. If such SI, and particularly broadside SI, is not properly attenuated, it may be harmful to many pre-imaging processes, such as, ghost wave elimination and multiple prediction, and post imaging processes such as AVO analysis (Gulunay et al. 2004).

Figure 1 shows two North Sea marine seismic shot gathers heavily affected by SI from a source that was ~15 km away. Most SI noise in marine seismic is in the form of energy which is trapped and reverberates between the sea-surface and the sea-bottom with relatively little attenuation. Such guided waves were first studied by Pekeris (1948). We refer to Jansen et al (2013) for an overview of some recent SI attenuation techniques. In Figure 1 we can typically observe the SI reverberations as parallel stripes.

Further looking at the SI, one can observe that it appears to be dispersive (the frequency content changes from the first to the last wave), while each reverberation appears to be fairly distinct and linear with very little spatial variation.

To avoid contamination by SI it is common practice in acquisition to commence time-sharing when the amplitude and/or moveout of the SI exceed certain predetermined limits. During the summer season in areas like the North Sea, it is not uncommon that seismic vessels spend up to 30% of their available time on standby due to such time-sharing arrangements. This is costly and often results in significant delays. In areas like the North Sea, where the water depth is typically 100-200 m and the sea floor is fairly hard, one can often observe significant SI from more than 100 km away. However, in deep water (like the GoM) or in very shallow areas, SI does not normally propagate that far. This is because the acoustic energy is absorbed in a greater volume of water (deep water) or by the frequent sea-bottom reflections that occur in shallow water.

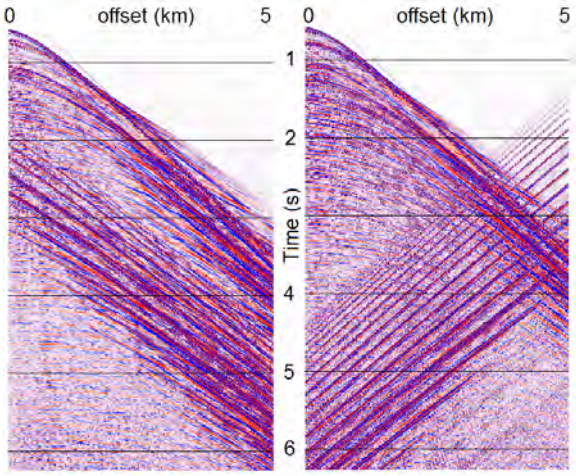

Figure 1. *Two North Sea shot gathers with seismic interference head to tail and tail to head.*

Acquisition and processing

In this paper we describe a recent acquisition and processing test from the central North Sea. One 2D line of SI, utilizing two vessels as illustrated in Figure 2, was acquired in May 2014. During the acquisition vessel #1 was firing its ~4200 cu.in source going southwards, while vessel #2 was recording (no shooting) SI from vessel #1 going northwards. The SI was recorded on a Sercel Sentinel streamer, provided full bandwidth SI noise records with varying vessel separation and azimuth. As initial processing, we applied swell-noise attenuation and a 2.5 Hz low-cut filter to all records.

The goal of the test was to investigate how variations in the shot point interval (SPI) and vessel speed between the SI and the real data vessel influenced our ability to attenuate the SI in processing. To do so we numerically manipulated the SI records and created 4 different ‘composite records’ (real SI + real data from a Variable Depth Streamer acquisition). The relevant parameters for the four datasets are given Table 1.

Dataset	Recording vessel SPI (m)	SI vessel SPI (m)	Vessel speeds (kn)
#1	18.75	18.75	~4.5
#2	18.75 ±200 ms jitter	18.75	~4.5
#3	18.75	18.75	~±4.5
#4	18.75	25	~4.5

Table 1. *The four composite datasets (seismic data + SI) used for the trial.*

The composite records were then put through a SI attenuation algorithm similar to the one described in Elboth et al. (2010). In a simple form the algorithm can be described as**:**

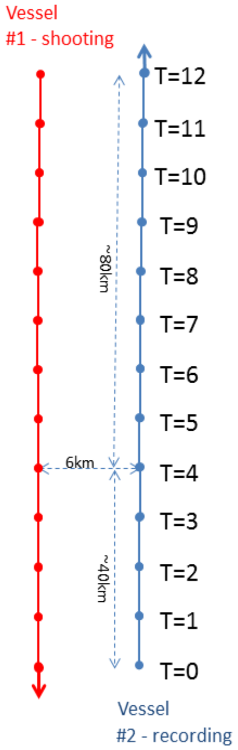

Figure 2. *The acquisition setup used to acquire the SI noise record.*

1. *Transform shots to the τ-p domain.*
2. *Apply multi-dimensional noise attenuation and output noise-model.*
3. *Inverse-transform noise model to the common shot domain.*
4. *Subtract the noise model from the input data*

This type of algorithm is appealing because it requires little user interaction once a few initial parameters have been set. This algorithm is also fairly insensitive to variations in azimuth, i.e., SI from all directions is attenuated equally well. A drawback with the algorithm is step 2 which implicitly assumes that any SI can be desynchronized by sorting the p-traces in the τ-p domain. Natural variations in vessel speeds, directions, shot point intervals will often fulfill this assumption. However, in some cases, this requirement is not fulfilled, resulting in suboptimal SI attenuation.
To overcome this problem we have developed dedicated navigation tools and procedures. For real surveys this enables us to quickly identify potential problematic SI and adjust our acquisition plan (vessel speed and choice of line) accordingly.

Data examples and discussion

SI attenuation on common shot gathers from dataset #3 is presented in Figure 3. In this dataset, we simulated a small velocity difference between the recording vessel and the SI generating vessel. This ensured that SI did not arrive at the same time from shot to shot and resulted in very good pre-stack and pre-migration SI attenuation for vessel separation as little as ~15 km.

The SI attenuation did not in any way affect the low-frequency part of the signal, and the weak remaining SI noise seen in the bottom row in Figure 3 can be effectively attenuated by additional passes of multi-dimensional random noise attenuation and high resolution (HR) Radon transforms for the head to tail SI and migration. Ghost elimination, velocity analysis and de-multiple flows will therefore not be significantly affected. In this context, it is also important to keep in mind that almost all types of data interpretation and analysis (including AVO) are done in the image domain (after migration).

Figure 4 shows brute-stacks from three of the four datasets from Table 1 where we have SI from as close as 6 km. This also illustrates the effects of the dedicated acquisition tools and procedures on our ability to attenuate SI. In dataset #1 (Figure 4c) the SI and the reflection data were acquired at almost identical velocity, direction and shot point interval. As a result, the denoising algorithm was not able to remove all the broadside SI noise. Adding a small random dither on the shot point interval (dataset #2 - not shown) improved the results only slightly. (This can probably be explained by looking at Figure 1, where the reverberating SI covers the reflection data for 3-4 s. A small dither from shot to shot is not sufficient to achieve a proper randomization of such noise-trains in the τ -p domain). However, very good denoising results were achieved when we simulated different vessel speeds (dataset #3 – Figure 4d and 4e). Such a speed adjustment is also in line with our navigation system suggestions for a real life situation. Finally, excellent results were obtained when we simulate different shot-point intervals (dataset #4 with 25 vs 18.75 m SPI – Figure 4f and g). Such acquisitions effectively randomized the arrival time of the SI which enabled the SI attenuation algorithm to remove practically all the SI. In the examples shown, only one pass of SI attenuation was applied. By processing the data through further denoising, HR Radon and migration, the remaining SI seen here would most likely not be visible.

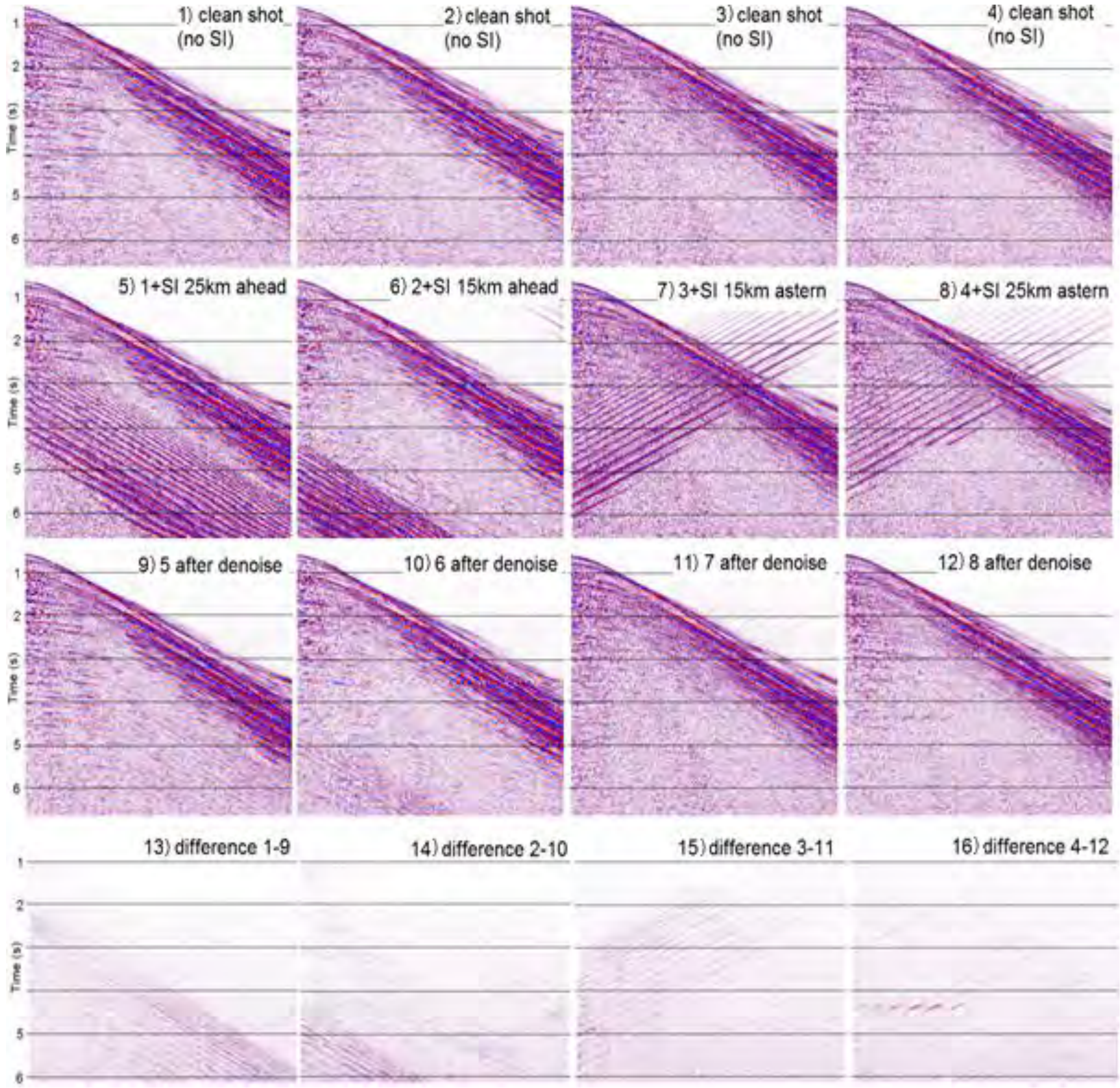

Figure 3: *Seismic interference noise removal results on four 6.5 s, 480 channel (6 km) shot gathers. From top to bottom: Clean gathers, clean gathers + SI noise, the gathers after denoising and the difference between the clean and the denoised gathers.*

Conclusions

For data acquired in the central North Sea, we show that proper planning, execution and denoising allows two or more vessels to operate very close to one another (~15 km) without significantly degrading the quality of pre-migrated seismic data. The amplitude of the SI does not appear to influence our ability to attenuate SI. However, SI from broadside is more difficult to remove than SI from the front or tail. To effectively handle broadside SI, it is necessary to make sure that the SI does not arrive at the same time on consecutive shots.

On 3-D migrated data, SI noise will generally not be significant even if the interfering vessel is very close.

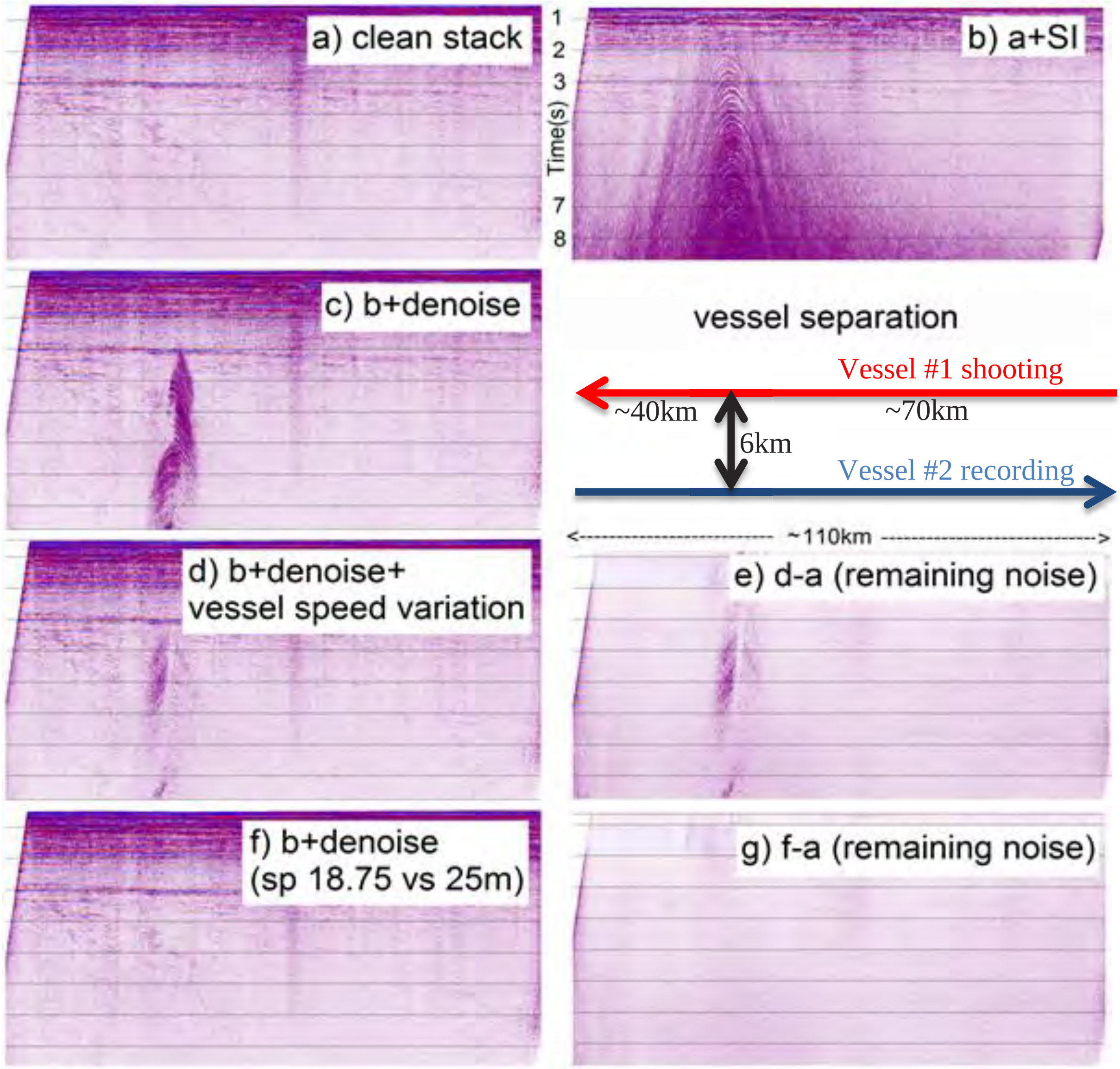

Figure 4: *Plots from 2-D brute stacks. The stacks illustrate the benefits of varying the shot point interval between the seismic recording vessel and the vessel causing the seismic interference. The distance and azimuth to the SI generating vessel are indicated in the figure.*

References

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