# Noise examples from towed marine seismic acquisition

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## Summary

In this work we give examples of noise as typically observed and recorded onboard marine seismic acquisition vessels. The selected noise sources considered here are seismic interference, swell, strumming, electrical leakage (cross-feed), snapping shrimp and feeding fish, respectively. We also present a novel approach of dealing with cross-feed and severe strum/tug noise during the acquisition. Proper identification and classification of noise is important since it can guide the processing geophysicist to properly attenuate the undesired noise. It can also support the decision-making process defining whether a 'noisy' line is to be accepted or not, during the acquisition phase.

## Introduction

Marine seismic data is always affected by various amounts of noise that are recorded during acquisition. Noise affects subsequent processing steps such as de-ghosting, de-multiple, velocity analysis and others, and if not handled properly, will reduce the quality of the seismic image and our ability to interpret the subsurface.

The first look at the raw data normally takes place onboard the seismic vessel(s) conducting the survey, where the goal is to check data integrity and perform quality control. This is very important, especially for occasions where the data is noisy or is borderline concerning the contractual specifications.

The question to answer is whether the data has sufficient quality to meet the subsurface imaging goals of the survey. If this is not the case, it needs to be reacquired, which is costly both in terms of time and money.

The various types of noise that are found in marine seismic records are never random. Instead, each type of noise normally has a very distinct character.

The goal of this paper is to give examples of types of noise that are encountered during marine seismic acquisition. Some are commonly encountered while others are quite rare such as fish feeding noise. The material presented here can be thought of as an extension to the work presented by Fulton (1985), where various noise examples are analyzed. We will explain the physical mechanisms that generate the selected types of noise, and present a novel processing approach to deal with some of the less common types of noise such as severe strum/tug and cross-feed noise.

Many authors have categorized the noise depending on its character. In this paper, we will follow Elboth *et al.* (2010) and classify the noise as background, source-generated or instrument noise. The presence of any of these can be simply categorized as coherent or non-coherent from trace to trace.

## Seismic Interference (SI) noise

SI is a typical background noise, which occurs when two or more seismic vessels operate in close proximity. Historically, in cases when the SI amplitudes and move-out exceeded a certain threshold, time-sharing scenarios were negotiated between the operating vessels. This is operationally expensive and becomes challenging in busy areas where more than two vessels operate at the same time. The industry has developed a number of methods for minimizing time-sharing. Most of the available algorithms depend on randomizing the noise by sorting to other domains followed by application of prediction filtering (Gulunay 2008, Elboth *et al.* 2010 and Zhang *et al.* 2015). The general concept not only for these but most of the de-noise methods consists of: (1) transform the data from time domain to another domain where the signal and noise component can be separated, (2) attenuate the noise, (3) map the data back to time domain.

The example, from a recent survey, in Figure 1(a) has interferences from two different sources. The first one, denoted with 1 in Figure 1(a), is high amplitude interference from another vessel. This SI consists of a train of events of approximately 1.5s which is non-coherent from shot-to-shot. Based on its characteristics and by implementing some of the above-mentioned algorithms, this SI can be attenuated – Figure 1(b). The noise denoted with 2 in Figure 1(a) is observed as almost horizontal stripes and the crew reported it to be produced by a nearby rig activity. Although not generated by a seismic vessel, we can still classify it as SI. This rig noise is broad-band and its move-out overlaps with the one of the reflections at the near offsets. Moreover, the noise train is also continuous and affects the whole record length which makes it shot-to-shot coherent. Combining all these effects makes the attenuation of such noise challenging. Once transformed to the tau-p domain, the interference maps into a narrow area as it is nearly linear in the time domain. However, as it is continuous in the time domain it remains continuous in the tau-p domain as well. In order to effectively evaluate the noise, the onboard crew employed the 'line-mixing' approach, described by Elboth *et al.* (2017), with results displayed in Figure 1(b). Based on the successful application of this approach and the quality control during the duration of the survey – there were zero lines rejected due to SI noise.

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## Swell noise

Low frequency swell noise is probably the most common non-coherent, background type of noise. Swell noise is normally caused by transversal vibrations on the streamers, that are induced by interaction between the streamer and mounted equipment, and the turbulent motion due to an unsteady water column, Parrish (2005). Many algorithms have been developed to tackle these problems. A few examples are: Sanchis *et al.* (2011), Bekara *et al.* (2010), Chen *et al.* (2014) and Turquais *et al.* (2017). Normally a combination of these techniques is used.

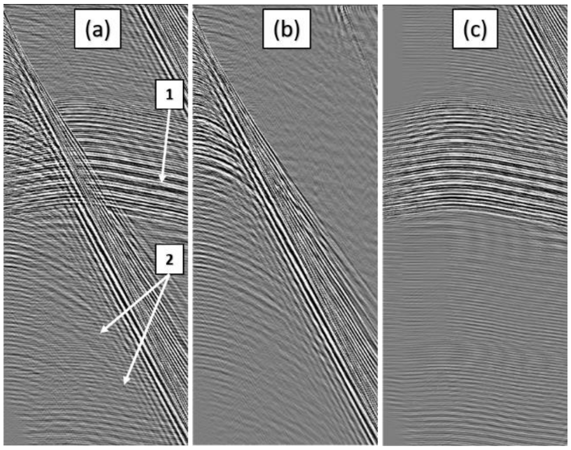

Figure 1: (a) – shot gather before SI attenuation; (b) – shot gather after SI removal; (c) – difference plot (a) minus (b).

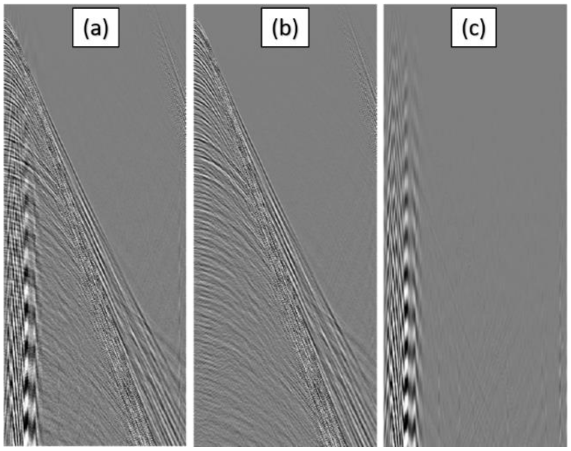

Figure 2: (a) – shot gather affected by swell noise; (b) – shot gather after attenuation; (c) – difference plot (a) minus (b).

The example in Figure 2(a) shows a shot gather affected by high amplitude swell noise from a recent survey. Several adjacent traces show increased levels of noise where the influenced frequencies are typically from 1-12Hz. As a variable streamer depth acquisition (Soubaras *et al.* 2011) was used, the swell has an effect mostly on the shallow part of the streamer – the front, compared to the far traces which are deployed deeper and are less affected by the sea state conditions. Figure 2(b) is after application of a de-swell tool and as seen from the display the affected noisy traces on the front of the streamer are well cleaned. Swell noise is easy to identify by the crew and a good level of expertise is built on most of the seismic vessels from using the tools available. As demonstrated from the results in Figure 2, the noise levels were reduced and the line was accepted. Less and less data is rejected due to excessive swell noise. Modern seismic vessels are now more commonly limited by the risk of damaging their in-sea equipment in cases of bad weather (rough seas), and not by swell-noise.

## Strumming / tugging noise

Strum or tug noise is caused by longitudinal vibration of the streamer produced by occasional increases in tension. This sudden change of the tension is a result of rapid movements of the vessel due to the sea state conditions. Generally, this type of noise mainly affects the outer streamers of the spread as these are also connected to the paravanes, which create extra tension. Its amplitude may vary, but it is often band-limited from 1-10Hz. This background noise normally propagates along the first few hundred meters of the streamer and it is coherent within the shot gather. In addition, the tail buoy is pulling the streamer from the back and similar noise is generated, but this time having opposite dip and propagation from the tail of the streamer.

The example shown in Figure 4(a) has strum noise, both from the tail and the head of the streamer. In this particular case, the amplitudes of the strum noise from the head of the streamer are higher than usual. It also affects the whole length of the streamer as opposed to the first few hundred meters. This noise is probably caused by debris caught on the separation ropes between the streamers, generating extra tension.

The typical application of f-k filtering used for such coherent events resulted in signal loss as the dip of the strum noise was partially overlapping with that of the signal (results not shown here). Therefore, for a quick assessment of the data the onboard team developed a novel model-based subtraction technique. Figure 3 shows the sequence used to address the noise, where Figure 3(a) is a shot gather affected by high amplitude strum noise. A linear-move-out (LMO) correction, following the dip/speed of the noise was applied to the data in order to 'flatten' the noise – result shown in Figure 3(b). Low pass filtering, keeping only the noisy frequencies is shown in Figure 3(c), followed by an f-k filter targeting only the 'flat' energy –

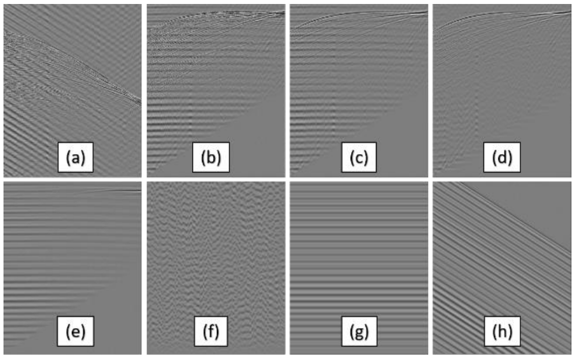

Figure 3: Strum noise model building: (a) – shot gather affected by strum noise; (b) – shot gather after forward LMO correction; (c) – gather after low pass filter; (d) – gather after f-k filter; (e) – difference (b) minus (d); (f) – shot stack of (e); (g) –stacked trace duplicated for all receivers in the shot group; (h) – reverse LMO correction – noise model.

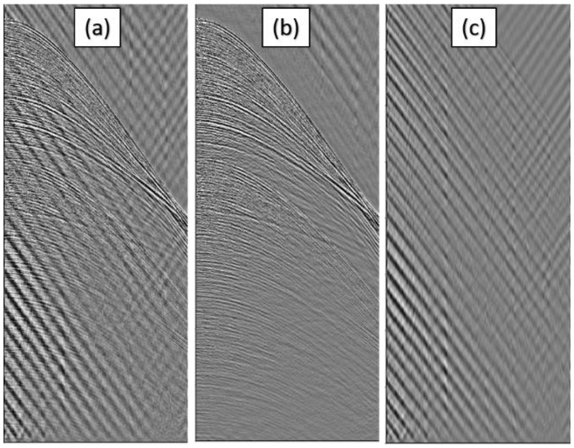

Figure 4: (a) – shot gather affected by strum noise; (b) – shot gather after attenuation; (c) – difference plot (a) minus (b).

Figure 3(d). By subtracting the filtered results (d) from the non-filtered input (b) we end with our initial noise model shown in (e). We call Figure 3(e) the initial model as there is some signal leakage seen. In order to overcome this signal loss we stack the first 100 traces. The resulted 'shot-stack' is displayed in Figure 3(f), where each stacked trace represents one shot gather. By padding the stacked trace we form a shot gather again - Figure 3(g). Reversing the LMO, and we finally obtain the noise model in Figure 3(h). This model was finally adaptively subtracted from the data (Figure 4). The output result from the complete de-noise sequence including the model-based subtraction of the strum noise is shown in Figure 4(b). No damage to the signal is observed. As demonstrated, these abnormal levels of strum noise could be effectively attenuated by processing. Therefore, no lines were rejected during the acquisition, which avoided the significant cost of re-acquiring the data.

### Cross-feed noise

A typical example of instrument noise is cross-feed. This type of noise is defined as an 'electrical noise' from channel to channel. Once apparent it propagates instantaneously (speed of light) to the other channels along the streamer as illustrated in Figure 5(a). A faulty trace or group of faulty traces is often the source of cross-feed. In most cases it is due to bad electrical insulation (water ingress) between the individual sections on the streamer. This electrical noise can also be generated by some of the devices mounted on a streamer. The presented example in Figure 5 is from a recent survey, where one of the streamers was reported to have electrical leakage causing cross-feed noise. Historically, when such a strong electrical noise is apparent, the streamer affected is typically flagged as 'Not To Be Processed' (NTBP) until the faulty equipment is repaired. In order to reduce the cost due to potential re-acquisition, the onboard processing team demonstrated that the noise could be effectively removed. This was achieved again by a novel approach of modelling the noise and subtracting it from the data in a similar approach to that outlined for the strum noise. First, all shots for the streamer in question were stacked. As the cross-feed appears as 'flat' (coherent) energy in shot domain, it stacks-in perfectly. It is represented as an individual spikes in the shot point stack section shown in Figure 5(a). Spike removal was applied and the result is displayed in Figure 5(b). The resulted difference in Figure 5(c), where each trace corresponds to one shot gather, represents the noise model. Each trace of the stacked noise model is then padded to form a shot gather again. Figure 6 shows results on a shot gather after subtracting the noise. Note the noise is attenuated almost completely. For that reason, the streamer was not removed from the coverage and no lines had to be re-acquired which reduced the acquisition cost significantly.

### 'Snapping shrimp' noise

The highlighted noise (white arrows) in the wiggle trace display in Figure 7(a) is quite unusual. These localized bursts of energy reported during the acquisition of a recent survey, are probably caused by 'snapping shrimps'. Everest *et al.* (1948) firstly mentioned this phenomenon. These small creatures are capable of producing loud sound by

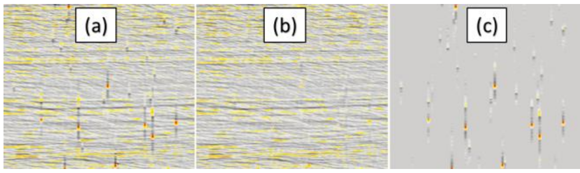

Figure 5: Cross-feed noise model building: (a) – shot stack affected by cross-feed; (b) – shot stack after spike removal; (c) – difference (a) minus (b) or initial noise model.

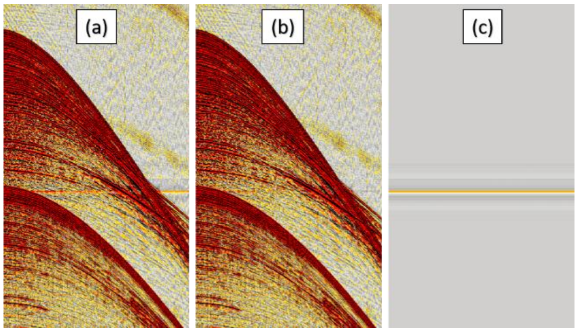

Figure 6: Example of cross-feed contaminating the streamer. (a) – shot gather affected by cross-feed; (b) – shot gather after attenuation of cross-feed; (c) – difference plot (a) minus (b).

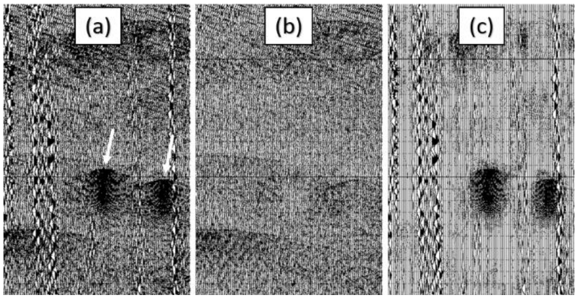

Figure 7: Snapping shrimp noise example; shot gather before attenuation; (b) – shot gather after attenuation of snapping shrimp noise; (c) – difference plot (a) minus (b).

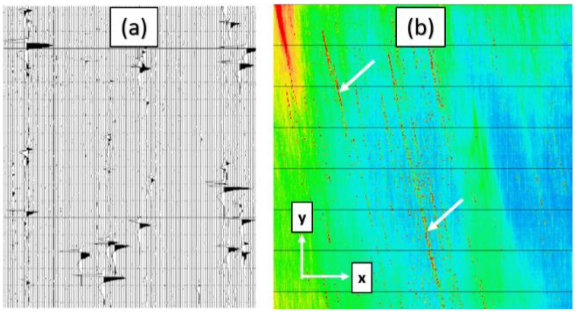

Figure 8: Feeding fish example; (a) – 'spiky' shot gather (zoom); (b) – RMS map, where the receivers are plotted along the abscisa and the shot points along the ordinate.

snapping their claws. Once the claw snaps, it emits cavitation bubbles capable of stunning a fish, Versluis *et al.* (2000). It is this that is eventually recorded by the receivers. Snapping shrimp noise has characteristics of a broad-band burst of noise, affecting several adjacent traces. This type of noise, albeit being not very common, can be quite challenging to deal with in processing.

However, once the data is sorted to another domain it will appear as a collection of random individual bursts of energy. This makes it removable by using some of the already mentioned de-noising tools available. Figure 7(b) shows the results after such de-noising, where along with the shrimp noise, swell noise was also removed.

Note that in areas where a big colony of such shrimp is present, which is typical in warm and shallow waters, we might experience more background noise compared to the one shown in our example. In such a case, a combination of different attenuation algorithms may be beneficial, together with application in more than one processing domain.

## Feeding fish noise

In our last data example in Figure 8, we show noise that puzzled the vessel crew for some time, having initially been misclassified. During a recent survey, random spikes appeared and disappeared on the data for several lines but not always on the same channels - Figure 8(a). The vessel crew initially believed that the noise was due to an electrical problem. However, the RMS plot in Figure 8(b) suggests that the individual spikes followed certain patterns in the source-receiver space, being close to stationary in the water. Moreover, the spikes amplitudes and shape varied. Combining all these characteristics led to the belief that it was an external source (background type) of noise or something colliding with the streamer. The workboat was launched to inspect the streamer immediately once the noise appeared again. Surprisingly, no debris was found and the spikes disappeared once the workboat approached the affected streamer, but appeared on an adjacent streamer. The crew reported the observation of jumping 'bait fish' during the workboat mission. Another issue during the survey was the barnacle growth on the streamers. The presence of clusters of small fish and barnacles pointed to the hypothesis that larger predators like tuna and barracuda might be attracted and feed around the area and occasionally hit the streamer. This idea is also supported by the absence of any sort of debris in the water reported during the survey.

Spikes are easily removable in processing since they are non-coherent individual pulses of energy. However, understanding the origin of the noise is also important as it might lead to costly incorrect decisions such as replacing undamaged streamer sections.

## Discussion

We have presented several examples from recent surveys where our increased understanding of various types of noise have allowed us to develop a number of new de-noising algorithms. This has improved the data quality, significantly, reduced vessel downtime, and increased the overall productivity. Accurate classification of noise can help with decision making process concerning the line-acceptance criteria and avoid significant costs.

## Acknowledgments

We thank CGG DataLibrary for permission to show these examples. The Research Council of Norway has supported this work through project number 297180.

**REFERENCE CHANGE:** Reference lists **will not** be included at the end of the expanded abstract, but should be prepared separately and entered during the submission process in the online form.

Bekara, M., and M. Baan, 2010, High-amplitude noise detection by the expectation-maximization algorithm with application to swell-noise attenuation: Geophysics, **75**, no. 3, V39–V49, doi: 10.1190/1.3428749

Chen, K., and M. D. Sacchi, 2014 - Robust reduced-rank filtering for erratic seismic noise attenuation: Geophysics, **80**, no. 1, V1-V11, doi: 10.1190/geo2014-0116.1

Elboth, T., I. Presterud, and D. Hermansen, 2010, Time-frequency seismic data de-noising: Geophysical Prospecting, **58**, 441-453, doi: 10.1111/j.1365-2478.2009.00846.x

Elboth, T., H. Shen, and J. Khan, 2017, Advances in Seismic Interference Noise Attenuation: 79th Conference and Exhibition, EAGE, Extended abstract, doi: 10.3997/2214-4609.201700579

Everest, F. A., R. W. Young, and M. W. Johnson, 1948, Acoustical characteristics of noise produced by snapping shrimp: The Journal of the Acoustical Society of America, **20**, 137–142.

Fulton, T., 1985, Some interesting seismic noise: The Leading Edge, 4, 70-75.

Gulunay, N., 2008, Two different algorithms for seismic interference noise attenuation: The Leading Edge, 27, 2, 176-181, doi: 10.1190/1.2840364

Parrish, J., 2005, Streamer string waves and swell noise: 75th Annual International Meeting, SEG, Expanded Abstracts, 72-75, doi: 10.1190/1.2144429

Sanchis, C., and A. Hanssen, 2011, Multiple-input adaptive seismic noise canceller for the attenuation of nonstationary coherent noise: Geophysics, **76**, no. 6, V139-V150, doi: 10.1190/geo2010-0367.1

Soubaras, R., and P. Whiting, 2011, Variable depth streamer — The new broadband acquisition system: 81st Annual International Meeting, SEG, Expanded Abstracts, 4349–4352, doi: 10.1190/1.3628115

Turquais, P., E. Asgedom, and W. Söllner, 2017, Coherent noise suppression by learning and analyzing the morphology of the data: Geophysics, **82**, no. 6, V397-V411, doi: 10.1190/geo2017-0092.1

Versluis, M., B. Schmitz, A. von der Heydt, and D. Lohse, 2000, How snapping shrimp snap: Through cavitating bubbles: Science, 289, 2114–2117.

Zhang, Z., and P. Wang, 2015, Seismic interference noise attenuation based on sparse inversion: 85st Annual International Meeting, SEG, Expanded Abstracts, 4662-4666, doi: 10.1190/segam2015-5877663.1