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# Noise attenuation of a 3D marine seismic reflection dataset - a case study in the Southwest Black Sea region

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**ABSTRACT**

Noises in marine seismic data are one of the biggest obstacles in seismic imaging. The most significant step in seismic data processing is the removal of seismic noise, which can be classified as instrument and background noise. Noise attenuation usually results in improved seismic interpretation by increasing the signal-to-noise ratio. In this study, we will focus on attenuating these seismic noises with several data processing techniques. A number of denoising examples describing swell, strumming/tugging, and cavitation, which are background-type noises, and streamer-mounted device noise (Nautilus), which is an instrument-type noise, were illustrated by analysing a marine 3D seismic dataset recorded by Oruç Reis Research Vessel in Black Sea project of Mineral Research and Exploration (MTA). This study was achieved by implementing an f-x prediction filter (SPARC, DENOISE3D) and f-k filter (DWATT) in the t-x domain, and radon filter (RADATT) in Tau-P domain by the use of Geovation 2.0 software.

## 1. Introduction

It is well known that noises in marine seismic are one of the biggest obstacles in seismic imaging. These noises can mask primary data and thus degrade the imaging which may lead to misinterpretation. In seismic exploration and processing, which are the main phases of determining the well location in oil and gas exploration (McConnell, 2000), such an inaccuracy that may result can cause millions of dollars in losses for companies when it comes to the interpretation stage. Therefore, it is very important to carefully eliminate the noise while preserving the underlying data.

Seismic noise can be distinguished on the basis of its seismic characteristic into coherent and random noise (Schoenberger and Mifsud, 1974; Dondurur, 2018). To better understand the origin of the seismic noise, Elboth et al. (2010) classified the noise as background, instrument, and source-generated type noise. However, source-generated noise will not be covered in this paper. One of the fundamentals of seismic data processing is eliminating noises originating from various sources. Although there are several attenuation techniques that have been exemplified in various studies (Yılmaz, 2001; Guo and Lin, 2003; Gülünay et al., 2004; Gülünay, 2008; Elboth et al., 2009; Elboth et al., 2010; Zhang and

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Wang, 2015), the methods most suitable for the dataset was applied and presented here.

In addition, preserving the primary signal (target reflections) plays a pivotal role in noise attenuation (Elboth et al., 2009). Filter parameters and time windows should be carefully designed so as not to damage the primary signal. Therefore, filters should be applied gently to the frequencies containing the primary signal. In this study, the application of noise attenuation was employed in order; swell noise, tugging/strumming noise, seismic interference, and bird noise.

The dataset presented here was collected by Oruc Reis R/V with acquisition parameters shown in Table 1. This study will firstly focus on methods of suppressing seismic noises that are swell, operational, strumming/tugging, streamer positioning instrument, and cavitation noise by applying f-x prediction filter and f-k filter in the t-x domain, radon filter in Tau-P domain, respectively. Then, the results of this study will be presented.

## 2. Common Noises in Marine Seismic

### 2.1. Background Noise

Background noises are types of ambient noises which are not generated by the seismic operation but uncontrollable external sources (Hlebnikov et al., 2021). Background noise types frequently encountered in marine seismic are swell noise, tugging/strumming noise, and cavitation noise. Below part, the results of these attenuation methods are shared.

#### *2.1.1. Swell Noise*

The swell noise is one of the most common and dominant noise types encountered in marine seismic, which can be classified as non-coherent background noise.

Two mechanisms have been proposed that can generate swell noise. According to this, the first mechanism is Bulge waves in the sea due to aggressive weather conditions, which cause a hydrostatic pressure difference on the streamer and the second mechanism is the ocean currents creating cross flow effect on the streamer (Dondurur, 2018).

Swell noise generally produces a high amplitude signal with a frequency range of 1-10 Hz, which can be observed as blobs on shot gathers in Figure 1a (Elboth et al., 2009). While the most common way to remove the swell noise is to apply a band-pass filter, this method is not only inadequate but also may cause data loss. Instead of this, an f-x projective filter was applied by processing for each frequency range belonging to different components of the swell noise with proper threshold values. F-x projection filtering is a statistical noise attenuation method in which the noise is eliminated by filtering the data with an auto-deconvolved prediction error filter (Soubaras, 1994, 1995).

F-x projection filter (SPARC) could be implemented into different time windows considering where the primaries are dominant in order to avoid affecting primary data. Therefore, the filter can be applied harshly with low threshold values and a broad frequency range in which primaries cannot be observed while it can be applied more moderately with high threshold values and a narrow frequency range in the primary zone time window.

Figure 1a shows a shot gathered heavily contaminated by the swell mostly in the middle. The effect of swell noise can be observed continuously throughout the shot gather. After the application of the projection filter, the swell noise is almost completely removed from the data while the primary reflections remain preserved thanks to the sensitive parameter and window design. (Figures 1b, c). F-k plots indicate that low-frequency content delineating swell energy has been successfully attenuated from the data (Figures 1d, e, f).

#### *2.1.2. Tugging/Strumming Noise*

Another challenge in marine seismic data processing is to remove tugging/strumming noise

Table 1- Acquisitions parameters of processed data.

| No. of Receivers | No. of Cables | Nominal Fold | Record Length | Shot Interval | Receiver Interval | Near / Far Offset | Source Type | Receiver Depth / Source Depth |
|---|---|---|---|---|---|---|---|---|
| 1920 | 4 | 60 | 10050 ms | 25 m (flip/flop) | 12.5 m | ~120 m / 6050 m | Bolt 1900 LLXT airgun 3480 $cu^3$ | 7 m / 6 m |

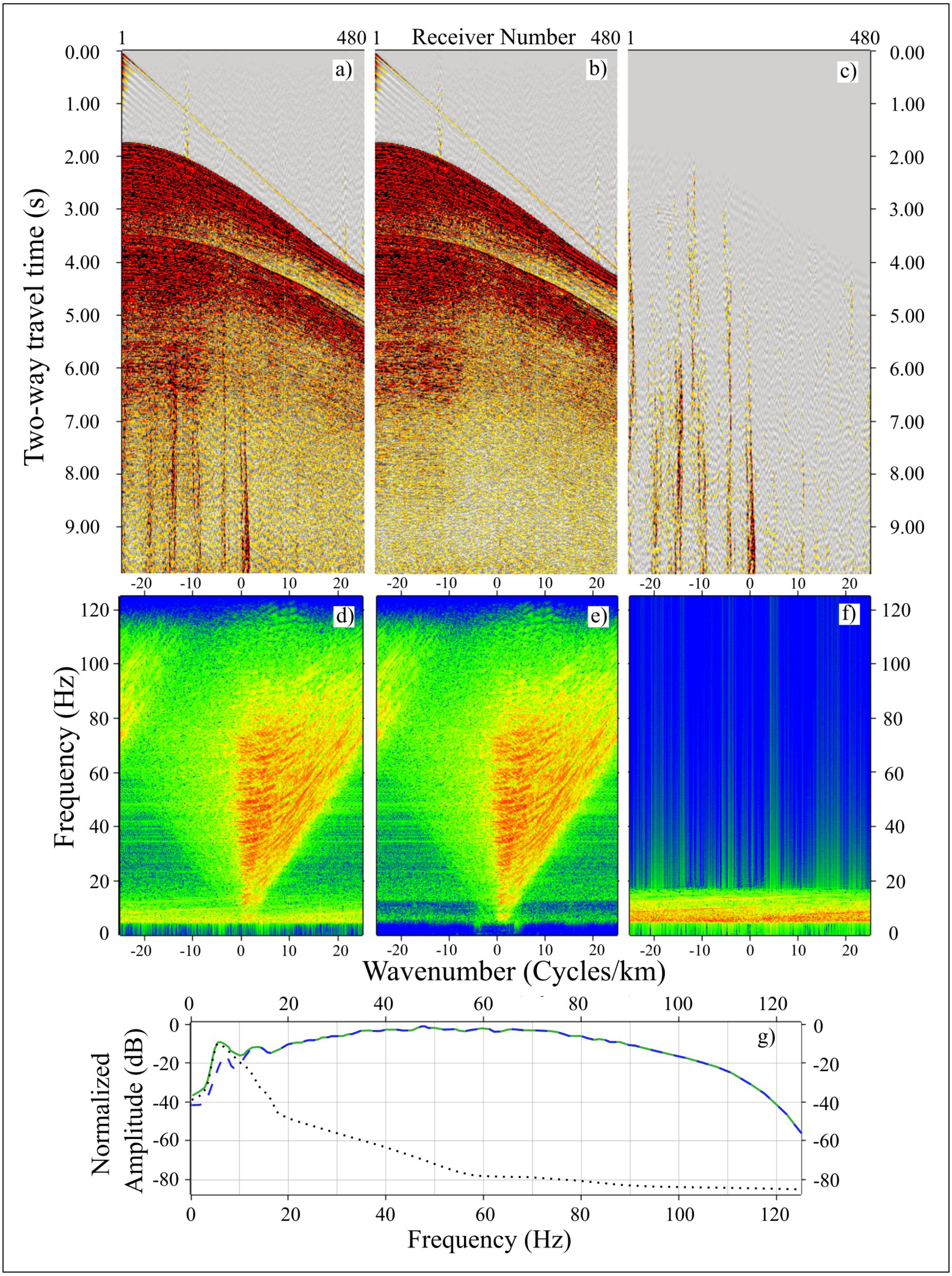


Figure 1- Swell noise attenuation; a) before SPARC application, b) after SPARC application, c) difference, d), e), f) f-k spectrum – before, after, difference, respectively, and g) amplitude spectrum before SPARC (green/straight line), after SPARC (blue/dashed line), difference (black/dotted).

which can be classified as coherent background noise (Hlebnikov et al., 2019). This noise type originated from longitudinal vibrations along the streamer. During the acquisition of seismic data, a vibration occurs on the streamer because of the tension between the vessel and towed streamer. In addition, the tension between the streamer and a tail buoy causes tugging/strumming noise (Parrish, 2005; Hlebnikov et al., 2019).

Since the tension is more dominant on the outer streamers in 3D projects, tug/strum noise is more evident and easily distinguishable in the shot gathers of these streamers. The vibrations created by the tows connecting the streamer to the ship and paravanes as a result of the ship movement appear in the gathers as linear events (head-to-tail) with a frequency range of 1-10 Hz (it can be observed up to 20 Hz), usually affecting near traces whereas the noise caused by the tail buoy has a negative moveout linear characteristic (tail-to-head) in far traces.

Linear noise can be removed by filtering the noise as a fan of apparent velocities in the f-k domain (Dondurur, 2018; Hlebnikov et al., 2021). A fan filter was designed that covers the velocities of tug noises in the t-x domain. Subsequently, using the DWATT module in Geovation 2.0, this fan filter in the t-x domain was transformed into the f-k domain, and then the filtered and modelled part was subtracted from the data.

Figure 2a demonstrates that near traces of the shot gather are dominated by tug noise while strum noise from the tail to head appears very weak in far traces. In Figures 2b, c, linear events are almost completely eliminated without damaging primary reflections with the help of a carefully designed fan filter. As can be seen in f-k spectra, linear noises with a frequency of up to 18 Hz, with 11-18 Hz being weak, have been discarded from the data (Figures 2d, e, f, g).

*2.1.3. Cavitation Noise*

Cavitation noise is a type of seismic interference (SI) caused by propellers of ships passing close to the streamer during the acquisition of seismic data (Elboth et al., 2009). This type of noise is quite common, especially in study areas where marine traffic is intense, and it is highly unlikely to avoid this noise during the towed-streamer acquisition.

Depending on the position of the noise-generating ship relative to the streamer, cavitation noise can be observed as either a linear or hyperbolic event in shot gathers with a broad frequency content. The cavitation noise repeats itself throughout the recording until the noise-generating vessel is outside the sensitivity range of the streamer. Our streamer recorded this noise (Figure 3a) for about 200 shots, generated by a passing vessel. Firstly, defining the frequency, move-out, and dipping of the noise in the shot gather is important to design the filter to properly eliminate the noise from the dataset. The noise for this case in the study has a frequency range of 40 Hz to 125 Hz. When the motion of the noise in the shooting pattern is examined, it appears as tail-to-head in shot gathers, becomes hyperbolic due to the relative motion between the two ships, then becomes head-to-tail and fades away from gather.

Although many approaches to eliminating cavitation noise have been proposed, two effective methods will be focused here. Firstly, Tau-P transformation in which it is possible to mute the p values related to the move outs of the propeller noise, which has different move outs from primaries in Tau-P domain was used (RADATT). In addition, in this stage, a frequency-limited filter was applied in order to preserve primary reflections.

Another SI attenuation algorithm presented by Gülünay et al. (2004) is a useful method based on FX prediction filters. Basically, this tool (SINAT module on Geovation 2.0) compares the contaminated shots with the adjacent shots in particular time and space windows to detect and flag the differences among them. However, in this shot-to-shot comparison, there are no differences (near to zero) within primary reflections. Thus, primaries are likely to be preserved in the dataset with this method. SINAT may require some conditions to work properly. These are:

- Amplitude of the noise should be higher than the underlying amplitude of the signal.
- Noise should be incoherent with the adjacent shots in designated time windows.
- Primaries and the SI noise should be monodip (Brittan et al., 2008; Gülünay, 2008).

Figure 3a shows that semi-symmetrical hyperbolas caused by the propeller of a close passing vessel

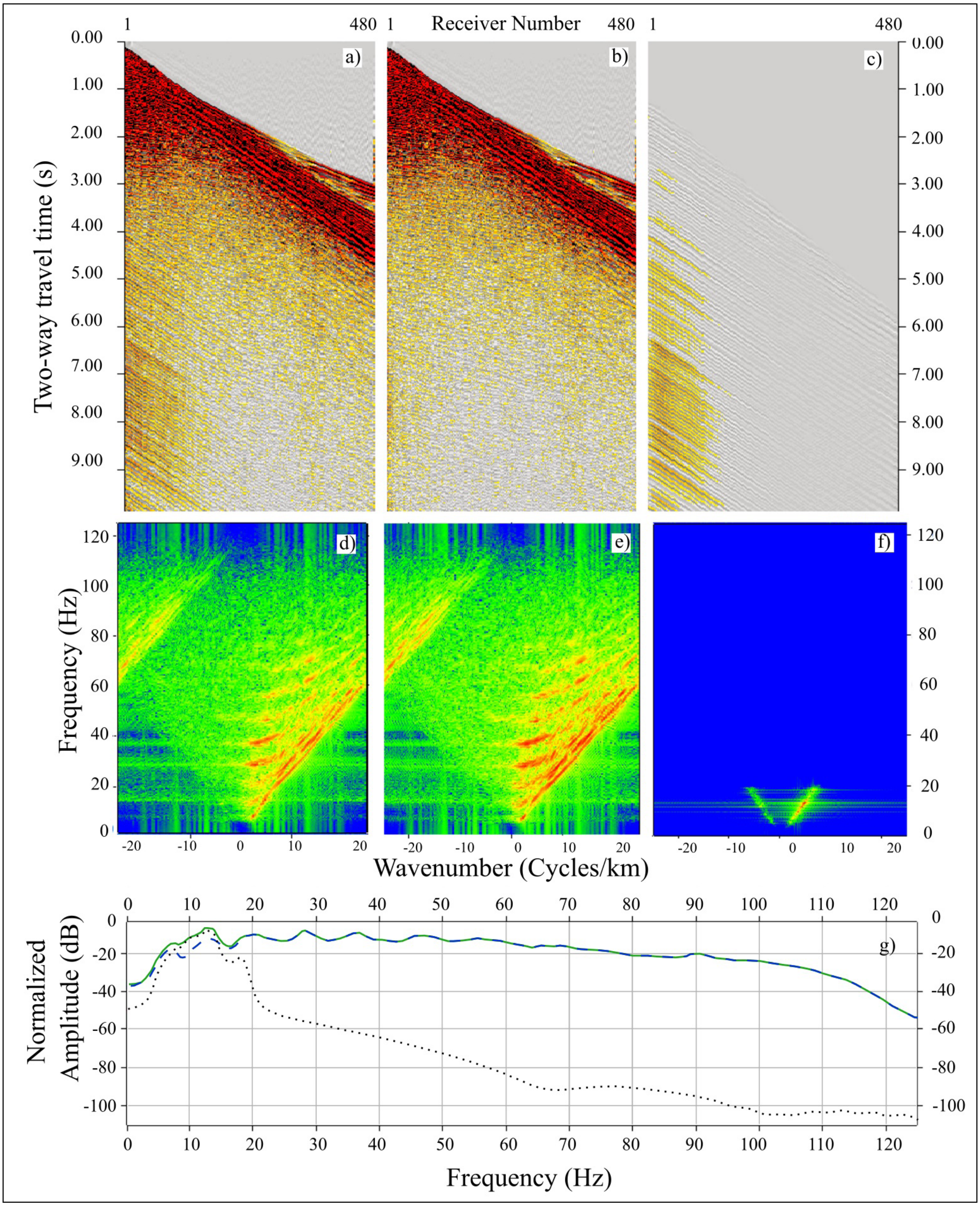


Figure 2- Tugging/strumming noise attenuation; a) before DWATT application, b) after DWATT application, c) difference, d), e), f) f-k spectrum – before, after, difference, respectively, and g) amplitude spectrum before DWATT (green/straight line), after DWATT (blue/dashed line), difference (black/dotted). Please note that the amplitudes in the f-k spectra are not balanced.

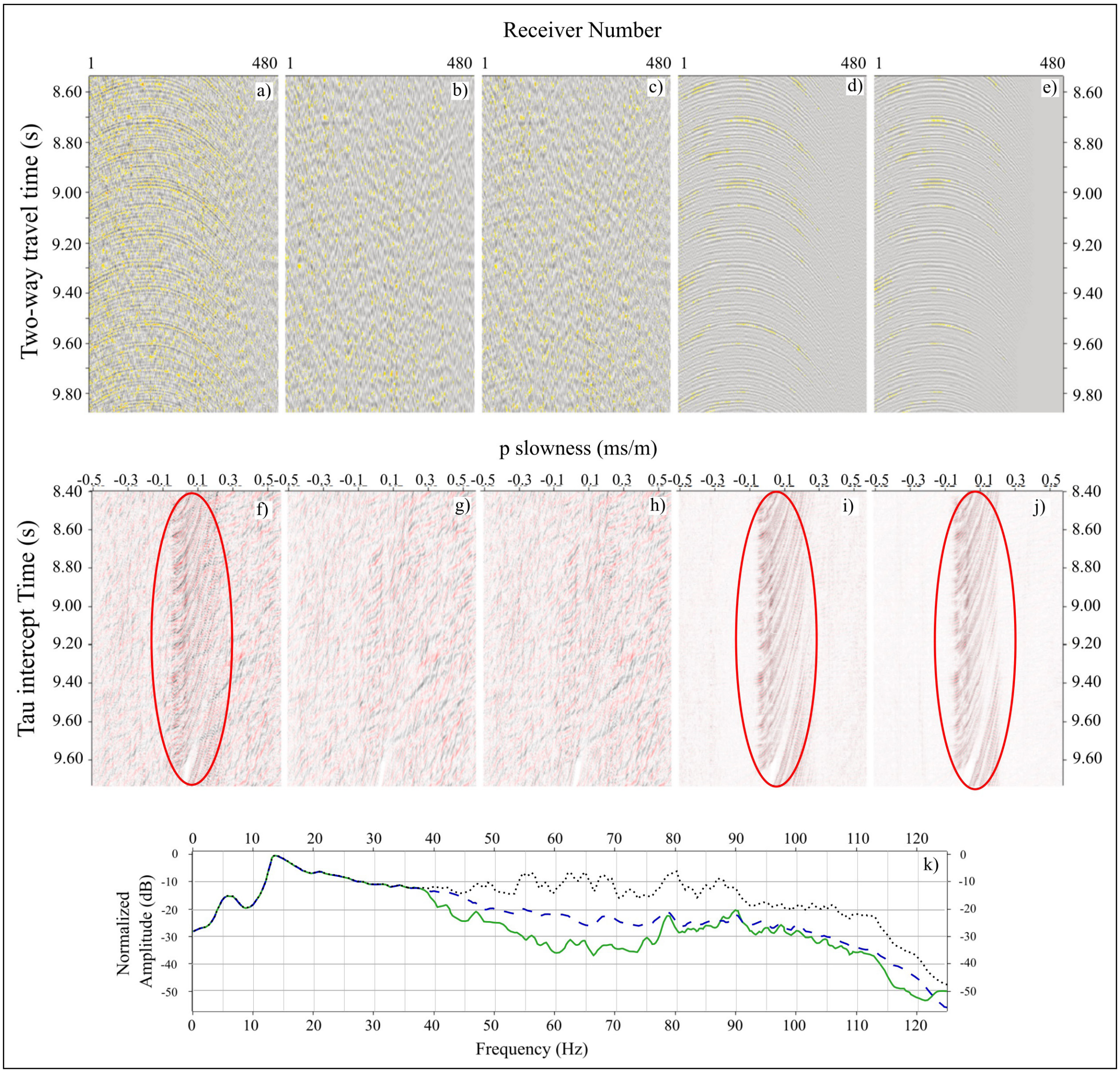


Figure 3- Seismic Interference Noise Attenuation; a) raw data, b) after RADATT application, c) after SINAT application, d) difference between RADATT and raw data, e) difference between SINAT and raw data, f), g), h), i) and j) Tau-P plots – raw data, RADATT applied, SINAT applied, the difference between raw data and RADATT, difference between raw data and SINAT, respectively. Red circles denote the hyperbolas of the cavitation noise, k) amplitude spectrum indicating raw data (black/dotted), RADATT (green/straight line), SINAT (blue/dashed line). Note that since the hyperbolas in the shot domain appear as inverted hyperbolas in the Tau-P domain, the Tau-P scale is given wider in the upward direction.

contaminate all the traces in the shot gather. These semi-symmetrical hyperbolas appear as upside hyperbolas in the Tau-P domain (Figure 3f). By the help of a Tau-P filter designed for the purpose, removing the cavitation noise without touching any other signal was managed (Figures 3b, d). A shot gathered in Tau-P domain focusing on the affected area clearly illustrates that the noise is no longer noticeable. The result of the FX prediction filter is also successful for the attenuation of the hyperbolas (Figures 3c, e, h, j). However, the Tau-P method gave a more satisfactory result specifically to the dataset used in this study (Figures 3b, d, g, i).

## 2.2. Instrument Noise

Instruments used in a seismic operation can cause unwanted noise due to malfunctions (electrical and mechanical errors) or operating principles such as steering and balancing of the streamer. The most obvious type of instrument noise is bird noise, which is defined as streamer-mounted unit noise in this study.

*2.2.1. Streamer-Mounted Unit Noise*

One of the most significant noises in marine seismic data is caused by streamer positioning and controlling devices (NAUTILUS), commonly called bird noise (Dondurur, 2018). This noise, which is non-coherent, is observed on the near traces where the devices are mounted on the streamer. These devices, causing stress on the streamer in their mounting locations (on and around the channel), create noise at a velocity of less than 1500 m/s.

The general characteristic of bird noise can be described as inverted v-shaped, with frequency content up to 18 Hz, regularly distributed over shot gathers (Figure 4a). Despite its simply recognizable character

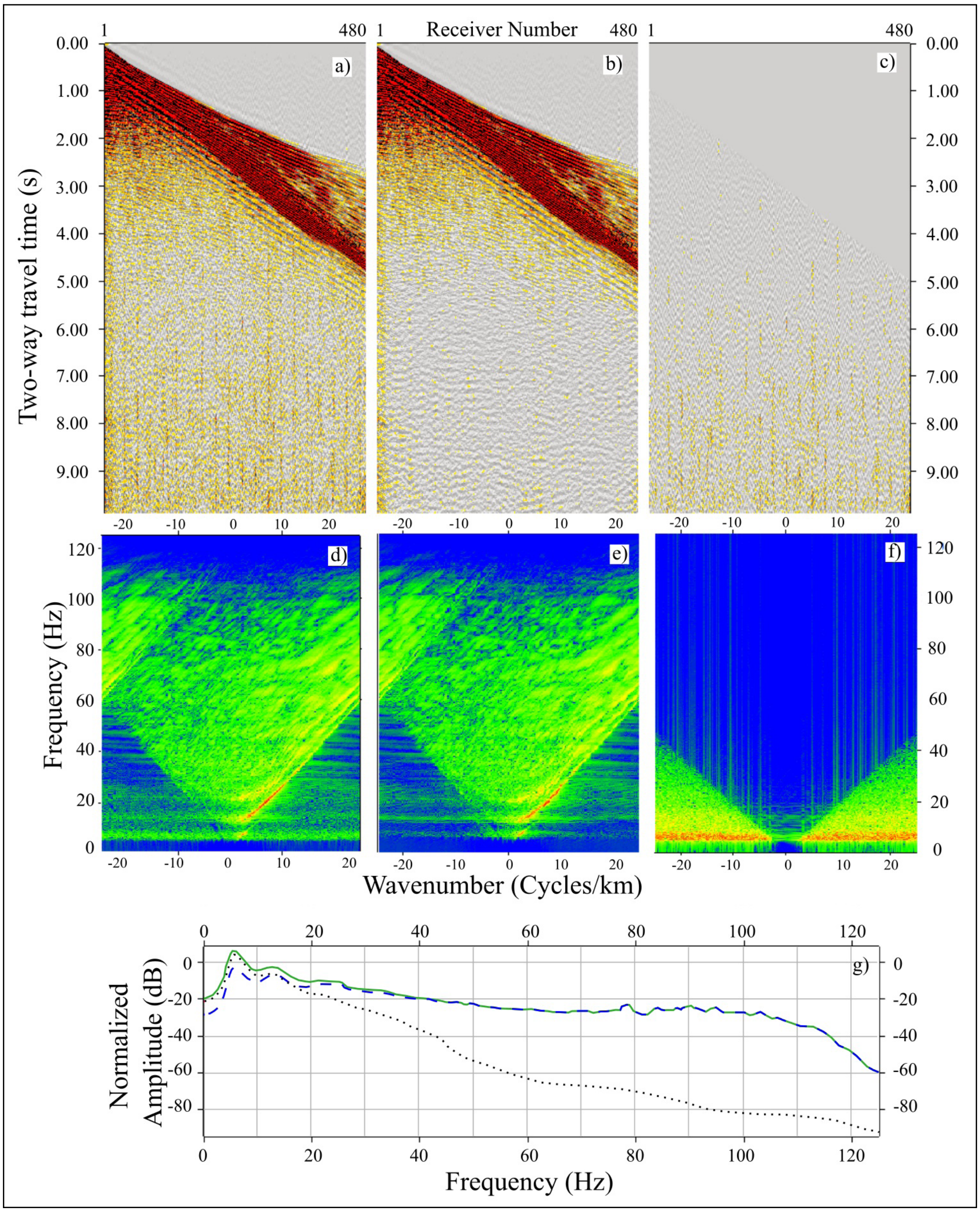


Figure 4- Bird Noise Attenuation; a) before BRDEN application, b) after BRDEN application, c) difference, d) to f) f-k spectrum – before, after, difference, respectively and g) amplitude spectrum before BRDEN (green/straight line), after BRDEN (blue/dashed line), difference (black/dotted).

in the record, it may be difficult to attenuate this noise from the signal. However, an f-k method filter (BRDEN-which was developed by CGG specifically to eliminate this noise) was applied to this data.

Figure 4a demonstrates that noise appearing at regular intervals generated by birds mounted on the streamer is clearly visible on the shot gather and the RMS amplitude map (Figure 5a). The filter is designed for the bird-related linear events which correspond to about 1300 m/s in the f-k domain. In order to avoid overlapping of linear events, it is suggested that the dataset is prepared in such a way that swell and tugging/strumming noise is attenuated beforehand. Figures 4b, c show that the bird noise is successfully discarded from the data. Figures 4d, e, f also reveal the attenuation of low-frequency bird noise in the f-k spectra of the corresponding gathers.

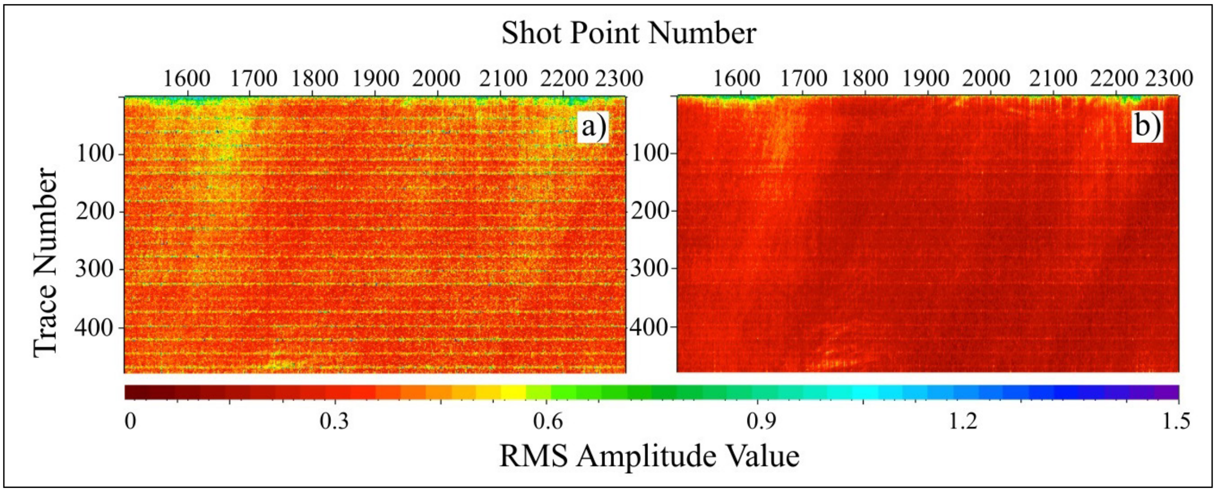


Figure 5- RMS Amplitude maps; a) before BRDEN application, b) after BRDEN application. Please note that the remaining noise in the second figure can be easily removed with a footprint correction that can be applied in later stages.

**3. Results**

The results of a series of marine seismic noise attenuation methods on a seismic dataset collected in the Southwest Black Sea are presented. Various specific methods were applied for the noises encountered in this study. When the results are evaluated, the noises are eliminated satisfactorily without damaging the primary reflections. However, one of the most essential points not to forget in seismic noise attenuation is that every type of noise is unique for every project dataset. Therefore, noise filtering is suggested to be designed uniquely for each project dataset. Furthermore, these illustrated methods might work for different circumstances but reaching perfection in noise attenuation requires numerous parameter tests, significant labour, a great deal of time, and computing capacity, all of which may be costly for companies. For that reason, the aim of the studies, the demands of the clients, and the deadline of the projects should be carefully assessed by the seismic data processing team to design cost-effective and optimum processing flows.

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