Attenuation of long period multiple using F-k filter and surface-related multiple elimination methods on 2D broadband seismic data from Morowali Waters, Sulawesi

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Abstract. Wide range frequency bandwidth on seismic data is a necessity due to its close relation to resolution and depth of target. High-frequency seismic waves provide high-resolution imaging that defines thin bed layers in shallow sediment, while low-frequency seismic waves can penetrate into deeper target depth. As a result of broadband seismic technology, its wide range of frequency bandwidth is a suitable geophysical exploration method in the oil and gas industry. A major obstacle that is frequently found in marine seismic data acquisition is the existence of multiples. Short period multiple and reverberation are commonly attenuated by the predictive deconvolution method on prestack data. Advanced methods are needed to suppress long period multiple in marine seismic data. The 2D broadband marine seismic data from deep Morowali Waters, Sulawesi, contains both short and long period multiples. The predictive deconvolution, which is applied to the processing sequences, successfully eliminates short period multiple on prestack data. The combination of F-k filter and Surface Related Multiple Elimination (SRME) methods are successful in attenuating long period multiple of the 2D broadband marine seismic data. The Prestack Time Migration section shows fine resolution of seismic images.

Keywords: Broadband seismic, F-k filter, Morowali Waters, multiple, Surface Related Multiple Elimination

1. Introduction

Seismic reflection is a geophysical method that is used to study the structure and strata of the earth's subsurface. Reflection seismic is highly accurate to delineate geology below the seabed, such as structures, thickness and volume of sediments, and the depth of the waters. Seismic reflection investigation is divided into three main stages, namely acquisition, processing, and interpretation of seismic data [1]. Multiple is a noise that is formed due to the high impedance contrast between layers. Seismic waves become trapped in the layer and will be reflected repeatedly before being recorded by the receiver. Multiple is generally found in marine seismic data because of the high impedance contrast between air, seawater, seabed layers and becomes a serious problem in seismic data interpretation as primary and multiple waves are difficult to distinguish. In seismic data processing, there are several methods to attenuate or eliminate multiple, and these methods include the F-k filtering and the Surface Related Multiple Elimination (SRME) [2]. The F-k filtering analyzes the presence of multiples by changing the data domain from time offset (t-x) to frequency-wave numbers (F-k domain). From the F-k spectrum, the presence of multiple can more clearly be seen so that it will apply the attenuation process.
Multiple attenuations with the SRME method is done by predicting multiples based on multiple surfaces and making multiple prediction models. Then the seismic recorded data that still contains multiples will be reduced by multiple predictions. Both methods are used to attenuate long period multiple that is recorded during the data acquisition process that interferes with the primary signal. In this study, we present a comparison of two methods for noise attenuation in 2D broadband seismic data from Morowali Waters, Sulawesi.

1.1. Multiple
Multiple is one part of coherent noise that occurs due to the trapping of seismic waves in seawater or soft layers. When there are repeated reflections or multiples, seismic waves will be reflected repeatedly on the same layer before being received by the receiver. In marine seismic data, multiple occurs because of the high contrast of impedance between the surface of the water and air layers. Multiple reflections can occur stronger than primary reflection with inverted polarity [3]. Multiple can be divided into two types based on the length of the period. The long-period multiple has a different arrival time than the primary wave, and the propagation trail is longer than the primary reflection. Short-period multiples are usually formed in the thin bed. Multiple signals interfere with the primary wave because it can change the shape of the primary wave. Types of multiple are shown in Figure 1.

1.2. F-k filter
The F-k filter is used to attenuate noise which has the same frequency as the primary signal frequency, but it has a different wavenumber. If the noise is removed with an ordinary frequency filter, the data information will also be lost. F-k filter is used so that data information remains intact and noise can be muffled [4].

1.3. Surface related multiple attenuations (SRME)
The SRME is a method to eliminate any type of multiple where wave propagation is in contact with the surface [2]. This method utilizes reflections contained in seismic data to predict multiples. The SRME does not require subsurface information but related information of the surface to predict the existence of multiples which is then modeled based on the prediction results.

2. Methodology
The study area is located in Morowali Waters, Sulawesi (Figure 2). Data acquisition was carried out in 2018 using multichannel seismic equipment.
2.1. Data analysis procedure
Processing started with field data pre-processing, processing, and then seismic section analysis and interpretation. The flow chart can be seen in Figure 3.
2.2. Pre-processing
The raw marine seismic data (SEG-D extension) on entering into a database of ProMAX 2D software needs to be pre-processed in several stages, which include geometry check, trace editing, true amplitude recovery (TAR) surface wave attenuation, deconvolution, and F-k filtering [5]. At the first stage of pre-processing raw seismic data is arranged into data shot gather data on ProMAX 2D software. Then geometry check is carried out according to field parameters during data acquisition. These parameters are shot points number, shot intervals, group intervals, and others. Data acquisition parameters of seismic line GS-10 can be seen in Table 1.

| Acquisition Parameters       | Unit | GS-10 |
|------------------------------|------|-------|
| Shot Point                   | -    | 556   |
| Shot Interval                | m    | 25    |
| Group Interval               | m    | 12.5  |
| Active Channel               | -    | 1-560 |
| Near/Minimum Offset          | m    | 150   |
| Nominal Source Depth         | m    | 6     |
| Nominal Receiver Depth       | m    | 7     |
| Sail Line Azimuth            | degree | 218  |

During trace editing, bad traces of seismic data are removed. In addition, data corrections are also carried out at this stage, including trace muting, trace length, and band-pass filtering [6]. The fourth stage is True Amplitude Recovery (TAR) and denoising where weak or lost seismic amplitude due to attenuation during propagation in the earth's layer is recovered. At the following Surface Wave Attenuation (SWA) process, noises originating from surface waves are attenuated. Surface waves are waves that propagate on the earth's surface and do not penetrate into the earth's medium. In order to increase the temporal resolution of seismic data, as well as to return wavelet form into a reflector wavelet form, signal deconvolution is carried out, which also plays a role in eliminating short period multiples. Predictive deconvolution was used by applying picking autocorrelation of seismic data. The picking is done by referring to the shape of the water bottom surface.

2.3. F-k filter
F-k filtering is carried out by transforming the seismic trace of the t x domain (time offset) into the F-k domain (wavenumber-frequency) with the 2D Fourier transform. Picking the F-k gate is done to determine the frequency value of primary reflectors against the noise frequency. The polygon picking results are then used as parameters to attenuate the multiple noises. The F-k analysis window and Frequency-wavenumber picking can be seen in Figure 4.
2.4. **SRME**
Surface Related Multiple Elimination (SRME) is a multiple elimination method that focuses on eliminating surface-related multiples contained in seismic data. Water bottom picking is used to predict surface-related multiples. There are several modules in the SRME method, such as SRME regularization, SRME Macro, and SRME Un-regularization.

2.5. **Prestack time migration (PSTM)**
Migration is the process of returning the reflector position that has shifted from its actual position and eliminating the effect of diffraction on seismic data [7]. The method used in this study is Kirchhoff migration which adds up amplitude from a reflector point into its possible actual location. The migration stage also results in better layer continuity.

3. **Result and discussion**
The long-period demultiple attenuates multiple long-period noises that have different arrival times from the primary wave. Such noises resulted from longer propagation than the primary reflection. The presence of multiple noises is disturbing, even damaging the primary signal, and complicates the
interpreter in translating seismic sections. The F-k filtering can attenuate long-period multiples by performing polygon picking at the expected frequency according to the data and wavenumber (k wavenumber). Based on the results of seismic data processing (Figure 5), multiple noises are seen at a time depth of 1500 ms (black circle). Seismic section view before (a) and after (b) F-k filtering can be seen in Figure 5.

![Figure 5. F-k filter results display before (a) and after (b).](image)

The black circle in Figure 5 is part of the near offset zone and indicates the presence of long-period multiples. The results of the F-k filtering show that multiple is not fully attenuated. This is because the seismic signal frequency in the multiple is the same as the primary seismic signal. The F-k filtering process attenuates multiple using the frequency domain and wavenumber (F-k). The analysis results by picking polygons at the frequency will attenuate the multiple noises indicated in the seismic data [8]. In addition to attenuating multiple signals, the F-k filtering also automatically attenuates the primary seismic signal. This is indicated by the main reflector, which is seen more clearly in the range of 700
ms to 1200 ms. Besides attenuating multiple, the F-k filtering can also attenuate other types of noises, such as linear noise and ground roll. SRME is used to attenuate multiples originating from repeated reflections by surfaces before being received by the receiver. The F-k Filtering output will be guaranteed input data in the SRME process which will be applied to the Kirchhoff 2D Time Migration Pre-stack migration in the Prestack Time Migration (PSTM) process. The seismic cross-section view after SRME can be seen in Figure 6.

![Figure 6. SRME results display.](image)

Figure 6 is a view of the seismic section GS-10 following SRME. The SRME and F-k filtering aim to attenuate multiples. SRME is applied to data gathered following F-k filtering. At a time depth of 1400 ms to 1700 ms, the SRME successfully attenuates multiple black circles on the seismic section shows the results of multiple long-period attenuations in the near offset zone. The SRME also retains main reflectors because this method implements a database that makes all processes in the SRME stage run automatically. The level of reflector continuity also increases following SRME application. The multiple attenuation results look more precise, especially in the near offset zone, so that the SRME can be regarded as successful in attenuating multiple in the near offset and middle offset zones [10].

![Figure 7. Pre-Stack Time Migration (PSTM) result display](image)
Application of PSTM on the same section results is in better visibility (Figure 7). As can be seen from the figure, noise attenuation and the visual texture of the reflector are firmer due to reduced wave diffraction and clear layer continuity [10]. The black circle in Figure 7 shows a better view of the section after SRME and the application of Pre-Stack Time Migration (PSTM). The diffraction effect (black box) is eliminated. The SRME is also effective in suppressing multiples, especially in the near offset and middle offset zones.

4. Conclusion

The F-k filter and Surface Related Multiple Elimination (SRME) application in attenuating long-period multiples was successful. The F-k filtering cannot attenuate the multiple maximally, but it amplifies the signal of the primary reflector. The application of the SRME for multiple attenuations is better, and it keeps the primary reflector intact with high continuity. Each method has advantages and disadvantages but can complement each other to attenuate noise.

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