Multiple attenuation methods in short-offset 2D marine seismic data: a case study in Cendrawasih Bay

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Abstract. Real marine seismic data are typically embedded with free-surface multiples energy, which are troublesome in imaging an accurate seismic cross-section. In addition, more challenging situation is to bring optimum result with a short-offset streamer due to the coherent nature of multiples. In this study, we present a comparison of three methods for attenuating free-surface multiples energy in short-offset 2D seismic data from Cendrawasih Bay. Multiple attenuation methods include F-K filter, Radon transform, and Surface Related Multiple Elimination (SRME) are processed until the final Pre-Stack Time Migration (PSTM) results. Predictive deconvolution is applied in order to suppress short period multiples prior to free-surface multiple attenuation method. Predictive deconvolution successfully identifies and removes the predictable wavelet of short period multiples. Radon transform shows poor result in short-offset seismic data even if it is combined with F-K filter method. Combination of both F-K filter and SRME are successfully attenuate free-surface multiples and should be considered as proper solution to increase signal to noise ratio.

1. Introduction

Seismic reflection is one of geophysical methods that applied in underwater exploration for imaging the subsurface condition. This method can characterize reservoirs to increase oil and gas zone information. In the seismic reflection process, there are three stages used, acquisition, processing, and interpretation [1]. Seismic acquisition digitally is recorded in magnetic tape, and still contains a lot of noise which are derived from seismic instruments, wave propagation, and the environment. The multiple, as part of noise, occurs cause the unsubstantial primary energy which are troublesome in imaging an accurate seismic cross-section. Seismic processing data purpose to increase the signal and suppress noise so that interpretation of the sub-surface’s layer can be interpreted as it is [2].

Multiple attenuation methods are the seismic processing techniques to attenuate the multiples. It is classified into three stages: firstly, deconvolution method that uses periodic repetition in suppressing multiple, secondly, filtering method that separate primary and multiple reflectors in certain domains, and lastly, wave prediction and subtraction from seismic data [3]. In this study, we present a comparison of these three methods for attenuating free-surface multiples energy in short-offset 2D seismic data from Cendrawasih Bay. Multiple attenuation methods include F-K filter, Radon transform, and Surface Related Multiple Elimination (SRME) are processed until the final Pre-Stack Time Migration (PSTM) results. Deconvolution also applied in order to suppress short period multiples prior to free-surface multiple attenuation method.
1.1. Multiple
Multiple is a repetition of reflected seismic energy, or any event in seismic data that has incurred more than one reflection in its travel path. The multiply reflected of seismic energy caused by trapped seismic waves in the water or soft rock layers. Multiple classified into several types. Based on consideration of interface reflection, multiple is divided into two, namely internal multiple and surface-related multiple. Internal multiple is a multiple that reflected downward on the first reflector before it reflected back upward and recorded by the receiver as shown in Figure 1 (a). Surface-related multiple can be seen as a combination of two primaries that connected to each other at the surface reflection point [4]. Based on their time delay from the primary events with which they are associated, multiples are characterized as short-path, implying that they are described not far from the primary event, or long-path, where they appear as separate events [5] as shown in Figure 2.

![Figure 1](image1.png)

Figure 1. (a) Internal multiple, (b) Surface-related multiple.

![Figure 2](image2.png)

Figure 2. (a) Long period multiple, (b) Short period multiple.

1.2. Deconvolution
Deconvolution is applied to compress the basic wavelet in the recorded seismogram, attenuate reverberations and short-period multiples, thus increases temporal resolution and yields a representation of subsurface reflectivity [6]. The recorded seismogram can be modeled as a convolution of the earth’s reflection with the seismic wavelet. As a result, the wavelet become wider and decreasing the amplitude. This wavelet has many components, including source signature, recording filter, surface reflections, and receiver-array response. Ideally, deconvolution should compress the wavelet components and eliminate multiples, leaving only the earth’s reflectivity in the seismic trace. Wavelet compression can be done using an inverse filter as a deconvolution operator. An inverse filter, when convolved with the seismic wavelet, converts it to a spike. The equation of deconvolution [6] is:

\[ R = W^{-1} \ast S \]  

Where R is the earth’s reflectivity, S is recorded signal, and W^{-1} is the inverse wavelet.

1.3. F-K filter
F-K filter is a filter in the frequency and wavenumber (f-k) domain. The filter will convert seismic data from time and distance (t-x) domain to frequency and wave number domain using Fourier transform. F-K filter is filtering out the desired signal by creating a polygon at all Field File Identification (FFID) in f-k domain. Coherent noise in the form of ground roll, direct wave and refraction wave which is the first reflection in seismic data can be handled by F-K filter [7]. F-K filter is also able to resolve an area with a steep slope structure, and it can be used in the low S/N ratio [8].
1.4. Radon transform
There are two types of Radon transform commonly used to suppress multiple, slant-stack or hyperbolic Radon transform and parabolic Radon transform [9]. Radon transform is applied to attenuate multiple based on move-out differences between primary and multiple waves. Radon transform converts the domain data from t-x domain to τ-p domain so that the primary and multiple move-out will be easily separated [10]. Radon transformation better used for deep waters, but this method is not suitable for complex subsurface [11].

1.5. Surface related multiple attenuation (SRME)
Appearance of surface related multiple described as two primary reflections that connected by a reflecting point on the surface water. SRME is a method that used to eliminate surface related multiple found in seismic data by utilizing the reflections in pre-stack seismic data to predict surface multiple models. SRME does not require subsurface information, but it predicts the surface multiple from water surface information which will be made a model of the predicted results. SRME method has several main stages, namely water bottom picking, offset reconstruction, multiple models, and adaptive subtractions.

1.6. Pre-stack time migration (PSTM)
Migration moves the position of the reflector to the actual reflected position and time based on the wave trajectory [12]. The goal of migration is to make the seismic section similar to the geological cross-section in depth along a seismic traverse. Migration can be processed prior the stacking (pre-stack migration) or after the stacking process (post-stack migration) [13]. Pre-stack time migration has better result than post-stack time migration, especially for complex geological structure. Therefore, seismic data that has a complex geological structure, pre-stack time migration (PSTM) is better method to be applied [14].

2. Methods

2.1. Study area
Seismic data used in this study are 2D marine seismic data online C07, L02, and L32. The field data collection process was carried out by Marine Geological Institute, Bandung in 2018 using R.V. GEOMARIN III with multi-channel seismic devices. The study area is located in the Waipoga Waters, Northeast Part of Cendrawasih Bay, Papua. Map of seismic lines location in this study can be seen in Figure 3.
2.2. Data processing methods

The processing sequences are started by de multiplexing the field data, then processing the data to obtain seismic cross section free from noise and multiple so that result can be analyzed and interpreted. The flow chart of seismic data processing can be seen in Figure 4.

![Flow chart of seismic data processing.](image-url)
2.3. Pre-processing
Pre-processing is the initial stage of seismic data processing. There are several stages in pre-processing which are: data input, de multiplexing, geometry, trace edit, True Amplitude Recovery (TAR), surface wave attenuation, and deconvolution.

Input data is the process of inputting data into software and reformatting into a software format. Field data in SEGD format are sorted into seismic processing software format, where data previously based on sequential series then changed to time series. The output of this process is raw data which has been gathered and used as the basis for processing seismic data in the next process.

The geometry process is carried out by entering parameters such as measurement direction, source and receiver distance, source interval, receiver interval, shot point coordinates, receiver coordinates, CDP (Common Depth Point) numbering, etc. This is conducted while the data is processed exactly like the real situation in the field. Acquisition parameters in lines C07, L02 and L32 can be seen in Table 1.

| Line name      | C07   | L02   | L32   |
|----------------|-------|-------|-------|
| Shot Point     | 1234  | 2140  | 1181  |
| Azimuth        | 124°  | 216°  | 304°  |
| Active Channel | 1-120 | 1-120 | 1-120 |
| Source Depth   | 8 m   | 8 m   | 8 m   |
| Receiver Depth | 9 m   | 9 m   | 9 m   |
| Shot Interval  | 25 m  | 25 m  | 25 m  |
| Group Interval | 12.5 m| 12.5 m| 12.5 m|
| Near Offset    | 75 m  | 75 m  | 75 m  |
| Far Offset     | 1562.5 m | 1562.5 m | 1562.5 m |
| Total Length   | 30.83 km | 53.48 km | 29.5 km |

Trace editing is the process of removing the corrupted data or noise that interfere data processing. Noise can cause ambiguity of seismic data so that trace editing stages need to be done to eliminate noise and increase the S/N ratio of seismic data. Trace editing that applied are trace muting, trace length and band pass filter.

The reduction in seismic wave energy during the spreading of the earth's surface is caused by geometrical spreading and rock characterization being traversed so that True Amplitude Recovery (TAR) is carried out. TAR is used to obtain the original amplitude of the seismic wave. This is conducted to get more representative amplitude in the investigation area.

Surface Wave Attenuation is used to weaken noise coming from surface waves by forming low frequency arrays. Next process is deconvolution which will increase the temporal resolution of seismic data. Deconvolution is applied to return the data wavelet form to a wavelet reflector, eliminating short multiple periods and reverberating effects. Predictive deconvolution is the best wavelet shape. In this study, autocorrelation sequence results the length of deconvolution operator is 250ms and the prediction distance of operator 14ms and 12ms.

2.4. Velocity analysis
Velocity analysis is a velocity model building analysis in order to get the appropriate velocity value. This is conducted using Semblance Velocity which has a plot of signal coherence in the velocity field with Two Way Travel time (TWT), then displayed in the form of contours with color with a cross-section. When picking velocity is done, Normal Move Out (NMO) can be activated. If picking velocity is too high, the CDP gather will curve downwards, then if picking velocity is too low, the CDP gather will curve upwards. The appropriate picking velocity will produce a straight or flat gather.

2.5. F-K filter
F-K filter convert seismic data from time and distance (t-x) domain to frequency and wave number domain using Fourier transform. F-K filter is filtering out the desired signal by creating a polygon at all
FFID in f-k domain. Polygon determination is carried out in the FK-analysis window. Multiple can be easily mapped in the FK analysis window so that it can be easily carry out the desired seismic data. Furthermore, the polygon picking are used as f-k filter parameters to reduce multiple and noise.

2.6. Radon transform
Radon transform convert seismic data from time-distance (t-x) domain to t-τ domain with source index number (SIN) as trace header, so that muting can be easily done to separate between primary and multiple. Radon transform is applied to CMP gather that has been corrected by NMO. On the t-τ semblance, muting process is done to separate the primary and multiple signals. But the muting process causes the preservation of primary reflectors to be more difficult when the primary and multiple reflectors are close [15]. Apply the inverse NMO to the Radon filter output and subtract it from the initial data so that the result is only the primary signal data.

2.7. SRME
SRME is a method that used to eliminate surface related multiple found in seismic data by utilizing the reflections in pre-stack seismic data to predict surface multiple models. SRME stages in the seismic processing software described into several modules, namely: SRME regularization, SRME Macro, SRME Un-regularization, SRME Match Filter, and SRME Adaptive subtraction.

2.7.1. SRME regularization. SRME Regularization is the offset regularization stage. In seismic data there will be a blank offset. It will be filled by extrapolating the existing seismic tracks. The output of SRME Regularization is CMP gather that has been regularized.

2.7.2. SRME macro. SRME Macro aims to create multiple estimation models from regulated data gather. The process of making the model using modelling algorithm. The more similarity of the multiple model with multiple both amplitude and phase, resulting better attenuation of surface multiple.

2.7.3. SRME un-regularization. SRME un-regularization aims to restore the zero offset multiple model be offset initially, then combine with the initial input data pre-processing result.

2.7.4. SRME match filter. SRME match filter aims to match multiple models with original multiple.

2.7.5. SRME adaptive subtractions. SRME adaptive subtraction aims to subtract the original multiple with multiple models that have matched the phase and amplitude. So that produce gather which is free from multiple.

2.7.6. Pre-stack time migration (PSTM). Pre-stack Time Migration is a seismic data migration technique that is applied before the stacking process. Kirchhoff Pre-stack 2D Time Migration method is applied in the PSTM process. Practically Kirchhoff's migration is done by summing the amplitude from a reflector point along a position which is a possible real location [16]. The Kirchhoff migration method provides better image of the subsurface because it can resolve steep slope structures. Before the migration process, it is necessary to apply True Amplitude Recovery (TAR) to restore the amplitude that might be lost after multiple attenuation processes.

3. Result and discussion
Multiple attenuation is done for attenuating multiple from primary. Seismic data in line C07, L02, and L32 are detected to have water bottom multiples. Multiple attenuation methods like Radon transform and Surface Related Multiple Elimination (SRME) are applied to the output of the FK filter and processed until the final Pre-Stack Time Migration (PSTM) results. Predictive deconvolution is applied in order to suppress short period multiples prior to free-surface multiple attenuation method. Comparison both of the multiple attenuation method in PSTM results can be seen in Figure 5, 6, and 7.
Figure 5. Pre-stack Kirchhoff 2D time migration results in line c07 with Radon transform (above) and with SRME (bottom).

Zone with black rectangles are comparison of main reflector which is erased due to multiple attenuation while zone with black ovals are comparison of multiple residues. In C07 seismic line the main reflector with Radon transform was erased in all zones, which are near offset, middle offset, and far offset. It is due to picking process of Radon transform. When multiple and primary have adjacent distances, the primary will also be erased. While SRME preserves most of the main reflectors. Radon transform still leaves multiple residues in near offset and middle offset, but it’s quite successfully removing multiple in the far offset cause of move-out difference between primary and multiple will clearly see. So that picking process becomes easier in the far offset [17].

While SRME successfully removes multiple in the near offset and middle offset but still leaves multiple residues in the far offset. This happens because SRME have to match multiple models with the original multiple. Multiple models which has been formed in the prior stage have amplitude differences with the original multiple, especially in the far offset. It’s caused by NMO too low or too high in the approximate parabola.
Figure 6. Pre-stack Kirchhoff 2D time migration results in line L02 with Radon transform (above) and with SRME (bottom).

Strong reflection coefficient in the water bottom layer produces strong surface multiple. Radon transform fails to remove strong multiple in the L02 seismic line. Radon transform also has low level of continuity of primary reflector in all zones can be seen in Figure 6. Whereas multiple attenuation using SRME successfully eliminates surface multiple in the near offset, middle offset, and far offset. SRME also keeps the main reflector intact with increased continuity on the main reflector.

Figure 7. Pre-stack Kirchhoff 2D time migration results in line L32 with Radon transform (above) and with SRME (bottom).
Radon transform that applied to the L32 seismic line fails to eliminate multiple in the near offset and middle offset. But after pre-stack time migration process, resulting seismic cross section that are free from multiple. Migration is one of the corrections that can be used to increase signal to noise ratio of seismic data and can reduce or eliminate noise [14]. This noise can be diffraction, multiple, and bowtie effects that make seismic data inaccurate. While multiple attenuation with SRME successfully eliminates multiple in the near and mid offset and also has better primary reflector compared to the Radon Transformation method.

4. Conclusion
Application of multiple attenuation method depends on the characteristics of multiple contained in seismic data. Radon Transform successfully attenuate multiple in far offset but fail in the near offset. Radon transform also fail to attenuate multiple at steep slope and the strong surface multiple. This method reduced multiple with distortion (reducing quality) in the primary reflector, so that the continuity becomes low. Conversely, multiple attenuation with SRME successfully applied to all short-offset seismic lines. It can attenuate multiple better than Radon Transform method and keep the primary reflector intact with high continuity.

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