Vz Noise Attenuation Using Dual-Tree Complex Wavelet Transform

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Summary

In ocean bottom seismic data, vertical components are frequently contaminated by converted shear waves due to the scattering in the shallow seabed. Proper removal of this energy is an important step in ocean bottom node processing because it can affect the P/Z wavefield separation to up- and down-going wavefields, using for example P/Z calibration and summation, and the subsequent processing results. This paper proposes the use of the dual-tree complex wavelet transform to attenuate the geophone noise, using a P/Z amplitude ratio thresholding approach. In this multi-dimensional domain with data being decomposed into different wavelet levels and orientations, the signal and noise separation is efficiently handled. This paper will describe the proposed method, compare it with a similar method in the curvelet domain and demonstrate it in a real data example.

Introduction

Ocean Bottom Node (OBN) and Ocean Bottom Cable (OBC) are technologies that record four component wavefield, the scalar pressure wavefield P, and three directional components (X, Y, Z). More specifically, hydrophone and vertical geophone data are usually combined with P/Z calibration and summation, which are essential steps to separate up-going and down-going wavefields. After wavefield separation, the receiver side ghosts are attenuated. A subsequent deconvolution of the up and downgoing wavefields attenuates the free surface multiples. However, contrary to the hydrophone, the vertical geophone component data is contaminated with noise of different origins, among them the Vz noise is probably the most prominent. The origin of this noise is still not very well known. One of the few studies that has investigated it is by Paffenholz et al. (2006a, 2006b) who suggested they arise from compressional wave scattering in the shallow subsurface. Removing such strong noise on the Z component would be the first important and crucial step in the OBN/OBC processing. For example, P/Z calibration using the cross-ghosting method (Soubaras, 1996) uses a long data record after the seismic source duration to derive the calibration function; the contamination of records by Vz noise would compromise the quality of the calibration. The same consequence would apply to up/down deconvolution which requires data being as clean of noise as possible.

Many methods have been proposed for Vz noise removal. Although differing in detail, all of them have the same goal, i.e., representing the data in a domain where signal and noise can be more easily distinguished. Shatilo et al. (2004) used the F-K domain with a dip filter to isolate signal and noise using common receiver records. Because the P component is usually free from the Vz noise, most of studies use it to guide the denoising of the Z component. Craft and Paffenholz (2007) looked at the problem in Tau-p domain using a method of envelope ratio scaling between P and Z components for simultaneous geophone noise attenuation and up-down wavefield separation. Poole et al. (2012) considered a similar approach in sparse tau-P domain that used P and down-going wavefield, so a fairly accurate P/Z calibration should be done beforehand.

The complex wavelet domain is another attractive domain that has been used in several studies to tackle Vz noise removal. Yu et al. (2001) proposed a local attribute matching filtering based on amplitude envelope of P and Z in 2D dual-tree complex wavelet domain (DTCWT). Peng et al. (2013) developed the method further with a high angular resolution complex wavelet transform for simultaneous P/Z matching and Vz attenuation. However, we believe that the two need to be treated separately because the P/Z matching for the up/down-going wavefield separation requires a more elaborated calibration step. Just matching the amplitude (envelope) of P and Z components may create over-corrections in the deghosting and demultiple steps. We present in this paper the use of DTCWT to attenuate the geophone noise with a P/Z amplitude ratio thresholding method and demonstrate its effectiveness for Vz noise removal in real seismic data. Our results will also be compared with those derived from Vz denoise in the curvelet domain.

Z-Phone Denoise in DTCWT Domain

The dual-tree complex wavelet transform (DTCWT) has been developed as an enhancement to the discrete wavelet transform (Selesnick et al., 2005). The DTCWT possesses several important properties that fit well for seismic data denoising: e.g., nearly smooth, non-oscillating magnitude,

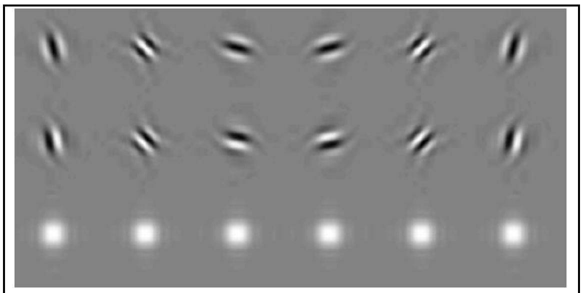

Figure 1: Wavelets associated with the 2-D dual-tree complex wavelet transform. Top and Middle: Wavelets for the real part and imaginary part of each complex wavelet, respectively. Bottom: Magnitude of the wavelets.

nearly shift-invariant magnitude, direction selective, and anti-aliasing. As shown in Figure 1, each scale of the DTCWT consists of real and imaginary components with each of them having six directions: ±15˚, ±45˚, ±75˚; this enables flexibility in the signal/noise handling in the wavelet domain. Because of the smoothly varying and nearly shift-invariant magnitude of its coefficients (Figure 1, bottom), the denoise operation will have minimum artefacts compared to the real wavelet domain.

The workflow we propose for Vz noise removal in DTCWT is as follows:

1) Use DTCWT to transform the P and Z data from T-X to wavelet domain;
2) Compute P/Z amplitude ratio in wavelet domain;
3) Use the thresholding approach on P/Z amplitude ratio for selecting wavelet components of Z data;
4) Use inverse DTCWT to transform denoised Z data back to T-X domain.

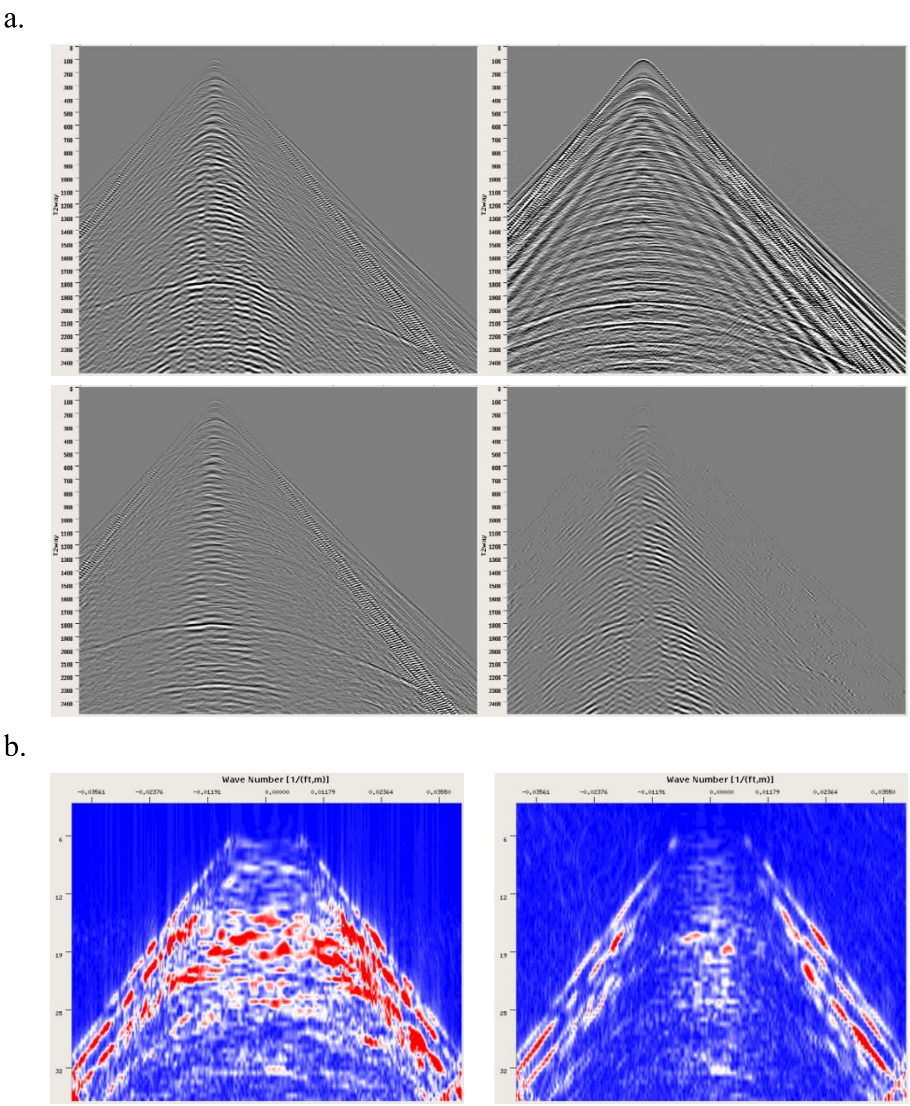

Figure 2: a): A receiver gather for a single shot-line of vertical geophone component before denoise (top left) and the corresponding hydrophone component (top right). Same vertical geophone gather after Vz noise removal (bottom left) and the removed Vz noise (bottom right). b): F-K transform of the same gather of vertical geophone component before (left) and after (right) the Vz noise attenuation.

Examples

In order to verify the performance of the methodology, we have applied our method on a real ocean bottom node dataset. The dataset presented in this paper is from the Utsira OBN survey in the North Sea, acquired in 2018-19. Figure 2 shows an illustration of Vz noise attenuation using DTCWT applied on a receiver gather of an example line from the Utsira project. Visual observations show that the hydrophone component is clean and free of Vz noise whereas, these are strongly present on the vertical geophone. The noise can be seen mainly at low frequencies between 12-30 Hz and across a broad range of wavenumbers, as such, some reflection events can be badly contaminated, as demonstrated in the F-K plots (Figure 2b, left). We show here, from the comparison between the vertical geophone data before and after applying the denoise in DTCWT domain, that the Vz noise has been significantly reduced with our method. Figure 2a shows that the reflection events on Vz component can be well recovered with little primary damage (Figure 2a, bottom right), and their curvatures are now more comparable to those of on P component.

The consistency and effectiveness of the method is further tested on one whole receiver line, which is then stacked. Figure 3a-top left shows a receiver line section of the vertical geophone stack, where the Vz noise contamination is so strong that reflection events are barely visible. It is highly possible that, for data with such noise contamination, P/Z calibration using the cross-ghosting approach could fail to derive a reliable calibration function, as such, the quality of the data after subsequent processing steps would be affected. After application of our method for Vz noise, the stack section for the vertical geophone has now become more comparable to that of the hydrophone component in terms of structural characteristics (Figure 3 top right and 3 bottom left). The removed Vz noise (Figure 3, bottom right) shows that although there is some signal left in the noise section (Figure 3 – areas with red arrows), this damage was quite limited.

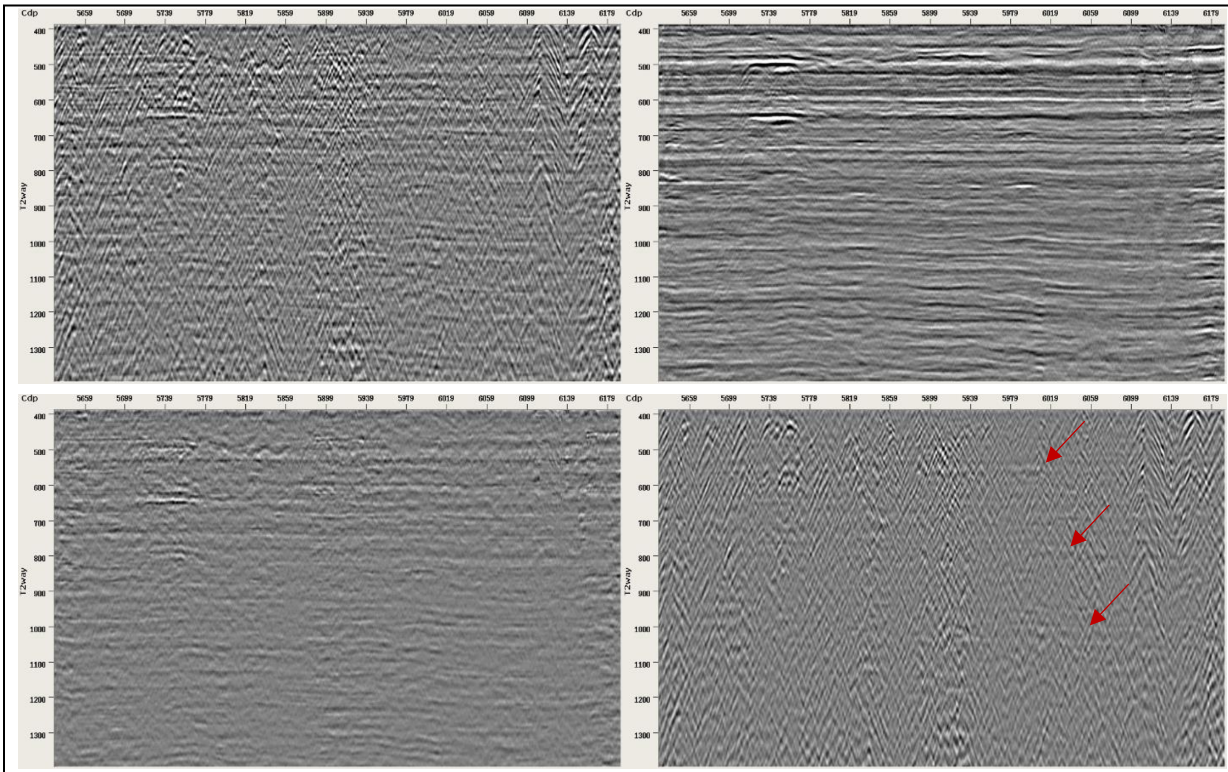

Figure 3: An example sub-section of a receiver line stack for a vertical geophone before Vz denoise (top left) and the corresponding hydrophone component (top right). Same receiver line stack after Vz denoise (bottom left) and the Vz noise that has been removed (bottom right).

Comparison with Vz Denoise in Curvelet Domain

The examples of applications on real data presented previously, have shown the effectiveness of the DTCWT in attenuating the Vz noise on vertical geophones, despite of having only six directional components in the wavelet domain. It is legitime to question whether using other more sophisticated domains such as the curvelet domain could be beneficial for the denoise application, because more wavelet directions are available in the decomposition. We have recently developed a similar approach using the curvelet domain for Vz noise attenuation (C.H. Yang, personal communication., March 2020), where additional dip information could be explored. Figure 4 shows a comparison of vertical geophone records after Vz noise attenuation using the DTCWT and curvelet transform domains. One can see that both methods yield comparable results, although the curvelet method appears to be handling the signal/noise separation a little bit more "gently", e.g., in preserving the signal (Figure 4, as indicated by red arrows). But overall, the DTCWT method compares well to the curvelet method both in terms of quality and computational requirements, which is sometimes crucial for projects with huge amounts of data.

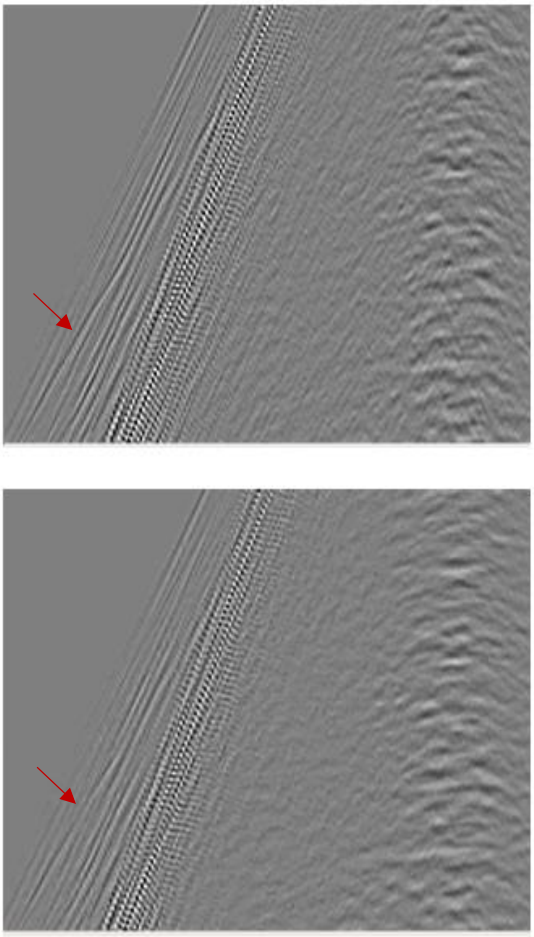

Figure 4: a): Top) A shot-line gather of vertical geophone component after denoise using curvelet transform. Bottom) Same gather of vertical geophone component after denoise using DTCWT. Red arrow shows some area where curvelet method is outperforming the DTCWT method.

Conclusions

We have presented a method of Vz attenuation for vertical geophones using a dual-tree complex wavelet transform for a sparse representation of signal/noise. Applying our approach to a real OBN dataset demonstrates that the DTCWT successfully attenuates vertical component geophone noise, while well preserving signal in the data. Vz noise attenuation using DTCWT offers a unique combination of strong noise attenuation characteristics at a relatively low computational cost. This combination is critical in an industry, where the survey size and data volumes are growing quickly and the computation resources are struggling to keep up. However, more future works could be investigated in order to decrease the primary leakage, such a two pass DTCWT denoise approach, e.g., a first pass with a mild thresholding using P and Z components before P/Z calibration and a second pass using P, up and downgoing wavefields. When efficiency is not the main concern, another way forward to improve the quality could be to use the curvelet domain as a first pass and DTCWT as a second pass. Careful Vz noise attenuation enables the use of vertical geophone records in conjunction with hydrophone records, which in turn facilitates demultiple and deghosting. Thereby, state-of-the-art Vz attenuation is critical in the delivery of superior imaging products for ocean bottom data.

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