Efficient Vz noise suppression by seismic polarization analysis of 6C seabed data

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Summary

We acquired data from a North Sea seabed seismic test measured by a 6-degree-of-freedom (6-DOF) sensor that provides three translational measurements (acceleration) along three axes and three rotational measurements of the angular motion of a particle about the axis. Portions of seismic records containing P, S and surface waves have different polarization motion patterns: linear, elliptical, or spherical and multiple energy arrivals can be present in a single seismic record. We applied polarization analysis to 6-C data to estimate elliptically polarized events and filter them out from the vertical component data. The proposed filtering process allows for the detection and separation of seismic events, even if they are not of a pure state. Our results show that polarization analysis of 6-C data can, with optimized scaling and thresholding, successfully reduce surface waves and other events with elliptical particle motion polarization from the vertical component record. We demonstrate that direct measurements of the rotational energy help to overcome multiple arrivals problem in the polarization analysis.

Introduction

Particle motion polarization provides information about phases in multicomponent seismic signals. Portions of seismic records containing P, S and surface waves have different polarization motion patterns: linear, elliptical, or spherical. Simple polarization analysis involves rotating data into different components to estimate polarization direction, more sophisticated methods use matrix analysis to estimate polarization status of seismic arrivals. However, issues arise when multiple energy arrivals are present, the polarization vector is not able to point on either arrival. In this paper we show that direct measurements of the rotational energy help to overcome multiple arrivals problem in the polarization analysis. Results from a North Sea seabed seismic test, incorporation a rotation sensor, demonstrate that this approach can successfully reduce surface waves and other events with elliptical polarization in the vertical component records.

Method

The 6-C data used in the study is acquired by a 6-degree-of-freedom (6-DOF) sensor that measures three translational measurements (acceleration) along three axes and three rotational measurements of the angular motion of a particle about the axis (Pedersen et al., 2023). In the polarization analysis we search for an eigen-solution of the correlation matrix, following Vidale (1986) and Greenhalgh et al. (2005) for 3-C data and Sollberger et al. (2017) for 6-C data.

To overcome the multi-arrival problem, we selected only four data components: translational vertical acceleration $\ddot{U}_z$ and three rotational components R_x, R_y, R_z to define the polarization vector in the ZXY plane with respect to contributions from rotation measurements to the vertical. The rotational acceleration measurements were transformed to velocities and scaled with apparent horizontal slowness $1/c_X$ to make translational and rotational records comparable. Each component of the correlation matrix is formed by taking the outer product of the signal vector $\vec{D} = [\ddot{U}_z, R_x, R_y, R_z]$ with itself and average it over a time window. We use S-transform to decompose analytical signals, formed by multicomponent records using Hilbert transform, to time-frequency plane and solve eigen problem, convolving the result with an averaging operator $W(\Delta\tau, \Delta f)$ in the time-frequency domain ($\Delta\tau \approx 0.250$s).

$$C(\tau, f) = W(\Delta\tau, \Delta f) * \tilde{\tilde{\vec{D}}}(\tau, f)\tilde{\tilde{\vec{D}}}(\tau, f)^H \qquad [C - \lambda_i I]\begin{bmatrix} V_{1i} \\ V_{2i} \\ V_{3i} \\ V_{4i} \end{bmatrix} = 0 \quad i = 1,2,3,4$$

The four eigenvalues and four eigenvectors $[V_{1i}, V_{2,i}, V_{3i}, V_{4,i}]$ are computed in each time-frequency window. The strongest eigenvalue provides an estimate of the main polarization vector.

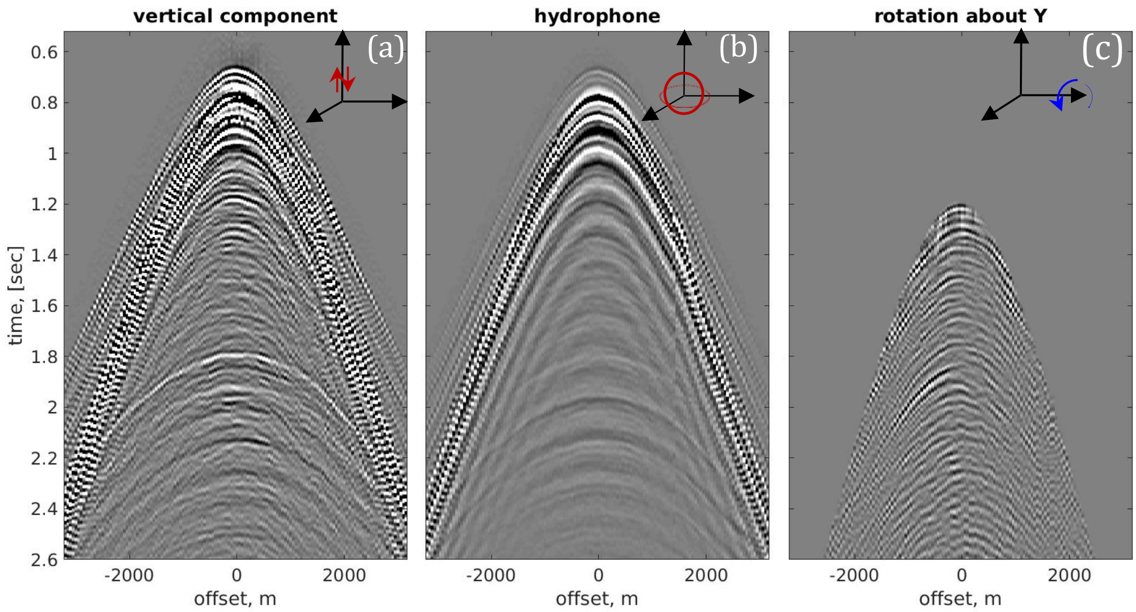

Figure 1: *Data from Ksphere: vertical translational component (a), hydrophone record (b), one of the rotational components, about Y axis (c).*

We use polarization vector to differentiate between rectilinear waveforms and elliptically polarized waveforms. Ellipticity is calculated as a ratio of imaginary and real parts of the polarization vector. A filtering process is applied to the input vertical component in the time-frequency domain to filter out events with high ellipticity degree but without isolating specific type of events (Figure 2).

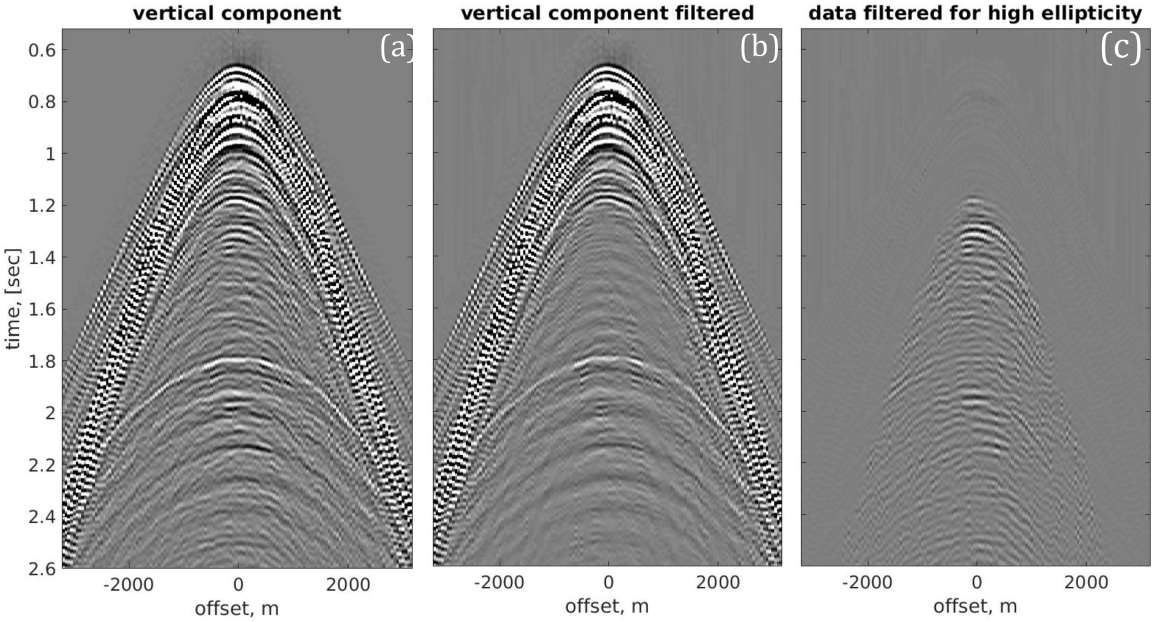

Figure 2: *Data from Ksphere vertical acceleration (a) and (b) filtered for high ellipticity in polarization vector in each time-frequency window. (c) extracted elliptically polarized waveforms identified in the polarization analysis using 3 rotational components.*

Results and Conclusions

We applied polarization analysis to 6-C data to estimate elliptically polarized events and filter them out from the vertical component data. The results show that polarization analysis of 6-C data can, with optimized scaling and thresholding, successfully reduce surface waves and other events with elliptical particle motion polarization from the vertical component record. The proposed filtering process, based on polarization analysis, allows for the detection and separation of seismic events, even if they are not of a pure state. The study concludes that using selected components for polarization analysis helps focus the rotational contributions and better estimate the polarization vector.

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