

TRIPLE SENSOR WAVEFIELD SEPARATION

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Summary

A method is described of identifying different wave modes recorded by ocean bottom multi-component detectors. Vertical geophone, horizontal geophone, and hydrophone data are combined to form filters which, when applied to the input wavefields, separate the upgoing P-waves, upgoing S-wave and downgoing P-waves.

Introduction

Four component ocean bottom hardware consists of three orthogonal geophones and a hydrophone. This allows for the recording of compressional as well as shear energy. Shear energy, mode converted from the compressional energy upon reflection, provides additional information about the subsurface. Benefits of mode-converted seismic include:

- i) the enhanced delineation of reservoirs (MacLeod et al., 1998)
- ii) the illumination of reservoirs beneath gas clouds (Thomsen et al., 1997)
- iii) the imaging of steeply dipping structures (Zhu et al., 1999)

The success of the multi-component method depends on our ability to identify and extract the various modes present in the recorded wavefield. In particular, it is necessary to discriminate between the faster P-P and the slower P-S modes. Ordinarily, velocity analysis is a good discriminator between these modes, but is oftentimes made difficult by the presence of water column reverberations.

The elimination of water column multiples can be achieved by combining the hydrophone and vertical geophone data. This method, introduced by Barr and Sanders (1989), and sometimes referred to as the dual sensor method, is used widely and in a variety of forms.

In this paper we describe the *triple sensor* method which combines:

- i) **V**: the vertical component of the wavefield recorded by the 3-C geophone;
- ii) **R**: the horizontal (or radial, source-receiver plane) component of the wavefield;
- iii) **H**: hydrophone data

to form three mask traces which when applied to the components V, R, and H, identify the modes P^{up} , S^{up} , and P^{down} in each of the components.

Method

The triple sensor method is based on the sign of the recorded amplitudes only. Referring to Figures 1a-1c, we use the following sign convention for the geophone data: upgoing movement of the vertical geophone is a positive number, downgoing movement is a negative number, movement to the right (in the horizontal plane) is positive, and movement to the left is negative. For the hydrophone we define a compression as a positive number, and a rarefaction as a negative number.

An upgoing P-wave (Figure 1a) will produce a geophone response whose vector sum will be in quadrants 1 or 3. Similarly, an upgoing S-wave (Figure 1b) will produce a geophone response whose vector sum is

in quadrants 2 and 4. It is not true to say, however, that a response in quadrants 2 and 4 implies an S-wave mode of propagation. A downgoing P-wave, either in the form of a direct arrival or water column reverberation will produce a geophone response whose vector sum is in the same quadrants (2 or 4).

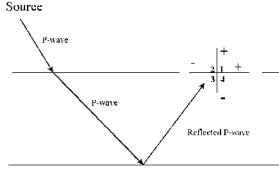


Figure 1a. A reflected upgoing P-wavefield will have geophone vector response in either quadrants 1 or 3.

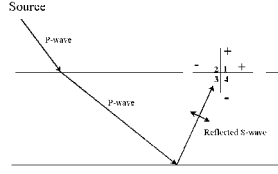


Figure 1b. A reflected upgoing S-wavefield will have geophone vector response in either quadrants 2 or 4.

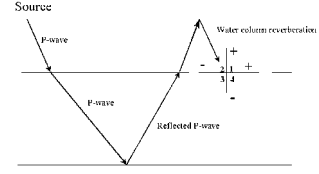


Figure 1c. A water column reverberation (source side) will have geophone vector response in either quadrants 2 or 4.

By combining these geophone vector response with the response of the hydrophone, we are able to distinguish between modes. In Table 1 the possible combinations of signs of each component are tabulated. For each set of input traces (V, R, and H), we compute (sample by sample) the products $\chi = \text{sign}(V) * \text{sign}(R)$ and $\alpha = \text{sign}(V) * \text{sign}(H)$.

$$P^{\text{up}} = \frac{1}{4}(1 + \alpha)(1 + \chi) \dots \dots \dots (1)$$

$$S^{\text{up}} = \frac{1}{4}(1 + \alpha)(1 - \chi) \dots \dots \dots (2)$$

$$P^{\text{down}} = \frac{1}{2}(1 - \alpha) \dots \dots \dots (3)$$

χ and α will assume the value of either +1 or -1. The mask traces P^{up} , S^{up} , and P^{down} are computed using equations (1), (2), and (3), and then applied multiplicatively to the input data V, R, and H.

V	R	H	$\chi = V * R$	$\alpha = V * H$	P^{up} Eq. 1	S^{up} Eq. 2	P^{down} Eq. 3
+	+	+	+	+	1	0	0
-	-	-	+	+	1	0	0
+	-	+	-	+	0	1	0
-	+	-	-	+	0	1	0
+	+	-	+	-	0	0	1
-	-	+	+	-	0	0	1
+	-	-	-	-	0	0	1
-	+	+	-	-	0	0	1

Table 1. Possible combinations of amplitude sign of components Vertical, Radial, and Hydrophone. P^{up} , S^{up} , or P^{down} form the mask traces.

Example

Using a full elastic modelling program (including water column reverberations), a hydrophone shot record, a vertical geophone shot record, and a horizontal (radial) geophone shot record were generated. These are shown in the first panel in each of Figures 2a, 2b, and 2c. The mask traces were then computed from these records using equations (1),(2) and(3), and then applied to the input records to produce the decomposed wavefields. Panels (ii), (iii), and (iv) of Figures 2a, 2b, and 2c correspond to the upgoing P-wavefield, upgoing S-wavefield, and downgoing P-wavefield respectively.

The method clearly identifies and extracts the three modes. P^{up} , S^{up} , and P^{down} from the total wavefields. The water column reverberations are isolated in the downgoing P-wavefield, and the the upgoing P- and upgoing S-wavefields are separated.

Since the amplitude of the mask trace is either 0 or 1, waveforms in the output can be truncated. So while the method is not amplitude preserving, it can be used to identify and isolate the different modes during processes such as velocity analysis.

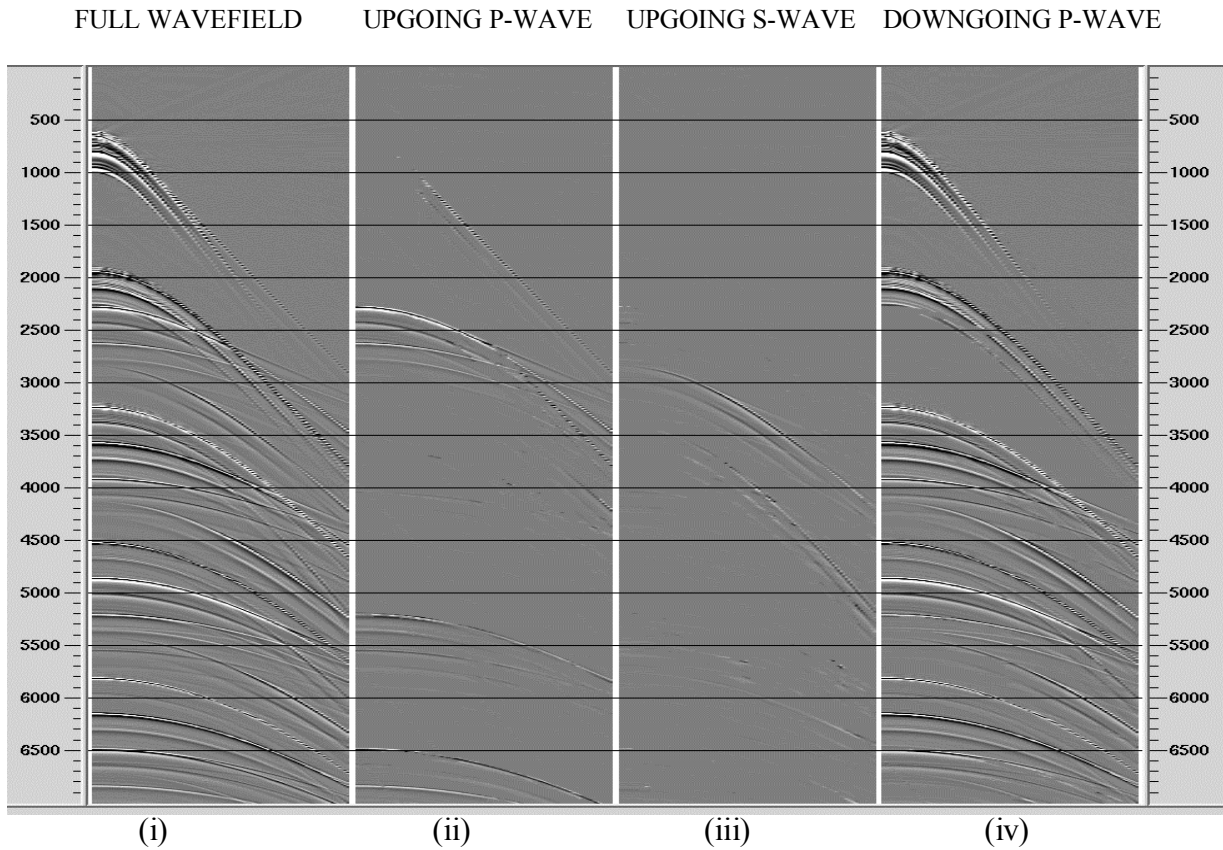


Figure 2a. Hydrophone data, full wavefield (i). Wavefield separation has been applied to separate the upgoing P-waves (ii), the upgoing S-waves (iii), and the downgoing P-wave (iv).

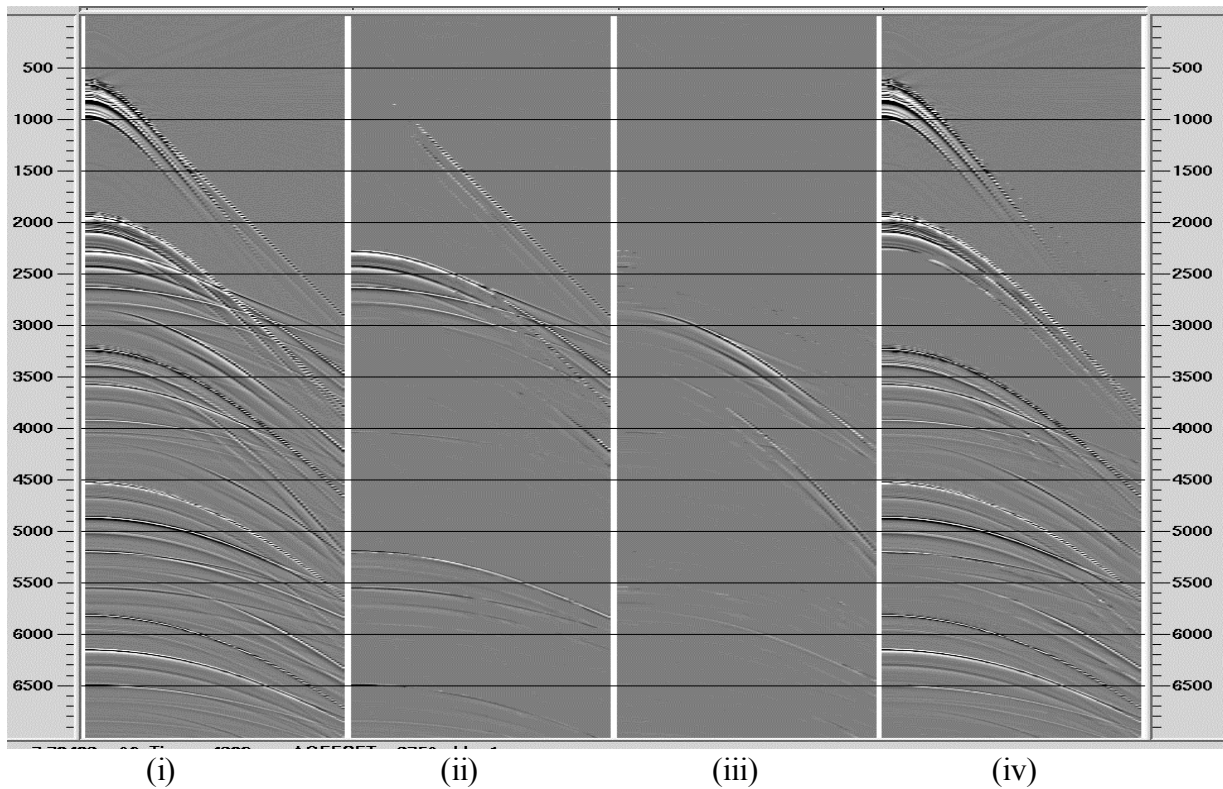


Figure 2b. Vertical Geophone, full wavefield (i). Wavefield separation has been applied to separate the upgoing P-waves (ii), the upgoing S-waves (iii), and the downgoing P-wave (iv).

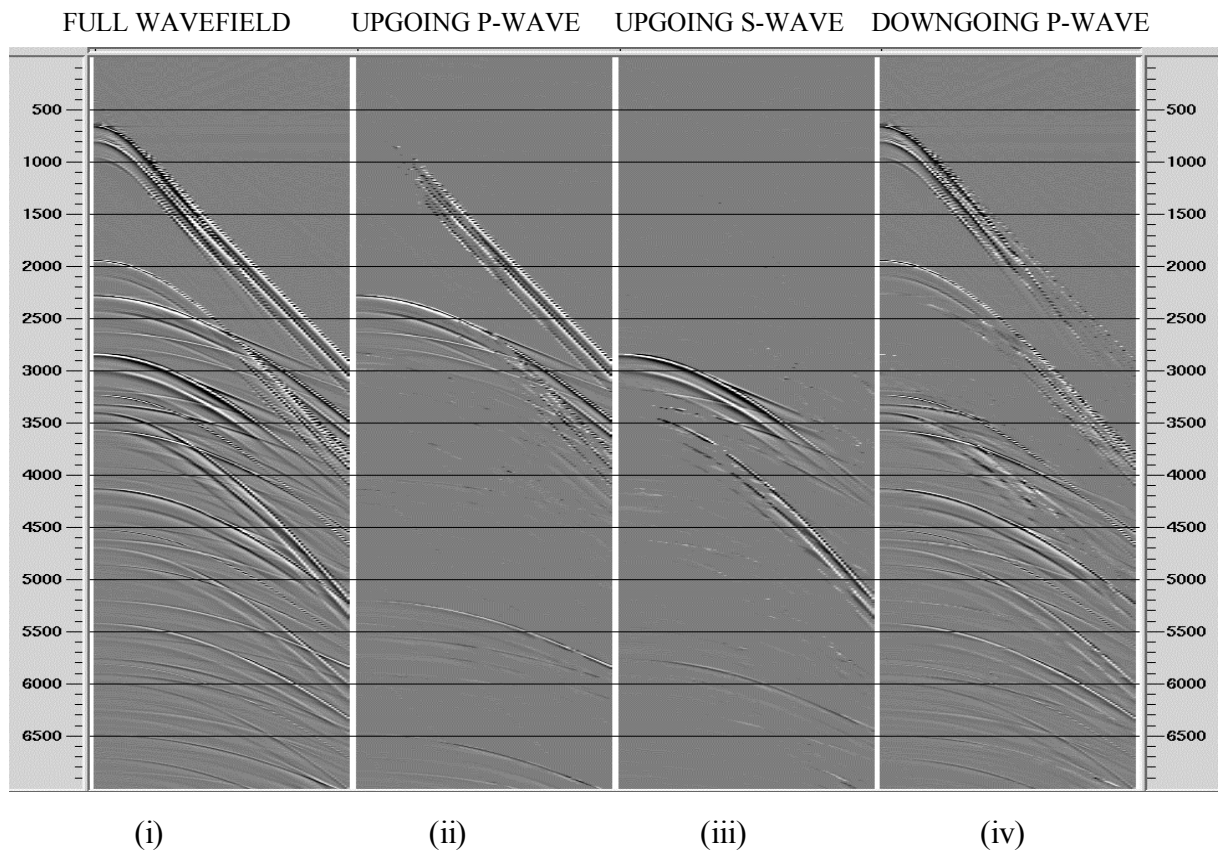


Figure 2c. Radial (horizontal) geophone, full wavefield (i). Wavefield separation has been applied to separate the upgoing P-waves (ii), the upgoing S-waves (iii), and the downgoing P-wave (iv).

Conclusion

We have presented a method that is capable of identifying and isolating the propagation modes in a multi-component wavefield. The method has application prior to velocity analysis, particularly of the radial component, where there is often ambiguity between mode converted S-wave energy and reverberating P-wave energy.

References

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