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Wavefield decomposition of multi-component OBS data to enhance the seismic signal

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ABSTRACT
The multi-component Ocean Bottom Seismometer (OBS) data captures full wave field by recording on three component geophone and one hydrophone. However, the resultant seismogram includes the free surface multiples that interfere with the recorded wavefield, which has to be removed for further processing. We find that PZ summation, along with the up/down deconvolution is very effective in removing them and renders the multiple-free wavefield. The method is illustrated here, using the OBS data acquired in the Mahanadi basin. In addition to the noise free P wave field, we also obtain the converted (PS) wave field using this approach.

Key words: OBS data, free surface multiples, converted waves, wavefield separation, PP & PS.

INTRODUCTION

Ocean Bottom Seismometer (OBS) instruments are being increasingly used in the hydrocarbon industry and academia so as to maximize the chances of precise identification of resources and in delineation of the crustal structure in most challenging environments. The biggest advantage of using the OBS nodes is that they can record on four components (hydrophone and a three component geophone), which can capture the full wavefield. Each OBS node contains one three 3 (Z,X,Y) component geophone and one hydrophone (P). The geophone records compressional wave on its vertical (Z) component and the converted wave on the two horizontal orthogonal (X,Y) components, while the hydrophone (P) records the pressure pulse data. Conventionally, seismic data is acquired by using surface towed streamers and the P-wave data thus generated is used in imaging the sub surface to a reasonable extent. However, such data has inherent limitations, like, lack of near offsets, no information about the shear waves, imaging problems for the near seafloor geology, acquisition in presence of sea bottom obstructions like pipelines, platforms etc. Multi-component OBS data offers an excellent alternative to handle these issues as the instruments record compressional, converted and pressure wave data that can be used to detect hydrocarbon formations more precisely. The shallow sediments have low rigidity and the vertical resolution available from PS data can be higher than the PP data. It is also noteworthy that the small changes in the rigidity can cause large fractional changes in the shear impedance but only small changes in the compressional impedance, and hence the PS data can contribute greatly in tracing the changes in rigidity, i.e., in detecting the changes that occur due to the changes in saturation, although the information will not help in establishing the composition of the fluid. However, the main difficulty with the OBS data is that it is contaminated by the surface related multiples to a considerable extent. The data recorded on the OBS includes free surface multiples, in addition to the general multiples that interfere with the recorded wavefield. Removal of the surface related multiples (to have noise-free recorded wavefield) is one of the most important processing steps to be performed before carrying out any processing routines and arriving at a meaningful interpretation. The OBS data collected in Mahanadi basin is presented in this manuscript to demonstrate the efficacy of the wave field decomposition and its utility in suppressing the multiples.

THEORY

The multiples, which are the major contributors to the total recorded wave field can be divided into two components, the receiver side and the source side multiples, shown in Figure 1. As the name itself explains, the receiver side multiples comprises of the receiver ghosts i.e., those events that are reflected from the subsurface, bounce off the seafloor and get recorded at the receiver. The source-side multiples are the reflections that are caused due to the source-ghosts, i.e., the source signal is first reflected off the seafloor and then hits the subsurface, gets reflected and then is recorded at the receiver.

The hydrophone sensors in the OBS are pressure sensitive, while the geophones are displacement sensors, i.e., sensitive to the particle motion and direction. The hydrophone (pressure) data is a scalar measurement and is not dependent on the direction of the particle motion, while the geophone (displacement) data is a vector measurement, and is dependent on the direction of the particle motion.

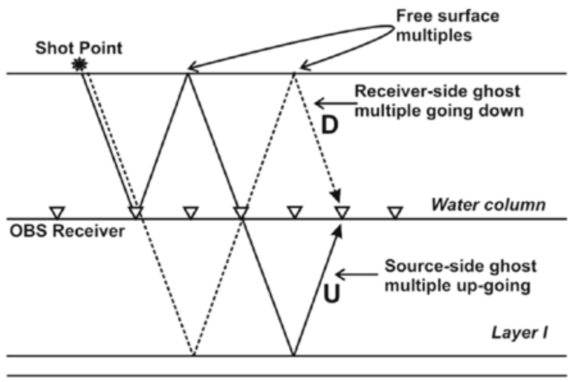

Figure 1. A schematic diagram showing the source-OBS configuration in a marine setting, along with the up-going and down-going waves and their travel paths.

The vertical geophone (Z) and hydrophone (P), present in the same OBS setup, therefore, record the multiple signals with opposite polarity and this can be used to attenuate the noise effectively and hence, a simple addition of the data on vertical (Z) component with the data on hydrophone (P) component can result in elimination of the free surface multiples. Following the approach of Backus et al (2012), and the sensor responses explained therein, the hydrophone response (P) and vertical response can be combined to create upgoing (U) wavefield and downgoing (D) wavefield as shown below, expressed in frequency domain:

$$D=P+Z/\cos(\phi) \quad (1)$$

$$U=P-Z/\cos(\phi) \quad (2)$$

where, ϕ is the angle of incidence.

However, the PZ summation requires that the datasets (P&Z) be calibrated to provide same response to up-travelling wave. This calibration is achieved either by applying a constant gain (Backus et al, 2006) or by using a calibration filter (Haines et al, 2010). This technique is popularly called as PZ summation (Barr and Sanders, 1989; Backus et al, 2006; Haines et al, 2011) and is very effective in attenuating all the "receiver side" multiple energy i.e, the energy which is down-going at the receiver location.

Having removed the receiver-side multiples, we are now left with the "source-side" multiples, which are not down-going at the receiver and are not attenuated by conventional PZ summation. These multiples can be attenuated by deconvolution of the down-going waves from the up-going waves. Fundamentally, the recorded wavefield is a combination (convolution) of the down-going wavefield and the earth's reflectivity and therefore a simple deconvolution of the down-going wavefield from the up-going wavefield would result in retrieval of earth's reflectivity. The up-going wavefield in a simple layered medium can be represented as,

$$U=DR \quad (3)$$

From the above equation, it follows that

$$R=U/D+\xi \quad (4)$$

where ξ is the stabilization factor.

Isolation of the PS wavefield can also be attempted using the same technique except that in this case the down-going wavefield has to be deconvolved with the horizontal component that records the maximum converted energy i.e., radial (R) component of the OBS data. Similar to the earlier case the calibration has to be carried out in this case also.

DATA AND METHODOLOGY

The OBS data used in this study was acquired in the Mahanadi offshore region during the year 2010 on board M/V Akademik Fersman. The shot spacing is 25m and the water depth is 2000m. Data up to 6sec with a sampling interval of 4ms is used here. The total shooting length is ~12km, with a maximum offset of 6km either side of the OBS. The data have been rotated from Z,X,Y components to the vertical , radial and transverse (Z,R,T) components and after the rotation, the maximum of the converted energy shifts to the radial, leaving little or no energy on the transverse component (Satyavani et al., 2013). Simple data processing was applied to the data so that the seismic amplitudes are not affected to a large extent. The steps include true amplitude recovery and a band pass filter in the range of 5-15-80-90Hz. The data was then flattened with respect to seafloor, as shown in Figure 2.

Prior to up/down separation, the data was calibrated so that the P and Z components of data have the same frequency response. In the present case, this calibration was achieved by applying a constant gain factor. From the calibrated data, the up-going and down- going fields are obtained using the equation 1 and equation 2. The angle of incidence (ϕ) is computed from the trace offset and OBS deployment depth. The data thus obtained is shown in Figure 3a and 3b. For display purposes, the data have been statically shifted and the seafloor is aligned at near zero

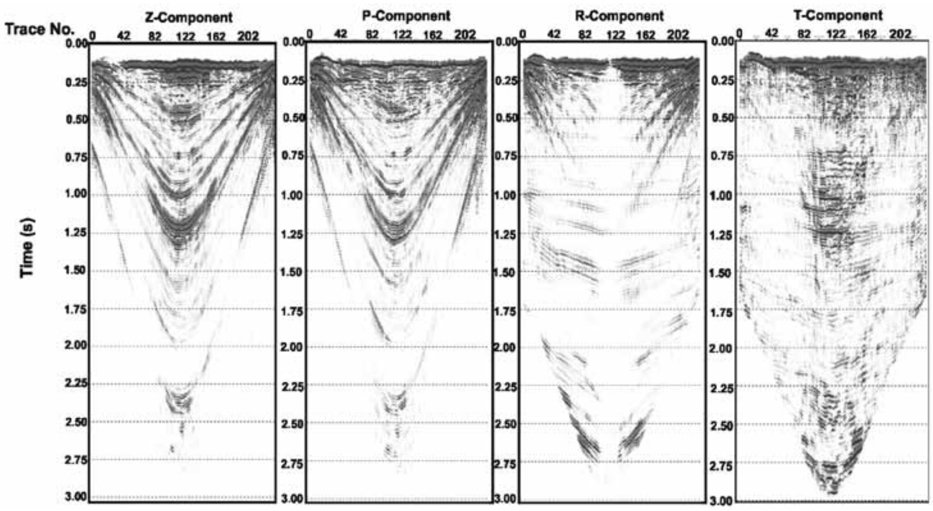

Figure 2. The OBS data acquired in the Mahanadi basin. The vertical (Z) component, the hydrophone (P) component data are retrieved from the instrument and can be treated as field data, while the radial (R) and the transverse (T) component of data are obtained by rotating the two orthogonal (X,Y) components from the field data, in such a way that the energy is maximum on the radial component.

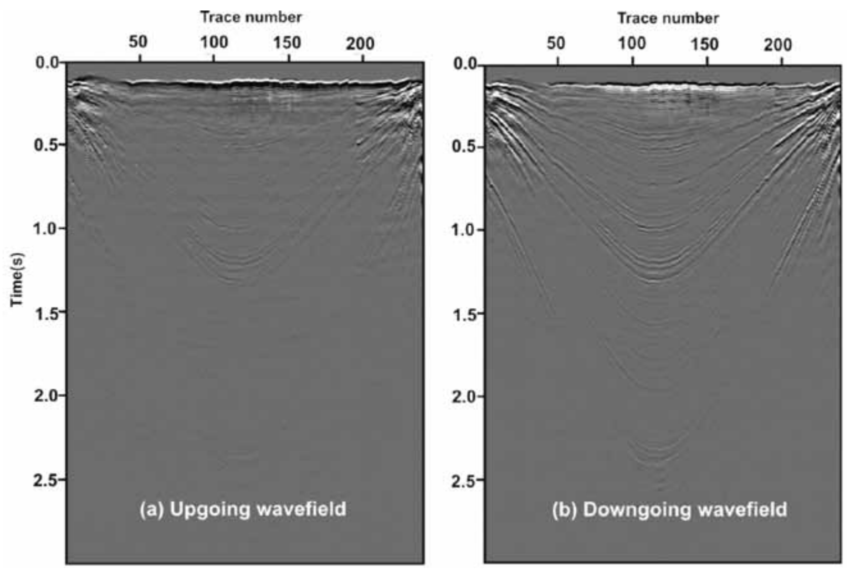

Figure 3. The result of the wave field decomposition. The recorded wavefield is decomposed into the (a) up-going wavefield and (b) down-going wavefield. The up-going wavefield is dominated by the shallow multiples, while the down-going wavefield shows the sharp down-going wavefield, which is later used in the deconvolution.

time. The down-going field shows good amount of multiple energy (seen as lines parallel to offset axis) and a feeble signature of the reflections, while the up-going wavefield shows the dominant reflection energy (seen as distinct hyperbola). The down-going P-wave generally represents the robust wavelet that changes with the receiver location and angle, which is subsequently used in the deconvolution purposes, to extract multiple-free vertical component data and more clear radial data. PZ summation is effective in removing "receiver-side" multiples. However, the "source-side" multiples still exist in the recorded data, which can be removed by up-down deconvolution.

RESULTS

The most reliable and effective way to remove the source-side multiples and extract the noise free P-wave field is to perform the up-down deconvolution. The deconvolution of the vertical component (Z) data with the down going wave field results in the retrieval of the noise-free P-wave field, which is now called as PP reflectivity. A comparison between the recorded P-wavefield and the retrieved PP reflectivity is shown in Figure 4 and the significant improvements in the data quality are highlighted. It is seen that the PP reflectivity (Figure 4a) has much clear,

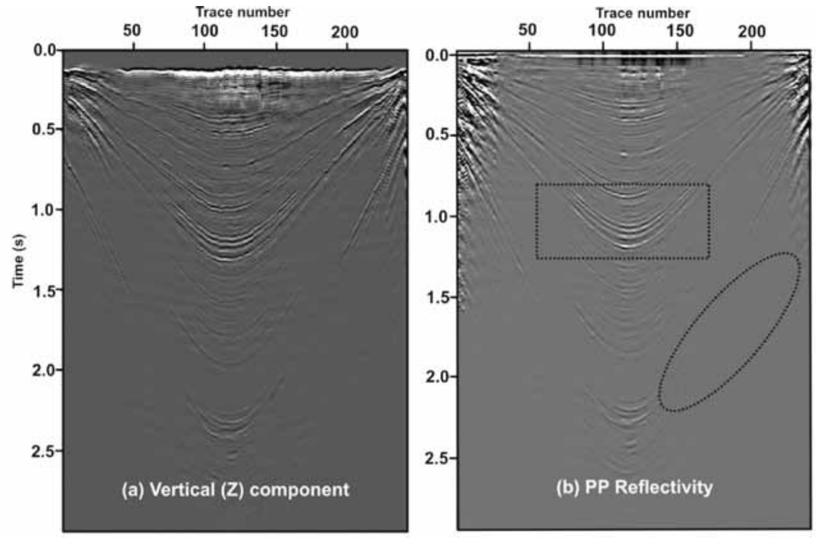

Figure 4. The result of deconvolution of the vertical component data with the downgoing wavefield. (a) shows the recorded vertical (Z) component, while (b) shows the PP reflectivity obtained as a result of deconvolution. Significant improvement in the signal resolution can be noticed in (b) and is highlighted as a dashed rectangle. The dashed oval in (b) shows the attenuation of the multiples and cleaner vision of the marked area compared to (a).

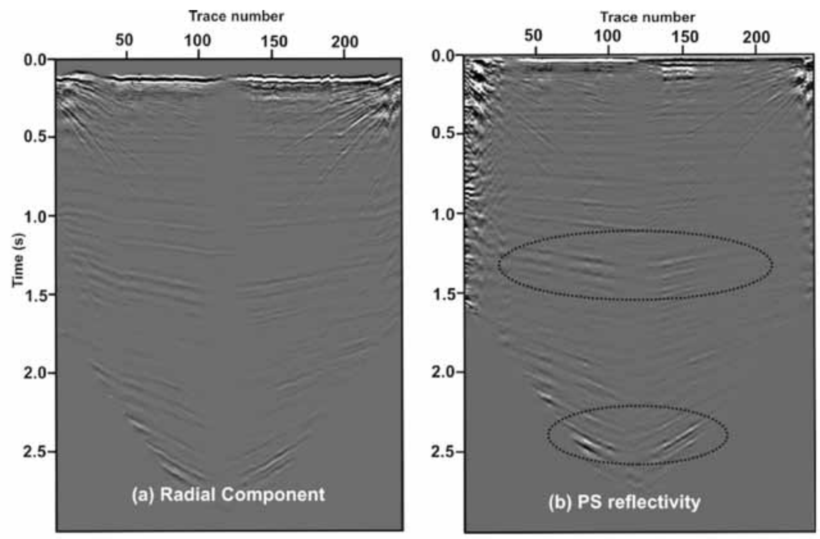

Figure 5. The result of deconvolution of the radial component data with the downgoing wavefield. (a) shows the radial (R) component, while (b) shows the PP reflectivity obtained as a result of deconvolution. Significant improvement in the signal resolution can be noticed in (b) at almost all times and is highlighted as dashed ovals.

highly resolvable PP arrivals compared to the vertical (Z) component (Figure 4b). This comparison proves that the deconvolution could effectively remove the multiple wavefield.

Similarly, the deconvolution of the radial component (R) of the data with the down-going wavefield results in the retrieval of the noise-free PS converted wavefield. Prior to the deconvolution, the radial data are to be calibrated with the down-going field so that they have the same frequency response. The deconvolution process yields the most reliable PS conversions and the deconvolved field is called PS reflectivity. A comparison between the radial component data and the down-going wave field are shown in Figure 5. The deconvolved wavefield (Figure 5b) shows a marked increase in the spatial and temporal resolution of the converted wavefield compared to the radial (R) component.

CONCLUSIONS

It may therefore, be concluded that the two tier process of PZ summation followed by up-down deconvolution is a significant step to be carried out before the processing of any multi-component dataset, especially the OBS datasets.

These steps provide very reliable, noise-free dataset, which when used in the later stages of processing, leads a consistent interpretation.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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Quotations on Imaging Ocean Bottom

"My soul is full of longing for the secret of the sea, and the heart of the great ocean sends a thrilling pulse through me."

Henry Wadsworth (1807-1882) was an American poet and educator.

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"There's nothing wrong with enjoying looking at the surface of the ocean itself, except that when you finally see what goes on underwater you realize that you've been missing the whole point of the ocean."

Dave Barry (1947--) is an American author and columnist.

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"At the bottom of the ocean is a layer of water that has never moved…"

Anne Carson (1950--) is a Canadian poet, essayist, translator and professor of Classics.

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The Ocean Stirs the heart, inspires the imagination and brings the eternal joy to the soul.

Robert Wyland (1956--) is an American artist.

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Being able to breathe underwater would be sweet. There is so much life underneath the water that we don't know about. I would love to check out the bottom of the ocean to see what's going on down there.

Cameron Bright (1993--) is a Canadian actor.