Effects of Acquisition Geometry to 3D Separated Wavefield Imaging

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SUMMARY

Separated wavefield imaging helps to improve the subsurface illumination when the towed streamer acquisition geometry is properly designed. Compared to the conventional imaging, which uses a full source wavefield generated by an impulse wavelet at the surface, the multiples imaging uses the down-going wavefield recorded at the streamers as the boundary source wavefield. Therefore, the streamer coverage, density and distribution are all crucial to make the method successful. Wide azimuth (WAZ) acquisition is important to record both the down-going (source) and up-going (receiver) wavefields. Anti-parallel shooting helps to image dipping targets of both facing and opposite to the streamer towing direction. Split-spread shooting geometry is optimum for imaging the dipping reflections of all directions. A field data NAZ survey and examples from 3D SEAM synthetics are tested to demonstrate the importance of acquisition geometry to 3D separated wavefield imaging.

Introduction

Compared to conventional migration, separated wavefield imaging using multiples produces high resolution 3D images for shallow water geology (Lu et al., 2013) and high quality images for greater depths using wide receiver arrays in deep water scenario (Lu et al. 2011). In general the method can be used for both shallow and deeper targets provided the towed streamer acquisition geometry is properly designed. The acquisition cable offset, streamer towing direction and source receiver distribution geometry are the most important factors to make the method successful.

In imaging of multiples using separated wavefields, the towed streamer cable acquisition offset determines both the source (down-going) and receiver (up-going) wavefield coverage. The broader and denser the streamer, the more complete are the extracted down-going and up-going wavefields, thereafter produce the better quality images. Single ended streamer acquisition causes a directional bias in the ability to image the multiples. For example, if a multiple generator is relatively flat, the direction of source (down-going) wavefield is mostly directed towards the cable tails. So, the multiples can illuminate small dips and also the dipping reflectors opposite to the towing direction. On the other hand, the multiples have limited ability to illuminate the dipping reflections facing the towing direction, especially when the target is deep relative to the longest offset [Figure 1A]. Anti-parallel shooting is able to help image the dipping target from the other shooting direction [Figure 1E]. The split-spread shot gather can be generated by using head-tail shooting, and is optimum for imaging the dipping reflections of all directions [Figure 1D]. By a similar argument, note that the cross-line offset of the receiver array will have a significant effect on the ability of multiples to image reflectors in the cross-line direction. A reduction in cross-line offset highly degrades or removes the ability of the multiples to image steeply dipping cross-line structures, particularly if the dipping reflectors are deep relative to the maximum cross-line offset (e.g. narrow azimuth surveys).

In this paper, a narrow azimuth (NAZ) single direction shooting field data example from East El Burullus area offshore Egypt is tested to show the effects of acquisition geometry to separated wavefield imaging. Examples of different survey designs are extracted from the 3D SEAM (SEG Advanced Modeling) synthetic sparse shooting dataset. Results from wide azimuth (WAZ) are compared to NAZ to demonstrate the importance of survey design to separated wavefield imaging.

Method

The idea of imaging sea surface related multiples as valuable information has been discussed by Berkout and Verschuur (1994) and Guitton (2002). We are using the methodology and work flow of separated wavefield imaging presented in Whitmore et al. (2010) and Lu et al. (2013).

Dual sensor acquisition is required to produce up and down-going wavefields (Carlson et al., 2007). Separated up and down-going wavefields are used for imaging of multiples. Image of primaries and image of multiples are generated from two migrations separately. In the migration step, one way wave equation extrapolator is used to propagate wavefields; followed by the deconvolution imaging condition [Equation 1] (Valenciano and Biondi, 2003; Guitton et al., 2007) to attenuate crosstalk noise. In Equation 1, I is the subsurface image; ε is a damping parameter to make the deconvolution imaging condition stable; $\langle\ \rangle_{(x,y)}$ stands for smoothing in the image space in the x, y directions.

$$I(\mathbf{x}) = \sum_{\mathbf{x}_s}\sum_{\omega} \frac{P^*_{down}(\mathbf{x},\mathbf{x}_s;\omega)P_{up}(\mathbf{x},\mathbf{x}_s;\omega)}{\langle P^*_{down}(\mathbf{x},\mathbf{x}_s;\omega)P_{down}(\mathbf{x},\mathbf{x}_s;\omega)\rangle_{(x,y)} + \varepsilon(\mathbf{x})} \qquad ---- (1)$$

Examples

The NAZ East El Burullus field data example is a dual sensor towed streamer survey of single direction shooting. The shooting boat is ahead of streamers, centered on the receiver cables, with flip-flop shooting. The ten streamer cables are 8km long and cover 1km cross-line region. Adjacent sail-lines have 500 meters overlaps. The water bottom depth of the test region is about 1.2~1.5km.

Images from primaries and from multiples up to 30Hz migration are compared in Figure 2. The inline and cross-line direction depth images are displayed from 1km to 5km from the sea surface. The depth slices are taken at 2km below the sea surface. The shallow parts of the images are comparable; dipping reflections of all directions are well imaged from both primaries and multiples. Figures 1A and 1E show how the shallow dipping targets can be imaged from either towing direction in multiples imaging. In the deeper section the image from multiples is missing the dipping reflections facing the towing direction (the dipping target inside the ovals in Figure 2). This is because either the source (down-going) or the receiver (up-going) wavefield is not recorded in the streamers. The corresponding ray diagrams are displayed in Figure 1A and Figure 1D, in which dashed lines are used to demonstrate the missing recorded wavefields. Primaries can image the dipping target using either shooting direction from shallow to deep because of the reciprocity property of primary imaging (ray diagrams are displayed in Figures 1B, 1C).

The 3D SEAM synthetic is the standard model of deep water Gulf of Mexico with the water bottom about 2km deep and total depth of 15km from the sea surface. The sparse shooting dataset (600m shot spacing) is used. A NAZ split-spread shooting example is extracted with 1km cross-line and 16km inline cable coverage. A WAZ split-spread shooting example is extracted with 8.4km cross-line and 14km inline cable coverage.

Figure 3 displays the images from the NAZ and WAZ examples out of 30Hz migration. In Figure 3, (A), (B) and (C) are the depth images in the cross-line direction from NAZ primaries, WAZ primaries and WAZ multiples. The NAZ image (A) is acceptable for parts of simple structure (sediments); however it has limited illumination of salt and subsalt regions. Both the images from WAZ primaries (B) and WAZ multiples (C) are better than image from NAZ (A). Particularly, if we look at the salt body (inside red dashed ovals), all of the complex structures are better illuminated by WAZ multiples (C) than WAZ primaries (B), including: dirty salt, salt flanks, base of salt and channel structures inside the salt body. Depth slices of the SEG logo are extracted from the bottom of the images. The "SEG" letters are poorly imaged by the NAZ primaries (D). WAZ primaries (E) do a better job to image the letters. WAZ multiples (F) illuminate the letters even better. From these examples, we say that WAZ acquisition geometry is important for both imaging of primaries and imaging of multiples. With WAZ acquisition, imaging of multiples using separated wavefields is helpful in improving the subsurface illumination.

Conclusions

In this paper, we have demonstrated the importance of acquisition geometry for separated wavefield imaging in deep water scenario. From the East El Burullus field data example, we have seen the limitation of separated wavefield imaging using NAZ single direction towed streamer data. Using the 3D SEAM synthetic sparse shooting dataset, we have shown the importance of the WAZ split-spread shooting geometry for both imaging of primaries and imaging of multiples using separated wavefields. Using the WAZ split-spread dataset, separated wavefield imaging helps to improve the subsurface illumination.

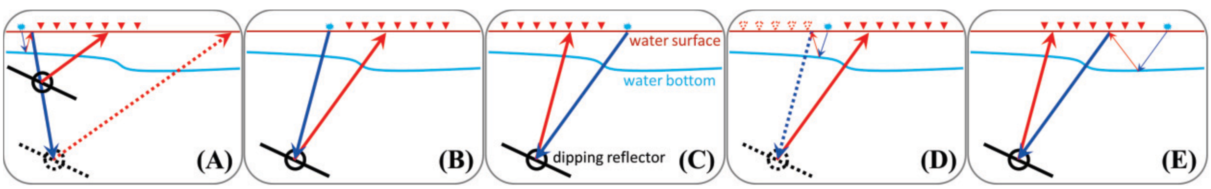

***Figure 1** schematic diagrams to illustrate effects of single direction shooting to separated wavefield imaging. (A,D,E) show ray paths of multiples imaging and (B,C) show ray paths of primaries imaging. (A) dipping reflection target facing the streamer towing direction can be imaged when both up and down-going wavefields are recorded (shallow); the target cannot be imaged if the up-going wavefield is missing recorded (deep). (B, C) imaging of primaries has reciprocity property; therefore the same dipping target can be imaged from either towing direction. (D) the dipping target can be*

imaged by using split-spread shot geometry, in which the down-going (source) and up-going (receiver) wavefields are recorded at different sides of the source location. (E) the dipping target can be imaged from the other towing direction.

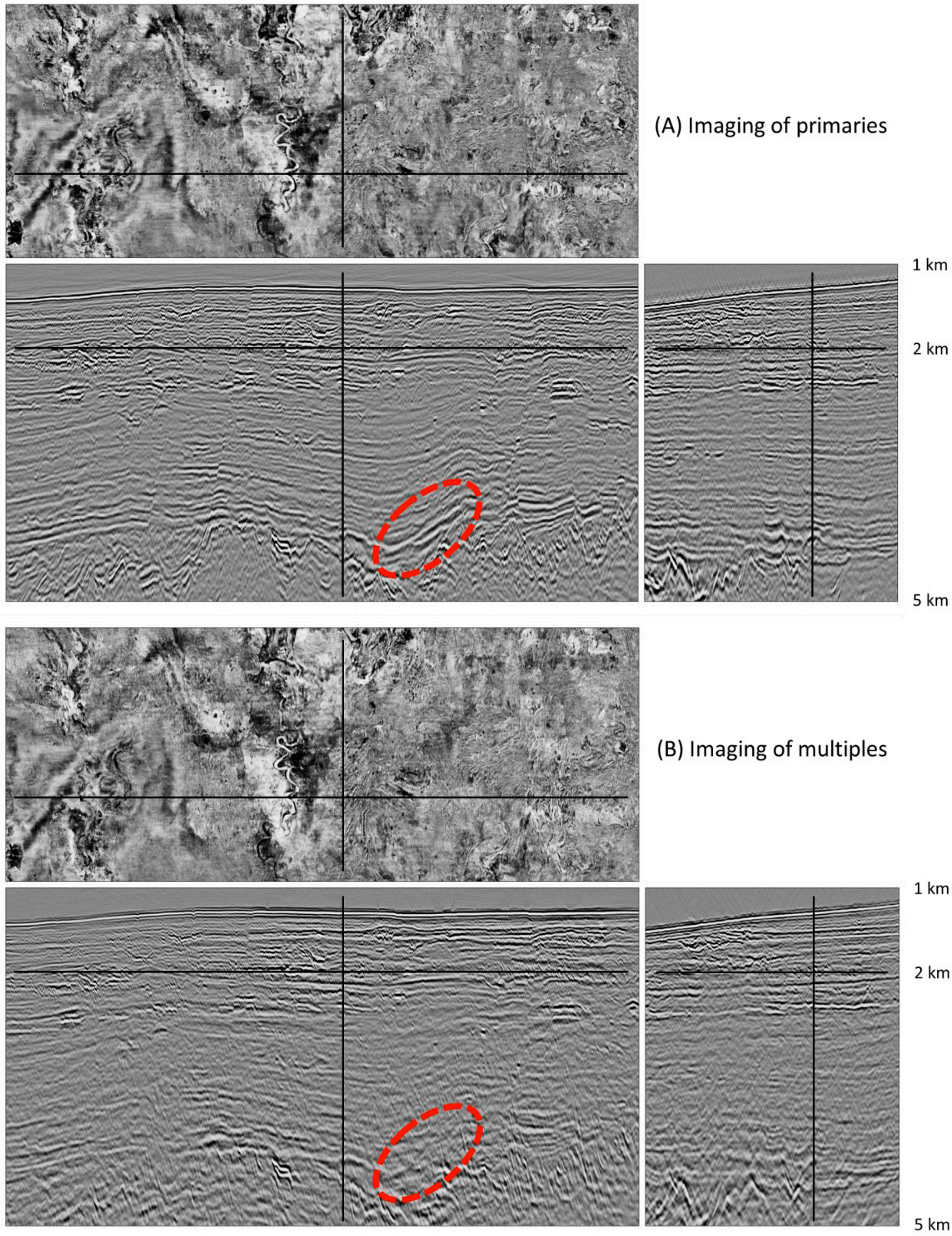

***Figure 2** depth images of primaries (A) and multiples (B) from the NAZ field data example. Shallow (2km) depth slices (top panels) are comparable. Images at the cross-line direction (right panels) are also similar due to the split-spread shot geometry in this direction. In the inline direction (bottom left panels), dipping target is missing (e.g. inside ovals) in the deeper part of the image from multiples,*

because the streamers are towed (from left to the right) facing the dipping reflection direction. The corresponding ray diagrams are displayed in Figure 1 to illustrate the issues.

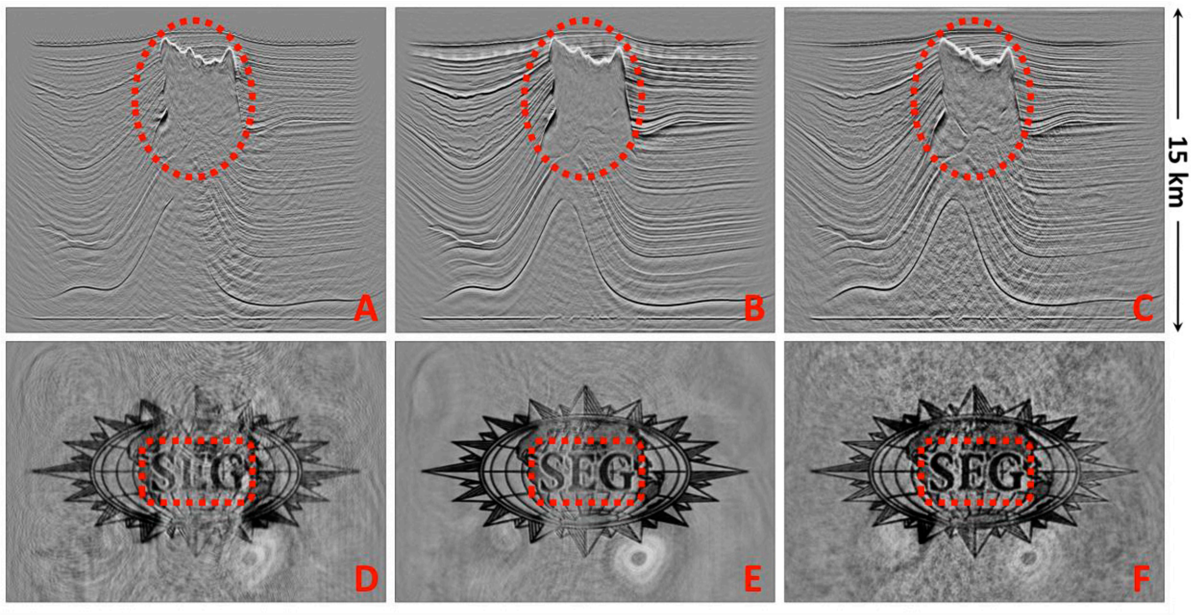

Figure 3 *images from primaries and multiples using 3D SEAM synthetic in the cross-line direction (A, B, C) and the depth slices (D, E, F). NAZ imaging of primaries (A, D) has less illumination of complex structures of salt and subsalt regions including "SEG" logo at the bottom of the model. WAZ imaging of primaries (B, E) has better illumination everywhere than NAZ. WAZ multiples imaging (C, F) helps to further improve subsurface illumination of the salt region (dirty salt, salt flanks, base of salt and channel structures inside salt body) and the bottom "SEG" logo.*

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