Challenges and Opportunities in 3D Imaging of Sea Surface Related Multiples

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Summary

Conventional shot domain migration constructs a subsurface image using the forward extrapolated (down-going) wavefield from a source and reverse extrapolated (up-going) wavefield originating at the surface receiver positions. Similarly, sea surface related multiples can also be used to construct an image of the subsurface where the boundary data for the down-going and up-going wavefields are generated at the receiver locations via wavefield separation. After up-down separation the down-going and up-going wavefields act as the source and receiver surface wavefields and exist only at the receiver positions. To properly image the subsurface with the multiples, the down-going and up-going wavefields must be both recorded. Therefore, the streamer coverage, receiver density, source-receiver distribution geometry and acquisition shooting direction as well as target depth and subsurface dip are controlling factors in the effectiveness of imaging with multiples. For example, wide azimuth (WAZ) acquisition generates large streamer coverage and enhances the use of both the down-going (source) and up-going (receiver) wavefields. Anti-parallel shooting is typically required to reduce the source (down-going) wavefield directional bias and image both updip and downdip targets. Split-spread shooting geometry uses rays including down-going and up-going wavefields recorded from different sides of the shot location and further enhances the subsurface illumination. In this paper, both synthetic and field data examples are used to demonstrate the challenges from acquisition geometry. A shallow water field data example shows the successful application of the technology to mitigate the acquisition footprint. The technology has the potential of reducing drilling hazard risks.

Introduction

Compared to conventional migration, imaging of multiples produces high quality images when using wide receiver arrays of full azimuth (FAZ) acquisition (Lu et al., 2011). In general the method can be useful to both WAZ and narrow azimuth (NAZ) scenarios provided the towed streamer acquisition geometry is properly designed.

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. Broader and denser streamer coverage produces better subsurface illumination. Figure 1 displays the results of imaging using multiples from WAZ and NAZ from one sailline of the SEAM (SEG Advanced Modeling) synthetics. For both the depth slices (A, B) and cross-line direction images (C, D), the comparison shows that WAZ generates much broader subsurface illumination than NAZ.

The image quality from multiples is also affected by acquisition shooting direction and source receiver distribution geometry. 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. Therefore, the multiples can image small dips, shallow dips and also the downdips [Figure 2C, 2D]. On the other hand, the multiples have limited ability to illuminate the updips, especially when the target is deep relative to the longest offset [Figure 2C, 2E]. Anti-parallel shooting is able to image the dipping target from the opposite shooting direction [Figure 2D]. The split-spread shot gather can use the down-going and up-going wavefields recorded at different sides of the shot location and image both updips and downdips from one shot [Figure 2F]. Split-spread shot gathers can be generated by using head-tail shooting.

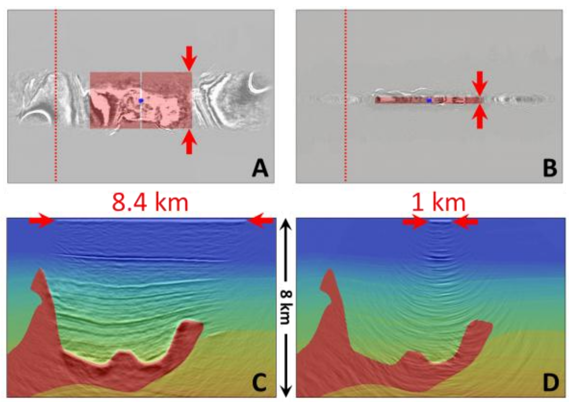

Figure 1 *images of multiples using one sailline from the SEAM model: WAZ (A, C) and NAZ (B, D). On top of the depth (at 2km) slices (A, B), the pink areas indicate shooting geometries (of one shot). The WAZ shot has 14km inline and 8.4km cross-line split-spread acquisition offset; the NAZ shot has 16km inline and 1km cross-line split-spread acquisition offset. (C, D) display cross-line direction depth images on top of the velocity model. The dashed red lines on (A, B) indicate the location where the cross-line images (C, D) are extracted from. The red arrows on (A, B) indicate the streamer offset at the cross-line direction, which are consistent with the strong coherent events in the cross-line direction at the sea surface (the red arrows on C, D).*

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In this paper, WAZ examples from the 3D SEAM synthetic sparse shooting dataset and a NAZ single direction shooting field data example from East El Burullus area offshore Egypt are used to demonstrate the effects of acquisition geometry to imaging of multiples. A successful application of the technology using a shallow water example from Asia-Pacific generates remarkable high resolution 3D images. The image from multiples has greater area of subsurface illumination, which mitigates the strong acquisition footprint. The method and results can be useful to reduce well drilling geohazard risks.

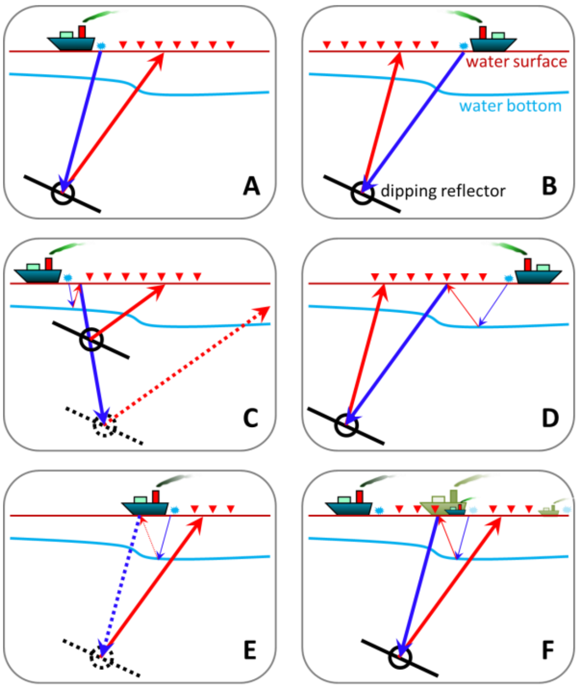

Figure 2 *schematic diagrams to demonstrate effects of acquisition geometry to imaging of multiples: arrows are used to display wavefields, blue = down-going; red = up-goings; solid = recorded; dashed = mis-recorded; solid circles = imaging construction points; dashed circles = none-imaging construction points. (A, B) show ray paths of primaries imaging, in which updip and downdip are imaged by equivalent ray paths from either shooting direction. (C, E) show that imaging of multiples has limitations to image updips. In (C) the updip could be imaged by multiples, when the target is shallow; however, deeper updip cannot be imaged because either source wavefield (down-going in E) or receiver wavefield (up-going in C) is not recorded. (D) shows that anti-parallel shooting is able to image the dipping target as the downdip from the opposite shooting direction. (F) shows that the split-spread shot can generate even more illumination by using down-going and up-going wavefields recorded from different sides of the shot location.*

Method

The idea of using sea surface related multiples in imaging was 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, a one way wave equation extrapolator is used to propagate wavefields; followed by the deconvolution imaging condition [Equation] (Valenciano and Biondi, 2003; Guitton et al., 2007) to attenuate crosstalk noise.

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

In this equation, 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.

Examples

The 3D SEAM synthetic is the standard model of deep water Gulf of Mexico. The sparse shooting dataset (600m by 600m shot spacing) is used in the imaging of multiples. Images from WAZ examples of single direction, anti-parallel and split-spread shooting geometries are compared. The WAZ acquisition has 7km inline and 8.4km cross-line cable offsets.

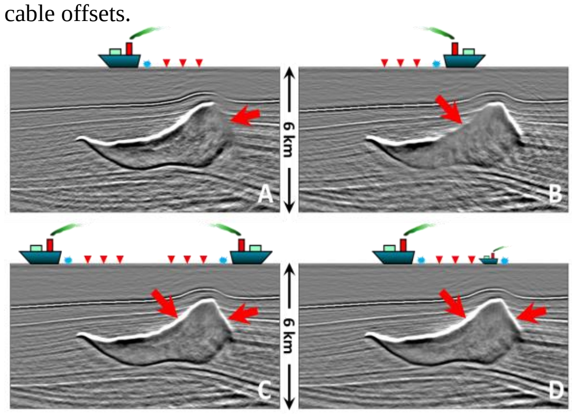

Figure 3 *inline direction images of multiples from using different shooting geometries (WAZ): (A, B) single direction shooting; (C) anti-parallel shooting; (D) split-spread shooting generated from head-tail shooting.*

Figure 3 shows images from multiples using different shooting geometries. Single direction shooting (A) and (B) have limitations in imaging the updips because either the source (down-going) or receiver (up-going) wavefield is not recorded (Figure 2C, 2E). Anti-parallel shooting (C) is a direct summation of (A) and (B), therefore the dips of both directions are imaged. Compared to (C), split-spread shooting (D) generates the best result by using extra ray paths in Figure 2F.

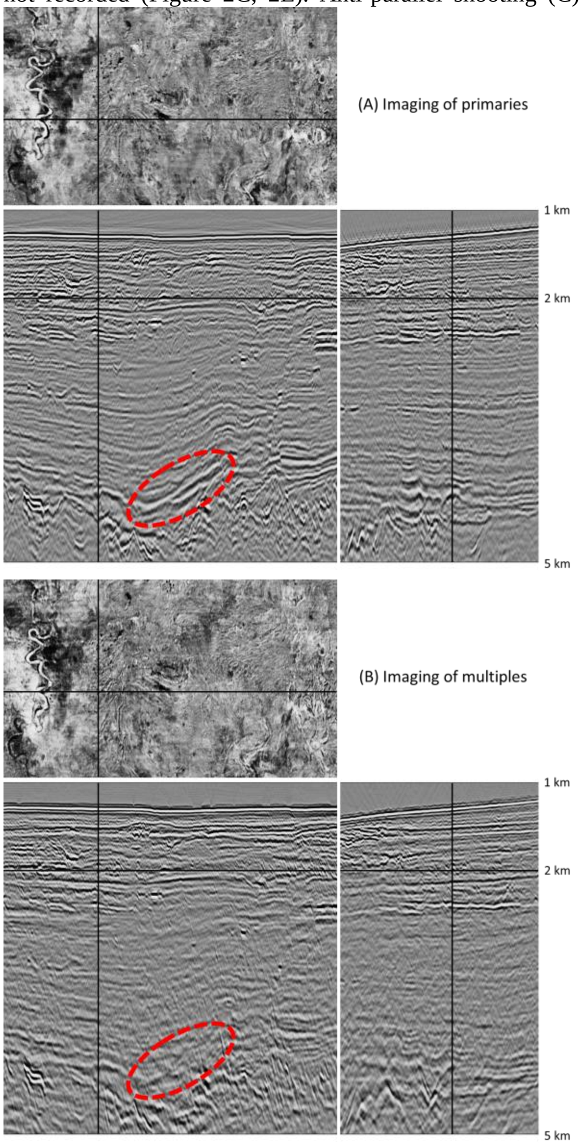

__Figure 4__ depth images of primaries (A) and multiples (B) from the NAZ field data example. Shallow (2km) depth slices (top panels) are comparable. Images at the cross-line direction (right panels) are also similar due to the split-spread shot geometry in this direction. In the inline direction (bottom left panels), updip targets are missing (e.g. inside ovals) in the deeper part of the image from multiples. The corresponding ray diagrams are displayed in Figure 2 to illustrate the issues.

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

Images from primaries and multiples using 30Hz migrations are compared in Figure 4. 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. In the deeper section, the image from multiples is missing the updips (the dipping target inside the ovals in Figure 4). This is because either the source (down-going) or the receiver (up-going) wavefield is not recorded in the streamers. Primaries can image the dipping target using equivalent ray paths from either shooting direction from shallow to deep. Ray diagrams are used to discuss these different scenarios in Figure 2.

The second field data example is a 3D dual-sensor towed streamer survey over the Tenggol Arch area in offshore Peninsula Malaysia. The migration is applied with a 585km^2 area extracted from the full survey. The dual-sensor survey is acquired using 12 cables with 4050m cable length and 75m cable spacing.

Up and down-going wavefield separation is applied in the shot domain to the surface data. The data has both a significant amount of short period and long period multiples, which are from the shallow water bottom and other major impedance changes. When imaging the multiples, the separated wavefields have no demultiple applied, which means many orders of sea surface related multiples are used. The deconvolution imaging condition is applied to attenuate both the cross talk and noise from different orders of multiples. The up-coming wavefield after signature deconvolution, τ-p deconvolution and SRME (Verschuur, 1991) demultiple is used to produce the primaries image with a cross correlation imaging condition.

Figures 5 and 6 show images of 80Hz depth migrations. Figure 5 compares the cross-line images from primaries and from multiples in depth (0-3km). The image of multiples mitigates the strong sailline acquisition footprint. The argument is more obvious when we compare the depth slices in Figure 6. Multiples completely diminish the acquisition footprint and generate very high resolution image especially in the shallow depths.

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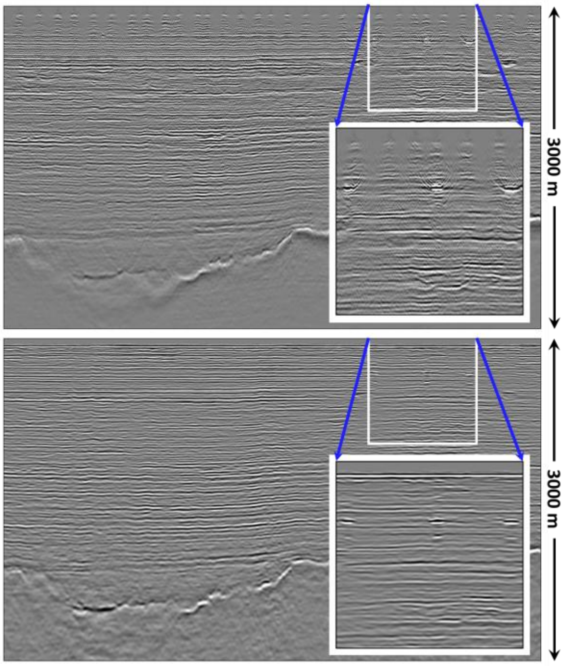

Figure 5 *images from primaries (top) and from multiples (bottom) in the cross-line direction. Shallow parts (inside the windows) of the images are zoomed to show the acquisition footprint. Multiples help to mitigate the acquisition footprint and generated very high resolution images from shallow to deep (3000 meters).*

Conclusions

From the 3D SEAM synthetic examples, we have demonstrated the importance of acquisition geometry for imaging of multiples in aspects of using WAZ, antiparallel shooting and split-spread shooting. The East El Burullus field data example shows the limitation of multiples imaging using NAZ single direction towed streamer data in deep water scenario. The successful application of imaging of multiples to the Tenggol Arch example demonstrates the great opportunities of this technology in the shallow water scenario. Reviewing all of the synthetic and field data examples, we demonstrate that the key element to make the technology successful is the ratio of the acquisition array coverage to the imaging target depth. Multiples can be used to generate very high resolution images of a shallow target even using NAZ acquisition (Tenggol Arch). Image quality for deep targets may be reduced when using NAZ acquisition (East El Burullus). The technology helps to improve overall subsurface illumination when WAZ acquisition is available (SEAM synthetic examples). Finally, the overall best image quality can be obtained from using both multiples and primaries combined.

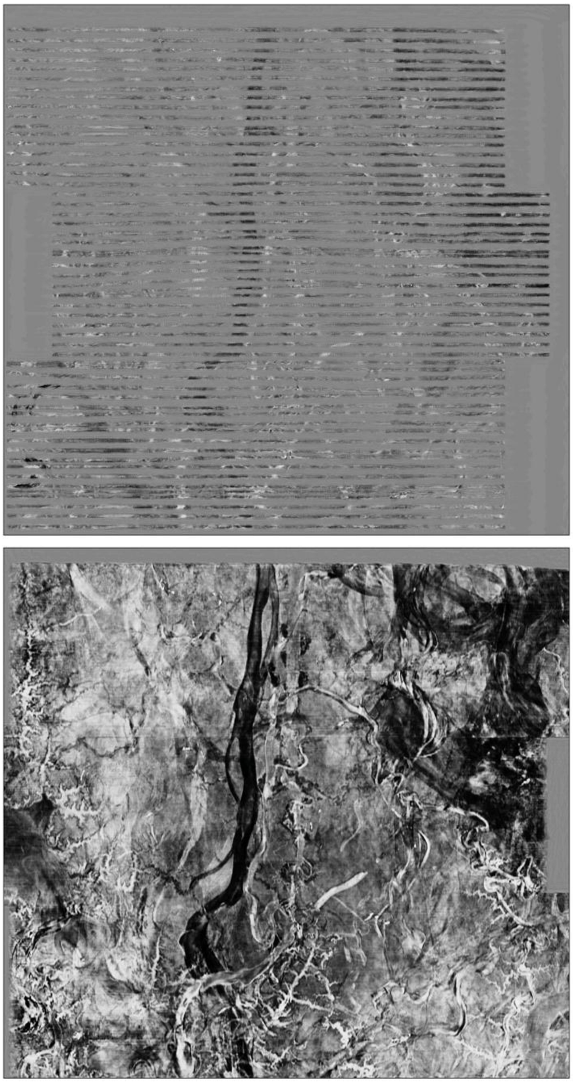

Figure 6 *depth slices at 105 meters from imaging of primaries (top) and multiples (bottom). Multiples very well mitigate the acquisition footprint and generate very high resolution 3D depth images, which could be useful to reduce well drilling geohazard risks.*

Acknowledgements

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EDITED REFERENCES

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