Migration with surface and internal multiples

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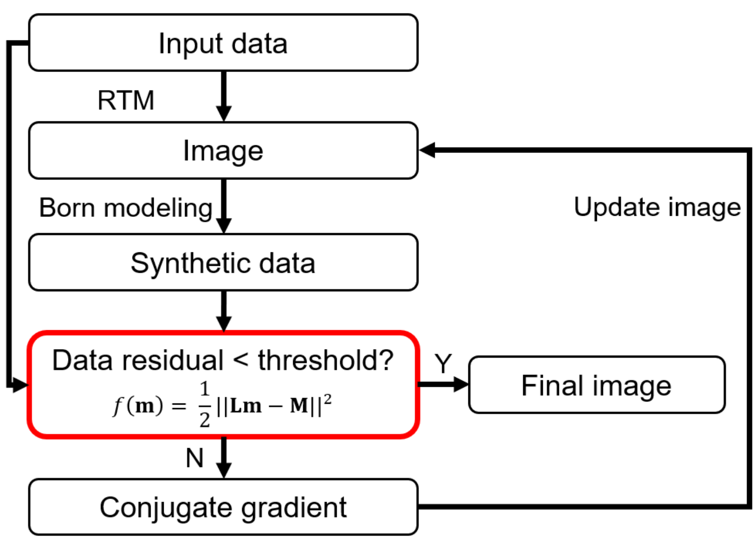
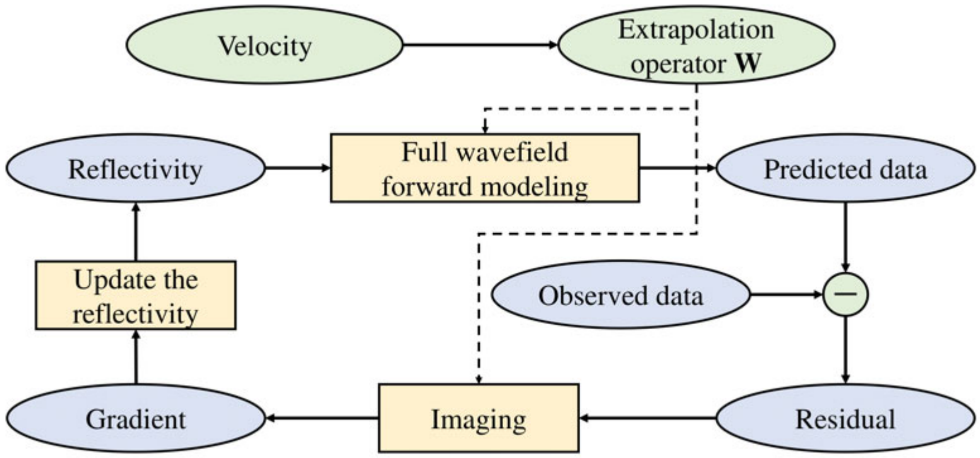
Summary

Multiples can provide additional information for subsurface structures compared with primary reflections. In this paper, we consider two different uses of multiples for imaging. First, we will look at the use of the first-order surface multiples for reverse time migration (RTM). RTM of surface multiples gives a more extensive illumination than RTM of primaries. In addition, least-squares reverse time migration (LSRTM) of surface multiples presents improved vertical resolution compared with RTM. Also, LSRTM of the first-order surface multiple can recover the information from upper-side dipping events as well as some small flanks. The main requirement of these benefits is, however, quite challenging: to achieve multiple separation before migration.

The second use of multiples we examine here is full-wavefield migration (FWM). A horizontal-layered model is used for proving the benefits of using FWM. Forward modelling by phase shift plus interpolation derives stable downgoing and upgoing wavefields separately, which can predict primary, surface multiples and internal multiples in a full-wavefield response. FWM of total wavefields can provide more details in the image compared with FWM of primary only. Adding energy from multiples into migration is not a replacement for migrating primary reflections, but it can be a useful complement to improve the image resolution and illumination for an accurate geological interpretation.



Workflow 1: Least-squares reverse time migration with the first-order surface multiple



Workflow 2: Full-wavefield migration (Adapted from Davydenko and Verschuur (2017))

Methodology and Results

Workflow 1 illustrates the mechanism of LSRTM for multiples (Zhang and Schuster, 2013). In this approach, a standard LSRTM algorithm can be used but the data consists of the first-order multiples and the source consists of the primaries. In the first example, we test whether the first-order surface multiple migration can handle both dips and curvatures. We used the velocity model Figure 1a with 501 X 501 cells and spacing internal of 10 meters to generate a synthetic shot gather. Velocity values varied from 1500 m/s to 3000 m/s. The receiver spacing was 20 meters and the shot was located at the center. We set the time length to 8.8 seconds with 0.0008 seconds time interval.

The RTM using the primary only (Figure 1b) shows concentrated illumination for the first horizontal layer, but poor illumination for the dipping and curve layers. On the other hand, RTM of the first-order multiple (Figure 1c) expands the aperture illumination for all the layers, although there are some new artifacts. It seems that the multiple also helps to enhance the vertical resolution. However, the curve reflector at the bottom in both images cannot be recovered in high quality. After five iterations, LSRTM of the surface multiple in Figure 1f flattens the horizontal reflector edges and enhances the amplitude of the upper-side dipping event. On the other hand, we expected that LSRTM would suppress artifacts but didn't, probably because we may need some additional constraints.

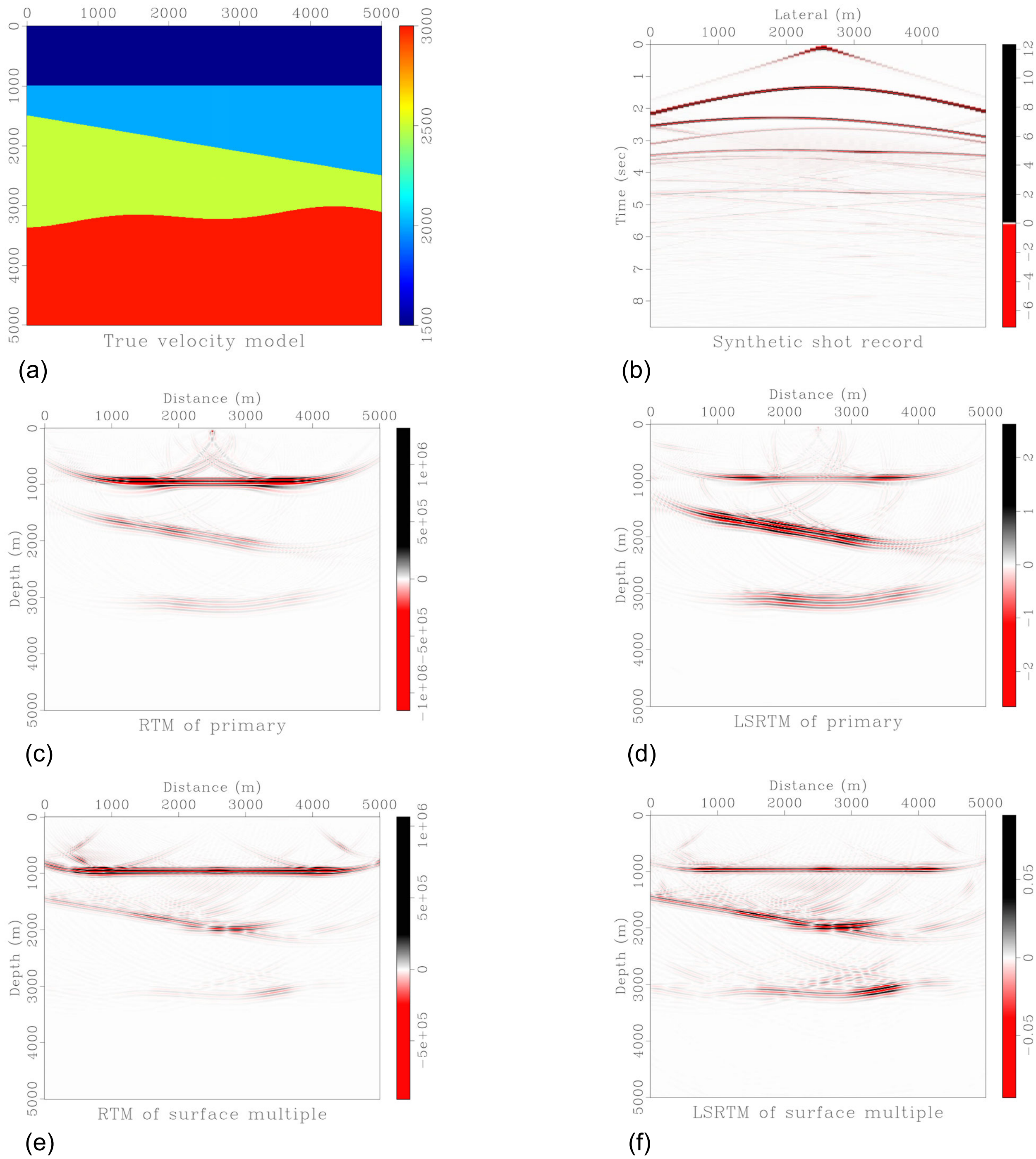


FIG. 1. Example of testing the image quality of RTM and LSRTM with the first-order surface multiple. (a) True velocity model. (b) Synthetic shot record where the shot was at the central horizontal distance. (c) RTM of the primary wave. (d) LSRTM of primary wave after five iterations. (e) RTM of the first-order surface multiple. (f) LSRTM of the first-order surface multiple after five iterations.

The second example is to test the result of using full-wavefield migration (Davydenko and Verschuur, 2017) shown in workflow 2 with primary reflection and total wavefields respectively. We used a three horizontal-layer model with velocities of 1500, 2000 and 3000 m/s and 400 meters thickness. Receivers were assigned on the surface with 5 meters spacing. One source was set in the centre of the model at 20 meters in depth using a minimum phase wavelet. We simulated with finite differences a maximum time of 1.024 seconds with a sampling rate of 1 millisecond.

For forward modelling, our predicted data with total wavefields (blue line in Figure 2) can predict most of the seismic events and add reflections from the surface and inter-bedding structure. Predicted data with primary only (orange line in Figure 2) has no data amplitude after 0.52 seconds compared with full-wavefield data where the surface and internal multiples should exist. The updated reflection coefficient after using full-wavefield migration (blue line in Figure 3) is more accurate and closer to the true reflection coefficient values compared with applying primary only (red line in Figure 3). However, FWM generates some unexpected crosstalks at depth 10 meters, an unstable step size might cause it.

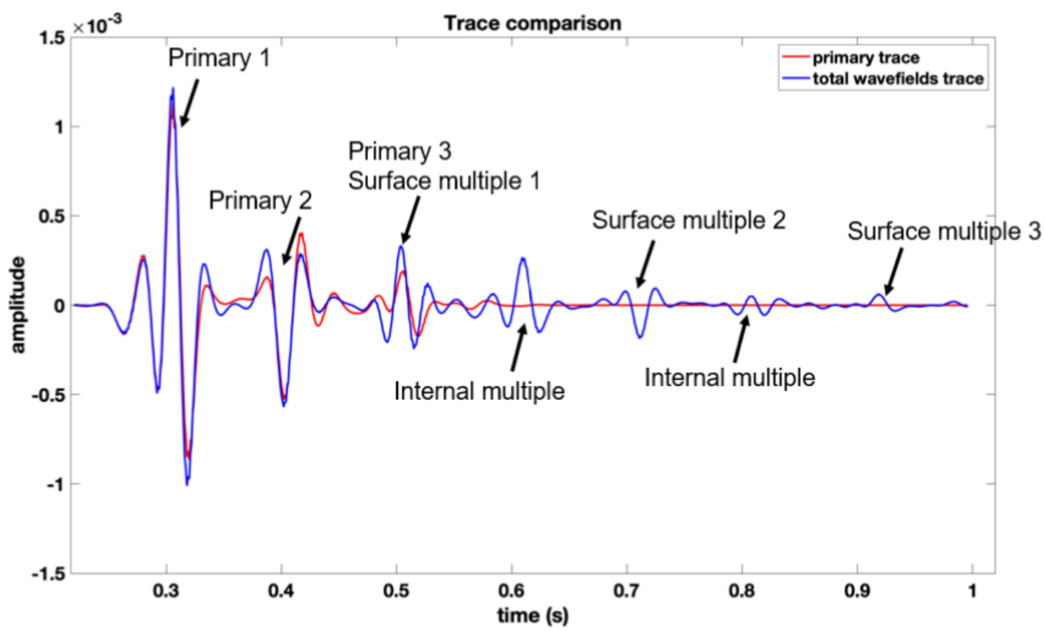


FIG. 2. Trace comparison. Primary reflection is in the red line and the total wavefield is in the blue line.

Conclusion

The main benefit of migration with multiples is to enhance the illumination and signal-to-noise ratio in the image, as well as improve resolution. Using surface multiples in reverse time migration is very promising but brings some extra sensitivity on velocities forcing one to have a better background velocity model. Full wavefield migration is an iterative inversion-based approach that can enhance the migration accuracy by calculating corrections to existing reflector amplitudes from the primary and multiple energy. This method is a controlled approach to considering reflection and transmission energy. The multiples are created by explicitly adding operator components that generate them during forward and inverse propagation. However, just as in RTM with multiples, if the background velocity model has significant errors, then it will lead to the wrong wavefield extrapolator.

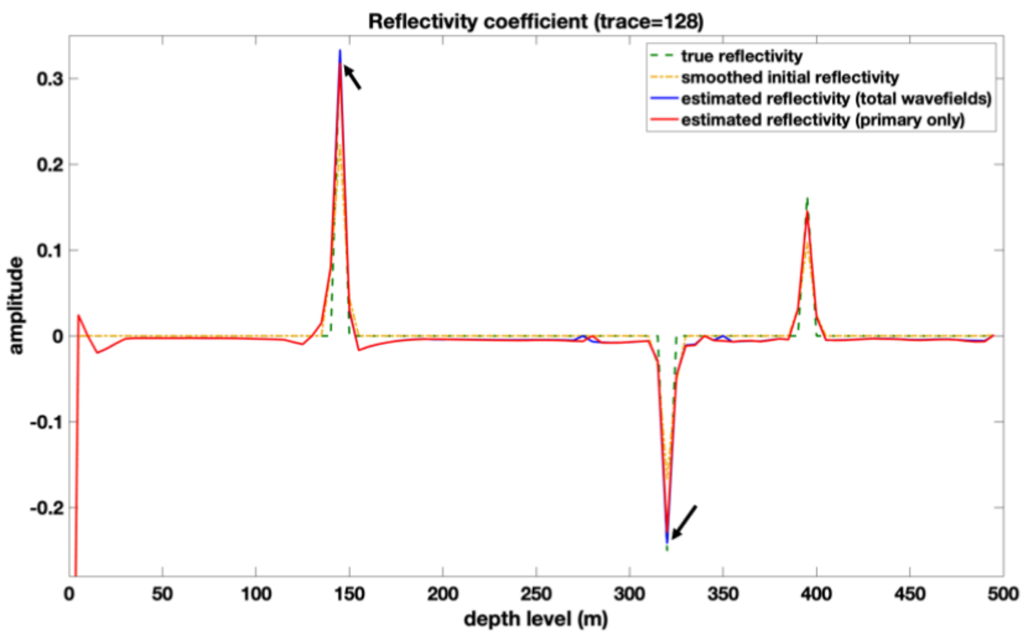


FIG. 3. Reflectivity coefficient comparison. Estimated reflectivity by full wavefield migration (FWM) is in the blue line and the result by primary wavefield migration (PWM) is in the red line.

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References

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