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Predicting Free Surface Multiples without the Water: SRME on Land

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Summary

We propose a method to adapt surface related multiple elimination (SRME) to land data, which accounts for the near surface by including differential static corrections during the prediction phase. Our surface corrected multiple elimination (SCME) is demonstrated using a synthetic test containing both primary and first order multiple events, which have been modelled using a near surface low velocity layer based on a real survey. Compared with using SRME from surface but with no near surface correction, we are better able to predict the complex structure of the multiple which arises from passage through the low velocity layer. We then apply the method on a real heavy oil dataset which contains a problematic multiple with velocity which is similar to the primary. This results in a substantial reduction of the multiple amplitude without damage to the primary events.

Introduction

Surface related multiple elimination (SRME) was introduced to industry by the Delphi Consortium at Delft University of Technology over 20 years ago (Verschuur et al., 1992). The fundamental idea is that multiples can be predicted by cross-convolving the primaries with the data. Moreover the primaries can be initially approximated by the recorded data, and the method applied recursively with successive estimates of primaries after each multiple removal step. Multiple removal is performed by adaptive subtraction of the multiple estimate from the data.

The earliest SRME codes were only 2-D and, though successful for certain cases, often struggled in the presence of 3-D geology and acquisition (Dragoset et al, 2009). For some years it was unclear how to perform 3-D SRME, because it requires shots and receivers at each position where a downward reflection from the free surface is considered. However, during the last 15 years practical methods for dealing with the geometry limitations have been implemented, such as choosing appropriate “proxy” traces which have similar offsets and CMP locations (Sun, 1999; Biersteker, 2001), so that 3-D SRME has become quite robust and widely used – in the marine environment.

This has not been the case with land data. Application of SRME to land data has proven more challenging, though recently interest in this idea has grown (Wang and Wang, 2013).

The first problem with surface related multiples on land is the recognition that they may be present. For marine data, multiples are often easy to spot on a stack because of their similarity to the multiple-generating reflector; this is usually the water bottom, but can also be a particularly strong reflector resulting in ‘peg-legs’. The geophysicist can pretty well do the mental reflection geometry to recognize the multiples. On land, the shape of a surface-related multiple can be quite difficult to anticipate, since it has been downward reflected from a non-planar surface, so that the multiple has shape characteristics which involve both the topography and the multiple generator. Application of statics to align reflections also makes the multiples harder to recognize.

Figure 1 shows a stacked section at a flat processing datum, taken from a 3-D seismic dataset acquired over a heavy-oil reservoir which contains a multiple. The multiple generating reflector is shown as the yellow horizon. The green line at the top represents zero time, as measured from the surface. Based upon a simple approach using just the zero offset times, we could double the time between the surface and the horizon to predict a multiple, as shown by the red horizon. This does agree well with what we now understand to be a multiple in the data.

A second problem for land data is the interplay between statics and free surface multiples. The primary reflections pass through the weathering layer twice – once at the source and once at the receiver – whereas the multiples pass through the weathering layer 2N additional times, typically at locations other than the shot or receiver, where N is the order of the multiple. For this reason it is generally assumed (e.g. Wang and Wang, 2013) that land SRME must be applied from surface. Even with this precaution, there are still problems caused by the variation of the near surface, which may not be sampled at the downward reflection locations.

Here, we propose to apply a Downward Reflection Point (DRP) static correction, using a model of the near surface statics, which can be performed either from surface or from a datum. Because our method is based on SRME, but with an additional correction for the near surface, we refer to it as "surface corrected multiple elimination" or SCME.

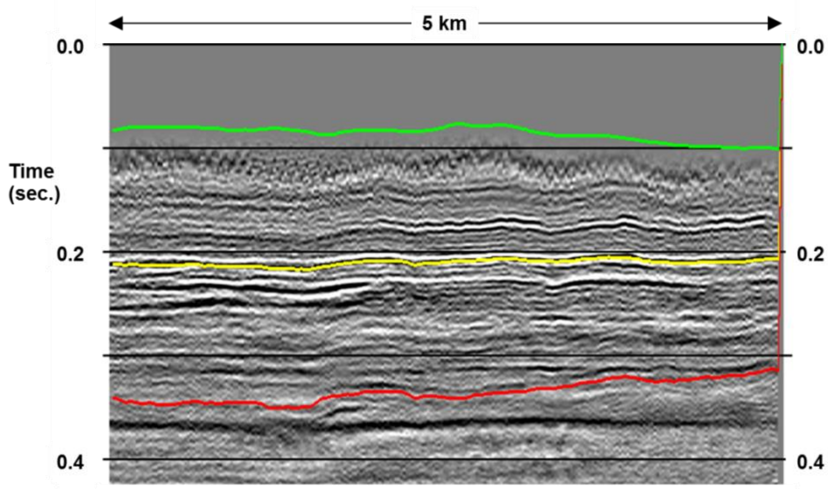

Figure 1. Identification of a free surface multiple on CMP stacked data from a heavy oil survey. The green line shows the location of zero time (i.e. the surface). The yellow horizon is the multiple generator. By doubling the time from the surface to the multiple generator, we can estimate the zero offset location of the 1st order multiple which bounces twice from this horizon, shown as the red horizon.

Theory

Conceptually SRME may be understood from the geometry depicted in figure 2. Any ray path which includes a downward bounce from the surface may be constructed from two ray-paths (blue and red) which have the DRP in common. The actual combination of ray-paths is performed through a cross-convolution of the data with a primary-only wavefield estimate, since convolution corresponds to the addition of travel times. The actual DRP is unknown as it will depend on the geology. Therefore an integral over all possible DRP positions is applied, and Fermat's principle (stationary phase) results in the true DRP being reconstructed. The set of traces which constitute cross-convolved data for all possible DRP locations is sometimes referred to as a "multiple contribution gather" or MCG.

Since the primary-only wavefield is not available at the outset, it is usual to commence the SRME process using the recorded data as an approximation of the primaries. As multiples are subsequently subtracted from the data, the results are used to improve the primary-only wavefield estimate for subsequent iterations.

In theory this requires a shot and a receiver both to be present at all DRP locations. For 3-D data, this will not be the case, and so it is necessary to either interpolate data or make adjustments to nearby traces or "proxies". For the marine case depicted in Figure 2(a), this is readily achieved by a simple differential NMO correction to transform the acquired data into the offsets that are needed.

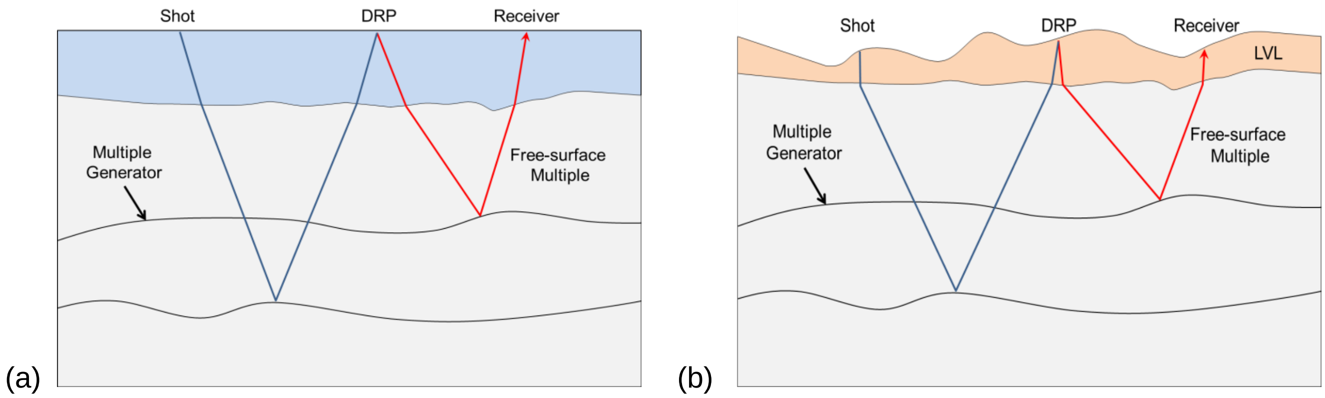

Figure 2.Principle of SRME depicted for: (a) marine situation, and; (b) land situation. In each case the multiple is predicted by the summation of ray-paths from shot to the downward reflection point and from the downward reflection point to the receiver.

For the land case however, differences in the near surface properties between the measured data and the desired locations must also be accounted for. This near surface correction used in SCME is illustrated in figure 3, which depicts the spatial locations of the actual shot and receiver, the DRP, and the selected proxy traces (dashed lines). Letting the near surface statics for the target shot and receiver be t_s and t_r, for the proxy trace shots and receivers be t_{s1} and t_{r1} and t_{s2} and t_{r2}, and the two way near surface static for the DRP be t_{drp}, then the correction to be applied is of the form

$$\Delta t = t_s + t_r + t_{drp} - \left(t_{s1} + t_{r1} + t_{s2} + t_{r2} \right) \qquad (1)$$

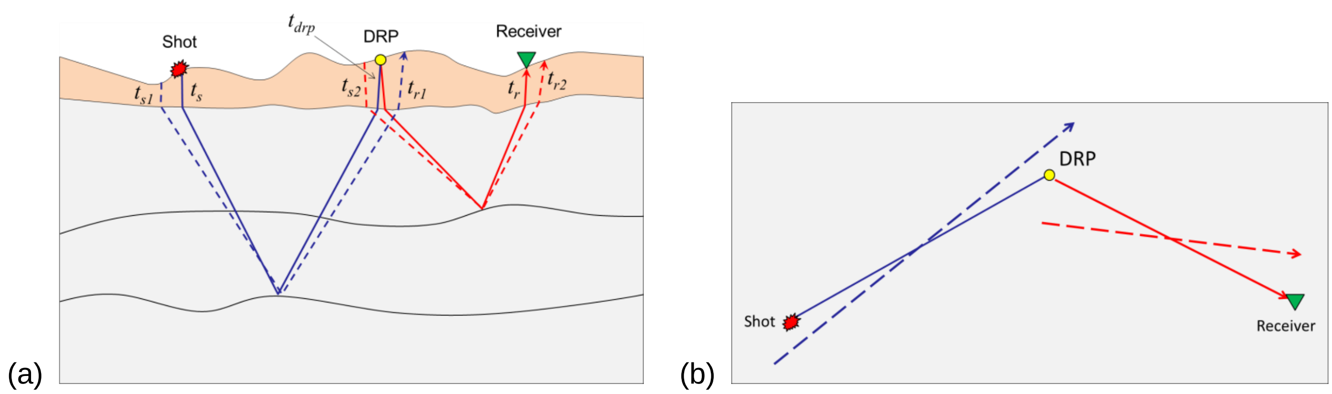

Figure 3. Near surface correction: (a) profile view (b) map view.

This correction can be applied from surface, in which case each term corresponds to the total static (elevation and weathering). With some minor modifications, these can be corrections from a smooth datum. All terms in equation 1 are already estimated during statics processing, except for the DRP static, t_{drp}, which must be interpolated. This places some limitation on the wavelengths which may be recovered during multiple prediction. Note that this is a fundamental limit imposed by our lack of information in places where the near surface has not been sampled by the survey. Alternative approaches, such as interpolation of traces to provide more accurate DRP estimates (Wang and Wang, 2013), are still faced with this fundamental absence of knowledge. In that case some assumptions must be made about the unknown near surface statics during trace interpolation.

After prediction of the multiple, the adaptive subtraction step is performed for SCME in the same way as for conventional SRME.

Synthetic Example

To test our method we used a synthetic which was constructed using a ray-based modelling code. To model the multiple, we used the principle of mirror reflection about a horizontal reflector which acts as our multiple generator. The principle is illustrated in figure 4, showing that the multiple is equivalent to a reflection from a mirror of the surface elevation. We model only the first order multiple.

The data are modelled using geometry from a real 3-D seismic dataset acquired over a heavy-oil reservoir. The near surface used in our synthetic was based on the actual total statics for the real data, converted into a weathering thickness with a velocity of 770m/s and interpolated onto the bin grid. To simulate the effect of unknown near surface statics, we then perturbed this thickness by 50% about a running mean and used this perturbed version for generating the synthetic only. We applied SCME assuming the original thickness - thus we are using a smoother version of the near surface weathering layer than was actually present in the synthetic, as would be the case for real data with unknown short wavelength statics.

Figure 5(a) shows the CMP stack of the data with no statics applied. Both the primary at 180ms and the multiple at about 360ms are degraded. Figure 5(b) shows the stack after application of elevation statics (we use a datum below the topography in this example, at the base of the low velocity layer). The primary is flat as expected, but the multiple bears the inverse profile of the surface topography. It is also surprisingly coherent and might easily be mistaken for a primary. This is because the additional near surface delays introduced for the multiple are at the downward reflection point (DRP in figure 4), and will be quite similar for all traces in the CMP gather, unlike the shot and receiver statics.

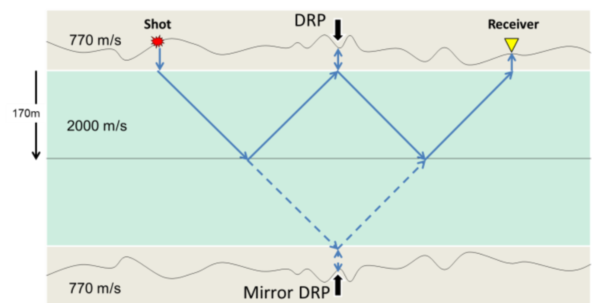

Figure 4. Mirror geometry of multiple for simple model. This is used to construct the synthetic test data.

This observation is particularly true for flat reflectors such as in this synthetic, but holds to some degree for more complex models. This behaviour is especially insidious, as it means free surface multilples are not only hard to predict in location (as mentioned earlier) but can also bear a convincing resemblance to real structure.

Figure 5(c) shows a CMP stack of the predicted multiple from conventional SRME applied to the synthetic data. Although it predicts the overall location of the multiple pretty well, the detailed character of the multiple is missing. Compare this with figure 5(d) which shows the result of multiple prediction with SCME, which takes proper account of the statics at the DRP location. Compared with 5(c), the near surface corrected multiple prediction captures more of the true multiple characteristics, including the sag due to increased weathering layer thickness on the right side of the section. Figures 5(e) and (f) show the results of adaptive subtraction of the multiple estimates in figures 5(c) and (d) respectively. These should be compared with the original stack in figure 5(b). The residual multiple energy left from the SCME is predominantly high frequency energy corresponding to short wavelength variations, which are subject to the limitations of the near surface representation, as expected. To see this, observe the spectral comparison at bottom of figure 5, which shows the increased attenuation of the multiple using SCME (green) when compared with conventional SRME (blue), particularly for the lower frequencies.

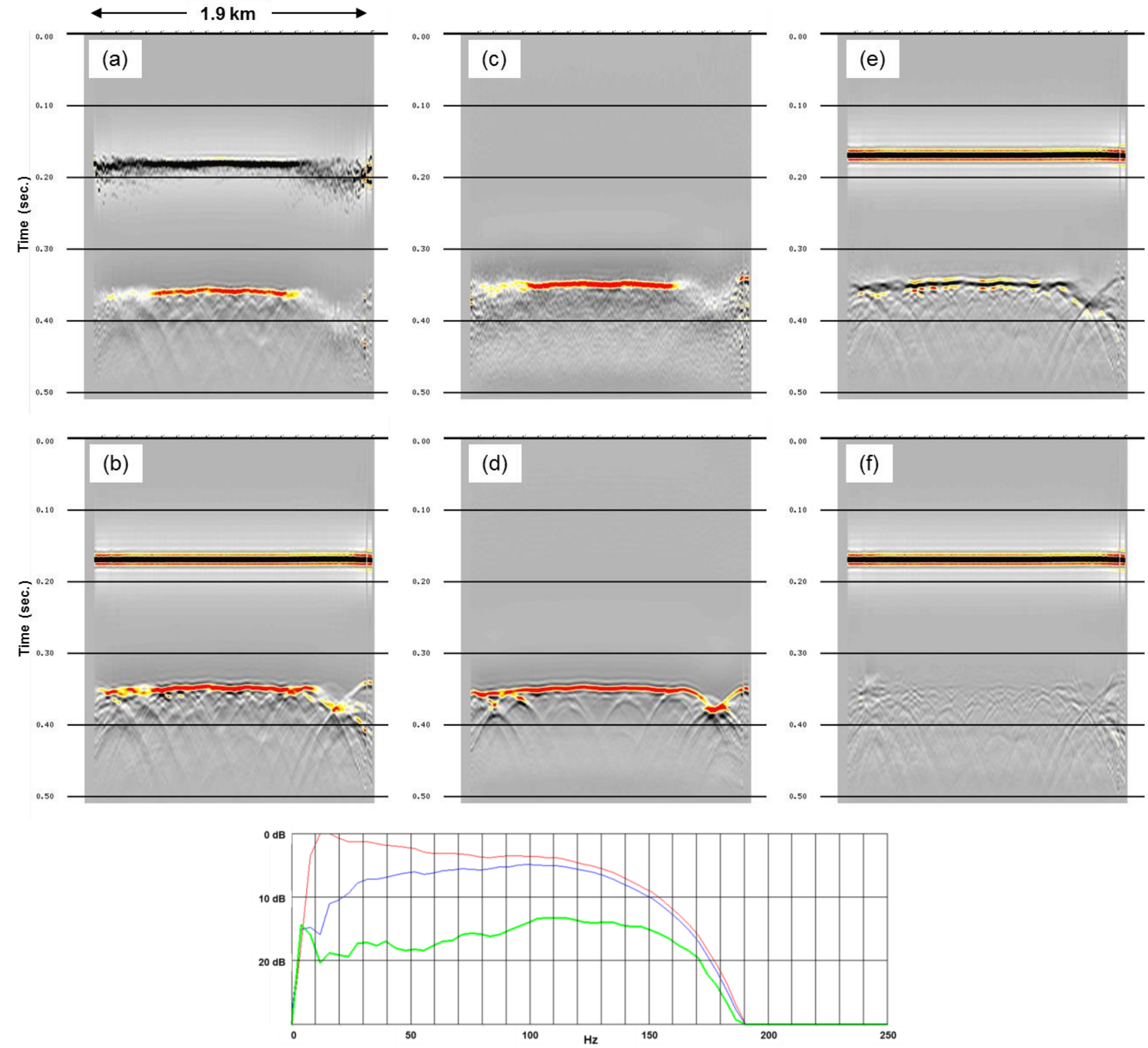

Figure 5. Synthetic example: (a) stack of synthetic data with no statics applied; (b) stack after application of statics; (c) stack of predicted multiple with conventional SRME method; (d) stack of predicted multiple with SCME; (e) adaptive subtraction of conventional multiple prediction from (c); (f) adaptive subtraction of near surface corrected multiple prediction from (d). At bottom is a comparison of the amplitude spectra measured over the window 300-500ms, containing the multiple, for figure (b), (e) and (f) in red, blue and green respectively.

Field Example

Figure 6 shows the application of SCME to data from a 3-D seismic dataset acquired over a heavy-oil reservoir. The multiples present in the data, indicated by the arrow, are problematic because they stack in with very similar velocities to the primaries, and are not easily removed by velocity based methods such as radon. The multiples could potentially have given rise to erroneous interpretation of the data if not identified.

The processing steps to generate the result in Figure 6 include the following:

1. Random and coherent noise attenuation
2. Data interpolation to ½ of the shot and receiver interval
3. Muting data above the multiple generator, at about 200ms
4. Multiple prediction using SCME, as described in this paper
5. Least squares adaptive subtraction of predicted multiple

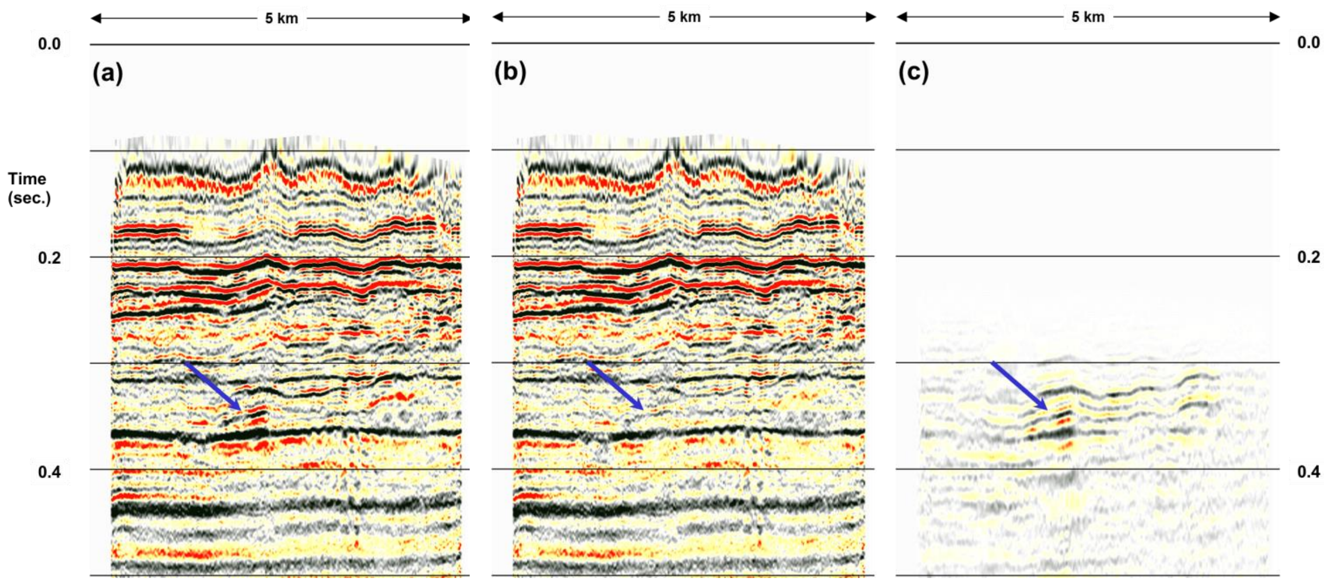

Figure 6. Heavy oil data example: (a) stack of data without multiple attenuation; (b) stack of data after SCME; (c) difference.

The results in figure 6 indicate a significant attenuation of the multiple, and, equally important, no obvious impact on the primary.

As mentioned earlier, a key advantage of SCME is that, unlike velocity based methods, it can work well even when there is relatively small differences between primary and multiple velocity. In figure 7 we compare the result of using SCME against a radon approach to multiple suppression on the migrated images. Figure 7(a) shows the reference result with no multiple attenuation. Figure 7(b) is the radon demultiple result and 7(c) is the SCME result. In this case the radon demultiple was difficult because multiple and primary velocities are similar, forcing the choice between either attacking the multiple at the expense of the primary or leaving significant multiple energy behind.

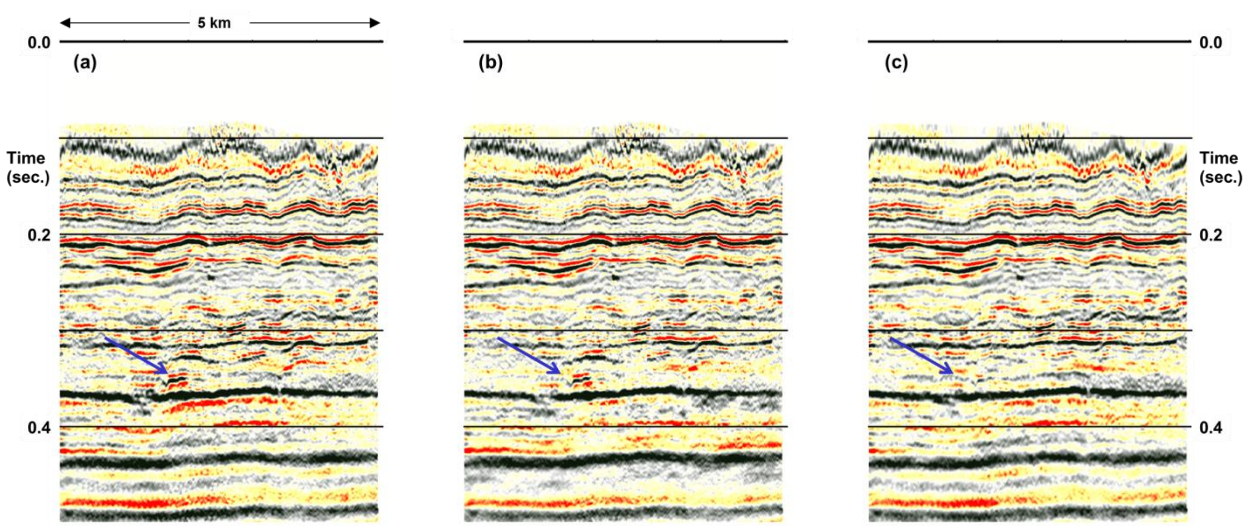

Figure 7. Migrated images after: (a) no multiple attenuation; (b) radon demultiple, and; (c) SCME. The multiple (blue arrows) is more effectively eliminated by the SCME than by radon.

Conclusions

SRME, which has been widely adopted for marine 3-D multiple attenuation, can be modified for use on land data. The application of SRME to land data is challenging because shots and receivers do not exist everywhere on the surface, so that we have incomplete measurements of the near surface at locations which affect the multiple. We have proposed a solution to this issue which we refer to as surface corrected multiple elimination (SCME), based on an interpolation of the near surface static correction to the required DRP locations. We have tested our method using a synthetic, for which SCME shows better attenuation than conventional SRME, and on a heavy oil dataset, where a problematic multiple with little velocity discrimination was predicted and removed.

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