Wave-equation based residual multiple prediction and elimination in migration depth domain as an aid to seismic interpretation

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Summary

We have developed a new methodology for predicting and removing multiples in the migration depth domain based on wavefield extrapolation and attribute based subtraction. The input for the prediction part is a 3D prestack depth migration volume and the corresponding velocity field. The output is the predicted multiple model (surface related or inter-bed) in the migration depth domain. The residual multiple removal technique combines the multiple prediction part with the recently developed attribute-based subtraction. Applications to both marine and land data have proven this methodology to be very effective in further reducing the residual multiples in the final migration images.

Introduction

There are many good articles discussing both surface-related and inter-bed multiple predictions. Among them, the papers of Verschuur et al. (1992), Weglein et al. (1997), Jakubowicz (1998), Berkhout (1999), Kelamis et al. (2002), Erez and Ikelle (2005), Matson and Xia (2007), Baunstein et al., (2006), Pica et al. (2005, 2008), and Dragoset et al. (2008) represent the significant efforts in this area.

In spite of great advance in this area, removing multiples continues to be a challenging task in seismic data processing. Frequently there are noticeable residual multiples remaining in the final migration image. There are numerous causes for these residual multiples and we will summarize a few of them. First, the predicted multiple models are not accurate enough because of insufficient data acquisition, or the data regularization does not generate the bounce points as needed. Second, subsequent subtraction techniques are too conservative in order to preserve weak primary reflections such as subsalt sediment events. Third, the prediction and removal of inter-bed multiples has not yet become routine. These types of residual multiples are commonly found in shallow marine or land data. Fourth, in the case of fast-track projects, there is often not enough time to apply the complex full blown 3D multiple removal techniques.

The residual multiples that are present in the final migration images can make the subsequent seismic interpretation work difficult and in some cases may lead to incorrect interpretation. In some areas like the Gulf of Mexico (GOM), these residual multiples can be mistakenly interpreted as subsalt primary reflections but can also lead to inaccurate salt body definition. For example, residual Top of Salt (TOS) multiples could be incorrectly interpreted as Base of Salt (BOS) resulting in an erroneous velocity model.

The objective of this research is to develop a method to predict multiples in the migration depth domain, in contrast to Pica et. al (2005, 2008)'s techniques, where the prediction is in the shot domain using input short records. There are a few benefits to predicting multiples in the migration depth domain. First, predicted multiple models can be used to guide seismic interpretation to avoid picking multiple events by comparing the multiple model in the migration depth domain with the final migration image. Since this new multiple prediction method operates in post-stack mode, it is very efficient and convenient for interactive use. In addition to this, the predicted multiple model can also be directly used to subtract the residual multiples from the final migration volume.

We have developed a new methodology for predicting and removing multiples in the migration depth domain. Our prediction technique is capable of predicting both surface-related multiples as well as inter-bed multiples. The removal of these multiples in migration depth domain combines the multiple prediction method with our recently developed attribute-based subtraction method (Guo et al., 2008). Applications to both marine and land data have proven this new methodology is very effective in enhancing the final image by reducing these residual multiples.

Multiple prediction in migration depth domain

The objective is to predict a multiple model which can be used to compare with the final migration image. Since this multiple prediction method operates in post-stack mode, it is extremely efficient.

The input volumes for this method include the 3D migration image cube and the corresponding migration velocity model. The output is the predicted multiple model in the migration depth domain. The method consists of the following major steps:

1) Using the migration image (as the reflectivity model) and the migration velocity model, we perform a post-

stack wave-equation based demigration to get zero-offset (post-stack) wavefield (Wang et al., 2005).
2) Using the demigrated wavefield as input, and adding a round-trip forward wavefield extrapolation (WFE), we obtain the multiple model in time domain.
3) Using the post-stack Wave-Equation Migration (WEM), we convert the predicted time domain multiple model, to the multiple model in the migration depth domain with the same migration velocity model.

Figure 1 is a 3D data example from GOM. Figure 1A is the migration velocity model. Figure 1B is the final migration image, which shows significant first-order residual multiple left in the final image. Figure 1C shows the well predicted multiples in the migration image domain including the weak second-order multiples.

For help with distinguishing primary from multiples, and understanding the causes of the multiples, it can sometimes be more meaningful to build a reflectivity model based on some specific horizons. The next example illustrates this using multiple prediction with interpreted water bottom, TOS and BOS horizons.

We have integrated this multiple prediction tool with our interactive salt model building tool based on interactive migration (Wang et al. 2008). Since this multiple prediction method is run in post-stack mode, it is very efficient and its response time is sufficient for an interactive application. The underlying concept for this prediction method is demigration, which is less sensitive to the migration velocity error. Often times, if the model is not very complex, even a 2D prediction is sufficient.

Using this interactive multiple prediction, the interpreter could quickly eliminate some of the salt interpretation scenarios, which are clearly multiple events. To gain better understanding of the source of the multiples, the reflectivity model is built based on interpreted horizons.

Figure 2 shows an example where the current BOS interpretation may be contaminated by the TOS multiple events. Figure 2A is the velocity model. Figure 2B is the migrated image generated from that model and Figure 2C is the predicted multiple model. Comparing Figure 2A, 2B, and 2C, we can see that the residual TOS multiple is at approximately the same depth as the interpreted BOS, which indicates there was a possibility of the residual TOS multiple being mistakenly picked as the BOS. The ability to visualize projected multiple locations can be a great aid during interpretation.

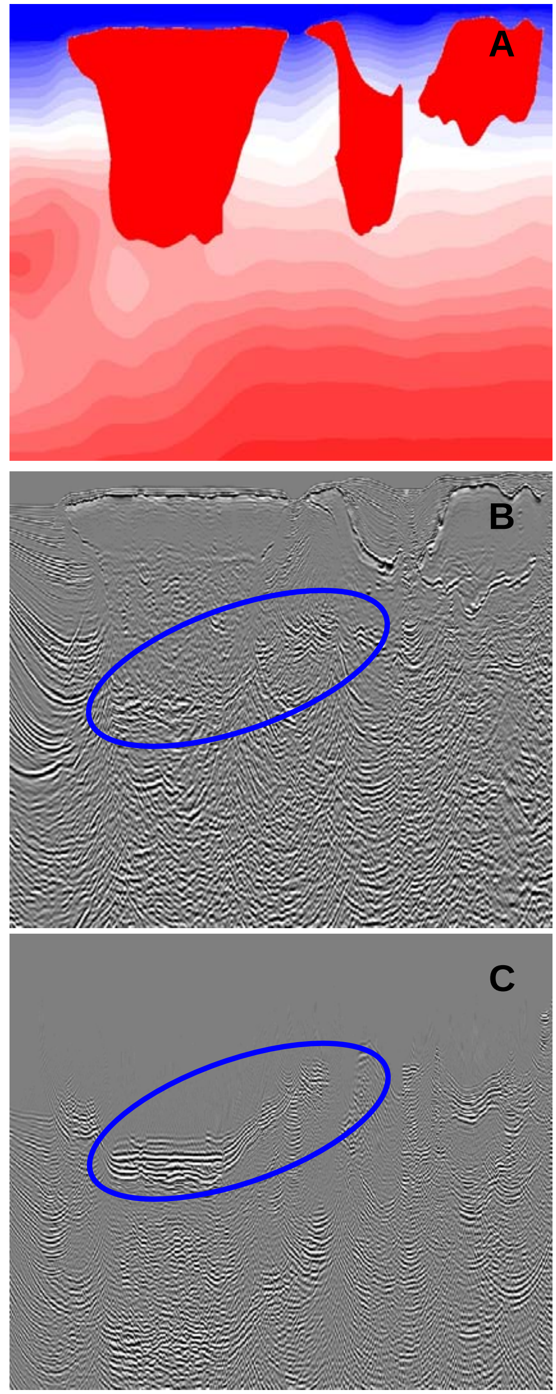

Figure 1: *A) Velocity model; B) Final migration image; C) Multiple model based on using migration image as the reflectivity.*

Inter-bed multiple prediction in migration depth domain

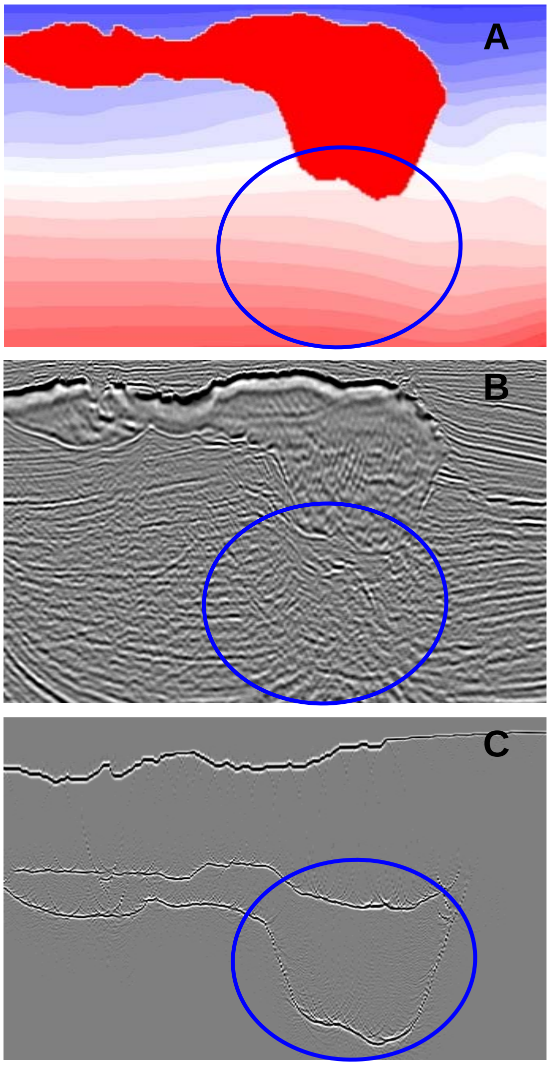

Figure 2: A) Velocity model; B) Final migration image; C) Multiple models based on horizon-based reflectivity.

The following are the main steps in this implementation:

1) Use the migration image (as the reflectivity model) and the migration velocity model to perform demigration to get zero-offset (post-stack) wavefield (Wang et al, 2005).
2) Input the demigrated wavefield, perform down-going one-way inverse wavefield extrapolation (WFE) to a subsurface datum which is sufficiently deep to include all the major inter-bed multiple generation interfaces. The wavefield is saved at each wavefield extrapolation step.
3) Starting from surface (or receiver datum), perform down going one-way forward WFE; at each depth step, add wavefield saved at step 2; and at the same time save the new composite wavefield.
4) Starting from this subsurface datum, perform one-way forward and upward wavefield extrapolation, at each depth step, add the saved wavefield described in step 3, after multiplying the reflectivity model which typically is the migration image.

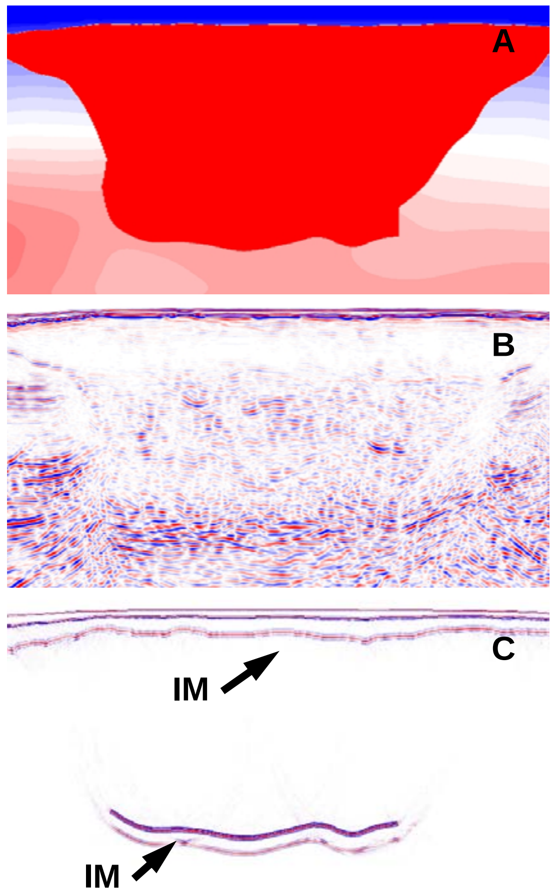

Figure 3: A) Velocity model; B) Final migration image; C) Primary plus predicted inter-bed multiples (IM).

Figure 3 shows an example of inter-bed multiple prediction in migration depth domain between water bottom and shallow TOS. Figures 3A and 3B are the migration velocity model and initial migration image respectively. Figure 3C shows the water bottom, TOS and BOS horizons and the resulting predicted inter-bed multiples.

Residual multiple removal in migration depth domain

This can be viewed as an advanced post-migration processing procedure. For what ever reason, when there are unacceptable residual multiples left in the final migration image this new methodology can be applied to reduce the residual multiples. There are two main steps of this methodology:

1) Create a multiple model in migration depth domain, using the method described in this paper.
2) Apply the attribute-based multiple subtraction techniques, which compares the seismic attributes (such as event-dip, absolute amplitude etc) of multiple model with the final migration image. The details are given in Guo et. al. (2008).

Figure 4 is the example of the post migration residual multiple removal by applying this new methodology. Figure 4A shows the predicted multiples which match closely the residual multiples in the original migration image in Figure 4B. Figure 4C show the results of the attribute–based subtraction applied on the migrated image. The water bottom peg-leg of TOS and BOS multiples are well predicted and removed. Primary reflectors are well behaved after the multiple removal.

Application to land field data has shown great promise and we expect to formally demonstrate this at presentation time pending approval of show rights.

Conclusions

We have developed a new and efficient method of predicting both surface-related multiples and inter-bed multiples in the migration depth domain using wave-equation based modelling. It operates in post-stack mode, and the multiple prediction model is in depth domain. Comparison of multiple prediction model with final migration image volume provides good information for seismic interpretation to avoid mis-interpret some residual multiple events as true subsurface structures.

Combining the multiple prediction method with the attribute-based subtraction method, we are able to reduce the residual multiples effectively in the final migration images in both land and marine data.

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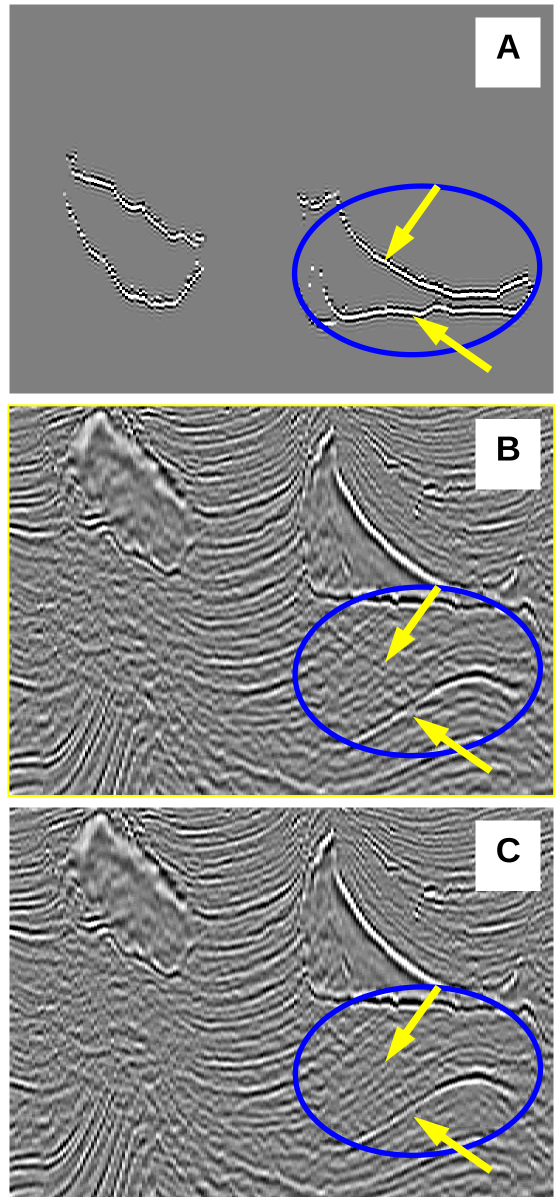

Figure 4: *A) Predicted multiples; B) Final migration image; C) After attribute-based multiple subtraction.*

EDITED REFERENCES

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