Summary

Reverse time migration (RTM) is theoretically more accurate than traditional migration methods because it computes numerical solutions to the complete wave equation. But RTM is computationally expensive especially for 3D data. To overcome this expense, Luo and Schuster (2004) suggested a bottom-up reverse time datuming (RTD) method that promised to significantly decrease the computational time for obtaining RTM images. Here we implement this idea for imaging of 3D synthetic data. The preliminary results indicate that the target-oriented RTD can reveal deep structures below the datum with less calculation effort than the full volume RTM.

Introduction

It is generally agreed that full-wave migration should be more accurate for accurately imaging waves that propagate through structures in highly complex media (Biondi, 2002). In contrast to Kirchhoff migration, RTM computes numerical solutions to the complete wave equation. Therefore, RTM usually provides more accurate seismic images than Kirchhoff migration, especially in highly complex media. But this technique is often not used in industry because it is computationally expensive.

As a cheaper alternative, target-oriented reverse-time data-datuming (Luo, 2002; Luo and Schuster, 2004) was proposed to extrapolate the wave field to a subsalt artificial datum using the expensive but accurate finite-difference full wave equation method. Instead of finite-difference (FD) solutions over a large area of point sources along the surface, they proposed FD solves over a small region in depth. Below the datum, a less expensive method such as phase shift or Kirchhoff migration can be used because the medium is less complex. Compared to RTM, RTD uses fewer FD solves. Thus, RTD takes much less computation time than RTM if the datum horizon is small. In this report, we apply the target-oriented RTD to a simple 3-D layered velocity model and 3-D SEG/EAGE salt model. Preliminary results show that target-oriented RTD can be much less expensive than traditional RTM.

Theory

Luo and Schuster (2004) expressed the RTD in the frequency domain as:

\[
d(x'|x'') = \int G^*(x'|x_s)G^*(x''|x_g)d(x_s|x_g)dx_sdx_g, \quad (1)
\]

where \(d(x'|x_s)\) is the input seismic trace in the frequency domain with a source at \(x_s\) and a receiver at \(x_g\); \(G(x'|x_s)\) and \(G(x''|x_g)\) terms represent the scattered Green’s function which propagates energy from the source point at \(x_s\) and \(x_g\) to the datuming points at \(x'\) and \(x''\) respectively; * denotes the conjugate. The redatumed data \(d(x'|x'')\) is the trace in the frequency domain with a source at \(x'\) and receiver at \(x''\). Equation 1 is very similar to the generalized equation for migration (Schuster and Luo, 2002) except that it does not apply the imaging condition. Equation 1 indicates that redatuming is the correlation of the data with Green’s functions, which play the role of extrapolating wave fields from one point to another. Accordingly, we can calculate the Green’s function by putting sources on the datum. Figure 1 depicts the key idea for target-oriented RTD, where the FD solves are for, relative to the large number of FD point source solves along the large surface plane, the small number of point sources along the datum plane.

![Figure 1: Green’s functions used in target-oriented RTD.](image)

Target-oriented RTD has several benefits. First, only the velocity model above the datum is used to calculate the Green’s function. No velocity model under the datum is required, unless turning waves are present. The redatumed data can then be imaged by less expensive methods in a less complex medium beneath the datum. Second, solving the wave equation for sources along the relatively small top of the target area along the datum plane is much
3D Target-Oriented Reverse Time Datuming

less expensive than solving the wave equation for many more sources along the free surface. In the 3-D case, it is computationally much faster than RTM in theory.

Numerical Results

We tested the target-oriented RTD on a simple 3-D layered velocity model depicted in Figure 2. There are three flat reflectors at depths of 625 m, 1375 m and 2000 m. The velocities of the four layers from the top to the bottom are 2000 m/s, 2200 m/s, 2400 m/s, 2600 m/s, respectively. We put the datum horizon at the depth of 1000 m. The synthetic seismic data are shown in Figure 3a. Figure 3b shows the computed Green’s function, with the source located at the datum and receivers located at the surface. Figure 3c shows a common shot gather on the datum after the reverse time datuming.

We also test the implementation of target-oriented RTD on a more complex model, the 3-D SEG/EAGE salt model. Figures 4 and 6 show 2D sections from the 3D velocity model for x = 2000 m and x = 2200 m respectively. The datum horizon is located beneath the salt, with a depth of 1240 m. Figure 5 shows 2D sections of the 3D migration results. Figure 5a is the Kirchhoff migration image obtained from the surface data; Figure 5b is the Kirchhoff migration image of the redatumed data. Comparison between these two sections shows that the migration image of the redatumed data has higher fidelity and is more accurate. Some structures, such as the faults, emerged in the migration image after redatuming, and there are fewer multiples in the redatumed migration image. Figure 7 shows similar results for another 2D section.

Conclusions

Reverse time datuming can back propagate the observed data to a datum accurately. Using the bottom-up approach of Luo and Schuster (2004) and target-oriented strategy, we can achieve greater computational efficiency. The preliminary results show that target-oriented RTD can effectively mitigate the effects of strong velocity variations. After redatuming, an inexpensive Kirchhoff method is used to image sediments beneath the datum. The resulting image is comparable with a RTM image with much less computation. Quantifying this reduction in computational expense is a goal for future research.

Acknowledgments

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Figure 4: Section of 3D SEG/EAGE velocity model at x=2000 m. The white line indicates the location of the datum horizon at the depth of 1240 m.

Figure 6: Section of 3D SEG/EAGE velocity model at x=2200 m. The white line indicates the location of the datum horizon at the depth of 1240 m.

Figure 5: 3D migration images of SEG/EAGE salt data at x=2000m. (a) Kirchhoff migration image obtained from the surface data; (b) Kirchhoff migration image obtained from redatumed data.

Figure 7: 3D migration images of SEG/EAGE salt data at x=2200 m. (a) Kirchhoff migration image obtained from the surface data; (b) Kirchhoff migration image obtained from redatumed data.
EDITED REFERENCES
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REFERENCES