Layer-stripping RTM based on wavefield redatuming

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Summary

Tilted Transverse Isotropic (TTI) Reverse Time Migration (RTM) is routinely used for depth velocity model building. To improve the efficiency of RTM we have developed an approach called layer-stripping RTM. For this method, we divide the model into two or three horizontal regions, then run RTM sequentially from top to bottom. The key ingredient for layer-stripping RTM is wavefield redatuming. For the top region, we run a regular RTM and save the wavefield at the bottom of the top region. The saved, redatumed wavefields become the input for the subsequent, deeper RTM run. This method can dramatically reduce computation cost and improve the efficiency of model updates, because we do not need to repeat the shallow wavefield extrapolation, and the grid size of the deeper migrations can be increased. Additionally, we present solutions to practical issues such as the 3D data explosion problem of redatumed wavefields.

Introduction

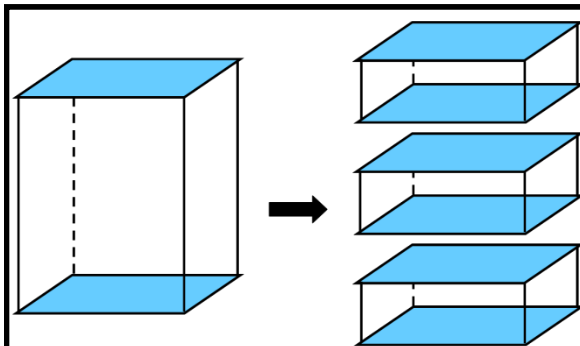
In complex geological areas such as the Gulf of Mexico (GOM), TTI RTM has been routinely used for velocity model building. In a typical GOM imaging project, multiple iterations of TTI RTM imaging are required for velocity modeling. Due to the large velocity contrast between the low velocity sediment and the high velocity salt, the accuracy of salt geometry has a first order impact on subsalt imaging. Because of the complexity of a typical GOM velocity model, ray-based migration algorithms such as Kirchhoff migration and beam migration may not be sufficient to produce acceptable subsalt imaging quality. It has become commonplace to find imaging projects that require three to ten TTI RTM runs in order to test different interpretation scenarios for the Base of Salt (BOS), before finalizing the BOS interpretation.

To allow multiple iterations of RTM while keeping the turnaround time within reasonable limits, we need to dramatically improve the RTM efficiency. We have developed an efficient variant of TTI RTM called layer-stripping TTI RTM. The key ingredient for layer-stripping RTM is wavefield redatuming (Berryhill, 1984; Bevc, 1997; Schuster and Zhou, 2006; Wang et. al., 2006).

By performing RTM using a redatumed wavefield below a subsurface datum, not only is the model size reduced, but also, and more importantly, the computation grid size can be increased. In this way layer-stripping RTM can achieve an order of magnitude speed-up for later iterations of RTM runs. Another benefit of layer-stripping RTM is that it reduces the computer hardware requirements such as memory and local disk size (Guan et al., 2009), enabling the running of higher-frequency TTI RTM jobs using existing computer hardware.

In this paper, we will describe the methodology of the layer-stripping RTM and present solutions to some of the practical issues of RTM using redatumed wavefields, such as the 3D input data explosion problem. We also demonstrate its effectiveness by showing some applications on real 3D data sets.

Layer-stripping RTM methodology



Each region can be migrated sequentially

Figure 1*: A model is divided into three horizontal regions, and RTM is run sequentially from top to bottom.*

As illustrated in Figure 1, for layer-stripping RTM, we divide the model into two or three horizontal regions and run RTM sequentially from top to bottom, For the top region, we run a regular RTM. When we run RTM for a shallow region, we save the wavefield at the bottom of the region. These saved redatumed wavefields become the input for the subsequent RTM run.

Figure 2 is a schematic diagram for wavefield redatuming. RTM is typically implemented in the shot domain. Wavefield redatuming is required on both the source side and the receiver side. As illustrated by Figure 2, a point source on the surface becomes an area source on the subsurface datum.

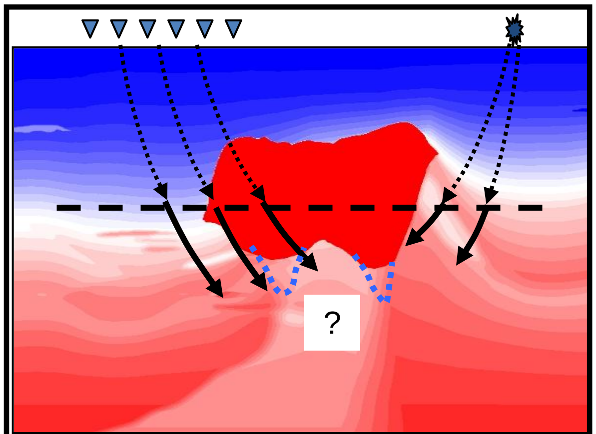


***Figure 2**: Schematic diagram showing redatuming of both receiver side and source side wavefields from the surface to a subsurface datum.*

RTM-based wavefield redatuming possesses a number of important benefits. For example, the computation cost can be dramatically reduced by performing RTM using only a redatumed wavefield below the subsurface datum. This reduction is due to a number of factors. Firstly, the computation grid size can be greatly increased without introducing dispersion noise, because the minimum velocity typically increases with depth. For example, assuming the minimum velocity is increased from 1.5 km/s at the surface to 2.5 km/s at the redatuming surface of 6 km depth, the computation grid size can be increased by a factor of 1.67. The speed-up scales as the fourth power of the grid size, considering three dimensions in space and one dimension in time. For this example it translates to a speed-up by a factor of seven.

Secondly, migrating from a subsurface datum reduces the computational model size. Actually the speed-up scales at least as the second power, because in addition to depth range reduction, the wavefield propogation time is also reduced. In fact, the deeper part of the velocity model is typically faster than the shallow part, therefore the number of time steps of wavefield propogation for the deeper part is further reduced.

Thirdly, the migration aperture for the shallower runs can also be greatly reduced since the required migration aperture is linearly proportional to the target depth. The computation savings due to the smaller required aperture is true for both the RTM-redatuming step as well as the subsequent multiple RTM runs using the redatumed wavefield. Additional cost savings can also be achieved by identifying and pre-selecting only those input shots which contribute to, or illuminate, the target areas.

Even though layer-stripping RTM can dramatically speed up the computation, it is able to maintain the RTM image quality. Figure 3 shows an example of an impulse response comparison between a regular TTI RTM and layer stripping TTI RTM. The layer-stripping TTI RTM impulse response is accurate and very comparable to the regular TTI RTM impulse response. The overturned events in Figure 3B demonstrate that the TTI RTM using the redatumed wavefield as input maintains the steep-dip and turning wave capability of two-way propagators.

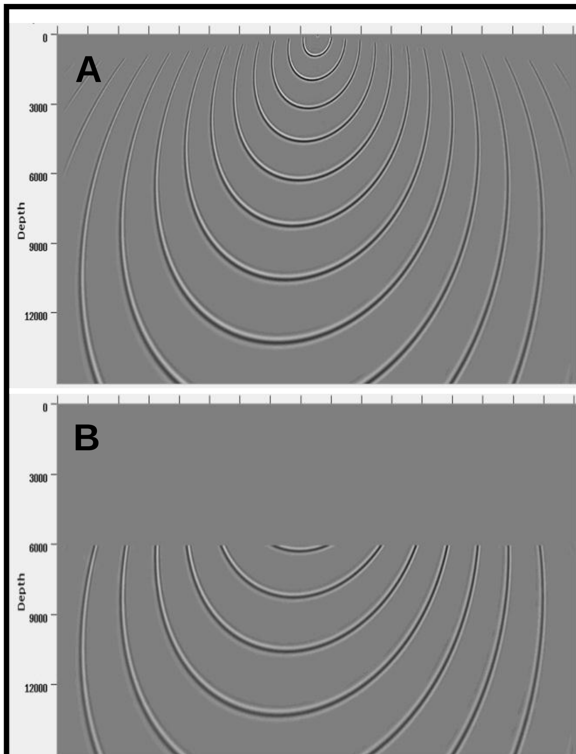


***Figure 3**: Impulse response: A) Regular RTM; B) Layer-stripping RTM using redatumed wavefields.*

Among practical issues for layer-stripping RTM is the input data handling of redatumed wavefields. There is a well-known problem with 3D wavefield redatuming called "data explosion". For a typical marine Narrow Azimuth (NAZ) survey, each shot has between 6 and 10 cables. For a WAZ survey, each supershot has up to 100 cables. However, after wavefield redatuming, the wavefield has to be sampled at every computation point on the redatumed surface, which will translate to hundreds or even thousands of lines. Additionally, both the receiver wavefield and source wavefield need to be saved at every computation grid point on the redatumed surface which typically increases the input data size by one to two orders of magnitude. This poses problems for the computer hardware in storing the data on the local disk and handling network bandwidth to efficiently transfer the data.

To solve this input "data explosion" problem, we have developed a 3D wavelet transform based data compression technique that is typically able to achieve 30 to 50 times data compression ratio. Figure 4 shows an example of data compression. With a 30:1 compression ratio, the difference between the original data and compressed data is negligible.

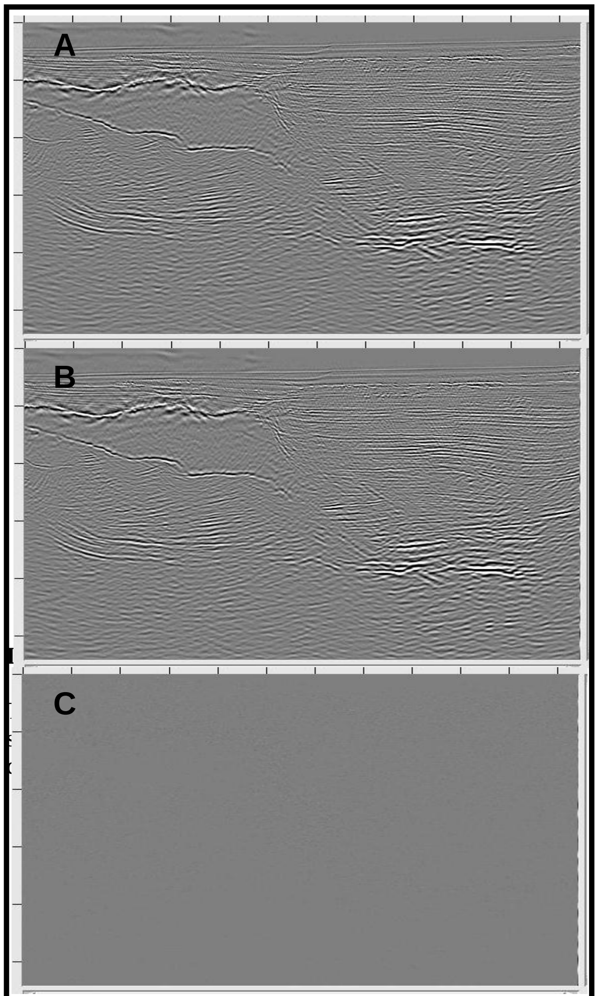


***Figure 4**: Wavelet transform based seismic data compression. A) Uncompressed data; B) With 30:1 compression ratio; C) Difference between A and B.*

Layer-stripping RTM applications

As indicated by Figure 2, layer-stripping RTM is ideally suited for testing different salt interpretation scenarios, such as testing the depth of a salt keel. Layer-stripping RTM has been applied to several production projects. Figure 5 shows a production example, where layer-stripping RTM was used to test different salt velocity models. For this example, three salt velocity models are prepared, and one layer-stripping RTM is run. Three velocity models were input into a single run, which not only makes it more efficient, but also saves the processing geophysicist time. By comparing the RTM images, our interpreter chose the salt interpretation shown at the bottom of the left column for the final model, based on subsalt event focusing and event dip orientation which fits the regional trend better.

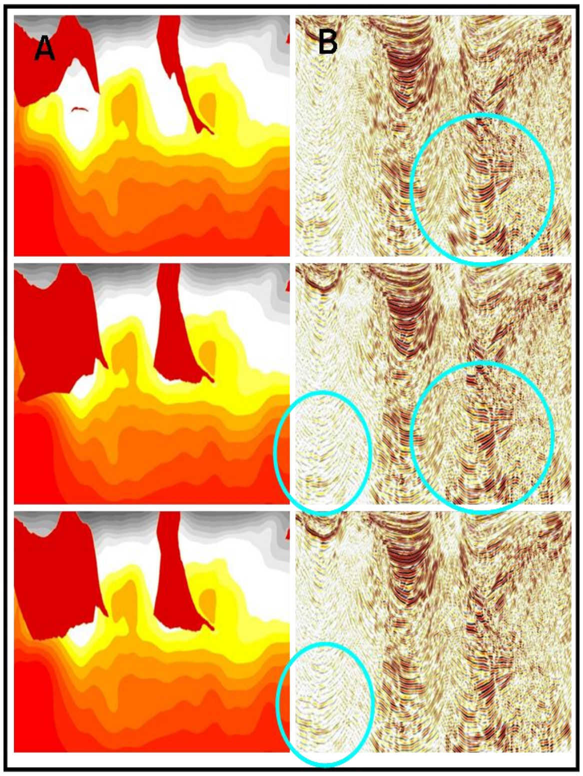


***Figure 5**: Testing velocity model scenarios. A) Velocity model; B) Corresponding Layer-stripping RTM*

Another benefit of layer-stripping RTM is that it provides the opportunity to optimize the computer resource usage. Typically, the data in the shallow part has more frequency content than the deeper part, such as in subsalt areas where, due to the attenuation or back-scattering, not much high frequency signal is present. Typically, we can run a little higher frequency for the shallow part to gain a high resolution image which also helps with the Top of Salt (TOS) definition. Higher frequency plus low minimum velocity demands a smaller computation grid size which translates to high CPU computation and large memory and local disk requirement. With layer-stripping RTM, we can easily achieve this by setting a smaller maximum depth, and, because the image target is shallower, we can also use a smaller migration aperture.

As indicated by the impulse response (Figure 3), layer-stripping RTM produces comparable image quality to regular RTM. If a smaller than required grid size is used in the shallow (to avoid dispersion noise), then the image quality of the deeper layer-stripping RTM could be even better than that of the regular RTM, because more signal is accurately preserved. As indicated by Figure 6, for the deep part of the section layer-stripping TTI RTM and the regular TTI RTM produced comparable image quality. For this project, during the layer-stripping RTM run for the shallow part, we used a smaller than required grid size which resulted in even better image quality for the deeper part than the regular RTM. In the highlighted subsalt area, layer-stripping RTM produced slightly better image quality, especially in the shallow area where more events show up and event termination towards the salt boundary was also improved.

Conclusions

We have developed an efficient variant of TTI RTM called layer-stripping TTI RTM. The quality of layer-stripping RTM in general is comparable to regular RTM. Among the many benefits of layer-stripping, are the ability to speed up the computation time and the ability to optimize the computation resources. This enables higher-frequency RTM to be run using existing computer hardware. One key ingredient for layer-stripping RTM is shot-based wavefield redatuming. One practical issue is the 3D input data explosion problem. We solved this problem by 3D wavelet transform based data compression. The layer-stripping RTM is ideally suited for velocity model building, especially when multiple salt interpretation scenarios need to be tested before the final salt interpretation.

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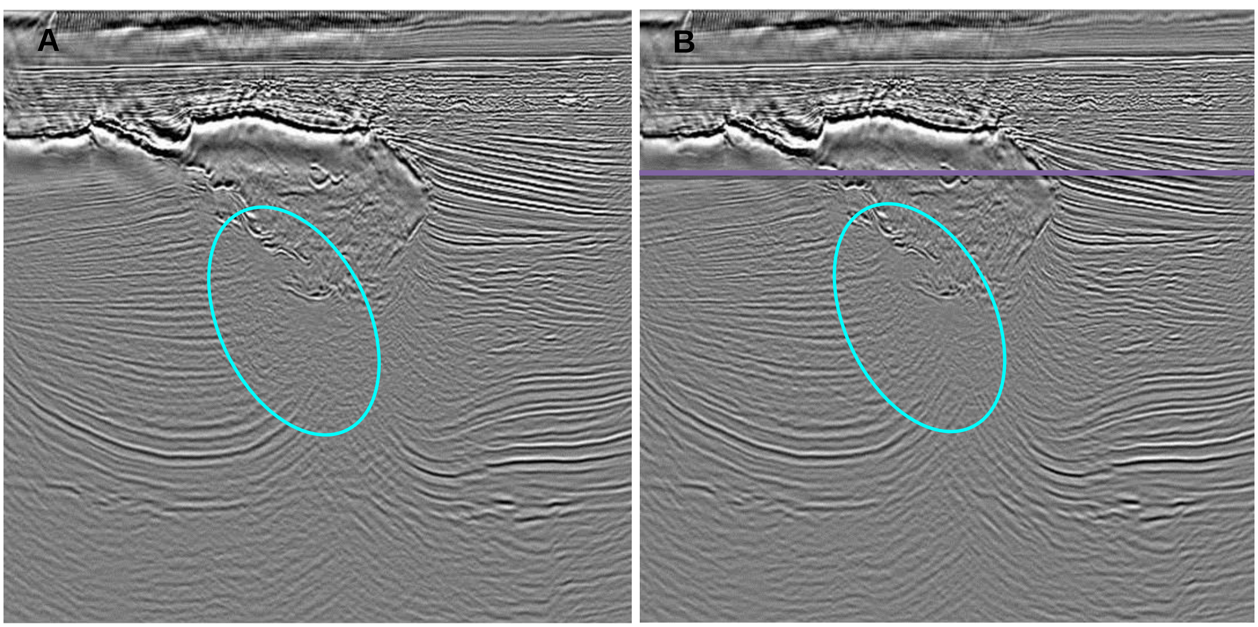

***Figure 6**: Comparisonn of regular RTM and layer-stripping RTM. A) Regular RTM image; B) Layer-stripping RTM images using the same velocity models.*

EDITED REFERENCES

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