Wave Equation illumination using RTM
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Summary

Despite recent dramatic advances in data processing and imaging algorithms, optimizing the acquisition geometry of seismic data still has a dominant effect on the quality of the seismic image. Optimizing acquisition is especially important when heterogeneous geology, such as salt, and acquisition holes caused by obstacles create irregular illumination.

We present several methods for analyzing illumination by using the same RTM that will be later used for imaging the acquired data. These methods are:

1) Migration of white noise filtered along dip of a desired horizon
2) Migration of white noise filtered for fault resolution along a horizon
3) Modeling and RTM migration of density blocks.
4) Analysis of the RTM imaging contribution of each shot to the illumination of a target.

We demonstrate these methods on the SEAM Gulf of Mexico model and compare our predicted results with the actual images.

Using RTM with its accurate wave propagation provides a wave equation based measure of illumination. Just as RTM was shown to produce better migration images than ray tracing Kirchhoff migration methods, we think wave equation migration methods are more accurate than conventional ray tracing illumination methods.

Resolution of faults is often a vital feature, but since illumination is direction based, illumination maps of horizons do not accurately predict whether the faults are smeared. However, proper horizon analysis of RTM noise output and density block modeling can predict whether faults are smeared.

Moreover, using the same or similar RTM for illumination analysis as for later imaging provides a more accurate prediction of the expected target resolution than using a different imaging algorithm. Not only do RTM algorithms provide some illumination balancing that we want to capture in analysis, there are other algorithm features that influence imaging that are best captured by

Introduction

Earlier work on resolving illumination focused on ray tracing for efficiency. These methods focused on producing illumination maps of target horizons. Examples of these ray based illumination methods are: Duquet et al, 1998; Schneider and Winbow, 1999; Bear et al, 1999; Muerdter and Ratchiff, 2000; and Muerdter, et al, 2001. Wave equation migrations methods were not commonly used at the time of these publications.

The importance of using wave equation methods for illumination analysis has been previously recognized by Laurain et al, 2004; Xie et al, 2006; Alve et al, 2009; Gherasim et al, 2010; Lapilli et al, 2010; da Silva et al, 2011.

Forward modeling and RTM testing of synthetic data for illumination has been used to motivate initial wide azimuth marine acquisition (Regone 2006, and Regone 2007) and circular acquisition (Moldoveanu, 2008).

We believe our use of white noise and density blocks are new. Density blocks in particular are a nice tool since they produce a migrated 3D result that directly shows predicted image quality. The edges of the blocks show the resolution of horizon termination, which predicts fault imaging.

Migration of white noise filtered along dip of a desired horizon

Migrating traces with white noise has the advantage of producing all dips in the image. The white noise migration of each shot can be filtered after migration to analyze the strength of the different dips present in the image as a measure of illumination.

A weakness of white noise illumination is that for a given shot if many receiver traces contribute to the illumination of location, the amplitude goes up by only \( \sqrt{N} \), rather than \( N \). This will create a bias to fewer high amplitude traces illuminating a location.

Migration of white noise filtered for fault resolution along a horizon

Resolution of faults is often critical to interpretation and reservoir characterization. However, illumination of the horizon dip does not contribute to illumination of faults on that horizon. Indeed, if only the dip of the horizon is illuminated strongly, then the faults will be smeared. Resolving faults requires illumination of many dips except those of the horizon. To analyze fault resolution, we sum these other dip illumination strengths along a horizon.
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Modeling and RTM migration of density blocks

Density blocks in particular are a nice tool since they produce a migrated 3D result that directly shows predicted image quality. The edges of the blocks show the resolution of horizon termination, which predicts fault imaging.

We produce the density block images by first moderately smoothing the sediments of the original SEAM model. We do this to eliminate sediment velocity reflections. We keep the salt shape exact since that is key to proper illumination.

We also smooth the density in the sediments to eliminate sediment density reflections. We then insert the density block variations such that the reflection strength of all the top and bottoms of the blocks should be of equal strength.

Analysis of the RTM imaging contribution of each shot to the illumination of a target

Often, one wants to identify which shots and what receiver pattern best illuminates a given target. This has been called visibility by Xie, Jin, and Wu, 2006.

One can perform this identification by either inserting a density block at the target or from white noise analysis. When performing shot migration of either the target density block or white noise, we individually analyze the result of each migrated shot to identify the image strength of the target for that shot.

Examples:

- Figure 1: SEAM model salt geometry.
- Figure 2: Migration of the SEAM data at Y=21,200.
- Figure 3: SEAM velocity slice at Y=21,200 after mild smoothing of the sediments.
- Figure 4: Horizon amplitude analysis of white noise RTM. The amplitude is the illumination strength of the dip along the horizon. The outline of the salt is marked for reference. Note the low amplitudes under the salt.
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Figure 5: Horizon amplitude analysis of white noise RTM. The amplitude is the illumination strength of faults along the horizon. Note the amplitude pattern under the salt changes significantly.

Figure 6: Horizon amplitude map of the Miocene 2 horizon for white noise RTM. The amplitude is the illumination strength of the dip along the horizon.

Figure 7: Horizon amplitude map of the Miocene 2 horizon for white noise RTM. The amplitude is the illumination strength of the faults along the horizon.

Figure 8: Density used for modeling with the blocks.

Figure 9: RTM of the density blocks without amplitude balancing in the RTM.

Figure 10: RTM of the density blocks with amplitude balancing in the RTM. Image under the salt changes significantly.

DOI http://dx.doi.org/10.1190/segam2013-1438.1
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Figure 11: Horizon amplitude map of the MCU horizon for density block RTM. Amplitude balancing was not performed.

Figure 12: Horizon amplitude map of the MCU horizon for density block RTM. Amplitude balancing was performed.

Figure 13: Marked horizon is used for target visibility analysis.

Figure 14: Map of amplitude strength of the shot images that contribute to the target horizon. This is a measure of how much each shot contributes to the resolution of the faults on the target horizon. Amplitudes are measured from white noise RTM. Shot spacing is 600x600 meters.

Conclusions

Using existing RTM algorithms provides a straightforward approach to performing wave equation illumination analysis. This is a direct, reliable way of predicting imaging quality.

Illumination analysis using RTM is flexible and can provide different types of valuable illumination information.

Acknowledgements:

We thank Landmark for making this paper possible by providing cluster resources, the processing software, and the interpretation analysis software.
EDITED REFERENCES
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REFERENCES


