



Automated geometry corrections on deep-marine seismic data using direct arrivals and non-linear refraction tomography

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Keywords

Non-linear refraction tomography, automated geometry corrections, direct arrivals, RMS misfits, Pick Similarity

Summary

Direct arrivals are often discarded in the usual marine data processing workflows. Again application of refraction tomography is mostly applied to land data, and rarely in deep-water marine data. The following study combines these two elements into an innovative workflow designed to reposition half the shots in a vintage marine survey populated with erroneous shot coordinates on the headers. The workflow has an in-built auto-correction that precisely repositions all the incorrect shots with the desired accuracy, without affecting the correctly positioned shots. The study shows the direct impact of this process by comparing the stacks before and after the application of this workflow. The value-addition obtained in the final deliverable by this workflow is also demonstrated by comparing the reprocessed stack with a legacy output.

Introduction

Geometry corrections are one of the most crucial parts of the processing sequence. In land seismic data processing, we usually find many examples of instances where geometry corrections are common due to logistics or some unforced errors during acquisition or reporting. These errors are usually very scattered and irregular in occurrence and pattern. However, in marine data, finding geometry errors are uncommon.

We might find geometry corrections necessary in exceptional conditions, especially working with vintage navigation merged marine datasets. The associated textual information in the headers or separately available logs is either not archived or difficult to obtain. The source of these errors can be due to various reasons starting from typographic errors or even as subtle as reporting incorrect shot positions, especially during flip-flop streamer data acquisitions.

The detection and correction of geometry errors in land data are usually performed by thorough quality checks of the applied first break mute and offset plots (Raef, 2009). These corrections are mostly performed interactively by the user. More recently, we often use the amplitude maximum of the first arrivals, linear move-out plots, etc., to correct these (Martin, 2001).

The problem mainly associated with any automation is precision, with which even small errors may be detected and rectified. The accuracy of the rectification is again another

concern. So the methodology that needs to be adopted should address the accuracy and the precession to a reasonable extent and simultaneously be efficient.

This study proposes a time-efficient and automated method that uses weak direct arrivals of deep marine data and non-linear refraction traveltome tomography (Zhang and Toksoz, 1998) to detect and correct positioning errors with the desired precision. The main efficacy of this workflow is that it is so designed that the errors if introduced (by the workflow), can be autocorrected within subsequent iterations.

Input Data

The present dataset was vintage deep-water 3D seismic data acquired a few decades ago. It is a four-streamer data with a cable length of 5100 m. The total number of channels was 204 per streamer. The source array center separation was 100m. The shot point interval was a 25m flip-flop.

The streamer depth was 7m, and the gun depth was 5m. The record length is 7168 ms and a sampling interval of 2ms. A low cut of 3Hz was applied to the data during acquisition.

Methodology

Direct Arrivals and Refraction Tomography

The first arrivals recorded in the data are used to estimate the velocity model of the near-surface. The extent to which this model will be valid is decided mostly by the velocity and the available offsets distribution.

In land, seismic data processing, this technology is often used to estimate the near-surface layer. It serves the crucial purpose of compensating the statics, and until more recently, they are used to update the depth velocity model for imaging.

In deep-water marine seismic data, it is counter-intuitive to apply this technology, which has a water depth of more than a kilometer, of near-homogeneous water velocity. Also, the offset range is only 5100 km, with no recorded earlier arrivals, but only direct arrivals from the water layer.

Indeed, this makes applying this technology in our workflow for auto-correction of acquisition geometry very intriguing. The idea that the velocity of the water layer is nearly constant, and can be easily estimated from flattening the linear direct arrivals is the basis of the workflow.

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Issues with the data

The vintage 3D marine seismic dataset used in the study is one instance wherein we are introduced to an error in reporting flip-flop shot geometry. This means all the shots are positioned along one line, as the navigation was recorded from only one shot array (Figure 1). This means all the alternate shots were in error. This does not necessarily mean we can rectify the errors by choosing the odd or even shots, as the pattern reverses as the sail-line changes after recording odd number shots. Secondly, as the sail-line changes, the direction of the ship changes, which means, the shot repositioning takes place in an opposite direction (see Figure 1 for details.). So, a single shift cannot be applied to alternate shots directly.

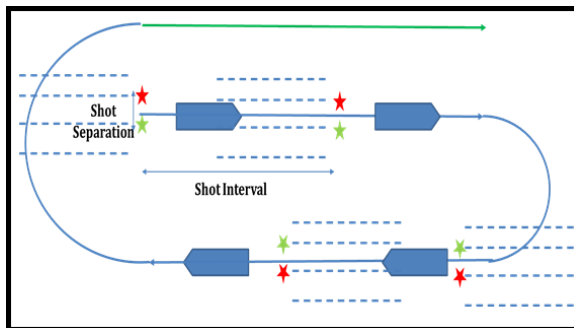


Figure 1. Schematic diagram of a flip-flop geometry. The navigations are only reported from the green shots, so the red shots are always in error. Now as the sail line and the ship's direction changes, the shift direction for repositioning also changes.

This error was present in the whole dataset, which means we see half the shots were reported incorrectly. Again, since the separation between the shots is only 100m (shot-array center separation), the error is difficult to detect for existing automation since the deviation in the shots is very little and regular. More importantly, since the error is regularly detected in half the shots, many automation methods might see this as a pattern and completely ignore errors in some shots.

So the required workflow should identify incorrect shots, annotate the sail line's direction, estimate the shift distance, and then reposition the shots to their correct position in space.

Workflow

The coordinates are rotated along the sail line at the beginning of the workflow (Figure 2). This ensures a vertical shift (Y-coordinate) in either a positive or a negative direction. We pick the first breaks on all the shots within a restricted offset of 1000 m. The direct arrivals are often weak, so the trace-to-trace deviation in the picks should be kept to a minimum, during picking. The picks can be sparse

but not erratic, which is crucial for the success of this method.

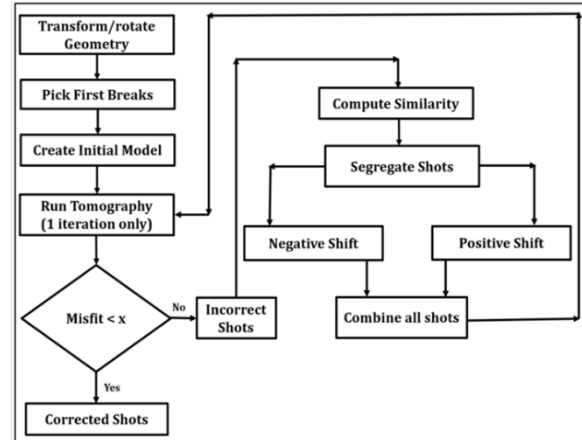


Figure 2. The adopted automation workflow

We create an initial model of a constant velocity of 1480 m/s, the water velocity. This velocity can be determined by flattening the direct arrivals with a linear move-out (LMO). We run one iteration of non-linear refraction tomography with this picks over the constant velocity initial model. Here, we restrict to one iteration, because we do not want tomography to update the model with the picks, but rather generate an RMS misfit map of each shot. The misfit is calculated by the L_2 norm of the observed (t_{obs}) and calculated (t_{cal}) traveltimes on each shot.

$$\varepsilon = \|(t_{obs} - t_{cal})\| \quad (1)$$

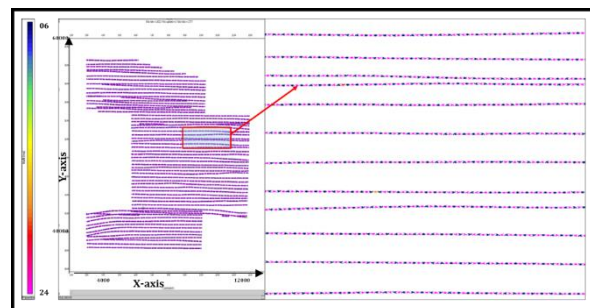


Figure 3. The plot of RMS misfit values on each shot over the entire survey. In the zoomed area, the blue colour shots are one with small misfits (correct geometry) and the pink colour shots are having incorrect geometry showing high misfit values.

Generally, a high misfit would prompt that there is either an error in the pick, model, or coordinates. Since our picks are along the direct arrivals, and we have restricted any trace-to-

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trace deviation, it can be safely assumed that the picks are all right. Secondly, the velocity model is assumed to be homogeneous and constant. Therefore, the contribution to the large RMS misfit value is due to the error in shot coordinates.

As apparent from Figure 3, the RMS misfit value shows a strong contrast and hence can be used to identify the shots with error. The shot-to-shot pick similarity is another tool that can identify the direction of the sail line. Mathematically, it calculates the L_2 norm of the difference in picks in one shot (t_i) with a reference shot (t_{ref}) defined below in (2).

$$\sigma_i = \|(t_i - t_{ref})\| \quad (2)$$

Thus, the shooting direction changes when the sail direction changes, so the trace-to-trace picks difference will be large, and a high similarity value is being prompted. The higher values indicate dissimilarity, hence a change in the direction of the sail line. This is observed in Figure 4; the zoomed portion of the map indicates a zone where we see changes in direction.

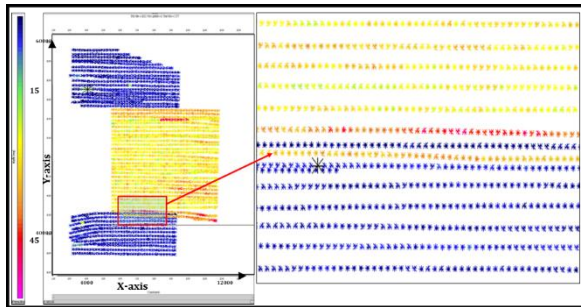


Figure 4. The plot of shot-to-shot similarity value, the zoomed portion on the right clearly shows shots oriented along the same sail line having low similarity (blue) the one oriented in the opposite sail line with a relatively high similarity value.

Using these two mathematical relations (1) and (2), we can identify the shots with incorrect geometry and the direction of shift, to be applied on those shots to reposition them correctly.

The amount of the shift is equal to the shot array separation distance. A few shots were isolated from the data, and this shift value was verified on those shots to ensure the accuracy of the shift before applying it to the entire data.

Thus with this workflow, we can precisely identify the shots with incorrect shot coordinates over the entire survey, filtering out nearly half the shots. The pick-similarity filter further decides the direction in which the shift has to be applied to reposition the shots with reasonable accuracy correctly. Once all the shots are rectified and repositioned, we rotate all the shots back to the original coordinates.

Results and Discussions

The workflow was applied to the data consisting of more than 17000 shots, and all shots with errors in the shot coordinate were repositioned within a few hours. The sheer volume of the required corrections was daunting initially, but the errors in the entire data could be fixed with a very innovative approach.

Another feature of the workflow is that the quality check is built into the workflow. This means if we re-run the workflow again on the corrected shots based on the RMS misfit, we can find any remnant shot which is incorrectly positioned and can be rectified if required. However, for this particular data, all the shots could be fixed in one iteration of the entire workflow.

The LMO-applied shots are plotted before and after geometry corrections. Before corrections, (Figure 5 (a) and (c)), the shot in the left (incorrect position) shows an inappropriate move-out. These two shots are chosen from different sail-line directions to highlight the properly applied coordinate shifts. The shots after the coordinate corrections (Figure 5 (b) and (d)) looks properly positioned. The shots whose coordinates were correct were left unchanged. This suggests that the workflow does not perturb the shots with proper coordinates.

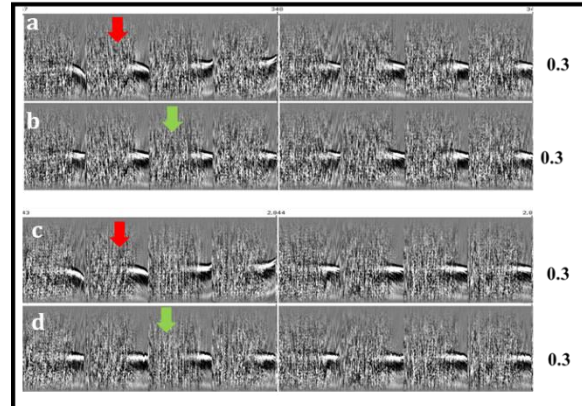


Figure 5. (a) Two shots with incorrect (left) and correct (right) shot coordinates are shown after applying LMO, (b) The same two LMO applied shots after geometry corrections. (c), and (d) shows similar alignment of direct arrivals on two separate shots chosen from a different sail line direction.

Another validation of the efficacy of the workflow is provided by comparing the stacks before and after the automated geometry corrections. The improvements are observed quite clearly in the in-line and cross-line stacks, as indicated with arrows (Figures 6 and 7). The impact of the corrections is prominently visible, especially in the sea-floor reflector, in both inline and cross-line stacks. A very basic

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processing flow was used to create both stacks, but we still see that the diffractions and other deeper events have been rendered clarity after automatic geometry corrections. However, the improvements noted in the in-line stacks are subtle, but when we compare the cross-line stacks, we see major changes in the reflector stand-outs.

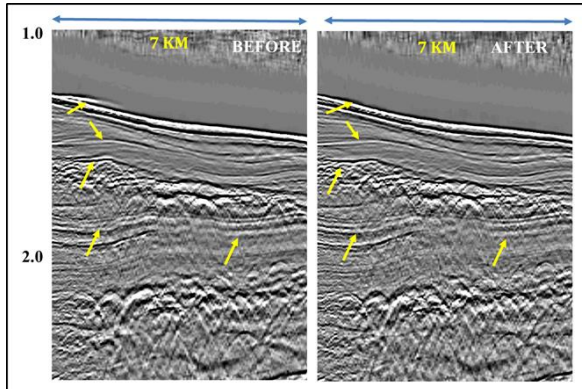


Figure 6. Representative Inline Un-migrated stacks before and after automated geometry corrections.

As apparent from the Figure 7, the improvements in the cross-line stacks are more emphasized after the corrections. Since the shifts were vertical, it was anticipated that after repositioning the cross-line wavefield would be better sampled in space.

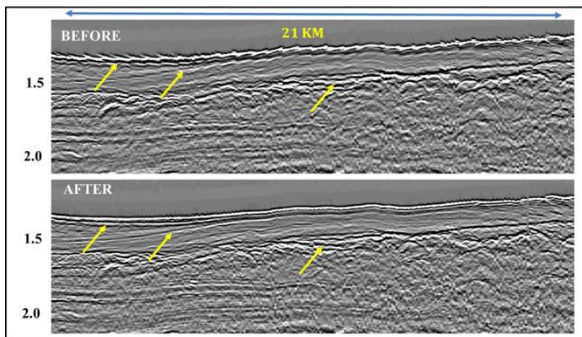


Figure 7. Representative Cross-line Un-migrated stacks before and after automated geometry corrections.

Geometry corrections are basic in nature but they would influence all processes which are applied further in the data. Therefore, any errors in geometry would definitely impact the efficacy of any advanced processes applied to the data. No processes can outbalance an incorrect geometry header, in fact, they might potentially degrade the final image quality. This is one reason perhaps the legacy processed

KPSTM data shows a completely different image as opposed to the final results obtained from advanced depth migrations as shown in Figure 8. Once we analyze the legacy time migrated stack, we clearly see imprints of un-collapsed migration impulse response all throughout the stacks, remnant multiples, and overall noisy unfocussed events. The deeper section does not contain the detailed toe-thrust structures which are expected in this geological setting and are visible in the reprocessed data. The reprocessed image shows a clear improvement and a major reason for this improvement can be attributed to geometry corrections, which have enhanced the efficacy of all other sophisticated processes applied in re-processing. These strongly suggest the importance of the innovative workflow undertaken in this study. Moreover, these corrections were performed in an efficient manner with required accuracy and precision.

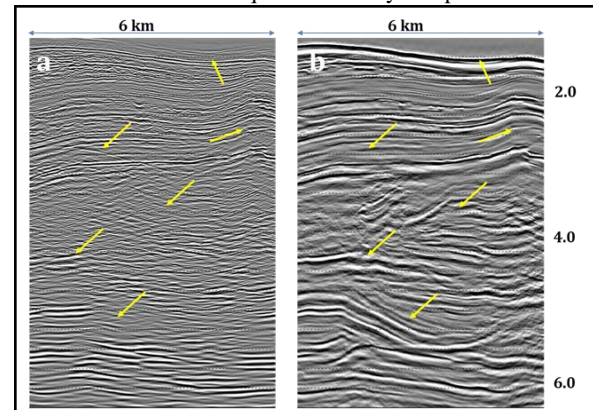


Figure 8. a) Legacy PSTM Stack, b) Reprocessed Depth Migrated Section post automated-geometry corrections, enhancing efficacy of all subsequent processes.

Conclusions

The issue discussed here is different from usual shot positioning-related errors, where we normally see the errors more dispersed and comparatively less in number. Here we have nearly 50 percent of erroneous shots. The error is also evenly distributed and regular spatially, making it difficult for existing methods. The method discussed here is quite innovative and practical and provides a quick and efficient solution, as timelines are critical for production processing. The precise impact this method of automated repositioning provides on the final stack is also commendable and further suggests the accuracy with which shots are repositioned. This method, with some minor modifications, can also be used for rough sea surface correction in high-resolution marine seismic imaging or to reposition ocean-bottom nodes by using direct arrivals.



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Acknowledgments

The authors are thankful to Mrs Sushma Rawat, Dir. (E), ONGC, for permitting the publication of this work. The authors acknowledge Sh J P Dobhriyal, CGM-HOI, GEOPIC, ONGC for providing the infra-structural facilities to carry out the work. The authors also express their heartfelt thanks to Sh. Ranbir Singh, CGM-Head Processing, for his constant suggestions and motivation to do this work. The authors also acknowledge the support and advice received from colleagues throughout this study.

The views expressed in the above article are entirely of the authors and not the organization.

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