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High-resolution Moveout Transform - A Robust Multiple Attenuation Technique

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SUMMARY

As an alternative to the conventional high-resolution Radon transform, we propose a time-domain approach to transform a gather of pre-stack seismic data into a gather of highly-resolved traces in the transformed domain. Using a range of various velocity functions in a standard NMO correction routine we iteratively identify the most energy-bearing functions and transfer the corresponding stackable energy consecutively. Iso-moveout functions can be used to avoid the distortions related to the NMO stretching. Application to synthetic and real data has shown improvements in resolution and performance. Higher resolution results in less ambiguous aperture compensation and therefore more successful reconstruction of stackable seismic events in the large gaps of missing data. This feature helps to improve the accuracy of modeling multiple events particularly in the near offset zone.

Introduction

The Radon transform is commonly used in seismic data processing especially for modeling and subtracting multiple events that have enough moveout separation relative to the primary events. The least-squares criterion involved in the standard Radon transformation results in a model in the transformed domain that when inversely transformed back to the time-offset domain, the difference with the original data is minimal.

The high-resolution Radon transform is a more advanced variety that improves the resolution in the transformed domain by introducing an extra constraint in the form of sparseness weights (Sacchi and Ulrych, 1995). This criterion requires extra computation but helps to reduce the overlap between the adjacent events in the transformed domain.

We introduce a new moveout-based technique, evolved from the Stepwise Multiple Elimination by Linear Transform (SMELT) method (Hardwick et al., 2010), which is more efficient and more robust than the existing high-resolution Radon algorithms.

High-resolution Moveout Transform (HMT)

Being a time-domain forward approach, HMT is fundamentally different from the Radon method. The objective here is to find a number of traces in the transformed domain that can optimally represent the energy of the input data in the largest proportions. This criterion implies a minimum number of iterations, which affects both speed and resolution. Every iteration begins with a search for the velocity function that serves the best in removing the highest energy proportion from the remainder of the previous round. Then, using conventional NMO correction and stacking routines, an optimized and stabilized fraction of the corresponding events is subtracted from the input data and added to the modeled data. Meanwhile, the corresponding normalized stacked data is used to update a trace in the $tau\text{-}p_{nmo}$ domain, where *tau* is the zero-offset intercept time and p_{nmo} represents the inverse of the NMO velocity.

Using this technique, the stackable seismic energy including primaries and multiples, and excluding background noise, can be mapped into a number of highly focused events along the stacked traces in the transformed domain. Inverse transformation is performed by reversing the stack and NMO-correction process, while accumulating the hyperbolic events expanded in all offsets. We have examined HMT with the following types of velocity functions:

1) Constant Velocity:
- Vertical lines in a time-velocity panel are used
- Large energy portions are addressed when multiples appear below the primaries of a similar velocity
- Shallow events may be affected by the stretching deficiency at far offsets

2) Constant Moveout:
- Iso-moveout curves in a time-velocity panel are used (Masoomzadeh et al., 2010)
- Helps to overcome the stretching deficiency
- Primaries appear as focused events in the transformed domain
- Multiples appear less focused due to different moveouts than the earlier primaries
- Multiples appear closer to primaries (iso-moveout curves converge in the larger times)

3) Hybrid function:
- A combination of the two latter approaches is used to merge the advantages of both
- A saw-tooth function is used so that its overall orientation is vertical but every segment of it follows a local iso-moveout curve
- Moveout correction is performed twice, using overlapping time windows

Figure 1 demonstrates constant-velocity and constant-moveout HMT of a gather of synthetic seismic data and compares the result with standard and high-resolution Radon transforms.

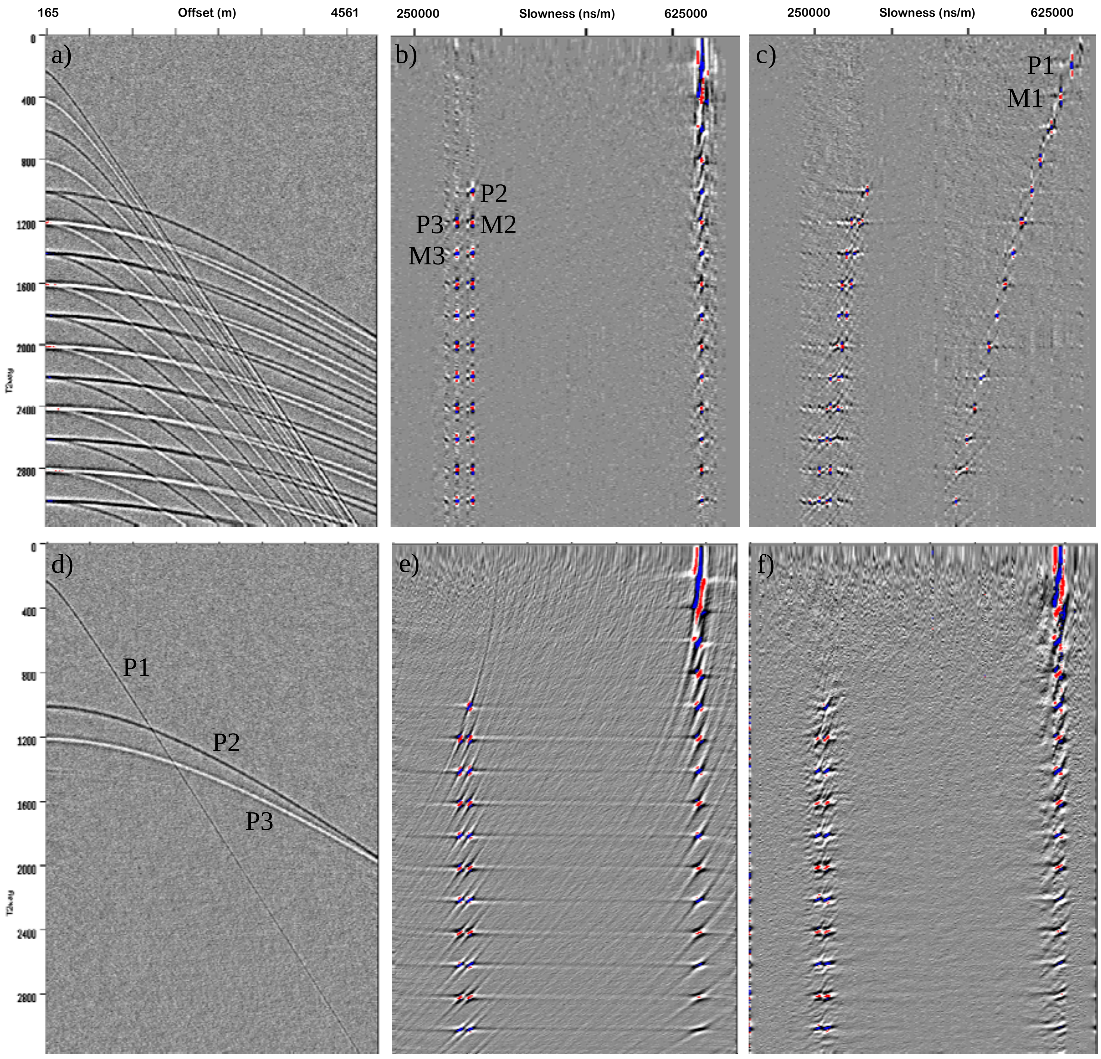

Figure 1 *a) A synthetic gather comprised of 3 primary events at 200, 1000 and 1200 ms, with NMO velocities of 1500, 3000 and 3200 m/s respectively, followed by some short-period multiples. b) As a) after constant-velocity HMT. Note the resolution of events (e.g. P3 and M2). c) As a) after constant-moveout HMT. Note the improvement in resolution of shallow events (e.g. P1and M1). d) Result of multiple attenuation using a velocity-guided mute after HMT. e) As a) after least-squared hyperbolic Radon transform (using parabolic transform after a time-squared stretching). f) After high-resolution Radon transform. Compare both resolution and artefacts with b) and c).*

Robustness of a high-resolution technique may be evaluated by its aperture-compensation power (Sacchi and Ulrych, 1995). Figure 2 demonstrates the application of HMT in missing-data reconstruction using the stackable component of the input data. A view of the un-stackable energy not being addressed by the transform, e.g. background noise, is provided as a side product.

Figure 3 shows a shot gather from the Faroe-Shetland Basin in the time-offset, HMT and Radon domains, demonstrating the superior resolution of HMT. Figure 4 compares the application of high-resolution Radon and HMT in modelling multiples of a post-migration data set from the North Sea.

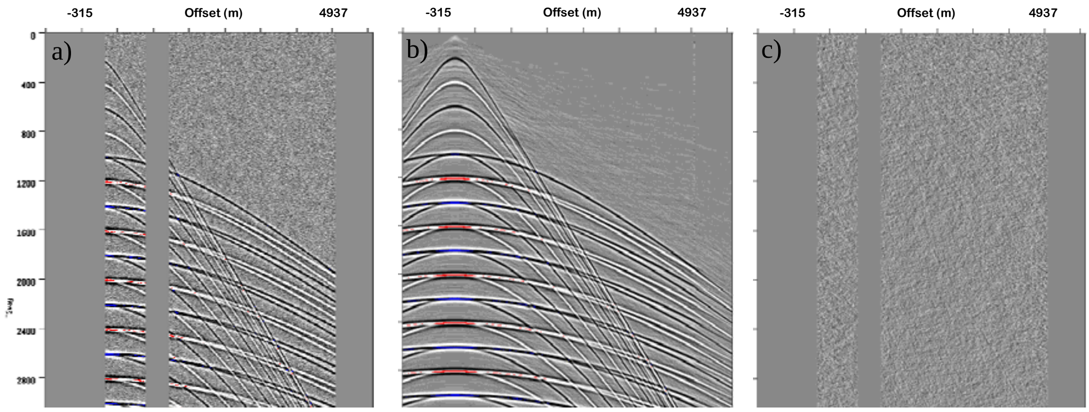

Figure 2 *a) Synthetic data with large gaps of missing data. b) Reconstructed data using HMT. c) Remaining energy not being addressed by the transform, including the un-stackable random noise.*

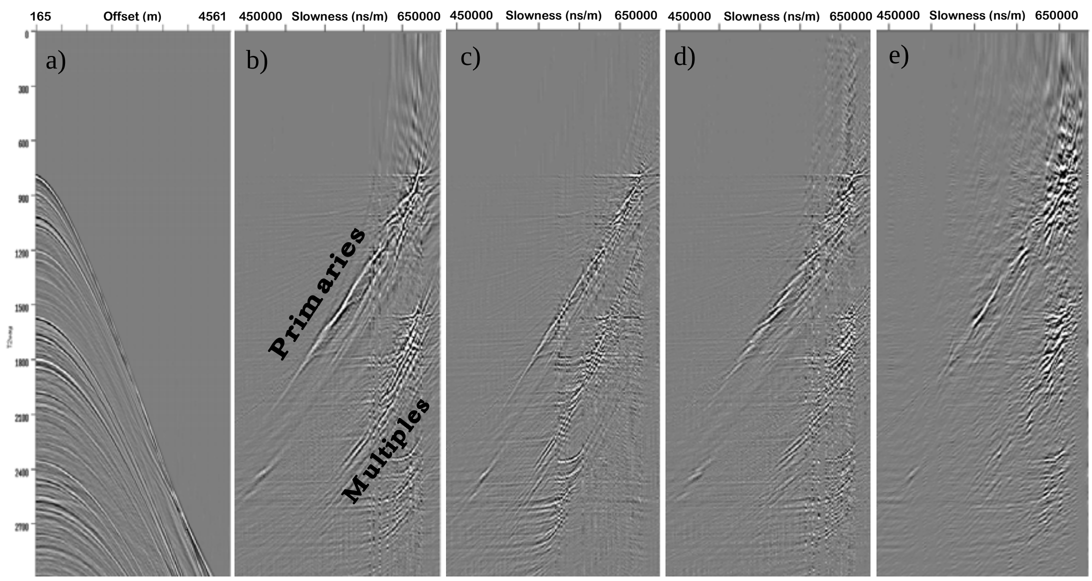

Figure 3 *a) A real shot gather in the time-offset domain. b) After constant-velocity HMT. Internal multiples may be observed just below the primaries. c) After constant-moveout HMT. Note the sharply focused primaries highlighting the loci of a stacking velocity/slowness function. d) After hybrid HMT. e) After high-resolution hyperbolic Radon transform (i.e. parabolic transform after time-squared stretching). Note that for a hyperbolic transform the input data does not need to be NMO corrected.*

Conclusions

We present a high-resolution moveout-based transformation that can be used instead of high-resolution Radon transform. Benefits include improved resolution, faster performance, improved multiple modeling in the near-offset zone and reduced ambiguity in data reconstruction at missing offsets. Moreover, being a time domain forward approach, HMT is not affected by inversion and frequency domain artifacts. This transform can address coherent stackable events, leaving behind a view of un-stackable energy. HMT technique is minimally sensitive to missing offsets and presents a robust expansion in the offset domain, providing superior demultiple power especially at near offsets. Enhanced resolution helps address internal multiples which often present small moveout differences with primaries.

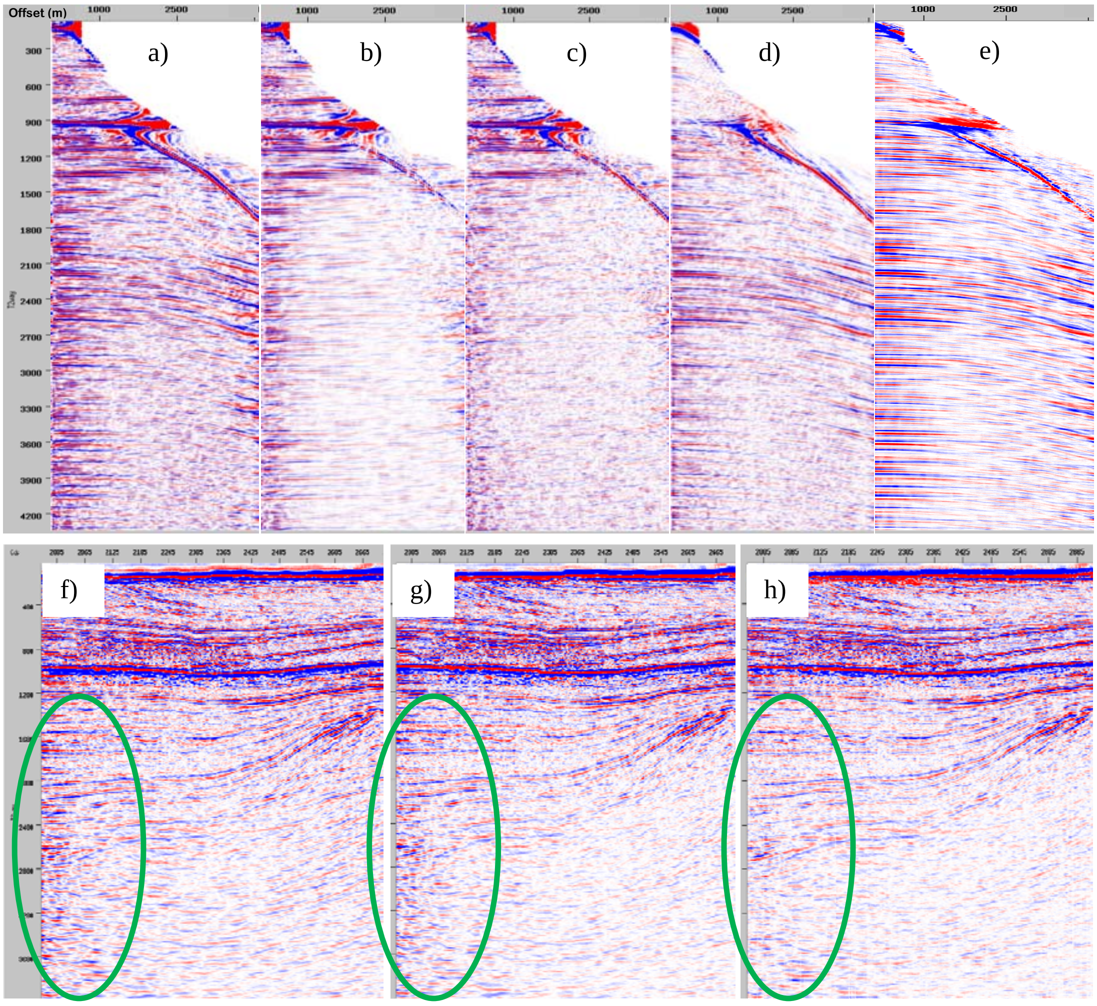

Figure 4 *a) A real post-migration CMP gather. b) As a) after demultiple using high-resolution Radon transform. c) As a) after demultiple using HMT. d) Multiple model from Radon method. e) Multiple model from HMT technique. Improvements are observed in addressing multiples in the near offsets. f) Stack before post-migration demultiple. g) Stack after demultiple by high-resolution parabolic Radon. h) Stack after demultiple by HMT. Improvements are observed especially at the beginning of the line where only near offsets are available. Leaving behind the un-stackable noise may be found desirable.*

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References

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