High-resolution Moveout Transform; a robust technique for modeling stackable seismic events

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Summary

We propose a time-domain approach to transform a gather of pre-stack seismic data into an ensemble of highly-resolved traces in the transformed domain. Using a range of various velocity functions in a standard NMO correction routine, we iteratively search for those velocity functions corresponding to the highest ratio of stackable seismic energy among their neighbouring functions, and remove the corresponding energy while updating a stacked trace in the transformed domain. Application of iso-moveout functions helps to avoid the NMO stretching distortions. Application to synthetic and real data shows improvements in resolution and performance. Compared with existing high-resolution Radon techniques, a superior resolution is achieved, resulting in less ambiguous aperture compensation and more accurate reconstruction of stackable seismic events, particularly multiples 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 helps to obtain an optimized model in the transformed domain so that when inversely transformed back to the time-offset domain, the remaining difference with the original data has minimum energy.

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 effort but helps to reduce the overlap between the adjacent events by placing more emphasize on the more energetic traces 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, this transform is fundamentally different from the Radon methods. The objective here is to find a number of optimized traces in the tau-p_{nmo} domain to represent the energy of an input gather in the time-offset domain, where tau is the zero-offset two-way time and p_{nmo} is the inverse of the velocity value being used to form a velocity function for NMO correction. Every iteration involves a search for the velocity function that helps addressing the highest proportion of the remaining untransformed energy. The first few iterations may involve a global search in a given p_{nmo} range, while the later iterations could perform faster searching in selected subsets of the entire range. Conventional NMO correction and stacking routines are then used to produce a sub-model of the data corresponding to that specified velocity function. This sub-model is then scaled and subtracted from the input data, while being added to the total model. Meanwhile, a normalized stacked trace of each sub-model is used to update the corresponding trace in the transformed domain.

Using this technique, the stackable coherent energy including primaries and multiples can be mapped into a number of highly focused events in the transformed domain. The inverse transformation may be achieved by repetition of every p_{nmo}-trace over a desired offset range before applying the corresponding inverse NMO correction and accumulating the reconstructed events in the time-offset domain. We have examined HMT with the following varieties 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:
- Stretching deficiency is avoided when NMO correction is performed by using an iso-moveout curve (Masoomzadeh et al., 2010) extracted for a primary two-way time corresponding to a given stacking velocity
- Shallow primaries may appear more focused when a more appropriate velocity function is used
- Multiples may appear less focused and also closer to primaries, due to the convergence of iso-moveout curves in the larger two-way times

Combinations of the above varieties can also be used in order to merge the advantages of both:

3) Mixed Functionality:
- Every other p_{nmo}-trace is obtained using either constant-velocity or constant-moveout function alternatively
- Both primaries and multiples may appear more focused
- Leakage of energy into the alternative group may be observed

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4) Zigzag Function:

- A pair of saw-tooth functions are used so that their overall orientations are vertical but every segment of them follows a local iso-moveout curve
- NMO correction is applied twice and the results were merged in overlapping tapered windows

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

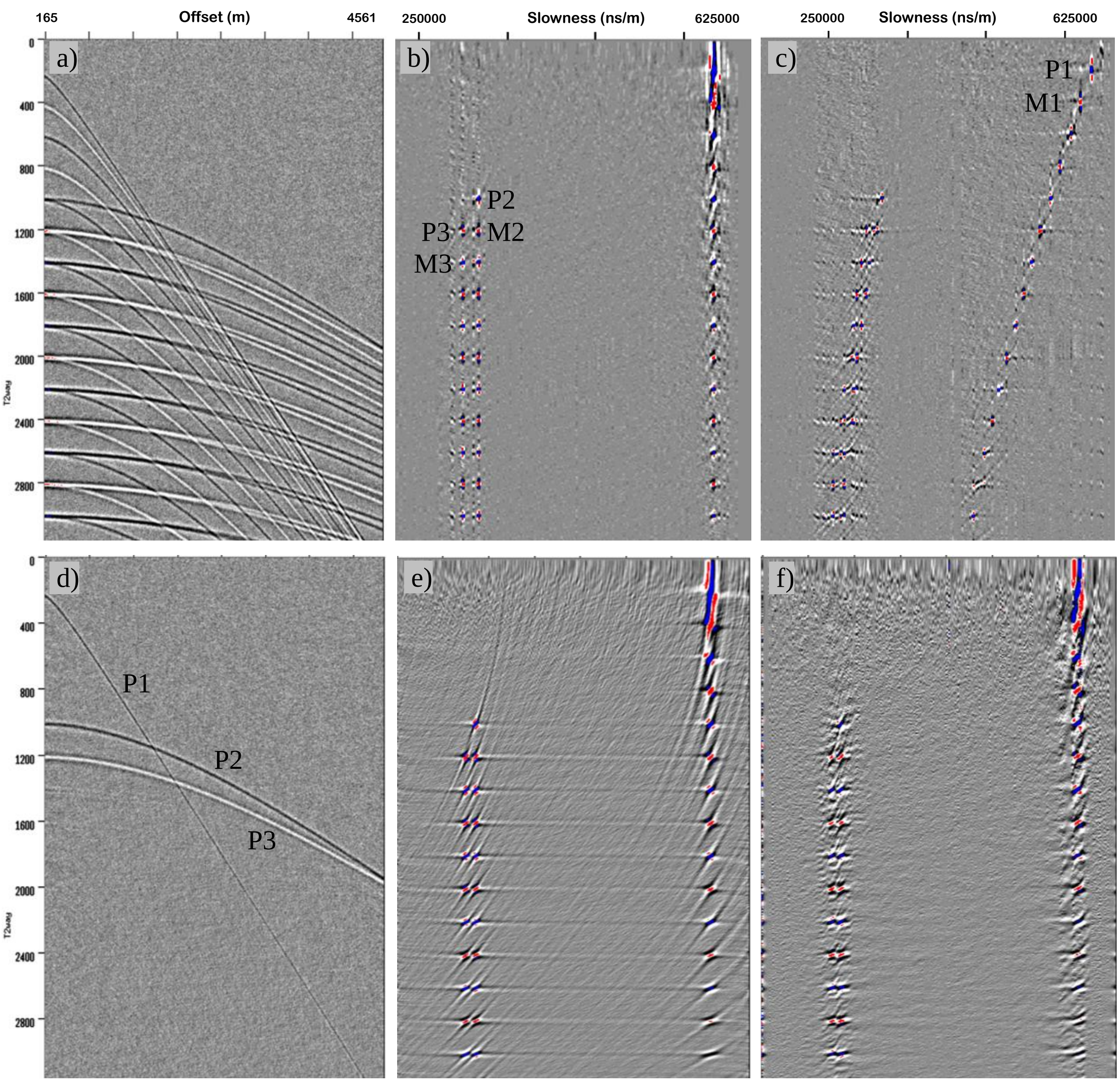

Figure 1: a) A synthetic gather comprised of 3 primary events at 200, 1000 and 1200 ms, with NMO velocities of 1500, 3000 and 3200 m/s respectively, followed by some short-period multiples. b) As a) after constant-velocity HMT. Note the resolution of events (e.g. P3 and M2). c) As a) after constant-moveout 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-squares hyperbolic Radon transform (using parabolic transform after a time-squared stretching). f) After high-resolution Radon transform. Compare both resolution and artifacts with b) and c).

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The robustness of a high-resolution technique may be related to its aperture-compensation capability (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 incoherent energy not being addressed by the transform can also be provided.

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 modeling multiples of a post-migration data set from the North Sea.

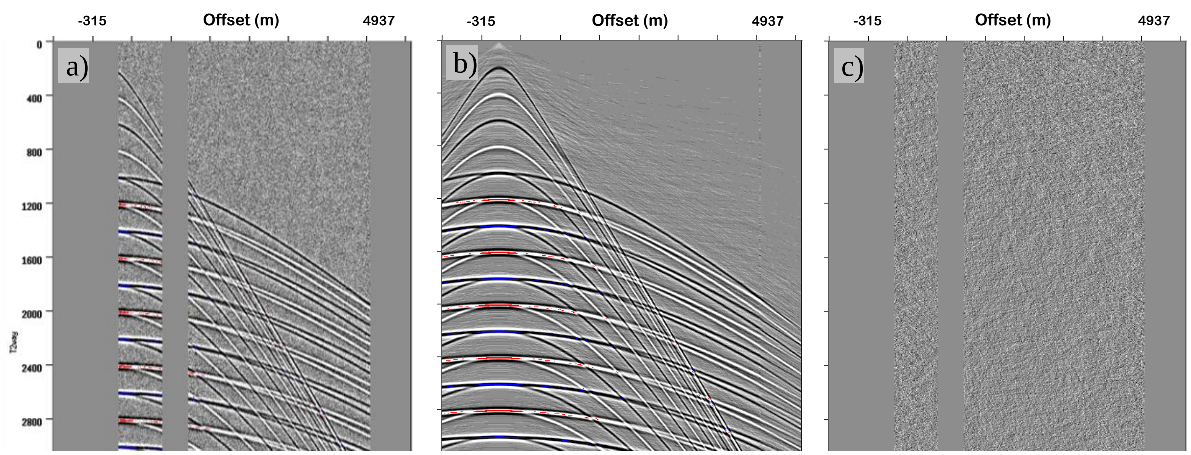

Figure 2: a) Synthetic data with large gaps of missing data. b) Reconstructed data using HMT. c) Remaining energy not being addressed by the transform, including the un-stackable random noise.

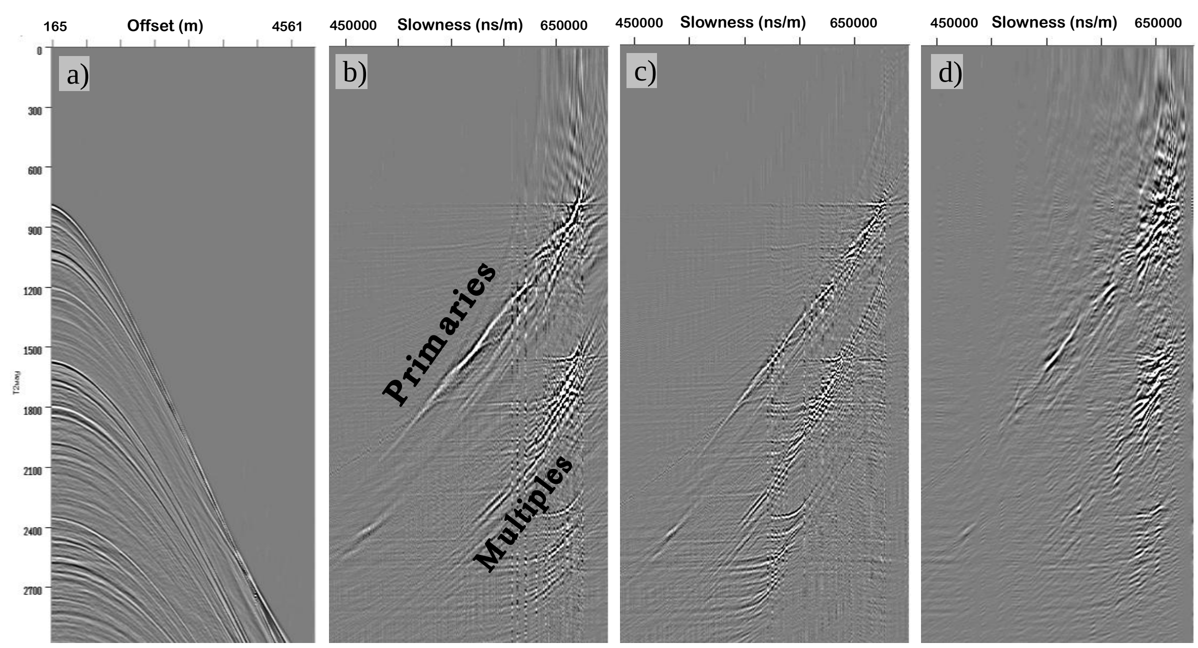

Figure 3: a) A real shot gather in the time-offset domain. b) After constant-velocity HMT. Internal multiples may be observed just below the primaries. c) After constant-moveout HMT. Note the sharply focused primaries highlighting the loci of a stacking velocity/slowness function. d) After high-resolution 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.

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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. Being a time domain forward approach, HMT is not affected by inversion and frequency domain artifacts. Moreover, non-hyperbolic moveout, apex shift and amplitude decay with offset can also be accomodated. This transform can address coherent stackable energy, 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.

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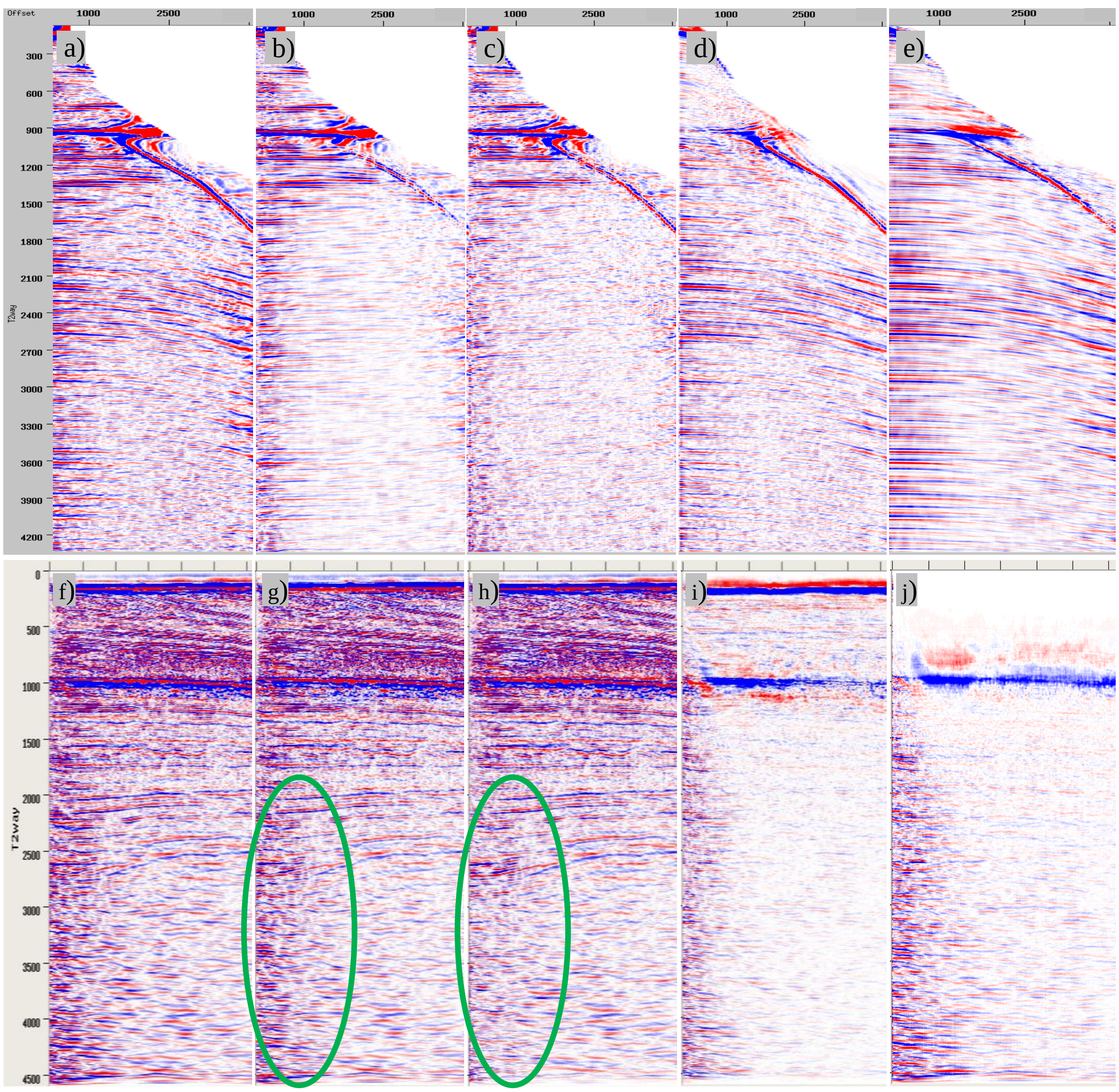

Figure 4: a) A real post-migration CMP gather. b) As a) after demultiple using high-resolution Radon transform. c) As a) after demultiple using HMT. d) Difference of a) and b). e) Difference of a) and c). Note the improvements observable in modeling multiples in the near offset zone. Leaving behind the un-stackable noise could be in fact desirable. f) Stack before post-migration demultiple. g) Stack after demultiple by high-resolution parabolic Radon. h) Stack after demultiple by HMT. i) Difference of f) and g). j) Difference of f) and h). Improvements are observed as more multiples are removed by HMT, especially at the beginning of the line where only near offsets are stacked.

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EDITED REFERENCES

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