

The *i*-stats: An Image-Based Effective-Medium Modeling of Near-Surface Anomalies

Oz Yilmaz*, GeoTomo LLC, Houston, TX

Summary

Near-surface modeling for statics corrections is an integral part of a land seismic data processing workflow. The past, present, and the future methods for near-surface modeling can be categorized into five groups: (1) uphole surveys, (2) shallow seismic surveys, (3) traveltimes tomography, (4) waveform inversion, and (5) joint inversion of seismic and non-seismic data.

I present the *i*-stats --- an image-based workflow for modeling near-surface anomalies, which

- (1) does not require first-break picking as for traveltimes tomography,
- (2) does not require source wavelet estimation as for waveform inversion,
- (3) does not fail velocity inversions as in traveltimes tomography,
- (4) does not suffer from velocity-depth ambiguity, and
- (5) does not exhaust computational resources as in waveform and joint inversions.

The *i*-stats method is based on prestack depth migration of shot records from topography using a range of near-surface velocities. The resulting depth images form an image volume which can then be interpreted to pick the reflector associated with the base of the near-surface and to pick the velocities for the near surface from the corresponding horizon-consistent semblance spectrum. The resulting 'effective-medium' model for the near-surface comprises laterally varying velocities, only, but yields essentially the same statics that one calculates from a more complicated model for the near-surface that may be estimated from tomography or inversion methods. The effective-medium model of the near-surface actually conforms to the assumption of vertical raypath within the near-surface that underlies the statics corrections. I demonstrate the *i*-stats method to correct for the deleterious effect of the near-surface anomalies associated with sand dunes on subsurface reflections.

The Sand Dune Problem

Shown in Figure 1a is the line traverse for seismic data recorded over the sand dunes of North Africa. While the receivers follow the almost straight line traverse over the dunes, shots are placed around the dunes because vibrators could not be deployed over the top of the dunes composed of dry, loose sand. Shown in Figure 1b is a shot record in the vicinity of one of the sand dunes. The distortions in the first-arrival times are caused by the irregular topography of the dunes and the complexity of the near-surface velocities.

I was compelled to pick the first breaks for all the shot records along the line traverse, mostly by the laborious manual method, for the precursors associated with the remnant of the sweep signal on the correlated vibroseis record poses a challenge to automatic picking algorithms based on correlation and energy criteria applied to first-arrival waveforms. First-break picking and editing, especially for vibroseis data, is indeed the most time consuming stage in near-surface modeling by traveltimes tomography.

I applied nonlinear traveltimes tomography (Zhang and Toksoz, 1998) to obtain the model for the near-surface shown in Figure 2a. This model accurately describes the anatomy of sand dunes: a low-velocity (around 500-600 m/s) cap on top of the dunes associated with dry sands, an interior with wet sands with velocity around 1,500 m/s, and a root with relatively higher velocity. The vertical velocity gradient within the sand dunes is a result of gradual accumulation of wind-swept sands within a topographic obstacle over several hundreds of years. Such a complex velocity field in the near-surface, if not corrected for, would give rise to amplitude and traveltimes distortions in moveout-corrected CMP gathers and thus in CMP stacked data (Figures 2b,c).

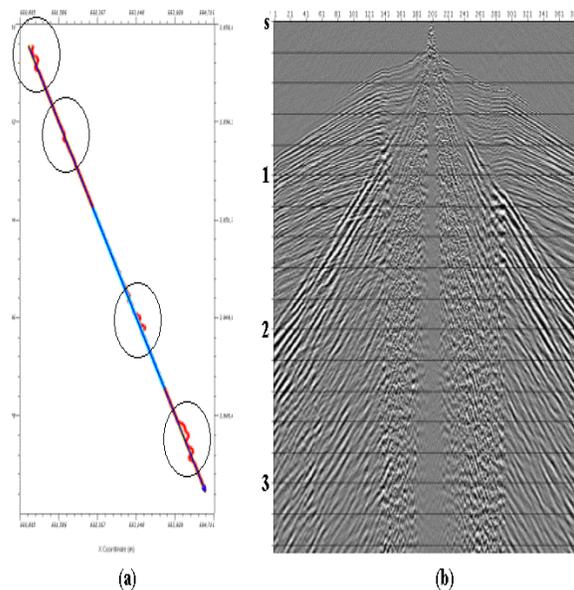


Figure 1. (a) The line traverse for the seismic data associated with the example shown in this paper. Note the shots placed around the sand dunes within the circles. The light blue line segment represents the receiver spread for the shot record shown in (b).

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The *i*-stats Workflow

The *i*-stats workflow include the following steps:

- (1) Perform signal processing on shot records, which may include geometric spreading correction, time-variant spectral whitening, and deconvolution. Since no statics corrections are applied at this stage, do not apply multichannel filtering such as f - x deconvolution or f - k filtering that can adversely distort the amplitudes and traveltimes of shallow reflections.
- (2) Define the near-surface region as a half-space and perform prestack depth migration of all the shot gathers from topography using a range of constant velocities associated with the near-surface velocity variations, and generate a set of image panels in depth accompanied with image gathers at desired interval along the line traverse (Reshef, 1997; Yilmaz, 2001).
- (3) Scan the depth image panels and identify the shallowmost reflector that may be associated with the base of the near-surface region, and pick the depth horizon corresponding to that reflector (Figure 3a), while, if possible, paying attention to the flatness of the reflector event on the image gathers. You may be required to pick the depth horizon for the reflector under consideration from multiple number of image panels based on the highest image amplitude criterion.
- (4) Extract the horizon-consistent semblance spectrum along the picked depth horizon from within the depth image volume and pick the interval velocity strand along the line traverse (Figure 3b).
- (5) Combine the horizon strand from the depth image with the velocity strand from the semblance spectrum to build the effective-medium velocity-depth model for the near-surface (Figure 3c).
- (6) Now calculate the shot-receiver statics to move the shots and receivers from topography down to the intermediate datum represented by the depth horizon picked in step 4 using the effective-medium velocities (Figure 4b) and back up to a floating datum using an appropriate replacement velocity. The shot-receiver statics are shown in Figure 4c.
- (7) Return to the signal processing step 1, add to the processing sequence the statics application and any multichannel filtering that is appropriate to attenuate coherent linear noise associated with guided waves and surface waves.
- (8) Repeat, if necessary, steps 1-7 until you have resolved all the velocity variations within the near-surface.
- (9) Then, perform residual statics estimation (Yilmaz, 2001) and apply to the shot gathers prior to rms velocity estimation and prestack time migration.

Figure 4 shows a comparison of the shot-receiver statics computed by using the near-surface model estimated by nonlinear traveltime tomography applied to the first-arrival

times and the shot-receiver statics computed by using the image-based effective-medium model estimated by the *i*-stats workflow described above. Note that, insofar as the long-wavelength solution for the shot-receiver statics, both methods yield almost equivalent results. Subsequent to the long-wavelength statics estimation, irrespective of the method used for, short-wavelength residual statics estimation must follow (Yilmaz, 2001). Since the ultimate deliverables from the near-surface modeling are shot-receiver statics, and not the near-surface model itself, which should be treated as an intermediate product, then, the image-based effective-medium modeling is just as valid as any other method for near-surface modeling. Moreover, the effective-medium model conforms more than any other method to the vertical-ray assumption underlying statics corrections.

Figure 5 shows the prestack time migration (PSTM) sections obtained from shot records with the same signal processing sequence but with statics corrections computed from the near-surface models estimated by traveltime tomography and the *i*-stats methods. They both should be compared with the CMP-stacked section, albeit unmigrated, shown in Figure 2c. Note that both the traveltime tomography and the *i*-stats methods have resolved the deleterious effect of the near-surface anomalies associated with the sand dunes along the line traverse on the amplitudes and geometry of the subsurface reflections. However, the traveltime tomography workflow consumed substantially more time to execute than the *i*-stats workflow because the former required accurate picking of the first breaks.

Conclusions

The *i*-stats method is an image-based effective-medium near-surface modeling method. It does not require first-break picking as for traveltime tomography, does not require source wavelet estimation as for waveform inversion, does not fail velocity inversions as in traveltime tomography, does not suffer from velocity-depth ambiguity, and does not exhaust computational resources as in waveform and joint inversions. I have demonstrated the *i*-stats workflow to resolve the near-surface anomalies associated with sand dunes. Although the example given is for a 2-D seismic line, the *i*-stats method also is readily applicable to 3-D land seismic data.

Acknowledgements

I sincerely thank Nasireddin Shibani, North African Geophysical Company (NAGECO) for providing the seismic field data associated with the example shown in this paper.

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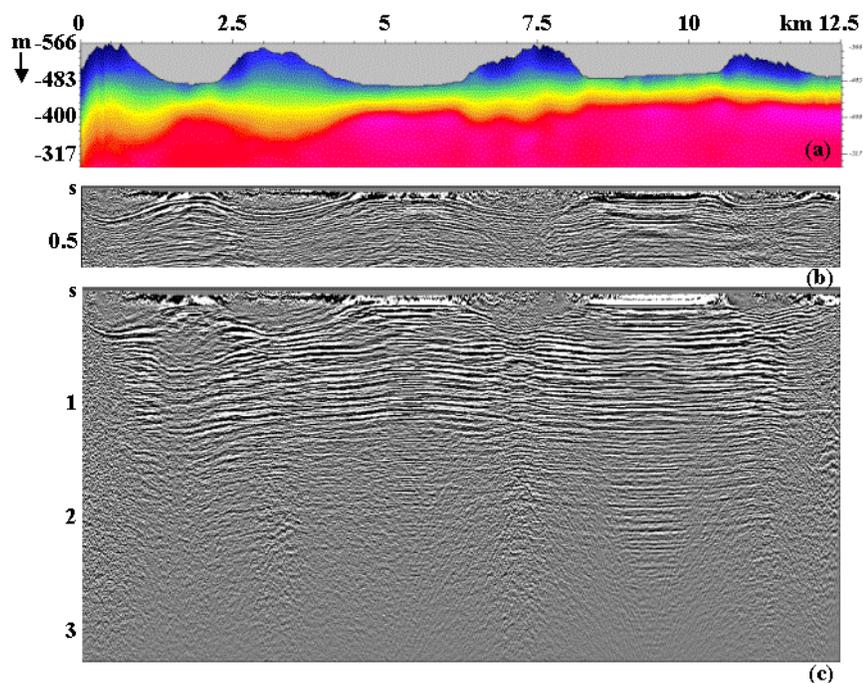


Figure 2. (a) The near-surface velocity-depth model estimated by the application of nonlinear traveltime tomography to the first-arrival times picked from the field records; (b) the portion of the constant-velocity stack associated with the near-surface velocity without near-surface corrections --- note the distortion of the geometry of the shallow reflection caused by the sand dunes; and (c) the constant-velocity stack associated with a subsurface velocity without near-surface corrections --- note the distortion of the geometry of the subsurface reflections caused by the near-surface complexity associated with the sand dunes.

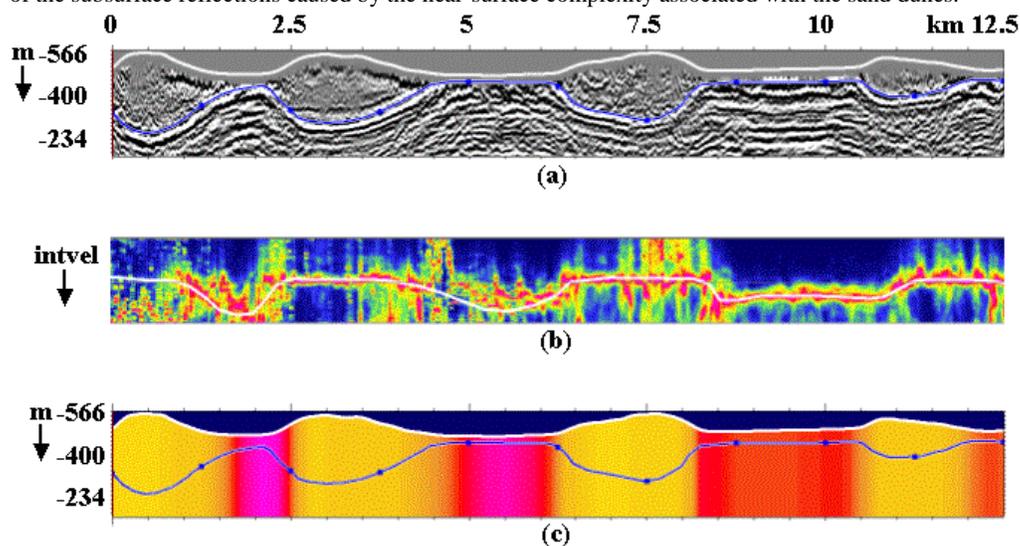


Figure 3. (a) A depth image panel generated by prestack depth migration of shot gathers from topography (step 2 of the *i*-stats workflow) and the horizon picked along the shallow reflector that may be treated as the base of the near-surface (step 3 of the *i*-stats workflow); (b) the horizon-consistent semblance spectrum extracted along the depth horizon in (a) from within the depth image volume (step 4 of the *i*-stats workflow) and the image-based interval velocity strand picked along the line traverse; and (c) the effective-medium model of the near-surface constructed by combining the horizon strand from the depth image shown in (a) with the velocity strand from the semblance spectrum shown in (b).

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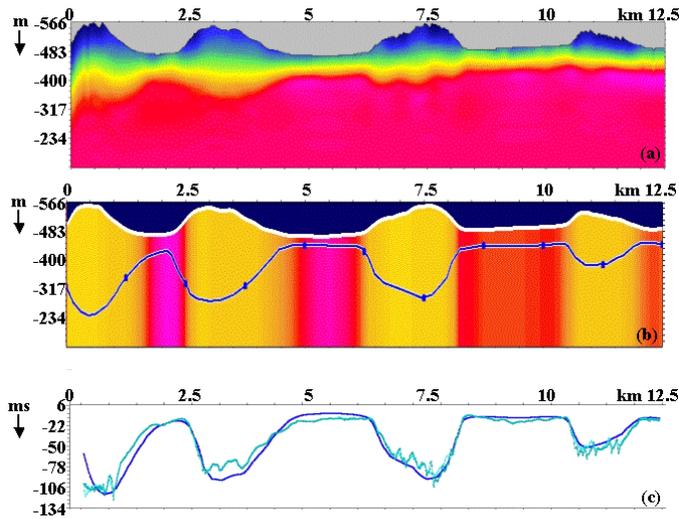


Figure 4. (a) The near-surface velocity-depth model estimated by the application of nonlinear traveltimes tomography to the first-arrival times picked from the field records; (b) the image-based effective-medium model estimated by the application of the *i*-stats workflow to the field records; and (c) the shot-receiver statics calculated from the tomographic model (light green) and the *i*-stats model (dark blue).

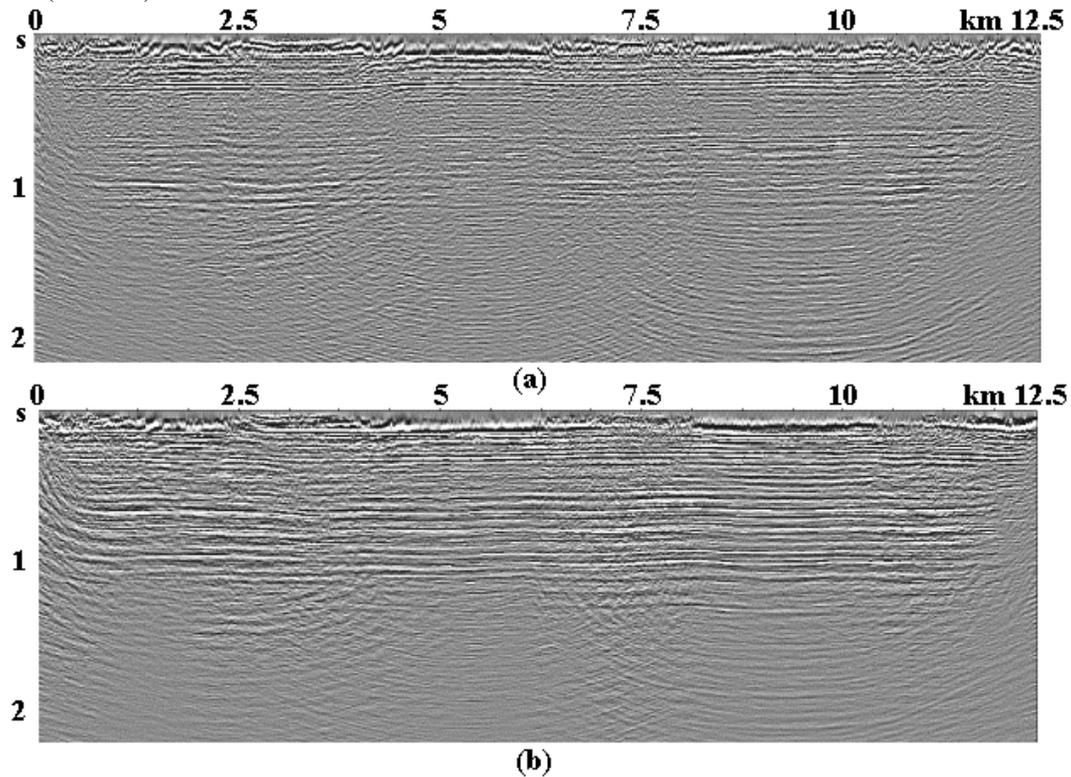


Figure 5. The prestack time migration (PSTM) sections obtained from shot records with the same signal processing sequence but with statics corrections computed from the near-surface models estimated by (a) traveltimes tomography and (b) the *i*-stats methods, followed by residual statics corrections.

EDITED REFERENCES

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REFERENCES

- Reshef, M., 1997, The use of 3-D prestack depth imaging to estimate layer velocities and reflector positions: *Geophysics*, **62**, 206–210, [doi:10.1190/1.1444120](https://doi.org/10.1190/1.1444120).
- Yilmaz, O., 2001, *Seismic data analysis: SEG Investigations in Geophysics No. 10*.
- Zhang, J., and M. N. Toksoz, 1998, Nonlinear refraction travelttime tomography: *Geophysics*, **63**, 1726–1737, [doi:10.1190/1.1444468](https://doi.org/10.1190/1.1444468).