

# The 2D/3D i-stats Workflow for Image-Based Near-Surface Modeling for Statics Corrections

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*With the i-stats workflow, you no longer need first-break picking as for travelttime tomography, you are not required to estimate a source wavelet as for full-waveform inversion, you do not fail velocity inversions as in travelttime tomography, you do not suffer from velocity-depth ambiguity, you are not required to perform data modeling as for any inversion method, and you do not exhaust computational resources as in full-waveform and joint inversions.*

GeoTomo's GeoThrust2D/3D seismic data processing software is now a mature system --- it has been in use by major oil companies, national oil companies, and service companies for more than twelve years. **To provide the GeoThrust user with streamlined solutions, we have constructed two uniquely image-based workflows --- the i-stats 2D/3D near-surface modeling and the i-cube 2D/3D subsurface imaging by using the various modules of GeoThrust.** In this document, we describe the i-stats workflow --- an image-based near-surface modeling for statics corrections.

**The i-stats workflow for near-surface modeling is superior to travelttime tomography and full-waveform inversion in many respects.** It does not require first-break picking as for travelttime tomography, does not require source wavelet estimation as for waveform inversion, does not fail velocity inversions as in travelttime tomography, does not suffer from velocity-depth ambiguity, does not require data modeling (travelttime or wave field) as for any inversion method, and does not exhaust computational resources as in waveform and joint inversions. In contrast with tedious and time-consuming first-break picking and editing required by travelttime tomography, the i-stats method is based on event and semblance picking --- interpretively appealing to the practicing geophysicist. In contrast with the yet-to-be-resolved practical aspects of waveform inversion and joint inversion methods, the intuitively appealing image-based i-stats method is extremely robust and efficient for modeling of near-surface anomalies. The i-stats method is applicable to correcting for near-surface anomalies associated with sand dunes, shallow anhydrites and salt bodies, shallow basalt layer, karstic formation, glacial tills, and permafrost.

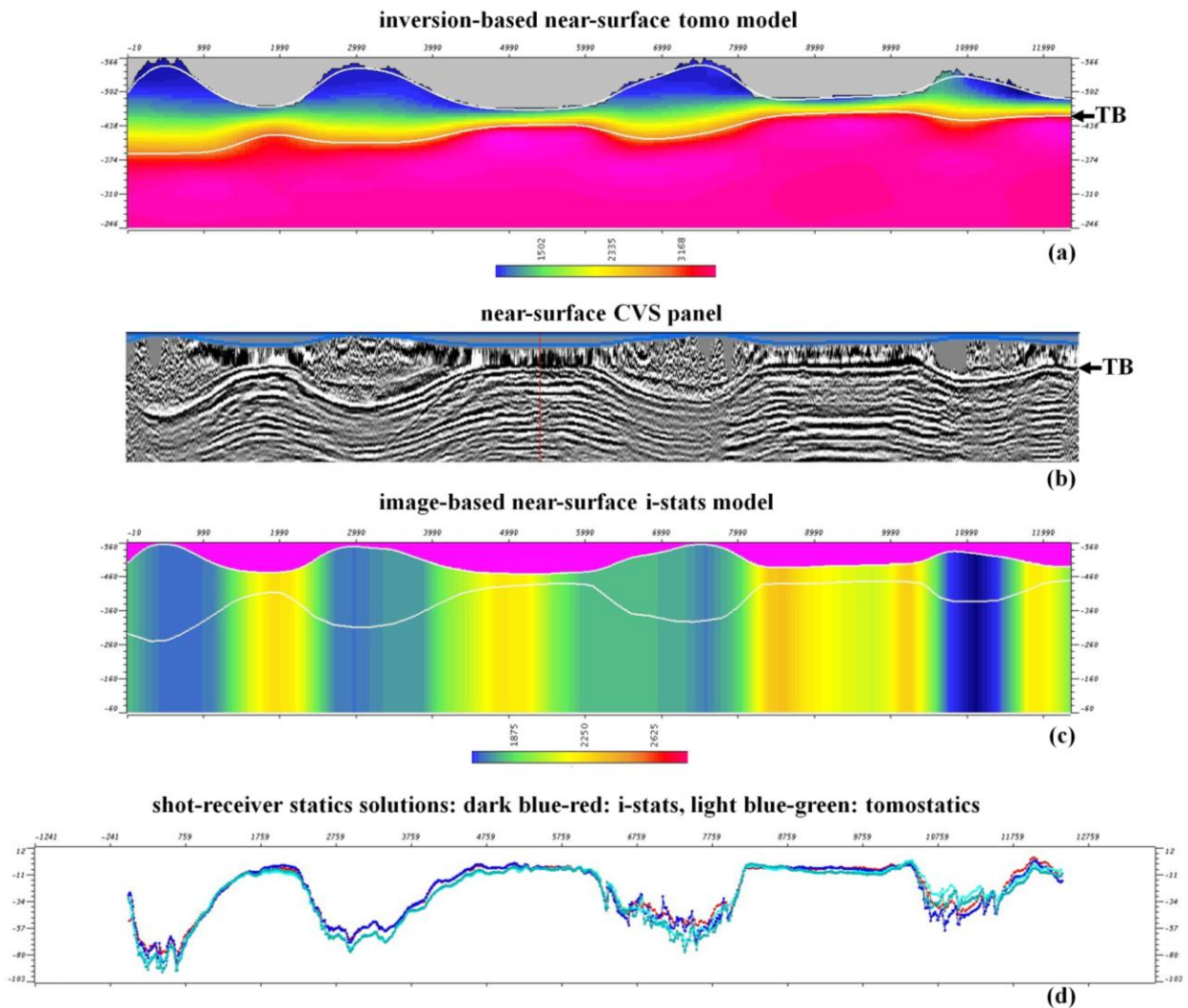
## The i-stats Workflow

**In exploration seismology, most common type of *the near-surface* is defined as the depth interval below the topography, composed of a low-velocity, unconsolidated, heterogeneous soil column and weathered rock layer.** As such, raypaths are close to vertical incidence within the near-surface --- a requirement for statics corrections to be acceptable. This definition of the near-surface does not apply to the case of a rock outcrop. Hence, if it is *near the surface*, it is not always *the near-surface* within the context of the definition above. In contrast with the near-surface defined above, the *subsurface* is composed of relatively higher velocity, consolidated rock layers. As such, the interface between the near-surface and the subsurface often gives rise to a strong shallow reflection.

**The i-stats makes use of the strong reflection at the base of the near-surface to estimate a model for the near-surface for statics corrections. The i-stats workflow can be applied to both 2-D and 3-D seismic data.** The method is based on prestack time migration of shot records from a floating datum that closely resembles surface topography using a range of near-surface velocities. The resulting image panels 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 rms velocities for the near surface from the corresponding horizon-consistent semblance spectrum or from the vertical semblance spectra to create the near-surface rms velocity field. This laterally varying, but vertically invariant, velocity field actually is equivalent to the near-surface interval velocity field, which can be used to perform prestack depth migration of shot records to obtain a shallow seismic image of the near-surface. Finally, the depth horizon associated with the base of the near-surface is delineated from this shallow seismic image. The near-surface equivalent-medium model to calculate shot-receiver statics is formed by combining this depth horizon with the interval velocity field. The estimated '*equivalent-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 inversion methods. The equivalent-medium model of the near-surface conforms to the vertical raypath assumption that underlies statics corrections.

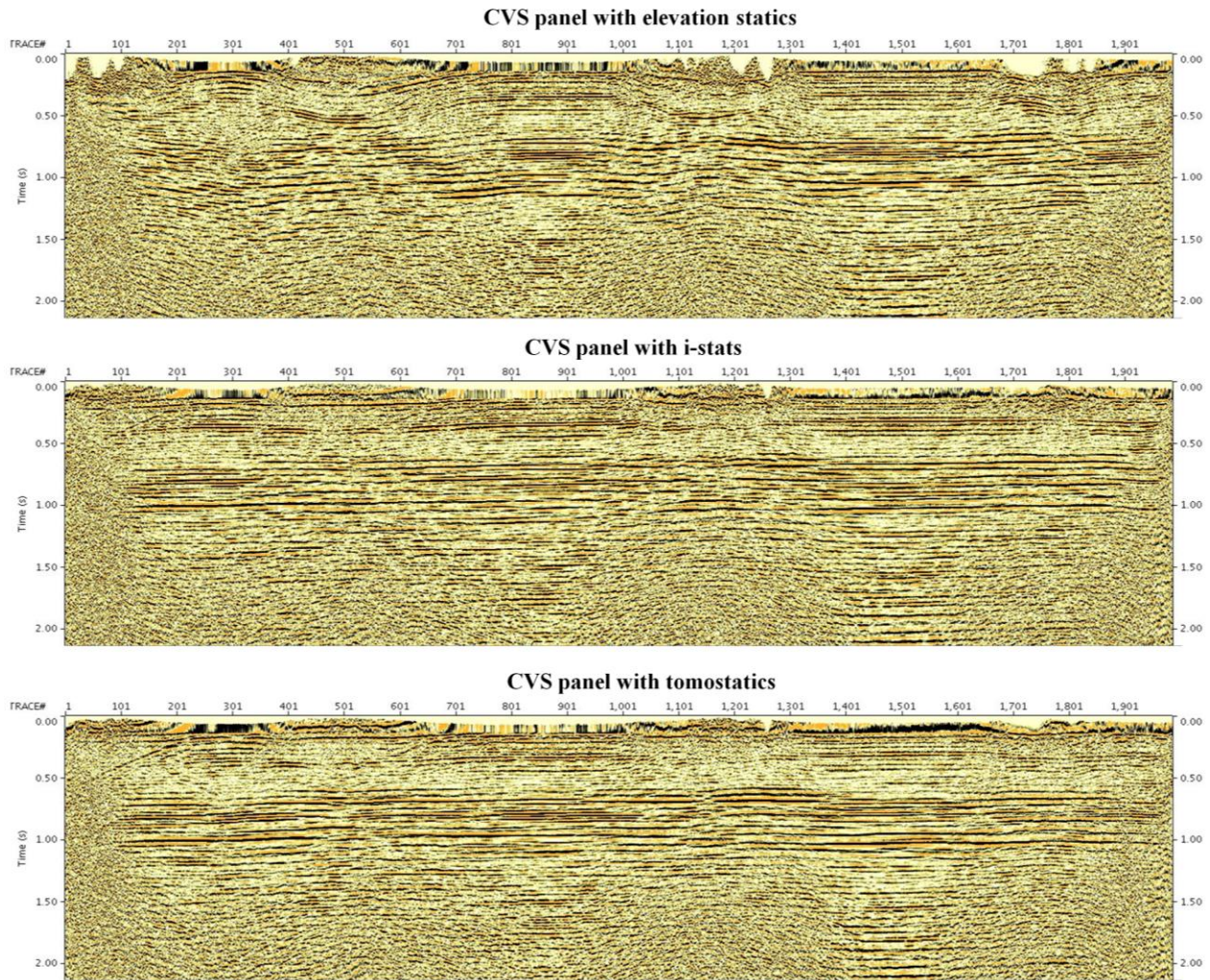
### The i-stats Case Study 1: Sand Dunes

Shown in Figure 1 is the case of a near-surface with sand dunes in North Africa. The vertical velocity gradient within the sand dunes is a result of gradual accumulation of wind-swept sands within a topographic obstacle (Figure 1a). The CVS panel with velocity optimum for the near-surface shown in Figure 1b exhibits a strong reflection that corresponds to the strong velocity contrast at the interface between the near-surface and the subsurface. Note that the geometry of the interface that represents the boundary between the near-surface and the subsurface, represented by the red color in the velocity-depth model (Figure 1a) closely follows the geometry of the strong reflection observed in the shallow CVS panel (Figure 1b). The image-based near-surface i-stats model based on the workflow described above is shown in Figure 1c. The shot-receiver statics computed from the inversion-based near-surface tomo model (Figure 1a) and the image-based near-surface i-stats model (Figure 1c) are shown in Figure 1d. Albeit the the i-stats model (Figure 1c), compared to the tomo model, is not physically plausible, the two solutions are in close agreement. The final deliverable from any near-surface modeling is the shot-receiver statics solution; thus, it is irrelevant how the near-surface model is estimated. The i-stats solution required less than only an hour of the user's time, whereas the tomo solution required more than a day, much of the time consumed by first-break picking and editing.



**Figure 1.** (a) The velocity-depth model for the near-surface with sand dunes from North Africa, estimated by travelt ime inversion applied to first-arrival times picked from the shot gathers; (b) near-surface CVS panel that exhibits a strong reflection (TB) associated with the interface between the near-surface above and the subsurface below; (c) effective-medium velocity-depth model estimated by the image-based i-stats workflow; (d) shot-receiver statics computed from the inversion-based tomo model in (a) and the image-based i-stats model in (c).

For an unbiased evaluation of statics corrections, we compare CVS panels with elevation statics, inversion-based tomostatics, and image-based i-stats. Any subsequent processing, such as stacking and migration of data with different statics application would require different velocities; this would then make it difficult to judge whether the differences are caused by different statics or different velocities. Figure 2a shows a CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections, but without any long-wavelength statics corrections applied. Figure 2b shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the inversion-based tomographic solution followed by residual statics corrections as shown in Figure 1d. Finally, Figure 3c shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the image-based i-stats solution followed by residual statics corrections as shown in Figure 1d.

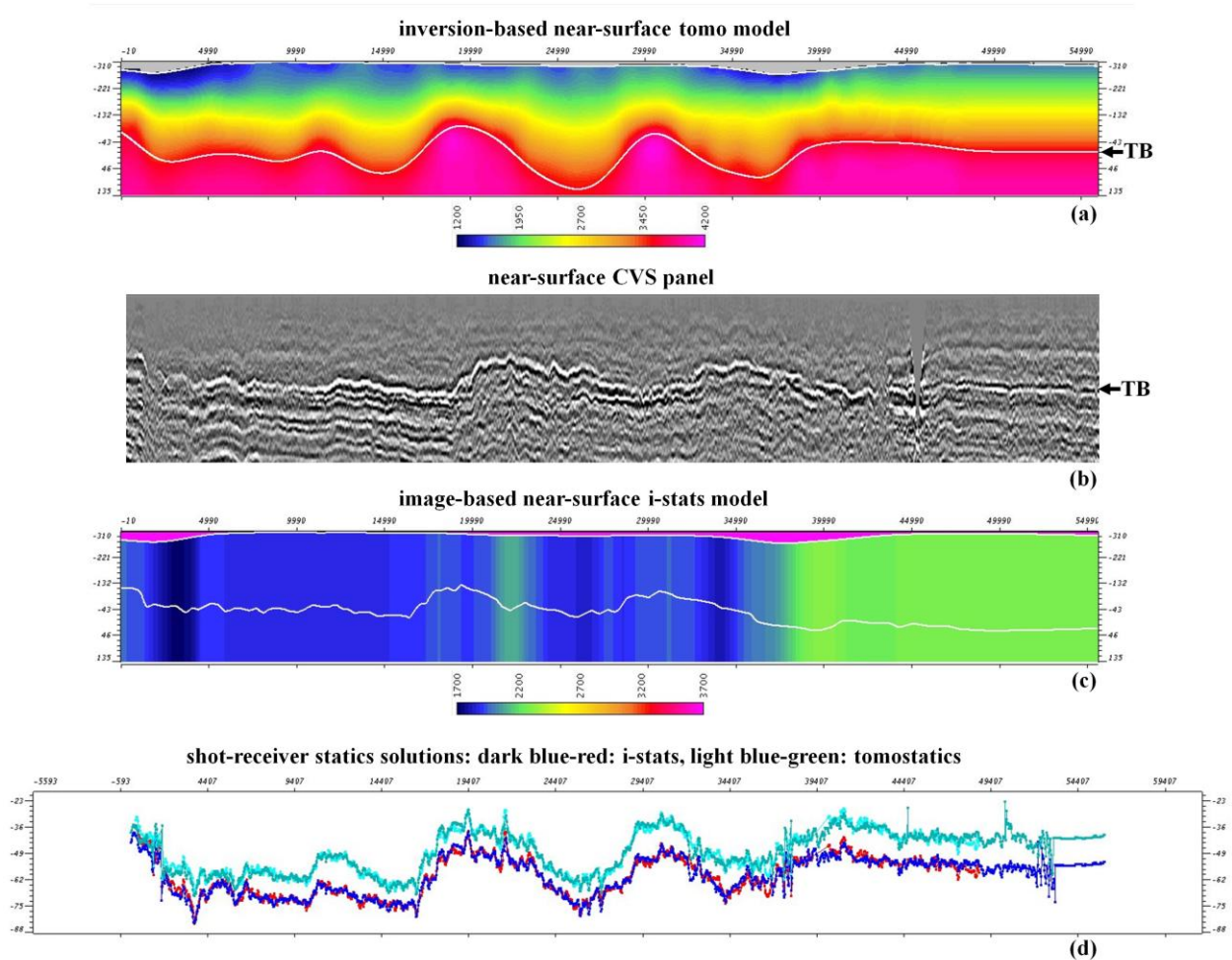


**Figure 2.** (a) A CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections; (b) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the tomographic solution followed by residual statics corrections as shown in Figure 1d; and (c) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the i-stats solution followed by residual statics corrections as shown in Figure 1d.

### The i-stats Case Study 2: Evaporite Layer with Solution Collapses

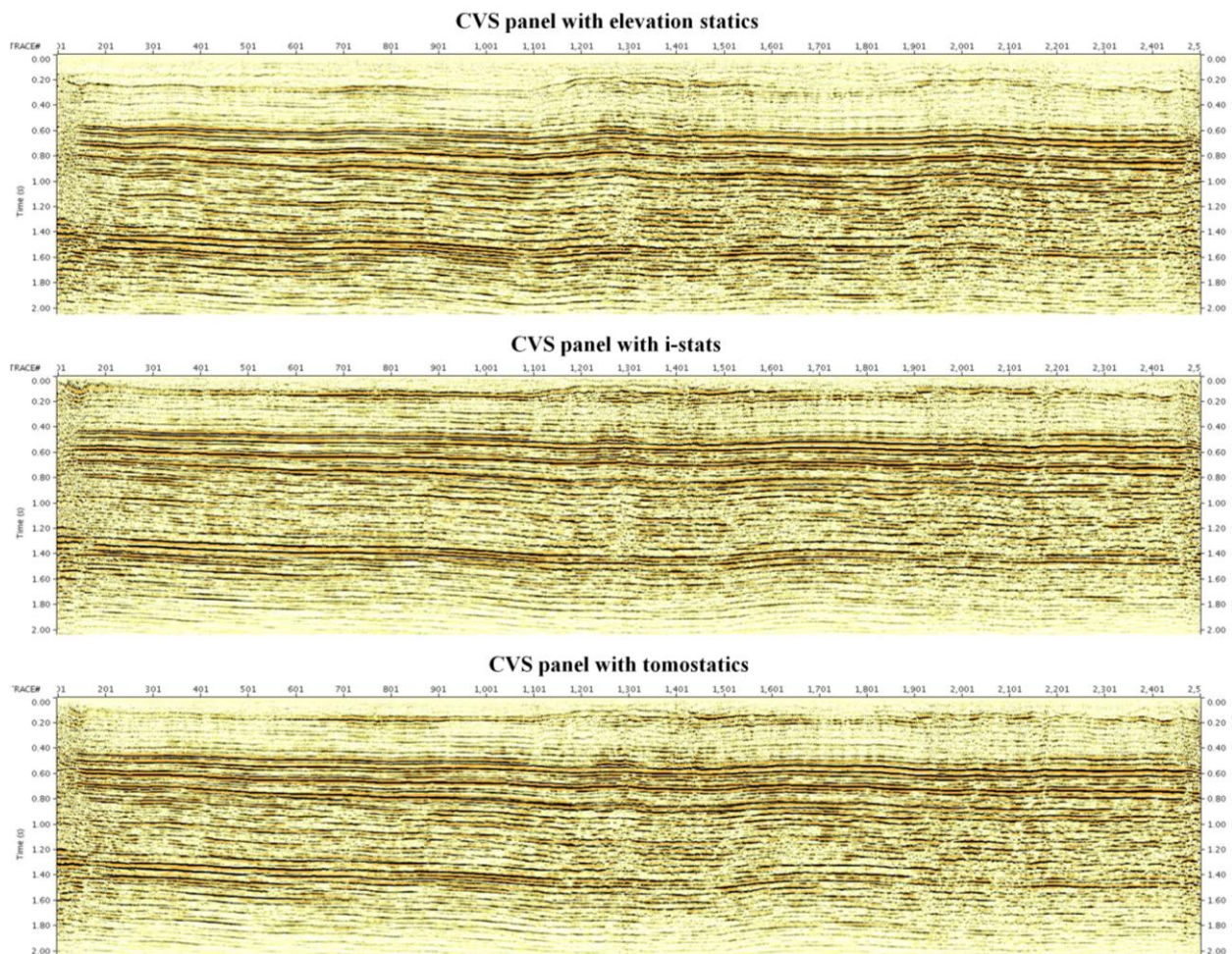
Shown in Figure 3 is the case of a near-surface above a shallow evaporite layer in the Middle East. The velocity-depth model exhibits the complexity of the shallow anhydrite layer resulting from solution collapses (Figure 3a). The CVS panel with velocity optimum for the near-surface shown in Figure 3b exhibits a strong reflection that corresponds to the strong velocity contrast at the interface between the near-surface and the subsurface. Note that the geometry of the interface that represents the boundary between the near-surface and the subsurface, represented by the red color in the velocity-depth model (Figure 3a) closely follows the geometry of the strong reflection observed in the shallow CVS panel (Figure 3b). The image-based near-surface i-stats model based on the workflow described above is shown in Figure 3c. The shot-receiver statics computed from the inversion-based near-surface tomo model (Figure 3a) and the image-based near-surface i-stats model (Figure 3c) are shown in Figure 3d. As long as the difference between

the two solutions is nearly constant, they can be considered equivalent. The choice of the intermediate datum in Figure 3a may have caused this constant time shift between the two solutions.



**Figure 3.** (a) The velocity-depth model for the near-surface above an evaporite layer with solution collapses from the Middle East, estimated by travelttime inversion applied to first-arrival times picked from the shot gathers; (b) near-surface CVS panel that exhibits a strong reflection (TB) associated with the interface between the near-surface above and the subsurface below; (c) effective-medium velocity-depth model estimated by the image-based i-stats workflow; (d) shot-receiver statics computed from the inversion-based tomo model in (a) and the image-based i-stats model in (c).

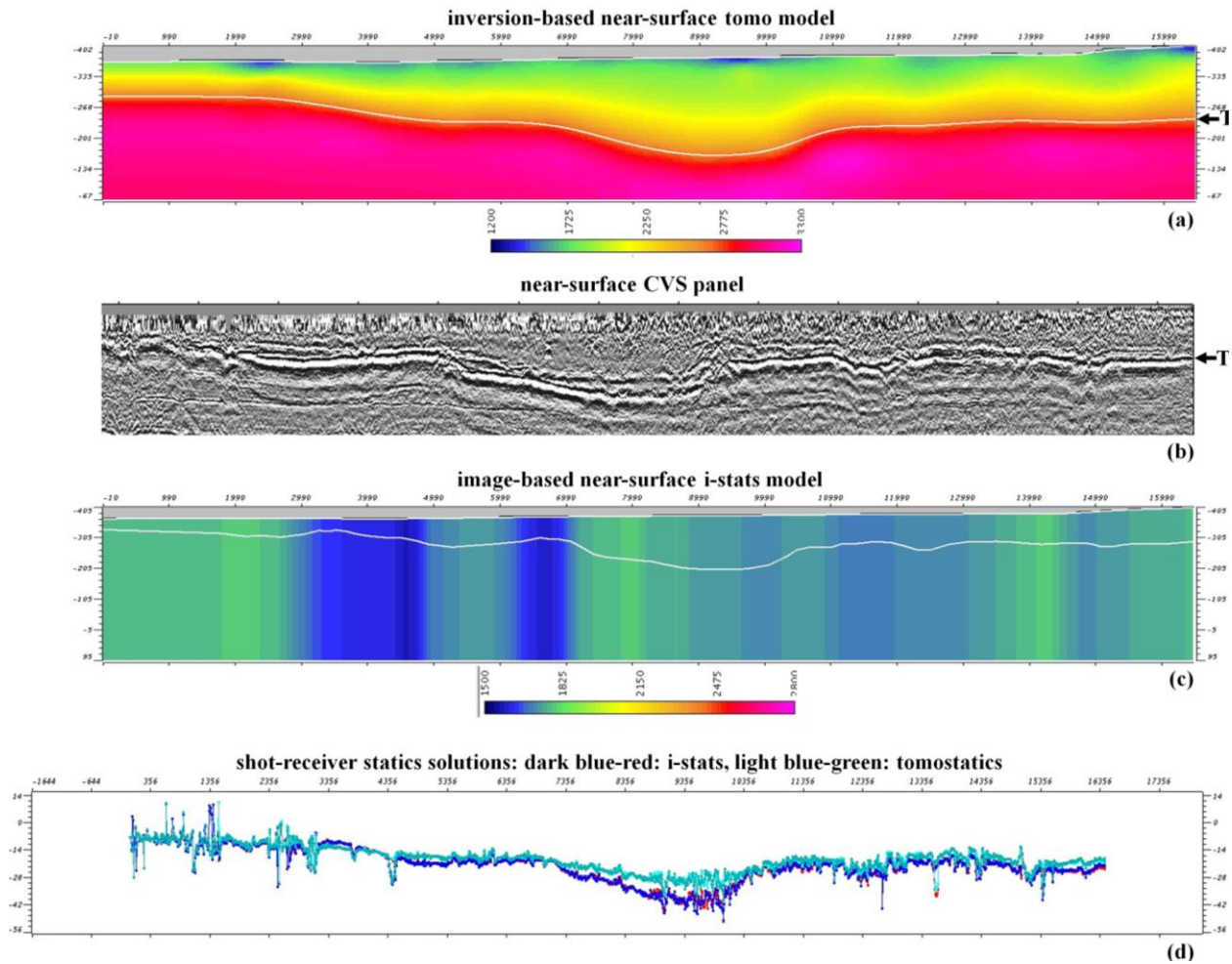
For evaluation of the statics corrections, we compare CVS panels with elevation statics, inversion-based tomostatics, and image-based i-stats. Figure 4a shows a CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections, but without any long-wavelength statics corrections applied. Figure 4b shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the inversion-based tomographic solution followed by residual statics corrections as shown in Figure 3d. Finally, Figure 4c shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the image-based i-stats solution followed by residual statics corrections as shown in Figure 3d.



**Figure 4.** (a) A CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections; (b) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the tomographic solution followed by residual statics corrections as shown in Figure 3d; and (c) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the i-stats solution followed by residual statics corrections as shown in Figure 3d.

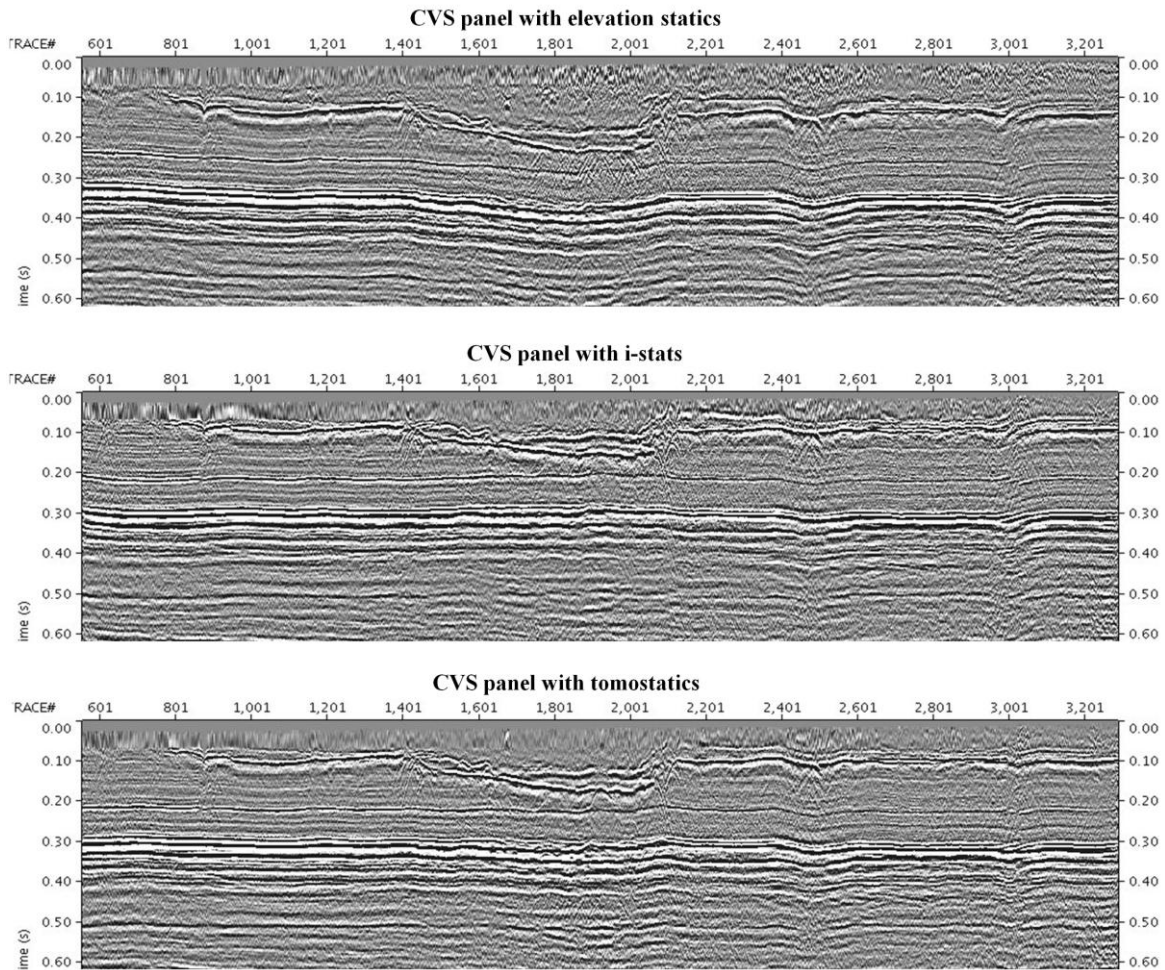
### The i-stats Case Study 3: Glacial Tills

Shown in Figure 5 is the case of a near-surface with glacial till comprising low-velocity material in Western Canada. The CVS panel with velocity optimum for the near-surface shown in Figure 5b exhibits a strong reflection that corresponds to the strong velocity contrast at the interface between the near-surface and the subsurface. Note that the geometry of the interface that represents the boundary between the near-surface and the subsurface, represented by the red color in the velocity-depth model (Figure 5a) closely follows the geometry of the strong reflection observed in the shallow CVS panel (Figure 5b). The image-based near-surface i-stats model based on the workflow described above is shown in Figure 5c. The shot-receiver statics computed from the inversion-based near-surface tomo model (Figure 5a) and the image-based near-surface i-stats model (Figure 5c) are shown in Figure 5d. The two solutions are in close agreement except at the center portion of the line, where the likely presence of a high-velocity layer above a low-velocity layer in the near-surface may not have been resolved by traveltime inversion.



**Figure 5.** (a) The velocity-depth model for the near-surface with glacial till from Western Canada, estimated by travelttime inversion applied to first-arrival times picked from the shot gathers; (b) near-surface CVS panel that exhibits a strong reflection (TB) associated with the interface between the near-surface above and the subsurface below; (c) effective-medium velocity-depth model estimated by the image-based i-stats workflow; (d) shot-receiver statics computed from the inversion-based tomo model in (a) and the image-based i-stats model in (c).

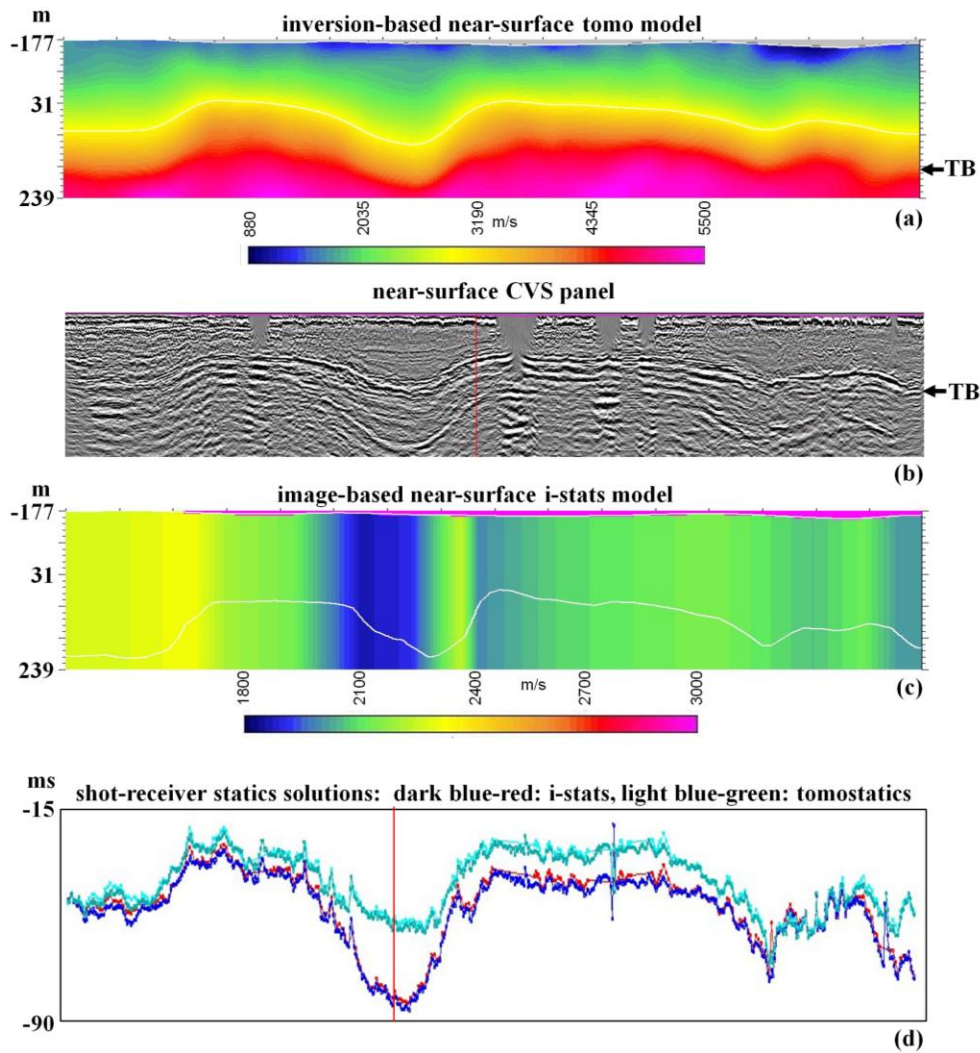
For evaluation of the statics corrections, we compare CVS panels with elevation statics, inversion-based tomostatics, and image-based i-stats. Figure 6a shows a CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections, but without any long-wavelength statics corrections applied. Figure 6b shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the inversion-based tomographic solution followed by residual statics corrections as shown in Figure 5d. Finally, Figure 6c shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the image-based i-stats solution followed by residual statics corrections as shown in Figure 5d.



**Figure 6.** (a) A CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections; (b) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the tomographic solution followed by residual statics corrections as shown in Figure 5d; and (c) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the i-stats solution followed by residual statics corrections as shown in Figure 5d.

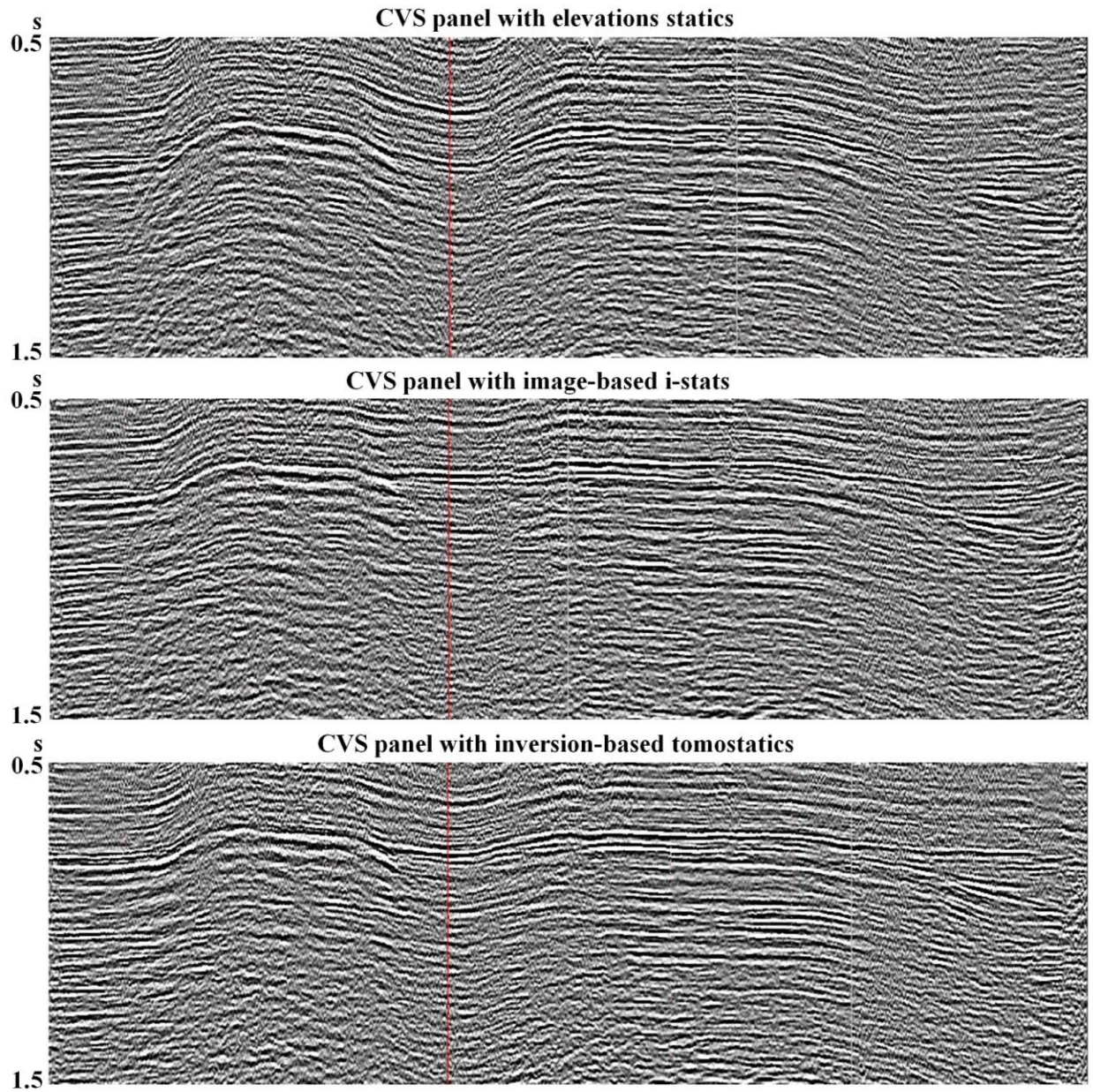
#### The i-stats Case Study 4: Karstic Formation

Shown in Figure 7 is the case of a near-surface with salt-filled karstic limestone from Western Siberia. The CVS panel with velocity optimum for the near-surface shown in Figure 7b exhibits a strong reflection that corresponds to the strong velocity contrast at the interface between the near-surface and the subsurface. Note that the geometry of the interface that represents the boundary between the near-surface and the subsurface, represented by the red color in the velocity-depth model (Figure 7a) closely follows the geometry of the strong reflection observed in the shallow CVS panel (Figure 7b). The image-based near-surface i-stats model based on the workflow described above is shown in Figure 7c. The shot-receiver statics computed from the inversion-based near-surface tomo model (Figure 7a) and the image-based near-surface i-stats model (Figure 7c) are shown in Figure 7d. The two solutions are in close agreement except at the center portion of the line, where velocity variations in the near-surface may not have been completely resolved by travelt ime inversion.



**Figure 7.** (a) The velocity-depth model for the near-surface with sand dunes from North Africa, estimated by travelt ime inversion applied to first-arrival times picked from the shot gathers; (b) near-surface CVS panel that exhibits a strong reflection (TB) associated with the interface between the near-surface above and the subsurface below; (c) effective-medium velocity-depth model estimated by the image-based i-stats workflow; (d) shot-receiver statics computed from the inversion-based tomo model in (a) and the image-based i-stats model in (c).

For evaluation of the statics corrections, we compare CVS panels with elevation statics, inversion-based tomostatics, and image-based i-stats. Figure 8a shows a CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections, but without any long-wavelength statics corrections applied. Figure 8b shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the inversion-based tomographic solution followed by residual statics corrections as shown in Figure 7d. Finally, Figure 8c shows a CVS panel with a velocity optimum for the subsurface with the application of long-wavelength shot-receiver statics calculated from the image-based i-stats solution followed by residual statics corrections as shown in Figure 7d.



**Figure 8.** (a) A CVS panel with a velocity optimum for the subsurface with elevation statics applied to lower the shots and receivers from topography to a floating datum followed by residual statics corrections; (b) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the tomographic solution followed by residual statics corrections as shown in Figure 7d; and (c) a CVS panel with a velocity optimum for the subsurface with the application of shot-receiver statics from the i-stats solution followed by residual statics corrections as shown in Figure 7d.

## Conclusions

The i-stats workflow provides an image-based equivalent-medium near-surface model for statics corrections. It does not require first-break picking as for traveltimes tomography, does not require source wavelet estimation as for waveform inversion, does not fail velocity inversions as in traveltimes tomography, does not suffer from velocity-depth ambiguity, does not require data modeling (traveltimes or wave field) as for any inversion method, and does not exhaust computational resources as in waveform and joint inversions. In contrast with tedious first-break picking in traveltimes tomography, the i-stats method is based on event and semblance picking --- interpretively appealing to the practicing geophysicist. In contrast with the yet-to-be-resolved practical aspects of waveform inversion and joint inversion methods, the intuitively appealing image-based i-stats method is extremely robust and efficient for modeling of near-surface anomalies.

Irrespective of the method for near-surface modeling, the objective with long-wavelength statics corrections is to remove the deleterious effect of the near-surface anomaly on reflection traveltimes. Subsequent to the long-wavelength statics estimation, irrespective of the method used, short-wavelength residual statics estimation must follow. Since the ultimate deliverables from the near-surface modeling are shot-receiver statics, not the near-surface model itself, which should be treated as an intermediate product, then, the image-based i-stats method is just as valid as any other method for near-surface corrections. Moreover, more than any other method, the i-stats near-surface model conforms to the vertical-ray assumption underlying statics corrections.