

Datuming and layer replacement: When are static corrections sufficient?

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Summary

Time distortions due to heterogeneity in the near-surface can seriously degrade the quality of migrated reflection seismic data. Using raypath-based kinematics for simple near-surface models, we examine the errors introduced into data by applying vertical-path, static corrections to finite-difference-modeled, unstacked data. We consider two alternative near-surface-correction techniques. The first one, layer replacement, simulates data that would be recorded at the original recording surface with the near-surface, weathered layer replaced by the higher velocity of subweathering. The second is downward continuation, which aims to simulate data that would be recorded at a datum level below the near-surface layer. For the simple models studied, static (i.e., vertical-path) velocity replacement tends to be a better approximation to true (i.e., slant-path) velocity replacement than static downward continuation is to true downward continuation. Migrations of variously static-corrected data are the basis for comparison.

Introduction

Commonly, the Earth's near-surface exhibits considerable lateral velocity variation and a velocity that is lower than that of underlying bedrock. A number of approaches (e.g., field static-, refraction static-, tomographic static-, and residual static-correction) aim to correct for the distortions a laterally varying low-velocity layer (LVL) introduces in reflection data (Yilmaz, 1987; Cox, 1999). No matter what approach is used or the quality of the assumptions (e.g., surface-consistency) that are made in derivation of the corrections, ultimately, some *correction* is actually applied to the data to reduce the influence of the variable near-surface. If the raypaths between two surfaces (such as the Earth's surface and some datum level) are vertical, static shifts are appropriate for upward or downward continuing data from one surface to the other. When the raypaths are not vertical, continuation of data requires that energy be moved laterally in space, as well as in time. Statics applications, however, do not accomplish the necessary lateral shift in space. (Throughout, we associate the word *statics* with vertical-path adjustment of data.) As illustrated by Beasley and Lynn (1992), both the apex time and curvature of a diffraction associated with a point scatterer in a homogeneous medium must change when a wavefield is upward or downward continued correctly between two horizontal layers. Datum-

ing with statics simply shifts diffractions, but does not change their shape. Such an incomplete process leads to degraded final images because migration with the true subsurface velocity model will collapse diffraction patterns whose shapes differ from those present in the vertical-path, static-corrected data.

Strictly, downward (and upward) continuation of data through the near-surface should be done with a method that honors wave theory, which treats dynamics as well as kinematics. For the simple models studied here, we can simulate the essential kinematic action of a wave-theoretical approach by basing the time corrections associated with wavefield continuation on slant (Snell's law) raypaths through the near-surface. Such slant-path corrections alter both times and lateral positions, thus making the appropriate changes in curvature of the diffractions.

Velocity replacement

Figure 1 shows the geometry of a subsurface consisting of a homogeneous half space with velocity V_b overlain by a horizontal LVL with velocity V_w . The raypath between a source (or receiver) located at $(\xi, 0)$ and the point scatterer D is the path from $(\xi, 0)$ through (ξ', h) to D . From a ray-kinematics viewpoint, in order to replace the LVL correctly with a layer whose velocity is V_b , the arrival recorded at $(\xi, 0)$ should undergo two steps. First, it is moved in space to the point (ξ', h) at the base of the weathering, and its time is reduced by an amount calculated from velocity V_w and the length of the slant-path between points $(\xi, 0)$ and (ξ', h) . In the second step, the arrival is moved to the point $(x, 0)$, and the time is increased by an amount calculated from replacement velocity V_b and the length of the slant-path between the points (ξ', h) and $(x, 0)$. The one-way traveltime obtained after slant-path velocity replacement is given by

$$T_{dat} = \frac{\sqrt{x^2 + \eta^2}}{V_b}, \quad (1)$$

where η is the depth of the scatterer. In practice, vertical-path, rather than slant-path, datuming is typically applied. The one-way traveltime, $T_{original}$, from D to a point located at $(x, 0)$ in the two-layer medium would be statically time shifted by an amount

$$T_{static} = \frac{h}{V_w} - \frac{h}{V_b} \quad (2)$$

to yield

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$$T_{adjust} = T_{original} - T_{static}. \quad (3)$$

No lateral shift takes place. From the geometry of the problem, T_{adjust} and T_{dat} satisfy

$$T_{adjust} = f_1 \cdot T_{dat}, \quad (4)$$

where

$$f_1 = \left(\frac{\eta - h}{\eta} \cdot \frac{\cos \phi}{\cos \theta} \right) \left[1 + \left(\frac{x - x'}{x'} \right) \left(\frac{V_b}{V_w} \right)^2 - \frac{h \sin \theta}{x'} \left(\frac{V_b - V_w}{V_w} \right) \right]. \quad (5)$$

Therefore, if f_1 is close enough to 1, then vertical-path velocity replacement is an acceptable approximation to slant-path velocity replacement (which, for this simple model, approximates the kinematics of wave-theoretical velocity replacement). The factor f_1 is always greater than 1, so T_{adjust} always exceeds T_{dat} .

For unstacked data, the total time correction for reflections on any trace would be the sum of time quantities, such as those above, associated with the locations of the source and receiver, for that trace, relative to the position of the scatterer.

Downward continuation

A similar analysis can be made for downward continuation of sources and receivers to a datum level below the LVL. Figure 1 shows such a level at depth d below the base of the LVL. To perform vertical-path downward continuation to the datum level for a source located at $(x, 0)$, we would apply a static shift of

$$\tilde{T}_{static} = \frac{h}{V_w} + \frac{d}{V_b} \quad (6)$$

to the one-way traveltime, $T_{original}$, to yield

$$\tilde{T}_{adjust} = T_{original} - \tilde{T}_{static}. \quad (7)$$

After slant-path downward continuation to the datum level, the one-way traveltime for the path between the point $(u'', h + d)$ and D is

$$\tilde{T}_{dat} = \frac{\sqrt{x^2 + (\eta - h - d)^2}}{V_b}. \quad (8)$$

The downward-continued traveltimes are related by

$$\tilde{T}_{adjust} = f_2 \cdot \tilde{T}_{dat}, \quad (9)$$

where

$$f_2 = \left(\frac{\eta - h}{\eta - h - d} \cdot \frac{\cos \beta}{\cos \theta} \right) \left[1 + \left(\frac{x - x'}{x'} \right) \left(\frac{V_b}{V_w} \right)^2 - \frac{\sin \theta}{x'} \left(h \frac{V_b}{V_w} + d \right) \right]. \quad (10)$$

Consequently, vertical-path downward continuation is close to slant-path downward continuation when $f_2 \approx 1$.

Numerical results

A velocity model used in the study is shown in Figure 2. A subweathering layer with velocity $V_b = 2500$ m/s, containing three point scatterers at lateral positions 4000 m, 5000 m, and 6000 m, each at depth 1950 m, is overlain by an LVL with velocity $V_w = 1000$ m/s. Over a portion of the model, the base of the LVL dips at slightly less than 5° . At lateral positions 2000 m and 8000 m, the LVL is 600-m and 100-m thick, respectively, with thickness varying linearly between those two positions. Unstacked synthetic data (60 shots, each recorded by 80 receivers, with shotpoint spacing 50 m and receiver group interval 25 m) were generated with a finite-difference code. Figure 3 shows the result of prestack Kirchhoff depth-migration of the data after velocity replacement with vertical-path statics, and Figure 4 shows the depth-migrated section after downward continuation to a datum level 620 m below the recording surface, also with vertical-path statics. The image of the data after vertical-path velocity replacement is slightly overmigrated (the imaged scatterers show a slight upturn relative to the result—not shown here—of migration of the original data from the surface of the model), whereas the image of the data after vertical-path downward continuation is significantly undermigrated.

If we assume that the base of the LVL dips gently enough that it can be considered locally horizontal, then the results in Figures 3 and 4 can be explained with the model shown in Figure 1. Figure 5 is a plot of $T_{adjust} - T_{dat}$, for vertical-path velocity replacement, versus the raypath angle from vertical, θ , in the subweathering layer, for a scatterer depth of 1950 m, $V_w = 1000$ m/s, $V_b = 2500$ m/s, and three different thicknesses of the LVL. The positive differences imply overmigration, as was seen in Figure 3. Figure 6 is a plot of $\tilde{T}_{adjust} - \tilde{T}_{dat}$ versus θ for vertical-path downward continuation to a level 620 m below the recording surface, for the same diffractor depth and medium velocities as in Figure 5, but for two different LVL thicknesses. The negative values for the differences explain the undermigration seen in Figure 4. For a given θ and h , the magnitude of the error due to vertical-path downward continuation is greater than that due to vertical-path velocity replacement. This explains the poorer quality imaging in Figure 4 as compared with that in Figure 3. From Figure 6, the magnitude of the error is larger, the deeper the datum level d . That observation matches our

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expectations: where d is large, the vertical-path assumption for a given scatterer depth η and lateral position x of the source or receiver relative to that of the scatterer is poor. When d is relatively small, the error magnitudes for the two techniques are comparable, as shown in Figures 5 and 6, for $h=500$ m.

Conclusion

Where correction for propagation through the near-surface is most needed, the near-surface is far more complicated than in the model shown here. Topography and base of weathering can be highly irregular, as can be the weathering velocity. The example here, however, indicates that, even when the near-surface is laterally smooth, layer replacement using simple vertical-path corrections can be considerably more robust than is downward continuation that is also based on vertical paths in the near-surface. More complex near-surface models that will be presented in the talk support this conclusion. Related, comparably important, issues that will be addressed in the talk include the comparative accuracy and value of vertical-path, versus slant-path, layer replacement and downward continuation (1) when information about the near-surface model is approximate, (2) when estimated velocities, rather than true velocities, are used for the migration, and (3) when the near-surface and base of weathering have irregular topography. For irregular topography, we also address the relative merits of doing upward continuation (via both vertical-path and slant-path correction) to a datum level above the highest point on the Earth's surface.

Acknowledgements

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References

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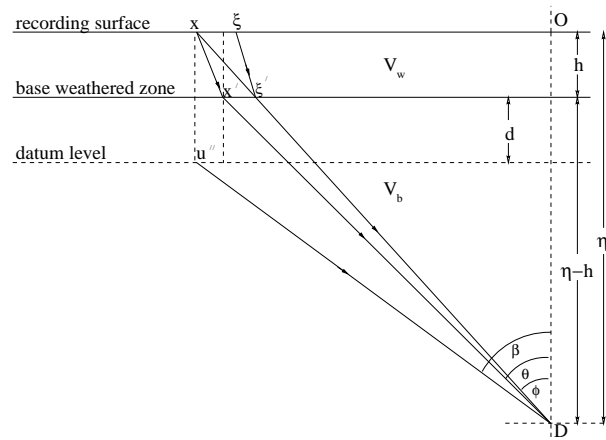


Figure 1. Schematic depth section showing raypaths between a point scatterer and locations on different recording levels.

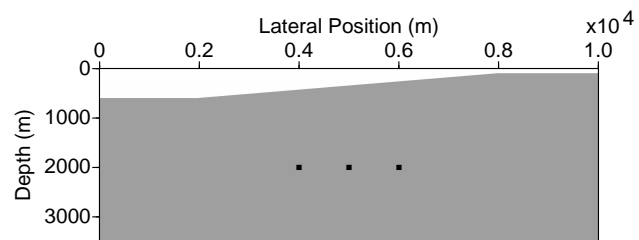


Figure 2. Velocity model.

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- Yilmaz, O., and Lucas, D., 1986, Prestack layer replacement: *Geophysics*, **51**, 1355-1369.
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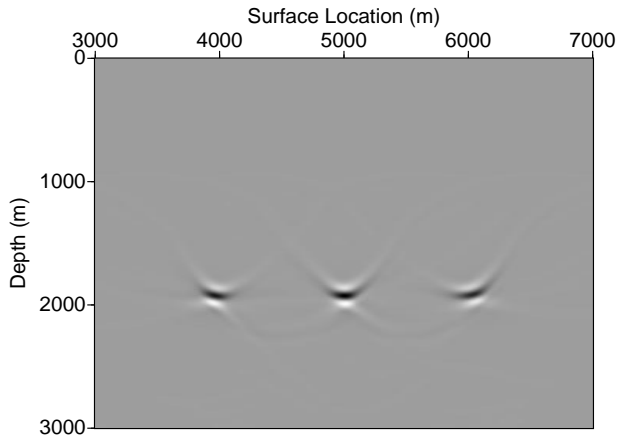


Figure 3. Migration of model data after static velocity replacement.

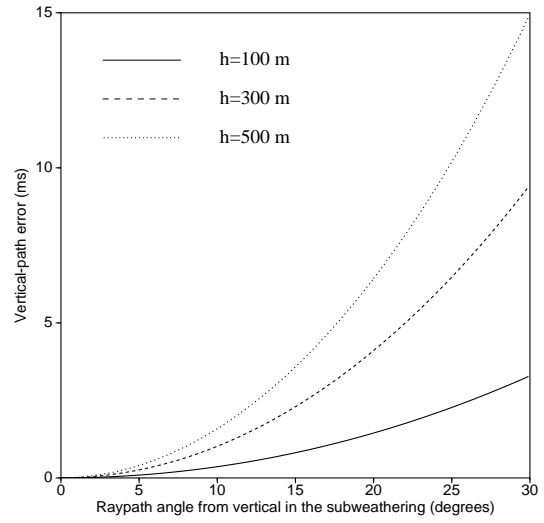


Figure 5. $(T_{adjust} - T_{dat})$ versus θ for velocity replacement.

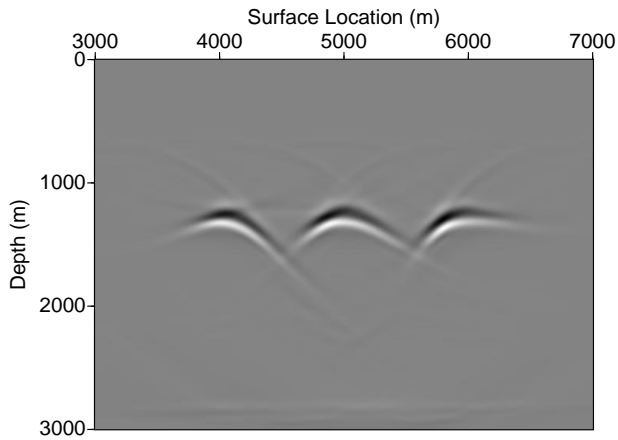


Figure 4. Migration of model data after static downward continuation.

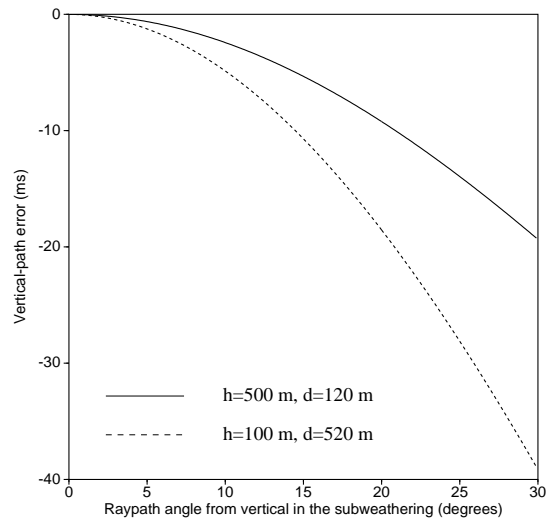


Figure 6. $(\tilde{T}_{adjust} - \tilde{T}_{dat})$ versus θ for downward continuation.