Migration redatuming and velocity conversion

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Summary

In order to take advantage of some efficient migration algorithms that assume input data are acquired on a horizontal plane, it is some times necessary to shift seismic data from the recording surface to a flat datum. The zero-velocity layer padding method works well when the datum is above the recording surface of the input data. When the datum is below the surface, the zero-velocity layer padding method breaks down, because it is chopping off a layer instead of padding a layer. A generalized method, velocity conversion, is developed to handle both cases.

Introduction

The assumption that the input data is referenced to a flat datum is required for some of the most efficient migration algorithms, like finite difference and phase shift. Seismic data has to be shifted from its recording surface to an arbitrary horizon (datum) by applying the long wavelength weathering static in order to use these algorithms. A common practice is to pad a zero-velocity layer (Higginbotham, et al, 1985, Beasley and Lynn, 1992) between the surface and datum. This method yields good results when the datum is higher than the surface. If the datum is lower than the surface, the zero-velocity layer method breaks down. The velocity field is chopped off at the top and will therefore be too slow to migrate data correctly. Migrating seismic lines from a datum below the recording surface is not preferred, but some times it is necessary. For example, a line may need to be processed at a datum below its recording surface in order to tie with old processing. One solution is to migrate the line at a higher datum and shift it back to the original datum after migration. A preferred solution is to develop a generalized method that still does the zero-velocity layer method when the datum is above the surface and handles cases when the datum is below the surface. This will simplify the processing flow and reduce the chances of mistakes.

Method

In Figure 1, a scatter point is located beneath the recording surface location O. The diffraction curve recorded is a branch of a hyperbola centred at O. When redatuming to level O’, another hyperbola centred at O’ is needed for migration to collapse energy along the curve. This new hyperbola should fit the original hyperbola. This new curve is defined by a new velocity.

The following is the travel time equation from surface to a scatter point:

$$t^2 = t_0^2 + \frac{4h^2}{v_{rms}^2}, \qquad (1)$$

where t is the two way travel time from the surface location to the scatter point, t_0 is the two way travel time from the surface projection of the scatter point to the scatter point, h is the horizontal distance from the source/receiver to the scatter point, and v_{rms} is the RMS velocity measured from the surface.

The time t and t_0 in equation (1) are measured from the recording surface. The hyperbola described in equation (1) asymptotes to time 0 at the surface. If migrating data from a datum other than the surface, the static component, s, needs to be considered (Figure 1). Equation (1) becomes (for h relatively small compared to the depth of the scatter point):

$$(t+s)^2 = (t_0+s)^2 + \frac{4h^2}{v_{new}^2}, \qquad (2)$$

where s is the static shift to move data from the surface to the datum. Equation (2) defines a hyperbola too, but this hyperbola asymptotes to a negative time $-s$ relative to the recording surface (Figure 1). It finds a branch of a hyperbola that fits a branch of another hyperbola with a different geometric centre. Substituting equation (1) into equation (2) to cancel h

$$1 + \frac{2s}{t+t_0} = \frac{v_{rms}^2}{v_{new}^2}. \qquad (3)$$

Equation (3) defines the velocity conversion from surface to datum. It shows that a new velocity is needed for the datum in order to migrate seismic data properly. There is no restriction on the static shift s. It can be positive or negative. The physical meaning of equation (3) is that the move-out using the new velocity from the datum at a reference offset is equal to the move-out using the old velocity from the surface. For a zero offset approximation, set $t = t_0$ and rearrange equation (3),

$$V_{new}^2 = \frac{t_0}{s+t_0} V_{rms}^2 \qquad (4)$$

In the case where the datum is below the surface, static shift s has a negative sign in equations (1) – (4), and the new hyperbola asymptotes to a positive time relative to the surface.

Now take a look at the RMS velocity from the datum by using zero-velocity layer padding method. Assuming a scatter point has an RMS velocity V_{rms} (Dix, 1955) measured on the surface,

$$V_{rms}^2 = \frac{\sum_i t_i V_i^2}{t_0}. \quad (5)$$

The RMS velocity measured from the datum is:

$$V_{new}^2 = \frac{sV_0^2 + \sum_i t_i V_i^2}{s + t_0} = \frac{\sum_i t_i V_i^2}{s + t_0} = \frac{t_0}{s + t_0} V_{rms}^2,$$

where V_0 (=0) is the velocity padded between the surface and the datum, t_i and V_i are the vertical travel time and interval velocity in ith layer, t_0 is the total vertical travel time from the surface down to the scatter point. So zero-velocity layer padding is the same as the velocity conversion in the case when the datum is above the surface.

Synthetic data test

A synthetic model is built to test the velocity conversion method. The model uses a 1-D velocity model and has three scatter points at different depths. A datum is chosen at 100 ms below the recording surface. The input section is shown in Figure 2. Both zero-velocity layer and velocity conversion methods are used to migrate this data set with the down shifted datum. A finite difference migration algorithm is used for the test. The result using the zero-velocity layer method is displayed in Figure 3. In this case, there is no layer to be padded but instead the top layer is chopped off. It is not surprising that the data is undermigrated. Figure 4 shows the migration using velocity conversion method. The three diffraction curves are nicely collapsed.

In contrast to shifting the datum downward, another example is given by shifting the datum upward. Figure 5 is from the same model as Figure 2, but shifted to a datum that is 100 ms above the surface. Migration results show that the zero-velocity layer method (Figure 6) and the velocity conversion method (Figure 7) are similar to each other.

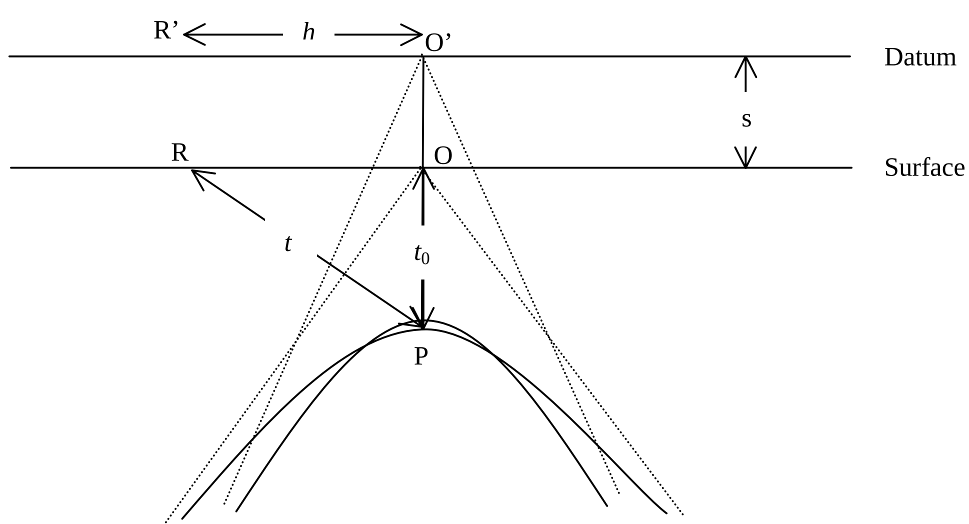

Figure 1: A new hyperbola is used to fit another hyperbola centred at a different location

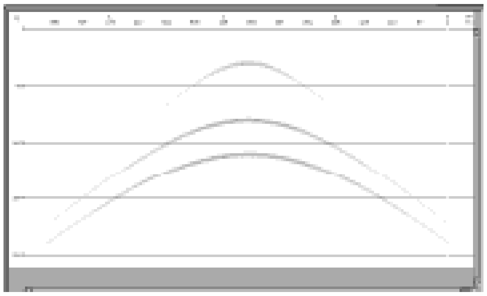

Figure 2: The synthetic data for test. The data has been shifted to a datum that is 100 ms below the surface.

Figure 3: The output using zero-velocity layer method.

Figure 4: The output using velocity conversion method.

Another synthetic data is used for testing, which is composed of three sets of hyperbolae at different depths with varying surface elevation and a constant velocity model (Figure8). Migration datum is set to the lowest elevation of the recording surface. Sections are shifted to the highest elevation of the recording surface after migration for illustration. Figure 9 shows the migration using zero-velocity padding (actually the layer above the lowest elevation of the recording surface is chopped off). The column of scatter points on the left is imaged correctly. Since these scatter points have the same recording surface elevation as the datum, datuming does not affect them. The right and middle columns of scatter points are undermigrated, more or less. This indicates that the migration velocity is too slow for these points.

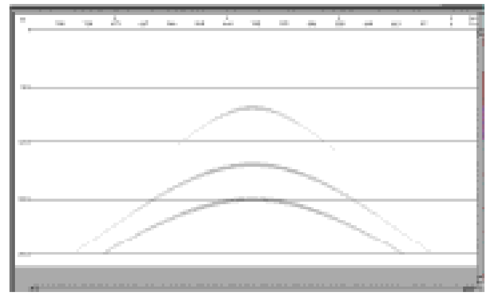

Figure 5: The synthetic data for test. The data has been shifted to a datum that is 100 ms above the surface

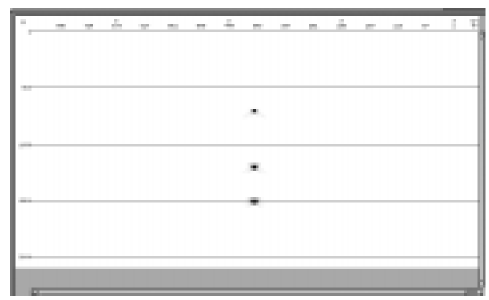

Figure 6: The output using zero-velocity layer method

Figure 7: The output using velocity conversion method

The method of velocity conversion converts the original velocity that is referenced to the recording surface to an equivalent velocity referenced to a flat datum, according to the different elevations of the recording surface (amount of static shift) on the seismic line at different locations. Figure 10 shows the migration result using the converted velocity. The image of the left column of scatter points is similar to that in Figure 9, where the datum is the same as the recording surface. However, the right and middle columns of the scatter points, where the datum is below the recording surface, focus better than that in Figure 9. The method of velocity conversion works well where the datum is below the recording surface, in the case the recording surface is not a flat plane.

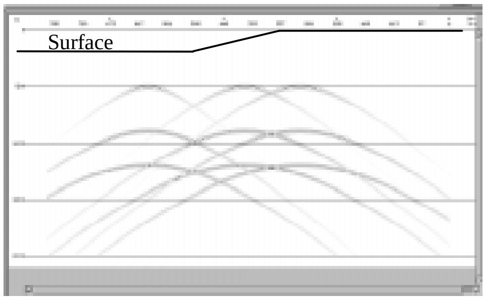

Figure 8: The synthetic data with an uneven recording surface. The datum is the lowest elevation of the recording surface.

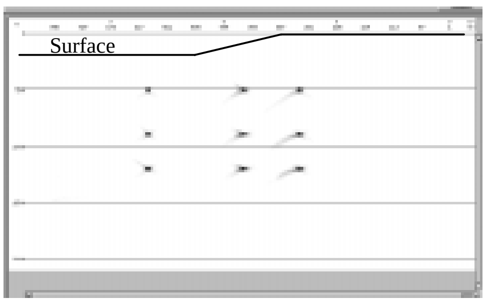

Figure 9: The output using zero-velocity layer method

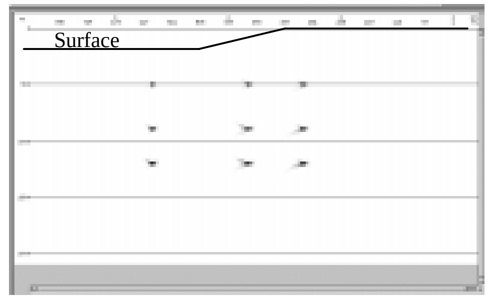

Figure 10: The output using velocity conversion method

Conclusions

A generalized method of zero-velocity layer padding, velocity conversion, makes migration redatuming more flexible. It can be used not only when a datum is higher than the recording surface (in this case the zero-velocity layer method works well), but also when a datum is below the recording surface (in this case the zero-velocity layer method is unable to handle). Synthetic tests show the velocity conversion method can successfully convert a velocity field for migrating data properly when the migration datum is below the recording surface.

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References

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