The NMO stretch factor and dip limits in EOM

John C. Bancroft

ABSTRACT

An advantage of equivalent offset migration is the compatibility of common scatter point gathers with conventional processing routines such as velocity analysis, NMO, and stacking. Care must be taken when using these conventional routines to ensure compatibility with the objectives of prestack migration. This paper discusses the NMO stretch factor and is the effects on migration dip limits.

INTRODUCTION

Dip limits of migration

An objective of migration is to collapse the energy in a diffraction to its scatter point. A question often raised is "how much of the diffraction is required to focus the energy to it minimal size?" or an equivalent question "what is the maximum dip that can be migrated with a particular algorithm?"

One approach has been to use the algorithm that contains the steepest dips, guided by the logic "it must be a better algorithm." There is validity to this argument, especially in areas with steep dips; however, there are many applications where the dipping energy is limited and the full dip range of migration is not required. In noisy areas, the retention of steep dips may contribute excessive noise to the migration.

Some algorithms such as those based on the FK or phase shift methods have the potential to migrate to and beyond dips of 90 degrees. Others, such as finite difference methods, have limits expressed as 15, 45 or 65 degrees of dip. The Kirchhoff method of migration has the ability to migrate to any dip limit.

Dip limits of Kirchhoff migration

The extent of the migration diffraction is effectively controlled by Kirchhoff time migration as illustrated by the scatter point in Figure 1. In part (a) of this figure, a subsurface cross-section shows a zero offset reflection at an angle β with a migration offset x. Part (b) shows a zero offset section with the time of the reflection T at x on the migration hyperbola at D. The slope on the diffraction at this time is given by the angle α. The angles α and β are related by the migrator's equation,

$$\tan\alpha = \sin\beta , \tag{1}$$

with T is also defined by

$$\frac{T_0}{T} = \cos\beta, \tag{2}$$

where T_0 is the vertical zero offset time at C.

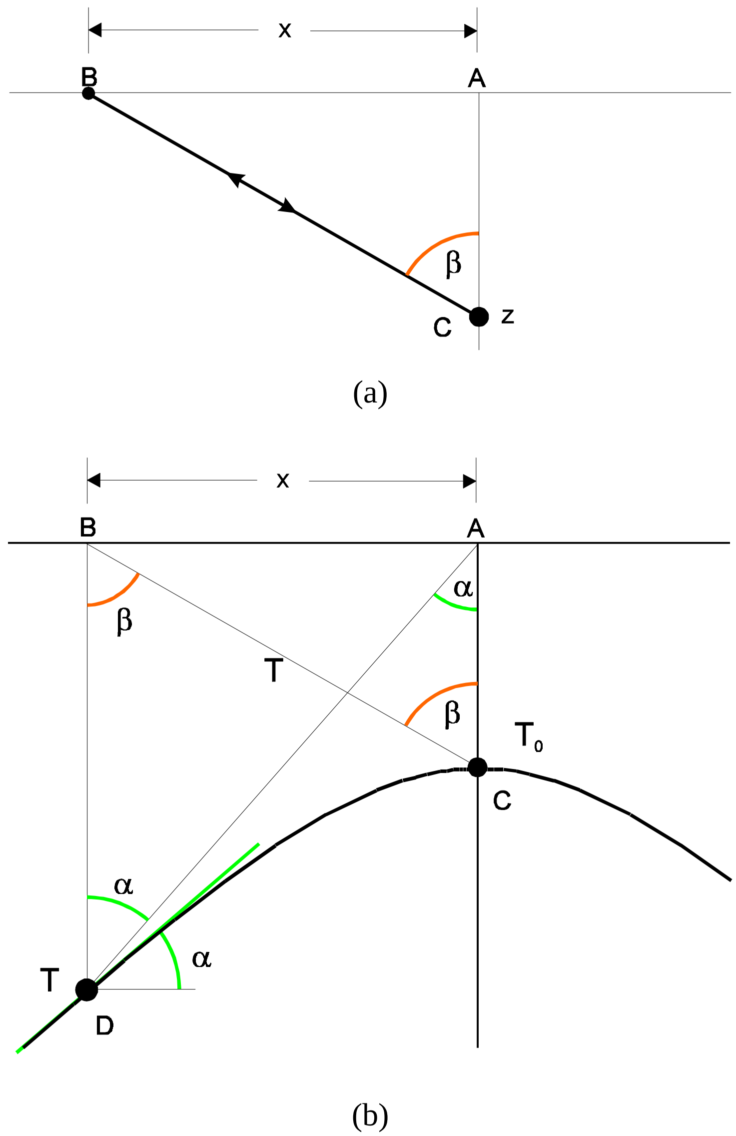

FIG. 1. Depth (a) and time (b) sections for identifying dip angles.

The angles of α and β represent the angles before and after migration and are shown on (b) as angles at A, B, C, and D. The migration dip limit of β_{max} may therefore be established by a dip limit of α_{max} on the time section at D by time T, or offset x_{max} .

Figure 2 shows a series of diffractions for a constant velocity section, and the maximum dip limit α_{max} intersecting all the diffractions. Energy summed on the diffraction would normally be tapered to zero at the maximum dip limit as illustrated by the slopping wedge of gray on the left side of the figure.

An additional benefit of limiting the dips in Kirchhoff migration is the saving of computational time.

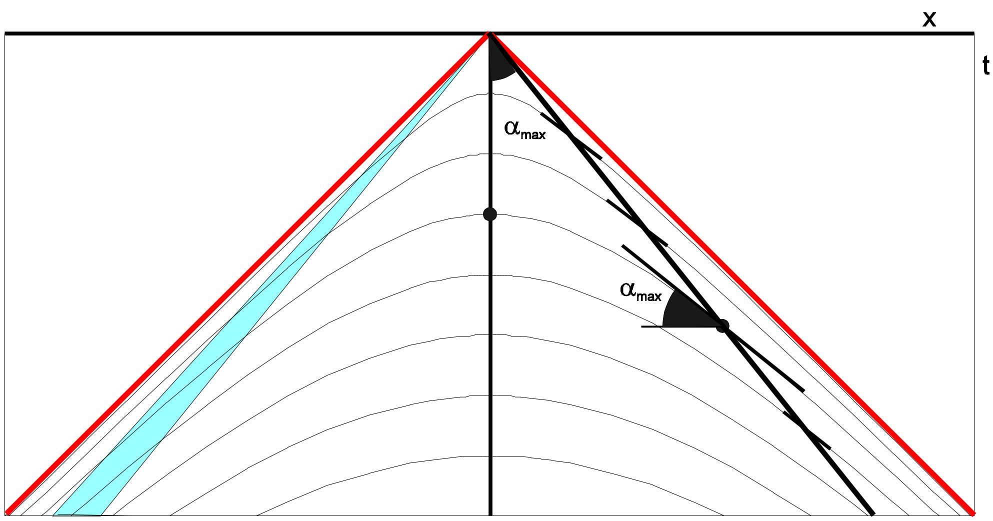

FIG. 2. Series of constant velocity diffractions illustrating the dip limit as a function of offset.

EOM, THE CSP GATHER, AND NMO

Equivalent offset migration (EOM) forms common scatter point (CSP) gathers as part of the prestack migration process. The data in these CSP gathers is similar to a common midpoint (CMP) gather prior to NMO removal. The time shifting part of Kirchhoff migration is identical to NMO removal and may therefore be accomplished with standard NMO algorithms. Migration requires scaling along with the additional steps of wavelet and antialiasing filtering that are omitted from conventional NMO processing.

NMO and the stretch factor

It is common practice in seismic processing to remove NMO from CMP gathers and then to apply a mute to prevent the inclusion of unwanted noisy data, or data over stretched by the NMO process. Some methods apply an automatic mute by limiting the amount of NMO stretch to a pre-defined limit referred to as the stretch factor. The stretch factor S is defined by a ratio of the incremental times δT and δT_0, measured before and after NMO removal and defined to be

$$S = \frac{\delta T}{\delta T_0} . \quad (3)$$

The stretching is demonstrated in Figure 3 where the NMO removal has caused energy on the hyperbola to be moved and stretched to the horizontal time at T_0.

To limit excessive stretching of the wavelet in conventional processing, the stretch factor is often set to a high value, limiting the stretch at T_0 to be less than 20 percent.

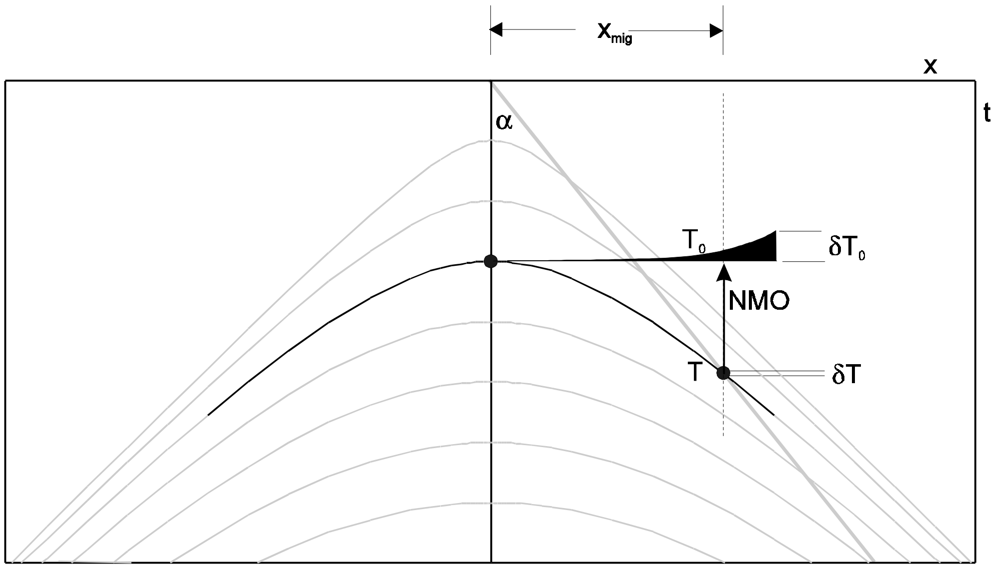

FIG. 3. Illustration of NMO stretch limited by a dip limit.

The stretch factor may be used as a method to limit the migration dips on CSP gathers when using conventional NMO removal, as also illustrated in Figure 3. The NMO and migration equation is

$$T^2 = T_0^2 + \frac{4x^2}{V^2} \tag{4}$$

where x is the half offset for NMO, and the scatter point to input trace offset for migration. When the velocity V is constant, the stretch factor S may be found by differentiating the NMO equation with respect to T_0 giving

$$2T\frac{dT}{dT_0} = 2T_0 \tag{5}$$

or

$$S = \frac{dT}{dT_0} = \frac{T_0}{T} \approx \frac{\delta T}{\delta T_0} \tag{6}$$

where δT_0 and δT are incremental times at T_0 and T. From equation (2), the constant velocity stretch factor S_{cv} may be observed to be equal to the cosine of the geological dip β, i.e.,

$$S_{cv} = \frac{T_0}{T} = \cos\beta \tag{7}$$

Equation (7) indicates a migration dip limit β_{mig} may be set by choosing a suitable stretch factor S_{mig} when using the conventional NMO process, i.e.,

$$S_{mig} = \cos\beta_{mig} \ . \tag{8}$$

It should be noted that for a given dip β_{mig} the stretch factor must be greater than S_{mig}, and that at a given T_0 the stretch factor reduces with offset.

The above equations are only valid for constant velocities. When the velocities increase with time (i.e. depth), there is an additional stretching δt of the wavelet at T_0 beyond that indicted by equation (6) giving a smaller stretch factor S_{lim} i.e.,

$$S_{\mathrm{lim}} = \frac{\delta T}{\delta T_0 + \delta t} \ . \tag{9}$$

The smaller stretch factor S_{lim} forces the offset x to be reduced until it is equal to the assigned limit S_{mig}. The result is a smaller migration dip limit than anticipated from linear velocities. Note however, that Snell's law will permit dips steeper than β_{mig} to pass, and thus tend to offset the limitations of equation (9).

If the stretch factor is determined directly from T_0/T, then the migration dip on the diffraction will honor the straight ray estimation, and will permit steeper dips than anticipated.

In all the above discussions it is assumed that the NMO process should have an adequate taper at the cutoff location.

CONCLUSION

Conventional NMO removal processes may be used to perform the time shifting for EOM with the stretch factor used to define the migration dip limit. Caution must be taken when using this method, as the stretch factor may include the additional effects due to increasing velocities or the NMO of refracted data, thus reducing the migration dip angle. It is preferable to define the dip limit by the cosine of T_0/T.