Summary
The tomography algorithm presented will generate an optimum velocity model for time migration. The velocity model is computed to flatten every sample on every common image gather. It is constrained to be smooth and bounded, and uses the correct relationship between residual curvature and velocity perturbations. This avoids the inconsistency of vertical updating which updates the velocity in a different manner from how the velocity is used for imaging. The resulting interval velocity model satisfies all available information and is shown to contain valid high resolution features. As a consequence, the updated velocity model gives an improved seismic image.

Introduction
With the correct velocity model, imaging algorithms are able to position acquired seismic data at their true subsurface location. Hence there is a great interest in obtaining an optimum velocity field. A good interval velocity model should be bounded and smooth within geologic layers. In addition, seismic data imaged with the velocity model should produce flat primary events on the common image gathers (CIGs). Because different imaging techniques use the velocity model in different ways, a good model can only be optimum for the particular imaging technique used.

Velocity analysis normally involves imaging the seismic data with an initial velocity model; residual curvature on the resulting CIGs is then used to update the velocity. Vertical updating (Deregowski, 1990) uses the normal moveout equation to relate the residual curvature to an updated RMS velocity. This is an inconsistent way of updating velocities when the imaging uses time or depth migration and can lead to non-optimum results. More sophisticated techniques employ tomography (e.g. Zhou et al, 2001) that more accurately relates residual curvature to the velocity model update. However, many of these methods struggle to honour the imaging operator correctly. For example, the azimuth of acquired data cannot usually be recovered after imaging. In addition, these methods normally only use the residual curvature on selected events and so fail to utilise all the available information.

The technique presented here attempts to overcome these problems by:
- explicitly measuring the relationship between residual curvature and velocity perturbation for the imaging algorithm used,
- using the residual curvature at every sample on all CIGs to update the velocity.

The resultant velocity model is then better constrained and produces an improved image. This method has been implemented for time migration and two examples are shown.

Tomographic Method
Figure 1 describes the technique. Fully imaged CIGs are generated using an initial velocity model and a set of perturbed velocity models. Each perturbed velocity model is identical to the initial velocity model except that a single element of the gridded model is changed by a small amount; every element of the grid is perturbed in turn. The resulting set of CIGs show how the image changes as the velocity varies. The residual curvature at each sample on

Figure 1: A schematic description of tomographic velocity update. The principle of the tomographic algorithm is to generate CIGs using an initial gridded velocity model and a set of perturbed models: each perturbed model is a copy of the initial model with a small change to just a single element of the velocity grid. By studying all of the CIGs, the effect of each perturbation upon the residual curvature of every event on every CIGs can be explicitly measured. The initial velocity model can then be updated to reduce the residual curvature of the CIGs. This process is then iterated until events on the CIG are considered to be flat.
every CIG is then measured and used to compute how the
velocity should be changed to reduce the residual
curvature. The coherence of the seismic data is also
measured so that noisy or incoherent events do not
contaminate the results. Using standard mathematical
methods, a smooth update to the interval velocity model is
produced that will reduce the residual curvature. The
technique is iterated until the residual curvature has been
minimised. As with any tomographic method, it is
important to ensure that energy from multiples is not used
in the analysis.

It is important to note that the new technique is fully
consistent with the imaging operator because the correct
relationship between CIG residual curvature and velocity is
measured. Because every sample of every CIG is used, the
resolution of the velocity update is only restricted by the
resolution of the seismic data. To aid stability, the velocity
update is normally constrained to be smooth.

This algorithm is computationally expensive and not yet
feasible with Kirchhoff depth migration. However, it is
viable to use it for Kirchhoff time migration. To reduce the
computational cost, the spatial resolution of the seismic
data used for the time migration can be reduced.
Decreasing the spatial sampling to 50m or 100m will be
suitable for velocity analysis, provided care is taken to
avoid aliasing.

Central North Sea

The time migration tomography algorithm was applied to
3D seismic data acquired from the central North Sea (UK
Quad 30). This survey area contains a chalk layer with a
tertiary overburden and salt diapir. A simple \( v(z) \) function
was used as the initial velocity. Twenty five iterations of
the time migration tomography were run, although the
velocity model effectively converged after the first ten
iterations.

Figure 2: CIGs from locations taken across a section before (top) and after
(bottom) the tomographic update. The offset ranges from 175 to 4075m.
Most events, both shallow and deep, have a much lower residual curvature
after the tomographic velocity update.

Figure 3. The residual curvature before (top) and after (bottom) the
tomographic update. A smooth velocity is used to reduce the residual
curvature. Consequently, the general trend is to minimise the residual
curvature, but not every sample has zero residual curvature.
Figure 2 shows two equivalent sub-sets of the CIGs from the survey. On the top are CIGs from the first iteration of the tomography algorithm (i.e. imaged with the initial velocity). On the bottom are gathers from the final iteration (i.e. after the tomography has converged). The tomographically updated velocity clearly flattens events on the CIGs, although there is some contamination from non-hyperbolic events and general noise in the gathers.

Figure 3 shows the picked residual curvature from the first (top) and final (bottom) iteration of the time migration tomography. Events with no residual curvature are shown as white, while events that curve up are blue, and events that curve down are red. Every sample on every CIG has been picked and used in the velocity update. Figure 3 shows that the updated velocity model significantly reduces the residual curvature on all events on every CIG, when compared with using the initial velocity model. Note that not every event is flat as the velocity update is constrained to be smooth, but on average, the events on the CIGs are flat.

Figure 4 shows two equivalent interval velocity profiles through the model, overlaid with the corresponding seismic image. The top image shows the initial interval velocity model, which does not correlate to the geology. The bottom image shows the updated interval velocity model, which is smooth and follows the geology well, especially at the top chalk (the chalk velocity is shown in red). The seismic image of the edges of the salt diapir (highlighted on the left of figure 4) has been much improved by the updated velocity. The interval velocity does show some instability around the base of the diapir; this may be due to the time migration algorithm being unable to correctly handle strong lateral velocity variations, as the CIGs around the base of the salt diapir have almost no residual moveout. Although the starting velocity model was far from correct in this example, the algorithm has produced velocities that flattened the gathers well and provide a good image.

Central North Sea – Gas Zone

The second example is also from the central North Sea, but in an area where there is a zone of gas. The initial velocity model, picked conventionally, is shown in Figure 5 (top) with the corresponding seismic image overlaid. A thin gas zone has been circled, but is not represented in the velocity field even though the velocity within the gas zone is slower than the surrounding sedimentary rock. Figure 5 (bottom) shows the interval velocity and imaged seismic after the tomographic update. The updated velocity model has more resolution than the initial model and, as we expect, the velocity within the gas has been slowed down.

Figure 6 shows a time-slice through the gas zone circled in Figure 5. The top image shows the initial interval velocity model and imaged seismic. The bottom image shows the tomographically-updated interval velocity model and corresponding seismic image. The seismic image clearly shows the outline of the gas zone where the tomographically updated velocity has been considerably reduced. The excellent correlation between the seismic image and updated velocity model shows the benefit of measuring and using the residual curvature at the highest resolution possible. The updated velocity also gave an improved seismic image here.
Time Migration Tomography

Conclusion

An algorithm for time migration tomography is described and demonstrated. The results confirm that the technique flattens events on CIGs while constraining the interval velocity to be smooth and bounded, yet still showing valid high resolution features. The tomography ensures that the updated velocity model is consistent with the imaging technique and gives an improved seismic image.

References
