Solutions for Deep Water Imaging

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Introduction :

Imaging in deep water environments poses a specific set of challenges, both in the data preconditioning and the imaging. In this paper, we have reviewed the current practise within GX Technology for addressing many of these issues, concentrating our attention on multiple suppression, scattered noise attenuation, iterative velocity model building and depth imaging.

Deep Water Issues :

The transition from the shallower coastal waters to the deep shelf often encounters significant topographical variation in the sea bed, which gives rise to numerous effects which must be dealt with by the processing geophysicist. These challenges include: deep channels, steep slopes, surface scatters (eg glacial scour, boulder fields), gas hydrates, cold-water column statics, etc.. Some areas also have a "hard" water bottom, resulting in high amplitude multiple reflections relative to primary energy. Scouring, channel formation and extreme rugosity can be common features of the outer slope. Diffracted and "out-of-plane" multiples present extreme challenges. Depending upon acquisition geometry, multiples are frequently aliased at far source-receiver offsets (Stewart, 2004).

Multiples: General Comments and Shallow Water Applications

It has become clear after extensive testing that "direct" multiples are best attenuated using the surface related multiple elimination (SRME) technique (Verschuur 1992). However, correct parameterization is critical for success. Predictive Deconvolution (Peacock 1969), Parabolic Radon (Hampson,1986) and TauP Deconvolution (Yilmaz 1987) all fail to adequately attenuate direct water bottom multiples. Whilst SRME performs well on the "direct" water bottom multiples, TauP deconvolution is the most effective in attenuating the "peg-leg" multiples. As before, good parameterization and data preparation are critical for success (we employ a non iterative, Hi-Resolution transform (Sacchi 1995)). One drawback with TauP Deconvolution, is that the entire ensemble passes through the transform. As a consequence, transform artefacts may be embedded in the data. Many multiple attenuation techniques (e.g. Parabolic Radon and SRME) model the multiple and subtract from the original. This helps minimize process-induced artefact. A modified TauP deconvolution method can also be used, which allows multiples to be modeled and subtracted, thus helping to minimize transform artefacts.

Multiples: Deeper Water Applications

Traditionally, differential velocity based methods such as Parabolic Radon have been used in deep water. These methods tend to fail on near offsets where there is little move-out difference between primaries and multiples. This problem becomes more serious with dip or where the multiple generators become more complex. Additionally, aliasing of the multiples on far offsets can lead to inadequate separation of primaries and multiples in transform space. This requires an additional de-alias step or a transform capable of handling aliased data. In recent years, the SRME technique has become popular in deep water. Near offset multiples in particular, are better attenuated than those with Parabolic Radon. Cascading SRME and Radon has become an industry standard approach. However, the complexity of the multiple generator and "out-of-plane" effects can severely limit even this combination. For this reason, a third level of attenuation is added.

Many of the residual multiples fall into a category of "Apex shifted hyperbolas" i.e. when viewed in common mid-point gathers the apex of the multiple is observed, not at zero offset, but at an offset shifted towards the mid offset range. Intuitively one would expect parabolic or hyperbolic radon to fail on these as they rely entirely on the assumption that the apex is at zero offset. With this zero-offset apex restriction in-mind, GXT have implemented a variant on the Radon approach to handle apex shifted events on CMP gathers. This has proven to be of great use for both diffracted multiples resulting from near surface 3D effects, and also for some classes of industrial noise. This method has been improved and is presented in this paper as Apex Shifted Multiple Attenuation (ASMA). As an alternative to ASMA, and more correct from a theoretical viewpoint, we have 3D SRME, which has come into industrial use over the past 12 months. Here, we model the true 3D ray-paths associated with free surface bounces from ocean-bottom and buried scatterers, as well as with complexities in the multiple wavefield resulting from the topography of the generating surface. Despite the issues related to acquisition and sampling, 3D SRME has proved to be a powerful new tool in the arsenal of multiple attenuation techniques, and has been particularly successful in deep-water sub-salt applications in the Gulf of Mexico.

Velocity Model Building & Pre-Stack Depth Migration

The debate over model representation has been underway for many years (eg. Lafond, et al, 2003, Jones, 2003). Whether it is better to use a strictly layer based model or a pure gridded model are the two extremes of the argument. We prefer to keep our options open, and adopt a hybrid approach, where we combine the benefits of both schemes: the ability of a gridded route to capture the subtle lateral velocity variation inherent to some strata, whilst keeping the sharp vertical breaks occasionally present in the earth (such as at chalk and salt boundaries). If we have sufficient well control, then we can also incorporate anisotropy in the earth model (Thomsen, 1986, Alkhalifa & Tsvankin, 1995, Jones, et al, 2003). However, for deep water exploration projects we often lack such control, and resort to isotropic migration. Following this hybrid route, we proceed in the following manner. The initial depth interval velocity is often built from the time-RMS stacking velocity (smoothed and converted to depth interval velocity). The water bottom is usually picked and gridded, and inserted in the initial model as an explicit layer (sometimes picked on a water-flood migration if the sea bed is rugose). Following this, several iterations of model update are performed (Hardy, 2003; Sugrue et al, 2004). For the purely gridded approach, each iteration of the tomographic velocity model update consists of the following steps:

1a) 3D preSDM on specified grid, outputting full offset gathers (eg. 25 x 25m or 50 x 50 m)
1b) Dense continuous automatic picking of the pre-stack depth migrated seismic gathers using GXT's proprietary plane-wave autopicker (APK), to determine dip, coherency, and residual curvature (velocity perturbation) fields
1c) Depth domain tomographic inversion to update the velocity model based on the residual moveout velocity and the local dip-field estimated during the auto-picking.

The autopicker is a proprietary GXT algorithm, based on plane-wave destructors (Claerbout, 1992; Hardy, 2003). A user-defined 3D probe containing trace portions for different CDP's and offsets is moved about the data. At each position, 2 slopes are computed (along the offset and CDP axis) which minimize the amplitude variation in a least square sense. The quality of this estimate is also computed. As a result of this picking, a 3D slope field and residual moveout estimate are determined. As a by-product of the autopicking, we also obtain a residual move-out (RMO) corrected stack of the image. This is a good indication of whether the autopicker has found the correct residual moveout in preparation for the tomographic update.

Following the autopicking, the tomography takes the RMO and dip field measurements in conjunction with weights based on the 'quality' of the autopicks, and generates a tomographic solution to minimize the residual moveout values (make the gathers flat and correctly position the data).

Hybrid Tomography & Styles of Layer Constraint

In the case where we intend to perform a structural update by picking a layer interface (the hybrid approach), we proceed from the previous iteration's velocity update by running a new 3D preSDM outputting only a restricted offset stack for the structural interpretation. A 'hard constraint' layer (such as at the sea bed, top and base chalk or salt, or pickable nearsurface channel), would result in the model being left unchanged in subsequent iterations above the picked layer. As such we move from a global tomography to a non-global tomography (but still using a gridded tomography with the layered constraint: i.e. the hybrid tomography). A 'soft constraint' layer, such as an ill-defined near-surface channel, would be used if the layer being picked was very uncertain, as is often the case for seismically transparent top-salt picks in the Zechstein sequence of the North Sea. In this latter case, we profit from having the salt velocity inserted in the model below the picked layer, which helps the convergence of the inversion, even though we allow the tomography to change both the velocity in the picked layer and the layer pick itself. In this case the model above the softconstraint pick can change.

QC

Various QC steps are involved during this iterative process, both for the autopicking and the tomography itself. QC products for velocity updating procedures include displays of image gathers before and after the update, stacks and residual depth error grids. A particularly effective QC in 3D is one whereby the residual depth error is displayed in a 3D volume such that it is transparent when depth error is zero (Hardy, 2003).

Imaging

Following completion of the model building, an amplitude preserving 3D Kirchhoff pre-stack depth migration is usually employed for outputting all gathers. However, for multi-pathing problems, we can use a Wavefield Extrapolation (WE) algorithm instead. However, whichever imaging algorithm is most appropriate for our imaging problem, we must ensure that we strive to preserve the bandwidth and resolution inherent in the data (Jones & Fruehn, 2003) and preserve any amplitude variation with offset (or angle) as required for subsequent attribute analysis (eg. Jones, et al, 2004).

Conclusion

For successful processing of seismic data, it is important to keep your options open. A diverse toolkit for noise and multiple attenuation, combined with a flexible model building system, and amplitude preserving imaging algorithms are necessary prerequisites to successfully accomplish this task.

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