Summary

An advantage of Kirchhoff depth migration is that it can perform common offset migration, which outputs common-offset image gathers (COIGs). These are typically used as input to a tomography program for velocity model building. For large surveys, the COIGs can be generated from relatively small common offset datasets which substantially reduces computational requirements in both memory and I/O.

However, common offset migration generally encounters a migration ambiguity problem. As a result, the COIG displays strong artifacts when the imaging ambiguity is present. Therefore, it causes problems in velocity analysis because automatic event pickers may not be able to distinguish the artifacts from true events. When artifacts are picked, conventional tomography fails for velocity estimation.

In this paper, we propose a tomography algorithm which effectively uses both the reflected events and artifacts in COIGs. It provides the correct velocity update even when artifacts have been picked. A GOM case shows promising results.

Introduction

Kirchhoff depth migration is conventionally used for large 3D marine surveys. It has advantages for both fast track imaging and velocity model building. Conventional model building requires a depth-migrated common-image gather (CIG) (Al-Yahya, 1989) in which the reflectors are migrated multiple times using a multi-channel input dataset. If the prestack migration uses the correct velocity the seismic events will focus properly in the CIG regardless of any redundant axes (offset, reflection angle etc.). Otherwise, the seismic event will appear at a different depth. The difference in depths, the so-called residual moveout, provides information to update the velocity model. Generally, the moveouts are automatically picked from coherent seismic events in CIGs and this process provides the basis for an iterative tomography algorithm for complex velocity model building.

CIG imaging can be performed in different domains. Two popular choices are common offset (Al-Yahya, 1989; Stork and Clayton, 1992; Stork, 1992; Liu and Bleistein 1995) and common reflection angle (Xu, et al., 2001). In the former, the input multi-channel data are sorted into common offset sub-datasets and each data set is passed through Kirchhoff migration. For a given CMP location, the collection of the resulting images then provides a common-offset image gather (COIG). In the latter method, output images are sorted by reflection angle and form a CIG with the reflection angle as a redundant axis. Moveout picked in either domain can then be input into tomographic inversion. We remark that reflection angle is a more natural domain.

There are practical limitations in using prestack Kirchhoff migration to form CIGs because the input is the whole data set and the output is all angle gathers. One way around this problem is the “input driven” method whereby the entire output target is kept in memory/disk and the input is migrated trace by trace until all input is used. Another is “output driven” in which the output target is divided into pieces and each pieces is obtained by migrating all traces within its aperture. The main limitation of the first method is that all output CIGs must be kept in memory/disk; the main limitation of the second is increased I/O cost because it requires repeated input access and reuses traces in overlapping regions.

On the other hand, traditional common offset Kirchhoff migration is very efficient because the output is a subset of all CIGs and the input is a subset of the large multi-channel dataset. Further, a common offset beam migration (Hill, 2001) can be used as an efficient migration engine.

A major disadvantage using common offset migration is its imaging ambiguity. A coherent seismic event in the common offset seismic section may focus at different depth. At most one of them is correct and the others are not (Nolan and Symes, 1996). This complicates model building because the automatic event picker cannot distinguish the true events from the artifacts.

In this paper, we discuss the migration artifacts and the relationship with migration velocity analysis. We propose a workflow for tomography which will cope with the migration artifacts in COIG for tomography.

Migration artifacts

For complex velocity models, Kirchhoff migration of a multi-channel data subset is generally susceptible to ambiguities. Typically, the subset is common offset, common shot, or common P (Xu and Lambaré, 1998; Zhang et al, 2005). When the velocity model has strong lateral variation and significant ray multi-pathing between
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Figure 1. Failure of imaging condition. Left: in common shot imaging, a locally coherent event can be interpreted by two pairs of ray segments reaching the surface with the same source and receiver positions, the same two-way traveltime and the same slope at the receiver position. Right: In common offset imaging, a locally coherent event can be also interpreted by two pairs of ray segments.

surface and imaged points, the imaging condition (Nolan and Symes, 1996) or travel time injective condition (TIC) (ten Kroode et al., 1998) fails. This failure leads to the appearance of artifacts in the images for the subset because coherent seismic events may focus on multiple locations. Examples are well known for common offset and common shot (cf. Xu et al. (2001)).

Figure 1 illustrates the imaging condition for a complex velocity model having strong lateral variation and the occurrence of multi-path rays. In the case of migrating a subset of multi-channel seismic data, e.g. common offset data, the local differential version of the TIC is helpful (Xu et al., 2001):

$$\left| P_s + P_r \right|^2 \frac{\partial h}{\partial \theta} \neq 0$$  \hspace{1cm} (1)

Here $P_s$ and $P_r$ are the slowness vectors at the image point for the source ray and receiver ray respectively, $h$ denotes the offset, and $\theta$ denotes the diffraction angle.

In fact, the common offset TIC is even easier to violate than examples in Xu et al. (2001) as can be seen with a very simple velocity model without lateral variation. Figure 2a shows a two-layered velocity model (no lateral variation) for which the common imaging condition fails (Figure 2c). Figure 2d illustrates a correctly migrated flat

Figure 2. Common offset migration artifacts in a very simple velocity model. (a) two-layered strong contrast velocity model; (b) synthetic CDP gather; (c) the ambiguity of common offset imaging; (d) the migrated CIG, strong artifacts appear in the CIG.
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Figure 3. Migration artifacts and velocity analysis; the automatic picker is not able to distinguish the event and artifacts. It is possible that both events are picked. The tomography algorithm is required to use both and without updating the velocity model, because this migration is under exact velocity model.

Algorithm

We now will describe an algorithm which can use any output (true event or artifact) of the automatic picker to update accurately the velocity model. Note that if the output is a downward slanting artifact (Figure 3) the conventional methodology would provide a velocity slowdown so that our method is indeed novel.

The first step in the algorithm after picking an event is to compute its derivative with respect to offset $\frac{\partial h}{\partial z}$. Next the event is demigrated to the surface by raytracing and the local surface ray emission angles $P_s$ and $P_r$ are saved. Finally a correction in the local direction is applied to account for the fact that the migrated event is not flat (the artifact event in Figure 3). The correction is given by (Chauris 2000):

$$\Delta P^k = \Delta P^s - \Delta P^r = \frac{\cos \varphi}{v} \frac{dz}{dh}$$

(2)

where $v$ is the initial velocity at image point and $\varphi$ is the local dip angle.

The Chauris correction helps remedy the ambiguity by updating $P^k$ so that $P^s$ and $P^r$ can be computed correctly from the updated value and $P^k$. Remigration will then focus this event at the correct depth and hence artifacts in the CIG will be migrated correctly. That is, the red artifact will refocus flatly at the same depth as the green event. Though the illustration shown is 2D the method also applies to 3D.

After rebuilding the surface local seismic event, we can use the approach of Billette and Lambaré (1998). Therefore, the workflow we propose for prestack velocity modeling is:

- Common offset Kirchhoff migration on initial velocity model.
- Automatic event picking of all strong events (including events and artifacts) and computing the local dip and offset derivative.
- Demigration of all picked events up to the surface and application of Chauris correction.
- Application of 3D slope tomography (Sword, 1986; Whiting, 1991; Billette and Lambaré, 1998) on demigrated data.

Applications

We tested our algorithm on Gulf of Mexico dataset for subsalt velocity update. Due to the complex overburden, velocity model building for subsalt imaging is very challenging. The multitude of wave propagation multi-paths surface point and image point creates many migration artifacts on common offset domain CIG (Nolan and Symes 1996). The COIGs are created by control-beam migration. Figure 4 shows the stack image with initial velocity model. Figure 5 shows the stack image after velocity update with the subsalt structure image improved.

Conclusion and Discussion

We propose a tomography algorithm based on the conventional common offset CIG because common offset Kirchhoff migration is efficient for large 3D marine surveys. Our algorithm does not suffer from ambiguity problems inherent in common offset Kirchhoff migration. The novelty of the algorithm is the use of the Chauris correction for the surface ray emission angle to provide correct initial data for remigration. We tested the algorithm on subsalt velocity update in Gulf of Mexico and observed improvements in the focusing of images.

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Figure 4. Migration stack for the initial velocity model.

Figure 5. Migration stack after tomography.