Kirchhoff prestack depth migration of locally coherent events

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Abstract

The slowness information is being used in seismic imaging and velocity model building algorithms. The use of this kinematic attribute to stack locally coherent events can increase the signal-to-noise ratio, improve image quality and reduce artifacts of the Kirchhoff imaging. Following this concept, we present a simple combination of classical Kirchhoff prestack depth migration (PreSDM) and a local linear stack based on the horizontal surface slowness information. This modified Kirchhoff migration was implemented to include the linear stacks for all horizontal slownesses determined from travel-time tables calculated during the migration process. We apply this slowness-driven Kirchhoff prestack migration algorithm to sparse synthetic ocean bottom data (OBS) data and the kinematic migrated image show significant improvements in image quality and a great reduction in the migration artifacts compared to a conventional Kirchhoff algorithm.

Introduction

In recent years seismic imaging and velocity model building methods were introduced based on finding the kinematic attributes related to locally coherent events. A successful application of using the local slowness attribute of seismic events is in stereotomography to determine the velocity model (Lambaré, 2008). Practical applications of locally coherent events can be found in ray based depth migrations that improve quality and efficiency (Sun et al. 2000; Baina et al. 2003).

Recently, in Hu and Stoffa (2009) the horizontal surface slowness component estimated from prestack data was used in Gaussian-beam prestack depth migration. The use of the instantaneous slowness information in the slowness-driven Gaussian-beam migration reduces the migration swing artifacts and improves image quality. Following the locally coherent event concept, we can see the Gaussian beam migration (e.g. Hill, 2001) as a local plane-wave decomposition of the recorded data performed by the local slant stack, where the migration process extrapolates back into the medium the local plane-waves. The local slant stacks are performed on the local tapered windows of traces for many *slowness* values corresponding to ray takeoff angles from the beam center (Gray et al, 2009).

Although the beam migration method provides higher quality images than Kirchhoff migration (Schneider, 1978), this classical migration method is still one of the most popular seismic imaging methods due to its great efficiency and flexibility for time and depth imaging, and for iterative velocity model building processes. This method is suitable to solve imaging problems in areas with smooth velocity variations but also provides reasonably accurate results in areas with moderately complex geologic structures.

Following the idea of using the locally coherent events in depth imaging, we present a modified version of the conventional Kirchhoff pre-stack depth migration to migrate locally coherent events. We apply prestack migration by considering all possible horizontal slowness components for the local slant stack of the traces in neighborhood of the trace to be migrated with the Kirchhoff operator. This slowness-driven Kirchhoff migration algorithms based on local slant stack are applied to synthetic OBS data, which has particular acquisition geometry with a limited number of receivers sparsely distributed on the seafloor and spatially dense sources near to the sea surface.

Method

Kirchhoff migration

Kirchhoff migration or diffraction stacking is characterized by weighted integration (summation) of the reflection amplitudes along the diffraction travel-time curves to obtain output images with reflection amplitudes proportional to the angular dependent reflection coefficients of the reflectors. In 2D, the Kirchhoff migration method can be summarized by the simple equation (Schleicher et al., 1993):

$$V(M) = \int_A \, d\xi \; W(\xi, M) D[U(\xi, t + \tau_D(\xi, M)] \qquad (1)$$

where the *V(M)* is the amplitude value resulting from the integration and assigned to one diffraction point *M* in the migrated image. The recorded wave field is denoted by $U(\xi,t)$ and ξ is the configuration parameter. The diffraction stacks are weighted by a property function $W(\xi,t)$ in order to remove the geometrical spreading loss. The operator *D* corresponds to the half-derivative time operator of the analytical input data. Then, to construct the back-propagated output image, for each point *M* the integral (1) is evaluated using the amplitude values in $U(\xi,t)$ along the diffraction curves, $\tau_D(\xi,t)$, inside aperture A.

Modified Kirchhoff migration

Following the concepts used in the migration algorithm proposed by Sun et al. (2000) and Hu & Stoffa (2009), we introduce a modified Kirchhoff migration based on locally coherent event information. In other words, along the diffraction stack are collected the contributions of locally coherent events that are obtained by local slant stacks defined by the horizontal component of the slowness. Considering the terminology given in (1), the local slant stack for a given diffraction time τ_D (intercept time), a local window of the wave field $U(\xi,t)$, a horizontal slowness or ray parameter p and a local traveltime, $t_D=\tau_D+\xi p$, can be defined as

$$\widehat{U}(\xi,p,\tau_D)=\int_{A^L} U(\xi,\xi^L,\tau_D+p\xi^L)\,d\xi^L. \qquad (2)$$

The symbol ξ^L denotes the position of the traces with respect to the center of the window, where the local slant stack is performed within the aperture A^L. The stacked value denoted $\widehat{U}(\xi,p,\tau_D)$ correspond to the locally coherence event contribution of the wave field. Then, introducing the local slant stack equation (2) in equation (1) we obtain the modified Kirchhoff migration:

$$I(M)=\int_A d\xi\, W(\xi,M)\int_{A^L} d\xi^L\, D\,[U(\xi,\xi^L,\tau_D+p\xi^L)], \qquad (3)$$

where *I(M)* is the migrated amplitude value for the point *M*. In equation (3) the second integral represents the data to be migrated. In other words, the input data for the Kirchhoff migration integral are the contributions of the locally coherent events collected in the neighborhood of the trace to be migrated. To determine the horizontal slowness for the local stack we can follow two procedures: (1) The instantaneous slowness can be estimated directly in the input data by using local slant stack and coherency analysis, therefore in the migration process we will take into account only the contribution of the locally coherent events related to instantaneous slowness. (2) During the migration process we can determine the slowness for all rays considered by the migration process, thereby including all the contributions of the locally coherent events. In this work, we use the second option for the determination of horizontal slowness and the implementation of the migration algorithm.

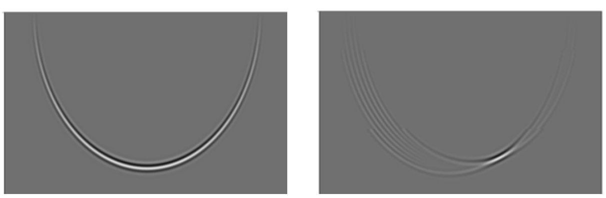

Figure 1: Impulse responses for a trace of a common-offset section of 100 m. Left: Kirchhoff integral. Right: Modified Kirchhoff integral.

To demonstrate how this modified Kirchhoff migration integral build the migrated image, we show the impulse response. Figure 1 shows the impulse response of the Kirchhoff migration integral (left) and the impulse response of the modified Kirchhoff integral (right). In the classical Kirchhoff migration a single input trace is smeared in all directions, whereas in the modified Kirchhoff migration the energy is focused where there is a reflector. This last result was constructed using all possible slownesses to do the local stack, in a similar way as the path-integral imaging process where the summation is performed over all possible traveltime trajectories (Landa et al., 2006).

OBS data application

To test the Kirchhoff slowness-driven migration algorithm we apply it to one of the synthetic OBS data used in Hu and Stoffa (2009). The subsurface model shown in Figure 2 is composed of a constant, 450m, depth water layer with an irregular thickness basalt body within the sedimentary layers. The seismic velocity of the basalt is 4500 m/s.

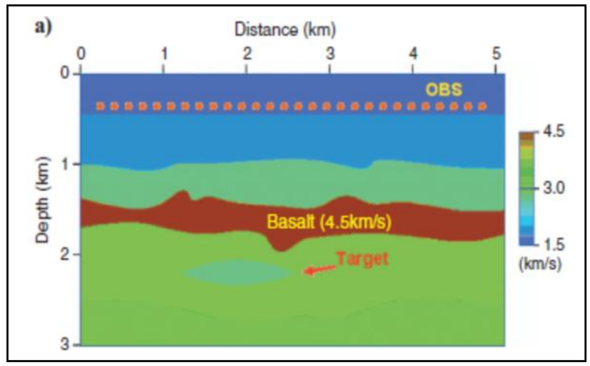

Figure 2: Subsurface velocity model with basal layer. The OBS data generated for this model consist in 50 ocean-bottom receivers distribuited on the wather bottom and 511 air-guns below the sea level (from Hu and Stoffa, 2009).

A target zone like a lens is located below the basal layer. With a nonstaggered-grid finite-difference modeling code data were generated for an OBS sparse acquisition geometry, consisting of 50 ocean-bottom receivers distributed with an interval of 100 m. 511 air-gun shots at 10 m below the water surface, with a 10 m interval between sources was used. Figure 3 shows an example of a receiver gather located in the center of the model (2600 m).

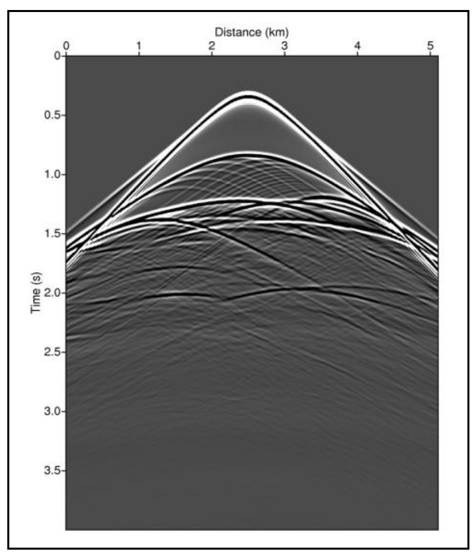

Figure 3: Receiver gather extracted from the OBS data generated for the model in Figure 2. It is composed of 511 traces every 10 m of especial interval, the time sampling interval is 4 ms.

In this work, for the migration tests presented below we used a finite-difference eikonal solver to calculate the traveltime tables. Application of the conventional Kirchhoff PreSDM to the synthetic OBS data is presented in Figure 4. For comparison purposes, this migration is kinematic, and we did not use any kind of taper function or aperture size limitation. As expected this result has strong migration artifacts, which severely affect the quality of the migration result. There are artifact effects throughout the whole section of Figure 4, where the first shallow reflector and the top of the basalt are the most damaged. Also the target reflectors beneath basalt have poor definition due to the presence of the coherent migration noise.

In Figure 5 we present the migration result using the contributions of the locally coherent events for all possible slownesses estimated during the migration. This result shows a significant improvement in quality in the whole section. The migration artifacts are attenuated and as a consequence all reflectors are very well defined, even the target zone reflectors below the basalt body. We would like remark that for attenuating the remaining artifacts, it is necessary to improve the Kirchhoff part of the migration algorithm, for example using other methods for the traveltime computation, applying appropriate taper functions and proper weight functions.

Conclusions

In the classical Kirchhoff migration a single trace contributes significant energy for all wave propagation angles in the subsurface image. The modified Kirchhoff migration integral based on the locally coherent event's contribution focused the energy in the subsurface image to a narrow band of propagation angles. The application example for synthetic OBS data of our proposed migration algorithm shows a good improvement in image quality and a strong attenuation of migration artifacts.

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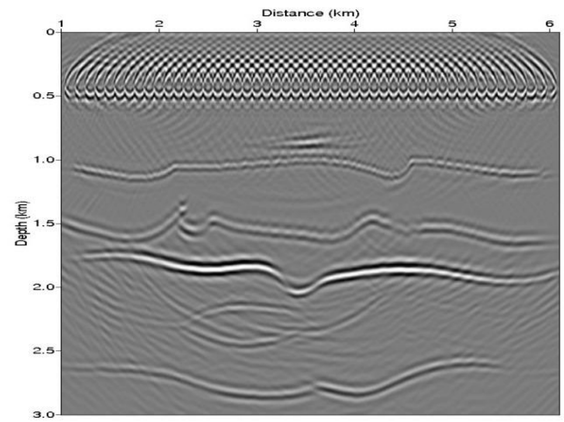

Figure 4: Conventional Kirchhoff prestack depth migrated section of the OBS synthetic data. The strong migration artifacts or noise are a result of the Kirchhoff migration method and in this example they severely affect the quality of the image.

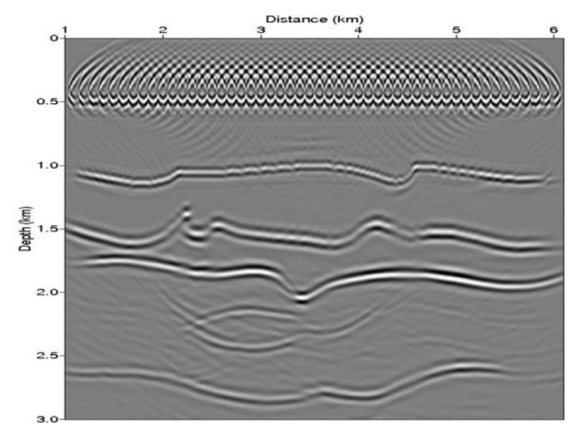

Figure 5: Prestack depth migrated section of the OBS synthetic data, obtained by the modified Kichhoff migration algorithm that uses the all possible slowness information estimated during the migration process. The migration artifacts are attenuated in the whole section.