Analyzing the impact of data coverage in Kirchhoff least-squares migration

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Abstract

Kirchhoff migration stands out as the predominant technique employed in the oil industry, known for its exceptional versatility and flexibility. However, an inherent limitation of Kirchhoff migration is its inability to preserve the true amplitude of seismic reflections. This limitation becomes more severe when dealing with complex geological media, often resulting in low-resolution images with artifacts. To overcome this problem, one can construct a reflectivity model by formulating an inverse problem. This formulation involves defining an additional operator that predicts the seismic data based on the reflectivity model. By iteratively updating the reflectivity model using this approach, we can improve the preservation of real seismic reflection amplitudes and mitigate artifacts in the resulting image. This approach is commonly known as Kirchhoff least-squares migration (LSM).

LSM is a powerful technique for estimating high-resolution subsurface reflectivity with reduced migration artifacts, although this is achieved at the expense of increased computational time. Irregularities and gaps in the source and receiver coordinates, particularly in land seismic acquisition, affect the convergence of LSM as it becomes a poorly conditioned problem when the input data is insufficient. This study comprehensively investigates the impact of different acquisition scenarios on the convergence and quality of Kirchhoff LSM.

To reduce the ill-conditioning affecting the inversion, we study different strategies for an efficient discretization of the model space. The model to invert is defined by the horizontal reflectivity coordinate, the true vertical time, and the offset discretization h_i, with $i = 1, \ldots, N_h$. Depending on the input data, the model offset ranges h_i may be poorly populated. In such cases, an alternative offset discretization is desired. In other words, we assess the impact of insufficient data coverage in the least-squares inversion and propose to discretize the model accordingly. This approach aims at improving the performance of prestack Kirchhoff's least-squares migration when the available input data is not optimal.

We conducted synthetic tests using a reflectivity model of moderate complexity with a thrust fault. To simulate different acquisition experiments, we present four different scenarios and analyze the LSM results, including (1) the best possible situation with full data coverage, (2) input data with poor near offsets, (3) input data with poor far offsets, and (4) input data with gaps representing typical acquisition problems. This allows us to define the strategy for selecting the discretization of the model offset. The study also incorporates the computation of the convergence curves for each situation and the improvement achieved when using the new proposed strategy. Finally, the adaptive model prestack Kirchhoff LSM method is applied to marine and land data of the public domain.