CRS-based onshore data preconditioning and Reverse Time Migration

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Abstract

The application of the reverse time migration (RTM) in land dataset is still a great challenge due to its low quality, low signal-to-noise ratio, irregular spatial sampling, acquisition gaps, missing traces, etc. Therefore, prior to the application of this kind of depth migration, the input prestack data must be conveniently preconditioned, that is, it must be interpolated, regularized, and enhanced. There are several methods for prestack seismic data preconditioning, but for 2D real land data, the common reflection surface (CRS) stack method provides enhanced preconditioned data, which is suitable for pre-stack depth migration and velocity analysis applications. We present an application of the prestack data preconditioning based on CRS stack and of the RTM in 2D land data of Parnaiba Basin, Brazil. The comparison with the Kirchhoff depth migration reveals that the RTM improves the quality and resolution of depth migrated images.

Introduction

Seismic depth migration of prestack data based on numerical solution of wave equation requires uniformly sampled data in spatial dimension. In real land datasets, denoising, interpolation and regularization of the prestack data are mandatory processes prior to the migration and inversion, because the noise and missing traces introduce artifacts that contaminate the migrated images and interfere in the obtaining of reliable properties of the medium. In this work, the precondition of prestack data will be performed using the Common Reflection Surface (CRS) stack method, which uses wavefield attributes and a stacking operator.

The CRS stack method, originally introduced for simulating enhanced zero-offset (ZO) stacked section (Jäger et al, 2001), is also applied for regularization and interpolation of prestack seismic data, where the non-zero-offset traces are reconstructed by partial CRS stack (Baykulov et al, 2012). Examples of prestack data preconditioning from sparse low quality and low fold real land data with the partial ZO CRS stack approach can be found in Eisenberg et al., (2008), Garabito et al., (2015), among the others. The ZO CRS stacking operator can be used for prestack data interpolation and regularization in any standard seismic configuration proper for a given prestack migration method, for instance, data regularization in common-offset gather is proper for Kirchhoff type migrations and data regularization in common-shot gather is required for wave equation migration methods. The preconditioned prestack clean data can also be used as input for velocity analysis techniques in time and/or depth domain. In this work, preconditioned prestack data by means of ZO CRS operator will be used for prestack depth migration.

The reverse time migration (RTM) is the most accurate migration method, which was developed based on finite-difference solution of two-way wave equation (Baysal et al., 1983; Whitmore, 1983). Application of the RTM in real land data is a great challenge because of the poor quality of the data with low signal-to-noise ratio and irregular spatial sampling due to acquisition gaps and missing traces. Usually, before applying the RTM, the prestack data is regularized and interpolated using technics based on Fourier Transform (Liu and Sacchi, 2004; Xu et al., 2005; Abma and Kabir, 2006). These methods provide very good results in 3D data sets, that is, for regularization and interpolation in 5D, however, in 2D data the results do not show significant improvements. Alternatively, in order to apply the RTM migration in noisy onshore data, the prestack data regularization and interpolation can be performed by using the ZO CRS stacking operator (Schuenemann, et al., 2011 and Gierse et al., 2015).

In this work, we address the prestack land data regularization and interpolation using the ZO CRS stacking operator to generate preconditioned input data for Kirchhoff and RTM depth migration methods, namely, we show how to use the same preconditioned data as input for both kinds of migrations. We also present some features of the RTM algorithm that uses a solution of the acoustic wave equation and the procedure for its application in real land data of Parnaiba Basin, Brazil. For comparison, the classical Kirchhoff depth migration is also applied in the same regularized prestack data.

Preconditioning of prestack data

The standard ZO CRS stack method provides, in 2D, a stacked ZO section and three kinematic wavefiled attributes sections, namely, the emergence angle of the ZO central ray and emerging wavefront curvatures of the Normal Incidence Point (NIP) wave and Normal wave. These three CRS-attributes are estimated from prestack data by means of optimization algorithms that use as objective function the coherence measure Semblance of the seismic signal. In this work, we apply the ZO CRS algorithm presented in Garabito et al., (2012) to determine simultaneously the CRS-attributes by using the Very Fast Simulated Annealing global optimization. Once the CRS attributes are estimated for all image points in the ZO section, they can be applied to determine the velocity, regularization, migration, etc. In this work, we apply them to regularize, interpolate and enhance the prestack onshore data. A seismic trace with finite-offset is reconstructed by summing of the neighboring traces, in other words, by stacking locally coherent events along the CRS operator defined in the vicinity of the target trace. In this way, the seismic traces can be interpolated and regularized in different seismic configurations, such as common-midpoint (CMP), common-offset (CO) and common-shots (CS).

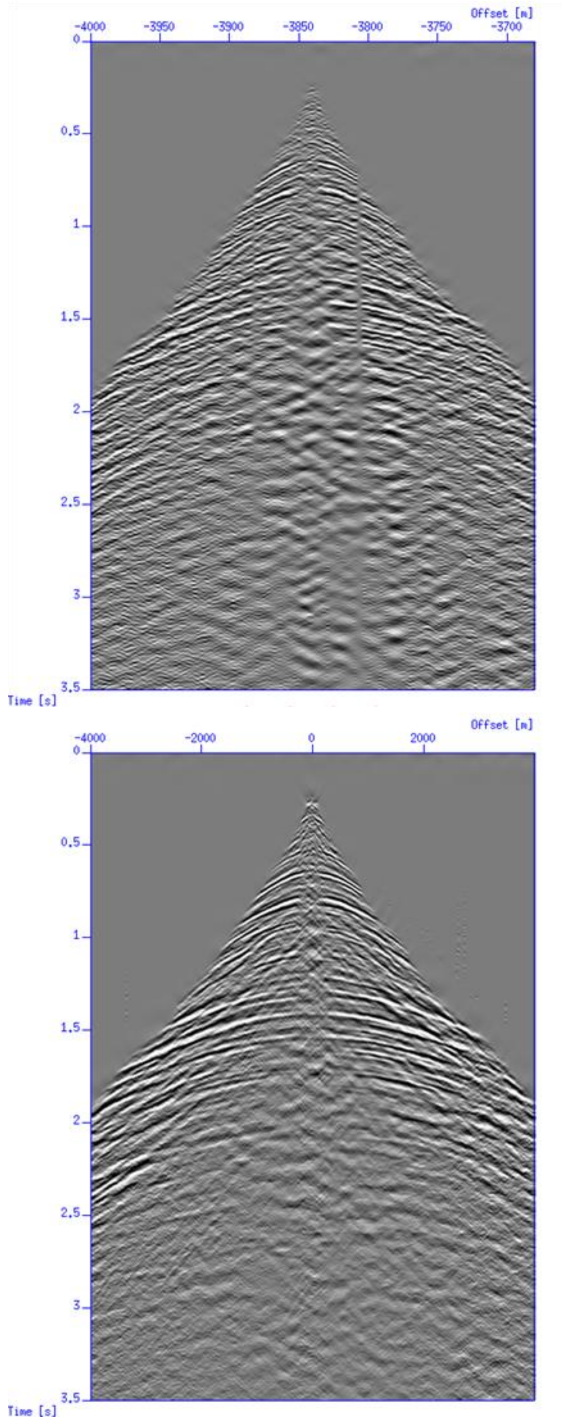
In this work, we apply the CRS-based regularization and interpolation to generate enhanced CS gathers from a real 2D land data of Parnaíba Basin, northeastern Brazil. Before applying CRS-based prestack data preconditioning, the dataset was submitted to the standard data processing steps, starting with the trace edition until the residual static correction. This processed prestack data is used as input for the CRS processing and the reverse time migration. We refer to the following two steps as CRS processing: the global search for CRS attributes and the preconditioning of prestack data by the local CRS stack.

In Figure 1a, we show a CS gather regularized, interpolated and enhanced (preconditioned) by the local CRS stack. Figure 1b shows the original CS gather with some missing traces and poor definition of the reflection events. The regularized data shows an increase in the signal-to-noise ratio, where the reflection events have stronger amplitudes and are better defined. This data is suitable for seismic imaging in the time and depth domains, and in this work, we use it for depth velocity model building and for prestack depth migration, but we will only show the results of the migration.

Reverse time migration

Although we also present the results of the classic Kirchhoff migration applied to land data of Parnaiba Basin, we describe only some features of the RTM algorithm and the requirements for its application. The RTM algorithm used in this work it is a full solution of the acoustic wave equation. The RTM codes were developed by the authors to apply particularly to the onshore prestack data preconditioned by the CRS local stack technique, and they are parallelized using the OpenMP (Open Multi-Processing) and MPI (message passing interface) resources.

In order to numerically calculate the spatial derivatives (or Laplacian) our RTM algorithm has two options: 1) differential convolutional operator or finite impulse response (FIR) (Zhou and Greenhalgh, 1992) and 2) the Pseudo-Spectral technique (Reshef, et al., 1988). The time derivative can be approximated using also two options: 1) by the second order finite-difference scheme and 2) the rapid expansion method (REM) (Kosloff et. all., 1989; Pestana and Stoffa, 2010). The latter scheme provides a more accurate solution for time derivative and time marching of the wave equation. For the application example presented below, we use the REM and Pseudo-Spectral options.



a)

b)

Figure 1 - Common-Shot gathers of the seismic line of the Parnaiba Basin: a) original section with missing traces and b) regularized, interpolated and enhanced section obtained by the local stack with the ZO CRS operator.

The regularized input data has 2 ms of time sampling and we use this time sample interval as the time step for time marching in the forward and backward propagations. As a source point signal, the Ricker wavelet with a dominant frequency of 30 hz was used.

Figure 2 shows the RTM image obtained from all migrated CS sections. For comparison, in Figure 3 is shown the Kirchhoff depth migrated image obtained from the same regularized dataset, but applied in the CO sections. Both final migrated images were obtained by applying the same mute on the common image gathers (CIGs) and stacking them.

The combination of CRS and RTM, in general, provided a cleaner image and with a higher resolution (Figure 2) than the image obtained by the classic Kirchhoff migration (Figure 3). As expected, the latter shows strong artifact of the migration operator at the edges of the image and as the depth increases. In both migrated images the reflections above the diabase sill intrusion are very similar. The top of the sill is slightly better defined in the Kirchhoff migration. However, the base of the diabase sill and the reflections below it are better defined in the RTM image.

Conclusions

The regularized, interpolated and enhanced prestack land data was successfully used for depth velocity model building and prestack depth migration with RTM and Kirchhoff. The RTM image shows good quality and significantly increases resolution with depth. This work shows that the combination of RTM and CRS-based data preconditioning is a viable and robust alternative for depth imaging of areas with complex geology and from land datasets.

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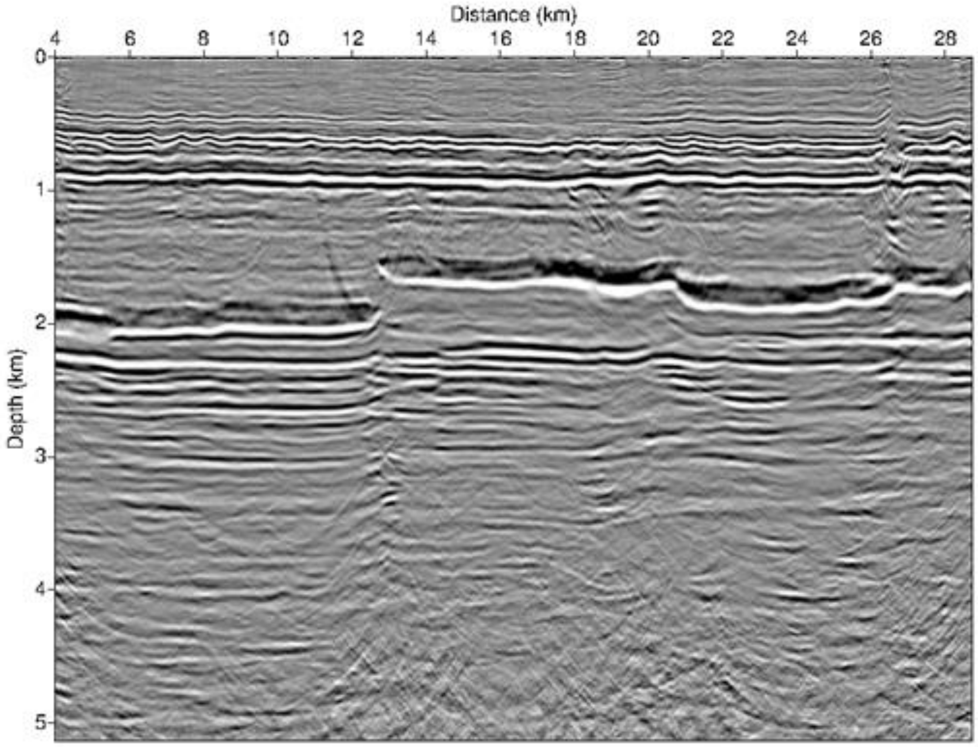

Figure 2 - RTM depth migrated image obtained from regularized CS gathers of the seismic line of the Parnaiba Basin.

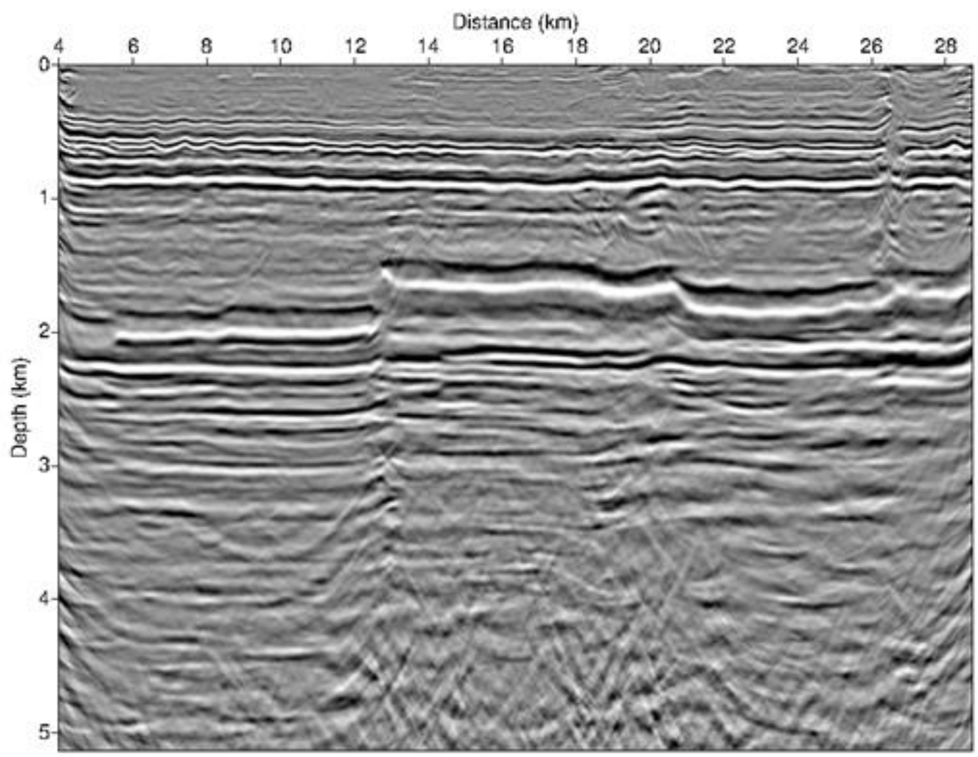

Figure 3 - Kirchhoff depth migrated image obtained from regularized CO gathers of the seismic line of the Parnaiba Basin.