# Data regularization using local operators

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## Abstract

A new data regularization method to generate common-offset data using a local operator is presented. The regularization is achieved in two steps: migration with proper weight function to compensate irregularities, and demigration for the desired source-receiver configuration. Two field data examples are presented, one 2D and another 3D. In both cases, gaps due missing traces are properly filled.

## Introduction

Several seismic processing algorithms are implemented assuming a regular spatial distribution of sources and receivers, such as any wave–equation migration. In general, seismic acquisition is planned considering a regular geometry, but in practice the planned configuration is almost impossible to be exactly achieved. The most popular seismic data regularization algorithm used in seismic processing involves a binning procedure associated with summation after AMO (Azimuth Moveout correction). In areas without structural complexity and with smooth velocity variation, reasonable results are obtained using partial NMO correction.

Kirchhoff migration is one of the imaging procedures that permit to handle with irregular distribution of sources and receivers in a natural way. Two aspects have to be considered to properly image irregular data with Kirchhoff algorithms: the use of the exact position of the source and receiver for traveltime computation and the use of a proper weight function during the integration, in order to compensate irregular spatial distribution of seismic traces.

The data regularization scheme explored in this article is based in a very simple and intuitive idea: migrate the irregular data by means of a proper designed Kirchhoff algorithm, and then demigrate the regular image to the desired source-receiver configuration. Although this intuitive algorithm is easily adapted to different source-receiver configuration, it demands high computational effort and requires a good approximation of the velocity field. I escape from these problems by making use of local coordinate systems to define local operators and perform integration.

The theoretical aspects involving amplitude preservation in Kirchhoff migration have been extensively investigated in the last decades. All the concepts and principles used in this article are extensively explored by Hubral  et. al (1996), and the kinematics and dynamics aspects related to the combination of migration and demigration integrals are discussed by Tygel et. al (1996).

For simplicity, all the pictures introducing concepts or describing methodology are 2D. In spite of this fact, the proposed data regularization method is fully 3D.

## The data regularization method

The objective of the proposed method is the construction of common azimuth volumes with constant offset. The input data is a set of seismic traces with an irregular spatial distribution of midpoints, and with offsets and azimuths varying in a selected range. Figure 1 illustrates how the proposed method works. The input traces are plotted in dark-gray, while the output traces are plotted in black. Observe that the input data have an irregular distribution of midpoints and contains traces with different offsets. After the regularization, traces are located at the desired midpoints location and have a unique offset.

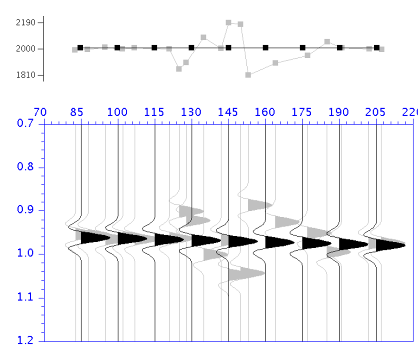


Figure 1. Construction of common-azimuth gathers with constant offset by means of data regularization. The input seismic traces are plotted in dark-gray wiggle and the output ones in black. The graphic above shows the offset distribution before (dark-gray) and after (black) data regularization. The synthetic traces are modeled considering a dip reflector in a homogenous media.

The construction of common-azimuth volumes with constant offset is achieved by means of two Kirchhoff-type integration procedures: migration and demigration, being both of them performed with operators defined in the local isochron coordinate system.

The basic idea:

Let's take a seismic trace of the common-azimuth section to be constructed, and consider its location as a reference position. The construction of that seismic trace assumes the existence of a virtual source-receiver pair with a reference offset, and can be achieved by following the sequence:

1. Select a set of input traces whose midpoints are inside a given aperture.
2. Create an empty depth migrated section to accumulate the contribution of input traces.
3. Migrate each input trace by properly weighting and distributing its amplitudes along specifics isochron curves in depth migrated section.
4. Demigrate the obtained migrated depth section by stacking amplitudes collected along the isochron curve defined for virtual source-receiver pair, this particular isochrone is denominated demigration stacking line.

Figure 2 illustrates the algorithm described above. Observe that all isochrones are tangent to the reflector at the point M, which is the stationary point of both migration and demigration integrals. It is important to highlight that the described sequence is an algorithm to generate just one seismic trace. For a complete common-azimuth section, the sequence has to be repeated as many times as the number of output traces.

The local isochron migration coordinate system:

A local coordinate system can be established by considering a set of isochron curves associated with the virtual source-receiver pair. These isochrones and its orthogonal lines form a curvilinear grid that can be used as coordinate system. The first isochrone is associated with the smallest traveltime for the given virtual source-receiver pair, which corresponds to the trajectory of the direct wave from the source to the receiver. As the first isochrone is a line connecting the virtual source-receiver pair, all orthogonal lines have their origin in somewhere between the source and the receiver, in such a way that the position of the origin can be used to discriminate each orthogonal gridline. As the offset distance of the reference source-receiver pair varies, the relative position of each orthogonal gridline origin can be used to identify it. Regardless of the reference offset, the relative position is a number between -1 and 1. From here, I assume the notation used by Silva and Sava (2009), and refer to these orthogonal lines as isochron rays.

Figures 2 and 3 together explain how the proposed data regularization method works. While Figure 2 summarizes the main idea in depth domain, Figure 3 reproduces the process in the local isochron coordinate system, where the horizontal coordinates are the relative position of isochron rays origins, and the vertical coordinates are the reflection time. Observe two relevant aspects related to the migration and demigration procedures in the local domain: all migration isochones are tangent to the reflector at the point M', and the demigration stacking line is horizontal.

The computational effort is severely reduced when the two steps are performed in the local domain, first because the number of grid points used to generate a migrated image is considerably smaller in the migration step, second because the demigration step becomes a simple horizontal stack.

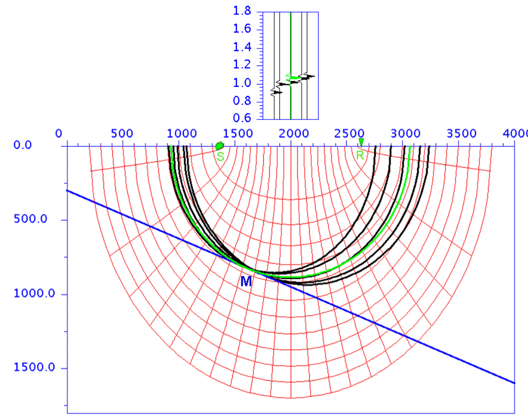


Figure 2: Data regularization scheme for the position of horizontal coordinate 2000. Considering the source-receiver pair SG, in green color, the set of isochrones and its orthogonal lines, in red, form a curvilinear coordinate system. The black traces in seismogram above represent the input data, while the green trace is the constructed output. The black curves below are the isochrones where the amplitudes of input traces are distributed after migration. The blue line represents a reflector in depth domain, while the green isochrone is the demigration stacking line, in which the integrated amplitudes has to be collected in demigration step. Obeserve that all lines in depth domain are tangent at the point M.

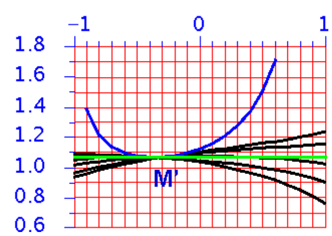


Figure 3:: Data regularization scheme in local isochron migration coordinate system. The black curves are the isochrones where the amplitudes of input traces are distributed after migration. The blue line represents a reflector in depth domain, while the green curve is the isochron where the integrated amplitudes have to be collected in demigration step. Obeserve that all lines in depth domain are tangent at the point M'.

## Data field example

The data field experiments consist of the application of the described regularization method in 2D and 3D datasets.

The 2D example consists of a seismic line with lack of traces due to acquisition problems. Figure 4 is a common-offset section of this line, and Figure 5 is the same common-offset section after regularization in the local isochron migration coordinate system.

The 3D dataset consists of a pre-processed volume, in which standard techniques were applied and the final image was generated by a Kirchhoff PSDM algorithm. From this dataset, two subsets were selected, one of which being, the common-offset migrated image related to the offset 2600 meters, and another being input data for the migration.

The input data for migration was also used as input data for the proposed regularization method, generating a common-azimuth volume with constant offset of 2600 meters. Then the common-azimuth volume was migrated with the same algorithm, using the same parameters and the same velocity model of the first time.

Figure 6 presents a comparison between the input data before and after regularization. Section A, on the left, is an inline extracted from the volume before regularization. Section B, on the right, is the corresponding inline after regularization. Observe that the proposed regularization method has the ability of generating missing traces, which is an inherent quality due to the migration step. In this case, the missing information comes from the neighbor lines.

Figure 7 permits to observe the benefits produced by the regularization before migration. Section A, on the left, is an inline extracted form the migrated common-offset image without regularization, while section B is the equivalent image using regularized data as input. Figure 8 shows in detail a piece (above on the right) of the same sections. Observe that the image after regularization is much cleaner than the image without regularization.

## Conclusions

The construction of regular common-azimuth gathers with constant offset can be achieved in two steps: migration designed to deal with irregular geometry, followed by demigration for the desired regular configuration. The application of this two-steps algorithm using a local operator defined using a isochron coordinate system considerably reduces the computational cost of the algorithm.

## Acknowledgments

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## References

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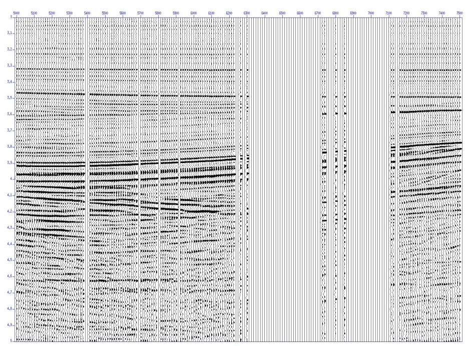

Figure 4: 2D common-offset section after applying a partial NMO correction.

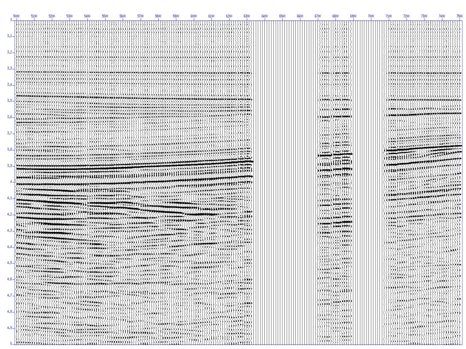

Figure 5: 2D common-offset section after data regularization in local isochron migration coordinates.

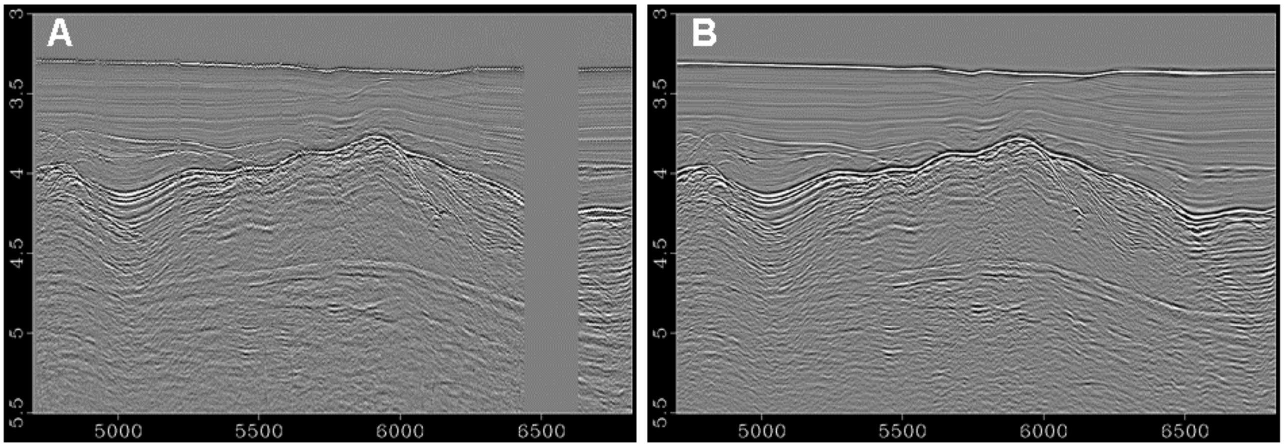


Figure 6: A: Common-offset section before data regularization. B: Common-azimuth section with constant offset after data regularization.

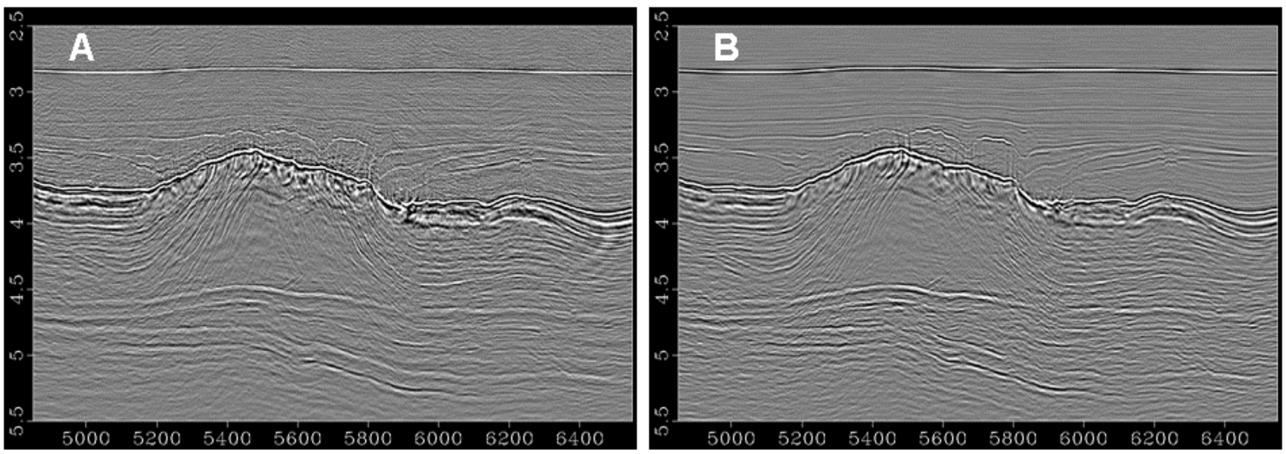


Figure 7: A: Common-offset depth migradted image without data regularization. B: Common-offset depth migrated image with data regularization.

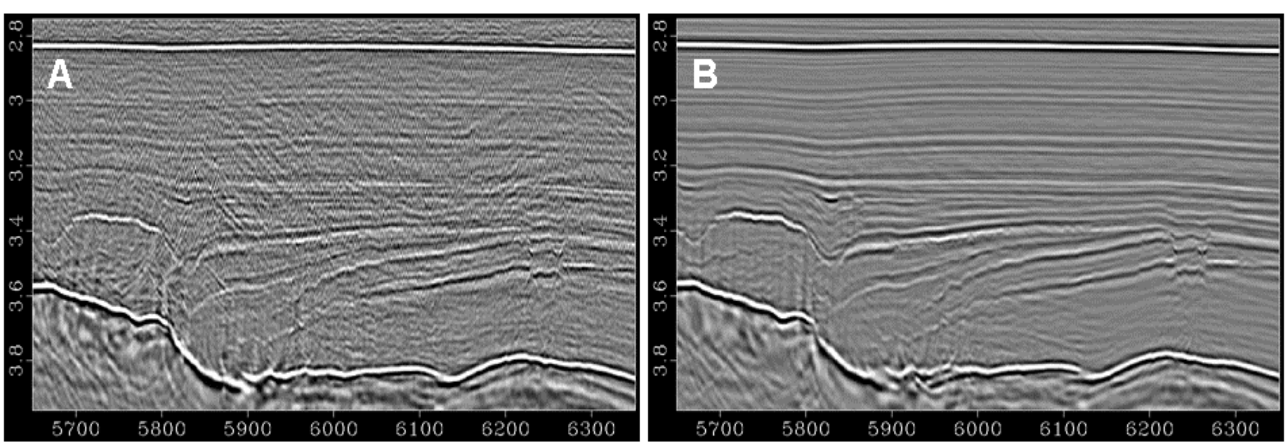


Figure 8: Detail (upper-rigth quarter) of common-offset depth migrated images. A: without data regularization. B: with data regularization.