A comparison of CMP and EO gathers for multiple-attenuation

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Abstract

Multiple-energy in seismic data continues to be a serious problem for imaging the earth's subsurface. Numerous techniques exist for removing multiples with varying degrees of success, complexity, and runtimes. Our approach uses the Radon transform method in which multiple-energy can be separated from the desired reflection energy, but rather than use the traditional common midpoint (CMP) gathers, we uses equivalent offset (EO) gathers. The differences between these gathers is illustrated with the Radon transform.

EO gathers are prestack migration gathers that only requires moveout correction and stacking to complete the prestack migration. High resolution semblance plots of EO gathers illustrate their ability to focus and separate the primary reflection energy from multiple- and mode-converted energy.

Introduction

Semblance plots, reflection energy, and the Radon transform

The semblance plot is a hyperbolic Radon transform, in which the amplitudes are smoothed, scaled, and contoured to produce a visual display. This transformed display has axis of time and velocity that are used to identify the velocities for normal moveout (NMO) correction of the CMP gathers. The hyperbolic moveout energy from primary reflections, multiples, and mode converted energy is focused to a small local area on the semblance plot, with its peak defining the moveout velocity.

When the velocity varies with depth, the moveout velocity for horizontal events is approximated by the RMS velocity, enabling estimates of the interval velocity. However, the moveout velocity of dipping events requires the RMS velocity to be divided by the cosine of the dip, preventing its direct use in estimating interval velocities. In addition, the reflection point of the dipping reflector is displaced from the CMP location.

Dip moveout (DMO) was introduced in an attempt to relocate the dipping energy, but it was true prestack migration that corrected the miss-positioning. The energy on conventional prestack migration gathers lies on horizontal paths, ready for stacking to complete the prestack migration. Deviations from the horizontal path give an indication of velocity errors. Unfortunately, the offset energy on conventional prestack migrations (common shot or common offset) do not align the velocity errors with offset, making it difficult to interpret velocity corrections.

The separation of multiple-energy from horizontal and dipping energy in CMP gathers has been attempted with various types of radon transform. For example, surface multiples become periodic in tau-P transforms and can be eliminated (in ideal conditions) with predictive deconvolution. Other methods used the hyperbolic Radon transform (similar to semblance plots) to focus the hyperbolic energy to localized areas that enable the identification, and then separation, of the reflection energy. These methods have produced reasonable results but have encountered limitations with structured geology and problems with gaps in the acquisition geometry.

Parabolic Radon transforms with a scaled time axis have similar properties to the hyperbolic Radon transform and are more suitable for inversion techniques. They conform to this presentation.

Equivalent offset method (EOM)

The equivalent offset method (EOM) (Bancroft et al 1998) is a prestack migration process that maps the energy from each input trace into all prestack migrated gathers. The offset of this energy is dependent on the location of the input trace relative to the location of the migrated trace. In essence, the double-square-root (DSR) equation that defines the geometry of the input trace is equated to a hyperbolic equation that contains a single equivalent offset (EO), identical to the hyperbolic NMO equation. Energy at a given time on the input trace is mapped to the prestack migration gather at that same time, but now at the equivalent offset. Reflection energy (both horizontal and dipping) lie on a hyperbolic paths defined by the RMS type velocity, smoothing the velocity function that is now ready for velocity analysis. Simple moveout correction and stacking complete the prestack migration with only one velocity analysis session required. In contrast, other prestack migrations typically require an accurate velocity model before the prestack migration gathers can be formed.

We refer to these prestack migration gathers as EO gathers (formally as common scatterpoint CSP gathers). These gathers may be formed for a prestack time migration using the RMS velocity assumptions, or formed using raytracing or traveltime mapping for a prestack depth migration.

Anisotropic traveltime equations that incorporate higher order anisotropic approximations may be included in the DSR equation when estimating the equivalent offset. This process will still map the anisotropic data to hyperbolic paths on the EO gathers. In addition, EO gathers may be formed directly from data acquired on a rugged surface, in bore holes, or vertical marine cables. The acquired data may even be in any mode, including converted waves.

The EO method is based on Kirchhoff migration principles and contains the benefits of arbitrary input geometry, and arbitrary output geometry. Each migrated trace can be computed separately and independently of all other traces. The method is much faster than comparable techniques as moveout correction, scaling, and antialiasing filters are postponed until after the gather have been formed

The Radon transform and EO gathers

The energy in the EO gathers is well suited for a hyperbolic Radon transform as the horizontal, dipping, and scattered energy lie on hyperbolic paths that are relative to that location. The multiple-energy also lies on hyperbolic paths, and it is this property that allows the hyperbolic Radon transform to focus the respective energy into more isolated locations for easier detection and separation.

Examples of EO gathers

Figure 1 contains three panels of trace gathers at the same CMP location from land data over a sedimentary basin. The first panel (a) contains a CMP gather with the traces ordered with offset. The second panel (b) contains the same traces as (a), but the traces are now located at the source-receiver offset. Note that there are many missing traces making velocity analysis difficult. A super-gather of neighbouring CMP gathers could be formed to help fill in the missing traces, but that will only be of benefit for horizontal reflectors as the energy from dipping reflectors would be smeared. Figure 1c contains an EO gather. This EO gather has been formed from all the prestack traces within the prestack migration aperture of this CMP location. The input traces have been added into bins of the EO gather at their equivalent offset. Therefore, each trace in the EO gather is the sum of all traces falling it its bin, causing a reinforcement of the reflection energy that improves the signal to noise ratio. Energy in neighbouring EO gathers will have similar input traces, but they will have a slightly different geometry that reinforces the reflection energy at its own location.

Note that the hyperbolic nature of the move out is more evident in the EO gather than either of the CMP gathers and that more reflections are identifiable. Especially note the discrimination of events at shallower times. (These figures are displayed in a larger format for a more effective evaluation.)

The equivalent offset is not limited by the maximum source receiver offset, but by the size of the migration aperture. For example, a zero offset trace, distant from the migration location would be placed at a large offset in the EO gather as it may contain diffraction or dipping energy. Consequently, the EO gather can contain offset that are much larger than a CMP gather, which is limited to the maximum source-receiver offset. Figure 2 illustrates this property using data from a crustal study that extends to eleven seconds; the Moho is expected to be close to the bottom.

Figure 2a contains a CMP gather and its semblance plot. Note that the velocities are only interpretable in the upper twenty five percent as multiples dominate the gather. That is not really obvious until we compare the results with the EO gather in part (b) of this figure. The EO gather has a much larger maximum offset and allows us to observe hyperbolic energy that is not obscured by the multiples. Especially note the hyperbolic energy towards the bottom of the EO gather below the black arrow. This high velocity event is well defined in the semblance plot of the EO gather, but is barely visible in the semblance plot of the CMP gather where it would have been considered to be noise. We believe that this reflection energy is from the Moho.

It is the improved separation of the primary reflection energy from the multiple-energy in an EO gather that makes it more suitable for use in multiple-attenuation using the hyperbolic Radon transform.

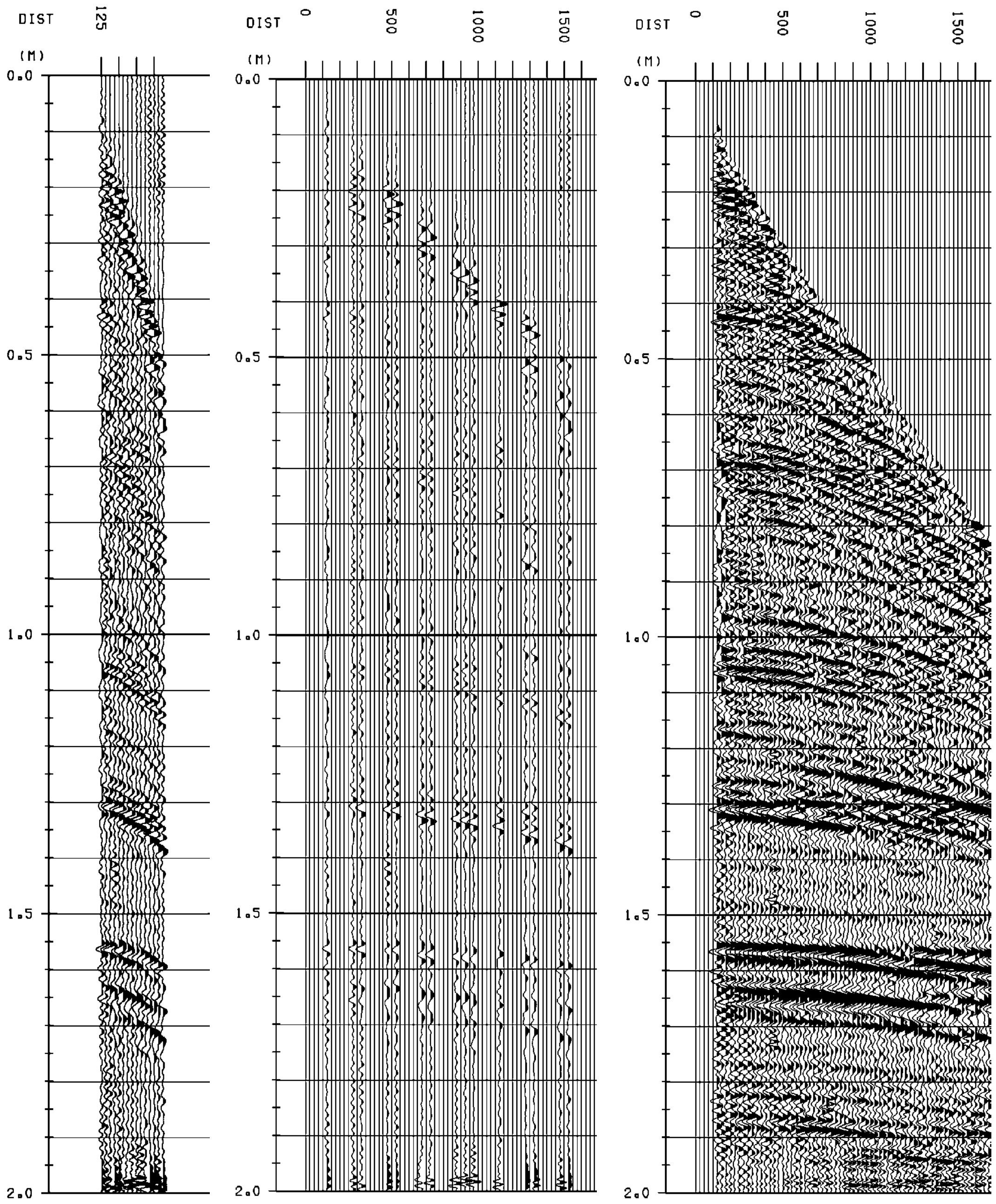
High resolution semblance plots are illustrated in Figure 3 that contains a super-CMP gather and an EO gather with their semblance plots. The land data is in an area with horizontal reflectors where dipping reflection energy does not harm the super-CMP gather. Note the presence of multiple- and mode-converted energy on both semblance plots, especially the multiple-energy near the surface. We believe that the primary reflecting energy is more identifiable and separable in the EO gather than the super-CMP gather and is therefore more suitable for multiple-attenuation.

Conclusions

The equivalent offset (EO) gather provides a data set that is superior to a CMP or super-CMP gather. The EO gathers provide a better signal to noise ratio, larger offsets, better resolution of the reflection energy, and velocities that gather are independent of dip. These features provide a better separation of the primary reflection energy, allowing a more effective attenuation of the multiple-energy.

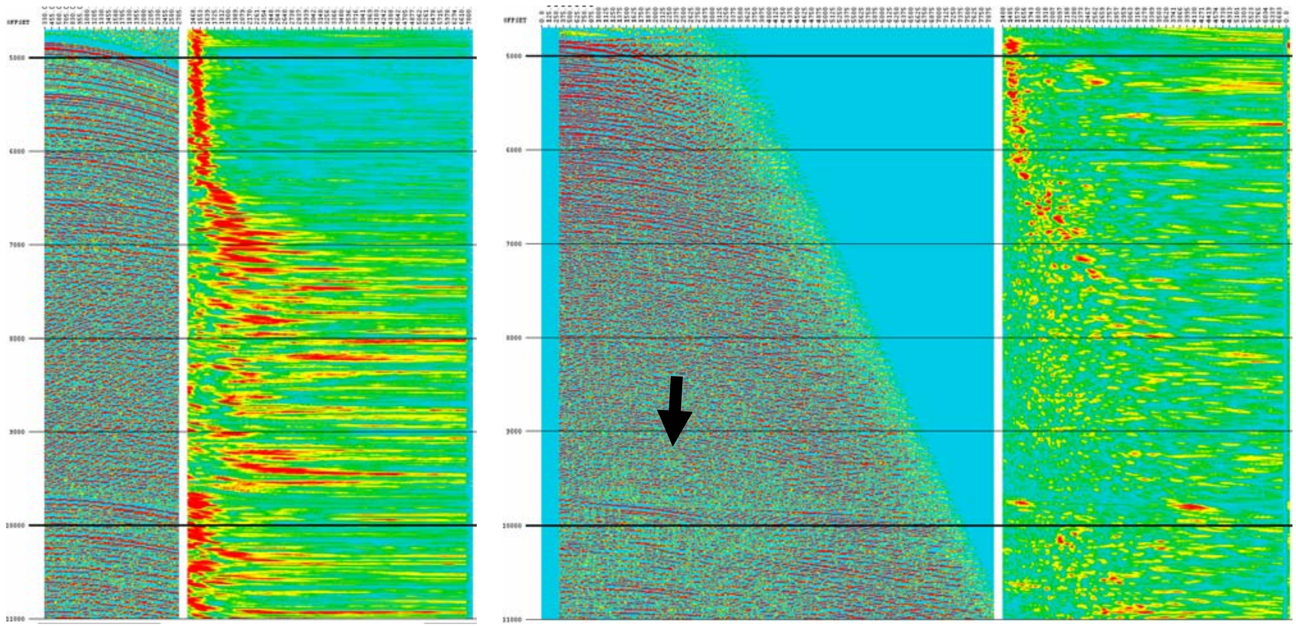
References

Bancroft, J.C., Geiger, H. D., and Margrave, G. F., 1998, The equivalent offset method of prestack time migration: Geophysics, Vol.63, N0. 6, P. 2042-2053.



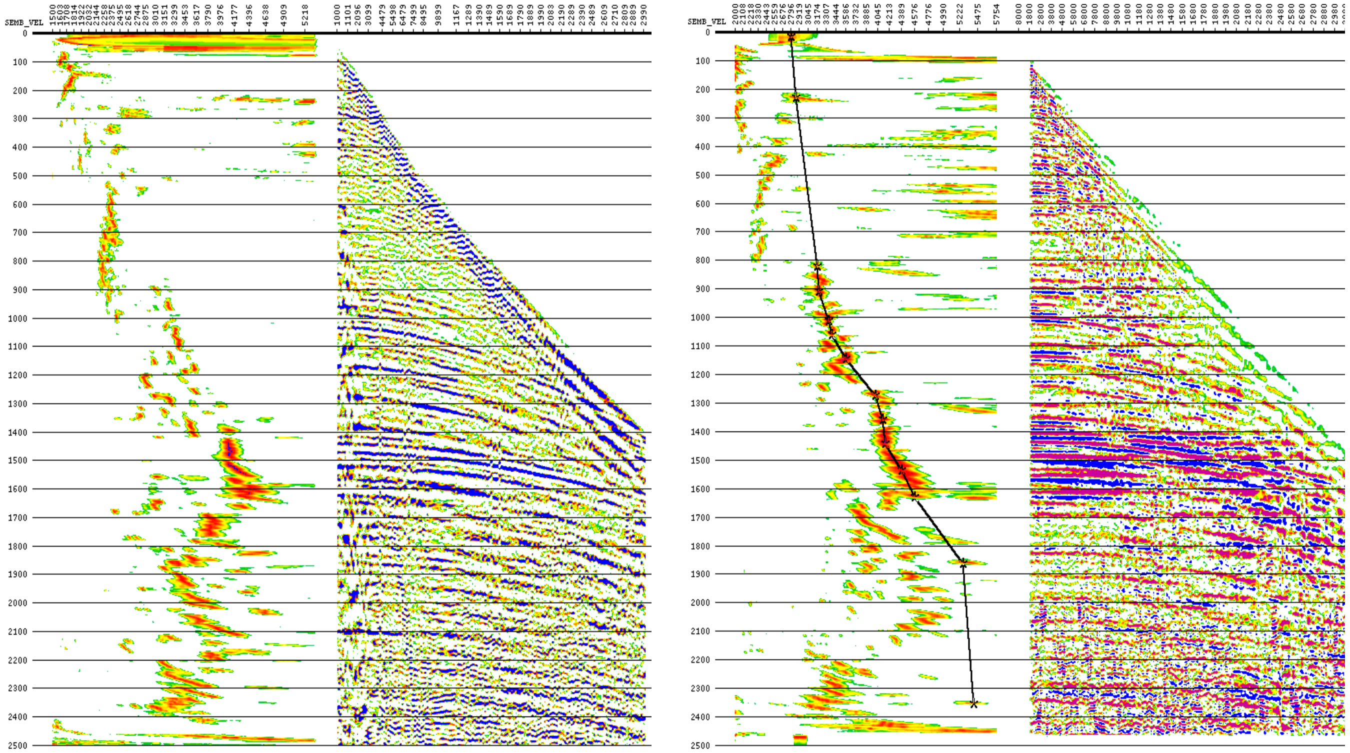
a) b) c)

Figure 1. Gathers at the same location with a) showing a CMP gather with traces ordered by offset, b) the same CMP gather with traces located at the source-receiver offset, and c) an EO prestack migration gather.



a) b)

Figure 2. Crustal data illustrating the offset differences between a) a super-CMP gather with its semblance plot and b) an EO gather with its semblance plot.



a) b)

Figure 3. The differences in high-resolution semblance plots for a) a super-CMP gather and b) an EO gather.