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Full-volume dip corrections for velocity analysis and MVA

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ABSTRACT

Picking of stacking velocities and residual migration velocities can be difficult in noisy data. Common solutions involve the creation of super-gathers, stacking semblance panels, and flattening data along picked horizons. This report shows that full-volume dip corrections can be used for practical enhancements to velocity analysis workflows. The dip fields are computed both with a semblance method and plane-wave deconstruction filters. Following equations from common reflection surface (CRS) processing, the dip fields are used to extend the standard move-out equations to more precisely describe reflections in super-gathers. This correction improves the sharpness of semblance panels and makes it possible to use larger panels than would be possible without the corrections. The report shows 3D examples of using the full-volume dip information both for conventional stacking and pre-stack time migration.

INTRODUCTION

In modern marine surveys with good signal quality, it is often easy to identify move-out curves for velocity analysis or migration velocity analysis (MVA), and automatic algorithms can pick semblance panels with little manual intervention. The main challenge becomes determining the depth migration velocity model that best fits the picked move-outs. But in other datasets, especially land datasets, it can be challenging even to hand-pick initial RMS velocity fields. A variety of practical solutions are used to overcome this challenge. One of the most common is the use of super-gathers, which are sets of adjacent common-midpoint (CMP) gathers treated as single larger CMP gathers. By including more traces in the computation of semblance panels, the signal-to-noise ratio (SNR) improves. However, the size of super-gathers must be limited in areas with steep dips because travel-time surfaces start to cut across reflections in the midpoint direction (Figure 1). A typical size for super-gathers is 3x3 or 3x5, with a larger size often used in the cross-line direction, which is likely to be flatter. When dips are so steep that the data is close to being spatially aliased, even 3x3 super-gathers can be problematic. To overcome this problem, it can be helpful to compute semblance panels on individual CMPs and then to stack adjacent semblance panels. This approach is unlikely to degrade the quality of the final panel, but stacking the all-positive semblance panels does not yield the same SNR improvements that are possible by including more data in a single semblance computation. For horizon-based velocity analysis, super-gathers are sometimes locally flattened using interpreted horizons. Because of the need for human interpretation, this approach is practical only for select horizons.

This report shows that full-volume dip fields can be used to make such corrections on the full volume of velocity panels. Dip fields can typically be computed automatically on stack sections. Because these sections, migrated or unmigrated, have higher SNR than prestack data, automatic dip scans are much more reliable than automatic velocity scans. The dip field is then used as input for a dip corrected velocity analysis. An example from a 3D land dataset shows that the quality of semblance panels improves, especially in the near surface, and that larger super-gathers can be used.

The dip corrections can be viewed either as extensions to standard move-out equations or as simplifications of common reflection surface (CRS) processing, which uses a series of searches for move-out curvature, dip, and reflection curvature to generate parametric descriptions of pre-stack data (e.g., Jäger and Hubral (2001)). CRS processing scans for semblance along travel-time surfaces in super-gathers similar to the surfaces described here, but searches in super-gathers are simultaneous searches for multiple parameters and are intended to be automatic. While convenient when they work, automatic searches may become instable in noisy data. The dip corrections in this report make use of a similar representation of move-out in super-gathers, but the application is changed to allow for manual picking and easier integration into standard processing workflows.

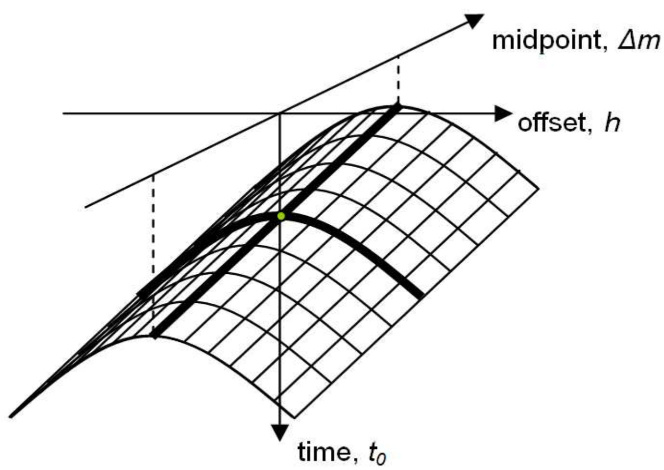

Figure 1: Semblance surface in a 2D super-gather. Uncorrected velocity analysis treats the top of hyperbolas as flat, but precomputed dips can be used to match the shape of reflections more accurately. This is also the surface for a 2D CRS stack. Note that stacking along this surface is equivalent to first summing along the hyperbolas (a conventional NMO stack), and then summing along the apexes (a post-stack slant-stack). rgunther1-supergather_moveout [NR]

EXTENSIONS TO THE MOVE-OUT FORMULAE

The move-out formulae used for both pre-migration velocity analysis and residual velocity analysis are typically simple hyperbolic equations which are functions of the time t_0 at the apex of the hyperbola and the half-offset h of a trace. For NMO velocity analysis, the travel-time t to a reflection is expressed by:

$$t^2 = t_0^2 + \frac{4h^2}{V_{RMS}^2}. \quad (1)$$

For residual velocity analysis, the equation is essentially the same. By convention, the use of a residual parameter r in the numerator rather than the denominator allows perfectly flat gathers to correspond to a residual of zero:

$$t^2 = t_0^2 + 4h^2 r. \tag{2}$$

It is implicit in these equations that all of the data used for the analysis have the same midpoint. Bins are usually chosen to be small enough that post-stack reflections are not aliased. Unmigrated data with midpoints at opposite ends of a bin are not likely to have significantly different t_0 times for a single reflection. For migrated data, the midpoints of all traces in a bin are by definition identical. But when super-gathers are formed, it is likely that the apex of dipping reflections from a trace at one end of the super-gather may be shifted from the apex in a trace at the other end. To correct for this problem, the solution is to extend the hyperbolic move-out equation to move the apex of the reflection up or down along dip. In order to accomplish this, the equation becomes a function of the vector distance $\Delta\mathbf{m}$ of a trace midpoint from the center of the gather and the apparent vector dip σ as determined from dip estimation on the stack section. In the case of NMO velocities, dip is estimated on an unmigrated stack, and in the case of residual velocities, it is estimated on a migrated stack. With these extensions, the move-out formulae become:

$$t^2 = (t_0^2 + \sigma \cdot \Delta\mathbf{m}) + \frac{4h^2}{V_{RMS}^2} \tag{3}$$

for NMO velocity analysis and

$$t^2 = (t_0^2 + \sigma \cdot \Delta\mathbf{m}) + 4h^2 r \tag{4}$$

for residual velocity analysis.

In this formulation, the only change to the equation is a shift in the apexes of travel-time hyperbolas. For the case of residual velocity analysis, this is the final form of the equation. For the NMO velocities, it is possible to use knowledge of the dips for an additional correction. The typical goal for pre-migration velocity analysis is to obtain velocities suitable for time migration. These velocities should be the zero-dip velocities obtained after dip move-out (DMO), not dip-dependant NMO velocities. DMO corrects the shape of reflections for all possible dips, but velocities are chosen from semblance panels, picks are typically made for strong individual reflections. Such reflections usually have well-defined dips that are identified by the dip scan. With knowledge of this dip, it is possible to make an explicit dip correction to the velocity term. It is convenient to convert the dip σ to azimuth α and dip angle β, where azimuth is the map-view angle and β is defined as:

$$\beta = \sin^{-1}\left(\frac{V \cdot \|\sigma\|}{2}\right) \tag{5}$$

The dip and azimuth variables extend the move-out formula with the familiar dip correction to velocity:

$$t^2 = (t_0 + \sigma \cdot \Delta\mathbf{m})^2 + \frac{4 \cdot \cos^2\beta \cdot (\cos\alpha \cdot h_x + sin\alpha \cdot h_y)^2 + (\sin\alpha \cdot h_x + \cos\alpha \cdot h_y)^2}{V_{RMS}^2}. \tag{6}$$

For offsets in the direction parallel to the dip, the velocities are decreased while the velocities for "strike" offsets remain unchanged. Because the same dip corrections can be achieved by applying DMO to the data prior to velocity analysis, this additional correction is neglected in the data examples, which instead focus on the affects of shifting t_0 up or down within super-gathers.

CRS Stack

The CRS move-out equations can be used not only for velocity analysis but also for stacking. By stacking along the CRS travel-time surface through super-gathers, it is possible to construct a stack with enhanced SNR. This so-called CRS stack can be constructed either by directly summing over the CRS travel-time surfaces or by first summing along individual hyperbolas—as implemented by a conventional NMO stack—and subsequently summing along the apexes of these hyperbolas—as implemented by a slant stack along a pre-computed dip field (see Figure 1). Thus, the SNR improvements of a CRS stack can be equivalently achieved with conventional stacking followed by a post-stack slant stack (Günther, 2006).

EXAMPLES

Stable estimate of dips in the stacked zero-offset or migrated section are required in order to make super-gather corrections. Typical results of such dip scans are shown for an inline of the SEG/EAGE Salt model (Figure 2). Claerbout (1992) introduces plane-wave deconstruction filters that locally decompose an image into plane waves, and Fomel (2002) extends the concept to a least-squares method for continuously decomposing an image into dips. Figure (3) shows the result of applying this algorithm to the 2D stack image. A semblance scan provides an alternative—and somewhat simpler—method for computing dips. This method is identical to CRS post-stack parameter estimation (Jäger and Hubral, 2001). At evenly spaced locations in the stack, a grid search maximizes semblance across circular slices through the volume for different values of the dip σ. For 3D data, the search iterates over both x- and y-components of the dip, so it can be expensive to finely sample the search space. A staged search strategy can help overcome this problem by first determining coarse dip estimates and then iteratively refining the results with finer search grids. Figure (4) shows the dip section from the semblance scan.

Figure (5) shows velocity spectra computed on a super-gather from the salt model. The gather contains data from 5 inlines and 5 crosslines, and the spectra are computed with NMO (left) and with the dip corrected move-out (right). While this example shows that dip corrections can improve the quality of semblance panels for super-gathers, it does not motivate the need for super-gathers. Since the salt model does not contain noise, a perfectly adequate velocity spectrum can be computed from a single CDP. But in real data, especially land datasets, noise is a major impediment for velocity analysis. The next example tests the correction on a 3D land dataset. The data were collected with 25m spacing in both the in-line and cross-line directions in a region with complex geology characterized by salt intrusions. With an average

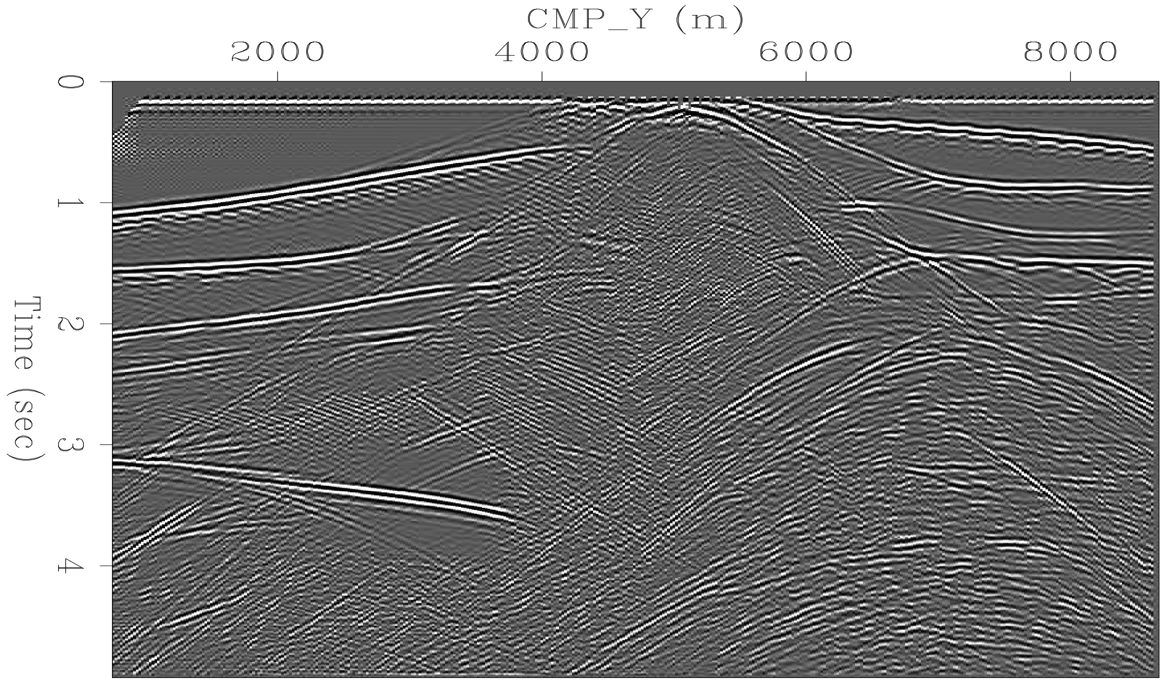

Figure 2: An inline from a zero-offset stack of the SEG/EAGE Salt model. rgunther1-seg_inline [ER]

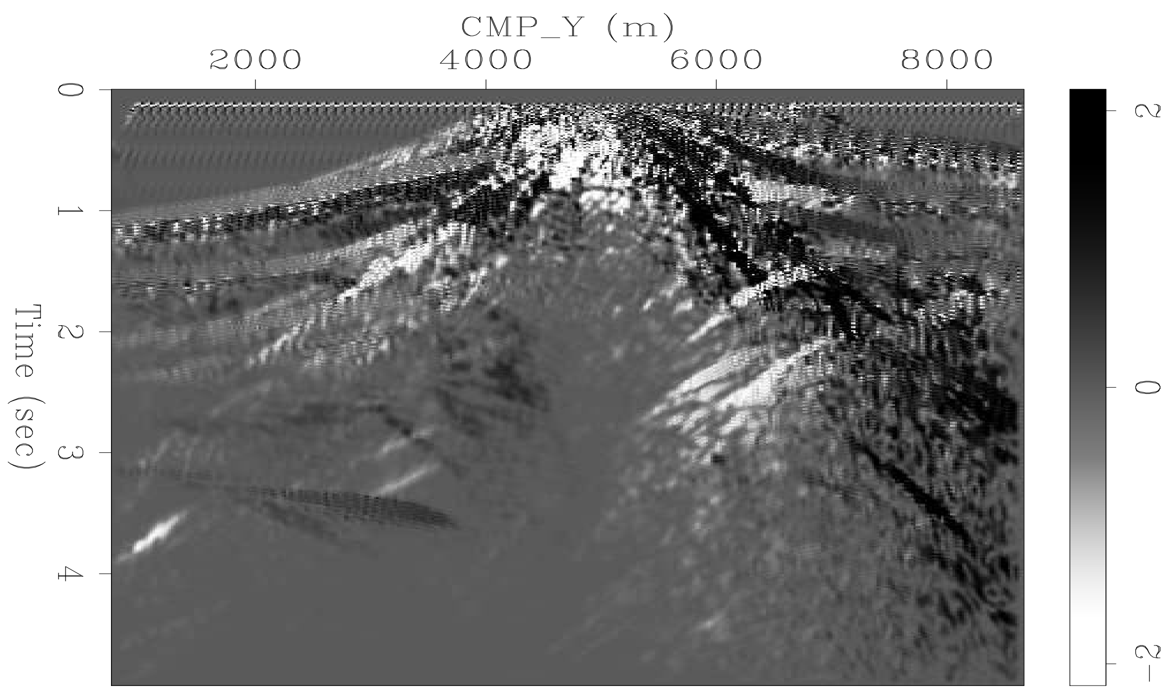

Figure 3: Dips computed for the SEG/EAGE Salt model after Fomel (2002). rgunther1-fomel_dips [ER]

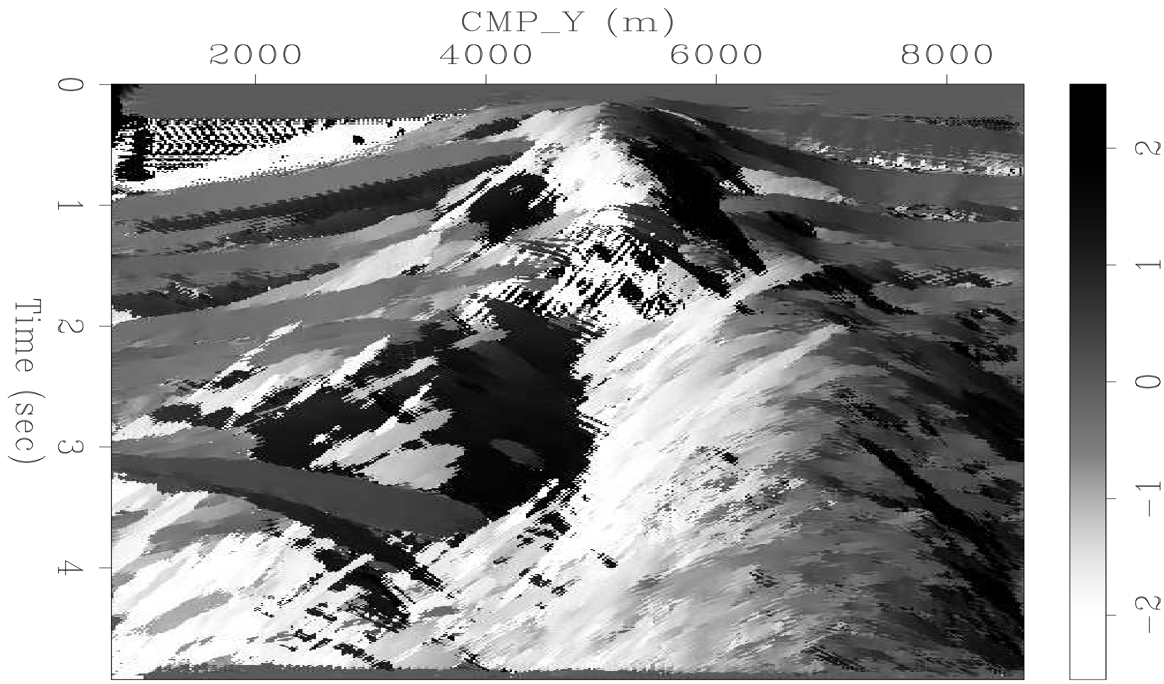

Figure 4: Dips computed for the SEG/EAGE Salt model using a semblance scan. rgunther1-semb_dips [ER]

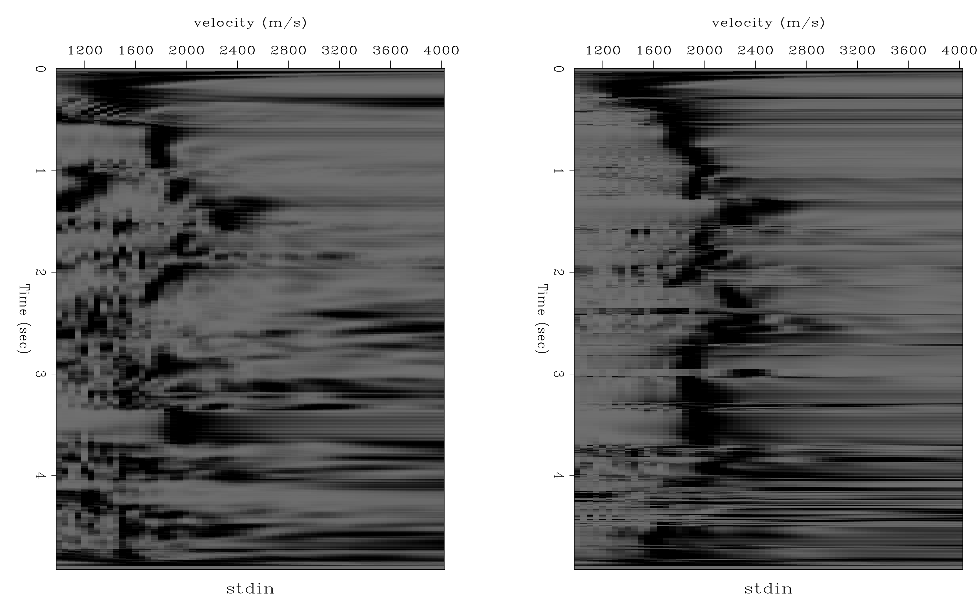

Figure 5: Velocity panel for a 5x5 super-gather computed without dip corrections (left) and with dip corrections (right). The dip corrections improve the coherence of the semblance peaks and make the panel easier to pick. rgunther1-seg_vel_pan [ER]

fold of 25, noise is a significant problem for velocity analysis.

Land example

Figure (6) shows dips estimated on a stacked section and semblance panels for both a small (3x3) and a large (11x11) super-gather, computed without (upper panels) and with dip corrections (lower panels). In the large super-gather, the results computed without dips are noisier than those from the small super-gather. For this reason, data processors often prefer to use small super-gathers in areas with significant structure. The best semblance panel is obtained when the large super-gather is combined with the dip correction. Note that the largest improvement is achieved in the near-surface. The higher frequency of the data in this region makes it more likely that the super-gathers cause degradation of the semblance peaks in uncorrected panels. The minimum dip that is spatially aliased is inversely proportional to the temporal frequency of the data, so higher frequencies make it more likely that uncorrected travel-time surfaces cut laterally across reflections.

Figure (7) shows RMO panels for 11x11 super-gathers of time-migrated CMPs at the same location as for the previous gathers. Where the data are migrated with the correct velocity, the semblance is centered on zero r in the middle of the panel. Semblance maxima at negative r indicate over-migrated data, while maxima at positive r indicate under-migrated data. The effect of the dip corrections is similar for the PSTM gathers as for the semblance panels.

CONCLUSIONS

With noise commonly plaguing the interpretation of velocity semblance panels, super-gathers are an important tool for increasing signal both for stacking and residual velocities. Though super-gathers are normally treated as conventional gathers, significant improvements in the quality of semblance panels are achieved by applying dip corrections. An application of the technique to 3D land dataset produces high quality semblance panels over complex geological structures where relatively steep dips are present. The size of super-gathers can be increased significantly beyond the point at which semblance panels would degrade without the corrections. Because the full-volume correction can be easily integrated with existing tools, it is likely to be useful for many different velocity analysis applications, including automatic picking and residual analysis after depth migration.

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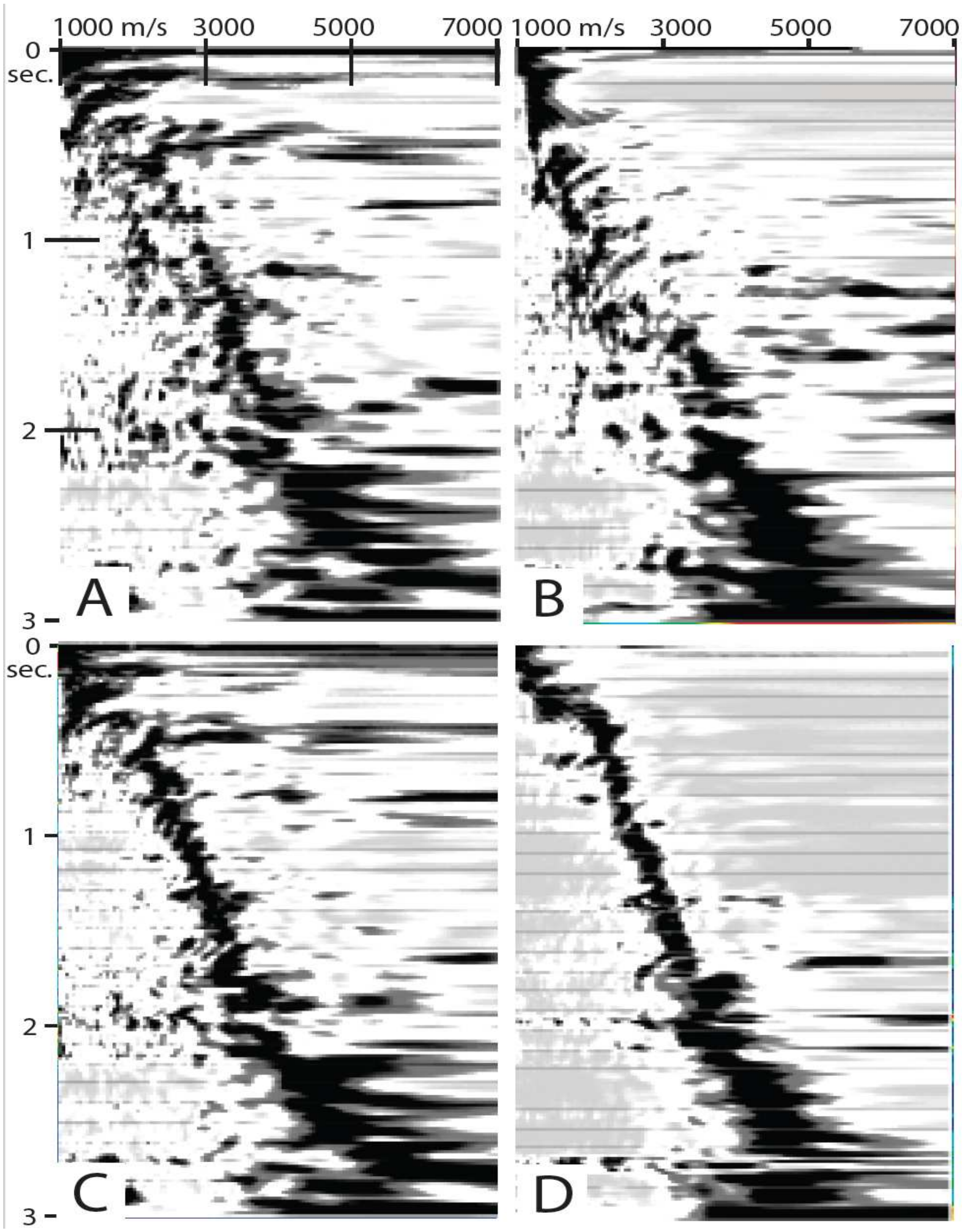

Figure 6: NMO semblance panels computed without dip corrections for 3x3 (A) and 11x11 (B) super-gathers; panels computed with dip corrections 3x3 (C) and 11x11 (D) super-gathers. The dip corrections improve the semblance quality for both the small and larger super-gathers. Note that without the correction, the smaller super-gather yields superior results while the opposite is true with the correction. rgunther1-land_nmo [NR]

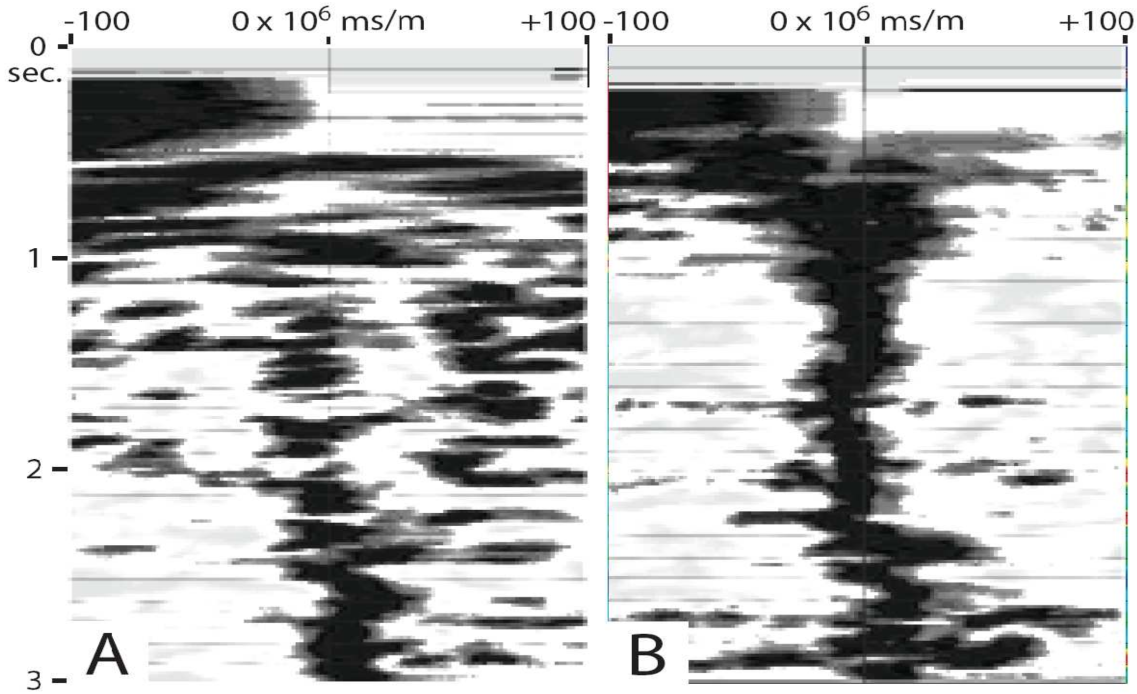

Figure 7: RMO semablance panels computed on an 11x11 super-gather without (A) and with (B) dip corrections. As for NMO velocity analysis, the dip corrections make the panel easier to pick. rgunther1-land_rmo [NR]

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