Kinematic Redatuming by Kirchhoff Summation

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Abstract

When land seismic data acquisition must account for the influence of a rugged topography and considerable velocity inhomogeneity (like a thick weathering layer) below the measurement surface, the various static correction methods usually provide incorrect temporal adjustments and thus incoherent sub-optimal stacks. The reason is that the time corrections are based on vertical ray trajectories between the measurement surface and the base of the weathering layer. They thus disregard lateral variations of the ray path. It is for this reason that we propose a geometric kinematic redatuming method that does not suffer from this problem. It results from cascading a Kirchhoff migration and demigration.

In view of the difficulties in the treatment of amplitudes on land data, we perform only kinematic (unweighted) stacks. This is enough to produce convincing results to justify the deployment of all usual pre- and poststack-processes and ultimately create seismic images which are consistent with the geology in question.

Introduction

It is known that static correction processes are largely adopted early in the processing flow. However, some severe hypotheses are made like a smooth variation of the surface topography, a reasonable weathering zone with little thickness and smooth variations of the velocity.

Static corrections in such situations assume vertical trajectories for the waves from the surface to the weathering base (Figure 1) and apply a time shift for each trace, which is independent from the deformed wave front. They consider mostly a smooth velocity distribution above the base. The reality is, however, not always as simple like this (Tegtmeier-Last, 2007). Therefore, in cases that depart from these assumptions, it becomes necessary to adopt alternative redatuming methods.

As important as finding consistent first breaks in multi-coverage land seismic data is the need to (a) compensate for the ruggedness of the surface topography and (b) account for non-regular source and receiver positions and (c) take care of the deformation of wave fronts due to a thick inhomogeneous near surface weathering layer.

Thanks to the use of migration and demigration algorithms, it is possible to transport sources and receivers from the acquisition surface to a datum, preferably fixed, where they are free from the influence of the relief and weathering zone.

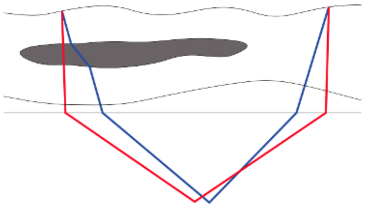

Figure 1 – Comparison between the ray path assumed by the static correction (red) and the true correction (blue).

The proposed algorithm treats – although it has the potential to be much more general - only the 2D case with a vertical inhomogeneous velocity below the horizontal datum. It is used to (a) evaluate the method with respect to dislocating sources and receivers from an irregular surface to the datum and (b) demonstrate that this can be done with an estimate of the velocity below the datum.

To achieve this goal, we use kinematic migration and demigration as used in Kirchhoff summation and assume that we have a geologically consistent velocity field above the datum. In this way we perform a prestack redatuming, but different from that applied by Berryhill (1984) for the 2D acoustic situation, which was modified by Kinneging et al. (1989) for the 3D acoustic situation. Other helpful references related to the subject are Bevc (1995), Hubral et al (1996) and Pila (2011).

Method

Considering that we can migrate any seismic data using a given velocity model and then retrieve it by the reverse operation (demigration) with the same velocity model, we can reposition the sources and receivers from the surface to any datum, provided we know the velocity distribution below the measurement surface down to the datum. However, it is important to remark that we do not need to know the correct velocity field below the datum. As our method shows, a good estimate is enough. The reason is that migration from the measurement surface and demigration to the datum (in our case below the surface) is insensitive to the difference between the true and estimated velocity below the datum if this is not too big.

We can, for instance, for a vertically inhomogeneous velocity field only use the estimated RMS velocity obtained from other processes.

We distinguish between the given irregular INPUT prestack data on the measurement surface and desired regular OUTPUT prestack data on a pre-specified regular grid on the datum. The transformation of the irregular input data to the regular output data can thus also be viewed as a REGULARISATION PROCESS.

The desired redatuming operator - to construct a common-offset (CO) section on the datum - is a stacking operator. This is constructed for a specified point on the desired regular CO output section, but applied to the irregular input data. How is it constructed?

The procedure is: Define the point P (Figure 2) on the common offset (CO) output data into which the stack result is to be put. Then construct for P the isochrone in the estimated velocity model below the datum. This is the ellipse in Figure 2 for a constant velocity. Then demigrate the isochrone to the measurement surface. In this way one obtains the kinematic REDATUMING OPERATOR along which the irregular prestack input data are summed (stacked) to provide the stack value in the output point P.

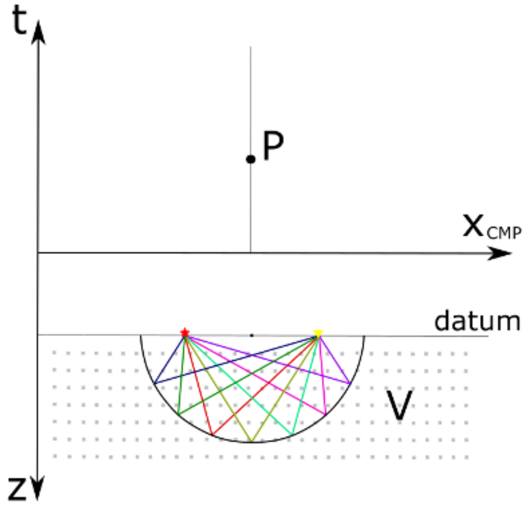

Figure 2 - Point P - in the desired CO output section on the datum - is migrated into depth within the z-x plane of the estimated velocity below the datum (here assumed to be constant). Note that the isochrone is defined in such a way that the reflection time between both focal points separated by 2h (h = half offset) corresponds to the time of point P.

The demigration is performed by ray tracing considering the isochrone to be the reflector. Some rays reflected from the isochrone that pass through its two focal points, which are equal to the shot-receiver pair for point P, are shown in Figure 3. The ray emergence points on the measurement surface do not coincide with its actual shot- and receiver positions. For this reason the redatuming operator for P gathers (collects, sums) interpolated amplitudes on the prestack data as indicated in the upper half of Figure 3.

Note that the method is based on determining first the rays reflected from the isochrone that arrive at the two focal points on the datum. They have certain emergence angles there, which are then used for tracing the rays up from the datum to the measurement surface.

By summing the interpolated amplitudes found along the redatuming operator for the specified point P, we obtain the value assigned to it. The procedure performed for P is the repeated for any other point P of the redatumed CO output section for the specified and any other given offset.

In this way the desired multi-coverage prestack data on the datum are constructed, which are free of the influence of the irregular topography and the complexity of the velocity above the datum.

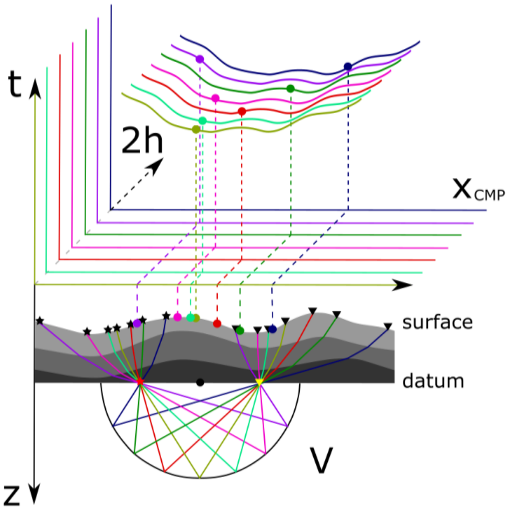

Figure 3 – Upper half: Domain of the 2D-multicoverage prestack input in t-x-h-space. Lower half: Depth-model with rays reflected from the isochrone between shot and receiver on the datum.

Results

The redatuming operator for a vertically inhomogeneous velocity model below the datum is essentially only determined by the topography of the surface and the velocity of the overburden of the datum. The difference between the true and estimated velocity below the datum on the kinematic redatuming operator is negligible for not too large incidence and emergence angles of the rays.

For initial tests, we use a model that only explores the capability of the algorithm to suppress the influence of topographic variation. We created a multi-coverage data set for the model shown in Figure 4 with the following geometry: 151 sources and 101 receivers for each spread, with source and receiver intervals of 20 meters. The traces had 2 seconds recording time and were sampled every 4 milliseconds.

The multi-coverage data set was then used to search for the input traces to construct the desired output common offset section. The aim of the test was to analyze the ability of the method to reposition the simulated reflection data on the rough surface to the flat datum below the weathering zone, in a way that is insensitive to the distribution of velocities below this flat surface.

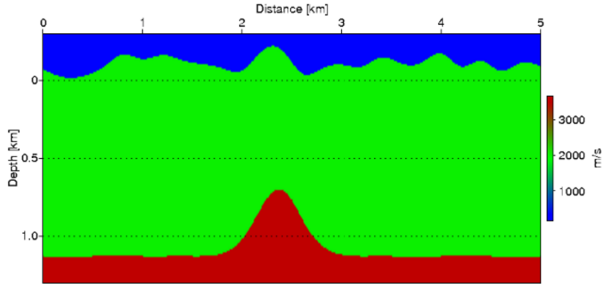

Figure 4 – Velocity model with rough topography and flat datum at depth=0 used for the test.

We simulated the reflection data by impulsive sources for the model shown in Figure 4. We obtained a set of prestack data that was later sorted and separated by common offset.

In order to show the advantageous characteristic of the method to increase the signal-to-noise, we added random noise to the generated data.

Figure 5 and Figure 6 show examples of the CO-sections extracted from the multi-coverage input data set, with 300 and 900 meters, respectively.

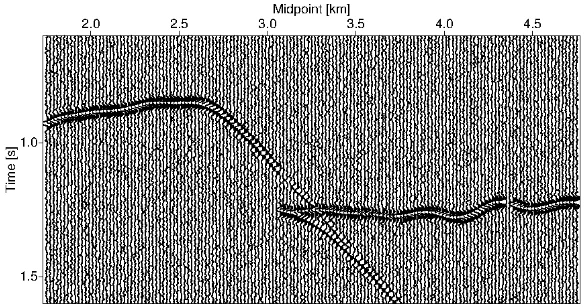

Figure 5 – Common-offset 300m – Part of input.

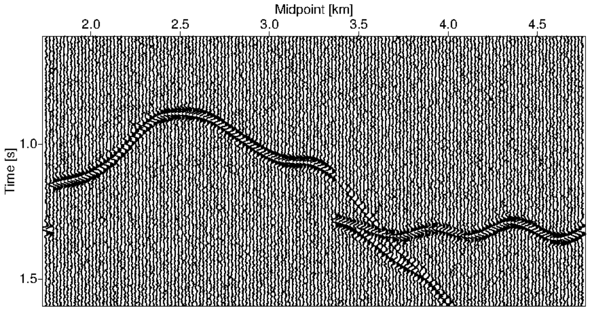

Figure 6 – Common-offset 900m – Part of input.

Figure 7 and Figure 8 show the redatumed result, i.e. the CO-sections with 2h = 300 m and 2h = 900 m, respectively, constructed from the input-multicoverage data.

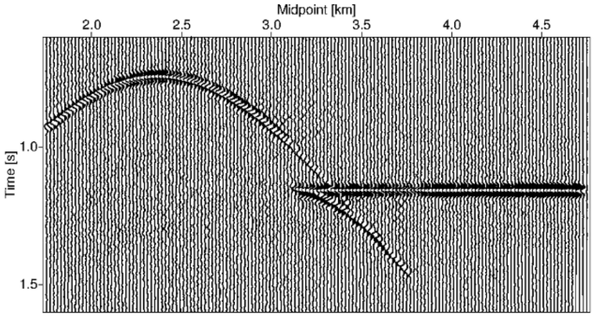

Figure 7 – Input: multi-coverage data – Output: 2h = 300m.

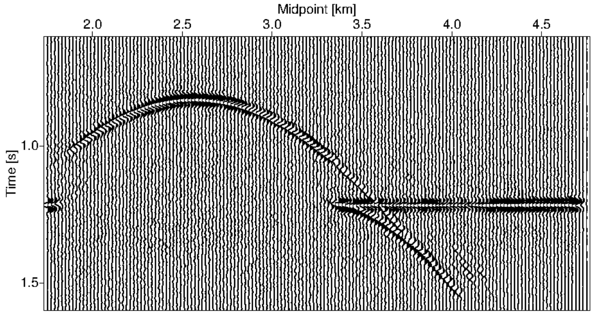

Figure 8 – Input: multi-coverage data – Output: 2h = 900m.

To ensure the correct repositioning of the CO-output section for 2h = 300 and 900 m, we migrated it to depth. The result is the image in Figure 9, which is completely consistent with the adopted model in Figure 4.

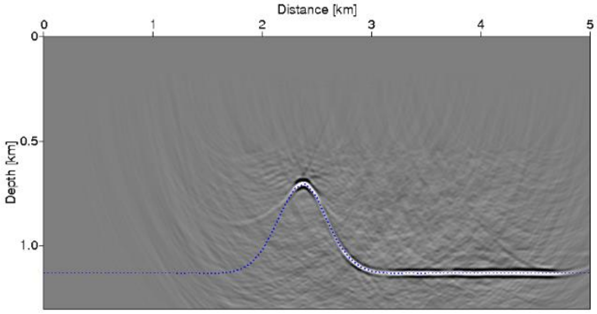

Figure 9 – Sum of Kirchhoff depth-migrated sections obtained from the redatumed CO-sections for 2h = 100, 300, 500, 700 and 900 meters.

Conclusions

We provided synthetic results for the proposed kinematic redatuming process for irregular prestack land seismic data with a complex topography and velocity overburden. We only treated the kinematic aspects, because most seismic processes for land data also do not worry about amplitudes. The method has the advantage to be a regularization and noise-reduction process that provides regularized redatumed seismic prestack data that can be submitted to standard processing and imaging procedures starting from the datum. The next step of our research will be to generalize the algorithm for an inhomogeneous overburden and finally apply it to real prestack land data!

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