Applications of the Unified Approach Theory

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ABSTRACT

Kirchhoff depth migration is a frequently used method to transform measured seismic reflection data from the time into the depth domain. The results of migrating seismic ZO sections obtained by the CRS Stack method reveal a clearer image of the subsurface compared to the depth-migrated seismograms obtained by the conventional NMO/DMO/Stack approach. Demigration is the asymptotic inverse process to migration and aims at reconstructing a seismic time section from a depth-migrated image. By combining Kirchhoff migration and demigration, several imaging problems can be solved. One application of cascading these processes is the interpolation of missing traces in seismic sections.

INTRODUCTION

Kirchhoff depth migration is a widely investigated and frequently used tool in the world of seismic exploration to transform measured reflection data from the time into the depth domain. Kirchhoff migration assumes the subsurface to be built up by potential diffraction points. The migration result for such a point is obtained by a summation of seismogram amplitudes along the diffraction traveltime surface (Huygens surface) of the considered depth point. In the last decades, the originally purely kinematic migration schemes were extended in order to relate the amplitudes in the migrated images to physical subsurface properties. This is achieved by compensating for the geometrical spreading effects by means of applying suitable weight functions during the stacking process. Amplitudes in a depth image that are free of spherical divergence effects are called “true” amplitudes. If other effects on the reflection amplitudes (as, e.g., transmission loss, scattering, or source and receiver effects) are negligible or corrected for, these true amplitudes in the migrated images are a measure of the angle dependent reflection coefficient. Therefore, true-amplitude prestack depth migration allows to extract AVO/AVA (amplitude versus offset/angle) information which can be of great use in the search for hydrocarbon reservoirs.

The asymptotic inverse process to migration is demigration. That is, demigration means the transformation of a migrated image into a seismic section in the time domain. The principle of

Kirchhoff demigration is analog to Kirchhoff migration: the value that is assigned to a point in the time domain is obtained by a stack of amplitudes in the migrated image which lie on the isochron of the point under consideration. While a true-amplitude migration compensates the geometrical spreading loss of the seismograms, true-amplitude demigration as its asymptotic inverse process has to re-introduce this effect back into the data. This can again be realized by applying an appropriate weight function during the stack. Defined in this way, true-amplitude demigration results in seismograms that are close to the actual recorded ones. True-amplitude migration and demigration can thus be applied one after the other without altering the amplitude information of the result.

The basic idea of the *Unified Approach Theory* presented by Hubral et al. (1996) (basic concepts) and Tygel et al. (1996) (theory) is to combine Kirchhoff migration and demigration. If the macro-velocity model, the considered ray code (e.g., PP, SS, PS) or the measurement configuration is changed in between these processes, a multitude of imaging problems can be solved. Migration and demigration can either be applied in sequence (cascaded solution) or they can be analytically chained which leads to a single-stack solution for each specific imaging problem. Tasks that can be addressed in this way include

- remigration, i.e., the updating of a migrated image according to a better velocity model or taking anisotropy information into account,
- ray-code transformations, e.g., the simulation of S-wave seismograms from a given P-wave data set,
- configuration transformations, i.e., the simulation of seismograms pertaining to certain measurement configurations,
- redatuming, i.e., the simulation of seismograms that would be recorded on a chosen (horizontal) datum plane using data recorded on a given topography.

Based on the *Unified Approach Theory* an imaging tool named “Uni3D” was developed by a working group at the Geophysical Institute, Karlsruhe University (see, e.g., Hertweck et al., 2001; Jäger, 2001). This program is currently able to handle 2.5D and 3D zero-offset data sets, and 2.5D multicoverage data. Due to the amount of data that would have to be processed and the limited computing resources, 3D prestack algorithms are not yet implemented. The main components of Uni3D are true-amplitude Kirchhoff migration and demigration for arbitrary macro-velocity models in 3D and 2.5D. By cascading these processes, we are able to address further imaging tasks. Due to practical reasons (Hertweck et al., 2001) the chained solution is, up to now, not considered. Kirchhoff (de)migration algorithms allow the computation of (de)migration results independently for all output- or input sample points. Thus, they are very suitable for parallel computation on multi-processor systems.

MIGRATION OF NMO/DMO/STACK AND CRS STACK RESULTS

Kirchhoff migration was applied to a real data set provided by the Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany. These data were acquired over the

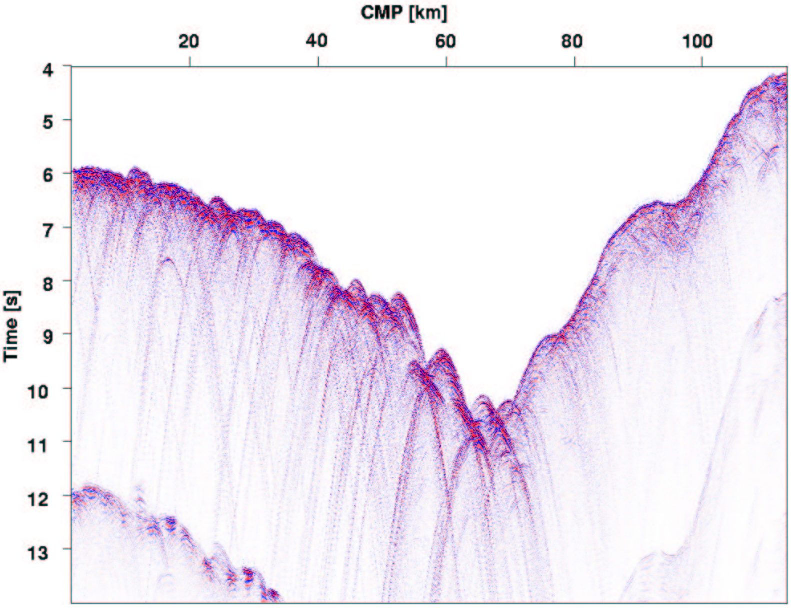


Figure 1: ZO section obtained by the CRS Stack

Chile Trench near $22°$S during the CINCA (*Crustal Investigations on- and offshore Nazca/Central Andes*) program in 1995. The sampling rate of the data is 4 ms and the total record length is 15 s. The streamer consisted of 120 receivers placed in intervals of 25 m. Thus, the largest acquired offset is about 3 km. This is relatively small compared with the water depth of around 7 km.

Figure 1 shows the simulated zero-offset (ZO) section obtained by the Common-Reflection-Surface (CRS) Stack method (see, e.g. Mann et al., 1999; Jäger et al., 2001). The sampling rate is 4 ms and the CMP spacing is 12.5 m. A subsurface structure beneath the clearly visible ocean bottom is hardly observable in the seismograms. The only strong event below the seafloor can be identified as a water multiple, its two-way traveltime is exactly twice the traveltime to the ocean bottom. It was attempted to attenuate this multiple during the CRS Stack, with more success on the right than on the left part of the image, as can be seen in the result. The entire seismic section is strongly dominated by diffraction patterns stemming from the rugged seafloor.

For a subsequent poststack migration a velocity model had to be created. We used a macro-velocity model constructed by C. Ranero from Geomar (Kiel, Germany). It covers the right part of the data set starting at $x = 58$ km and reaches down to a depth of 20 km. Figure 2 shows the smoothed version of the original model, and is the one that was actually used to calculate the relevant part of the Green's functions. The simulated zero-offset section was depth-migrated by means of a 2.5D weighted Kirchhoff migration to a target zone identical to the size of the macro-velocity model. To speed up the migration process and to avoid operator aliasing, the size of the stacking operator was restricted by limiting its maximum dip to $35°$. To attenuate boundary effects due to this limited aperture the operator was not truncated but tapered smoothly to zero over an additional range of $10°$ using a two-sided Hanning window.

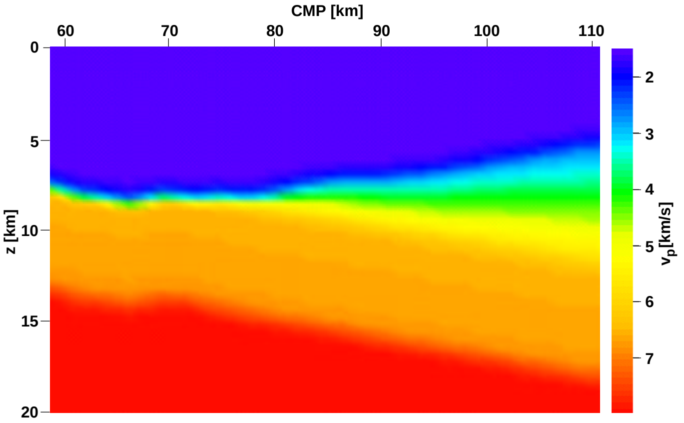


Figure 2: Macro-velocity model used for migration (after C. Ranero).

Figure 3 shows the upper part of the depth-migrated image. Below $z = 11$ km no coherent events are visible. For displaying purpose, an AGC (window length: 750 samples $\widehat{=}$ 4500 m) was applied to the migrated image. Visible events can be identified with corresponding subsurface structures of an interpreted time section provided by the BGR (see Figure 4). When comparing the depth-migrated image with Figure 4 one has to take into account that the interpreted section is displayed in the time domain. The water velocity is (nearly) constant and thus the bathymetry of the ocean bottom is directly comparable between the interpreted time domain image and the depth-migrated image. Below the sea bottom there is no such one to one relationship. Position and slope of events differ in the images but they can, nevertheless, be associated to each other. On the lower right border of the depth-migrated image a migration smile resulting from an isolated high amplitude value of the water multiple is visible.

In addition to the prestack data that served as input for the CRS Stack, the BGR also provided us with a simulated ZO section obtained by means of the conventional processing sequence NMO/DMO/Stack. This section was depth-migrated using the same 2.5D Kirchhoff migration scheme and the same velocity model. The result is depicted in Figure 5. The ZO section simulated by NMO/DMO/Stack does only cover the left part of the section obtained by the CRS Stack. Thus, an optimized CRS Stack result for this smaller target zone was depth-migrated using again the same migration parameters for comparison. The result is displayed in Figure 6. In this CRS-based result the oceanic crust is better defined compared to Figure 5. Further areas showing significant difference between both results are marked by boxes.

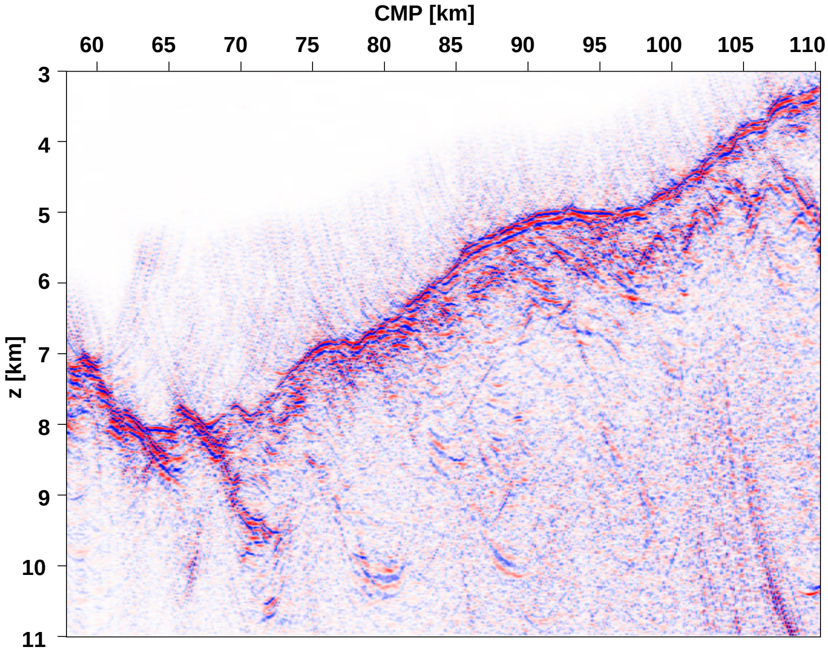


Figure 3: Poststack depth migration of CRS Stack result

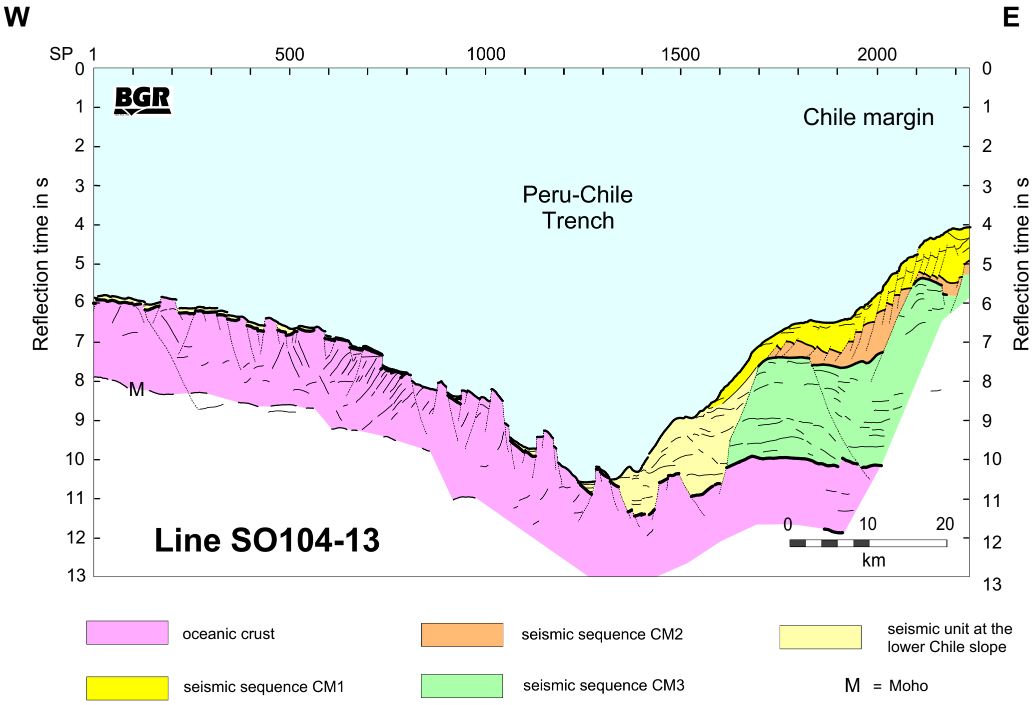


Figure 4: Interpreted time section provided by the BGR, Hannover, Germany. The depth-migrated section in Figure 3 corresponds to the part right of CMP 1100.

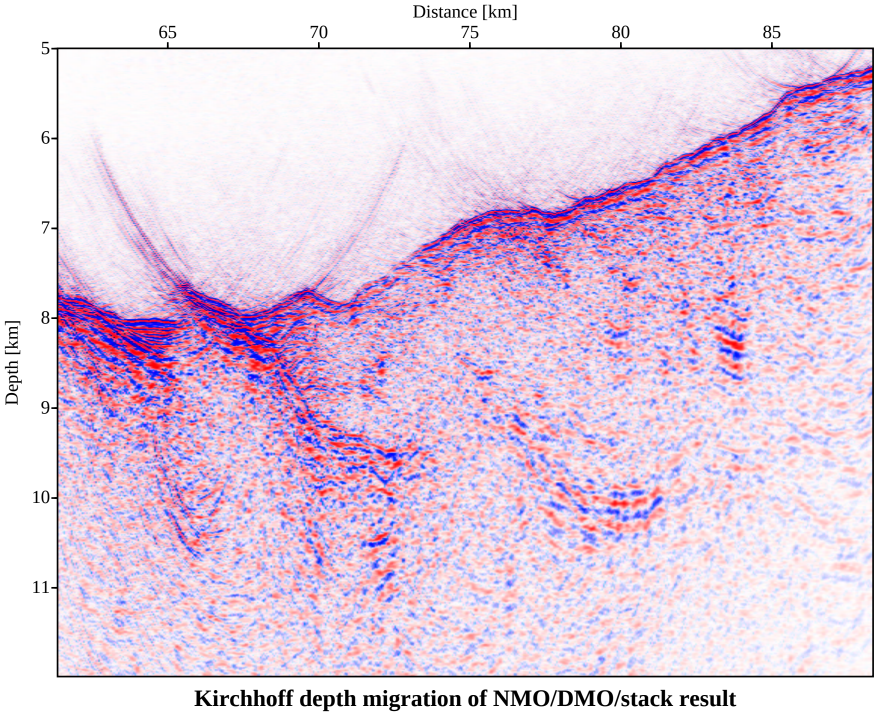


Figure 5: Poststack depth migration of NMO/DMO/Stack result

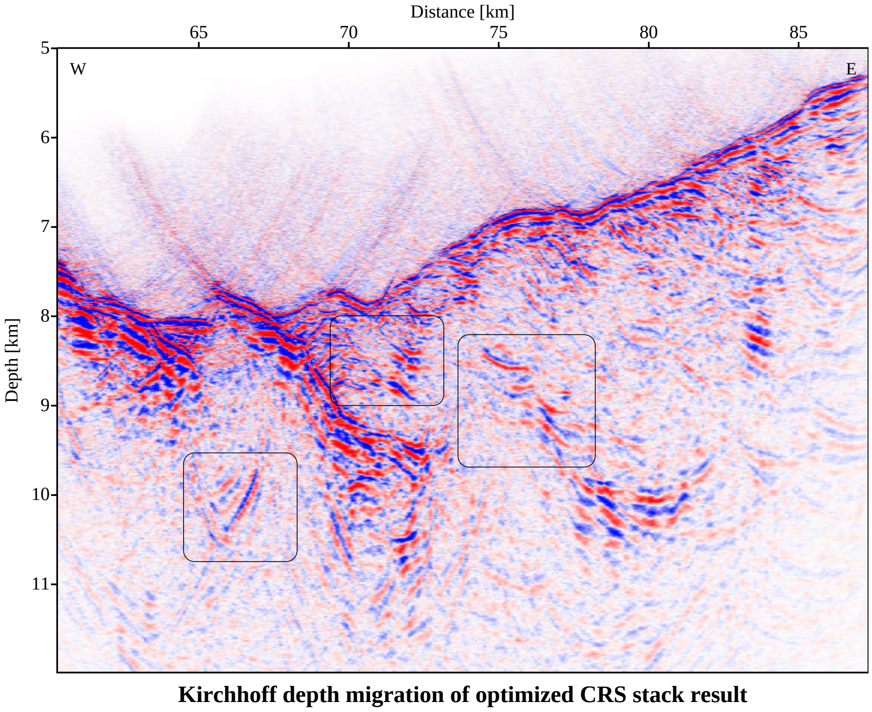


Figure 6: Poststack depth migration of CRS Stack result; same target zone as in Figure 5.

TRACE INTERPOLATION BY CASCADING MIGRATION AND DEMIGRATION

True-amplitude Kirchhoff migration and demigration can be combined in order to address various imaging problems. A simple application of cascading migration/demigration is the interpolation of missing traces in seismic sections. Such missing traces can result from, e.g., “dead” receivers. In a similar way, poor receiver coupling can cause traces with very low amplitudes compared to neighboring ones. These could be balanced in the same physically sound way.

In order to investigate the possibility of trace interpolation by cascading migration and demigration, a simple experiment for a single plane reflector was carried out (10 Hz zero-phase Ricker wavelet, ZO seismic section with a CMP spacing of 5 m and a time sampling of 4 ms). One trace was zeroed in the original seismic section, and then a constant-velocity migration and demigration process was applied to the data. After the complete cycle, the gap in the seismic section is closed. Figure 7 shows the interpolated trace (dashed line) and the trace that was zeroed out (solid line) for comparison. Despite of a small amplitude error (that is explained below) the wavelets match perfectly.

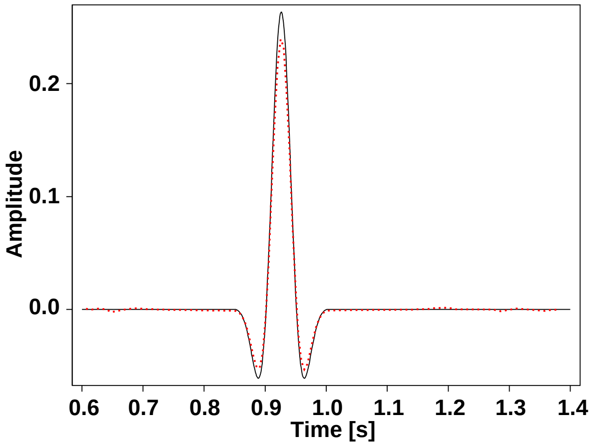
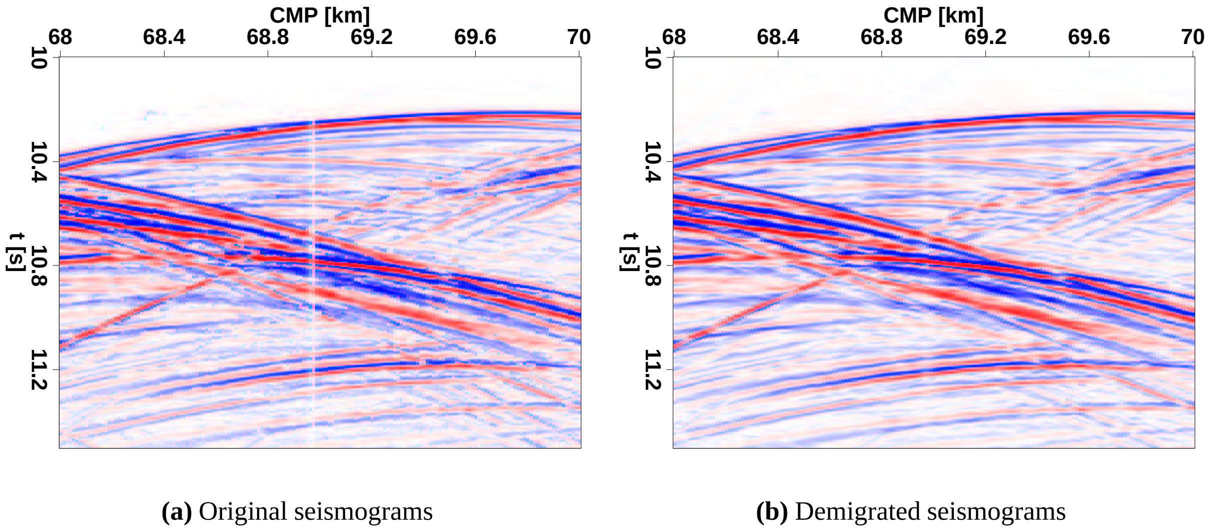


Figure 7: Interpolated (dashed line) and original (solid line) trace of the synthetic data example.

Due to these encouraging results, a similar experiment was performed for the real data set provided by the BGR. We zeroed a trace near CMP location 69 km in the simulated ZO seismograms (Figure 1). A zoom of the region around the zeroed trace is shown in Figure 8(a). Our aim was to interpolate this missing trace. Since migration and demigration are asymptotic inverse processes and we do not have to change any parameters in between these steps for the purpose of trace interpolation, the subsequent migration/demigration process should be insensitive to the used macro-velocity model. Therefore we assumed also for the real data example a constant-velocity background model for both transformations which leads to a considerable speedup of the (de)migration algorithms. The region around CMP location 69 km after the migration/demigration cycle is shown in Figure 8(b). Of course, it would have been possible to demigrate the depth image only to one single trace which leads to an additional speedup of the whole process.



(a) Original seismograms

(b) Demigrated seismograms

Figure 8: (a) Zoom of the CRS Stack result around CMP 69 km. One trace was zeroed out. (b) The same seismic section after applying a true-amplitude migration and demigration. The missing trace was interpolated.

A detailed comparison of the resulting trace after migration/demigration and the original trace (that was zeroed out) is shown in Figure 9. The waveform of the missing trace could be estimated very well and also the amplitudes of the interpolated trace are a good approximation of the original ones.

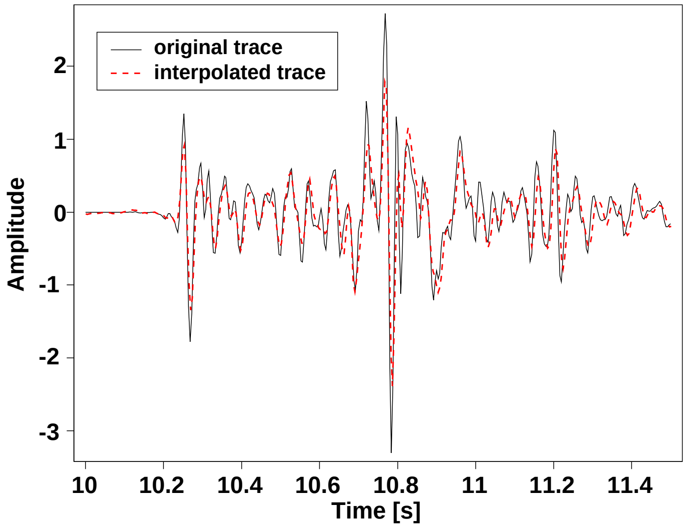


Figure 9: Comparison of the original trace (which was zeroed in the initial section, depicted as solid curve) and the interpolated trace after applying a constant-velocity migration and demigration (dashed curve).

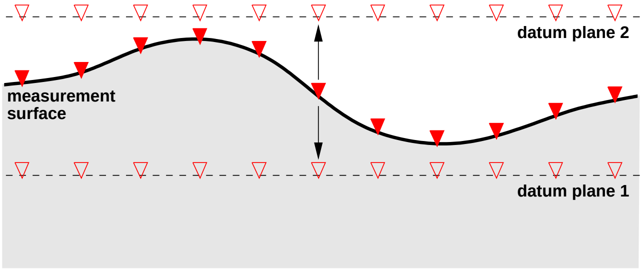


Figure 10: Sketch showing the aim of redatuming, namely the simulation of data recorded on one of the indicated reference planes, using data measured on a topography. The triangles denote sources/receivers.

Why does the interpolation work? The migration process is performed by stacking along Huygens curves which is implicitly a smoothing process. Hence, although there are some missing traces in the time domain, the reflectors in the depth domain will be continuous because several traces within the migration aperture contribute to the value assigned to one depth point. However, the amplitude of the reflector element formed by depth points that have Huygens curves with stationary points in the region of the missing trace will not be correct. This effect propagates into the demigrated section. Therefore, amplitudes of the interpolated traces in the seismic section are usually smaller than the original ones. Nevertheless, the method of trace interpolation outlined above provides a more physical and illustrative way than other frequently used methods.

Similar to the described trace interpolation, we plan to realize the important process of redatuming by means of subsequent migration and demigration. Redatuming is the simulation of data that would be recorded on a (horizontal) datum plane using data acquired on a given topography. This situation is illustrated in Figure 10. Redatuming is often required in practice because most algorithms are optimized for regularly-sampled data referenced to a flat datum. Under certain conditions the rugged topography problem can be compensated for by redatuming with static shift. However, if the underlying assumptions are violated, subsequent processing and imaging is degraded. Our idea is to address the problem by applying migration and demigration in sequence or—after implementing a ray tracer in our imaging program—by chaining migration and demigration to obtain one single process.

CONCLUSIONS

We presented the two imaging processes (true-amplitude) Kirchhoff migration and demigration and their application to real offshore data. By depth-migrating ZO sections simulated by means of the CRS Stack as well as by the conventional NMO/DMO/Stack we could show that the CRS Stack method helps to obtain a clearer image of the subsurface. Furthermore, we have shown that cascading constant velocity Kirchhoff migration and demigration is an efficient and physically sound method for trace interpolation. In a similar way, we propose to investigate the potential of cascaded migration/demigration for redatuming.

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