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Modeling by demigration

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ABSTRACT

Kirchhoff-type, isochrone-stack demigration is a natural asymptotic inverse to classical Kirchhoff or diffraction-stack migration. Both operations can be made true amplitude by an appropriate selection of weight functions. Isochrone-stack demigration can be also used for modeling purposes. The idea is to attach to each reflector in the model a spatial wavelet with an appropriate stretch and reflection coefficient, so that the model has the form of a true-amplitude migrated section. The modeling is then realized by a true-amplitude demigration operation. An example of a simple cases is computed and the results are discussed.

INTRODUCTION

True-amplitude, Kirchhoff depth migration is a seismic imaging operation that transforms a given time section into a depth-migrated section in which the migrated migrated seismic pulses along the reflectors are free from geometrical spreading losses (see, e.g., Bleistein, 1987, or Schleicher et al., 1993). Neglecting all other factors that affect amplitudes (e.g., transmission and attenuation losses) and also assuming no multiple arrivals present in the original seismic data, the true-amplitude migration output at each point of a reflector is a measure of the reflection coefficient. This coefficient pertains to the primary reflection ray joining the source to the receiver position in the given measurement configuration. The considered point on the reflector is the specular reflection point of this ray.

Moreover, each reflector in the migrated section appears as a certain spatial wavelet. In other words, we may say that the reflector image is a certain strip of varying width. The form and width of this spatial wavelet are determined by the input temporal wavelet, as well as by the so-called stretch factor that describes the frequency shift of the pulse due to the migration process (Brown, 1994; Tygel et al., 1994b).

The diffraction-stack or Kirchhoff migration integral can be understood, in an asymptotic sense (Tygel et al., 1994a), as the inverse operation to the classical Kirchhoff integral (Frazer and Sen, 1985). In the same way as the Kirchhoff integral can be used to propagate a given incident wavefield from the reflector location to the receiver point, the

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Kirchhoff migration integral serves to reconstruct the Huygens' secondary sources along the reflector in position and strength from the measured wavefield at several receiver positions along the seismic line.

As discussed by Hubral et al. (1996) and mathematically shown by Tygel et al. (1996), there exists another, structurely similar, inverse to the Kirchhoff migration integral (also in an asymptotic sense). This is given by an isochrone-stack demigration to be performed on a depth-migrated section. In other words, in the same way as the Kirchhoff migrated section is constructed by stacking the original seismic data along certain model-based stacking lines (or surfaces) without the need to determine the location of the reflection traveltime surfaces in the seismic section, its inverse can be realized by a similar stack along related lines (or surfaces) without knowing the location of the reflectors in the migrated section. The stacking lines (or surfaces) are simply the isochrones, i.e, the lines of equal reflection time between a given source and receiver. These isochrones (ellipses or ellipsoids in the constant-velocity case) are defined by the same traveltimes as the diffraction traveltime curves (hyperbolas or hyperboloids in the constant-velocity case) that define the stacking lines (or surfaces) for migration. Thus, all that is to be known to actually perform the inverse stacking process called *Kirchhoff demigration* is the same macro velocity model that was used for the Kirchhoff migration before.

The fact that the Kirchhoff migration integral has two inverse integrals (in an asymptotic sense) has led us to the conclusion that it should be possible to use the second (i.e., Kirchhoff demigration) to achieve the goals of the first (i.e., Kirchhoff modeling). In this paper, we elaborate on how this can be done.

To better explain the idea of modeling by demigration, let us firstly comment on the basic characteristics of modeling and migration, so as to appreciate their similarities and differences.

Modeling, as we understand it, means the analytical or numerical simulation of a physical process given all the equations and parameters for its complete description. In our case, the physical process to be simulated is seismic wave propagation. It is described, e.g., by the acoustic wave equation and the parameters are the velocity and density distributions within the medium, the source and receiver locations, and the source wavelet together with appropriate boundary and initial conditions. Modeling is, then, the implementation of the wave equation (e.g., using finite differences or the Born or Kirchhoff representation integrals) or its approximate solutions (like ray theory) to obtain a simulated approximate equivalent of the seismic data that would have been recorded if the very same experiment had been actually carried out. For the meaningful case of a layered model, we need, in particular, the precise location and description of the interfaces, as well as the appropriate boundary conditions on them.

Demigration, on the other hand, although it may provide very similar results, uses a conceptually different approach. The aim of demigration is to reconstruct a seismic time section out of a corresponding depth migrated section. In other words, demigration aims to invert the process of migration. Of course, as migration is based on the wave equation, also its inverse process, demigration, has to have its fundamentals in that equation.

As opposed to modeling, however, we do not have to precisely know all the true model parameters to actually perform the demigration process. Neither the true velocity distribution in the earth, nor the source wavelet nor, above all, the position of the reflecting interfaces have to be known in order to apply a demigration. All that is needed is, in fact, the macro-velocity model that has been used for the migration process which produced the migrated section. Of course, the better the macro-velocity model is, the better will be the corresponding migrated section. This is, however, a problem of migration and not of demigration. Even if the velocity model used for the original migration was very poor and thus the migrated image is of very bad quality, demigration will work without any restrictions, if only the same model is used for demigration.

After we have stated the similarities and differences of modeling and demigration, let us address the basic question of this paper: How can we make use of the demigration procedure for modeling purposes? Well, for a given subsurface model, we have to appropriately *simulate* a corresponding depth-migrated section *as if* obtained from a previously applied Kirchhoff migration. The time section obtained by demigration of this *artificially constructed* migrated section will then be a reasonable equivalent to the one directly obtained from conventional modeling applied to the original subsurface model or from the physical process of wave propagation itself.

Of course, the construction of the mentioned artificial migrated section has, in principle, to be done from the very same parameters that are needed for modeling. This artificial section is then to be demigrated. Note that, although a natural choice is to assume the true velocity distribution for this purpose, this is not necessarily the case. We might also use any other demigration velocity model if we are able to construct the corresponding artificial migrated section.

Constructing an artificial migrated section is not very difficult if one is only interested in the correct modeling of the wavefield at points on the reflection traveltime curves corresponding to the target reflectors. To achieve truly modeled reflection times and wavefield amplitudes, all one has to do is to put the desired wavelet with the correct amplitude, that is, the reflection coefficient, along the reflector image in the artificial migrated section. Application of the true-amplitude demigration algorithm to this section will then result in a seismic data section which, within the validity limits of zero-order ray theory, is correct. In this sense, the modeling has been successfully done.

The situation is not as simple, however, if one also considers the points in the resulting time section which are slightly away from the reflection traveltime curves. This is due to the fact that like migration, also demigration is subjected to a certain wavelet stretch, while modeling is not. So, to obtain the very same section as by any other conventional modeling method, demigration has to handle the pulse stretch correctly. This can be achieved by placing the correctly stretched signal (again *as if* obtained from migration) to the reflector. Demigration will then, because it is the inverse process to migration, "unstretch" the wavelet, so that the resulting modeled section does not suffer from any stretch.

Unfortunately, this is, however, a tedious way of solving the problem, because for each dip and each different source receiver pair, a differently stretched wavelet is to be used. Further investigations are to be carried out on whether it is possible to use the information of the reflector location during the demigration process (which, of course, could not be done for a true demigration, but is a reasonable proceeding for modeling by demigration), to eliminate the stretch *during* the modeling-by-demigration process, thus making it possible to use the very same constructed artificial migrated section for the computation of time sections for various different seismic data acquisition geometries.

CONCLUSION

We have suggested a new forward modeling scheme that we have called modeling by demigration. For a given subsurface model, the process consists of (a) transforming the model into a fictitious, true-amplitude depth-migrated section and of (b) applying to this artificially generated migrated section a true-amplitude demigration. For a single reflector situation where a caustic point is present, we have compared the results obtained by the proposed scheme with their conventional Kirchhoff and ray-theoretical counterparts. For this example, modeling by demigration combines the advantages of Kirchhoff modeling and dynamic ray tracing, treating diffractions and caustic events correctly. In particular, the results provided by the new method have suffered less from pulse stretch or amplitude losses than conventional Kirchhoff modeling.

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PUBLICATIONS

Detailed results have been submitted to Geophysical Journal International (Santos et al., 1997).