Z-99 IMPROVING GEOLOGICAL MODELING AND INTERPRETATION BY SIMULATED MIGRATED SEISMICS

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Abstract

Using a combined Forward and Inverse operator (resolution function), a fast method is presented to construct a simulated migrated seismic section from a geological depth model. Unlike the 1D convolution model, the resolution function expresses both vertical and horizontal resolution. This gives an interpreter a powerful tool to create simulated migrated seismics, which includes migration effects. Further due to its low computational costs, different geological models can rapidly be evaluated.

Introduction

(Simulated) Seismics is an important tool for 'understanding' the subsurface geology. A prerequisite for such an understanding is a clear relation between the seismic image and the complex Geological Model. Let the collection of seismograms in general be given by the following representation

$$\text{Data}(\mathbf{x}^{\text{R}},\mathbf{x}^{\text{S}},t)=\text{Forward Operator }\{\text{Geological Model}(\mathbf{x})\},$$

where Data denotes the recording of the (simulated) seismic experiment in time t, measured at position $\mathbf{x}^{\text{R}}$ due to a seismic source at the location $\mathbf{x}^{\text{S}}$. The Forward Operator symbolizes either the seismic experiment in the field itself or stands for a computational procedure. To capture the geology from seismics finally an Image Operator has to be applied

$$\text{Depth Image}(\mathbf{x})=\text{ Image Operator }\{\text{Data}(\mathbf{x}^{\text{R}},\mathbf{x}^{\text{S}},t)\}.$$

The Depth Image should be representative for the Geological Model. However the Image Operator is not straightforward, as a consequence the Image Operator has to be designed with care and needs geological a-priori information. In the synthesis stage the geologist is concerned with the question how and to what extent geological details are visible in the seismic image. The following relation will be investigated

$$\text{Depth Image}(\mathbf{x})=\text{ Image Operator }\{\text{ Forward Operator }\{\text{Geological Model }(\mathbf{x})\}\}$$

which is the compound operation of the aforementioned processes.

This paper considers the use of a combined operator to construct simulated migrated seismics. Unlike the 1D convolution model, which is commonly used to create synthetic seismics (e.g. recently by [1] and [2]), the combined operators express in addition to the vertical resolution also

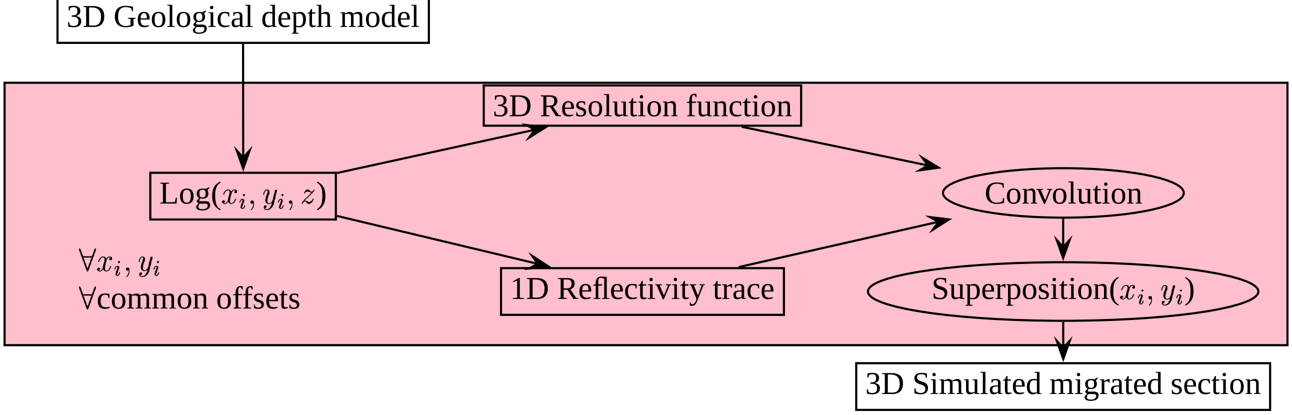

Figure 1: Framework to obtain a simulated migrated seismic section. Summarized by convolving the resolution function (upper flow) with a reflectivity trace (lower flow), followed by superposition of all convolution products for all reflectivity traces.

the horizontal resolution of primary waves. Compared to other forward and migration techniques (e.g. based on finite differences) it considerably saves on computation time and storage, because we do not have to output the intermediate full 3D recordings. This procedure will e.g. facilitate the interpretation work of geologists and aid in the geological modeling. The paper starts by presenting a framework for the combined operators, followed by a discussion on the resolution function. Finally two synthetic examples are given. Note that we will not address the question on how to actual compare a real time or depth migrated section with a simulated migrated seismic section.

Framework for combined operator

Figure 1 shows the framework to simulate a migrated seismic section. Input is a 3D (shared earth) geological depth model containing gridded P,S-wave velocity and rock density data. The framework can be summarized by convolving the 3D resolution function (upper flow) with a 1D reflectivity trace (lower flow), followed by superposition of all convolution products for all reflectivity traces. The resolution function is the result of the combined operators and will be considered in more detail in the next section. The Zoeppritz equations are used to calculate the reflectivity. In the convolution the resolution function is assumed to be constant over a specific vertical range. Note that the examples are presented for zero-offset data in two dimensions. Note, however that the proposed concept is also applicable for prestack data in three dimensions.

Resolution function

The zero-offset response of a scatterer is acquired using the exploding reflector analogy and the Gazdag phase shift operator as a forward wavefield extrapolator. After phase shift migration the result is a so-called resolution function or ”focusing cross”, which is well known in migration [3]. Figure 2 (a) illustrates an acquisition setup. For two different acquisition setups the influence on the representation of the resolution function will be considered. In the model three equal strength point scatterers are located at 500,1500 and 2500 meters in a homogeneous medium with P-wave velocity of 2000 m/s. During modeling, dz=2 and dx=5 meters. The Ricker wavelet has a center frequency of 40 Hz. First we consider the acquisition setup with an ”infinitely” large aperture and maximum propagation angle (α_{max}) of 90^o. Figure 2 (b) shows that the resolution functions are nearly one-dimensional and can be interpreted as point scatterers convolved with the used wavelet. It is important to notice that the 1D convolution model would have given almost the same result. In the second more common acquisition setup, $\alpha_{max} = 60^o$ and the aperture width is limited to 3000 meters (Figure 2 (c)).The 2D resolution functions are now ”smeared” out compared to the first acquisition setup and vary with depth. This has two reasons: first less angle information is available due to the maximum angle of propagation. But second the limited aperture width makes that the effective receiver array becomes smaller with increasing depth. As a consequence the deeper point scatterers have less angle information available and thus less spatial resolution.

Examples

From the previous discussion we conclude that the presented method simulates migration effects. Together with a geological model builder (e.g. [4]) this will help a seismic interpreter to understand these effects on a Geological Model. Further, due to its low computational costs an interpreter can easily test the different responses of various possible Geological Models. The comparison of the real and simulated data may as well be extended to include the comparison of equally derived attributes of the migrated section. The interpreter may use this attribute comparison to further understand the geology and adjust the model according to the attribute comparison. Note at this point that the presented method cannot be used to investigate time-to-depth conversion effects, because the geological input model is already in depth. As a first example the horizontal resolution limit of different point scatters in a homogeneous medium is investigated. Horizontal resolution refers to how close reflecting point scatters can be situated horizontally, and still be recognized as separate. In the medium three different horizontal arrays of six point scatterers with equal strength are located at 500,1500 and 2500 meters depth. Within each array the point scatterers have a spacing of 5,15 and 20 meter, as denoted at the top of Figure 3. To construct the simulated migrated image, an operator length of 31 points of the resolution function shown in Figure 2 (c) is used for the convolution process. The simulated migrated section and, for comparison, the synthetic section using the 1D convolution model are shown in Figures 3 (a) and (b), respectively. The simulated migrated section clearly shows that horizontal resolution is decreasing with depth. This is best seen from the three different depth arrays with a gap spacing of 20 meters. At 500 meters depth the separate points can be identified, however at 2500 meters the scatterers act as one reflector. Comparing Figures 3 (a) and (b), the latter only shows the vertical resolution but the horizontal resolution is neglected. In the second example the tuning phenomenon is investigated (see Figure 4 (a)). The simulated migrated section is created using the 2D resolution function at 1000 meters depth (Figure 4 (b)). For comparison in Figure 4 (c) the 1D convolution result is given. Comparison shows that the vertical resolution is approximately the same. The horizontal resolution differs, especially in Figure 4 (b) the end point is smeared out.

Conclusions

The presented method is an extension to the commonly used 1D convolution model to create simulated seismic of a Geological Model. Using a combined operator (resolution function), we present a fast method to create a simulated migrated seismic section. This enables an interpreter to understand migration effects and further to rapidly evaluate the response of different Geological Models.

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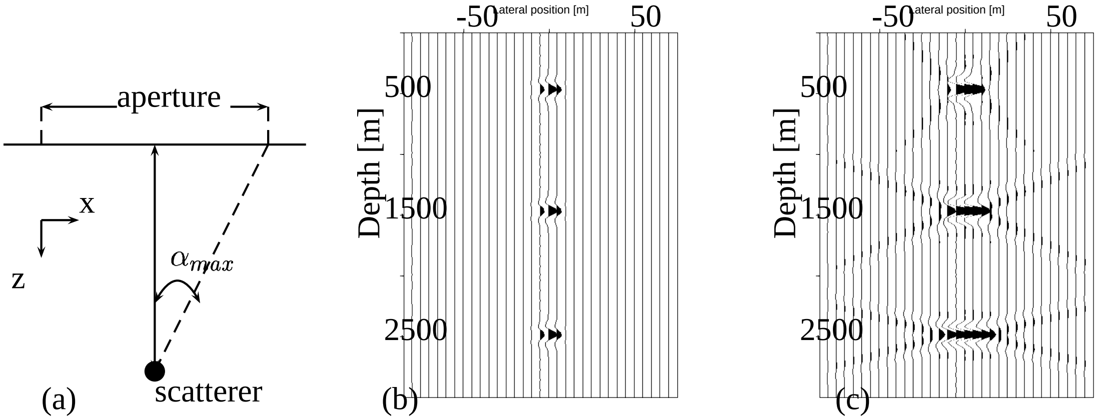

Figure 2: Resolution functions. (a) Acquisition setup. Note that for display purposes the z-axis is reduced. (b) Recording ”infinite” aperture and all propagation angles. Note that almost the same result would be obtained with the 1D convolution model. (c) $\alpha_{max} = 60\,^{o}$ together with an aperture width of 3000 meters. The 2D resolution function is ”smeared” out and varies in depth.

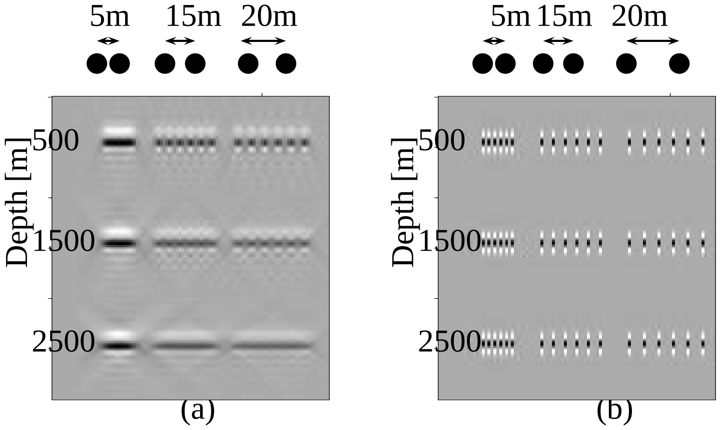

Figure 3: (a) A simulated migrated section from a homogeneous medium with constant P-wave velocity of 2000 m/s. Each array consists of three groups of six point scatters each with spacings as indicated at the top. Deeper, closer spaced scatterers cannot be distinguished as separate scatterers. (b) The synthetic section using the 1D convolution model, is only valid to evaluate the vertical resolution.

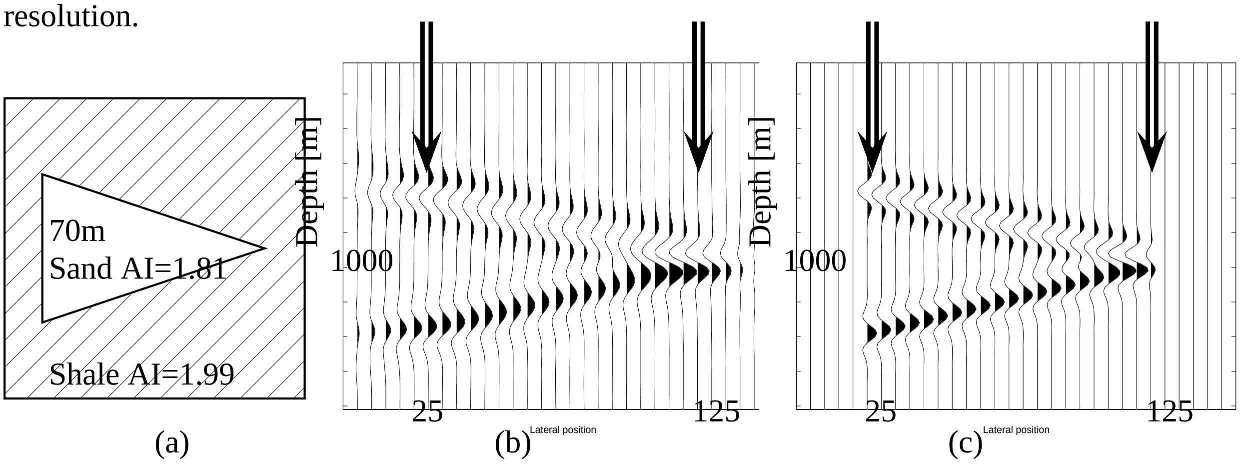

Figure 4: (a) Sand wedge model. (b) Simulated migrated image of sand wedge placed at 1000 meters depth. (c) For comparison the 1D convolved sand wedge. The simulated migrated image shows a decrease in horizontal resolution (arrows) and approximately same the vertical resolution.