Offset Dependent Errors in an Amplitude Preserving Kirchhoff Migration

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Summary

Amplitude variation with offset (AVO) techniques exploit the relative changes in seismic reflection amplitudes at varying incident angles. This can be useful in quantifying the changes in elastic properties at reflection boundaries, thus providing the means to characterize subsurface lithological and fluid properties. Amplitude preservation is therefore critical to ensure accuracy of the technique.

Bleistein's implementation of Kirchhoff migration provides the means to preserve the relative amplitudes during the imaging stage. Bleistein's method is applied to a dataset from the Rocky Mountain House area in central Alberta to investigate the errors present after migration. The migration results are compared against a synthetic result generated from measured well data.

Introduction

Kirchhoff type migrations (Schneider, 1978) have become the workhorse of the oil and gas industry in the imaging of subsurface reflectors. Its popularity can be attributed to its intuitive conceptual formulation and its versatility in addressing practical issues such as topography and irregular wavefield sampling. These benefits along with its efficient implementation make Kirchhoff migration the standard in most subsurface imaging projects.

Although the primary objective of any migration is to position reflection events in their correct temporal and spatial locations, the amplitudes of these events is also of great importance. Amplitude variation with offset (AVO) is the study of these reflection amplitudes as a function of source receiver offset or angle of incidence upon the reflector. Correctly preserved amplitude information can be useful in post imaging studies such as AVO, where elastic properties can be derived through parameter estimation or inversion and used to predict lithological and fluid properties.

In this study, Bleistein's implementation of Kirchhoff migration (Bleistein, 1987) is explored using a dataset from the Rocky Mountain House area in central Alberta. To validate the results, migration amplitudes were compared to synthetic data generated using measured well data.

Method

To validate the migration results generated by the Bleistein inversion operators, a section of seismic data were migrated into a common-mid-point (CMP) location that contains measured well data (P-wave velocity, S-wave velocity and density). Using the Zoeppritz equations, an angle or offset dependent model reflectivity response can be generated. This modeled response must then be convolved with a seismic wavelet to generate the synthetic seismic for comparison.

In deriving the seismic wavelet, a mid range angle stack was created around the well location along with an angle reflectivity calculated from the well logs. The limited angle band used minimizes the effect of any AVO in the wavelet extraction. Subsequent to a time conversion and resampling of the well logs, the wavelet was extracted by solving an inverse problem according to the convolutional model of the seismic trace where a least squares solution was obtained (Figure 1).

Subsequently, a synthetic CMP gather sorted by offset was created using the Zoeppritz calculated offset reflectivity convolved with the extracted wavelet. This assumes stationarity of the seismic wavelet for the synthetic. In addition, to compare the results, the synthetic and migrated gathers were normalized to obtain the relative amplitudes at each time value.

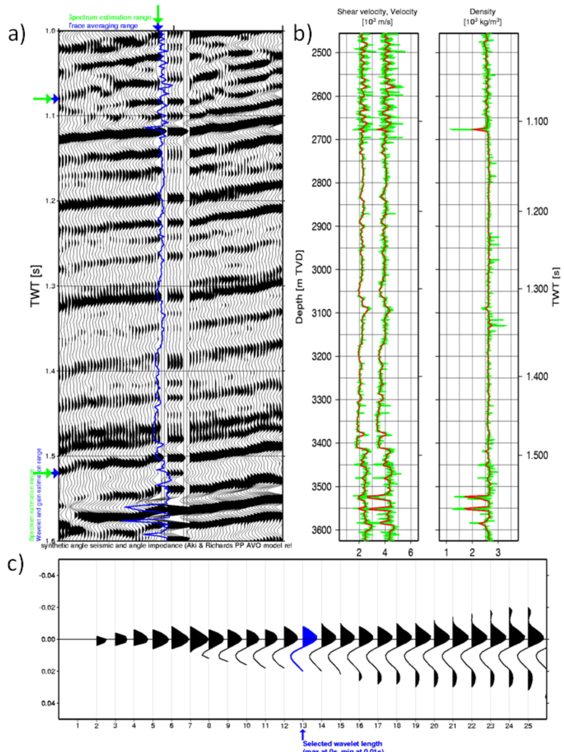

Figure 1: a) Mid range angle stack section with a well synthetic insert and the angle impedance log in blue. b) P-wave velocity, S-wave velocity and density well logs. The green curve represents the raw logs and the red curve represents the logs resampled to the seismic sample rate. c) Wavelet suite from the least squares wavelet extraction with increasing number of samples to the right. The synthetic was generated using a reflectivity calculated from the well logs in b) convolved with the blue wavelet in c).

Results

Figure 2a shows the synthetic and migrated CMP gathers. No additional noise attenuation or conditioning was performed on the migrated gather to determine the AVO errors that need to be addressed pre or post migration. Figure 2b shows the relative amplitudes for the synthetic and migrated gathers at three time values. The blue event exhibits the largest error at the far offsets. Inspection of the gather indicates a curling up of the event, which could be due to anisotropy or an NMO velocity that is too slow. The red and green events exhibit the largest error at the near offsets. This could be due to a variety of reasons including multiple contamination and migration artifacts caused by sparse acquisition typical in a land setting. Nonetheless, the migrated and synthetic amplitudes follow like trends.

To analyze the relative amplitudes for all time values, the migrated gather was subtracted from the synthetic gather to obtain a measure of the error relative to the synthetic result. For each offset, the errors were then binned to create a histogram that represents the distribution of errors around the synthetic. In order to extract statistical measurements associated with the distribution, the area of the histogram was normalized to unity to create a probability density function (PDF) (Figure 3).

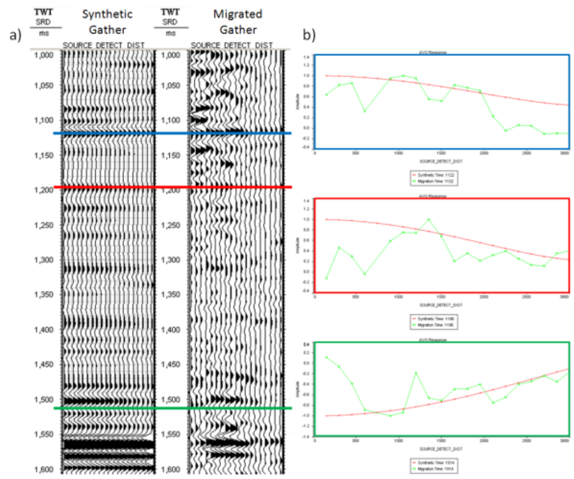

Figure 2: a) The synthetic (left) and migrated (right) CMP gathers. Note the random noise and multiples remaining in the migrated gather. b) Relative amplitudes for the synthetic and migrated gathers extracted along three time values.

The PDF illustrates that at the near offsets, there is a multimodal distribution and at the larger offsets, it becomes progressively more Gaussian. The Gaussian distribution of errors for the larger offsets is attributed to random noise in the system, thus conventional stacking techniques (creating angle stacks for AVO analysis) could reduce the errors. The multimodal distribution of errors for the near offsets however, cannot be addressed by stacking and will require additional attention.

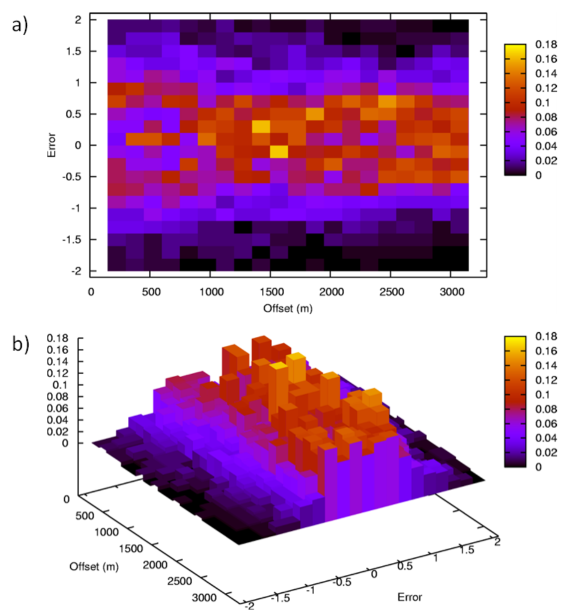

Figure 3: a) 2D view of the error PDFs for each offset. The distributions appear to become more Gaussian with increasing offset. b) 3D view of the error PDFs.

The expected value (a) and the standard deviation (b) of the PDFs are illustrated in Figure 4. The expected value of the error for all offsets are <0.05 with a maximum error of ±2. If the amplitude is considered to be a random variable, this states that the migration performed is expected to have an error of close to zero for each amplitude realization. The standard deviation curve provides a measure of the magnitude of the error as a function of offset and suggests that errors are greatest at the near offsets and decrease for larger offsets.

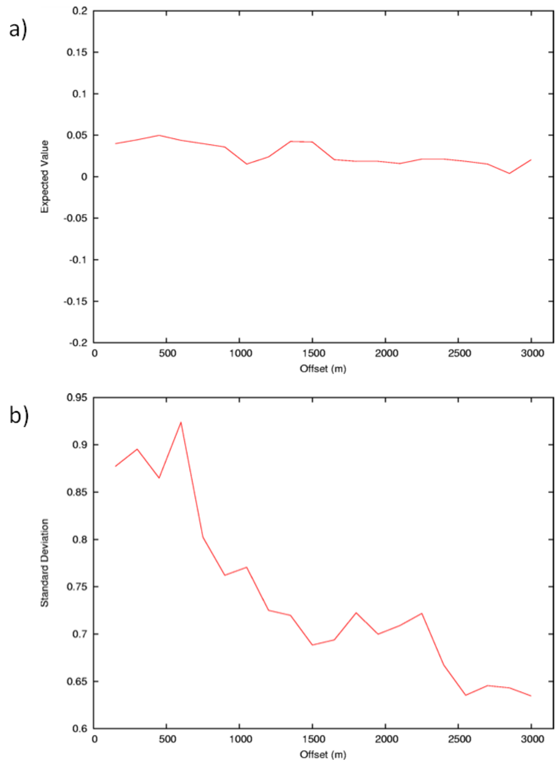

Figure 4: a) Expected value of the error as a function of offset. This suggests that the errors are expected to be near zero. b) Standard deviation of the error as a function of offset. The magnitude of errors decrease with increasing offset.

Conclusions

A dataset from the Rocky Mountain House area was migrated using Bleistein's Kirchhoff migration to investigate the AVO errors present after migration. A synthetic response generated from measured well data was used as a baseline for the output of the migration. Results demonstrate that the largest error occurs at near offsets, where it is characterized by a multimodal distribution that cannot be address by conventional stacking techniques. This suggests that for AVO studies, the near offsets should be excluded to avoid contamination of the AVO response if the near offset errors are not properly addressed. Future work will attempt to address the errors of the near offsets and reduce the overall noise while preserving the AVO response. This includes interpolation tests pre-migration to regularize and improve the offset distribution going into migration. In addition, various noise removal techniques will be tested to attenuate multiples and reduce random noise.

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