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Improved Subsalt Images with Shot Patch-based Angle Gather Illumination Weighting

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SUMMARY

One way to address the problem of weak subsalt illumination is through angle gather illumination weighting (AGILW). In this technique, synthetic data mimicking the field data are generated and migrated the same way as the field data. Illumination weighting scalars are obtained by measuring coherent amplitude on the synthetic migration gather. This weighting scalar can be applied to field data to enhance signal and attenuate noise. In this abstract, we propose a refinement of this approach: shot patch-based angle gather illumination weighting, based on reverse time migration (RTM) 3D angle gathers. Instead of using the traditional approach of migrating all shots in a survey to form one set of angle gathers, we partition the input shots from both field and synthetic data into smaller shot patches and keep the migration gathers separate for each shot patch. This new approach can limit crosstalk between signal and noise from different shot patches, and can more effectively attenuate noise and improve subsalt images. We demonstrate the effectiveness of our method with both 2D synthetic data and 3D field data.

Introduction

Subsalt imaging has long been a focus in Gulf of Mexico (GOM) exploration. In areas with complex salt bodies, poor subsalt illumination and strong coherent noise, such as interbed multiples and converted-wave energy, create challenges for correctly imaging and interpreting subsalt structures. Advanced seismic acquisition techniques including full azimuth and long offsets provide a better chance to illuminate difficult areas, but acquisition alone cannot fully compensate for poor illumination, which causes low signal-to-noise ratio (S/N), especially for steeply dipping events truncating against salt (e.g., three-way closures).

In recent years, imaging technologies have made noticeable progress in imaging difficult subsalt areas by suppressing noise and enhancing signal. In many cases, signal and noise can be partially separated either in pre-migration shot gathers or in the post-migration image. One pre-migration separation method is based on the illumination study of target events, after which only shots with significant contribution are selected for migration. As a result, the image quality is improved by discarding noisy shots (Jin and Xu, 2010). This approach is target-oriented and is suitable for scenario tests. Xu *et al*. (2011) proposed a scheme to divide the reverse time migration (RTM) output by the vector offset outputs (VOO) relative to the shot location. A cleaner stack image can be obtained by applying different weighting to each VOO sector based on its dip consistency to the interpretation guide. Li *et al*. (2012) introduced a dip gather approach to enhance the subsalt image by stacking dips with better agreement with *a priori* knowledge of subsalt structure.

Other methods propose improving the subsalt image by compensating for poor illumination below a complex salt body. Least-squares migration (LSM) provides a comprehensive framework to correct for illumination effects (Nemeth *et al*. 1999). With LSM, the optimized image is obtained iteratively by minimizing mismatch between demigrated data and field data. This inversion process remedies the illumination issue naturally, but it is expensive because of the multiple iterations of de-migration and re-migration. Other approximations to reduce the cost include migration deconvolution (Hu *et al*. 2001; Yu *et al*. 2006). Chazalnoel *et al*. (2012) proposed a scheme to combine the deconvolution imaging condition and VOO to mitigate illumination issues and improve the subsalt image, especially around three-way closures.

Here, we present a shot patch-based angle gather illumination weighting (AGILW) scheme with RTM 3D angle gathers to improve the subsalt image. The scheme is an extended version of the illumination compensation approach (Gherasim *et al*. 2010), which has been proven to be effective for improving image quality in different scenarios (Gherasim *et al*. 2012, 2014; Shen *et al*. 2011). Different from previous implementations of AGILW, our approach introduces the shot-patch concept as an additional dimension to further separate signal and noise. By doing so, we can limit the cross-talk between the signal and noise coming from different shot patches; thus the method can more effectively enhance signal and attenuate noise. We demonstrate the effectiveness of our method using 2D Sigsbee2B synthetic data and 3D field data from Walker Ridge, GOM.

Method

We use RTM 3D angle domain common image gathers (ADCIGs), which are generated by a local wave-field decomposition before applying the imaging condition (Xu *et al*. 2011). The migration output is separated into different azimuths and reflection angles at each subsurface location. We compare these gathers with equivalent RTM ADCIGs obtained using synthetic data from the geologic model and the actual acquisition geometry. This allows us to estimate a weighting scalar for each angle and each location from the coherent amplitude of the synthetic image. We apply these scalars to the field gathers to improve subsalt image quality of the real data (Gherasim *et al*. 2010, 2012, and 2014; Shen *et al*. 2011). The novelty of our method resides with the shot-patch concept. Instead of using the traditional approach of stacking the migration of all shots in a survey to form one set of image gathers, we partition shots from both field and synthetic data into smaller shot patches and keep migration gathers separated for each shot patch. After that, weighting scalars are estimated from each synthetic gathers and applied to field gathers of the corresponding shot patch. The single-patch application is the same as that described by Shen *et al*. (2011). The final image is obtained by stacking all angles and shot patches. We call this approach shot patch-based AGILW. The workflow of shot patch-based angle gather illumination weighting is the following:

1) For each shot patch, produce field data RTM 3D ADCIGs $R(x, \theta, \varphi, sp)$, where x is the imaging location, θ is the reflection angle, φ is the azimuth, and sp is the shot patch number.
2) Generate the stacked image by summing over all angles and shot patches.
3) Interpret target horizons on the stacked image, and then create a reflector model.
4) Generate synthetic traces without free-surface multiples at real data locations using acoustic wave-equation modelling with the velocity model and the reflector model.
5) For each shot patch of the synthetic data, produce RTM 3D ADCIGs in the same way as field data using the velocity model.
6) Extract the amplitude and create illumination weighting scalars $S(x, \theta, \varphi, sp)$ for each shot patch from the synthetic angle gathers.
7) Apply the illumination scalars to the real angle gathers, and generate the stacked image: $I(x) = \sum S(x, \theta, \varphi, sp) * R(x, \theta, \varphi, sp)$.

2D Synthetic Example

First, we apply this scheme to the 2D Sigsbee2B synthetic data set. We begin with data that includes free-surface multiples and performs the demultiple process. However, the data still contains a significant amount of residual multiple energy caused by the complex salt geometry, including interbed multiples, as often seen in real data with similar salt geometry.

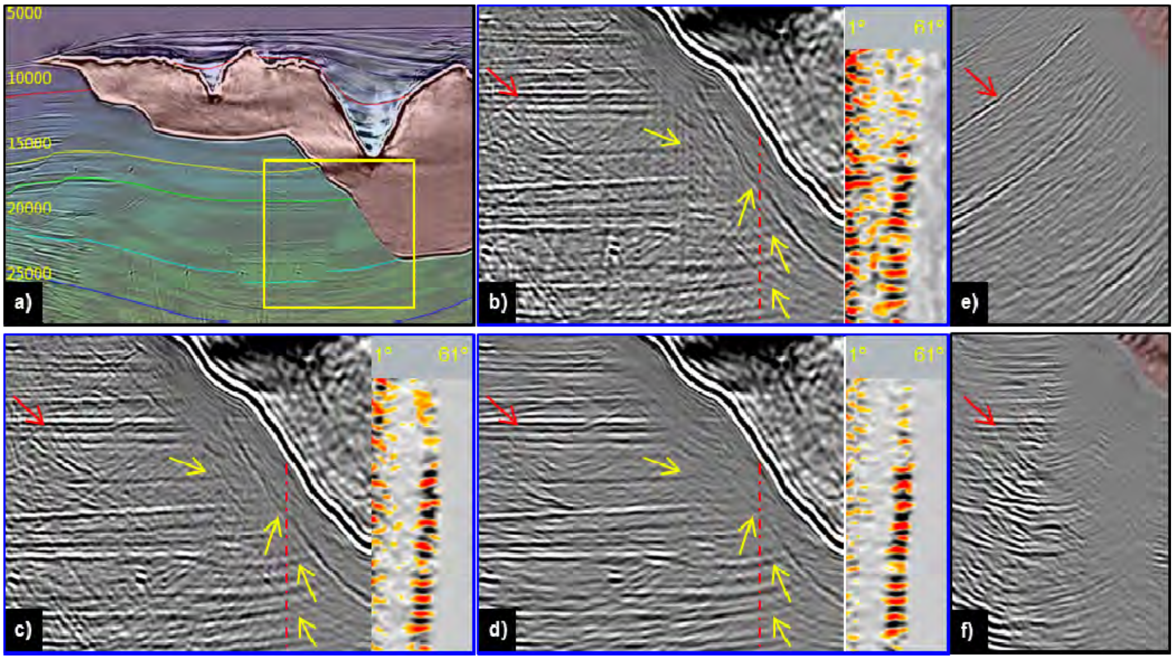

Figure 1 *(a) Velocity model overlaid with RTM image and interpreted horizons. The yellow box shows the zoomed-in areas for (b) the raw stacked image and gather, (c) the stack image and gather after traditional AGILW, and (d) those after shot patch-based AGILW. The near-angle stack from 1 to 10 degrees from (e) one noisy shot patch with mostly swings and (f) one shot patch with high S/N (indicated by red arrow where the true events are flat) are also shown. The gather is located at the red vertical dashed line on the stack images.*

The data contains 496 shots with a shot interval of 150 ft. Sets of 20 shots are grouped together to form shot patches with no overlapping. Several geological events are interpreted on the stacked image (Figure 1a). After migration, signal and noise concentration differ among shot patches, even for some events at the same incident angle range (Figures 1e and 1f). Here, we use two shot patches to demonstrate the process. The final image of the traditional approach for the particular angle will be:

$$(W_A + W_B)(S_A + N_B) \approx W_A S_A + W_A N_B \,, \tag{1}$$

where W is the weighting scalar, S is the signal, N is noise, and A and B represent two shot patches with (for example) high S/N patch A and noisy patch B. Because patch B contains only noise in the field data, the synthetic image of the same patch will not have much coherent energy following the true structure. As a result, the amplitude measurement of this coherent energy W_B is small and can be ignored in Equation (1). The final image of the shot patch-based approach for the same angle will be:

$$W_A S_A + W_B N_B \approx W_A S_A \,. \tag{2}$$

The 2nd term on the right hand side of Equation (1), $W_A N_B$, is cross-talk noise that is not present in the shot patch-based approach in Equation (2). Figures 1c and 1d show that the noise indicated by the red arrow is still present after the traditional approach, but it is attenuated after the new approach. Gather QC further confirms that the new approach is more effective than the traditional approach for attenuating noise that is more concentrated at near angles (Figures 1c and 1d, gather display). As a result, the shot patch-based AGILW produces a cleaner subsalt image compared with the traditional AGILW image (Figures 1c and 1d), and both are better than the raw image (Figure 1b).

3D Wide Azimuth Field Data Example

We apply the flow to 3D wide azimuth (WAZ) field data from the Walker Ridge area, GOM. The data have two tiles with a maximum crossline offset of 2500 m. Shot patches are formed by grouping shots in a 2 km by 2 km area. RTM 3D ADCIGs are produced at two dominant azimuths, 45 and 135 degrees. The raw RTM image is generated by stacking all angles and all shot patches (Figure 2b). In this area, the subsalt image, especially near the three-way closure events, has poor subsalt illumination and a low S/N caused by the complex salt body (Figure 2a). In the raw gather display (Figure 2b), the energy spreads from the near- to middle-angle range, up to an approximate 30-degree incident angle, and it is difficult to differentiate noise from the signal by looking at the gather alone.

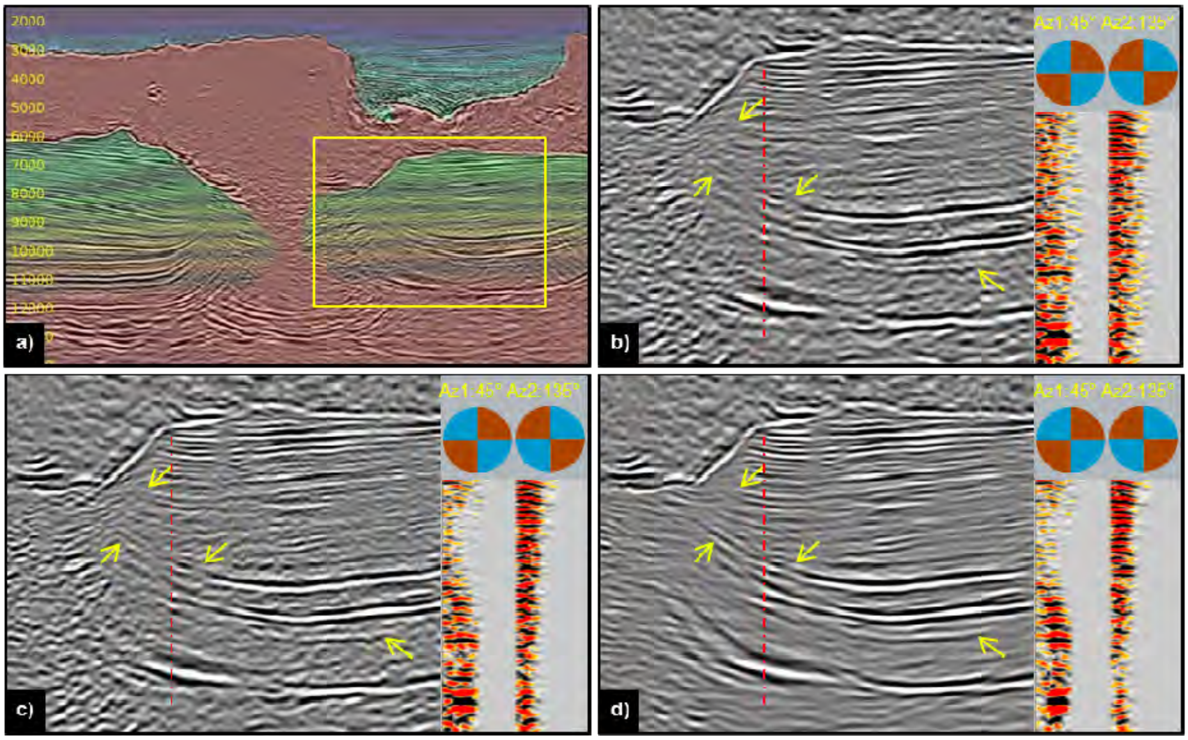

Figure 2 *(a) Velocity model overlaid with stacked image. The yellow box shows the zoomed-in area for (b) the raw stack image and gather, (c) the stack image and gather after traditional AGILW and (d) those after shot patch-based AGILW. The gather located at the red vertical dashed line on the stack image is in the 1- to 47-degree range.*

We apply both the traditional and shot patch-based AGILW approaches to the data (Figures 2c and 2d, respectively). In both approaches, far angles in the 135-degree azimuth and some near angles in the 45-degree azimuth are attenuated, and more compensation is observed with the shot patch-based approach. Compared to the raw RTM image, the subsalt image is cleaner with better event continuity in both approaches, and some three-way events become more visible(indicated by the yellow arrows). Compared to the traditional approach, the shot patch-based illumination compensation approach produces a cleaner subsalt image that is easier to interpret.

Conclusions

We present a shot patch-based angle gather illumination weighting approach to improve subsalt imaging. Compared to the traditional AGILW, our approach can limit the cross-talk between signal and noise coming from different shot patches, which results in more effective signal enhancement and noise attenuation. Using 2D synthetic and 3D field data, we demonstrate that the shot patch-based approach produces a better subsalt image than the traditional one. In theory, this method is most accurate when performing shot-by-shot illumination compensation; however, this is an expensive approach that is not practical for now. Both approaches are intended singularly for improving images and are not suitable for amplitude variation with angle analysis at present.

Acknowledgements

The authors thank CGG and BP for permission to publish this work. We thank Hao Shen, Sabaresan Mothi and Katherine Schwarz for very fruitful discussion.

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