Comparison of different schemes of image amplitude correction in prestack depth migration
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Summary
We compare different schemes of amplitude correction from the viewpoint of amplitude gain control (AGC) factors with different approximations. Four kinds of amplitude corrections are considered: the traditional vertical AGC, space-domain correction based on total illumination, correction in local scattering angle-domains, and the correction in local dip-angle domain. We analyze the different approximations involved in these schemes and compare their results of amplitude correction for the migrated images of Sigsbee2A model. The advantages of the correction in dip-angle domain can be seen clearly. The image quality of subsalt structures is greatly improved and the image amplitudes along subsalt faults are more balanced. In the meanwhile the noises and migration artifacts become smaller than other schemes.

Introduction
Amplitude correction in local angle-domain for wave equation based migration method is currently a focus of investigation (e.g. Mosher et al., 1997; Rickett and Sava, 2002). Wu et al. (2004) proposed a amplitude correction scheme using local image matrix defined in local angle-domain by beamlet decomposition of the Green’s functions. The aperture correction is done in the dip-angle domain. The new theory and method of amplitude correction include both the effects of acquisition system configuration and the propagation through complex overburden. In this paper we compare the new scheme of amplitude correction in local dip-angle domain with other correction schemes from the viewpoint of amplitude gain control (AGC) factors with different approximations. The 2D Sigsbee2A model dataset is used to demonstrate the effects of different corrections.

Local image matrix (LIM) and the final image amplitude
Traditionally the final migrated image is plot as a map of image strength represented by a scalar quality at each point in the image space. In order to relate the image strength to the local scattering property of heterogeneity, the image amplitudes of migrated image need to be corrected to eliminate the influences of different factors, such as (1) geometric spreading in complex media, (2) path effects (absorption and scattering losses during propagation), (3) acquisition aperture effects. It turned out that the acquisition aperture effect is the most significant one among these factors. Although the image amplitude is a scalar quality, it is shown that a scalar correction factor directly applied to the final image strength cannot remove the acquisition aperture influence effectively, and the correction must be done in the local angle domain using local image matrix (LIM) (Wu at al., 2004a, b). Some operations must be applied to the matrix before the summation over matrix elements to get the final image strength.

A local image matrix $L(\vec{\theta}_i, \vec{\theta}_r)$ can be obtained for each image point in the image space during the migration process, where $\vec{\theta}_i, \vec{\theta}_r$ are the incident and receiving angles respectively. If we define a reflector-normal direction as the direction that bisect the source direction $\vec{\theta}_i$ and the receiving direction, $\vec{\theta}_r$, we can change $(\vec{\theta}_i, \vec{\theta}_r)$ into $(\vec{n}_x, \vec{\theta}_n)$ with $\vec{n}_x = (\vec{\theta}_i + \vec{\theta}_r)/2$, $\vec{\theta}_n = (\vec{\theta}_r - \vec{\theta}_i)/2$, where $\vec{n}_x$ is reflector-normal angle and $\vec{\theta}_n$ is the reflection angle with respect to the normal. Note that reflector-normal is opposite to the migration-dip in direction, but $\vec{n}_x$ is equal to the dip-angle (the angle between X-direction and the dip direction).

Depending on the purpose of the final image, the amplitude correction can be implemented in different ways:

1) CRA (Common Reflection-Angle) imaging:
In this case the amplitude dip-angle correction is done to the matrix element of LIM. True amplitude CRA image gathers can be used for local AVA (amplitude vs. angle) analysis.

2) Total Strength imaging:
In this case the amplitude correction can be done to CDA (common dip-angle) images (see Wu et al., 2004b):
$$|I(x)|^2 = \sum_{\vec{\theta}_i, \vec{\theta}_r} |\sum_{\vec{\theta}_n} L(\vec{x}, \vec{\theta}_i, \vec{\theta}_r)|^2 / |D(\vec{x}, \vec{\theta}_n)|^2 + \epsilon \quad (1)$$
where $\epsilon$ is a damping factor for regularization, $-\vec{\theta}_i$ and $\vec{\theta}_r$ form the angle-span for the dip-angle summation, and $D(\vec{x}, \vec{\theta}_n)$ is the dip correction factor of the acquisition system. From (1) we see that the final image amplitude (a scalar) is the summation of the matrix elements of LIM after dip-angle correction.
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Comparison of different approximations for image amplitude correction

In this paper we concentrate on the total strength $I(x)$ imaging. In this case amplitude corrections can be considered as applying amplitude gain (AG) factors to the migrated images in prestack depth migration. We will compare four different schemes with different degrees of approximation:

1) Correction in local dip-angle domain

For amplitude correction in local dip-angle domain, the amplitude gain (AG) factor is a dip-angle and space dependent function $A(\vec{x}, \vec{\theta}) = 1/D(\vec{x}, \vec{\theta})$, as can be seen from equation 1. The correction can be rewritten as

$$|I(x)|^2 = \sum_{\vec{n}, \vec{\theta}_n} |I_m(\vec{x}, \vec{\theta}_n)|^2 A(\vec{x}, \vec{\theta})^2,$$

(2)

where $I_m(\vec{x}, \vec{\theta}_n)$ is the raw migrated image field in local dip-angle domain (common dip-angle image gathers),

$$|I_m(\vec{x}, \vec{\theta}_n)|^2 = \sum_{\vec{\theta}_n} |I(\vec{x}, \vec{\theta}_n)|^2$$

(3)

2) Correction in other local angle domains

If we do not apply the correction in dip-angle domain, and instead work on common scattering-angle (or reflection-angle) image gathers, the correction then becomes

$$|I(x)|^2 = \sum_{\vec{n}, \vec{\theta}_n} |I_m(\vec{x}, \vec{\theta}_n)|^2 A(\vec{x}, \vec{\theta})^2$$

(4)

In the same way we can apply the correction to common receiving-angle image gathers or other gathers. However, these corrections cannot correctly handle the acquisition aperture effects, because the aperture effect is mainly dip-dependent.

3) Correction in space-domain alone

If we totally neglect the angle dependence of aperture correction, the AG factors are only space dependent

$$|I(x)| = |I_m(\vec{x}, \vec{\theta}_n)| A(\vec{x}, \vec{\theta})$$

(5)

where

$$|I_m(\vec{x}, \vec{\theta}_n)|^2 = \sum_{\vec{\theta}_n} |I_m(\vec{x}, \vec{\theta}_n)|^2$$

(6)

4) Correction by vertical AGC

The conventional AGC is the simplest amplitude correction, which has an AG factor dependent only on $z$:

$$|I(x, z)| = |I_m(x, z)| A(z)$$

(7)

Application to the imaging of Sigsbee2A salt model

We apply various image amplitude gain factors defined in the previous section to prestack depth migration for Sigsbee2A model. Local cosine beamlet (LCB) prestack migration method (Wu et al., 2000; Wang and Wu, 2002; Luo and Wu, 2003, Luo et al., 2004, Luo and Wu, 2005) is employed for the imaging. The velocity model and the raw image of prestack depth migration are shown in Figure 1.

Figure 1. 2D Sigsbee2A velocity model and its raw prestack depth migration image by LCB method

We start from the simplest vertical gain control AGC factor $A(z)$. Figure 2 gives the AG factor distribution and the image after the AGC correction. We see that although image amplitudes are increased for the deep targets, but the noise background is also amplified at depth. The image in the shadow zones did not improve much.

Figure 2. AG factor and the image after AGC

Figure 3 gives the corresponding results for the correction on total strength (equation (5)). This correction corresponds to a
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spatially varying AGC, which extends the vertical AGC to include the laterally variation of acquisition and propagation effects. We see that the amplitude balance and image quality have been improved. However, the signal and noise are enhanced simultaneously in the weak illuminated areas.

Figure 3, AG factor and corrected image for the total strength.

Next we show the results of amplitude corrections in local angle-domain. To calculate the correct AG factors, the effects of acquisition aperture to local reflectors with different dips must be taken into account. Without this consideration, even corrections in angle domain, such as that for offset plane waves, or the correction in receiving angle-domain for common-shot migration, will not give the correct AG factors for the purpose of true-reflection imaging. Figure 4 shows the results for the amplitude corrections in local receiving-angle domain. We have tested also the case of correction in common scattering-angle domain. The results are similar. We see that even though the image quality and amplitude balance are improved, however, the noise background is also increased.

Finally we show the results of corrections in local dip-angle domain in Figure 6. The AG factor for dip=−40°, 0°, and 40° are given in Figure 6a, b, and c. The image after correction is given in Figure 6d. We can see the superior performance of this scheme. While the images of reflectors in the subsalt region are enhanced, the noises in the same region are depressed compared with other schemes. The AG factors in the image quality of subsalt structures, the amplitude balance, the continuity of the subsalt reflectors are all improved by the amplitude correction in local dip-angle domain. The improvement in signal to noise ratio is not as dramatic as in the case of SEG/EAGE salt model (Wu et al., 2004b), because the target structures and the noise structures beneath the salt body are orthogonal to each other, and the correction in local dip-angle domain is most suitable for case. In any case, the correction in local dip-angle domain has the greatest potential in improving the image amplitude and quality, and increases the S/N in the subsalt region.

The last figure (Figure 6) summarizes the comparison of
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image qualities in a zoomed subsalt region for different amplitude corrections. The features of different correction schemes can be seen more clearly in the zoomed regions.

(a) image of the subsalt part without correction
(b) image of the subsalt region after AGC
(c) image of the subsalt region after total strength correction
(d) image of the subsalt region after receiving angle correction
(e) image of the subsalt region after dip-angle correction

Figure 6, comparison of images of the subsalt region by the four kinds of amplitude corrections

Conclusion

We compared the four kinds of amplitude correction schemes from the viewpoint of amplitude gain factors with different approximations: traditional vertical AGC, space-domain correction based on total illumination, and correction in scattering angle domain and correction in dip-angle domains. Through the tests using the SEG/EAGE salt model (Wu et al., 2004b) and the Sigsbee2A salt model (this paper), we see clearly the superior performance of the dip-angle domain correction scheme.

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