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Full-waveform Inversion Applying Over/under Towed-streamer Data

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SUMMARY

As over/under towed-streamer acquisition system has been increasingly used for marine hydrocarbon exploration in recent decades, and the advantages of this method can well remedy the drawbacks of full-waveform inversion (FWI) in ghost, bandwidth and low-frequency component, the method which combining variable-depth acquisition and FWI can greatly improve the resolution of seismic imaging. This paper combines and tests a 2D frequency domain L-BFGS-based FWI algorithm using over/under towed-streamer data on Mamousi model. The main advantage of this approach is that the combined over/under towed-streamer data can provide lower frequency component and broader bandwidth, and has deghosting effect at the same time. A synthetic data example shows the effectiveness of this new method.

Introduction

Full-waveform inversion (FWI) is a challenging data-fitting procedure based on full-wavefield modeling to extract quantitative information from seismograms. Low-frequency and broadband components are important in seismic waveform inversion. However, in conventional seismic survey, the range of acquired frequencies is limited, which lower and higher frequencies cannot be recorded. Over/under towed-streamer acquisition system can retrieve these limitations and has the deghosting effect to some extent.

This paper uses combined over/under towed-streamer data instead of traditional single streamer data in the process of full-waveform inversion, and improves the inversion result.

Method

Over/under towed-streamer acquisition is a novel seismic survey system in a few decades, which has the effect of improving the energy of low-frequency and broadening the bandwidth, as well as deghosting effect. The characteristics of this system can be well utilized by full-waveform inversion, enhancing the stability and convergency of the result. As introduced by Özdemir A K et al (2008), the recorded seismic wavefields S at streamer 1 (over) and streamer 2 (under) comprise upgoing (U) and downgoing (D) wavefields and measurement noise (N), respectively:

$$\begin{aligned} S_1 &= U_1 + D_1 + N_1 \\ S_2 &= U_2 + D_2 + N_2 \end{aligned} \quad (1)$$

According to the DPS (diphase, spectral whitening, sum) method (Posthumus,1993), the combined wavefield of two streamers can be written as:

$$S_{o/u,DPS} = \frac{\overline{G_1}S_1 + \overline{G_2}S_2}{|G_1|^2 + |G_2|^2} \quad (2)$$

where G_1 and G_2 are ghost operators:

$$\begin{aligned} G_1 &= (1 - e^{j4\pi k_z z_1}) \\ G_2 &= (1 - e^{j4\pi k_z z_2})e^{j2\pi k_z (z_1 - z_2)} \end{aligned} \quad (3)$$

$\overline{G_i}$ denotes the complex conjugate of G_i , $j = \sqrt{-1}$, z_1 and z_2 are the depth of over and under streamers, and k_z is the real valued vertical wavenumber.

We use the combined data instead of traditional towed-streamer data in full-waveform inversion. The component of low-frequency and extended bandwidth can greatly improve the result of inversion.

Examples

We illustrate the result of this method with a 2D synthetic data on Mamousi model (figure 1a). Full-waveform inversion is performed in frequency domain (Pratt R G,1999) based on L-BFGS algorithm. Figure 1b is the initial model. Figure 1c and Figure 1d are the results of FWI using combined over/under towed streamer data and conventional single towed-streamer data respectively. We can see from the figure that figure 1c has more detail informations than figure 1d, especially in the deep depth. That's because the combined data has more low-frequency energy and broader bandwidth which wave can penetrate more deeper.

Figure 1 Results of FWI inversion: a) true model; b) initial velocity model; c) FWI result with the combined over/under towed-streamer data; d) FWI result with conventional single towed-streamer data.

Conclusions

This paper uses combined over/under towed-streamer data instead of traditional single streamer data in full-waveform inversion. The combined data possesses more low-frequency component and broader bandwidth than single streamer data, and has deghosting effect to some extent. Synthetic examples show that a better inversion result has been obtained using combined over/under towed-streamer data. The stability and convergency of full-waveform inversion are improved at the same time.

References

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