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3D PRESTACK DEPTH MIGRATION WITH FACTORIZATION FOUR-WAY SPLITTING SCHEME

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Abstract. 3D prestack depth migration is an important and commonly used way to obtain the images of complex structures in seismic date processing. In this paper, 3D prestack depth migration with hybrid four-way splitting scheme is investigated. Wavefield extrapolation is based on the 3D acoustic one-way. The hybrid four-way splitting algorithm based on factorization is derived. Numerical calculations of 3D post-stack depth migration for an impulse and 3D prestack depth migration for SEG/EAEG benchmark model are implemented. The result of 3D post-stack depth migration show that the numerical anisotropic errors can be reduced effectively and the errors are small when the lateral velocity variations is small. Moreover, the 3D prestack depth migration for SEG/EAEG model both with two-way and four-way hybrid splitting scheme can yield its good images. The Message Passing Interface (MPI) programme is adopted on PC cluster as the large scale computation of 3D prestack depth migration. The parallel efficiency is high because of high parallel feature of 3D prestack depth migration. The methods presented in this paper can be applied in field data processing.

Key Words. 3D, acoustic wave equation, hybrid method, factorization, four-way splitting, MPI.

1. Introduction

3D prestack depth migration is an important tool for complex structure imaging. There are two kinds of imaging methods. One is the Kirchhoff integral method based on ray tracing. The other is the non-Kirchhoff integral method based on wavefield extrapolation. Kirchhoff integral method is a high-frequency approximation method, which has difficulties in imaging complex structures. However, it can adapt sources and receivers configuration easily and has the advantage of less computation cost. Therefore it is still the dominant method of 3D prestack migration in oil industry. Non-Kirchhoff integral method, such as the finite-difference method, the phase-shift method (Gazdag, 1978), the split-step Fourier (SSF) method (Stoffa et al., 1990) and the Fourier finite-difference (FFD) method (Ristow and Ruhül, 1995), do wavefield extrapolation with one-way wave equation. It can yield precise images even in the case of complex structures or large lateral velocity variations. The FFD method is one of the most typical hybrid method, which combines both advantages of the phase-shift method and the finite-difference method.
Prestack depth migration can be implemented in the common-shot domain or in the common-offset domain. The full 3D common-offset prestack depth migration still has more difficulties in application because of its huge computational cost.

Compared with the shot-profile migration, the synthesized-shot migration has less computation cost. The synthesized-shot migration, which is based on the wavefield synthesis, first stacks or synthesises shot-gather records and sources, then extrapolates the synthesized wavefield. Therefore, its computation cost is comparable with that of multi-poststack migration. As the principle of the synthesized-shot migration is the same with that of the shot-profile migration, their imaging precisions are comparable.

For 3D one-way wave equation, a direct solution with stable implicit finite-difference scheme may lead to a non tri-diagonal system, which is computationally expensive. In order to decrease computation cost, the alternatively directional implicit (ADI) scheme is usually used. However, the two-way ADI algorithm may cause the problem of numerical anisotropic errors, which reaches maximum at 45° and 135° directions. In order to eliminate these errors, several authors proposed the multi-way splitting methods (Ristow and Rühl 1994; Collino and Joly, 1995). Among the multi-way splitting methods, such as three-way, four-way and six-way splitting methods, the four-way method is preferred as its computational grid is the retangle or square grid and there is no need to transform wavefield onto the triangle or hexagonal grid which three-way or six-way splitting method requires. It is well known that the seismic data observed on the surface is usually on the regular retangle or square grid. In this paper, the four-way splitting method based on factorization is proposed. It contributes to solve the tri-diagonal system both along 0°, 90° and 45°, 135° two ways respectively. Thus the high computational efficiency can be expected. Numerical calculations of 3D post-stack depth migration for an impulse and 3D prestack depth migration for SEG/EAEG benchmark model are completed. The results of 3D post-stack depth migration show that the numerical anisotropic errors can be eliminated effectively and the errors are small when the lateral velocity variations are small. Moreover, the results of 3D prestack depth migration both with hybrid two-way and four-way splitting schemes can give good images of the geologically complex structures of the SEG/EAEG model.

2. Methodology

2.1. four-way splitting scheme. Consider 3D acoustic wave equation

$$\frac{1}{v^2(x,y,z)}\frac{\partial^2 p}{\partial t^2} = \frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 p}{\partial z^2}, \tag{1}$$

where $p(x,y,z;\omega)$ is the pressure wavefiled at position (x,y,z), $v(x,y,z)$ is the media velocity. It is well known that the one-way wave equations for downgoing wave and upcoming wave in the frequency-space domain are given by

$$\frac{\partial P}{\partial z} = \pm i\frac{\omega}{v}\sqrt{1 + \frac{v^2}{\omega^2}\frac{\partial^2}{\partial x^2} + \frac{v^2}{\omega^2}\frac{\partial^2}{\partial y^2}}P, \tag{2}$$

where ω is the circular frequency, i is the imaginary unit. The plus sign before the square-root represents downgoing wave and the minus sign represents upcoming wave. $P(x,y,z,\omega)$ is the wavefield in the frequency domain. Denote the square-root with A, i.e.,

$$A = \frac{i\omega}{v}\sqrt{1 + \frac{v^2}{\omega^2}(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2})}. \tag{3}$$