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Dreamlet: A New Representation and Migration of Seismic Wavefield in Full Local Domains

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Abstract. Seismic events have limited time duration, vary with space/traveltime and interact with the local subsurface medium during propagation. Partitioning is a valuable strategy for nonstationary seismic data analysis, processing and wave propagation. It has the potential for sparse data representation, flexible data operation and highly accurate local wave propagation. Various local transforms are powerful tools for seismic data segmentation and representation. In this paper, a detailed description of a multi-dimensional local harmonic transformed domain wave propagation and imaging method is given. Using a tensor product of a Local Exponential Frame (LEF) vector as the time-frequency atom (a drumbeat) and a Local Cosine Basis (LCB) function as the space-wavenumber atom (a beamlet), we construct a time-frequency-space-wavenumber local atom-***dreamlet***, which is a combination of drumbeat and beamlet. The dreamlet atoms have limited spatial extension and temporal duration and constitute a complete set of frames, termed as dreamlet frames, to decompose and represent the wavefield. The dreamlet transform first partitions the wavefields using time-space supporting functions and then the data in each time-space blocks is represented by local harmonic bases. The transformed wavefield is downward-continued by the dreamlet propagator, which is the dreamlet atom evolution weightings deduced from the phase-shift one-way propagator. The dreamlet imaging method is formulated with a local background propagator for large-scale medium propagation and combined with a local phase-screen correction for small-scale perturbations. The features of dreamlet migration and imaging include sparse seismic data representation, accurate wave propagation and the flexibility of localized time operations during migration. Numerical tests using Sigsbee 2A synthetic data set and real marine seismic data demonstrate the validity and accuracy of this method. With time-domain localization being involved, the dreamlet method can also be applied effectively to target-oriented migration and imaging.

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1 Introduction

In practice, the event in seismic section is not stationary, i.e., it changes with offsets and traveltimes. It also has limited time duration and interacts with the local subsurface medium during propagation. The linearity of the seismic events can only be approximated locally in the time space seismogram. For the seismic data compression, localized basis can represent the seismic signals sparsely while still preserving useful information [1–4].

During last decade, wave equation based localized wave propagation and imaging is developed to overcome the limitations of many global migration methods. In strong contrast medium, the wave-equation-based migration methods are accurate, stable and yield results of high quality compared to the algorithms based on eikonal equation solvers, such as Kirchhoff migration [5]. The phase-shift method [6] is accurate, economical and unconditionally stable for media with vertical velocity gradient. Split-Step Fourier (SSF) migration [7] can handle velocity with smooth lateral variations and small lateral contrast. Various phase-screen methods [8–11] extend the concepts of the phase-shift and SSF methods. In such methods, to take lateral velocity variations into account, the medium is decomposed at each level into a global reference velocity and perturbations. For strong contrast media, the perturbations can be very large, leading to difficulties in correctly propagating large-angle waves.

In order to overcome the accuracy limitation for large-angle waves in strong contrast media, several methods based on the local perturbation theory or Locally Homogeneous Approximation (LHA) have been developed. Windowed screen method [12, 13] introduces the local background velocity and local perturbations through Windowed Fourier Transform (WFT). However, since the perfect WFT reconstruction is formidably expensive, the method relies on the much broadly overlapped windows and empirical interpolations. Therefore, it is applicable only in the case where only a few distinctive material boundaries exist. Beamlet migration approach based on the local perturbation theory has been proposed using the Gabor-Daubechies Frame (GDF) [14, 15] and the Local Cosine Basis (LCB) [16, 17]. In these methods, the wavefield at every depth is spatially localized with local windows and propagated with beamlet propagators (sparse propagator matrices), followed by local perturbation corrections. Ma and Margrave [18] develops a velocity adaptive partitioning scheme that relates window width to lateral velocity gradient and wider windows are used when the lateral velocity gradient is weak since computation cost is directly proportional to the number of windows. Mousa [19] treats the