Accurate Computation of High Frequency Wavefield Computations in Pseudo-spectral Method Using Rapid Expansion Method

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Among forward modeling, reverse-time migration and wave form tomography all based on the time evolution computation of wave fields. Pseudo-spectral time-domain staggered grid computation with efficient and parallelized Fourier transform spatial differential operator and rapid calculation on time integration is test and analysis for various numerical tests and practical applications. The rapid expansion method (REM) provides very high degree of machine accuracy and therefore most suitable for grid-based numerical wave field computational methods including high-order finite-differences (FD), finite-element (FE), Fourier collocation methods or hybrid approach like spectral-element (SE) method.

One-step extrapolation direct method can also be implemented for a spatially varying velocity where no intermediate time responses are required. The method is based on Chebyshev expansion of the solution to wave equation and does not suffer from numerical instability or numerical dispersion problems. The cost-effective and high-quality approach for infinite accuracy both in time and in space is most suitable for high-frequency, high-accuracy computation requirement in forward simulation, reverse-time migration (RTM) and full wave form inversion (FWI). For example, using limit number of Chebyshev polynomial expansion terms follow by using an analytical approximation for the Bessel functions for sufficient small time steps, we achieved accuracy to low-order time differential approximation. The conventional second order finite difference time integration approximation can be achieved when considering only two terms in the resulting Chebyshev expansion in REM computation. The use of more terms provides the basis for a recursive solution to advance the computed wavefields in time, results in a procedure that is numerically stable and allows us to march in large time steps or even for arbitrary variable time steps. Thus, less computational coast is achieved than conventional methods involving finite difference time integration scheme needed such as in FEM, FDM, SEM and traditional time-marching PSM computations.

Despite its machine accuracy, perhaps the only disadvantage is that it requires more storage when many snapshots and time sections are desired. We also noted that for modeling the storage can be very significantly reduced by saving the required Chebyshev polynomials only for the spatial positions which are of interest, e.g. at the receiver position for numerical Green function bank type of computations.