Efficient Calculation of Complete Short-Period Synthetic Seismograms for Spherically Symmetric Earth Models by Normal-Mode Summation

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Abstract

Progress in the determination of three-dimensional multiscale Earth structures requires high-quality seismic data and accurate synthetic waveforms. To extract and interpret the full waveform information from widely available broadband records, we have to be able to accurately calculate complete broadband synthetic seismograms. Normal-mode theory provides the exact solutions to the wave equation in spherically symmetric Earth models, and the efficiency afforded by the usage of precalculated eigenfunction databases makes normal-mode summation the preferred approach for calculating complete synthetic seismograms in spherically symmetric (1-D) Earth models. Reliable synthetics require accurate normal-mode eigenfunctions, whose calculation becomes extremely difficult at higher frequencies. So far, normal-mode summation has only been used to compute synthetic seismograms up to 8-sec period (Ekström 1995). The degradation in accuracy in calculating higher-frequency normal modes is caused by two phenomena. One is that the eigenfunctions of short-period normal modes are highly oscillatory functions of radius, and the other is that the eigenfunctions of certain modes, such as the inner-core shear modes (J modes) and the Stoneley modes at fluid-solid boundaries, are evanescent at the surface. In this study, we explore the possibility of increasing the high-frequency limit in normal-mode calculation by investigating these two problems. We implement a flexible radial sampling scheme that improves the accuracy of the secular equation when the eigenfunctions are highly oscillatory. Although numerical errors for some evanescent waves still remain, accurate eigenfunctions can be obtained for all of the toroidal modes and for about 94% of the spheroidal modes below 1 Hz. This allows us to reliably compute accurate and complete synthetic seismograms up to at least 0.4 Hz. Synthetic seismograms calculated by other numerical methods such as the Direct Solution Method (Kawai et al. 2006) are compared with our normal-mode results.

Rapid advances in computing and storage facilities make it practical to compute and store normal-mode eigenfunctions up to an unprecedented frequency range (≥ 1 Hz). The advantages of the normal-mode eigenfunction databases are not only in efficient evaluations of complete short-period synthetic seismograms but also in the calculation of full-wave Fréchet kernels for regional and global source and structure studies.

References

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