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Seismic waves in the atmosphere and oceans

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We developed a new method to calculate normal modes of the earth and planets. It can treat anelasticity directly as imaginary parts of elastic constants and leaky modes due to the open boundary condition set at the upper atmosphere. The eigenvalue problem is described in complex numbers. It is similar to the Henyey type relaxation method used in solar seismology but a different method. In our method, the complex eigenvalue problem of a large system is reduced to an eigenvalue problem of a quite small size matrix. The eigenvalue of the small problem is a correction of an assumed complex eigenfrequency and components of the eigenvector are values of eigenfunctions at the outer boundary. Starting from an arbitrary complex frequency around the eigenfrequency of a target mode, we can arrive there within, at most, a dozen of steps of iterative calculations. Numerical examples show good behavior of the convergence to complex eigenfrequencies. Even for a model with an atmosphere in which the fundamental spheroidal mode 0S29 and the fundamental acoustic mode 0P29 nearly degenerate, we can easily reach the eigenfrequency of 0S29 and distinguish it from that of 0P29 without any confusion. In addition to the efficiency in the convergence to the eigenfrequencies, numerical tests show strong numerical stability of the method. For those reasons, we propose the method as an efficient way in calculating synthetic sesimograms, barograms and ionograms for recently observed phenomena relating with coupling between the solid earth, the oceans and the atmosphere. Using this method, we show some examples of synthetic seismic waves which are sum of normal modes along Rayleigh branch and Tsunami branch excited by large earthquakes. In paticular, we focus on wave fields of Rayleigh and Tsunami waves in the atmosphere. Rayleigh waves have disturbances propagating vertically with a speed of sound velocity and Tsunami waves have features of gravity waves in the atmosphere.