Zonal winds and Earth's free oscillations

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Ten years have passed since the first report by Nawa et al. (1997) on the continuous excitation of Earth' free oscillations were published. From many analyses of the oscillations, we have found that the atmosphere plays an important role on the excitation. In particular, amplitudes of a mode at a branch crossing with acoustic modes are larger about 40% than those of neighboring modes and show a strong annual variation. This resonance strongly depends on the thermal structure of the atmosphere since a change in sound speed shifts the locations of the branch crossings. In addition, it is well known that winds also affect sound wave propagation. Changes in effective sound speed by winds reaches 20% and are larger than the thermal effect. We also know that TEC in the ionosphere is influenced by waves excited by a large earthquake. These oscillations are surely affected by winds in the atmosphere. Accordingly, it is important that we study effects of winds on the free oscillations.

In this paper, I study effects of zonal winds on the spheroidal modes of the solid earth. For this purpose, we used relatively simple model. We used the standard earth model PREM for the solid parts and ocean and spherically symmetric atmospheric model (based on NRLMSISE-00) that is averaged globally and is averaged over local time. We added zonal wind model (HWM/CIRA86) on this spherical symmetric model. Using the synthetic model, we studied effects of zonal winds on eigenfrequencies and eigenfunctions of spheroidal oscillation modes.

Eigenfrequency of a mode is degenerate (2l+1)-folds for a spherically symmetric model. Zonal winds destroy the symmetry in the model and cause splitting of the eigenfrequency. In this case, eignefrequencies of a mode depend on the azimuthal order m of the oscillation mode since Rayleigh waves propagating eastward and those doing westward are diffracted by the zonal winds in a different manner. Zonal winds can be expressed by toroidal fields with azimuthal order 0. In these fields, a toroidal field of 1st angular degree produces splitting that is linearly depending the azimuthal order m of the oscillation modes. Toroidal fields of higher degree produces coupling among modes having different angular degree. However, a spheroidal mode is a solid mode and its characteristics are mainly determined by the elastic structure of the solid Earth (including oceans and the fluid core). Their splittings and couplings by zonal winds are accordingly small as expected. On the other hand, those of the acoustic modes are larger and should affect the resonance with spheroidal modes. As a result, zonal winds produce anomalous amplitudes of spheroidal oscillations in the atmosphere. We cannot evaluate those amplitudes using 1st order perturbation theory in a single multiplet even if only the 1st order toroidal field is applied. Therefore we calculate eigenfrequencies and eigenfunctions for each $Y_l{}^m$ by solving simultaneous ordinary differential equations with respect to the radius using a mode calculation method developed by Kobayashi (2007) that have an advantage in this kind of problems.

If the above story is effective, we can observe a dependence of amplitudes of the resonant spheroidal modes on their propagation direction. Since zonal winds are different between winter and summer, they are important for the excitation of the resonant free oscillation modes.