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Tidal resonance of higher-degree modes in the early Earth's ocean and its effect on the lunar-orbit evolution

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The ocean tide is one of the important factors for the evolution of the Earth-Moon system in association with generating significant dissipation of the energy (e.g. Lambeck, 1977). The energy dissipation is generally described by quality factor Q, which can be calculated for the ocean tide and the body tides of the solid Earth. Webb (1982) explicitly showed effects of the ocean tide on the evolution of the Earth-Moon system from numerical simulation of the hemispherical ocean model. Previous studies suggested that Q value of the ocean is smaller than of the solid Earth at present due to the bottom friction. Although the potential of semi-diurnal tides (corresponding to spherical harmonics Y22) was much larger in the ancient time, it would significantly be attenuated due to mechanical response of water motion (e.g. Hansen, 1982; Abe and Ooe, 2001). In this study, we have obtained a semi-analytical response function on a sphere with bottom friction in order to estimate the tidal amplitude of the ocean in detail. We analyzed oceanic tidal response on the early Earth using a model of constant-depth ocean covering the entire surface of the Earth. At first, eigen-frequencies and eigen-functions of the ocean on a rotating sphere with no friction were calculated on the basis of previous study (Longuet-Higgins, 1968). The tidal potential and its response of the ocean tide are expressed by the eigen-function, yielding the complex response function as an approximation form. The response function in the present study shows good agreement with the numerical simulation result of the tidal torque response of Y22 (Abe et al., 1997). Applying our response function, we can easily calculate the ocean tide for various parameters such as the ocean depth, bottom friction coefficient and the Earth's rotation rate. It is found that resonance could occur for higher-degree modes (degree: $n>2$, order: $m=2$). For example, assuming the ocean depth is 2600 m, the resonance of higher-degree mode ($n=4, m=2$) could occur when LOD (Length of Day) is about 15 hours. Preliminary results show that this resonance could be enhanced about 1 billion years after the formation of the Earth-Moon system. We will discuss possible effects of the Earth's semidiurnal tide with higher-degree modes on the lunar-orbit evolution.