Possible evolution paths of the lunar orbit based on tidal response in the global ocean model of the early Earth

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The Moon's orbital evolution has been affected by the Earth's ocean tide as well as the solid Earth's tide (e.g. MacDonald, 1964, Kaula, 1964). Many previous studies pointed out that the continental crusts would be few amounts in the early Earth (e.g. Stein & Ben-Avraham, 2007, Rino et. al., 2004), possibly with larger seawater volume than the present day (e.g. Kurokawa et al., 2018, Korenaga et. al., 2017). Thus the early Earth is considered to have been covered by the global ocean for a long time, strongly implying the importance of the ocean tide for the early evolution of the Earth-Moon system. Most of previous studies of the evolution of the Earth-Moon system calculated back to the past with the initial condition of the present state (e.g. Abe et. al., 1997, Rubincam, 2015). The backward calculation is inappropriate to estimate the effects of various parameters concerning the early Earth’s ocean, since there are many uncertain factors such as continental drift. Thus we carried out forward calculation of the lunar orbit from the past for the first 2 billion years to understand characteristic effects of the ocean state in the global ocean model.
Energy dissipation mechanism of the ocean is one of the critical factors in the Moon’s orbital evolution (e.g. Webb, 1982, Lambeck, 1977). Recent studies have revealed that the internal gravity wave, so-called internal tide, is a main mechanism of tidal energy dissipation in the deep ocean (e.g. Taguchi et. al., 2014, Egbert & Ray, 2000). In this study, we considered its effect on the early evolution, assuming the early ocean is as deep as the present abyssal depth.
Our results show that the eigenmode resonance occurs once or more for the first 2 billion years. The Earth-Moon distance rapidly increases with a step-like change at the eigenmode resonance. In the case of the ocean depth decreasing linearly to the time, it is found that the torque due to the oceanic tidal bulge causes continuous increase in the Earth-Moon distance with an especial response of eigenmode oscillation. These acceleration effects could work in the coevolution of the early Earth-Moon system.

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