Effects of thermal evolution and continental growth on climate evolution of Earth-like planets

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A planet, like the Earth, orbiting within the habitable zone (HZ) and with carbonate-silicate geochemical cycle is considered to have a warm climate for the early in its history owing to a high CO_2 degassing rate due to a high mantle temperature and consequent high heat flow from the mantle. However, recent studies pointed out that high mantle temperature does not always result in high heat flow from the mantle because the mantle convection is suppressed by stiff lithosphere due to dehydration of the hot mantle. Accordingly, the CO_2 degassing rate might not be so high as it was considered. In such a case, the Earth-like planet even orbiting within the HZ may be unable to remain warm climate. On the other hand, the climate of the Earth-like planet also depends on size and distribution of continents because CO_2 degassing should balance with CO_2 uptake via silicate weathering on the continents. Hence, the continental growth should be another important factor which affects the climatic evolution of the Earth-like planet.

In this study, we investigate the effects of CO_2 degassing history due to thermal evolution of mantle, and of size and distribution of continents on the climate of the Earth-like planet in terms of carbonate-silicate geochemical cycle. We also investigated the climatic evolution of the Earth-like planet, considering the continental growth, with a parameterized convection model.
The dependence of the mantle heat flow on the average mantle temperature is usually represented by the exponent of the Nusselt-Rayleigh number power-law relation (b). When the exponent, b, becomes 0, the dependency of the heat flow on the mantle temperature becomes weak and independent at b=0. The CO_2 degassing rate is lower for b=0 than the case for b=1/3 (the value used in the traditional models) through the planetary history. As a result, assuming a constant size of continents, the Earth-like planet is colder for b=0 than the case for b=1/3 through the history, and even in the snowball climate in its early stage. The climate is, however, warm when the continental growth is assumed in the model. In this case, the results are similar to those of the case for b=1/3 with/without continental growth. The continental growth is, therefore, a very important factor which controls climate evolution of the Earth-like planet, in addition to the evolution of the CO_2 degassing via volcanism.

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