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Thermal evolution of an early magma ocean in interaction with the atmosphere: conditions for the condensation of a water ocean

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The thermal evolution of magma oceans produced by collision with giant impactors late in planetary accretion is expected to depend on the composition and structure of the atmosphere through the greenhouse effect of CO_2 and H_2O released from the magma during its crystallization. In order to constrain the various cooling timescales of the system, we developed a 1D parameterized convection model of the thermal evolution of a magma ocean coupled with a 1D radiative-convective model of a primitive atmosphere. We conducted a parametric study to investigate the influence of the initial volatile inventories, the initial depth of the magma ocean and the radiogenic heat production rate on the cooling sequence. Our results show that the presence of a convective-radiative steam atmosphere has a strong influence on the duration of the magma ocean phase, which varies from a few thousand years without atmosphere to typically 1 Myr when a steam atmosphere is present. Moreover, the time required for the formation of a water ocean on the planet surface is respectively 0.1 Myr, 1.5 Myr and 10 Myr for Mars, Earth and Venus. This time would be virtually infinite for an Earth-sized planet located closer than 0.66 AU from the Sun. For Mars and the Earth, these times are definitely shorter than the average time between major impacts, so that successive water oceans could have developed during accretion, facilitating the loss of their atmospheres by impact erosion. On the contrary, Venus could have remained in the magma ocean stage for most of its accretion.