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From the interior to the atmosphere: volatile chemical speciation and Earth magma ocean evolution

Gianluigi Ortenzi (1,2), Athanasia Nikolaou (1,3), Nisha Katyal (1,3), Lena Noack (2), and Frank Sohl (1)
(1) DLR, Berlin, Germany (gianluigi.ortenzi@dlr.de), (2) Free University of Berlin, (3) Technical University of Berlin

The early history of the Earth was characterized by a magma ocean stage. The principal aim of this research is a better investigation of the magma ocean interior-surface-atmosphere interactions by combining several modelling approaches. We analyse the degassing rate during the early phase of the magma ocean and the related chemical speciation of the outgassed volatile phases. Moreover, by simulating the structure of the atmosphere we calculate the cooling rate at its top, and therefore of the whole planet.

The degassing rate is provided by a 1D interior-atmosphere coupled model that resolves the magma ocean solidification and its thermal evolution. The two volatile species H_2O and CO_2 included are dissolved in the melt and they are degassed when their solubility in the melt is exceeded. Progressive solidification of the mantle ensures an increase in the cumulative atmospheric mass. Moreover, the volatile chemical speciation of the C-O-H system is analysed with the equilibrium and mass balance method. Since the gas chemical composition is affected by the volatile availability of the magma ocean and by the melt oxygen fugacity, this method shows the direct link between the interior and the development of the atmosphere. We observed that under reduced condition (QIF and IW mineral buffers) the dominant outgassed gas phases are H_2 and CO. On the other hand, with an oxidizing ambient (NiNiO and QIF mineral buffers) the principal gas phases are H_2O and CO_2. Furthermore, the structure and the evolution of the atmosphere are investigated. We calculate the outgoing longwave radiation at the top of the atmosphere using the line-by-line radiative transfer code GARLIC.

The results of the present research show that an interdisciplinary approach is a key point to shed light on the interior-surface-atmosphere interactions and on the early Earth evolution. The transition of the volatiles from the interior to the surface was affected both by the thermal and redox evolution of the mantle. These interactions influenced the composition of the early atmosphere and the related cooling rate of the planet. Lastly, considering an extension of the present scope, this analytical technique has the potential also to characterise the volatile behaviour and the thermal evolution of solid exoplanets.