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A computational approach to modelling magma ocean evolution in 2-D and 3-D

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Models of magma ocean evolution have typically been performed in 1-D (e.g. Abe, PEPI 1997; Solomatov and Stevenson, JGR 1993; Elkins-Tanton EPSL 2008). However, 1-D models may miss important aspects of the process, in particular the possible development of solid-state convection before the magma ocean has completely crystallised, and possible large-scale overturn driven by thermal and/or compositional gradients. On the other hand, fully resolving magma ocean evolution in 2-D or 3-D would be extremely challenging due to the small time-scales and length-scales associated with turbulent convection in the magma and the extreme viscosity contrast between regions of high melt fraction and regions of low melt fraction, which are separated by a rheological threshold associated with the solid forming an interconnected matrix. Here, an intermediate approach to treat these has been implemented within the framework of the mantle convection code StagYY (Tackley, PEPI 2008). The basic approach is to resolve processes that occur in the mostly solid state (i.e. below the rheological threshold) while parameterising processes that occur in the mostly liquid state, based largely on the works of Y. Abe. Thus, turbulent convection in magma-rich regions is treated using an effective thermal conductivity based on mixing-length theory, and segregation of solid and liquid is treated using Darcy's law for low melt fractions or crystal settling (offset by vigorous convection) for high melt fractions. At the outer surface a combined radiative-conductive heat balance is implemented, including the temperature drop over a very thin ($\sim$cm) thermal boundary layer and reduction of radiative heat loss by an atmosphere. Key to the whole process is petrology: the coexisting compositions of magma and solid under various conditions including possible fractionation, and for this different approaches have been parameterised ranging from a simple basalt-harzburgite parameterisation to a bi-eutectic lower mantle melting model based on ab initio and laboratory experiments.