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# Thermo-chemical convection in planetary mantles: advection methods and magma ocean overturn simulations

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Thermal and chemical convection in planetary mantles are the most dominant dynamical processes influencing the thermal and geological evolution of a planet. After the planetary formation, convection in the interior is one of the most prominent processes being responsible for the heat transport efficiency, the interior structure, the magnetic field generation and the geological structures at the surface of a planet such as volcanoes, rifts and others. The slow creep of the silicate materials that make up the mantle of terrestrial planets (i.e. Mercury, Venus, the Earth and Mars) is driven by a combination of thermal and compositional buoyancy. On the one hand, the primordial heat accumulated after accretion and core formation and the heat released by the decay of radiogenic isotopes are transported from the interior to the surface by thermal convection. This process involves the transfer of heat both via diffusion, which occurs mainly across thermal boundary layers, and advection due to fluid motion in the bulk of the mantle. On the other hand, density anomalies of non-thermal origin associated with chemical (i.e. compositional) heterogeneities provide an additional source of buoyancy that actively contributes to the transport of energy and mass.

In the present work we discuss the modeling of active compositional fields in the framework of solid-state mantle convection using the 3D spherical/2D cylindrical code Gaia [1, 2].

Numerical methods for the advection of active compositional fields fall in two main categories [3, 4]. They are based either on a fixed computational grid (Eulerian methods) or on evolving grids or moving particles (Lagrangian methods).

We compare an Eulerian method based on double-diffusive convection against a Lagrangian, particle-based method. Though straightforward, the first method generally suffers from non-negligible numerical diffusion and demands then the use of grids with a high resolution. Moreover, its accuracy can substantially degrade when it comes to treat sharp interfaces separating materials with strongly distinct properties (such as density and viscosity) whereas the particle-based Lagrangian methods, albeit computationally demanding, do not suffer from the above mentioned problems.

Through a series of increasingly complex benchmark tests, we show the superiority of the particle method when it comes to model the advection of compositional interfaces with sharp density and viscosity contrasts. We finally apply this technique to simulate the Rayleigh-Taylor overturn of the Mars' and Mercury's primordial magma oceans [5, 6].

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