12th International Workshop on Modeling of Mantle Convection
and Lithospheric Dynamics

August 20th to 25th 2011, Döllnsee Germany

Double-diffusive convection - A potential mechanism for a dynamical layer formation in an early stage of Earth's history

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The dynamical evolution of the Earth and other planets, their chemical differentiation and reactions of their interior with the atmosphere is largely determined be convective processes. Convection does not always tend to homogenize the interior. It can rather establish structure such as layers which can stay intact for geological significant time. We will demonstrate that distinct convective layers can form as self-organized structures from an initially non-layered state, without pre-existing density jumps, once the effects of thermal and compositional contributions to the density are taken into account (double-diffusive convection).

Layer formation is a prominent phenomenon in many natural systems, like the Earth's oceans, magma chambers or on larger scale the mantle of planetary bodies. Especially the internal structure of the Earth's mantle was and is still highly debated. There are different factors that indicate the existence of distinct layers. Geochemical differences between MORB (Mid Ocean Ridge Basalts) and OIB (Oceanic Island Basalts) and the increase of seismic velocity at a depth of 660km suggest the presence of at least two different reservoirs inside the Earth's mantle.

We carried out a series of two dimensional numerical experiments, ranging from a constant viscosity fluid to a strongly temperature and stress dependent viscosity fluid, to study the process of layer formation and the finally evolving structures.
A stable compositional gradient, heated from below and cooled from above resembles one reasonable scenario for the Earth's mantle after core formation. In this configuration a layered mantle emerges with the individual layers displaying different stabilities (see Figure 1). The intermittent breakdown of individual layers leads to a strong episodicity in the thermal and chemical evolution of the system.
In all scenarios initial plumes from the bottom boundary start homogenize the lower layer which subsequently thickens. This layer heats up and initiate the layers above. This creates dynamically a sequence of separately convecting layers with a significantly larger bottom layer.

Strongly temperature dependent viscosity tends to stabilize the layers and leads to the evolution of more distinct layers. We will also show that the consideration of a stress dependency generates a plate-like scenario with some subducted slabs penetrating the established internal boundaries. However the layers finally collapse and the system establish a convective mode that is equal to pure thermal convection.
Our results indicate that distinct layers in planetary mantles are formed by a dynamical fractionation and are thus likely to appear as a generic feature in the process of planet formation.

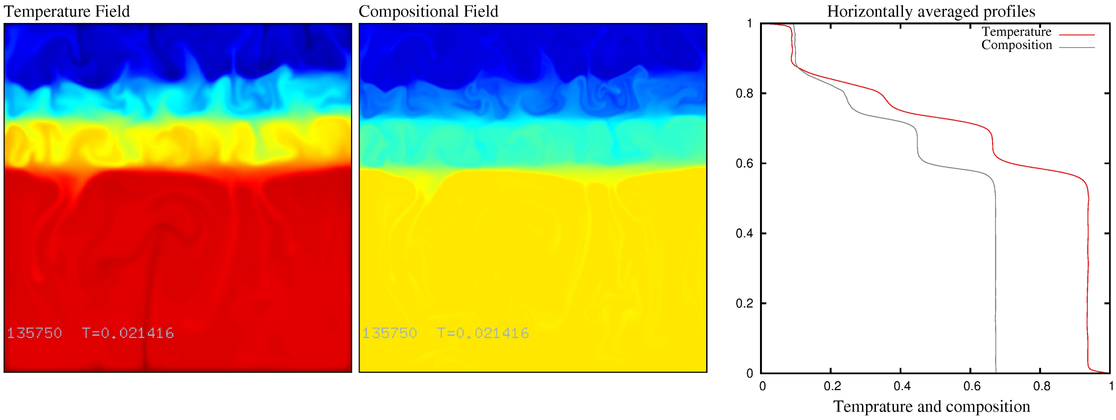

Figure 1: The temperature (left), composition (middle) and the associated horizontally averaged profiles (left) for an isoviscous double-diffusive system with Ra = 10^9, $Ra_C = 2x10^9$, Le = 10. The snapshots are taken at a later stage of the temporal evolution.