Chapter 16
High–Performance Modelling in Geodynamics

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ABSTRACT

Modelling of geodynamic processes like mantle or core convection has strongly improved over the last two decades thanks to the steady development of numerical codes that tend to incorporate a more and more realistic physics. High-performance parallel computations allow the simulation of complex problems, such as the self-consistent generation of tectonic plates or the formation of planetary magnetic fields. However, the need to perform broad explorations of the parameter space and the large computational demands imposed by the non-linear, multi-scale nature of convection, requires several simplifications, in the domain geometry as well as in the physical complexity of the problem. In this chapter, the authors give an overview of the state-of-the-art convection simulations in planetary mantles, the different models and geometries used, and various methods to simplify the computations.

INTRODUCTION

Planetary sciences embrace a wide variety of disciplines, among which astronomy, geology, geochemistry and geophysics are but a few of them, and involve the study of objects ranging in size from small meteorites and comets to giant gaseous planets, such as Jupiter and Saturn, or entire planetary systems. In this context, the study of terrestrial (i.e. rocky) bodies, such as

Mercury, Mars, Venus, the Moon and the Earth, occupies a prominent role. On the one hand, the analysis of surface phenomena, like tectonic and atmospheric processes, can benefit of a large diversity of observations conducted both from Earth and from space. On the other hand, the deep interior of solid bodies can only be probed indirectly thanks to seismic observations, which however are available solely for the Earth and, to a lesser extent, for the Moon, or by investigating

the properties of minerals at extreme conditions of pressure and temperature.

In the first approximation, the Earth is composed of different material layers with distinct mechanical and chemical properties. The radial structure of the Earth has been known for some decades thanks to the study of earthquake-generated elastic waves that propagate through the interior of the planet (Dziewonski & Anderson, 1981). Seen from the centre to the surface, the Earth consists of a solid iron core, a fluid layer of iron mixed with lighter elements such as sulphur, and a rocky mantle composed of mostly solid, but also partially molten, silicate minerals. This is surrounded by thin, oceanic and continental plates of basaltic and felsic composition, respectively. The basic structure of the Earth is depicted in Figure 1 together with the assumed radial profile of the temperature in the mantle and the core.

A terrestrial planet is in general defined as a body differentiated into an iron core, a rocky mantle and a crust on top. Mercury, Mars, Venus, the Earth and the Moon, but also several moons of the Solar System and exo-planets orbiting other stars, are thought to possess the same basic internal structure.

Planets gain heat early during their formation process, where impacts and collisions lead to the accumulation of a vast amount of energy. Besides this form of primordial heat, thermal and compositional convection in the liquid core also deliver heat into the mantle. Moreover, radioactive elements, stored in the mantle during accretion, decay over time and supply the planet with additional thermal energy for billions of years. Because of thermal expansion and contraction, the material at the base of the mantle, heated by the core, is less dense than the material at the surface, which cools as it radiates heat to space. This results in gravitational instability, with hot and buoyant mantle rocks rising towards the surface, from which cooler and denser material descends back into the mantle. Even though the mantle is by all means solid, it behaves like a

Figure 1. A terrestrial planet is divided into an inner and outer iron core, a rocky mantle, and a crust (left). The mantle temperature (red line) increases sharply across two thermal boundary layers at the surface and at the core-mantle boundary (CMB), where heat is transported mostly by conduction. In the bulk of the mantle and in the core, instead, the temperature increase is essentially adiabatic. The Earth further has oceans and continents at the surface and a stable atmosphere (right).
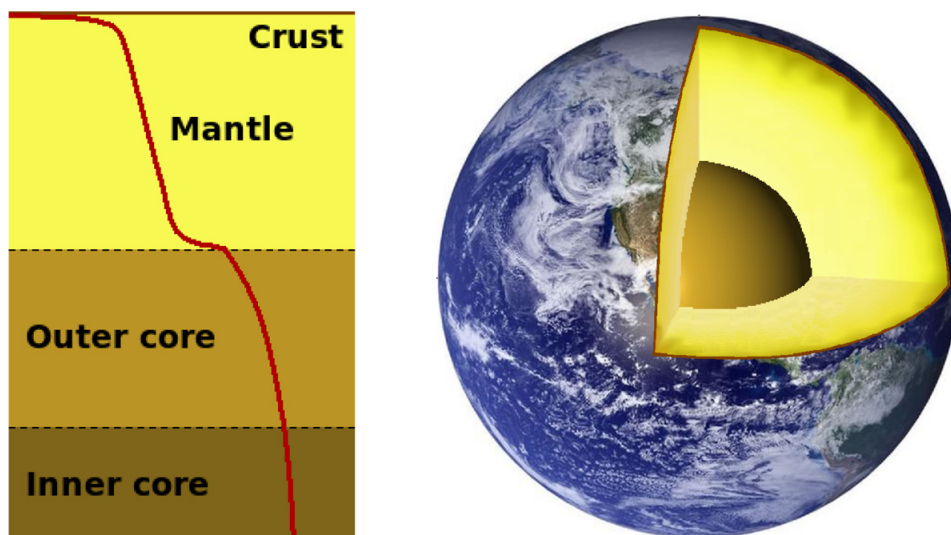
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