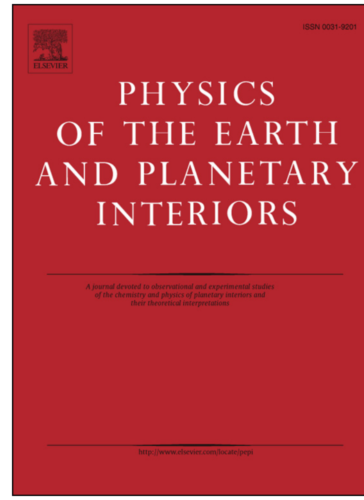

Impact of compressibility on heat transport characteristics of large terrestrial planets

Hana Č í žková, Arie van den Berg, Michel Jacobs

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Impact of compressibility on heat transport characteristics of large terrestrial planets

Hana Čížková[a 1], Arie van den Berg[b], Michel Jacobs[c]

[a]Charles University, Faculty of Mathematics and Physics, Department of Geophysics, Czech Republic

[b]Utrecht University, Institute of Earth Sciences, Department of Theoretical Geophysics, Netherlands

[c]TU Clausthal, Institut für Metallurgie, Germany

Abstract

We present heat transport characteristics for mantle convection in large terrestrial exoplanets ($M \leq 8M_{\oplus}$). Our thermal convection model is based on a truncated anelastic liquid approximation (TALA) for compressible fluids and takes into account a selfconsistent thermodynamic description of material properties derived from mineral physics based on a multi-Einstein vibrational approach. We compare heat transport characteristics in compressible models with those obtained with incompressible models based on the classical- and extended Boussinesq approximation (BA and EBA respectively). Our scaling analysis shows that heat flux scales with effective dissipation number as $\mathrm{Nu} \sim \mathrm{Di_{eff}}^{-0.71}$ and with Rayleigh number as $\mathrm{Nu} \sim \mathrm{Ra_{eff}}^{0.27}$. The surface heat flux of the BA models strongly overestimates the values from the corresponding compressible models, whereas the EBA models systematically underestimate the heat flux by $\sim 10\% - 15\%$ with respect to a corresponding compressible case. Compressible models are also systematically warmer than the EBA models. Compressibility effects are therefore important for mantle dynamic processes, especially for large rocky exoplanets and consequently also for formation of planetary atmospheres, through outgassing, and the existence of a magnetic field, through thermal coupling of mantle and core dynamic systems.

Keywords: compressible mantle convection, terrestrial exoplanets, heat transport

1 Introduction

Recent progress in detection techniques resulted in discoveries of numerous terrestrial (rocky) exoplanets (eg. Mayor et al., 2009; Fressin et al., 2012; Batalha et al., 2013). This has inspired an increasing number of studies focused on their internal dynamics (e.g. Valencia et al., 2006, van den Berg et al., 2010; Tachinami et al., 2011; Tackley et al., 2013). Mantle dynamics of terrestrial (exo)planets has traditionally been studied in terms of incompressible Boussinesq models (e.g. Běhounková et al., 2010; de Vries et al., 2010; van den Berg et al., 2010; van Summeren et al., 2011; van Heck and Tackley, 2011; Stamenkovic et al., 2012).

These models may be reasonably applicable to the Earth and planets of a comparable or smaller size, where the effects of compressibility are relatively small. They have however also been applied to larger planetary bodies where pressure and resulting selfcompression are much higher than in the Earth's mantle.

These incompressible models have provided various insights into convection characteristics e.g. in models including selfconsistently generated plate tectonics, and rheological weakening in the lower

[1]Corresponding author: Department of Geophysics, V Holešovičkách 2, 180 00 Prague 8, Czech Republic, e-mail: Hana.Cizkova@mff.cuni.cz