Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SIT03-17 会場:106 時間:5 月 26 日 09:30-09:45

物性の空間変化と強い圧縮性を持つ流体中の熱対流に関する線形解析: スーパー地球のマントル対流に関する考察
Linear analysis on the onset of thermal convection of highly compressible fluids with variable physical properties

亀山 真典 [1*]
KAMEYAMA, Masanori[1*]

[1] 愛媛大学地球深部ダイナミクス研究センター
[1]Geodynamics Research Center, Ehime University

A series of linear analysis was performed on the onset of thermal convection in a highly compressible fluid with variable physical properties, in order to study the fundamental nature of mantle convection of massive super-Earths in the presence of strong adiabatic compression. We consider the temporal evolution (growth or decay) of an infinitesimal perturbation superimposed to a highly compressible fluid which is in a hydrostatic (motionless) and conductive state in a basally-heated horizontal layer. As a model of spatial variations in physical properties, we employed an exponential dependence of thermodynamic properties (thermal expansivity and reference density), together with the spatial variations in transport properties (thermal conductivity and viscosity). The linearized equations for conservation of mass, momentum and internal (thermal) energy are numerically solved for the critical Rayleigh number as well as the vertical profiles of eigenfunctions for infinitesimal perturbations. The above calculations are repeatedly carried out by systematically varying (i) the dissipation number which measures the effect of adiabatic compression, (ii) the temperature at the top surface and (iii) the magnitude of spatial variations in physical properties of the modeled fluid.

By first analyzing the roles of thermodynamic properties, we found that the onset of thermal convection is strongly affected by the adiabatic compression, through the modulation of the static stability of thermal stratification in the fluid layer. For sufficiently strong adiabatic compression where a very thick "stratosphere" of stable stratification develops in the layer, for example, the critical Rayleigh number explosively increases with the dissipation number. The explosive changes in the critical Rayleigh number are associated with drastic decreases in the length scales of perturbations both in vertical and horizontal directions. In addition, when the effect of adiabatic compression is extremely strong so that the thermal stratification becomes stable in the entire layer, no perturbation is allowed to grow with time regardless of the Rayleigh number and/or the horizontal wavelength.

We also found that the critical states of thermal convection are greatly altered by introducing the depth-dependence in thermal conductivity: the increase in thermal conductivity counteracts the decrease in thermal expansivity with depth by raising the adiabatic temperature change and, hence, enhancing the stability of thermal stratification. In particular, for the cases where a "stratosphere" occurs at the mid-depth of the fluid layer owing to the moderate depth-dependence both in thermal expansivity and conductivity, we observed discontinuous changes in the structures of incipient flows with the dissipation number, depending on the concentration of flows either in the upper and lower "tropospheres". Our findings suggest that a delicate interplay between the depth-dependent thermal expansivity and conductivity is of crucial importance in understanding the dynamic nature of the mantle convection of massive super-Earths.

キーワード: スーパー地球, マントル対流, 断熱圧縮, 熱膨張率, 熱伝導率
Keywords: super-Earths, mantle convection, adiabatic compression, thermal expansivity, thermal conductivity