Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

MIS021-P01 Room:Convention Hall Time:May 22 14:00-16:30

Entropy Production in Planetary Atmospheres: Earth, Mars, Titan

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We explore the state of the atmosphere of Earth, Mars, and Titan through the hypothesis: the mean state of the planetary atmosphere is consistent with a maximum entropy production (MEP) state due to nonlinear heat transport in the turbulent atmosphere [Sawada, 1981].

We estimate latitudinal distribution of temperature and longwave and shortwave radiation with the multi-box model based on a two-box model for latitudinal heat transport [Lorenz et al., 2001]. The model may be useful in the point of calculability with a few parameters.

The results of estimate values indicate good agreement with the observed values of Earth and Mars except for Martian shortwave radiation and Titan‘s values. They will be much better if the model includes latitudinal dependence of albedo and cloud effect for Earth. There is an error (-10 to +5) for Titan‘s temperature.

The investigation is now in progress, for the reason of error and the lack of observed radiation data for Mars and Titan.

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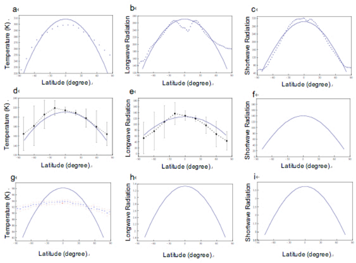

Figure 1, Latitudinal distributions of (a) surface temperature, (b) longwave radiation (W/m^2), (c) shortwave radiation (W/m^2) in the Earth. Latitudinal distributions of (d) surface temperature, (e) longwave radiation (W/m^2), (f) shortwave radiation (W/m^2) in Mars. Latitudinal distributions of (g) surface temperature, (h) longwave radiation (W/m^2), (i) shortwave radiation (W/m^2) in Titan. Solid line curves indicate those predicted with the model of maximum entropy production. Dotted lines indicate those observed. The error bars (d, e) are caused by seasonal changes.

Keywords: Entropy Production, Planetary Atmosphere, Radiation

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Liner stability of thermal convection in rotating spherical shells with fixed heat flux boundaries

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Thermal convection of Bussinesq fluid in a rotating sphere and spherical shells has been studied vigorously in order to consider the fundamental features of fluid motions of geophysical and astronomical bodies. Most studies so far used a fixed temperature as a thermal boundary conditions. However the fixed heat flux condition may be important from geophysical viewpoints. For example, it is sometimes discussed that convection in the fluid core of the earth is controlled by the heat flow imposed by convection in the overlying mantle. Actually, as a model of the earth's fluid core, some MHD dynamo calculations are conducted under the fixed heat flux condition (e.g.[1],[2]). However, knowledge about the effects of the thermal boundary condition on the solutions is fragmentary.

It is well known that convection structure drastically changes in a no-rotating plane-layer system depending on the thermal boundary condition ([3]). Convection cells with aspect ratio of about two emerges as the critical mode under the fixed temperature condition, whereas horizontally elongated convection cells appear as the critical mode in the case of fixed heat flux condition. The effects of the rotation is investigated using a rotating annulus model with inclined top and bottom boundaries, which is a model for the columnar convection in rotating spherical shells ([4]). It is expected that convection cells with the smallest longitudinal wavenumber would emerge as the critical mode, even when the topographic beta effect is included. However, full rotating spherical shell cases have not been investigated in detail so far.

In this study, we conduct linear stability analyses of thermal convection in rotating spherical shells with fixed heat flux boundaries systematically. The Prandtl number and Ekman number are fixed to 1 and 10^{-3}, respectively, while radius ratio of the inner and outer radii, the dynamical boundary condition, and the existence of homogeneous internal heating are varied. As supplemental calculations, the Ekman number is reduced to 10^{-4} in some cases.

The results are as follows.

(1) The case with homogeneous internal heating

When the free-slip boundary condition is applied, the critical longitudinal wavenumber is changed depending on the radius ratio. The critical longitudinal wavenumber is 3 to 4 in the cases of thick shells, while the critical wavenumber is 1 in the cases of thin shells. The neutral curves are not monotonic, but characterized by a local minimum at a certain high wavenumber. These results are consistent with the expectation by the annulus model([4]).

On the other hand, when the no-slip boundary condition is applied, the critical longitudinal wavenumber becomes 1 regardless of the radius ratio. The neutral curves increase monotonically as the increase of the wavenumber. However, similarly to the case of the free-slip boundaries, a local minimum appears on the neutral curve when the Ekman number is reduced.

(2) The case without homogeneous internal heating

The mode with the longitudinal wavenumber of 1 becomes the critical mode regardless of the dynamical boundary condition.

When the both boundaries are free-slip, the neutral curves increase monotonically as the increase of the wavenumber in the cases of thick shells, whereas a local minimum appears on the neutral curve in the cases of thin shells or the lower Ekman number. On the other hand, when the both boundaries are no-slip, the neutral curves increase monotonically as the increase of the wavenumber regardless of the thickness of the shell.

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Keywords: Thermal convection in a rotating spherical shells, Thermal boundary condition, Fixed heat flux condition

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Hydroelectric coupling in a porous medium heated from below

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The mechanism of convection and electric phenomena around an isolated heat source in a fluid saturated porous media is of interest in geothermal processes and volcanology. Laboratory and numerical experiments (2D-3D) of transient convective flows and induced electric potentials in a porous layer with a local bottom heat source are reported. Axisymetric laminar plumes are experimentally generated by a small electric heater in a tank filled with water-saturated glass beads. The flow pattern is investigated for Rayleigh numbers up to 8000. Plumes ascent in two different regimes. For Ra$<$1600, the velocity of the plume head slowly decreases during the ascension in the porous medium (consistent with Elder, 1967). For Ra$>$1600, the velocity increases owing to the development of the thermal boundary layer, remains nearly constant during the rise, before decreasing at the top of the tank. Finally, the electric potentials induced by the development of the plume are analyzed. It is shown that the signal systematically decreases when the plume is detaching itself from the bottom, before increasing during the ascension of the water. This study is the first step to further experimental and numerical works on convective cells generation and induced electrokinetic potentials in a high permeability porous medium.

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Keywords: Analog Experiment, Convection, Self-Potentials, Hydroelectric Coupling, Porous medium, Numerical modeling

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Nonlinear solutions of inviscid magnetostrophic dynamo

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The Earth's core convection is believed to be in a dynamical state where (1) viscosity has almost nothing to do with the flow and (2) the magnetic energy density is much greater than the kinetic energy density. In previous numerical simulations of the core convection, viscosity is set as small as possible to increase the effect of rotation and realize a strong-field solution. In this approach, the Navier-Stokes equation is solved numerically, and there occurs no technical problem in time integration. The problem is that the required grid and timestep sizes become small as the fluid viscosity is reduced and therefore the computation time becomes longer. This would be a straightforward approach to the geodynamo problem, by which we could understand the MHD turbulence in the core and the origins of the short-period geomagnetic field variations.

Another approach is the magnetostrophic approximation in the limit of zero viscosity and infinite magnetic energy density. As the viscous and inertial (advection) terms are neglected in the momentum equation, thin viscous boundary layers and short-period MHD waves do not appear. Therefore, this method would be important in considering how the large-scale flow and magnetic field are organized and how they change in relatively long timescales.

Two years ago, I gave a presentation about this magnetostrophic dynamo at the same session, but did not succeed in obtaining nonlinear solutions. Here, I summarize characteristics and numerical difficulties of the magnetostrophic dynamo and report on some progress made in the last two years.

Keywords: geomagnetic field, planetary magnetic field, magnetohydrodynamics