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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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