Advection and shape transition of vortices in a rotating Rayleigh-Bénard convection

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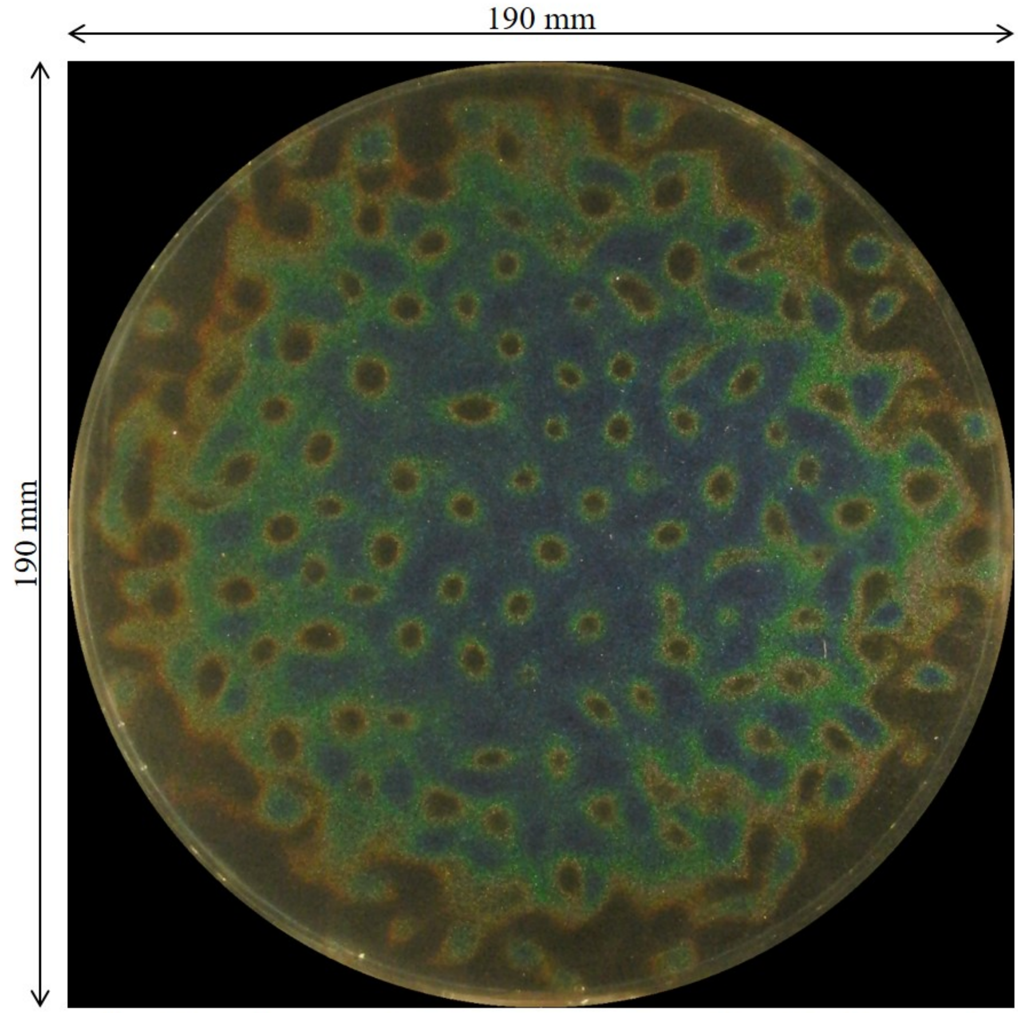
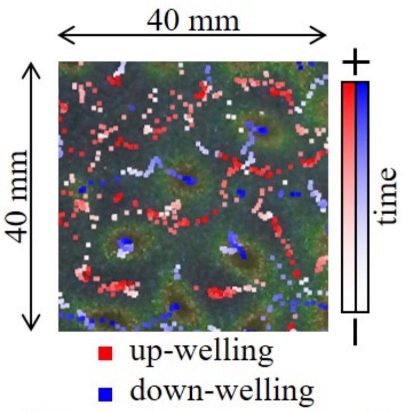
Thermal convection confined between two parallel plates is called Rayleigh-Bénard convection. In considering various fluid dynamics appearing in natural phenomena, this system is the most fundamental one to investigate from perspectives of theoretical, numerical, and experimental approaches. Taking geophysical fluid dynamics, such as atmosphere, ocean, and convection in the outer core, into consideration, the effect of background rotation should be conceived and inevitable. Certainly, the Rayleigh-Bénard convection in a rotating field induces roughly divided two fascinating events. The first one is the appearance of vortical structures because of the influence of the Coriolis force. In non-rotating fields, convection cells or rolls appear, however such structures are transformed by the Coriolis force in a rotating field. Another event is the enhancement of heat transfer because of the Ekman pumping. The phenomena appearing in rotating Rayleigh-Bénard convection are organized by three dimensionless numbers, Rayleigh number *Ra*, Prandtl number *Pr*, and Taylor number *Ta*. Especially, the vortex behavior under the enhancement of heat transfer is paid attention in this study. The objective is to elucidate the vortex dynamics experimentally and quantitatively.
Water suspended with temperature-sensitive liquid crystals is used as a working fluid in order to visualize vortical structures. The fluid layer is composed of an acrylic cylindrical wall with the inner diameter 190 mm and the height 40 mm, which giving aspect ratio 4.75. The fluid layer is heated from the bottom with heater and cooled from above through a glass plate with circulating water from a thermostatic bath. All the parameters are fixed at $Ra = 1\times10^7$, $Ta = 1\times10^8$, $Pr = 7.01$. Photographing is performed by 3-seconds interval from above the fluid layer by a digital camera.
From visualized images, the horizontal temperature fields are obtained by means of a kind of temperature calibration method. The unevenness in the temperature fields are regarded as the vortices. To detect vortices, the template matching, which is well known as one of the pattern recognition techniques, is performed. Additionally, detected vortices are categorized into several patterns depending on its temperature distribution shapes using the equation of ellipsoid. In this process, radius representing the size of a vortex, height expressing the temperature gap between the center and edge in a single vortex, and curvature showing the temperature gradient, can be modified and categorized. From these procedures, the coordinates and temperature distribution shapes of vortices are determined.
By tracking vortex advections for time course, the vortex dynamics is revealed. In a short time scale, the direction of vortex advection is disorderly. In a longer time scale, the path-lines of up-welling vortices draw hexagonal patterns around a down-welling vortex. In a much longer time scale, the advection is dominated in the radial direction because of the centrifugal force. Such extremely complicated vortex dynamics are observed in entire the fluid layer and thought to be caused by mutual interaction among vortices and the centrifugal force. Accordingly, further experimental studies should be performed.
Moreover, the temperature distribution shapes categorized by the vortex detection method are also tracked for time course. In accordance with the transition of the shapes, as for up-welling vortices, generation occurs near the sidewall and moves toward the center of the fluid layer. The height is getting shorter and the curvature is getting larger along the advection. On the other hand, as for down-welling vortices, generation occurs in the center and moves to the sidewall of the fluid layer. The height becomes shorter and shorter, and the curvature is getting smaller along the advection. Such transition of

temperature distribution shapes along the vortex advection seem to relate the enhancement of heat transfer.

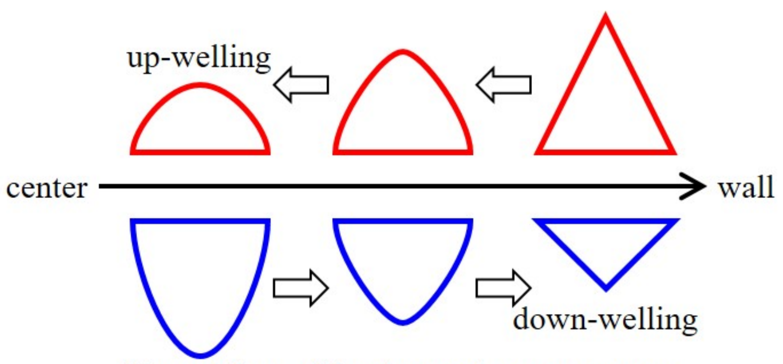
Keywords: Natural convection, Rotating field, Flow pattern, Image processing



Visualized image using temperature-sensitive liquid crystals



Path-lines of vortices for 90 s



Transition of horizontal temperature distribution shape of vortices

