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Investigation of cell patterns on a rotating convection by ultrasonic velocity profile measurements

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Rayleigh-Benard convection is the well-known topic as fundamental system in fluid dynamics. In particular, the effect of rotating field on the convection is one of essential piece for geophysics. The influence of centrifugal force and Coriolis force on convection pattern formation was experimentally showed by Rossby (1969). The flow structure of Rayleigh-Benard convection in a rotating field is described by Rayleigh number (Ra), Taylor number (Ta) and Prandtl number (Pr). Especially, it is important to study the behavior of low Pr fluid like liquid metals, because this knowledge helps to understand the dynamics of metallic cores in planets. In low Pr fluids, the flow regimes dramatically changes in comparison with ordinal fluid with Pr >1. For example, Rayleigh-Benard convections in a liquid metal layer easily take transition to turbulent state. Generally, adding rotating field stabilizes the flow. On the other hand, flows of low Pr fluids with background rotation are expected to become oscillatory and irregular motion near the marginal stability conditions. These characteristics of low Pr fluids, however, have not been studied experimentally so much, because it is impossible to capture the convection patterns of liquid metal flows optically. To solve this problem, the authors adopt Ultrasonic Velocity Profile (UVP) method to visualize convective flow of liquid metal in a rotating field. As the data set of UVP measurement is one-dimensional velocity distribution, it is difficult to guess flow fields of convection from only a result of UVP without any criterion of translation. In this study, as preparations for liquid metal experiments, we performed two different visualizations using optics and ultrasound on ordinal transparent fluid, water (Pr = 7), to understand flow field from spatio-temporal velocity distribution obtained by UVP. Optical visualization provides path line images for the comparison. In addition, we purpose to take the knowledge about spatio-temporal velocity distribution of high Pr contrasted with low Pr.

Experiments were performed on a rotating table. The vessel of fluid layer has a square geometry, which aspect ratio is seven. The bottom of fluid layer was heated by electrical heating and the upper surface was cooled by circulating water through flow channel made of glass plate. Optical visualization images were obtained from a horizontal section of the fluid layer. An ultrasonic transducer for UVP measurement was mounted horizontally on the side wall of fluid layer.

The path line showed many small round convective cells in the fluid layer, and it represented that the size of cells become smaller as Ta takes larger. In addition, the size of cell and cell motions were also detected by spatio-temporal velocity distributions acquired by UVP. For example, cells moved in certain direction and passed over measurement line of transducer. Staying time of cell on the line was observed and means speed of cells moving. As Ta gets larger, it was found that the speed of each cell motion became slower. The cell diameter was calculated from velocity data. When cells stay next to each other, there is 0 mm/s on cells boundaries in spatial velocity distribution at the time. We defined distances between neighboring cells on the spatial line respectively as scales of cell size. Then we extracted all distances from spatio-temporal distribution and calculated the expected value of these. The expected value represents dominant cell diameter. We confirmed that the cell size on the distribution roughly corresponds to that on the path line. Thereby we obtained information of convective cell from only UVP data.

Keywords: Rayleigh Benard convection, Rotating field, Flow pattern