Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

MIS21-01 Room:301A Time:May 22 16:15-16:30

Regime diagram of thermal convection pattern under horizontal magnetic field in liquid metal

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The study on the nature of thermal convection in liquid metals under a magnetic field is important for the dynamics of planetary metallic cores. Electric current is induced when a flow of liquid metal crosses a magnetic field, and it generates Lorentz force. The Lorentz force changes the force balance, making the flow behavior different from no-magnetic field situations. In general, viscosity of liquid metals is very low and their flow easily becomes turbulent, but when a magnetic field is applied on liquid metals, it makes anisotropic flow structure with suppression of turbulence depending on its direction and intensity. To quantify the effect of magnetic field on flow patterns, we performed laboratory experiments of Rayleigh-Benard convection by using liquid gallium, with various intensities of a uniform horizontal magnetic field B. The vessel we used has a square geometry with aspect ratio five. Flow patterns with their time variation were visualized by ultrasonic velocity profiling method. The range of Rayleigh number (Ra) is from critical value to 100 times above it. The range of Chandrasekhar number (Q), which is proportional to the square of the intensity of B, is from 0 to 1000.

We recognized five flow regimes depending on Ra and Q, that is, (1) isotropic large-scale cell pattern, (2) anisotropic cell with larger flow velocity perpendicular to B, (3) short-period oscillatory behavior of rolls aligned in the direction of B, (4) continuous transitions between roll numbers in the vessel, and (5) steady 2-D rolls. In (4), reversals of the flow direction in rolls were observed several times. These behaviors are summarized as a regime diagram of convection patterns in relation to Ra and Q. The key mechanisms for the variation are the enhancement of two-dimensionality and increase of roll number for larger Q situations. These flow regimes can be classified by Ra/Q, that is the ratio of buoyancy force to the Lorentz force. If buoyancy force is much larger than Lorentz force, the flow is turbulent and isotropic structure is dominant. Short-period of oscillation (3) is observed where the ratio Ra/Q is lower than 100. Continuous transitions of roll numbers (4) are observed at Ra/Q between 10 and 30, and convection pattern keeps steady roll (5) at Ra/Q smaller than 10. We also performed numerical simulations of thermal convection with imposed horizontal magnetic field. Both the Prandlt number and magnetic Prandtl number of the working fluid are set small to simulate liquid metals. Our numerical result successfully reproduced all regimes that observed in the experiments.

Keywords: thermal convection, liquid metal, magnetic field, pattern

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Periodic flow reversals in a MHD Rayleigh-Benard convection

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A spontaneous reversal of flow direction in Rayleigh-Benard convection is an active topic to help our understanding of natural flow motions in the Earth. In a previous study, our group has investigated Rayleigh-Benard convection in a shallow liquid metal layer with relatively large aspect ratio under horizontal magnetic field. The dimension of the fluid layer is 200*200*40 mm giving an aspect ratio of 5. Applying the horizontal magnetic field suppresses isotropic turbulent fluctuation of the flow and thus quasi-two dimensional convection rolls appear. These rolls aligned with the direction of applied magnetic field. In the experiments with modifying both Rayleigh number, Ra and Chandrasekhar number, Q, various convection states were observed on the diagram with Ra and Q. Spatio-temporal velocity profile measurements by Ultrasonic Velocity Profiling indicate 3, 4, or 5 steady rolls regimes and also transitional states between each steady state. We reported that flow reversals occur spontaneously in these transitional states and it is a random event regarding time (Yanagisawa, et al., PRE, 2011).

In this paper, we have reported a new regime and also mentioned that a certain inertial factor of the system can regularize the flow reversals into a very periodic event. We have conducted the Rayleigh-Benard experiments in the same vessel as previous one but using other magnetic generator at Helmholtz-Zentrum Dresden-Rossendorf (HZDR). This system can generate much larger magnetic field than the previous employed system. Thus, we could extend a regime diagram (in Ra-Q parameter space) to higher region regarding Chandrasekhar number, Q. In large Q-space, a new flow regime, six rolls, could be observed. The higher magnetic field also strongly suppressed the onset of convection and fluctuation of the convection rolls. These results are well supportable for our previous results and understanding. On the other hand, there is also remarkable difference from our prediction. The flow reversals occurred as very periodic events in this new system. Additionally, we found that the rolls are not always parallel to the magnetic field, but they are with an angle to the magnetic field direction. The most different point between the old and new system is magnitude of non-uniformity of the magnetic field. The new one has a little larger difference of intensity of the magnetic field in the test section. Therefore, one of the possible reasons of the inclination and periodic flow reversals is the non-uniformity of the applied magnetic field. Also, other factors are possible reasons such as small tilting of the fluid vessel to the magnetic field lines and higher values of the Chandrasekhar number Q. From detailed analysis of the velocity information, it will be discussed how the inertial factor of the system like non-uniformity of the magnetic field works on the regularization of the originally random event.

Keywords: liquid metal, flow reversal, horizontal magnetic field, regularization

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Influence of rotating field on the cell pattern formation of internal heating convection

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Influence of a background rotation on the transition of flows is one of the interesting topics in fluid mechanics. The influence in thermal convections also has great importance not only for fluid mechanics but also for geophysics to understand large scale phenomena in the planets. Many studies about influence of rotation on Rayleigh-Benard convection have been carried out. For example, formation of the spiral flow in convection cells is theoretically predicted by Chandrasekhar(1961). On the other hand, only a few research of the effect of rotation on the internally heating convection has investigated. In generally, convection cells occurring in the internally heating convection expand as increasing Rayleigh number. Conversely, convection cells shrunk as the effect of background rotation. As described above, the increasing rotation speed and increasing Rayleigh number provide the opposite effect on the size of convection cells. The aim of this study is to clarify how the convection pattern changes with changing balance of these opposite effect.

This experimental study deals in the response of thin horizontal fluid layer with background rotation. The bottom boundary of the layer is composed by an insulating glass plate. And the top boundary is contact with copper plate where the temperature is kept constant by circulating water from a thermo-static bath. Internally heat generation is induced by Joule heating due to passing electric current in the ionic fluid. After electrifying to fluid layer, rotation immediately is begun.

Four characteristic flow patterns were observed with modifying the rotation speed and power of the heat generation. First one is that there are stable, polygonal convection cells. Second, flow pattern is irregular without forming any cell structure. Third is the unsteady cell pattern formation: roll or polygonal cells form but immediately change into different form with combining and dividing. The fourth one is conduction state without convection.

We have organized the results by Rossby number showing the relationship between the Rayleigh number and Taylor number. The convection cell is stable when Rossby number is greater than 3 or less than 0.7. But the cell pattern formation becomes unstable and repeats split and join when the Rossby number is around zero. In addition, when Taylor number is greater than 1000, convection does not form cell structure even if Rossby number is greater than 3.

When we focus on the parameter region of stable convectional cell, flow structure and cell size differ between Rossby number is less than 0.7 and greater than 3. The shape of convectional cell is regular hexagon and the flow inside the cell takes large distortion due to Coriolis force when Rossby number is less than 0.7, in other word the effect of rotation is relatively stronger than the effect of convection. On the other hand, when Rossby number is greater than 3, the shape of cell is irregular polygon and the flow inside the cell has little distortion as the effect of rotation.

Keywords: natural convection, internally heating, rotating field, flow pattern

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The effect of wind waves on the upper ocean circulation

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There is an ongoing discussion in the community concerning the wave-averaged momentum equations in the hybrid vertically Lagrangian and horizontally Eulerian (VL) framework and, in particular, the form stress term (representing the residual effect of pressure perturbations) which is thought to restrict the handling of higher order waves in terms of a perturbation expansion. The present study shows that the traditional pressure-based form stress term can be transformed into a set of terms that do not contain any pressure quantities but do contain the time derivative of a wave-induced velocity. This wave-induced velocity is referred to as the pseudomomentum in the VL framework, as it is analogous to the generalized pseudomomentum in Andrews and McIntyre. This enables the second expression for the wave-averaged momentum equations in the VL framework (this time for the development of the total transport velocity minus the VL pseudomomentum) to be derived together with the vortex force. The velocity-based expression of the form stress term also contains the residual effect of the turbulent viscosity, which is useful for understanding the dissipation of wave energy leading to transfer of momentum from waves to circulation. It is found that the concept of the virtual wave stress of Longuet-Higgins is applicable to quite general situations: it does not matter whether there is wind forcing or not, the waves can have slow variations, and the viscosity coefficient can vary in the vertical. These results provide a basis for revisiting the surface boundary condition used in numerical circulation models.

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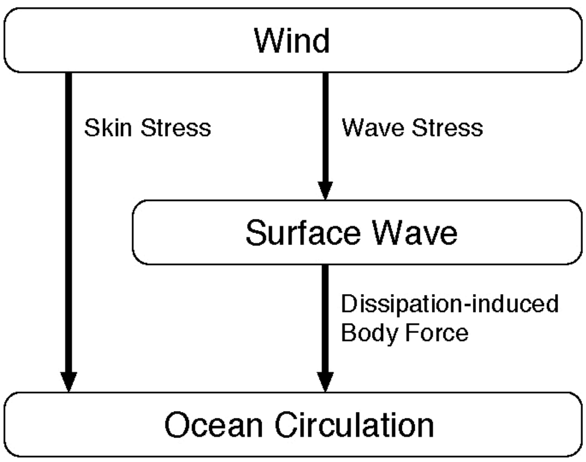
Keywords: Wind waves, Wind stress, Wave dissipation, Momentum transfer, Lagrangian coordinates



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A theoretical study on the mechanism for spontaneous gravity wave generation using the renormalized perturbation method

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Gravity waves (GW) are categorized into orographic ones and non-orographic ones. The mechanisms for non-orographic GW generation are not clear, because the dynamics is quite nonlinear and complicated unlike orographic GW. Recently, it has been revealed that GW are spontaneously radiated from an approximately-balanced flow, especially in the jet/front systems (e.g. O'Sullivan & Dunkerton 1995). The balanced adjustment theory proposed by Plougonven & Zhang (2007) is considered to be the most likely to describe the spontaneous radiation. However, their theory has the following three flaws. [1] The physical interpretation for GW sources is not given. [2] The (singular) perturbation method is not used. [3] The reaction by GW radiation to the vortical flow is not considered. In this study, we propose a new theory, which is free from all these flaws. Validity of this new theory is carefully examined by using the result of numerical model simulation.

The essence of this new theory is that GW are radiated from the slaved components of the vortical flow through a quasi-resonance, when the ground-based frequencies of GW are significantly Doppler-shifted by the vortical flow and have timescales comparable to that of the slaved components.

So as to make the physics clear, linear potential vorticity (q), horizontal divergence (d), and ageostrophic vorticity (g) are used as dependent variables. The vortical flow is defined as the flow associated with q, and the slaved components are defined as d and g that are diagnostically determined from the distribution of q. In the linear theory, d and g contain high ground-based frequency components. As the nonlinear terms in these high frequency components contain slowly varying components with timescales comparable to that of q, it is necessary to include them in the theory. Thus, in order to consider both GW and these slowly varying components, five variables are used to construct the theory which describes the spontaneous radiation through the quasi-resonance (problem [1] is solved): q, two variables (d^{GW}, g^{GW}) for GW, and two variables (d^{diag}, g^{diag}) for slowly varying components.

For theoretical formulation, we use the renormalized perturbation method which is one of singular perturbation methods (problem [2] is solved). In addition, in order to take account of the Doppler shift, the eigenmode expansion in a given arbitrary vortical flow field is made for d^{GW} and g^{GW}. On the other hand, the ordinary renormalized perturbation method is applied to d^{diag} and g^{diag}. Diagnostic components, d^{diag} and g^{diag}, are separated into two parts: the GW radiation reaction and slaved component. The derived theoretical equations also contain the variation of q by the GW radiation reaction. This means that the problem [3] is solved.

In order to examine validity of the theory, the quasi-steady spontaneous radiation of GW in a vortex dipole is simulated using the Japan Meteorological Agency nonhydrostatic mesoscale model (NHM). The modon solution, that is an exact solution for three dimensional QG equations on the beta plane, is given as initial values to perform numerical integrations of the compressible nonhydrostatic equations. Similar to the previous studies, GW are radiated upward and downward from the jet exit region. GW phase structure is almost symmetric around the jet axis in the vertical cross section. The nearer to the dipole edge, the shorter the GW wavelength becomes. The GW are wrapped into the dipole vortices at its edge. Next, the renormalized group equations are integrated with GW sources obtained from the initial modon field that does not include GW. As a result, it turns out that these equations successfully reproduce spontaneously radiated GW in the jet exit region as is consistent with the result of NHM.

Keywords: spontaneous radiation, gravity wave, renormalized perturbation method

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Consideration of latent heat transport processes in the Penman-Monteith equation

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It is considered that there are two processes in the latent heat transport, which are turbulent diffusion and molecular diffusion, but when we estimate the latent heat flux from the place whose spatial scale is as large as the plant community (tens to thousands meters), the expression is often used taking into account only the turbulent diffusion process and the molecular diffusion process is rarely considered.

However, Furuya et al. (2011, JpGU meeting) suggested that molecular diffusion process, compared to turbulent diffusion process, contributes to the sensible heat transport near land surface, and if we estimate the sensible heat flux, we should use the estimation formula considering molecular diffusion process because the formula expresses the real physical mechanism. This can be said about the latent heat transport.

Therefore, we calculated Penman ? Monteith equation (Monteith, 1968) which is often used to estimate the latent heat flux assuming turbulent diffusion or molecular diffusion and compared the estimations with the observed interception loss which is reported by Furuya et al.(2012, JpGU meeting).

In result, whether the estimated values fit the observed value depended on the day, but the estimations with two different theories were similar.

We used values by Rutter et al. (1971) to calculate the estimation assuming turbulent diffusion but the values are not in accordance with the physical law and they are decided in order to fit with observations, while the calculation with molecular diffusion has no arbitrary constant. Considering this point, this result showed that the method assuming molecular diffusion to estimate latent heat flux can explain the real mechanism.

Keywords: latent heat, heat transport, land surface process, atmospheric boundary layer, vegetation