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

MIS021-01 Room:202 Time:May 22 09:00-09:15

Generation and development of a polar low under the influence of a vortex aloft

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Polar lows are mesoscale cyclones that develop over high-latitude oceans in winter. The influence of an upper-level vortex on the generation and development of a polar low is investigated through numerical simulation in an idealized atmosphere.

In previous works which focus on this mechanism, the initial configuration is modeled by an upper-level vortex upstream of a lower-level vortex, and the importance of the relative distribution of these vortices has been shown. However, it is possible that a lower-level disturbance is formed by the influence of an upper-level disturbance. Therefore, it is investigated whether a lower-level disturbance is initiated by an upper-level vortex to develop into a polar low. The three-dimentional nonhydrostatic model simulated the polar low that is spinuped due to the influence of upper-level vortex and developed into a polar low with comma-shaped cloud pattern.

The process of formation of lower-level vortex due to upper-level vortex is investigated. Two mechanisms have been suggested in formation of a surface disturbance due to upper-level vortex. One is that a surface vortex is stretched by the upward motion aloft driven by the upper-level vortex and the other is that a surface vortex is stretched by surface potential temperature deviation in association with potential temperature advection, where the lower-level baroclinicity is emphasized. Considering that the condensation is of less importance in the generation stage of a polar low, the results of a dry-experiment without moist process are analyzed. It was shown that lower-level vortex is formed by the stretching in association with upward motion aloft driven by the upper-level vortex. On the other hand, the vortex moves southward so that the latter mechanism did not contribute to the formation of the lower-level vortex.

The southward displacement of the lower-level vortex was investigated. In this experiment, polar low moves not only eastward but southward during the most part of the calculation time, although it displaces northward a little in its mature stage. It was found that the northward displacement of the vortex is caused by a vorticity streching on the northern side of the vortex due to the active convection with condensation, while an existence of an anticyclone vortex behind the vortex which form a vortex pair caused the southward displacement of the vortex.

Keywords: polar low, vortex aloft, baroclinicity, comma-shaped cloud

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A case study on the meso-scale disturbances causing the severe snowstorm in Niigata Prefecture on 13 January 2010

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Previous studies have revealed that mesoscale vortical disturbances are formed over the Japan Sea in winter and that they cause heavy snowfall and severe wind hazards in the coastal region of the Hokuriku District. The vortical disturbances often develop into meso-alpha or meso-beta scale disturbances (MASDs and MBSDs, respectively). It's important to know the generation and development processes and internal structures of these disturbances in order to prevent and mitigate disasters.

In this study, we investigate the development processes and the 3-dimensional structure of MBSDs that approached the Hokuriku District on 13th January 2010. By the passage of the MBSDs, the JMA surface observation at Aikawa recorded a maximum wind speed of 40.0 m/s at 0745JST, and the snowstorm caused several power failures and traffic accidents in the Niigata prefecture. The JMA operational radar displayed five MBSDs between 00JST and 12JST on 13. Two of them moved ahead toward east-northeast. Thereafter, the other three moved toward southeast, two of which are considered the cause of the heavy snowfall and severe winds. The surface observation showed that the temperature within the eastern part of the MBSDs were higher than that in other areas. We suppose that the positive temperature deviation represented the warm core (hereafter WC) of the MBSDs.

In order to examine the internal structure of the MBSDs, we performed numerical simulations using a JMA-nonhydrostatic model (Saito et al. 2006) with a horizontal resolution of 2km. Three telescoping one-way nested grids (horizontal grid spacing of 20km; 20km-NHM, 5km; 5km-NHM, and 2km; 2km-NHM) were used. The initial and boundary conditions of the 20km-NHM were produced from the GANAL. The settings of each proccess in the 5km/2km-NHM are the same as that of Saito et al.(2007).

The 2km-NHM reproduces MBSDs moving toward either east-northeast or southeast. As for the MBSDs causing the snowstorm, the horizontal scale of the distribution of the simulated snow particles was larger than that by JMA radar observation. However the simulated MBSD moved a little southly and made landfall in Niigata prefecture 2-hour earlier than the observation, features (wind, decreased pressure, and WC) of the observed MBSD were well simulated.

Previous studies suggest that MBSDs have a WC (Ninomiya et al. 1990) and the WC is produced by the advection of airmass with high equivalent potential temperature from the major cyclone passing over Japan, diabatic heating due to condensation, and adiabatic heating due to downdraught (Murakami et al. 2005). In order to investigate the genesis of WC, we analysed the backward trajectories of particles around the center of MBSD. The result of the analysis shows that there were no airmass advection from the major cyclone. In the vicinity of the simulated MBSD, there existed convective clouds with heavy snowfall accompanied by updraghts instead of downdraughts. In order to investigate the effect of diabatic heating due to condensation on the development of the MBSDs, we performed a sensitivity experiment using a dry model without the condensation process. The MBSDs moving toward southeast were well simulated, but they had no WC or severe winds. In addition, the MBSDs moving toward east-northeast stalled off the coast of Niigata prefecture maintaining the WC structure which was given initially. As the MBSDs moving toward southeast were approaching the WC of the stalling MBSDs, severe winds appeared around the center of the MBSDs. The result implies that the WC of MBSDs causing a severe snowstorm was mainly produced by diabatic heating due to condensation in this case, and further suggests the possibility that it plays a major role in the development of MBSDs with severe winds. The MBSD was also collocated underneath the upper vortex with high potential vorticity dipping down into low levels. This suggests the possibility that the upper vortex contribute the development of MBSDs.

Keywords: vortical disturbances, NHM

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Influence of atmospheric absorption on time change of thunder spectrum

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Lightning discharge is a large-scale spark discharge that takes place in nature. Thunder is the sound wave from lightning. The sound wave from familiar short-distance spark discharge like a static electrical spark is pulse-like one, that has flat frequency characteristics. However in thunder low-frequency component is dominant. Foregoing rumbling of thunder has been discussed. Atmospheric absorption and interference of sound waves from spatially-dispersed sound source are thought as causes of rumbling. However quantitative understanding of these is insufficient.

We observed thunder and examined time change of its amplitude spectrum. Here the spectrum at a certain time is an analysis of about 0.5 seconds around the time. We did such an analysis through one thunder and obtained time change of thunder spectrum. As a result, the gradient of the spectrum of a thunder was found to become steep at a rate of about 0.002 dB/Hz a second; attenuation occurs from high-frequency component.

On the other hand, we calculated thunder as superposition of sound waves from each point on lightning channel. Here we approximate lightning channel by a simple straight line sound source and a pulse is generated from each point on the line source. Each pulse attenuates depending on frequency by atmospheric absorption. We used standard atmosphere model to calculate attenuation. Amount of attenuation increases with duration, because the waves from distant source arrive late and attenuate greatly. As a result, the spectrum steepened at a rate of about 0.002 dB/Hz a second. This almost corresponds to observation and indicates the effect of atmospheric absorption on rumbling of thunder.

Keywords: thunder, atmospheric absorption, lightning channel

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Is the atmosphere cooled by the ground?

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Generally the atmosphere is cooled by the ground. As the result of our observation, the routinely situation is that the ground surface temperature is higher than air temperature all day. Then how may the air temperature is lower the than the ground surface temperature?

We observe how to cool each air temperature at 5 points different altitude in Kyoto city. There observation points are the top of Mt.Hiei (800 meters), 550 meters point at Mt.Hiei, Hiei-daira (370 meters), Kamitakano (100 meters) and Kyoto university(50 meters). This observation is only air temperature. When we analyze it, we selected some fine day to remove influence by the weather.

As a result, a similar bedding process was verified through the year. It is a concept exactly that the max potential temperature is the same each altitude. And then, they fall together and gradually steady from the top of Mt.Hiei in due order. In other words the atmosphere does bedding from the sky. This result is different from the concept. Naturally we should be able to see the process that the atmosphere does bedding of from the low place of the meters above to sea level if the atmosphere is cooled by the ground. When not the concept of the convection we think in a concept of the radioactive equilibrium, will not the atmosphere do bedding from the sky? In this announcement, we report it about the actual situation of the cooling process of the atmosphere through these observation results.

Keywords: atmospheric boundary layer, bedding process, cooling, radiation

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For the bulk exchange coefficient Ch

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The bulk method is often used to calculate momentum flux, sensible heat flux, latent heat flux in the atmospheric boundary layer, and assumes that heat exchange of air occurs due to turbulent diffusion. However, in this research, it is proved that vertical profile of air temperature is almost uniform by convection from the surface 0.5 cm above and there is a heat boundary layer near the land surface where turbulent diffusion does not occur. Therefore we concluded that we cannot use the bulk formulation which assumes turbulent diffusion to calculate the vertical profile of air temperature and heat balance near the surface. But then suggesting the sensible heat is transported because of thermal conduction through the heat boundary layer of 0.5 cm near the surface, we calculated the bulk exchange coefficient Ch, which means the vertical exchange rate of air masses of different temperatures in the bulk formulation, and confirmed that this Ch is nearly equal to the Ch which is estimated assuming turbulent diffusion. Consequently, it is suggested that we should recognize Ch means the heat transport rate because of not turbulence diffusion but thermal conduction.

Keywords: bulk formulation, boundary layer, sensible heat

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Wind stress of fractal stracture

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The concept of fractal was advocated by Mandelbrot in 1975. This succeeded in the description of a lot of objects and phenomena of the natural world that were not able to be described up to now vaguely by a new dimension of fractal dimension. However, the character that the fractal in a physical phenomenon shows had been hardly researched in a current research as for the fractal dimension of various objects and phenomena though it had been requested. The one is a research of the flow around the fractal. In the present study, it paid attention vaguely of the fractal structure, and the meaning that the vagueness showed was verified from an experimental standpoint of wind tunnel experiment by the wind tunnel of making to visible experiment and the air resistance measurement experiment. The wind tunnel experiment device was made, and it requested there, and concretely, the screen where the plane was distributed in the fractal, random, and the checker was put, the differential pressure before and after the observation and each distribution directly of the flow by the experiment of making to visible that made smoke a tracer was measured directly, and the wind drag of each sample was requested by it. As a result, the wind drag that the fractal received indicated big values next smallest in order in which it was random and was checkered though the width of the diffusion of smoke in the wind tunnel did not change so much. It compares besides, a big whirlpool is generated easily, and, therefore, this is thought that it is because the energy penalty because of the whirlpool generation is small for the fractal. After all, it can be said that the most effective distribution in the flow is a fractal that is not random that is not the checker that is regular distribution but irregular distribution, and the vaguest distribution. In a word, it has the structure that the fractal with vagueness ventilates easily most.

Keywords: fractal, wind stress

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Dependence of the characteristics of an atmospheric general circulation on the planetary parameters from Earth to Mars

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We have been developing an atmospheric general circulation model (GCM) aiming at investigating general circulation of planetary atmospheres, such as the Mars, the Earth, the Venus, and ideal planets which may have some characteristics of exoplanets. Purposes of the model development are to enable us to investigate, with a common dynamical framework, possible varieties of general circulations of planetary atmospheres, and to understand underlying mechanisms that realize the varieties of circulations to extend our knowledge on planetary atmospheres. In the followings, the model which is being developed is described, and some preliminary results of experiments for the Earth- and Mars-like planetary atmospheres are presented.

An atmospheric GCM, dcpam (http://www.gfd-dennou.org/library/dcpam/index.htm.en), is developed with the basis of the Geophysical Fluid Dynamics (GFD) Dennou Club atmospheric GCM (http://www.gfd-dennou.org/library/agcm5/index.htm.en). Dynamical core of dcpam solves the primitive equation system by using spectral transform method with the finite difference method in vertical direction. The included physical processes are the radiative, the turbulent mixing, and the surface processes. Further, simple condensation scheme of CO2, which does not consider mass change due to condensation, is included for Mars experiment. The radiation models currently implemented in the model are those for Mars' and the Earth's atmospheres. The radiation model for grey atmosphere is also prepared for experiments for ideal planets. In addition, the simple forcing for the dynamical core test of Held and Suarez (1994) and for an experiment of Venus-like atmosphere following Yamamoto and Takahashi (2003) are also implemented.

By the use of this model, several experiments have been performed. In the followings, preliminary results of sequential experiments from an Earth-like to a Mars-like planet are presented. Following six sequential experiments are performed: (I) the Earth experiment, in which Earth's topography and land-ocean contrast are used and planetary radius and length of day in a year are Earth's values, (II) same as (I) but without orographic variation, (III) same as (II) but without ozone heating, (IV) same as (III) but without water/moist processes in the system, (V) same as (IV) but with planetary radius of Mars' value, and (VI) same as (V) but with length of days in a year of Mars' value (669 days). In the experiments (I)-(III), the Earth's land-ocean distribution is used and the climatological sea surface temperature is prescribed on the ocean grid point. Those experiments are performed with the horizontal resolution of T42 and 16 vertical levels. The horizontal resolution of T42 is equivalent to about 2.8 degrees longitude-latitude grid. Under these conditions, the model is integrated for 20 years from an initial condition of isothermal atmosphere at rest. The result during last 10 years is analyzed.

In this study, we focus on the structure of Hadley circulation at solstitial seasons when the structure is asymmetric with respect to the equator. The results show that one of the most important differences in Hadley circulation is caused by existence or absence of water in the system, as expected. It affects intensity and vertical extent of Hadley circulation significantly. This is qualitatively interpreted by the difference in moist and dry adiabatic lapse rate, if the surface temperature does not change significantly. In addition, the difference in planetary radius appears to have some influence on the latitudinal width of Hadley circulation. An additional experiment with quarter of Earth's radius shows that the latitudinal width of Hadley circulation is larger than that in the experiment with Mars' radius. In the presentation, these features will be discussed with showing results of additional experiments.

Keywords: planetary atmosphere, Mars, Earth, general circulation model

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An eddy-feedback mechanism for the maintenance of atmospheric blocking

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Atmospheric blocking is a stationary coherent dipole-eddy with an anticyclone (blocking-high) centered to the north of a cyclone (blocking-low) in the westerly jetstream at mid-latitude, and has the recursiveness and persistency. Blocking is the phenomenon that the dynamical mechanism is not succinctly understood although they appear in simple dynamical models such as that of the quasi-geostrophic shallow-water equations, so it should be studied by the approach from the geophysical fluid dynamics.

About the notable persistency of blocking, in its dynamics, many studies have been devoted to the maintenance mechanism after the work of Green (1977) in which a feedback mechanism in the system between blocking and synoptic eddies (migrating highs and lows) is proposed. Hereafter, it is called the eddy-feedback mechanism. In this manner, Shutts (1983) particularly discussed about the essential points of the eddy-feedback mechanism by using both an analytical method and simple numerical experiments, and proposed the Eddy Straining Mechanism (hereafter referred to as ESM). It is the mechanism that synoptic eddies strained in the north-south direction by blocking provide negative/positive vorticity to a blocking high/low and this vorticity forcing, i.e., the second-order flow maintains the blocking dipole structure against dissipation such as friction. Some recent studies, however, showed that the ESM can act efficiently only when the eddies or the stormtrack which corresponds the ensemble-behavior of eddies satisfies some specific conditions that is difficult for the persistent periods of blocking in the real. Then, we propose and consider a more realistic eddy-feedback mechanism alternative to the ESM.

The eddy-feedback mechanism is based on the following two views in terms of potential vorticity (PV), which is a conserved quantity in a frictionless and adiabatic atmosphere. The first is to grasp the maintenance mechanism as the supply mechanism of anticyclonic/cyclonic PV air to a blocking high/low, and the second is the vortex-vortex interaction mechanism that an eddy actively attracts and absorbs one with the same polarity selectively, whereas separates one with the reverse polarity. The latter is essentially the same as the ‘Fujiwhara-effect’ or the ‘beta-drift’ but the more quantified mechanism by the use of PV. In this mechanism, a blocking anticyclone (cyclone) actively and selectively absorbs synoptic eddies with the same polarity, and then makes a feedback system by reinforcing its own persistence. The heart of this mechanism is the vortex-vortex interaction so it is a different mechanism from the ESM. The difference between these two mechanisms can also be discussed from the mathematical formulations (Yamazaki and Itoh 2009). In this study we verify our proposed mechanism by conducting a numerical experiment with some different conditions.

Using the nonlinear equivalent-barotropic PV equation model as Shutts (1983), the effectiveness of our mechanism is investigated. In this mechanism, a blocking could persist not depending on some valiabilities of stormtrack. As an experimental design, the blocking flows as modon solutions are put on the center of the model-domain. Experiments are performed for the following 3 cases; i) there is no stormtrack, ii) the stormtrack is put on the same latitude as the blocking center (the center latitude of the domain), and iii) the stormtrack is put on the latitude of 1,000 km south of the blocking center, which is too large variability for the ESM to acts effectively. The results show that, on both a beta-plane channel and sphere, our eddy-feedback mechanism effectively works to maintain the blocking without depending on the characteristics of stormtrack (synoptic eddies).

Keywords: Atmospheric dynamics, Low-frequency valiability, Synoptic-scale meteorology, atmospheric blocking, nonlinear, Tropospheric Science

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Numerical experiments of large-scale vortices in Jupiter's atmosphere: The generation mechanism of large-scale vortices

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1. Introduction

The Great Red Spot is a large-scale vortex in Jupiter's atmosphere larger than 20000 km in diameter and exists for more than a century. Williams(1996; here after W96) reproduced large-scale vortices resembling the Great Red Spot in size by using a three-dimensional numerical model. However, the strength of the jets (zonal mean zonal velocity) and vortices became weaker after long-time integration. If the strength of the jets is maintained, behavior of vortices is expected to change. Therefore, we try to maintain the strength of the jets by introducing forcings that maintain zonal mean state and examine how the behavior of vortices depends on the intensity of the forcings.

2. Model and Setup

We perform numerical experiments by using a three dimensional model on a sphere based on the primitive equation of the Boussinesq fluid with parameters in Jupiter's atmosphere. Experimental setup is almost the same as the case A4 of W96, in which stable "weather layer" and alternating jets are confined to the upper region of the vertical domain. However, in this study, we introduce forcings that maintain zonal mean state so as to maintain the jets. We conduct 19 experiments with four types of forcings: (1) no forcing, (2) momentum forcing that damps zonal mean zonal winds to the initial zonal wind, (3) thermal forcing that damps zonal mean temperature to the initial temperature, (4) both (2) and (3) with the same damping time. Six values of damping time, 30, 100, 300, 1000, 2000, and 4000 days, are used for both the thermal and momentum forcing terms. Each numerical experiment is continued for 10000 - 70000 days.

3. Results

Only in the four cases of both thermal and momentum forcings with damping time 100, 300, 1000, 2000 days, zonal mean fields and wave fields reach statistically steady states. In these cases, behavior of disturbances depends on the strength of the damping and can be classified into two groups.

In the cases of the strong forcings (damping time are 100 and 300 days), many large-scale vortices are generated continuously at 500 -1000 days intervals but their lifetime are short (500 -1000 days) (size is about 90000 km in longitude and 10000 km in latitude). The large-scale vortices exist across the latitude Phi_0 where the meridional gradient of zonal mean potential vorticity change sign horizontally. The disturbances with the scale of the large-scale vortices have an ability to transport westerly momentum latitudinally. As for the energy conversion property from zonal mean to wave field, barotropic conversion is positive for the disturbances.

In the cases of weak forcings (damping time are 1000 and 2000 days) , no large-scale vortices appear and waves exist on the north and south of Phi_0 with different scale. On the north (south) of Phi_0, small (large) scale wave exists and baroclinic (barotropic) conversion is positive.

We conduct a linear stability analysis for the time and zonal mean fields in the cases with strong and weak forcing. In the analysis, linear instability modes are found, whose zonal wave lengths, phase structures, and energy conversion properties are similar to those of the disturbances in nonlinear calculation shown above. For this reason, it is suggested that the disturbances in nonlinear calculation are generated by linear instabilities of the basic states. In addition, it is also suggested that the generation mechanism of the large-scale vortices in the case of strong forcing is not upward-cascade by small scale vortices but barotropic instability.

Keywords: Jupiter's Atmosphere, large-scale vorticies, The Great Red Spot, numerical experiment, barotropic instability, linear stability analisis

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The interaction between zonal jets on a beta plane

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It has been well known that, in the forced two-dimensional barotropic incompressible flows on a rotating sphere, a structure with many alternating eastward and westward jets emerges in the course of time development (Nozawa and Yoden[1]). The multiple zonal jets experience gradual mergers/disappearances, and then a structure with two or three alternating large zonal jets is realised asymptotically (Huang *et al.*[2], Obuse *et al.*[3]).

One of the possible interpretations of such a merger/disappearance of zonal jets is that the state with multiple zonal jets may be dynamically unstable and transitions to a stable state with wider and fewer zonal jets occur. It is accordingly tempted to examine the stability of zonal jets driven and maintained by a small-scale forcing and background small-scale turbulent motions.

Zonal jets having a transverse sinusoidal background flow on a beta plane is one of the models used to investigate the effect of the turbulence and the mechanism of mergers/disappearances of the jets described above. This model was originally introduced and numerically investigated in Manfroi and Young [4], and is known to show a structure with many zonal jets that slowly disappear one by one.

In our study, we use an analytical stationary solution of the governing equation of the zonal jets U_0 (x) (Obuse *et al.* [5]) and estimate the weak interaction between two zonal jets by a perturbation method to discuss the jets' gradual mergers/disappearances.

When two zonal jets are weakly interacting with each other though their small tails of O(e), we assume that the total velocity U(x, t) is approximately written as $U(x, t) = U_0(x - l_1(t)) + U_0(x - l_2(t)) + V(x, t)$, and put assumptions that $l_1(t)$, $l_2(t) = O(1)$, $V(x, t) = O(e^3)$, time derivative = $O(e^2)$, x-derivative = O(1). Here l_1 and l_2 are the centre positions of two jets and V is a two jets' deviation from stationary solution. The time derivative of the distance between two jets obtained from a perturbation method utilizing the small parameter e and the assumptions above well coincides with the one obtained from numerical time integration of the governing equation of U(x, t) in terms of the behavior. This may suggest that the mergers/disappearances seen in the numerical simulation can be explained by the weak interaction between two zonal jets though their tails.

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Keywords: rotating fluid, barotropic flow, turbulent flow, zonal jets, beta effect

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Mean-zonal-flow generation in Boussinesq thermal convection in a rotating spherical shell

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Global thermal convection is considered to take place in stellar interiors, the atmospheres of the giant planets, and the fluid cores of the terrestrial planets in the presence of the internal heat sources and/or the external cooling. The Boussinesq thermal convection in a rotating spherical shell, which is one of the most fundamental frameworks to investigate characteristics of these global phenomena, was proposed by Chandrasekhar half a century ago, and has been investigated extensively. However, fundamental properties of its bifurcation structure including the convection patterns bifurcating at the critical point and their stability, are not well understood yet.

Recently we studied the stability and the bifurcation structure of (nonlinear) traveling waves propagating in the longitudinal direction, and found that when the ratio of inner and outer radii is 0.4, the Prandtl number is 1 and the Taylor number is from 52^2 to 500^2, the traveling wave TW4s, which have four-fold symmetry in the longitudinal (azimuthal) direction, bifurcate supercritically at the critical point and are stable for $\mathrm{Ra}_c < \mathrm{Ra} < 1.2\ \mathrm{Ra}_c$–$2\mathrm{Ra}_c$, where Ra and Ra_c are the Rayleigh number and its marginal stability value[1]. The propagating direction of the traveling wave changes from retrograde to prograde on the neutral stability curve as the Taylor number is increased. However, as the Rayleigh number is increased, the direction is found to change again from prograde to retrograde except for the case of small Taylor number.

The change of the propagating direction on the neutral stability curve is explained by the elongation and contraction of vortices[2], while the the direction change with increasing Rayleigh number is interpreted as an advection of the convection cell by the retrograde mean zonal flow generated by the nonlinear effect of the thermal convection.

Here we study the generation mechanism of the mean zonal flow which is crucial for the longitudinal propagation of the finite-amplitude traveling wave, employing the weakly nonlinear analysis[3]. We deal with the parameter region of the supercritical bifurcation of TW4s solution, where the ratio of the inner and outer radii is 0.4, the Prandtl number 1 and the Taylor number from 52^2 to 860^2.

We linearize the governing equation around the state of rest in the rotating frame of reference, and obtain the critical mode. We then calculate the secondary mean flows by substituting the critical mode into the nonlinear terms. There are four nonlinear terms in the governing equations, which we classify into three groups as follows:

(1) the longitudinal velocity component of the Navier-Stokes equation,
(2) the colatitudinal and radial velocity components of the Navier-Stokes equation,
(3) the energy equation.

Each nonlinear term generates the mean zonal flow in the following mechanisms:

(1): the meridional transfer of the angular momentum by the Reynolds stress generates the mean zonal flow,
(2): the Coriolis force against the mean meridional flow induced by the Reynolds stress generates the mean zonal flow,
(3): the Coriolis force against the mean meridonal flow induced by the latitudinal gradient of the secondary mean temperature disturbance, which is caused by the convective heat transfer, generates the mean zonal flow.

We numerically evaluate the mean zonal flow generated by the nonlinear terms (1)–(3), and find that the nonlinear term (3) generates the strong retrograde zonal flow near the middle of equator, which is observed at large Taylor number, several times stronger than those by the nonlinear terms (1) and (2).

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Keywords: bifurcation, traveling wave, mean zonal flow, weakly nonlinear analysis

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MIS021-12 Room:202 Time:May 22 12:00-12:15

Long-term variations of the upstream Kuroshio Extension based on self-sustained dynamic modes.

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1.Introduction

Variations of upstream KE jet exhibits two flow patterns (Qui and Chen, 2005). The first pattern is quasi-stationary meanders of two bumps with intensive southern recirculation gyre (first mode). Another flow pattern is unstable and shows high-amplitude meanders with a weakened southern recirculation gyre (second mode). The upstream KE jet varies between the first mode and the second mode with decadal time scales.

Many studies have pointed out the importance of nonlinearity in the ocean by itself to induce the decadal time scale changes (Primeau and Newman 2008, Shimokawa and Matsuura 2011), which is main topic of this study. Firstly, using self-organaization map (SOM) analysis we examine the variations of upstream KE jet in more detail and variation pattern were sorted out. Secondly, we make a reconstruction of attractor of Sea-Surface Hight (SSH) to reveal whether this phenomenon is the chaotic one or not.

Moreover, we investigate this phenomenon by simulating an OGCM (MOM3) of the North Pacific Ocean forced by seasonal climatological winds for 30 years.

2.Used data and methods

SSH data of MOVE/MRI.COM-WNP were used to analyze the characteristics of KE jet. The used data are averaged over 10 days from early January 1993 to late December 2005. The domain of MOVE/MRI.COM-WNP covers over the sea areas of 117E - 160W, 15N - 65N in the North Pacific. The horizontal resolution is 0.1x 0.1.

SSH are extracted in the ocean area of 141E - 153E , 30N - 40N to carry out SOM analysis and to estimate the mean strength of the upstream KE jet. The size of SOM in our analysis is 169, that is 13 x 13 matrix. We make a reconstruction of attractor of the time series of SSH anomalies by transforming observed time series into delayed time series.

Moreover, we simulated the North Pacifoc Ocean to confirm the long-term variations of the upstream KE based on self-organized dynamic modes. The OGCM used in this study is the GFDL Modular Ocean Model version 3 (MOM3). Computational domain covers the North Pacific (110E-75W, 20S-60N). The model has a horizontal resolution varying from 1/12 around Japan (125E-160E, 20N-50N) to 1/2. The model topography is based on 1/12 ETOPO5 data.

3. Result

The time series of strength of upstream KE jet obtained from ocean data assimilation corresponds well to Topex/Poseidon altimeter results of Qiu and Chen (2005). The upstream KE jet was strong in 1993-94, weakened to 1997 , and strengthened to 2004 again.

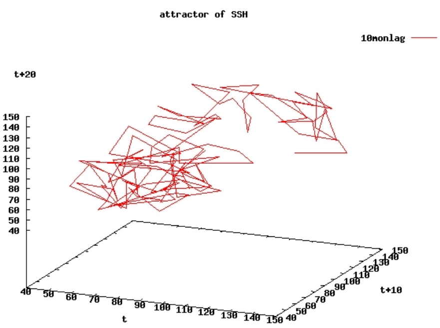
SOM analysis revealed two long-term disparate variation patterns. The first is the stable pattern with strengthening southern recirculation. The second is the unstable pattern with weak southern recirculation. Patterns in 1993-94 and 2002-2005 were sorted out as the stable pattern and pattern in 1996-2001 was sorted out as the unstable pattern.

As a result of a reconstruction of attractor, an obtained pattern could not be recognized as the strange attractor completely. However, it was spatially divided into two parts.

The interannual variability appeared in SSH data obtained from a simulation of the OGCM (MOM3). In particular, the variability in the simulation showed strengthening/weakening of southern recirculation and north-south shift of upstream KE jet axis which confirmed by analyzing MOVE/MRI.COM-WNP.

4. Discussion

It is clear that the variability in strength of upstream KE jet corresponds to the variability in stable-unstable pattern. In particular, when upstream KE jet is stable (unstable), the strength of upstream KE jet is strong (weak). Obtained attractor which was spatially divided into two parts indicates that the time series of strength of upstream KE jet is not completely random, but it possess certain unique behavior. The results of OGCM simulation indicate that the nonlinearity in the ocean itself affects on variations between stable and unstable of the upstream KE jet and north-south shifts of KE jet axis.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Japan Geoscience Union Meeting 2011
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MIS021-13 Room:202 Time:May 22 12:15-12:30

Thermal convection in low Prandtl number fluids: generation of oscillatory phenomena by numerical simulations

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The study on the nature of thermal convection in low Prandtl number (Pr) fluids is essential for the dynamics of the Earth's outer core, and the difference of the flow behavior from Pr~1 fluids like water and air is very important. In lower Pr fluids, the two-dimensional steady roll structure emerging at the onset of convective flow easily becomes time-dependent just above the critical Rayleigh number (Ra), and theoretical studies propose oscillatory instability such as "traveling-wave convection" in the direction of the roll axis. Transition to turbulence with increases in Ra in low Pr fluids occurs at much lower Ra than water or air, and large-scale flow is also expected to emerge easily.

Our laboratory experiments on thermal convection with liquid metal by using an ultrasonic velocity profile measurements visualized the flow pattern in a gallium layer with simultaneous measurements of the temperature fluctuations, from 10 to 200 times above the critical Ra (Yanagisawa et al., 2010). In those experiments, the presence of a roll-like structure with oscillatory behavior was established, even in the Ra range where the power spectrum of the temperature fluctuation shows features of developed turbulence. The flow structure was interpreted as a continuously developed one from the oscillatory instability of two-dimensional roll convection around the critical Ra. It was shown that both the velocity of the flows and the frequency of the oscillation increase proportional to the square root of Ra, and that the oscillation time of the roll structure is comparable to the time to complete one circulation of the flow.

We made up a code for numerical simulation of thermal convection to compare with the results obtained by the laboratory experiments. Furthermore, we analyzed the fine scale structure and short time variation relating to turbulence, those are difficult to obtain by laboratory experiments due to the limitation of measurements. The numerical simulation is performed for three dimensional rectangular box, with no-slip boundary conditions at all boundaries, fixed temperature at the top and bottom, and insulating at side walls. The range of Ra for numerical simulations is from critical value to 200 times above it. The material properties of the working fluid are those of liquid gallium and Pr=0.025. We used enough grid points to resolve the small-scale behavior without any assumption for the turbulence. Our numerical result reproduced oscillatory convection patterns as observed in the experiments. Statistical values, such as the relation of the circulation time and oscillation period, Rayleigh number dependence of the mean velocity and the oscillation frequency, are good agreement in both laboratory and numerical studies. This confirms that both of our laboratory experiment and numerical simulation are reliable ones. The series of numerical simulations with the increase in Ra revealed the onset point of oscillatory convection and subsequent transition to turbulence. The power spectrum densities calculated from the velocity and temperature dataset clearly indicate the feature of low Pr fluid, that is, temperature is more diffusive than momentum and the corner frequency is higher for velocity spectrum in the region of developed turbulence.

Keywords: thermal convection, low Prandtl number, numerical simulation, pattern, turbulence

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MIS021-14 Room:202 Time:May 22 12:30-12:45

Deformation of water surface rotating in a cylindrical tank

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In the terrestrial and planetary atmospheres, the axisymmetry of a vortex occasionally breaks and vortices with various structures are observed. Similar phenomena are observed on water surface in laboratory experiments in which water layer in a right cylindrical tank is driven by a rapidly-rotating bottom disk: the shape of the water surface is modified to be a polygon.

In this study, we have performed the laboratory experiments, focused on the range of the parameter values in which the axisymmetry breaks, and found two interesting phenomena. One is a vacillation in which the water surface oscillates greatly and becomes calm alternately. The other is a hysteresis in which there are two different states for the same rotation rate accordingly when it is increasing and decreasing. We investigated the dependence of these phenomena on experimental parameters: the initial water depth and the rotation rate. The oscillation occurs only in the condition in which the initial water depth is larger than a certain value. As the depth becomes larger, the rotation rate for the oscillation phenomenon becomes smaller, while that for the hysteresis phenomenon becomes lager.

We examined the experimental results using a simple dynamical model. In this model, the current velocity is represented only by two values; inner and outer velocities. The disturbance grows through instability of the axial flow. The exchange of momentum by the disturbance is taken into this model. We succeeded in reproducing the hysteresis as observed in the laboratory experiments with this simple model.

Keywords: rotating fluid, laboratory experiment, oscilation, hysteresis

Japan Geoscience Union Meeting 2011
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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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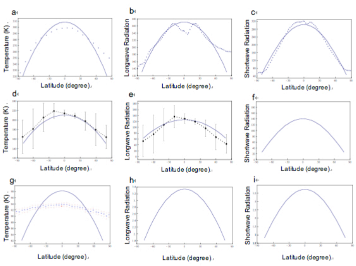

Figure 1, Latitudinal distributions of (a) surface temperature, (b) longwave radiation (W/m^2), (c) shortwave radiation (W/m^2) in the Earth. Latitudinal distributions of (d) surface temperature, (e) longwave radiation (W/m^2), (f) shortwave radiation (W/m^2) in Mars. Latitudinal distributions of (g) 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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MIS021-P02 Room:Convention Hall Time:May 22 14:00-16:30

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

Japan Geoscience Union Meeting 2011
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MIS021-P03 Room:Convention Hall Time:May 22 14:00-16:30

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

Japan Geoscience Union Meeting 2011
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MIS021-P04 Room:Convention Hall Time:May 22 14:00-16:30

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