The circulation structure in the Martian atmospheric boundary layer obtained by high resolution LES

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1. Introduction

Dust in the Martian atmosphere has a great influence on the temperature structure of the atmosphere (Montabone et al., 2005). Dust is lifted from the ground by the wind in the atmospheric boundary layer. In many studies using atmospheric general circulation models (GCMs), dust lifting by the subgrid scale wind is parameterized. Validity of parameterization schemes has been examined through comparisons of distributions of dust optical depth and temperature obtained by calculations with observational results.

More direct validation dust lifting parameterization comparing with the microstructure of wind fields in the atmospheric boundary layer is desirable, but has not been conducted. Instead, examinations with the results of large eddy simulations (LESs) have been performed. Fenton and Michaels (2010) conducted LESs whose horizontal resolution was 100 m. They used initial states with various horizontal wind distributions. Their results suggest that certain initial wind distributions cause dust lifting. However, effects of phenomena such as the dust devils with horizontal scale of dozens of meters could not be represented because of coarse resolution. Nishizawa et al. (2016) conducted LESs where several different grid spacing ranging from 100m to 5m were employed to examine resolution dependence. The isotropic grid spacing of 5 m is the highest resolution among Martian LESs performed so far. The initial state is a horizontally uniform rest atmosphere. They examined vorticity and vertical wind at altitude of 62.5 m. The vertical wind has cellular structures whose boundaries are composed of narrow regions with strong upward winds. With the higher resolution, the intensity of vorticity becomes stronger and radius of vorticity becomes smaller. In the previous studies described above, the circulation field near surface has not been examined, although the circulation field is related to dust lifting.

Our aim is to understand the relationship between the circulation structure and the surface stress. In this presentation, we show the results of analysis focusing on the lowest level of the model (z = 2.5 m).

2. Data

We use the data calculated by Nishizawa et al. (2016) which utilized SCALE - LES ver. 3 developed by RIKEN / AICS. The values of model parameters are those of Mars. The model domain is 19.2 km ×19.2 km ×21 km. Five experiments with the resolutions ranging from 100 m to 5 m were analyzed. The heating rate and the surface temperature are given externally from one-dimensional simulation by Odaka et al. (2001). Horizontally periodic boundary conditions are adopted. Except for the 5 m resolution run, the vertical temperature profile of initial state is obtained from Odaka et al. (2001) and tiny random perturbations are added. For the 5 m resolution run, integration is performed for 1 hour from the result at 14:00 (local time) obtained by the 10 m resolution run. In this study, we use the data at 14:30 obtained with the 5 m resolution run. Surface stress is calculated using the same scheme as Nishizawa et al. (2016).

3. Results

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In order to compare the surface stress distributions with the circulation structures, we examine the wind velocity distributions at the lowest level of the model. To estimate the frequency of dust lifting, we investigate the histogram of intensity for the surface stress. In this presentation, we will show these results in detail. We are now proceeding analyses of the data at the time other than 14:30 and other resolutions. With considering the results, we will obtain an understanding on the relationship between surface stress field and circulation field.

Keywords: Mars, Atmospheric Boundary Layer, High Resolution Large Eddy Simulation, Dry Convection, Surface Stress, Dust Lifting

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A numerical study on the impact of ocean general circulation on aquaplanet climate with a coupled atmosphere-ocean-sea ice model

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1. Introduction

The discovery of many exoplanets attracts the attention of planetary atmospheric scientists because the diversity of climates is expected on exoplanets. In order to understand the role of atmospheric circulation on determining the planetary climates, our research group also has explored the climates on a planet globally covered with water (aquaplanet) with an atmospheric general circulation model (AGCM) (Ishiwatari et al., 1998; Ishiwatari et al., 2007; hereinafter, referred as INTH98 and INTH07, respectively). In their study, ocean general circulation was not considered. However, ocean heat transport also may have a significant impact on the climate. The recent development of computational science enables a long time integration to be carried out with coupled atmosphere-ocean-sea ice models, and some studies of aquaplanet climates with considering ocean general circulation explicitly has been performed (e.g., Marshall et al., 2007; Rose et al., 2015). By their pioneering works, the dependence of climates of coupled aquaplanet system on some fundamental parameters, such as solar constant or planetary rotation period, has been obtained. However, in order to accumulate knowledge about the diversity of exoplanet climates, further parameter studies are needed (e.g., the dependence of aquaplanet climate on solar constant in the case of oceanic salinity much different from one on present earth) in addition to revisit the probability of previous results. So, we have developed our own ocean model, and coupled model.

In this study, using our coupled model, we perform solar constant dependence experiments in INTH07 with considering ocean general circulation, and the impact on determining aquaplanet climates are focused. In this presentation, we show some simulation results for present earth solar constant.

2. Numerical Model

The atmosphere model is an AGCM, DCPAM (https://www.gfd-dennou.org/library/dcpam/), in which 3-dimensional primitive equations and a transport equation for water vapor are solved. To reproduce INTH98 result, a gray atmosphere radiation scheme (Nakajima et al., 1992) and moist convective adjustment (Manabe et al., 1965) are used. The ocean model is a zonally averaged 2-dimensional ocean general circulation model in which hydrostatic Boussinesq equations are solved. The effect of meso-scale eddies and convection are parameterized (Gent and McWilliams, 1990; Marotzke, 1991). The model calculates the velocity, temperature and salinity. The sea ice model is a thermodynamics model based on Winton (2000), and calculates the thickness and temperature. The atmosphere, ocean and sea ice models are coupled with a coupler library (Arakawa et al., 2011).

3. Results

First, we have a numerical experiment in which surface albedo is fixed to zero everywhere same as experiments by INTH98. After the integration for several ten thousands of years, we obtain a statically equilibrium state with ice-line latitude of about 50°. The global circulation patterns are similar to that in Marshall et al. (2007), while the strength of circulations is quite smaller. In order to evaluate the effect of ocean circulation, we conduct further two experiments in which dynamical ocean is replaced by swamp or

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slab ocean. According to the comparison of three experiments, ocean general circulation decreases the temperature difference between middle and low latitudes by about 5 K, and reduces the sea surface temperature (SST) at equator by about 4 K. However, the ice-line latitude and global mean SST in all cases are almost same. We also investigate the impact of ocean general circulation on the climate including ice-albedo feedback as INTH07. The result shows that, due to ocean large thermal inertia and motion, ice-line latitude retreats by about 10° and correspondingly global mean SST increases by about 5 K. As suggested in Rose et al. (2015), this indicates ocean inertia and heat transport have more significant impact on the climates in including ice-albedo feedback. In order to obtain a deeper understanding of ocean role on determining aquaplanet climates, we will perform solar constant dependence experiments.

Keywords: coupled atmosphere-ocean-sea ice model, aquaplanet climate, atmosphere and ocean heat transport, ice-albedo feedback

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Effects of radial distribution of thermal diffusivity on critical modes of anelasticthermal convection in rotating spherical shells

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Linear stability analysis of anelasitc thermal convection in a rotating spherical shell with thermal diffusivities varying in the radial direction is performed. The structures of critical convection are obtained in the cases of four different radial distributions of thermal diffusivity; (1) κ is constant, (2) κT_0 is constant, (3) $\kappa \rho_0$ is constant, and (4) $\kappa \rho_0 T_0$ is constant, where κ is the thermal diffusivity, T_0 is the temperature of basic state, and ρ_0 is the density of basic state, respectively. The ratio of inner and outer radii, the Prandtl number, the polytrope index, and the density ratio are 0.35, 1, 2, and 5, respectively. The value of the Ekman number is 10^{-3} or 10^{-5} . In the case of (1), where the setup is same as that of the anelastic dynamo benchmark (Jones et al., 2011), the structure of critical convection is concentrated near the outer boundary of the spherical shell around the equator. However, in the cases of (2), (3) and (4), the convection columns attach the inner boundary of the spherical shell.

A rapidly rotating annuls model for anelastic systems is developed by assuming that convection structure is uniform in the axial direction taking into account the strong effect of Coriolis force. The annulus model well explains the characteristics of critical convection obtained numerically, such as critical azimuthal wavenumber, frequency, Rayleigh number, and the cylindrically radial location of convection coulumns.

The radial distribution of thermal diffusivity is important for convection structure, because it determines the distribution of radial basic entropy gradient which is crucial for location of convection columns.

Keywords: Critical convection, Anelastic fluid, Jovian planets

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Numerical simulation of circumplanetary disk formation for estimating the disk size and surface density

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Circumplanetary disks are possible targets for future observations and include some information on planet formation. Numerical simulation is useful to predict such observations.
To investigate the structure of circumplanetary disk and its environment, extremely high resolution is required. Hence we parallelize a three-dimensional hydrodynamic simulation code of static mesh refinement method. The parallelized code enables us to compute 10 times higher spatial resolution than previous studies. When 15 times Hill radius is adopted as the computational domain in the radial direction, the finest spatial resolution is 10^{-3} of the Hill radius which is comparable to the present Jovian radius. The resolution is sufficient to investigate circumplanetary disk structure.
We perform a numerical simulation of circumplanetary disk formation around a planet embedded in protoplanetary disk. We consider a local rotating Cartesian coordinate. The coordinate is rotating around a star with Keplerian angular velocity and curvature is neglected. Basic equations of inviscid fluid hydrodynamic without self-gravity are solved. Some symmetric boundary conditions are imposed to accelerate the calculation, in which rotational, periodic, and mirror symmetries are imposed as radial, azimuthal and vertical directions respectively. The other side boundaries in the radial direction and in the vertical direction of computational domain are connected to unperturbed flow.
In this resolution, the angular momentum of the initial condition can not be neglected. Then a artificial retrograde circumplanetary disk forms potentially and the disk is not dissipative even in long time integration. To avoid the problem, we introduce sink cells around protoplanet. Finally, a prograde disk is formed.

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Keywords: circumplanetary disk, hydrodynamics, numerical simulation

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