Development of a three dimensional non-hydrostatic model for Martian atmosphere and a numerical simulation of thermal convection.

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Introdution

Thermal convection in the Martian atmosphere is major thermal transport process near the surface, and the horizontal temperature difference results from the thermal convection influence on large scale circulation. Rafkin *et al*.[1] develop a three dimensional non-hydrostatic model for Martian atmosphere based on RAMS which is that for terrestrial atmosphere[2], and perform a numerical simulation of thermal convection in the Martian atmosphere with background wind and characteristic dust radiative heating. The result shows that the horizontal and vertical scale of convection cell in day time are about 3 km and 5 km respectively, and the vertical wind velocity associated with thermal convection reaches 10 m/sec [3]. Toigo *et al*.[4] perform a numerical simulation of thermal convection with characteristic dust radiative heating and investigate influence of background wind velocity on generation of vertical vortex like dust devils by using Mars MM5 which is based on another three dimensional non-hydrostatic model for terrestrial atmosphere, MM5[5, 6].

In these previous studies, background wind and radiative heating due to dust are introduce to their numerical models to compare results of their numerical simulations with observations. To reveal feature of thermal convection in the Martian atmosphere, however, it is necessary to perform a numerical simulation without background wind and dust heating. We performed such numerical simulations, though they use two dimensional model [7, 8]. In this study, we develop a three dimensional non-hydrostatic model based on the two dimensional quasi-compressible model developed by Sugiyama *et al*.[9] and perform a numerical simulation of thermal convection in the Martian atmosphere without background wind and dust radiative heating.

Model description and set up of simulation

The basic equation of the model is based on quasi-compressible system [10]. The eddy mixing coefficients are diagnosed from the turbulent kinetic energy that is predicted by a prognostic equation [10]. The surface heat and momentum fluxes are estimated by the bulk formula and the bulk coefficient is 0.01[7]. The atmospheric radiative transfer is not calculated explicitly, and a horizontally uniform body cooling is introduced. The space derivatives are approximated by the fourth-order centered difference scheme for advection terms, and the second-order centered difference scheme for the other terms. The time integration is performed by using time-splitting method which the acoustic mode is integrated with a short time step and the other modes are integrated with a long time step[10]. The acoustic mode is treated by the HE-VI scheme where the horizontal propagation of sound waves is treated explicitly (Euler scheme) and the vertical propagation is treated implicitly (Crank-Nicolson scheme). The other modes are treated by the leap-frog scheme with Asselin time filter [12]. The coefficient of Asselin time filter is 0.1. The model source code is open to the public at http://www.gfd-dennou.org/library/deepconv/.

The computational domain extends 20 km horizontally 10 km vertically. The horizontal and vertical grid intervals are 100 m. The horizontal boundary is cyclic and vertical velocity is set to be 0 m/sec at the upper and lower boundaries. The horizontally uniform body cooling is introduced below 5 km height and its amplitude is the same value of parameterized convective heating estimated by one-dimensional model[11]. The ground surface temperature is fixed to be 270 K. Initial atmospheric surface pressure and temperature are 6 hPa and 245 K, respectively. Initial atmospheric temperature profile is adiabatic below 5 km height (245 K) and isothermal above 5 km height (220 K). Random potential temperature perturbation its maximum amplitude is 1 K are given at the lowest level grid point to develop convective motion. The numerical integration time is 12 hours.

Results

Fig.1 shows horizontal distribution of vertical wind at z = 2450 m height after 12 hours of integration. The horizontal scale of updraft region is several km and the ratio of upsraft region to downdraf region is about 1:2. The updraft wind velocity is 10$\sim$15 m/src and downdraft wind velocity is almost below 5 m/sec. These magunitude of vertical wind velocity are smaller than those simulated by using two-dimensional verion of our model with same simulation condition.

Fig.3 shows horizontal distribution of vertical component of vorticity at the lowest level of model (z = 50 m height) after 12 hours of integration. The many isolated vortices develop at the region where the updraft wind velocity is relatively large at middle level of convection layer. Characteristic horizontal scale of the vortcies is 200∼ 400 and life time is ranged from several to about 30 minuits. Fig.4 shows vertical cross section of vertical component of vorticity, horizontal wind normal to the cross section, and potential temperature deviation from its horizontal mean value at $x = 8450$ m after 12 hours of integration. The vertical scale of vortex in Fig.4 is about 2 km. The horizontal wind velocity associated with the vortex is several m/sec. The potential temperature deviation at the center of vortex is positive and its magnitude is 2∼3 K. The horizontal scale of the vortex corresponds to that of the positive potential temperature anomaly region (i.e., convective plumes).

Discussion

The magnitude of vertical wind velocity simulated by using our three-dimensional model are smaller than those simulated by using two-dimensional version of our model. This feature was reported by previous numerical study which consider atmospheric radiative transfer process and diurnal change[3]. Its mechanism, however, may be different because the thermal forcing introduced to our model is different from that of previous numerical study. To investigate the difference of wind velocity between three- and two- dimensional models further more, it is necessary to perform sensitivity experiment of physical processes incorporated into the model and its parameters.

The result shown by Fig.3 suggests that the isolated vertical vortices depvelops spontaneously without background wind. The vortices develops at the region where the updraft wind velocity is relatively large at middle level of convection layer and the potential temperature deviation at the center of vortices is positive. These characteristics suggest that the isolated vertical vortices are generated by vortex streching of small vortices near the surface.

Acknowledgement

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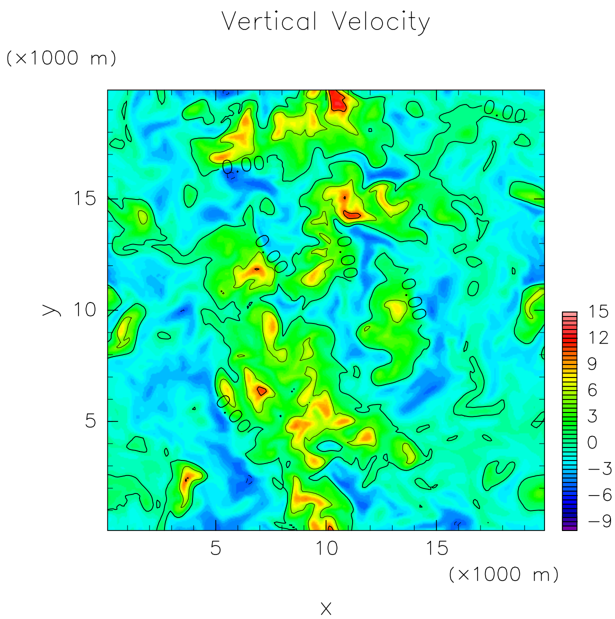

Figure 1: The horizontal distribution of vertical wind (m/sec) at $z = 2450$ m height after 12 hours of integration. The contour interval is 5 m/sec.

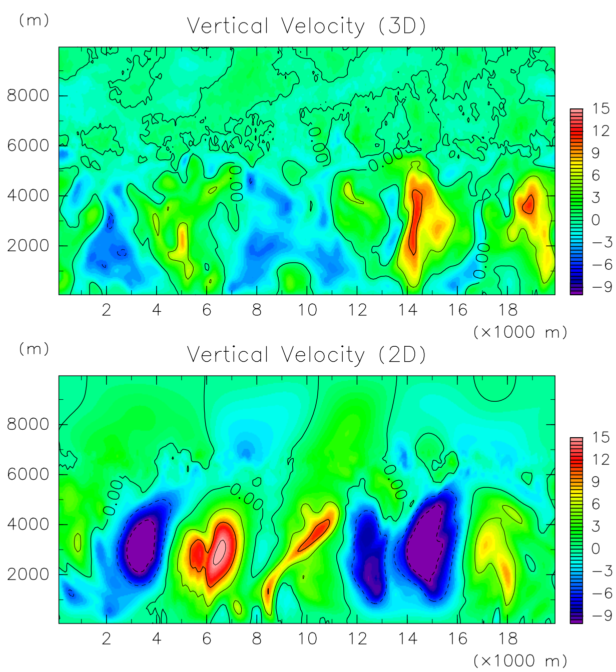

Figure 2: The vertical cross section of vertical wind field (m/sec) at $x = 10950$ m after 12 hours of integration (upper panel) and that calculated by two dimensional version of our model with same experimental setup (lower panel). The contour interval in each panel is 5 m/sec.

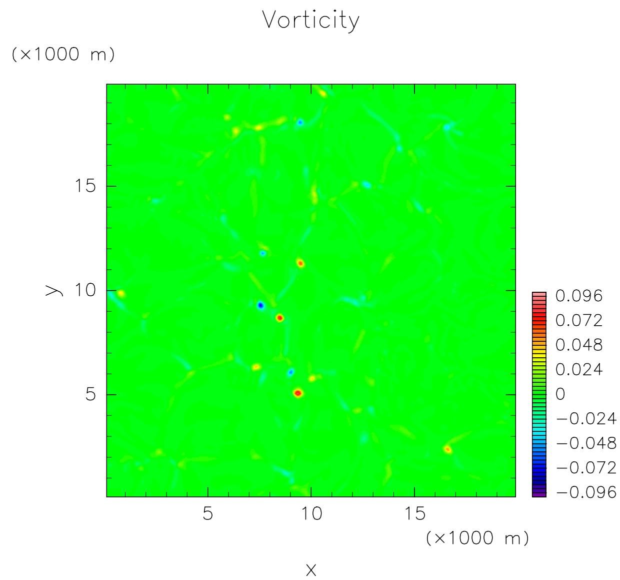

Figure 3: The horizontal distribution of vertical component of vorticity (sec^{-1}) at $z = 50$ m height after 12 hours of integration.

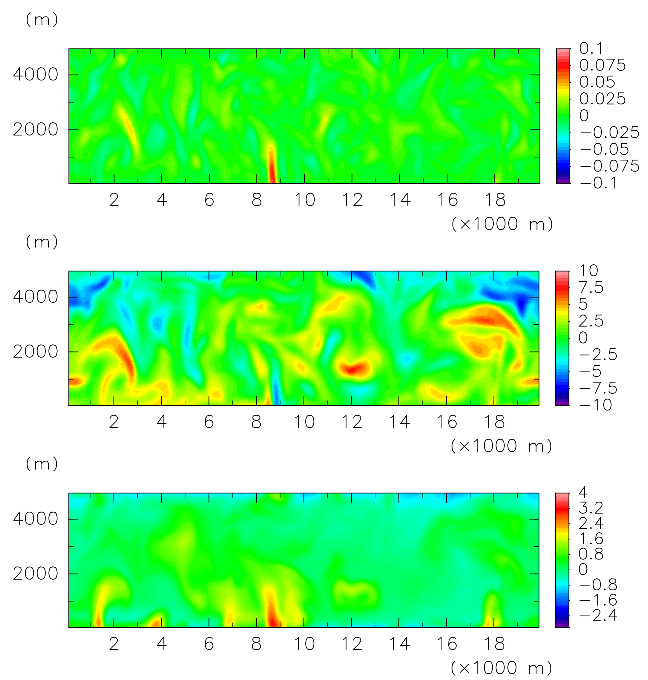

Figure 4: The vertical cross section of vertical component of vorticity (upper panel, sec^{-1}), horizontal wind normal to the cross section (middle panel, m/sec), and potential temperature deviation from its horizontal mean value (lower panel, K) at $x = 8450$ m after 12 hours of integration.