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Two-dimensional model simulation of Martian atmospheric convection with condensation of the major component under fixed thermal forcing

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Abstract

We perform a numerical simulation of cloud convection by using two-dimensional nonhydrostatic model for the purpose of investigating the structure of cloud convection with condensation of the major component when significant high supersaturation is not allowed. In quasi-equilibrium state, horizontally uniform cloud layer is formed above the condensation level, and the dry adiabatic layer is formed below the level. The updraft and downdraft associated with convection extends from near the surface to the top of the model atmosphere. The updraft and downdraft in the cloud layer seem to be maintained by buoyancy in the dry adiabatic layer.

1. Introduction

In Martian atmosphere, atmospheric major component, CO_2, condenses. In current Martian polar regions, CO_2 ice clouds are known to exist, and there is a possibility that these clouds are formed by convective motion [1]. Studies on the early Mars suggested that the scattering greenhouse effect of CO_2 ice clouds had a significant effect on the climate [3, 5].

One of the important characteristics of the system whose major component condenses is that an adiabatically ascending air parcel can hardly obtain buoyancy; the temperature of the parcel has to be equal to that of the almost saturated surrounding atmosphere in thermodynamical equilibrium state. One-dimensional model show that strong vertical motion develops in cloud layer only when the critical saturation ratio for condensation $S_{cr} > 1.0$ [1]. However, because their purpose is to investigate a vertical profile of an updraft region only, their model can not calculate whole structure of convection explicitly.

We have been developing a numerical model of cloud convection that directly calculates convective fluid motion and incorporates a simplified cloud microphysics process (e.g., [7, 8, 9]). In this work, as a first step before starting a parameter studies of the critical saturation ratio, we perform a long-time numerical simulation of cloud convection in Martian atmosphere in order to investigate the structure of cloud convection in the case of S_{cr} = 1.0.

2. Model and Set up of experiments

The dynamical framework is based on the quasi-compressible system [4]. The cloud microphysics is based on a diffusion growth theory of cloud particles of Martian atmosphere [10]. Gravitational settling of cloud particles and drag force due to cloud particles are not considered. The critical saturation ratio S_{cr} is set to be 1.0.

The model atmosphere is subjected to an externally-given thermal forcing that is a substitute for radiative cooling. The region between z = 1 km and z = 15 km is cooled with a constant value (-5.0 K/day). The region between the lower boundary and z = 1 km is heated so that the sum of the thermal energy supply by the cooling and heating is zero.

The initial vertical profile of temperature is based on that observed in Martian winter polar cap [2]. The initial vertical profile of temperature is given as 165 K at the lower boundary (7 hPa), dry adiabatic from the lower boundary to z = 4 km, moist adiabatic from z = 4 km to z = 15 km, and isothermal above.

The model used is two-dimensional (2D) in the horizontal and vertical directions. The domain extends 20 km in the vertical direction and 50 km in the horizontal direction. The spatial resolution is 200 m in both the horizontal and the vertical directions. The cyclic boundary condition is applied in the horizontal direction. At the upper and lower boundary, the conditions of stress-free, no normal flow, no heat flux are assumed. Time integration is continued up to about 6×10^5 sec (about 7 days).

3. Results and Discussion

The total cloud mass and the total kinetic energy reach almost steady state after 3.5 days. Therefore, we consider the model is in quasi-equilibrium state at 4th day and investigate convective motion at the time.

Figure 1a and figure 1b show distribution of cloud density and vertical velocity at 4th day. Above the condensation level ($z \approx 7$ km), clouds whose density is horizontally uniform are formed. Below the condensation level, vertical temperature structure is almost dry adiabatic (hereafter, we call the region above the condensation level as “cloud layer” and under the condensation level as “dry adiabatic layer”). The vertical motion associated with convection extends from near the surface to the top of model atmosphere. The upward velocity is maximum in the cloud layer and the condensation level is not boundary for vertical motion.

Figure 1c shows distribution of potential temperature deviation from its horizontal mean value. In the cloud layer, updraft region is relatively cool and downdraft region is relatively warm. This feature is in contrast to those of the terrestrial and Jovian cloud convection for which updraft region is relatively warm and downdraft region is relatively cool. The reason why strong vertical motion is maintained in the cloud layer seems to be that potential temperature deviation and associated buoyancy in the dry adiabatic layer are sufficiently larger than those in the cloud layer.

Our results in this study may be affected by some parameters and processes. There is possibility that vertical motion in the cloud layer become stronger as S_{cr} become larger, as suggested by [1]. On the other hands, vertical motion in the cloud layer may be suppressed by taking into account the effect of gravitational settling of cloud particles and drag force due to cloud particles, as shown by [6]. Further investigations are necessary to reveal whether these factors affect the structure of the convective motion or not.

Acknowledgements

Figures are plotted by using the softwares developed by Dennou Ruby Project (http://ruby.gfd-dennou.org/). Calculations are performed by SX8-R of the NIES supercomputer system.

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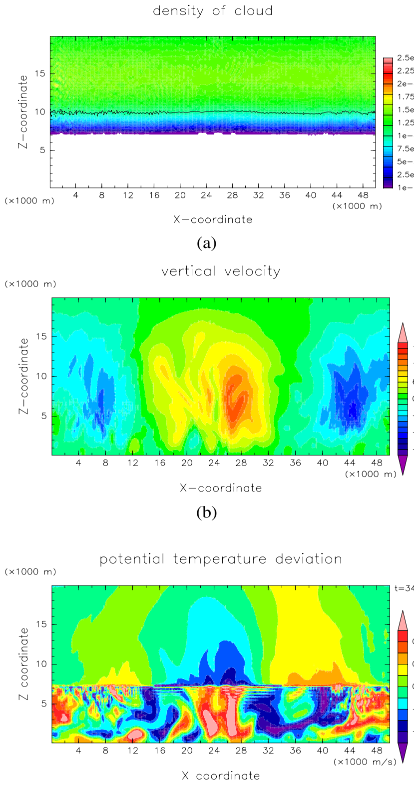

(a)

(b)

(c)

Figure 1: Snapshots of distributions of (a) density of cloud [kg/m^3], (b) vertical velocity [m/sec] and (c) deviation potential temperature from its horizontal mean value [K] at 4 th day.