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Microscale simulations of convective adjustment and mixing in the Venusian cloud layer

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Abstract

The present work examined transport processes of heat, material and momentum in the Venusian cloud layer using a microscale atmospheric model. The temporal variation of convective activity with periods of a few hours and the wave-like profile of the static stability in the upper cloud are found in several cases. The eddy diffusion coefficients are estimated from the model output. Such microscale simulations are expected to contribute to physical interpretations of the balloon and radio science experiment data and improvements of the eddy diffusion coefficients in the Venus general circulation model and chemical and aerosol transport models.

1. Introduction

Microscale and mesoscale transport processes of heat, momentum and material are important in subgrid-scale parameterization of the Venus general circulation model (VGCM). Two-dimensional simulations of thermal and wave-breaking convection have been conducted in previous works [1][2][6][7]. On the other hand, three-dimensional microscale dynamics of Venus' convection have yet to be fully examined using a fully compressible and nonhydrostatic model. Recently, Weather Research and Forecasting (WRF) model [5] has been applied to planetary sciences [4]. Yamamoto [8] conducted microscale atmospheric simulations by changing the astronomical and physical parameters in the Advanced Research WRF model. An ideal LES case in the Advanced Research WRF model was applied to idealized Venus surface conditions. When convective adjustment occurs, the heat and passive tracer are rapidly mixed into the upper stable layer with convective penetration. The convective adjustment and mixing produce high eddy diffusion coefficients of heat and passive tracer, which may explain the large eddy diffusion coefficients estimated in radiative-convective equilibrium model [3]. In the case that values of surface heat flux Q_S is larger than a threshold, the convectively mixed layer with high eddy diffusion coefficients grows with time. In contrast, the mixed layer decays with time in the case of Q_S smaller than the threshold. The thermal structure near the surface is controlled not only by radiative processes with extremely long time scales, but also by microscale dynamical processes with short time scales. A mixed layer with high eddy diffusion coefficients may be maintained or grow with time in the regions where the surface heat flux is high (e.g., the volcanic hotspot and adjacent areas).

2. Microscale simulations in the Venusian cloud layer

The abovementioned microscale atmospheric model [8] is applied to dynamical processes in the unstable/neutral layer of the Venusian cloud (50-55 km). The model with a 100-m resolution has a domain of 4 × 4 × 8 km, which corresponds to the equatorial atmosphere of 50 to 58 km. The initial buoyancy frequency is set at 0.02 s^{-1} (or 0.01 s^{-1}) above the 55-km level in the simulations.

Convective adjustment in the Venusian cloud is simulated under the condition that the bottom heat flux Q_B is set to zero in case A (Sec. 2.1). The initial lapse rate of potential temperature Γ_{LAP} is changed from 0.2 to 3 K/km below the 55-km level.

The sensitivity of the mixed layer to the convective heat flux is investigated in case B (Sec. 2.2). In this case, Γ_{LAP} is set to zero below the 55-km level, and Q_B is changed from 0 to 0.256 K m s^{-1}.

2.1 Convective adjustment (case A)

Maximum magnitudes of eddy fluxes of momentum, heat and passive tracer become larger with increasing Γ_{LAP}. In the unstable/neutral layer, the eddy diffusion coefficients of ~ 10^3 m^2 s^{-1} are estimated for momentum, heat and passive tracer. This is consistent with locally large eddy diffusion coefficients estimated in radiative-convective equilibrium model [3].

2.2 Thermal convection induced by heat flux (case B)

Maximum magnitudes of the eddy fluxes and mean eddy diffusion coefficients become larger with increasing Q_B. The temporal variation of convective activity with periods of a few hours and the wave-like profile of the static stability in the upper cloud are found in several cases.

2.3 Effect of vertical wind shear

In the simulations that vertical wind shear is given for initial zonal winds in cases A and B, strong wind shear is formed near the top of the convectively mixed layer after the first strong convection. The convective motions maintain the strong shear zone near the boundary of the mixed layer.

3. Summary

A microscale atmospheric model [8] is applied to dynamical processes in the unstable/neutral layer of the Venusian cloud (50-55 km), and the microscale convective dynamics is examined in the present study. Maximum magnitudes of eddy fluxes of momentum, heat and passive tracer become larger with increasing Γ_{LAP} and Q_B. In the unstable/neutral layer, the eddy diffusion coefficients are considerably high. The temporal variation of convective activity with periods of a few hours and the wave-like profile of the static stability in the upper cloud are found in several cases. These microscale simulations are expected to contribute to physical interpretations of the balloon and radio science experiment data and improvements of the eddy diffusion coefficients in VGCM and chemical and aerosol transport models.

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