MERIDIONAL CIRCULATION OF MARTIAN MIDDLE ATMOSPHERE SIMULATED BY A MARS GENERAL CIRCULATION MODEL.

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Introduction: Observations by Mars Climate Sounder (MCS) onboard Mars Reconnaissance Orbiter spacecraft provided the meridional temperature structure of Martian middle atmosphere up to about 90 km altitude as well as lower atmosphere with a precedented spatial and temporal coverage [1]. These observations enable us to compare the model produced middle atmosphere with observational ones and examine the nature of Martian middle atmosphere. The understanding of the dynamical nature of Martian middle atmosphere is important, since past observations and model simulations showed that the high latitude temperature in a lower atmosphere increased significantly by the effects of meridional circulation extending into the middle atmosphere, especially during the planet encircling dust storms [2,3]. Further, the circulation in a middle atmosphere controls the transport of materials from the lower atmosphere to upper atmosphere. As for the Earth's middle atmosphere, it is well known that the meridional circulation is driven by atmospheric waves, such as synoptic waves, planetary waves, and gravity waves [4]. However, the nature of Martian middle atmosphere has not been understood, yet. In this study, structure of Martian middle atmosphere is investigated by use of a Mars General Circulation Model (GCM). In the followings, the model used in this study is described, and some results of experiments are presented.

Model description: A planetary atmosphere GCM, dcpam [5], is used in this study. This model is developed with the basis of the Geophysical Fluid Dynamics (GFD) Dennou Club atmospheric GCM [6] to perform simulations of planetary atmospheres of a variety of planets including the Earth, Mars, Venus, plausible exoplanets, and so on. Dynamical core of dcpam solves the primitive equation system by use of spectral transform method with the finite difference method in vertical direction. The included physical processes are the radiative process, the turbulent mixing process based on Mellor and Yamada [7] level 2 scheme, and the surface processes based on Louis [8]. Further, a condensation scheme of CO_2 is included for Mars experiment. The radiation models currently implemented in the model are those for Mars' atmosphere [9,10] and the Earth's atmosphere. The radiation model for grey atmosphere is also prepared for experiments for ideal planets. In addition, the simple forcing of Newtonian cooling and Rayleigh friction are also implemented for tests and idealized experiments.

By the use of a "Mars mode" of this model, several experiments have been performed. In the experiments, the dust distribution in the atmosphere is prescribed. In the vertical direction, the Conrath-type distribution [11,12] is assumed. In the horizontal direction, the optical depth is prescribed in two ways. Those distributions will be described below.

The resolutions used for this study is T21L32, which is equivalent to about 5.6 degrees longitude-latitude grid and has 32 vertical levels. Under these conditions, the model is integrated for 5 Mars years from an initial condition of isothermal atmosphere at rest. The result during the last Martian year is analyzed.

Comparison of temperature structure: The model performance is evaluated by comparing the temperature structure simulated by the model with that observed by the MCS. In the simulation, the dust optical depth is prescribed based on the "climatology", which has been created by averaging dust optical depth observed by Thermal Emission Spectrometer onboard Mars Global Surveyor spacecraft.

Figure 1 shows temperature distributions simulated by the model (a) and observed by MCS (b) at northern summer (Ls=60°-90°) and 3 AM. It is found that the gross features of temperature structure observed by MCS are represented by the model, such as the strong latitudinal temperature gradient at southern middle latitude, and the latitude of highest near surface temperature. However, some differences can also be observed. One of that is the strength of temperature increase in southern middle and high latitude at about 1 Pa pressure level (~60 km). This temperature increase is caused by adiabatic heating in a descending branch of meridional circulation. The difference of this temperature increase between the model and observation implies the failure in representing strength of meridional circulation in the model. One of the most plausible explanations for the failure would be the lack of representation of the effects of subgrid scale atmospheric waves, such as gravity waves. Similar biases were observed in Earth's atmosphere models without (non-orographic) gravity wave drag parameterization.

Meridional circulation in middle atmosphere: The structure and strength of meridional circulation in the Martian middle atmosphere are investigated by analyzing the model results. In this study, the peak value of mass stream function at 1 Pa pressure level is considered as a measure of the strength of meridional circulation in the middle atmosphere.

Analysis of the simulation results show that the seasonal variation of strength of meridional circulation in the middle atmosphere is as large as about factor of 2. For example, peak values of mass stream function at 1 Pa are 0.2×10^8, 0.3×10^8, 0.2×10^8, and 0.4×10^8 kg/s at northern spring, summer, fall, and winter, respectively. This seasonal variation is much smaller than that in the lower atmosphere, where the peak value of mass stream function changes by a factor of ~10 over the course of a Martian year. This would reflect the difference of driving mechanism of meridional circulation between lower and middle atmospheres.

In order to examine the sensitivity of strength of meridional circulation on dust amount in the atmosphere, a dust storm experiment is performed. In this experiment, dust optical depth is prescribed based on Viking observation, which is uniform in horizontal direction and has two planet-encircling dust storms at northern fall and winter. A peak value of mass stream function at 1 Pa at northern winter in this experiment is 4×10^8 kg/s. It is revealed that a strong heating associated with radiative effect of dust and large amplitude tide excited during a planet-encircling dust storm strengthens the meridional circulation by a factor of ~10 in the middle atmosphere.

Driving mechanisms of meridional circulation: In order to examine the driving mechanisms of meridional circulation in the middle atmosphere, three experiments are performed: (I) an experiment with Rayleigh friction in the middle atmosphere, (II) an experiment with diurnally mean solar insolation, and (III) an experiment with zonally averaged surface topography, albedo, and thermal inertia. Those three experiments are intended to examine the effects of subgrid scale atmospheric waves, such as gravity wave, thermal tides, and orographically related waves, such as topographic Rossby waves, respectively. The Rayleigh friction coefficient in the experiment (I) is chosen to reproduce the middle atmospheric polar temperature increase observed by MCS roughly. The difference in peak values of mass stream function between each experiment and control experiment at northern winter are 0.2×10^8, 0.15×10^8, and 0.15×10^8 kg/s, respectively. This result implies that the subgrid scale atmospheric waves, the thermal tides, and the orographically related waves contribute to middle atmospheric meridional circulation by the similar degree.

References:

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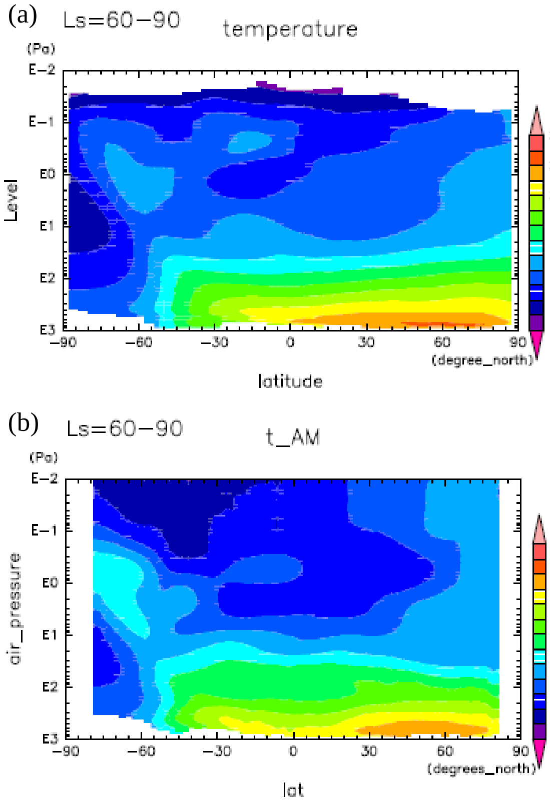

Figure 1. Meridional Temperature distribution simulated by the model (a) and observed by the MCS (b) at northern summer (Ls=60°-90°) at 3 AM.