High Resolution Simulations of the General Circulation of the Martian Atmosphere: Small and Medium Scale Disturbances and Dust Lifting Processes.

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Introduction

One of the issues about the Martian atmosphere is to reveal possible circulation features of small and medium scale disturbances ranging between thermal convection and baroclinic waves. In order to obtain some insights into this aspect, we are performing high resolution simulations of the Martian atmosphere by using a Mars general circulation model (GCM). We anticipate that those simulations will also provide some insights into dust cycle in the Martian atmosphere, since small and medium scale disturbances may play important roles on atmospheric dust lifting and transport. In the followings, some of the features of atmospheric disturbances and the dust lifting processes represented in our high resolution GCM simulations are presented.

Model Description

The model used in this study consists of the dynamical core of AFES[1] (AGCM (Atmospheric GCM) for the Earth Simulator), and the physical processes introduced from the Mars GCM[2, 3] which has been developed by our group so far. AFES is based on the version 5.4.02 of the AGCM[4] jointly developed at the Center for Climate System Research, University of Tokyo, and the Japanese National Institute for Environmental Studies, and is optimized to perform high resolution simulations on the Earth Simulator. As for the physical processes, the radiative, the turbulent mixing, the atmospheric mass change due to condensation and sublimation of CO_2, and the surface process are introduced from our previous Mars GCM. In addition, the dust lifting process and the gravitational sedimentation are implemented. The dust lifting process is the same as one of "threshold-sensitive surface stress lifting" parameterizations proposed by Newman et al. (2002)[5].

By the use of this GCM, simulations are performed under the condition of northern fall season ($L_s \sim 210°$), which is a part of well-known "dust storm season". The resolution of control simulation is T319L96, which is equivalent to about 22 km horizontal grid size, and 96 vertical layers. The model is integrated for 33 Martian days, and the data during the last 28 Martian days is used for analysis. In addition to this control simulation, simulations with the lower resolutions, T79L96 and T159L96, are performed to examine the resolution dependence of the results. The horizontal grid sizes of T79 and T159 resolutions are equivalent to about 90 and 45 km, respectively.

The initial conditions for these simulations are obtained step by step integration of the lower resolution models. First, the model with the resolution of T39L96 is integrated for seven years from an isothermal atmosphere at rest. Then, the model with the resolution of T79L96 is integrated from the result of the above seven year integration. The result of this T79L96 one year integration is interpolated to T319L96 and T159L96 resolution data, which are used as the initial conditions for those high resolution simulations, respectively.

Atmospheric Disturbances in the Model

The result of T319L96 simulation shows many kind of atmospheric disturbances whose horizontal scales range from the global scale to tens of kilometers. For example, in the northern middle latitude, a baroclinic wave with zonal wavenumber two is observed around the northern polar cap edge. Associated with ths wave, narrow frontal structures can be observed clearly.

In the lees of several mountains in the northern hemisphere, the medium scale vortices are observed. Those medium scale vortices are produced periodically with a period of one Martian day. The region where the most prominent vortices appear is the Alba Patera. The horizontal size of these vortices generated in that region is almost the same as that of the Alba Patera and is about 300 km.

In the low latitude regions, a lot of small scale vortices whose horizontal scale is about 50–60 km are observed. The region of vortex generation moves westward; the vortices are generated in the afternoon, and dissipated in the night. It is considered that these vortices are generated as a result of local thermal convection represented in the T319 resolution model. These small scale vortices do not appeare in the low resolution simulation, such as T79 simulation.

Another small scale disturbance is a movement of horizontal shear line in the western slope of the Tharsis plateau. The horizontal shear line extends about 1500

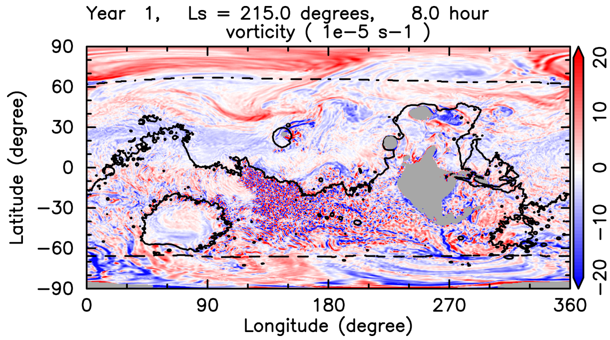

Figure 1: An example of global vorticity distribution at 4 hPa pressure level in the northern fall (L_s = 215°). Also shown are the areoid (solid line) and the location of polar cap edge (dashed line). Gray areas represent mountains at 4 hPa pressure level.

km, appears diurnally, and moves westward and downward along the slope. It is supposed that diurnal slope winds or gravity waves excited by the diurnal solar heating and mountain topography would be reflected in this phenomenon.

Dust Lifting Processes in the Model

Associated with many kinds of atmospheric disturbances described above, a number of dust lifting events can be observed in the simulations. The major dust lifting regions during the simulation period are the polar cap edge in the northern hemisphere, the Elysium, the Alba Patera, and the Hellas basin. The dust is also lifted in the low latitude regions including the Valles Marineris region, although the dust amount lifted by each event is not large.

Among those major dust lifting regions, the most striking dust lifting events are those around the northern polar cap edge. The active events are observed in the two longitudinal areas, 60°–120°E and 240°–360°E. These are caused by the baroclinic waves, especially the strong winds associated with the fronts. Some of those dust events transport dust from the mid latitude into the low latitude regions, like “flushing dust storm” observed by spacecraft.

One of simple methods to examine the importance of small and medium scale disturbances on dust lifting is to compare the results of simulations with different resolutions. In this study, the results of simulations with T79L96 and T159L96 resolutions are compared with that of T319L96 resolution.

In view of location of major dust lifting regions, the results of those three simulations do not change so much, and the major dust lifting regions are almost the same among them. However, the comparison of global mean dust lifting amounts averaged over 28 Martian days in three experiments shows that the dust mass flux increases by about 35% with increasing horizontal resolution from T79 to T319. This indicates that the small and medium scale disturbances that can be represented in the T319 resolution model, but in the T79 one, certainly play a role to lift dust into the atmosphere.

In order to investigate what kind of small and medium scale atmospheric disturbances contribute to the dust lifting, the spatial variation of resolution dependence of dust mass flux is examined. It shows that the increase of dust lifting amount with increasing resolution is mainly attributed to several particular regions. Those are the regions around lee of Alba Patera, around Valles-Marineris, and the southern slope of Hellas basin.

The dust lifting in the Valles-Marineris is an interesting example of Martian particularity. The analysis of the dust lifting events in the region indicates that dust is lifted due to the intense wind caused by the superposition of the local circulation and the global meridional circulation. On Mars, one of the most important circulation components is the diurnally varying slope wind; they are observed in many regions on Mars including the Valles-Marineris. In addition, the return flow of low latitude meridional circulation is northerly in this season. The superposition of meridional circulation and the local slope wind which is better represented in the high resolution model causes the strong resolution dependence of dust lifting in this region.

Acknowledgments

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