HIGH RESOLUTION GENERAL CIRCULATION MODEL EXPERIMENTS OF THE MARTIAN ATMOSPHERE: RESOLUTION DEPENDENCE OF DISTURBANCE AND SURFACE STRESS.

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Introduction

High resolution experiments of Martian atmosphere have continued to be performed by using a general circulation model (GCM). One of the purposes of high resolution experiments is to investigate the small and medium scale disturbances whose horizontal scales range from thermal convection to baroclinic waves. The other purpose of high resolution experiments is to have some insights into dust lifting processes on Mars, since the small and medium scale disturbances may have important roles on atmospheric dust lifting and transport. In the followings, some features of atmospheric disturbances observed in our model are presented. Further, the effects of those on dust lifting are shown in view of probability function of surface stress. In this study, the circulation structure and effects of disturbances on dust lifting are investigated by focusing on its resolution dependence.

Model description

The model used in this study consists of the dynamical core of AFES (*Ohfuchi et al.*, 2004), and the physical processes introduced from the Mars GCM which has been developed by our group so far (*Takahashi et al.*, 2003, 2004, 2006). The AFES is a spectral primitive equation model and is based on CCSR/NIES AGCM 5.4.02 (*Numaguti et al.*, 1997). The AFES was optimized to the Earth Simulator to conduct high resolution experiments of the Earth's atmosphere.

The introduced physical processes include the radiative, the turbulent mixing, and the surface processes. The radiation scheme considers absorption by CO_2 gas, and absorption and scattering by dust suspended in the atmosphere. The turbulent mixing is evaluated by using a simplified *Mellor and Yamada* (1982) level 2.5 scheme, in which the advection of eddy kinetic energy is neglected. In addition, the dust lifting process is implemented to diagnose the dust mass flux in the model. The dust lifting process is the same as one of "threshold-sensitive surface stress lifting" parameterizations used by *Newman et al.* (2002). This parameterization is a GCM implementation of the process of dust lifting by the surface stress, whose characteristics is that dust is lifted only when the surface friction velocity exceeds a certain threshold value.

The surface orographic height and albedo variation are based on the Mars Global Surveyor (MGS) observations (*Smith et al.*, 1999; *Christensen et al.*, 2001). The distribution of soil thermal inertia specified in the model is the same as that used by *Pollack et al.* (1990). But, in some experiments, uniform surface properties are used to investigate atmospheric disturbances that are not forced by variations of surface properties, orography, albedo and thermal inertia variations.

By the use of this GCM, we performed experiments at northern fall condition with horizontal resolutions of T79, T159, T319, and T639, and number of vertical layers of 96. Horizontal resolutions of T79, T159, T319, and T639 are equivalent to about 89, 44, 22, and 11 km grid size, respectively. In these experiments, the dust distribution used for radiative heating rate calculation is assumed to be uniform horizontally with dust optical depth of 0.2.

Results

Atmospheric disturbances

Figure 1 shows distribution of vorticity at 4 hPa pressure level at northern fall ($L_s = 212°$) by T319 resolution experiment. A lot of atmospheric disturbances are observed in the model. Some of those are baroclinic waves in northern middle and high latitude, fronts associated with them, vortices in the lees of mountains such as Alba Patera and Elysium, several streaks to the north of the Hellas basin, and a lot of small scale vortices in low latitudes observed around Tharsis region in Figure 1.

Figure 2 shows distribution of vorticity at 4 hPa pressure level at northern fall ($L_s = 212°$) by T79 resolution experiment. Comparing the vorticity distributions by T319 and T79 resolution experiments, it can be seen that the many disturbances, such as baroclinic wave, fronts, and vortices in the lees of Alba Patera, are observed in the T79 resolution model. Further, the existence of streaks to the north of the Hellas basin and small scale vortices in low latitude is implied. But by increasing the model resolution, the structures of streaks become clear. As for the small scale vortices in low latitude, the horizontal size decreases and the strength increases as the increase of horizontal resolution. In addition, the local time when the small scale vortices develop tend to

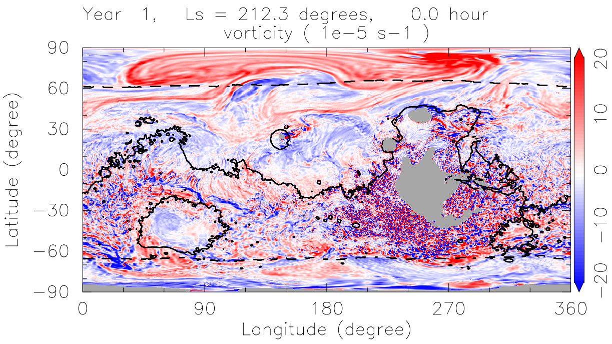

Figure 1: Distribution of vorticity at 4 hPa pressure leve by T319 experiment at northern fall (L_s = 212°). Also shown are the areoid (solid line) and the location of polar cap edge (dashed line). Gray areas represent mountains at 4 hPa pressure level.

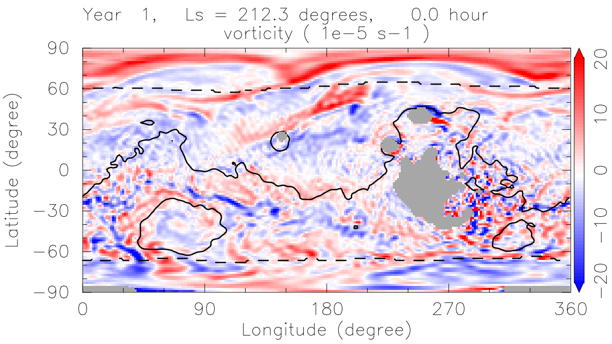

Figure 2: Same as Figure 1, but by T79 experiment.

become early by the increase of horizontal resolution. It is considered that these small scale vortices are caused by convective activity represented by the model. These are the results of the change of model representation of convective motion.

In Figures 1 and 2, a lot of disturbances forced by surface property variations (orographic height, albedo, and thermal inertia variations) are observed. One of simple questions one might raise is the features of atmospheric disturbances which develop under the condition of uniform surface properties, and their effects on dust lifting. In order to examine these, the experiments with uniform surface properties have also been performed. Figure 3 shows a distribution of vorticity in such an experiment. In this figure, baroclinic waves, fronts, and small scale vortices are observed. The strength and horizontal size of small scale vortices do not change from those observed in the experiment with surface property variations. This shows that local surface property variation, such as small scale orographic variation, does not play an important role in generating these vortices.

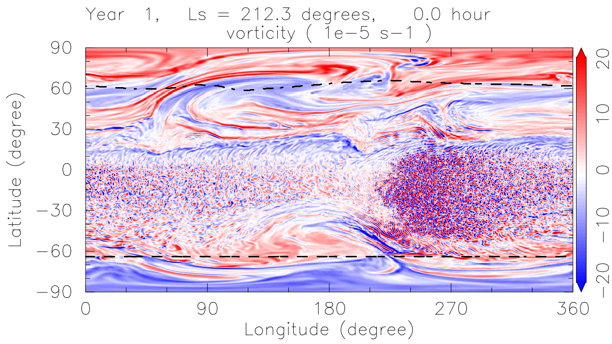

Figure 3: Same as Figure 1, but by the experiment with uniform surface properties.

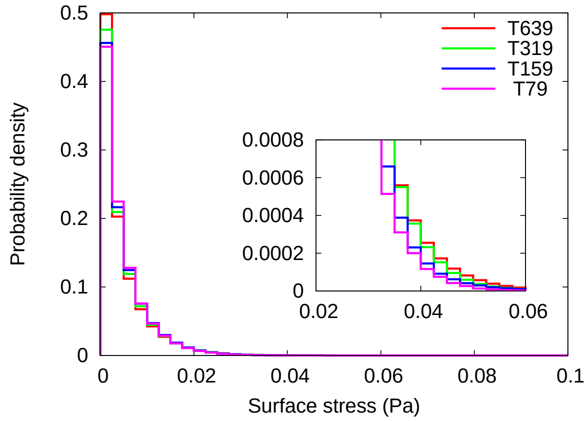

Figure 4: Martian surface area as a function of surface stress at northern fall by T639, T319, T159, and T79 experiments. Surface area is normalized with global Martian area. Results for 20 sols are used for T319, T159, and T79 experiments, and results for 10 sols are used for T639 experiment.

Probability distribution function of surface stress

As a measure of the effects of disturbances on dust lifting the probability functions of surface stress in the model are examined. Figure 4 shows the normalized area of Martian surface as a function of surface stress in T639, T319, T159, and T79 resolution experiments at northern fall. If we focus on the large surface stress range greater than about 0.02 Pa, it is shown that the surface area increases with increasing resolution slightly. This is a result of good representation of small and short time scale disturbances in the high resolution model.

In order to investigate the effects of disturbances on the dust lifting, diagnosed dust mass flux as a function of surface stress is examined. Figure 5 shows dust mass flux as a function of surface stress by T639, T319, T159, and T79 resolution experiments. The threshold surface stress for dust lifting by the current dust lifting parameterization is about 0.02 Pa. Over all surface stress range, dust mass flux increases with increasing reso-

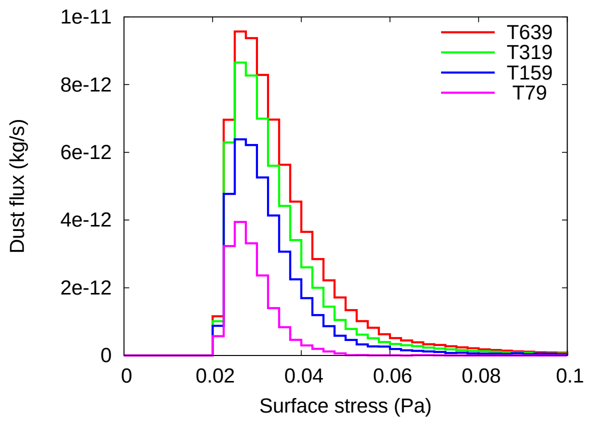

Figure 5: Dust mass flux as a function of surface stress by T639, T319, T159, and T79 experiments. Results for 20 sols are used for T319, T159, and T79 experiments, and results for 10 sols are used for T639 experiment. It should be noticed that the absolute value of dust flux is meaningless because of the arbitrarily chosen dust lifting efficiency in the dust lifting parameterization.

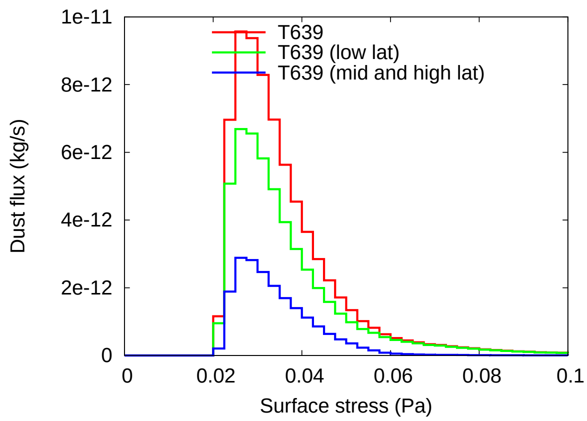

Figure 6: Dust mass flux as a function of surface stress in three latitudinal bands by T639 experiment. Red, green, and blue lines indicate histgrams in global area, low latitude (60°S $< \phi <$ 30°N), and middle and high latitude ($\phi <$ 60°S and $\phi >$ 30°N). Results for 10 sols are used. It should be noticed that the absolute value of dust flux is meaningless because of the arbitrarily chosen dust lifting efficiency in the dust lifting parameterization.

lution, though the value of surface stress which yields maximum dust flux does not change. As a result, global mean dust mass flux significantly increases with increasing resolution.

In order to have some implications on atmospheric disturbances which cause dust lifting in this model, regional dependence of dust mass flux as a function of surface stress is examined. Figure 6 shows dust mass flux as a function of surface stress in global area, low latitudes (60°S $< \phi <$ 30°N), and middle and high latitudes ($\phi <$ 60°S and $\phi >$ 30°N). It is clearly shown that the atmospheric disturbances in low latitudes play important roles to generate large dust flux. Figure 7 is the same as Figure 6, but by an experiment with uniform surface properties. The effects of disturbances in low latitude region plays dominant role in the experiment with uniform surface properties, too. These results strongly suggest that the some convective motion in the model is dominant contributor to the increase of dust flux with increasing resolution.

Summary

High resolution GCM experiments of the Martian atmosphere have been performed to investigate features of small and medium scale atmospheric disturbances. In addition, the effects of atmospheric disturbances on dust lifting are investigated by focusing on the probability functions of surface stress. Especially, in this study, the experiments with several horizontal resolutions from T79 to T639 have been performed to have some insights into the importance of effects of disturbances on dust lifting.

The high resolution experiments show many kinds of atmospheric disturbances, such as baroclinic waves, fronts, lee vortices, streaks, and small scale vortices. Although baroclinic waves, fronts, and lee vortices can be observed even in T79 resolution experiment, streaks and small scale vortices are well represented in models with the horizontal resolution greater than T159. Further, the small scale vortices develop early local time in higher resolution model.

Examination of probability functions of surface stress shows surface area exerted by surface stress greater than dust lifting threshold increases with increasing resolution, and the lifted dust mass flux also increases with increasing resolutions. These are clearly the results of small scale disturbances which are well represented in high resolution model. Further, the latitudinal dependence of dust mass flux shows the large dust flux is lifted in low latitude region where the small scale vortices are generated. This strongly suggests that the small scale disturbances which would be caused by convective motions represented in the model play important role to generate large surface stress and lifting dust flux in the model.

Acknowledgements

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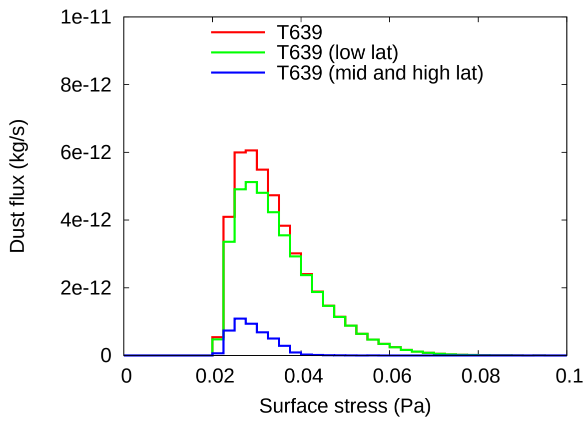

Figure 7: Same as Figure 6, but for experiments with uniform surface properties.

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