Resolution dependence of dust mass flux simulated by Mars general circulation model

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Introduction

Dust is an important element in controlling thermal forcing of the Martian atmosphere. A good amount of dust is always suspended in the atmosphere. Coupled with circulation systems, there appear dust storms of various temporal and spatial scales. However, the lifting process of dust and the generation and development processes of dust storms have not been well described yet. Our group has been investigating possible structures of disturbances with a horizontal scales less than a few hundreds of kilometers by using a Mars general circulation model (GCM), and their roles in dust lifting and dust storm formation.

One of the possible problems in modeling dust lifting for GCMs is resolution dependence of surface stress. It is expected that, as the increase of resolution, wind speed fluctuation represented in the model might increase, and the probability of exceeding threshold wind stress to eject dust into the atmosphere increase, which might cause substantial change of the total amount of dust in the atmosphere.

This is a preliminary report to investigate possible influence of the horizontal resolution of a GCM on the evaluation of surface stress and dust lifting.

Mars GCM

The model used in this study consists of the dynamical core of a terrestrial GCM, AFES (Atmospheric general Circulation Model for the Earth Simulator, Ohfuchi et al, 2004), and the physical processes of the current version of our Mars GCM (Takahashi et al., 2003, 2006) that has been developed in our group.

- AFES (Ohfuchi et al., 2004)
  - AFES is based on the version 5.4.02 of the Center for Climate System Research (CCSR) / National Institute for Environmental Studies (NIES) AGCM, and is highly optimized to the Earth Simulator
    - Spectral Eulerian primitive equation model
- Physics of our Mars GCM (Takahashi et al., 2003, 2006)
  - Standard physical processes appropriate for Martian condition are included.
    - Radiation (carbon dioxide and dust, four bands)
      - Delta-Eddington approximation for visible
      - Absorption of solar near infrared radiation by Forget et al. (1999).
      - Hemispheric mean approximation with source function technique for infrared except for CO2 15 μ
      - Scattering is not included for CO2 15 μ band
    - Turbulent vertical mixing by Mellor and Yamada Level 2.5 (Mellor and Yamada, 1982)
    - Ground temperature is calculated with 13 levels below the ground surface
    - Formation of polar caps
    - Dust lifting and gravitational settling processes
      - Dust lifting scheme is "threshold-sensitive surface stress lifting" scheme by Newman et al. (2002).
      - Only model-resolved wind contributes to dust lifting.
      - Dust lifting does not occur on the polar caps.
- Season
  - Northern fall; solar declination angle is about -13º
- Integration Period
  - 33 Martian days
- Resolution
  - 96 vertical layers up to about 90 km height
  - Three horizontal resolutions: T319 (~22 km) , T159 (~44 km), T79 (~89 km)
- Orography
  - Realistic orography runs vs. no orography runs

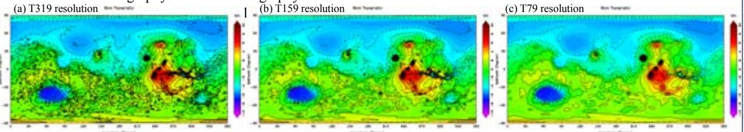

Figure 1. Topography used in the experiments: (a) T319, (b) T159, and (c) T79 resolutions.

Vorticity distribution and dust lifting processes in the experiments

As the increase of resolution, small scale disturbances caused by (1) "convection" associated with solar migration and (2) orography become evident. Figure 1 shows those distaurbances represented by vorticity.

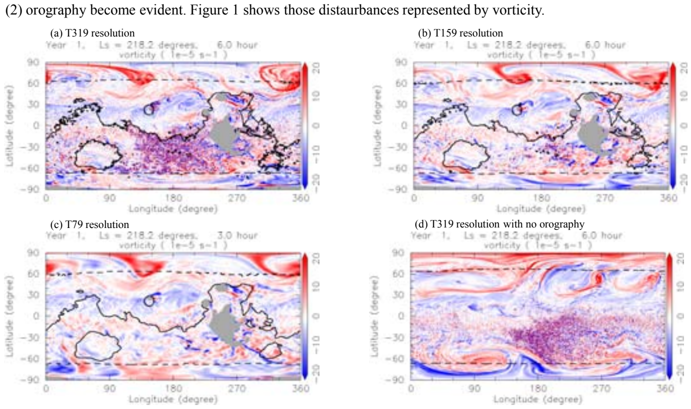

Figure 2. Distribution of relative vorticity at 4 hPa pressure level at 6 "MUT (Mars Universal Time)": (a) T319, (b) T159, (c) T79 resolutions, and (d) T319 with no orography. Also shown is the areoid (solid line) and polar cap edge (dashed line). Gray regions represent mountains at the 4 hPa pressure level.

According to the T319 run with orography, the most prominent dust lifting events occur in the frontal regions. Disturbances associated with orography and solar migration also contribute dust ejection. However, as seen by the time mean amount of dust lifting, the most prominent contributor is those associated with orography.

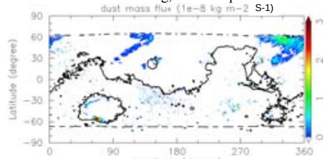

Figure 3. Distribution of dust mass flux averaged over 1/24 Martian day around the same time shown in Figure 2a.

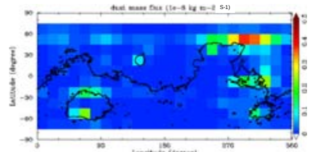

Figure 4. Distribution of areal mean dust mass flux averaged over 28 Martian days (28x24 data).

Resolution dependence of dust lifting, surface stress and wind

Global mean dust mass flux does increase as the increase of resolution. However, the most effective contributor toward T319 is that caused by disturbances associated with characteristic orography.

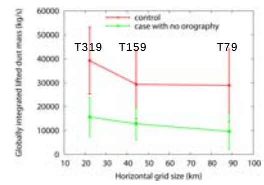

Figure 5. Resolution dependence of globally integrated dust flux averaged over 28 Martian days; orography runs (red) and no orography runs (green). Error bars indicate standard deviation measured by the time series obtained by averaging over 1/24 Martian day.

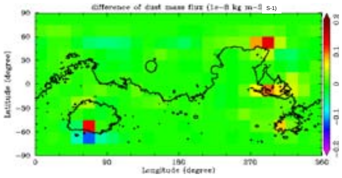

Figure 6. Distribution of the difference of areal mean dust mass flux averaged over 28 Martian days between T319 run and T79 run with orography.

The area of large surface stress increases from T159 to T319 resolutions. The largest value of surface stress for the T319 run with orography becomes twice of that for the T159 run. Dust lifting is caused by surface stress larger than about 0.3 Pa.

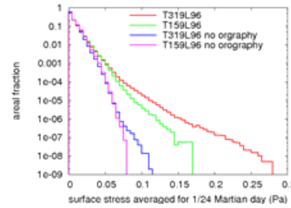

Figure 7. Areal fraction as a function of surface stress averaged over 1/24 Martian day. Plotted are the average over 28 Martian days (28x24 data).

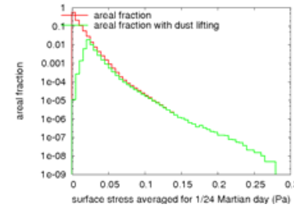

Figure 8. Same as Figure 8, but with areal fraction with dust lifting for the T319 run with orography (green).

Fluctuation of horizontal wind velocity near the surface in the T319 runs are larger than those of the T159 runs, regardless of presence of orography in the model. Dust lifting is caused by wind velocity larger than about 7 m/s at the lowest model level.

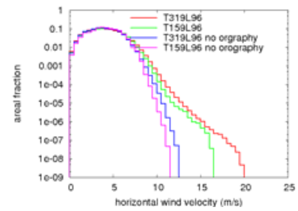

Figure 9. Areal fraction as a function of magnitude of horizontal wind velocity at the lowest model level (~5 m). Plotted are the average over 28 Martian days (28x24 data).

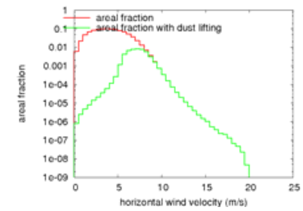

Figure 10. Same as Figure 9, but with areal fraction with dust lifting for the T319 run with orography (green).

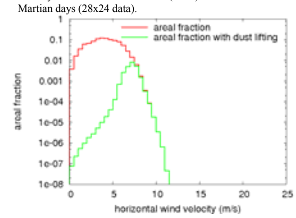

Figure 11. Same as Figure 10, but for T159 without orography (green).

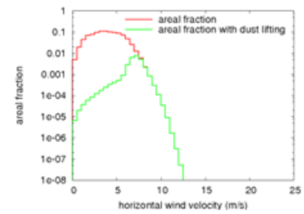

Figure 12. Same as Figure 10, but for T319 without orography (green).

Summary

- Dust mass flux does increase as the increase of resolution.
- However, the most effective contributor from T159 to T319 is orographic wind.
  - By observing the increse of dust lifting around Valles Marineris, the increase of surface wind seems to be caused by the downslope wind adding on the seasonal mean circulation.
- There is a possibility that a change of the horizontal resolution of a GCM may change the global climate state of Martian atmospehre through the change of dust amount suspended in the atmosphere.

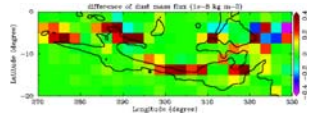

Figure 13. Same as Figure 6 but for a magnified region around Valles Marineris.

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