Numerical simulation of water cycle in a Martian atmosphere by the use of a planetary atmosphere general circulation model, DCPAM

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Spacecraft observations of Mars revealed distributions of water vapor and water ice cloud in the Martian atmosphere. Those observations covered an almost global region and a long period. For example, the Mars Global Surveyor (MGS) observed column densities of water vapor and water ice cloud for about 9 Martian years. The MGS observation characterizes the seasonal variation of the water distribution in the Martian atmosphere. On the other hand, general circulation models (GCMs) have been used to investigate water cycle in the Martian atmosphere. Those models represented distributions of water vapor and water ice cloud consistent with observed ones, successfully.

In our group, we have been developing an atmosphere GCM, DCPAM, which is applicable to planetary atmospheres. By the use of the DCPAM, we have been performed simulations of Martian atmosphere without water cycle. In this study, the simulations of water cycle in the Martian atmosphere are performed by implementing relevant processes in the DCPAM. By performing the simulations, features of water cycle in the Martian atmosphere will be investigated and the model will be validated under a condition of Mars.

The DCPAM used in this study consists of a dynamical core based on the primitive equation system and physical processes relevant to Martian atmosphere. The dynamical core solves the primitive equation system by the use of spectral transform method with the finite difference method in vertical direction. The included physical processes are the radiation, the turbulent mixing, the surface processes, the CO2 and H2O condensation, and gravitational sedimentation. In the model, the radius of cloud particles is assumed to be a constant. 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 is assumed. In the horizontal direction, the optical depth is prescribed following observations. In order to simulate water cycle, large amount of water ice is placed north of 80N. Further, the surface temperature south of 85S is fixed to 145 K to represent a permanent CO2 ice cap. Those H2O and CO2 ices at southern and northern high latitude regions act as source and sink of the water. The resolutions used for this study is T21L36, which is equivalent to about 5.6 degrees longitude-latitude grid and has 36 vertical levels. Under these conditions, the model is integrated for 10 Mars years from an initial condition of isothermal atmosphere at rest. The result during the last Martian year is analyzed.

The model is evaluated by comparing the column densities of water vapor and water ice cloud simulated by the model with those observed by the MGS. The simulations with ice cloud radius of 7 micron meter show following features of seasonal variation of those values which are roughly consistent with observations. From northern summer to northern fall, the water vapor is transported from northern cap to low latitude. At the same time, water ice cloud forms in northern low latitude where the ascending motion of Hadley circulation occurs. However, the low latitude water ice cloud from northern winter to northern spring is slightly thicker in the model than observed one. This may be caused by crude treatment of ice cloud in the model. In the presentation, features of water cycle represented in the model will be presented in more details.

Keywords: planetary atmosphere, general circulation model, Mars, water cycle

Diagnostic experiments of lifted dust flux at the surface with Mars GCM: Consideration of the effects of topography

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The Martian dust influences atmospheric thermal structure (e.g. Liu et al., 2003). Some research groups have made efforts simulating the Martian dust cycle with general circulation models (e.g. Newman et al., 2002, Basu et al., 2004, Kahre et al., 2006). We also implemented two dust lifting schemes into DCPAM (Takahashi et al., 2014) which is a general circulation model developed by our group: One is the lifting scheme with model resolved wind stress, and the other is the scheme with model unresolved vortices such as dust devils. And, we performed diagnostic experiments of the lifted dust flux with these schemes (Ogihara et al., 2014). Characteristics of the lifted dust flux of this result are roughly consistent with those of previous studies. But, because the behavior of dust lifting schemes is complex due to topography, we could not completely understand how the lifted dust flux distribution is decided. In order to understand effects of topography on the behavior of the dust devil lifting scheme, in the work we perform two diagnostic experiments of dust lifting with the flat topography and zonal mean topography. And, we compare the results of the experiment used the flat topography with those of used the zonal mean topography.
The model utilized is DCPAM. DCPAM adopts three dimensions primitive equations. The radiative scheme by Takahashi et al.(2003, 2006) is used. This includes the radiative effects of gaseous CO_2 and dust. And, dust distribution is spatially and temporally fixed. The turbulent process is expressed by using vertical diffusivity based on Mellor and Yamada (1982). The surface process is expressed based on Beljaars and Holtslag (1991), Beljarrs (1994). We employ a dust devil lifting scheme used by Newman et al. (2002). This scheme calculates the lifted dust flux intensity with the surface sensible heat flux and the thermodynamic efficiency, which depends on the depth of the convective layer. The horizontal discretization is the spectral method, and the truncation wavenumber is 21. The vertical discretization is the finite difference method, and the number of levels is 36. We integrate 4 Mars years, and use the last 1 Mars year for analysis. We investigate about two regions: latitude 25N degree and 25S degree. And, we focus on the season during the spring and summer in each hemisphere, when dust is intensely lifted. We perform two diagnostic experiments of the lifted dust flux with fixed a surface distribution of thermal inertia and albedo. One is the experiment with flat topography (Case F) and the other is with zonal mean topography (Case Z).
First, results for regions around 25N degree are as follows. The zonal mean lifted dust flux of Case Z is smaller than that of Case F. Thermal budget analyses show that the heating the upper layer due to the convective adjustment of Case Z is less effective and meridional circulation is weaker as compared to Case F. So, the lower atmosphere of Case Z is more stable than that of Case F and the surface sensible heat flux of Case Z is less intensive than that of Case F. Therefore in Case Z the dust devil lifting is less active than that in Case F.
Second, results for regions around 25S degree are as follows. The zonal mean lifted dust flux of Case Z is greater than that of Case F. Thermal budget analyses show that the heating the upper layer due to the convective adjustment of Case Z is more effective and meridional circulation is more intensive as compared to Case F. So, the lower atmosphere of Case Z is more unstable than that of Case F and the depth of the convective layer of Case Z is larger than that of Case F. Therefore in Case Z the dust devil lifting is more active than that in Case F.

These results indicate that if the convective adjustment heats the upper layer and meridional circulation enhances, the dust devil lifting intensify.
In the future, we will investigate what does observed topography effect on the dust devil lifting.

Keywords: Mars, Dust, General Circulation Model, Dust Devil, Dust lifting

Assessment of the generation and propagation of the gravity waves in the Martian atmosphere using a high-resolution general circulation model

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Gravity waves (GWs) are small-scale atmospheric waves generated by various geophysical processes, such as topography, convection, and dynamical instability. On Mars, several observations and simulations have revealed that GWs strongly affect temperature and wind fields in the middle and upper atmosphere. Our previous study using the Max Planck Institute Mars General Circulation Model (MGCM) and the nonlinear spectral whole atmosphere parameterization of small-scale GWs by Yigit et al. [2008] have shown that the dynamical forcing of GWs significantly change the winds, reversing its direction above ~100 km [Medvedev et al., 2011]. We also have shown that the thermal effects induced by GWs can be the main source of cooling above ~120 km, reproducing the observed temperature structure on Mars [Medvedev and Yigit, 2012]. Similar physical importance of GWs has previously been demonstrated for the general circulation of Earth's upper atmosphere using the whole atmosphere parameterization [Yigit et al., 2009; Yigit and Medvedev, 2009]. Despite numerous observations however, the global picture of GW activity is yet to be revealed both on Earth and Mars.

In order to investigate the global distribution of small-scale GWs in the Martian atmosphere, we have conducted the first simulations with a high-resolution MGCM, using the DRAMATIC (Dynamics, RAdiation, MAterial Transport and their mutual InteraCtions) MGCM [e.g., Kuroda et al., 2005, 2013]. The MGCM was run at the T106 spectral truncation, which corresponds approximately to a 1.1^{o} x 1.1^{o} (or ~60 km) horizontal resolution. In the vertical direction, the model domain extends from the surface to ~80-100 km and is represented by 49 sigma-levels. Such setup allows for realistically capturing generation and propagation of GWs with horizontal wavelengths of ~180 km and longer and, to some extent, their vertical attenuation due to nonlinear processes. We considered horizontal-scale fluctuations with a total wave number of larger than 60 (horizontal wavelengths of less than ~350 km) as GW-induced disturbances.

We investigated the spatial distributions of potential and kinetic energies associated with GW activity in the northern winter solstice. The simulated GW potential energy distribution is in a good agreement with available radio occultation data [Creasey et al., 2006] in the lower atmosphere between 10 and 30 km. The model reveals a latitudinal asymmetry with stronger wave generation in the winter hemisphere, and investigations from the ratio of potential and kinetic energies show that there are two distinctive sources of GWs: mountainous regions and the meandering winter polar jet. Orographic GWs are filtered upon propagating upward, and the mesosphere is primarily dominated by waves with faster horizontal phase velocities. Wave fluxes are directed mainly against the local wind, with a clear relation between wave dissipation and wind acceleration. GW dissipation in the upper mesosphere generates a body force per unit mass of tens of m s^{-1} per Martian solar day (sol^{-1}), which tends to close the simulated jets. Effects of horizontal propagation of GWs on the acceleration are much smaller than those of vertical propagation, and the results of acceleration rates are comparable to those obtained from the application of the GW parameterization by Yigit et al. [2008], which considers only the vertical propagations of a broad spectrum of GWs.

The results represent a realistic surrogate for missing observations, which can be used to further constrain existing GW parameterizations and validate GCMs. Also the observational investigations of GW signatures in the thermosphere by the MAVEN mission would help better understand propagation and

dissipation mechanisms of GWs.

Keywords: Mars, Atmospheric dynamics, Gravity waves, General circulation model, MAVEN

Fluorescence Life-Time (FLiT) instrument for space missions

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While we detail the design of the Life-Detection Microscope (LDM), a high spatial resolution fluorescence microscope, alternative ways of detecting extraterrestrial life have been under consideration. One of such is the "fluorescence lief-time (FLT)" measurement. FLT has been widely used in biophysical studies of proteins as FLT by its nature is one of the most robust fluorescence parameters. To examine the possibility of applying the FLT measurement to the space missions, we have developed a Bread Board Model (BBM), called FLiT. The method we use is the "time-domain" method in which the sample is illuminated with a short pulse laser and the decay time of the fluorescence is measured.
The pulse laser of FLiT is a 488-nm laser diode (Nichia NDS4116) to which pulses of 1-ns full width at half maximum is fed by the driver electronics. One pulse may excite just one fluorophore and the photon from it will be detected by an avalanche photo diode (APD) in the photon-counting mode (MPPC C13001-01 from Hamamatsu Photonics). The time delay from the start trigger (1-ns pulse) to the stop trigger (photon detection in MPPC) is measured by the time-to-digital converter (TDC7200 from TI). Such measurement will be repeated and a histogram of delays is obtained from which the fluorescence life-time of the sample material is inferred. This potentially allows us to distinguish organisms from minerals in the Martian soil. The FLiT BBM is now under the characterization phase, to evaluate possible delays in the electronics (including cables) and their stability. Details of the FLiT BBM as well as results of initial tests will be presented.

Keywords: Fluorescence life-time, Martian life, Life-detection microscope

