惑星大気大循環モデル DCPAM を用いた火星大気中の水循環の数値シミュレーション
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.

キーワード：惑星大気、大気大循環モデル、火星、水循環
Keywords: planetary atmosphere, general circulation model, Mars, water cycle

火星大気大循環モデルを用いた表面ダスト巻き上げフラックス診断実験: 地形の効果によって受ける影響についての考察

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

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火星ではダストが大気熱構造に影響を与えている (例えば, Liu et al., 2003). 各国の研究グループで火星のダスト循環を大気大循環モデルで再現しようという試みが行われている (例えば, Newman et al., 2002, Basu et al., 2004, Kahre et al., 2006). 我々もこれまで開発を進めてきた大気大循環モデル DCPAM (高橋他, 2014) へモデルで直接表現できる風応力によるダスト巻き上げと直接表現できない対流渦 (ダストデビル) によるダスト巻き上げを実装しダスト巻き上げ実験をおこなった (荻原他, 2014). そこで得られたダスト巻き上げフラックスの特徴は先行研究と大まかに一致した. しかし, ダスト巻き上げパラメタリゼーション, 特にダストデビルによるダスト巻き上げパラメタリゼーションの振る舞いは地形によって複雑な挙動を示し, 分布がどのように決まるかまでは理解することはできなかった. そのために本研究では, 地形がどのようにダストデビルによるダスト巻き上げパラメタリゼーションの振る舞いへ影響を及ぼすか理解することを目指す. それゆえに単純化した地形で考える. ここでは, 水平一様な地形と東西平均された地形という二つの単純な地形を用いてダスト巻き上げ実験を行い, その結果を比較する.
ここで用いるモデルは DCPAM である. DCPAM では 3 次元球面プリミティブ方程式を用いている. 放射過程では CO_2 と大気ダストを考慮し, Takahashi et al.(2003, 2006) のスキームを用いる. 放射スキームに与えるダスト分布は固定したものを用いる. 乱流過程は Mellor and Yamada (1982) の方法に従って決めた鉛直拡散係数を用いて評価する. 地表面過程は Beljaars and Holtslag (1991), Beljarrs (1994) の方法に従って評価する. ダストデビルによるダスト巻き上げスキームとして DDA スキーム (Newman et al., 2002) を用いた. このスキームはダストデビルを熱エンジンと見なし, 顕熱フラックスと対流層の厚さに依存する熱力学効率を用いてダスト巻き上げ量を決める. 水平離散化にはスペクトル法を用い全波数 21 で打ち切りを行う, 鉛直方向には差分法を用い, 鉛直層数は 36 とする. 積分時間は 4 火星年であり, 最後の 1 火星年分の解析を行った. 北緯 25 度と南緯 25 度の二つの緯度領域について調べる. 共に, ダスト巻き上げフラックスが増加するそれぞれの半球における春から夏の季節に着目する. 地表面熱慣性, 地表面アルベドは固定した. 地形高度として水平一様な地形を用いた場合 (実験 F) とグローバルサーベイヤーの観測結果を東西平均した地形を用いた場合 (実験 Z) で, ダストデビルによるダスト巻き上げパラメタリゼーションのダスト巻き上げ実験を行い, それぞれの結果を比べてみた.
まず, 北緯 25 度付近の場合の結果を述べる. 東西平均したダスト巻き上げフラックスを比べてみると, 実験 Z の場合は 実験 F の場合のよりも小さくなった. 熱収支の解析から, 実験 Z の場合は 実験 F の場合に比べて下層で対流調節が余り働かず上層を加熱できなく, 子午面循環が弱められる. それにより, 大気が安定状態になり顕熱フラックスが小さくなったことによってダスト巻き上げフラックスが小さくなった.
次に南緯 25 度付近の場合の結果を述べる. 同様に, 東西平均したダスト巻き上げフラックスを比べてみると, 実験 Z の場合は 実験 F の場合に比べて大きくなった. 熱収支の解析から, 実験 Z の場合は 実験 F の場合に比べて下層の対流調節が良く働き上層を加熱し, 子午面循環が強くなり, 対流層が厚くなった. よって, ダスト巻き上げフラックスが大きくなった.
これらの結果から, どの季節でも対流調節が上層を加熱し, 子午面循環が強められるとダストデビルによるダストの巻き上げが大きくなると思われる.
今後は観測された地形における東西方向の起伏の違いによるダストデビルのダスト巻き上げフラックスへの影響を考察する予定である.

キーワード：火星、ダスト、大気大循環モデル、ダストデビル、ダスト巻き上げ
Keywords: Mars, Dust, General Circulation Model, Dust Devil, Dust lifting

高分解能大気大循環モデルを用いた火星大気重力波の励起と伝播の評価
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.

キーワード：火星、大気力学、重力波、大気大循環モデル、MAVEN
Keywords: Mars, Atmospheric dynamics, Gravity waves, General circulation model, MAVEN

Fluorescence Life-Time (FLiT) instrument for space missions
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.

キーワード：蛍光寿命、火星生命、生命探査顕微鏡
Keywords: Fluorescence life-time, Martian life, Life-detection microscope

