火星探査衛星MAVEN搭載IUVSと大気大循環モデルの比較で得られた熱圏密度温度構造

Comparison of the Martian thermospheric density and temperature from IUVS/MAVEN data and general circulation modeling

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The Mars Atmosphere and Volatile Evolution (MAVEN) Mission, which operates for slightly over one year to date, has been specifically designed for investigating the upper atmosphere. The Imaging Ultraviolet Spectrograph (IUVS) onboard MAVEN measures spectra of mid- and far UV atmospheric emission, which are used for retrieving vertical density profiles of CO2 and other species.
Newly released IUVS/MAVEN measurements of CO2 density in the Martian thermosphere have been used for comparison with the predictions of the Max Planck Institute Martian General Circulation Model (MPI-MGCM). In this study, we focus on the October 2014 campaign in which a total of 122 density profiles were obtained for the period between 18 and 22 October (Ls=216.68-218.94). IUVS nicely covers the thermosphere in the altitude range of 130-220 km. The MGCM demonstrated the sensitivity of simulated density and temperature profiles on (i) solar flux, (ii) atomic oxygen, and (iii) small-scale gravity waves (GWs). It is the only MGCM to date that includes a parameterization of effects of subgrid-scale GWs with broad spectra.
The simulations reproduced (within one standard deviation) the available zonal mean density and derived temperature above 130 km. The comparison shows a great role of gravity waves in the thermosphere, and in bringing the simulated density and temperature closer to observations.
The MGCM replicated the observed dominant zonal wavenumber-3 non-migrating tide, which was already reported by MAVEN measurements (Lo et al., 2015). The simulations also demonstrated that it represents a non-moving imprint of the topography in the thermosphere.
This comparison confirms that, with the current state of knowledge of the Martian thermospheric physics, MGCM can reproduce its state and variability. Further observations will help to constrain physical parameterizations and improve modeling capabilities.

キーワード：重力波、熱潮汐、MAVEN
Keywords: Gravity waves, Tides, MAVEN

Runaway acidification on early Mars triggered by atmospheric evolution

Runaway acidification on early Mars triggered by atmospheric evolution

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Mineralogical and chemical observational data of sedimentary rocks deposited on early Mars suggest that chemistry of Mars' surface water had shifted from neutral pH (pH~7-9) to highly acidic (pH~2) at around 3.5 billion years ago (Ga) (Bibring et al., 2006; Ehlmann et al., 2011). One proposed mechanism for this acidification is photo-oxidation of ferrous iron dissolved in surface water (Hurowitz et al., 2010). When UV light is irradiated to surface water, ferrous iron are oxidized to ferric iron by producing H^+ with precipitation of Fe^{3+} minerals (see Equations 1 and 2 below). Hurowitz et al. (2010) show that H^+ produced via this mechanism are quantitatively sufficient to explain the mineralogical and chemical compositions of sedimentary rocks in Meridiani Planum observed by Mars Exploration Rover, Opportunity (e.g., Tosca et al. 2005).

$Fe^{2+}_{aq} + 2H_2O \rightarrow Fe^{3+}O(OH)\downarrow + H_2\uparrow + 2H^+$ (eq. 1)

$Fe(OH)^+ + H_2O \rightarrow Fe^{3+}O(OH)\downarrow + H_2\uparrow + H^+$ (eq. 2)

Although this mechanism would have promoted acidification at 3.5 Ga on Mars, it remains unsolved why surface water with neutral pH had been maintained before 3.5 Ga, and what the trigger for the acidification was. In this study, we propose a new hypothetical scenario to explain the chemical transition of surface water from neutral to acidic pH by considering positive and negative feedbacks in association with photo-oxidation of ferrous iron.

Ferrous iron has two stable dissolved species; Fe^{2+} and $Fe(OH)^+$, depending on pH of water. It has been reported that both species are oxidized when irradiated with UV (< 200 nm). But, $Fe(OH)^+$, which becomes the dominant species at pH > 9, is also oxidized with irradiation of visible light (300-400 nm) (Braterman et al., 1983). In a thick CO_2 atmosphere (~1 bar) with several ppms of SO_2, UV light with short wavelength (< 300 nm) is shielded by the atmospheric gas species. In this case, photo-oxidation of $Fe(OH)^+$ proceeds in surface water, whereas that of Fe^{2+} is limited. In surface water with neutral to alkaline pH, photo-oxidation of $Fe(OH)^+$ acidifies the water forming H^+. However, the concentration of $Fe(OH)^+$ drastically decreases around pH~6.5 via the conversion into Fe^{2+}. This decrease in $Fe(OH)^+$ concentration, in turn, results in dampening $Fe(OH)^+$ photo-oxidation. Consequently, in a thick atmosphere, pH dependence of $Fe(OH)^+$ photo-oxidation works as a negative feedback to maintain surface water pH around neutral.

On the other hand, in a thin CO_2 atmosphere (0.1 bar or less) with < 1 ppm of SO_2, UV light reaches to the surface water, leading to photo-oxidation of both Fe^{2+} and $Fe(OH)^+$ in surface water. In this case, even if the concentration of $Fe(OH)^+$ in surface water decrease at pH~6.5, acidification proceeds via photo-oxidation of Fe^{2+}. As a result, a runaway acidification to highly acidic surface water occurs via this positive feedback.

Here, we discuss the above possibility more quantitatively using the previous laboratory data on photo-oxidation rates of Fe^{2+} under acidic conditions by Jortner et al. (1962) and those by Braterman et al. (1983) under neutral pH conditions. We calculate the total production rate of H^+ both via the photo-oxidation of Fe^{2+} and $Fe(OH)^+$ for various atmospheric compositions and pressures. Based on our sensitivity study of the abundances of CO_2 and SO_2 to acidification of surface water, the critical atmospheric compositions to drive the runaway acidification are discussed.

キーワード：火星、酸性化、大気進化、光酸化、地球化学
Keywords: Mars, acidification, atmospheric evolution, photooxidation, geochemistry

Warmer Wetter Mars in the Past?

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The isotopes of CO_2 ($^{13}C/^{12}C$, $^{18}O/^{16}O$), H_2O (D/H), N_2 ($^{15}N/^{14}N$), Ar (^{38},$^{40}Ar/^{36}Ar$), Kr and Xe are excellent indicators of climate change in the atmosphere of Mars. Recent high precision measurements of those isotopes with the quadrupole mass spectrometer and the tunable laser spectrometer of the Sample Analysis (SAM) suite of instruments on the Curiosity Rover clearly show that the atmosphere of Mars has been substantially depleted over the past four billion years. At the same time, both geological evidence and a comparison of the D/H isotope ratios in water vapor in the atmosphere with the Hesperian-era Gale Crater smectite rock fines, and even older Mars meteorites suggest a relatively large abundance of (liquid) water on the surface of Mars in the past. With the exception of xenon, the above isotopes inform about the change since roughly 4 Ga. The isotopic fractionations in xenon suggest, in addition, a massive H_2-driven hydrodynamic escape very early in the geologic history of Mars. Employing the isotopic record in the atmosphere and rock fines, we investigate a scenario of Mars where atmospheric composition and relatively high atmospheric pressure resulted in warmer conditions necessary for maintaining surface liquid water at least intermittently through late Noachian/early Hesperian, followed by a gradual loss of the atmosphere by escape since then, hence warmer and wetter conditions in the past compared to Mars' present cold and arid state.

Keywords: Mars, Climate Evolution, Isotopes

Viking Lander 2搭載地震計データ復元の現状
Current status of data restoration of the seismometer onboard Viking Lander 2

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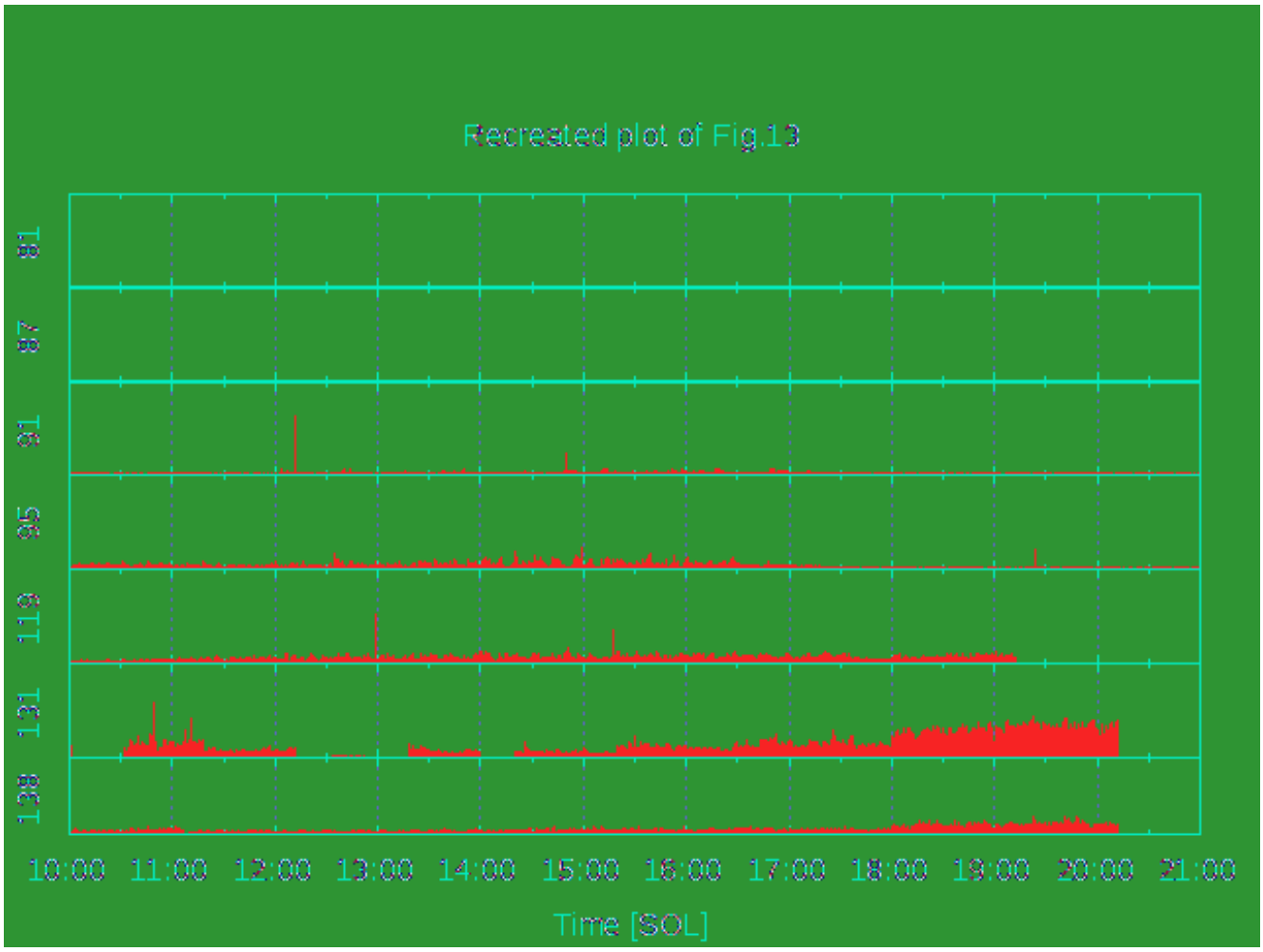
1975年に打ち上げられたViking Lander 2には地震計が搭載された。40年が経過した現在も、人類が保有する唯一の火星における地震計データである。このデータは火星での地震活動を発見するに至らなかったが、データそのものが整備されておらず、検証を行える状況になかった。我々はこの地震計データの復元を試み、過去の論文で図示されたデータと一致する結果を得ることができた。これを元に全データを処理したところ、源泉データに幾つかの問題点が存在し、そのままでは科学解析を行う上で前処理として多大な労力が必要となることが判明した。本研究では、これらの課題を克服し、新しいデータセットを提供することを目的とし、データ処理を進めている。

キーワード：ヴァイキング、地震計、データ
Keywords: Viking, Seismometer, data



火星大気中音波検出器の開発のための過酷環境試験下マイク動作特性の解析
Analysis of microphones operating characteristics under harsh environment in order to develop a sound detector in Martian atomosphere

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１．背景
2020年代，宇宙航空研究開発機構(JAXA)により火星探査機の打ち上げが計画されており、シリーズ的な火星探査の実現が期待されている．2016年現在，火星大気中における音波観測は未だ行われていない．そこで探査用ローバーに本研究を反映して設計・開発するマイクを搭載すれば，ダスト現象に伴う火星大気中の音の計測だけでなく，大気中の物理量の間接計測も可能になるとともに，春先の季節に発生する可能性のあるガス放出現象など最近注目され始めた火星地表面活動にもフォーカスしたリモートセンシングに応用できると期待される．
２.目的
火星探査機に搭載するマイクの過酷環境下での試験を行い，コンデンサマイクおよびMEMS（Micro Electro Mechanical Systems)マイクの二種類のマイク評価モデル(BBM)を試作し，どちらが火星大気での動作に適しているか評価・選定を行うこと，およびマイクアレイによる検知性能向上について調整することを目的とする．
３．実験概要
火星地表大気条件として、CO_2成分が95%を占め，地表面気圧7 hPa，夜間気温-120 ℃という過酷環境を模した試験を2015年1月に千葉工業大学にて行った．さらに高知工科大学にてマイクBBMの較正実験を行った．可聴音の下限である20 Hz以下の音をインフラサウンドと呼び，将来の火星大気中でのインフラサウンド信号の検知も目標としているため，可聴音の他にインフラサウンドを入力し，較正データとして用いた．真空チャンバを密閉容器として使用し，これに接続した微小容積のシリンジを使って周期的に圧縮・吸引を行い，大気圧に対する微気圧変動を精密波形として作り出し，この波形をインフラサウンド入力とし較正実験を行った．実験系に周波数0.1 Hz，振幅1 Paの波形を入力した時の結果から既存のインフラサウンドセンサ(Chaparral Physics製Model25)とマイクBBMの性能評価を行った．
４．実験結果
高知工科大学で行った実験より,インフラサウンドを用いた測定結果では共に0.1 Hzに一致するスペクトルピークが得られ，波形の最大振幅はChaparral Physics製Model25が0.05989 Pa，コンデンサマイクが0.07657 Paとなった．このことより、使用したコンデンサマイクは0.1 Hz帯では既存のインフラサウンドセンサより高い検出精度をもつことが分かった。その後，同じ0.1 Hz，1 Paの波形入力にてコンデンサマイクとMEMSマイクの比較を行った．コンデンサマイクは0.1 Hzのインフラサウンドを検出できているがMEMSマイクはほとんど検出できていないことが分かった．
５.考察
千葉工業大学の実験では模擬火星大気中での動作が確認されたが，さらに低圧の1 hPaではMEMSマイクのみ出力信号が乱れ動作が確認できなかった．さらに高知工科大学の実験より，0.1 Hzの波形に対してコンデンサマイクBBMはModel25インフラサウンドセンサに対し約1.28倍の受信性能を持っていることが分かる．これよりコンデンサマイクには0.1 Hz帯での優れたインフラサウンド受音性能があることが分かった．2種類のマイクBBMを比較するとコンデンサマイクは0.1 Hzを入力値の約1/10の圧力で検出することが可能であるがMEMSマイクは同帯域を検出できていないことが分かる。千葉工業大学，高知工科大学にて実施した両実験より，耐苛酷，環境面，検出性能面においてMEMSマイクに比べ，コンデンサマイクが火星大気中の音波検出器として適していると言える．
６．結論
火星大気模擬環境下において，コンデンサマイク，MEMSマイクの2種類のBBMを試作して動作比較を行い，大気

を模擬した環境下での動作に適したマイクの選定を行った．火星探査における最終的な観測方法は長距離伝搬可能なインフラサウンド帯域での多地点観測に重点を置いている．そのため高知工科大学での実験結果の通り，0.1 Hz程度までのインフラサウンドを観測可能なコンデンサマイクを火星探査用マイクに使用するべきであると結論付ける．

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キーワード：火星、インフラサウンド
Keywords: Mars, Infrasound

火星表面での細胞のその場観察：生命探査顕微鏡
LDM (Life Detection Microscope): In situ imaging of living cells on surface of Mars

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Past trial of detection of life on Mars by 1970's Viking mission ended up with a negative conclusion [1]. Whereas, numbers of new finding provided by Mars exploration missions in the last decade indicate that there are good reasons to perform another life detection program. The sensitivity of GC-MS onboard the Viking mission was not very high, and was not able to detect the microbes 10**6 cells in 1 gram clay [2,3]. Here we propose Life Detection Microscope (LDM) that has much higher sensitivity than the instrument onboard Viking.
Resent observations on Mars have found the evidences of past water activities. MSL Curiosity has reported the temporal increase of methane concentration in Martian atmosphere [4]. The presence of reduced sulfur compound such as pyrite in Martian soil was also detected by MSL [5]. Methane and reduced sulfur compound can be the energy source to support the growth of chemoautotrophic microbes [6]. Possible presence of liquid water at Recurring Slope Lineae has been supported by the detection of hydrated salts [7]. The presence of organic compounds of Martian origin has been reported [8]. These evidences tend to support the possible presence of living microbes near the surface of Mars.
Physical and chemical limits for terrestrial life have been major foci in astrobiology [9], and are summarized in ref. [6]. Combining the environmental factors, anywhere in the Martian environment where we can find the three components, water molecules, reducing compounds and oxidative compounds could be an environment where life can be sustained for long periods of time, if other factors such as temperature, pressure, UV and other radiations permit [6]. Among these factors, most of the factors including ionic radiation, can be endured by terrestrial extremophiles. Only UV can kill the most UV-resistant microbes within minutes. However, UV can be shielded by a-few-centimeter sail layer. These evaluation lead to the conclusion that the Martian soil under a few cm can be the place to support the growth of microbes, if the water activity is higher than 0.6.
We will report the current status of the development of the LDM. We propose to search for cells from a depth of about 5 - 10 cm below the surface, which is feasible with current technology. Microscopic observation has the potential to detect single cells. We have developed the solution and combination of fluorescence pigments to detect organic compounds, and to differentiate organic compounds surrounded by membrane. The subsequent analysis of amino acids, in the following mission, will provide the information needed to elucidate the origin of the cell.
LDM that we propose here could detect less than 10**4 cells in 1 gram clay [6]. LDM is capable of

identifying what we think to be the most fundamental features that a cell should possess to constitute life. Our Investigation Goals are the followings. 1) Identify cell-like structure in which organic compounds are enveloped by membrane, which may represent Martian life. 2) Search for any type of organic compounds in Mars surface samples. The compounds include cells, other biological materials, and abiotic polycyclic aromatic hydrocarbon (PAH). 3) High-resolution characterization of regolith and dust particles.

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キーワード：火星、蛍光顕微鏡、生命探査
Keywords: Mars, Fluorescence microscope, Life search

Tracking the MSL-SAM methane detection source location Through Mars Regional Atmospheric Modeling System (MRAMS)

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The putative in situ detection of methane by SAM instrument has garnered significant attention. There are many major unresolved questions regarding this detection: 1) Where is the release location? 2) How spatially extensive is the release? 3) For how long is CH4 released? In an effort to better address the potential mixing and remaining questions, atmospheric circulation studies of Gale Crater were performed with the Mars Regional Atmospheric Modeling System (MRAMS). The model was focused on rover locations using nested grids with a spacing of 330 meters on the innermost grid that is centered over the landing. MRAMS is ideally suited for this investigation. In order to characterize seasonal mixing changes throughout the Martian year, simulations were conducted at Ls 0, 90, 180 and 270. Two additional simulations at Ls 225 and 315 were explored to better understand the unique meteorological setting centered around Ls 270. Ls 270 was shown to be an anomalous season when air within and outside the crater was well mixed by strong, flushing, northerly flow and large amplitude breaking mountain waves: air flowing downslope at night is cold enough to penetrate all the way to the surface. At other seasons, the air in the crater is more isolated -but not completely- from the surrounding environment: mesoscale simulations indicate that the air flowing down the crater rims does not easily make it to the crater floor. Instead, the air encounters very cold and stable air pooled in the bottom of the crater, which forces the air to glide right over the colder, more dense air below. Thus, the mixing of near surface crater air with the external environment is potentially more limited at seasons other than around Ls 270. The rise in CH4 concentration was reported to start around sol 300 (~Ls 336), peaked shortly after sol 520 (~Ls 82), and then dropped to background values prior to sol 575 (~Ls 103). Two scenarios are considered in the context of the circulations predicted by MRAMS. The first scenario is the release of methane from somewhere outside the crater. The second is a release of methane within the crater. In both cases, the release is assumed to take place near the season when the rise of concentration was first noted (~Ls 336). This is a transitional time at Gale Crater, when the flushing winds are giving way to the more isolated crater scenario. Some preliminary work, including tracer gases into the model, is being performed to establish the amount of mixing during the limited mixing epochs. Preliminary results may support the idea that during periods of limited mixing, there could be enough time for methane to bind to activated mineral surfaces through wind erosion.

Keywords: Mars meteorology, Mars atmosphere, Mars Science Laboratory, Gale crater, methane

火星ユートピア平原におけるフィロケイ酸塩分布
Distribution of phyllosilicates on Utopia Planitia, Mars

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Many studies suggest that abundant liquid water existed in the past on the Martian surface, although there is currently no liquid water on the surface of Mars. The hydrated minerals are generally formed through long-term contact with water or alternation by water. We can get a key to understand the water environment of Mars by studying the observed hydrated minerals.

The wider distribution of hydrated minerals on the southern hemisphere on Mars has been reported in previous studies [e.g. Carter et al., 2013], however, only a limited number of outcrops of hydrated minerals are detected so far in the northern lowlands. The surface of northern lowlands is basically young being covered with lava materials in Hesperian through Amazonian ages. We expect that the deposition below the younger crust of the northern lowlands should host hydrated minerals commonly. The purpose of this study is to examine the distribution of hydrated minerals in the northern lowlands of Mars.

We focus on the comparatively larger craters which should expose the subsurface minerals by impact gardening in the northern lowlands of Mars. Our analysis targets are the craters with diameters ≥ 10km in Utopia Planitia ranging 25-50N, 90-140E. The number of the craters amounts to 14 in total. We used the data from CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) onboard Mars Reconnaissance Orbiter. The spectral data cover near-infrared wavelengths. We tried to detect the absorption features characteristic to the phyllosilicates. We used CAT (CRISM Analysis Toolkit) combined with ENVI spectral analyst tool to analyze the latest CRISM data observed in the study area in detail.

As a result, phyllosilicates-bearing minerals were detected at 5 impact craters among 14 impact craters examined in this study. The 5 craters are: 2 craters where phyllosilicate hadn't been detected by Fairén et al. [2012], 2 craters not examined so far and 1 crater where phyllosilicates are already detected by Fairén et al. [2012]. The four kinds of phyllisilicates were detected: illite, smectite, vermiculate and a small number of saponite. We saw no discrete distribution according to the kind of minerals but we found that the distribution of phyllosilicates-bearing minerals strongly connects with erosional areas. We observed that phyllosillicates distribute at the rim, wall, floor, ejecta and around the central peak of the craters. These detected phyllosilicates are interpreted that deposited under the younger crust of the northern lowlands are emitted on the surface by impact gardening by Carter et al. [2010].

The number of samples in this study is still small, but the detection ratio of phyllosilicates seems significantly larger than Carter et al. [2013]. The results imply that hydrated minerals are possibly more widespread in the northern lowlands of Mars. Such detailed examination that uses the latest observation data and smart tools should result in increasing ratio of detecting phyllosilicates and contribute to clarification of water environment in the northern lowlands of Mars.

キーワード：火星、含水鉱物、フィロケイ酸塩、赤外分光、CRISM/MRO
Keywords: Mars, hydrated minerals, phyllosilicate, infrared spectra, CRISM/MRO

火星境界層の高解像度LES実験

High resolution Large eddy simulation on Martian planetary boundary layer

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A large-eddy simulation (LES) on Martian planetary boundary layer has been performed to examine structure and characteristics of turbulence in the layer and their dependency on experimental resolution. SCALE-LES, which is an LES model for large domain and high resolution experiments developed in RIKEN AICS (http://scale.aics.riken.jp/), is used in this study. Spatial resolution is swept from 100m to 5m. Domain size is about 20km in horizontal and vertical. Horizontal boundary condition is double periodic condition. Heating rate calculated by an offline one-dimensional experiment (Odaka et al. 2001) is used instead of explicit calculation of the radiative transform process.
Well-known features of the boundary layer, such as hexagonal structure of convective cells and the -5/3 energy spectrum, are reasonably simulated. Dependency of several physical quantities at 14:00-15:00 local time, when the boundary layer is almost mature, on the resolution is analyzed. We found that vertical heat flux and variance of vertical velocity of resolved component show convergence or systematic tendency with the resolution. Convective vortices are developed and most of them are located near the upward reasion.

キーワード：火星境界層
Keywords: Martian Planetary Boundary Layer

火星大気北半球冬季におけるCO_2過飽和の経度依存性

Longitudinal dependence of CO_2 supersaturation during northern winter in the Martian atmosphere

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米国の火星探査機であるマーズ・グローバル・サーベイヤー（MGS）で行われた電波掩蔽観測では、長期間（1998-2007）にわたる気温の高度分布データが得られている。このデータを解析した結果、北半球冬季の高緯度（北緯60-80度）において、大気主成分であるCO_2の過飽和の発生に強い経度依存性が見られることがわかった。CO_2過飽和が頻発するのは、約400-30 Paの高度領域においては東経90-180度と270-360度の地域であった。気温の東西偏差と比較すると、およそ低温部に一致することがわかった。

キーワード：火星、過飽和、二酸化炭素
Keywords: Mars, supersaturation, CO2

