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Simulation of the high-resolution water cycle and HDO/H_2O isotopic fractionation on Mars using DRAMATIC MGCM

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Abstract

We are starting to simulate the water cycle of the present Martian environment using a Mars general circulation model (MGCM) for the investigations of the water cycle system and related material transport on Mars in collaboration with the current and future observations. We performed the horizontal high-resolution simulations with the grid intervals of ~67 km, showing the relationships between water transport and atmospheric dynamics more clearly than the previous low-resolution simulations. Our results show the consistent seasonal and latitudinal changes of zonal-mean water vapor column density and ice opacity with observations in the run without the radiative effects of water ice clouds. Also, we have implemented the HDO/H_2O isotopic fractionations, and reproduced the qualitatively consistent seasonal and latitudinal changes of the ratio with a preceding simulation.

1. Introduction

The spacecraft on the Mars orbit, such as Mars Global Surveyor (MGS), Mars Odyssey, Mars Express and Mars Reconnaissance Orbiter (MRO), have continuously observed the global distributions of water vapor and water ice clouds for these 18 years (almost a Martian decade). In parallel with the reservoir of observational data, simulations of the water cycle on Mars using Martian General Circulation Models (MGCMs) have been performed in several groups [1-3], providing a lot of improvements of the physical processes such as cloud microphysics [4] and implementation of the radiative effects of water ice clouds [5]. Also, the detailed observations of HDO/H_2O isotopic ratio are planned by the ExoMars Trace Gas Orbiter (EMTGO), for the detections of age and transport processes of water. Moreover, horizontal high-resolution simulation would be helpful for the investigations including small-scale dynamical features to support the ongoing observations by EMTGO and ground-based telescopes.

2. Model description

The DRAMATIC (Dynamics, RAdiation, MAterial Transport and their mutual InteraCtions) MGCM [6-8] used in this study is based on the dynamical core of the CCSR/NIES/FRCGC MIROC model [9]. The MGCM has a spectral solver for the three-dimensional primitive equations, and the runs are performed with the horizontal resolution of T106 (about 1.1°×1.1°, ~67 km at equator), and vertical 49 sigma-levels (the altitude of the lowest layer is ~50 m) up to ~90 km. Physical parameterizations for the present Mars environment are described in [6] with updates in [7], and the implementations of water cycle and HDO/H_2O isotopic fractionations are as described in [10]. The calculations started from the 'dry' iso-thermal state without water vapor/ice in the at-mosphere and on surface except the permanent water ice cap in the north of 80° N. The isotopic ratio of the permanent north polar water ice cap is set to 7.0 VSMOW (Vienna Standard Mean Ocean Water, $[HDO]/[H_2O]= 3.1\times10^{-4}$).

3. Results

With the run for ~10 Martian years from the isothermal state, the results of annual water cycle become in equilibrium in overall. Without the radiative effects of water ice clouds, we could reproduce the seasonal changes of water vapor column density and water ice opacity agreeing with the MGS-Thermal Emission Spectrometer (TES) observations [11]. Also, we simulated the seasonal and latitudinal changes of HDO/H_2O ratio, which were in overall consistent qualitatively with a preceding simulation [12].

Figures 1 and 2 show the snapshots of water vapor column density and HDO/H_2O ratio at L_s~9°

(northern spring), localtime of 0600 at 0° longitude. In both figures the structure of baroclinic waves with zonal wavenumbers of 1 and 2 is seen in northern mid-latitudes, as well as weaker zonal wavenumber 2 structure in southern mid-latitudes, which may transport the water vapor to polar regions. Moreover, the thermal tide may affect to strengthen the transport, as the strong flow to northeast is seen around 60° E (close to the sub-solar longitude) in northern high-latitudes. These features are more clearly seen in Figure 2, which indicates that the mapping of HDO/H_2O ratio with time sequences (for several hours or a few days) from the observations by EMTGO and/or ground-based telescopes would work to clarify the meridional transport of water.

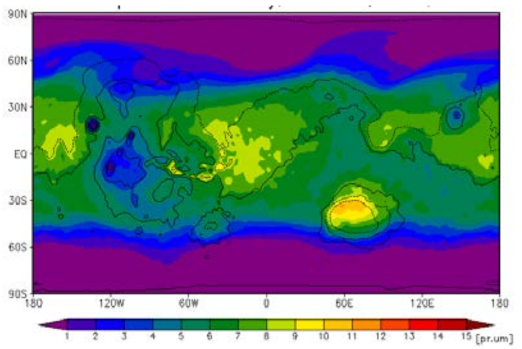

Figure 1: A snapshot of the horizontal distribution of water vapor column density in our T106 simulation, at L_s~9° at localtime of 0600 at 0° longitude.

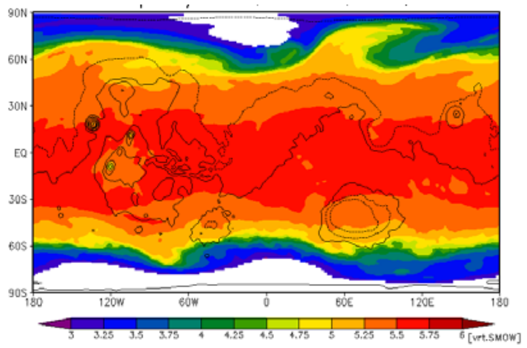

Figure 2: Same as Figure 1, except HDO/H_2O ratio in vapor column density.

4. Summary and notes

It needs to be noted that there are two main problems in our current simulation: (1) We need to make the particle size of water ice in the equatorial cloud belt unrealistically large (up to ~12 μm) to reproduce the observed cloud opacity. (2) If the radiative effects of water ice clouds are included, the atmospheric temperature becomes unrealistically high, which results in the increase of the equatorial cloud belt altitude in ~20 km and significant decrease of the opacity of equatorial cloud belt during northern summer (~1/10).

We need to improve the above points, but, nevertheless, our model has two main advantages: (1) HDO/H_2O isotopic fractionation and (2) horizontal high-resolution simulation in which the small-scale dynamical features can be reflected. With this MGCM, we intend to support the MRO and EMTGO missions which observe the water in lower atmosphere, and, moreover, the MAVEN (Mars Atmosphere and Volatile EvolutioN) mission which observe the compositions in the upper atmosphere with planned future implementation of the photochemical processes and extension of the model to the thermosphere.

Acknowledgements

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References

[1] Richardson, M.I. and Wilson, R.J., J. Geophys. Res., 107(E5), 5031, doi:10.1029/2001JE001536, 2002.

[2] Richardson, M.I. et al., J. Geophys. Res., 107(E9), 5064, doi:10.1029/2001JE001804, 2002.

[3] Montmessin, F. et al., J. Geophys. Res., 109, E10004, doi:10.1029/2004JE002284, 2004.

[4] Navarro, T. et al., J. Geophys. Res. Planets, 119, 1479–1495, doi:10.1002/2013JE004550, 2014.

[5] Wilson, R.J. et al., Geophys. Res. Lett., 35, L07202, doi:10.1029/2007GL032405, 2008.

[6] Kuroda, T. et al., J. Meteorol. Soc. Jpn., 83, 1–19, 2005.

[7] Kuroda, T. et al., Geophys. Res. Lett., 40, 1484–1488, doi:10.1002/grl.50326, 2013.

[8] Kuroda, T. et al., Geophys. Res. Lett., 42, 9213–9222, doi:10.1002/2015GL066332, 2015.

[9] K-1 Model Developers, K-1 Tech. Rep., 1, Univ. of Tokyo, 1–34, 2004.

[10] Kuroda, T., Abstract book of ‘Sixth international workshop on the Mars atmosphere: modelling and observations’, Univ. of Granada, 2017.

[11] Smith, M.D., Annu. Rev. Earth Planet. Sci., 36, 191–219, doi:10.1146/annurev.earth.36.031207.124334, 2008.

[12] Montmessin, F. et al., J. Geophys. Res., 110, E03006, doi:10.1029/2004JE002357, 2005.