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Modeling the HDO cycle with the LMD Mars GCM

Margaux Vals[1], Loïc Rossi[1], Franck Montmessin[1], François Forget[2], Ehouarn Millour[2], Kevin Olsen[3], Anna Fedorova[4], Alexander Trokhimovskiy[4], and Oleg Korablev[4]
[1]LATMOS, Université Paris-Saclay, UVSQ, CNRS, Guyancourt, France.
[2]CNRS, Laboratoire de Météorologie Dynamique, UPMC, Paris, Paris, France (margaux.vals@lmd.jussieu.fr)
[3]Department of Physics, University of Oxford, UK
[4]IKI : Space Research Institute (IKI), Moscow, Russia

Abstract

HDO and the D/H ratio are important in order to understand Mars past and present climate, in particular with regards to the evolution through ages of the Martian water cycle. We present here further modeling developments of the HDO cycle with the LMD Mars GCM (Forget et al. 1999), in continuation of the work presented by L. Rossi in session TP16 ("Modeling of the effect of the MY34 Global Dust Storm on the martian HDO cycle."). These improvements are led with the perspective of comparison with the new observations provided by the Atmospheric Chemistry Suite (ACS) on board the ESA/Roscosmos Trace Gas Orbiter.

Introduction

The D/H ratio observed in a planetary atmosphere is a proxy for the ratio of the current water reservoir over the initial water reservoir of the planet. The current D/H ratio measured in the Martian atmosphere is at least five that of the Vienna Standard Mean Ocean Water (SMOW) (Owen et al. 1988 , Encrenaz et al. 2018, Krasnopolsky 2015, Villanueva et al. 2015). This high value of the martian D/H ratio, derived from the HDO/H_2O abundance ratio, is a precious indicator of the large escape of water from the martian atmosphere along time. Apart from the mass difference between both isotopes, the differential escape of H and D comes from the preferential photolysis of H_2O over HDO (Cheng et al. 1999) and the Vapor Pressure Isotope Effect (VPIE) that produces an isotopic fractionation at condensation (Krasnopolsky, 2000, Bertaux et al. 2001, Fouchet et al. 2000).

Modeling HDO

Although the version of the model used by L. Rossi et al. comprises the main last developments of the code, it uses a simplified version of the water cycle (no radiative effect of clouds, simple conversion from vapour to ice to reach the saturation pressure) to deal with a consistent comparison with the previous study led by Montmessin et al. 2005. We present here the results of the HDO cycle modeled with the complete representation of the water cycle, including the activation of the radiative effect of clouds and the microphysics (referring to the parametrization of the different processes of formation of the clouds as nucleation of the ice particles on dust particles, water ice growth, dust scavenging end supersaturation) implemented in the model by Navarro et al. 2014. Indeed, these achievements have been proved to considerably improve the representation of the water cycle in comparison to available observations.

Preliminary results

The reinforcement of the Hadley circulation by the radiative effect of clouds, so as the involvement of dust in the cloud formation, obviously affect the transport of HDO and its vertical distribution, which directly impacts the D/H ratio in the atmosphere. The results of a GCM simulation run over three martian years reveal a persistent behaviour of the D/H cycle. The D/H ratio cycle of the vapour phase is close to the one observed by Montmessin et al. 2005, and also by L. Rossi in the abstract submitted to session TP16, with an emphasis of the latitudinal gradient appearing during the Northern Hemisphere Summer, probably due to the reinforcement of the Hadley cell generated by the radiative effect of clouds (see Figure 1). The D/H ratio cycle of the ice phase presents a strong dichotomy between what happens during the first and the second part of the martian year. In particular, the high values of D/H (~6) appearing in the tropics during the Southern Hemisphere spring and summer, while the corresponding amounts of the HDO and H_2O ice are quite low (respectively around 10~ppb and 5000~ppb), have to be further investigated (see Figure 1). The vertical profiles of HDO and D/H seem also impacted by the modified structure of the clouds led by the integration of the microphysics (see Figure 2).

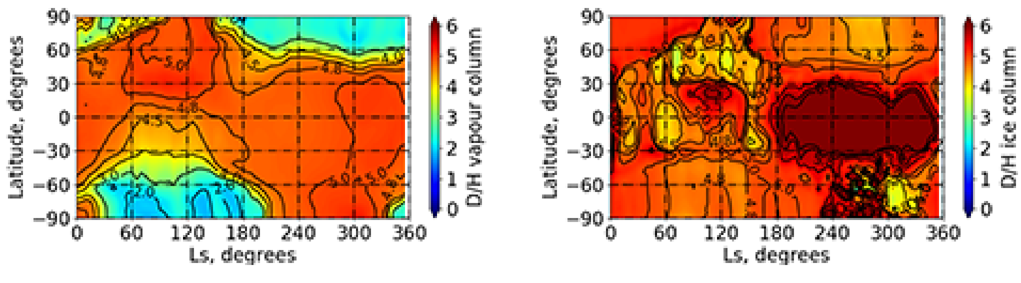

Figure 1: Zonal mean of the integrated column of D/H vapor and ice ratio over a martian year at the local time 14:00, binning by 5° of Ls (Solar Longitude). GCM simulation run with the radiative active water ice clouds and the microphysics.

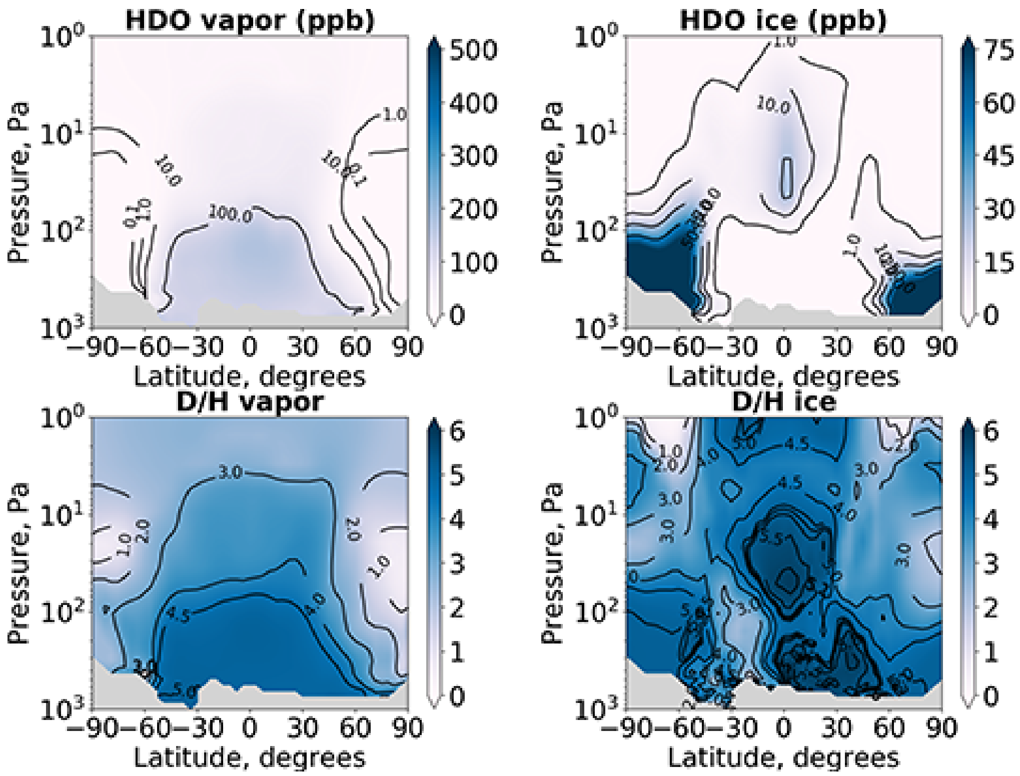

Figure 2: Zonal mean cross sections of HDO vapor, HDO ice, D/H vapor and D/H ice during southern spring (Ls =180°).

Conclusion

While the results of the simple physics of clouds allow a straightforward analysis of the fractionation effect and the behaviour of HDO regarding H_2O, the last simulations obtained with the microphysics of clouds account for a more realistic representation of the HDO cycle and will offer the best basis for interpretation and comparison with the observations. For now, the here-presented simulations extend to an altitude of around 120~km and they don't include the parametrizations of the thermosphere (Angelats i Coll et al. 2005, Gonzalez-Galindo et al. 2009) and the photochemistry (Lefèvre et al. 2004, 2008). The ultimate goal of this work is the development of a complete representation of the deuterium cycle, from its source as HDO in the lower atmosphere to its photodissociation in the thermosphere.

Results of the last achievements will be presented at the conference.

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