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Modeling of the effect of the MY34 Global Dust Storm on the martian HDO cycle.

Loïc Rossi et al.

Abstract

HDO and the D/H ratio are important in order to understand Mars past and present climate, in particular through ages of the Martian water cycle. We present here new modeling efforts aimed at rejuvenating LMD Mars GCM, with the perspective of comparison with the new observations provided by the Atmosphere Trace Gas Orbiter board the ESA/Roscosmos Trace Gas Orbiter.

Introduction

Mars is known to have had a significant liquid water reservoir on the surface and the D/H ratio derived from the ratio is a sensitive tool to constrain the primordial abundance of the water reservoir on Mars and its ratio is at least five times that of the Vienna Standard Mean Ocean Water (SMOW) (Owen et al. 2002, Krasnopolsky 2015, Villanueva et al. 2015).

H and D atoms in the upper atmosphere are coming from H₂O and HDO, their sole precursor in the lower atmosphere. The ratio of H over D atoms and the fact that H₂O is preferentially photolysed over HDO (Cheng et al. 1999) are the main factors affecting these two elements. Also, the heavier isotope, HDO, has a lower vapor pressure than H₂O, which leads to the depletion of the deuterated isotope in the solid phase of water. This effect is known as the Vapor Pressure Isotope Effect. The D/H ratio above the condensation level to values as low as 10% of the D/H ratio near the surface (Berthelin et al. 2000). Fractionation should affect the amount of HDO depending on latitude, longitude, altitude and season.

Modeling HDO

In particular, a previous model (Montmessin et al., 2005) has predicted that an isotopic gradient should exist where condensation depletes the atmosphere in HDO and the warmer, condensation-free, regions where H₂O is dominant. This leads to a latitudinal gradient of D/H (with variations greater than a factor of 5) between the warm

and the cold and dry winter hemisphere. This gradient was later confirmed by several Earth observations (Villanueva et al. 2015, Encrenaz et al. 2018, Aoki et al. 2019). Yet some observations (Villanueva et al. 2015) have revealed longitudinal variations of D/H ratios which have remained unexplained and are not reproduced by the current models.

It is therefore essential to model the HDO cycle and the associated processes of fractionation in a 3D climate model. With the Trace Gas Orbiter (TGO) mission now in its mission phase, very strong and precise constraints are needed to evaluate the GCM prediction capability.

We present here the results from our (re)integration of the HDO cycle into the LMD Mars GCM, taking into account condensation and ice phases in the atmosphere, and as surface ice. The model presented here uses a simplified condensation nuclei. The updated model is in good agreement with the results of Montmessin et al. (2015) regarding the latitudinal gradient between cold and warm regions and its seasonal variation (see fig 1)

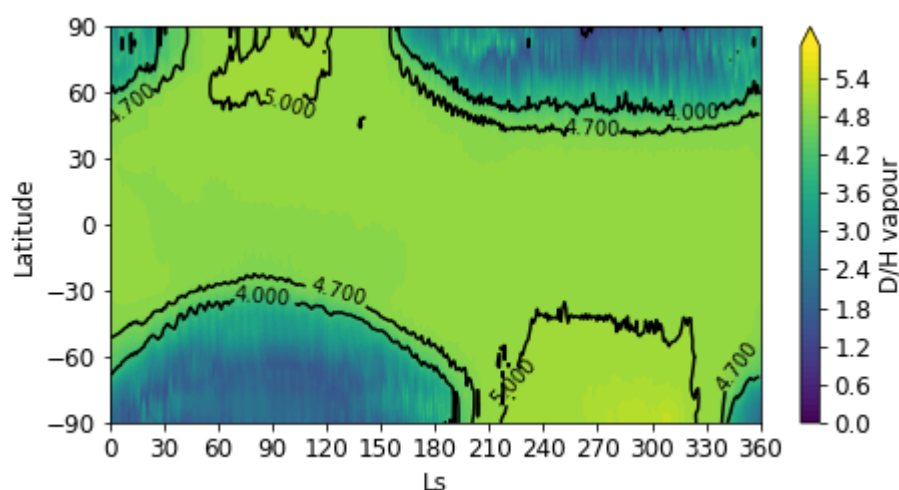


Figure 1 : Latitudinal and seasonal variation of the zonally averaged D/H ratio in the vapor phase, as predicted by the LMD Mars GCM.

The present study gives a 3D climate model projection of the behavior of HDO in the context of a dust storm season and spatial evolution observed during Martian Year 34 (MY34) and including the occurrence of a Global Dust Storm (GDS). The simulations reported here emphasize the contrast in HDO behavior between a perturbed traditional MY where the seasonal evolution of dust obeys a recurrent and more quiet, so-called "climatic" scenario.

The simulations (see fig. 2) show that in the climatological scenario the cloud formation, and the subsequent trapping of HDO within the ice particles, depleting the vapour phase above the condensation level (the so-called "ice trap").

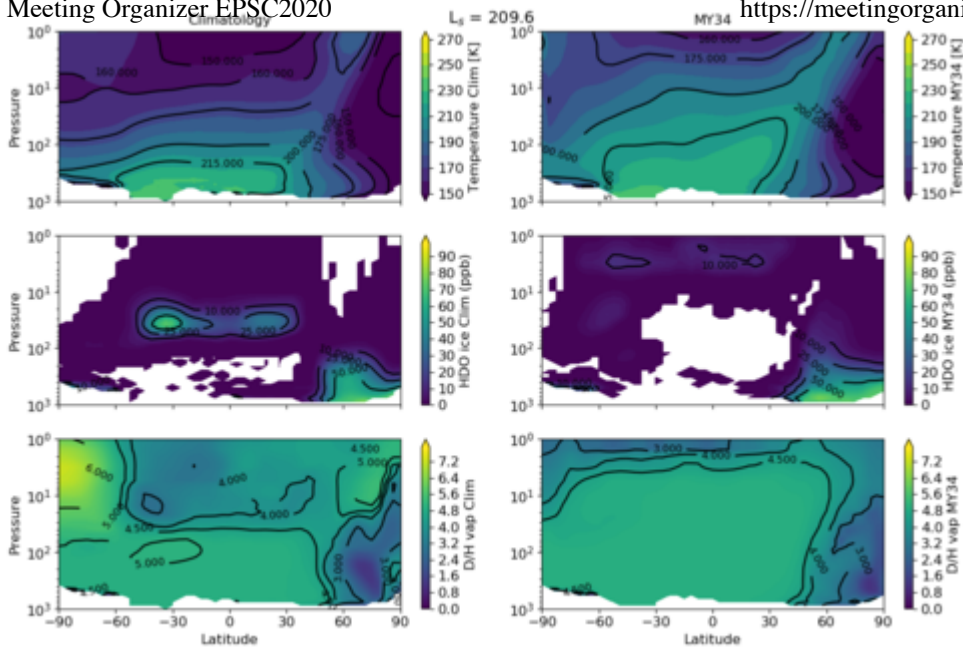


Figure 2 : Zonally averaged meridional profiles of temperature, HDO ice mixing ratio and D/H ratio of scenario and (right) the MY34 scenario, at $L_s = 210$, during the GDS.

By comparison, during the GDS, the dust has a strong effect on the temperature field, and therefore formation. Since clouds are forming at higher altitude (if at all), the deuterium is less constrained vertical altitudes. A similar effect being observed for water vapour (Fedorova et al., 2020).

Early observations with the ACS and NOMAD instruments, on board the ExoMars Trace Gas Orb distribution is indeed affected by the GDS, in qualitative agreement with our model (Vandaele et al., 2020). We will here present the results of these comparative simulations and discuss the differences and similarities with ACS and NOMAD.

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