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Simulation of the Hydrogen escape from Mars using a Global Climate Model

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Introduction

The thermal (Jeans) escape of Hydrogen accumulated during the history of Mars has been one of the major mechanisms explaining the transition of Mars from a thicker and wetter atmosphere in the past to the current thin and dry atmosphere (Brain et al., 2017). Recent observations (Heavens et al., 2018, Chaffin et al., 2021) have revealed a clear link between the water cycle in the lower atmosphere, the transport of water to the middle/upper atmosphere, and the thermal escape of Hydrogen. However, many unknowns remain, including the role of the different processes responsible of transporting water from the lower to the upper atmosphere and converting it to Hydrogen atoms, or the effects of global dust storms (GDS hereafter) compared to the regular seasonal variability.

While different 1D models have been used to reproduce and understand some of the observations (e.g. Chaffin et al., 2017), until now global models have failed to reproduce the observed variability of the H escape. In particular, a recent study with the Laboratoire de Météorologie Dynamique Mars Global Climate Model (LMD-MGCM hereafter) evidences that the model significantly underestimates the H escape rate when comparing with Mars Express SPICAM observations, in particular during the perihelion season (Chaufray et al., 2021).

In this work we will summarize the recent improvements that we have included in the LMD-MGCM in order to better reproduce the observed Hydrogen escape rate, and will discuss some of the results obtained with the improved model.

Model description

We have included three improvements with respect to the version of the LMD-MGCM used in Chaufray et al., 2021.

First, we have incorporated in the simulations a sophisticated model of the microphysics of water ice clouds allowing for the formation of supersaturated water layers (Navarro et al., 2014). Second, we have extended the photochemical model in the LMD-MGCM to incorporate the chemistry of H_2O^+ and derived ions, as well as of deuterated (both neutral and ion) species. Third, we have also included in the calculations an improved model of deuterium fractionation (Vals et al., 2022). While this allows us to study the D escape, we will focus here only on the H escape; simulations of the deuterium escape are discussed in Chaufray et al. (this issue).

Preliminary results

The incorporation in the calculations of the microphysical model allowing for the formation of supersaturated water layers significantly increases the amount of water in the upper atmosphere of the planet with respect to the previous calculations, producing a strong enhancement of up to one order of magnitude in the H escape rate. The incorporation of the chemistry of water-derived ions further increases the escape rate in between ~20 and ~40%, depending on the season. This results in a better agreement with observations of H escape (figure 1). However, significant differences still remain. In particular, the decrease in the rate of H escape at the end of the year is not well captured by the model, suggesting that, in the model, water remains in the upper atmosphere longer than observed.

We study also the interannual variability of the simulated escape rate. While the solar activity seems to play a secondary role, dust storms in the lower atmosphere have a clear effect over the H escape rate. Our simulations show, for example, that the global dust storm in MY34 increased the annually integrated H escape rate in about 30%. This confirms the importance of taking into account the effects of GDSs when calculating the accumulated escape rate over Martian history.

This work opens the doors to studying the H escape rate at past Mars conditions characterized by different orbital parameters (e.g. obliquity, time of perihelion, etc.). See Gilli et al., this issue, for a first study in this direction.

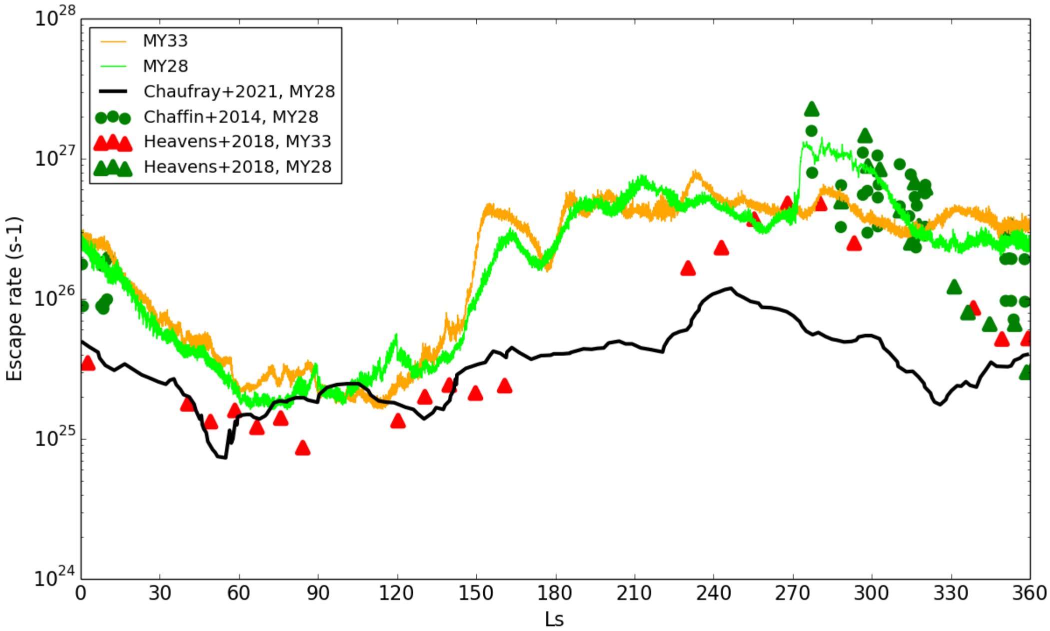

Figure 1. H escape rate simulated for MY28 (light green line) and MY33 (orange line). The black thin line shows the escape rate for MY28 simulated with the previous model version, taken from Chaufray et al. (2021). The green and red symbols represent measured values of the H escape rate during MY28 and MY33, respectively, taken from Chaffin et al. (2014) and Heavens et al. (2018)

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