HIGH ALTITUDE WATER POWERS MARS H ESCAPE.

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Introduction

H escape in the Mars atmosphere is variable and appears closely tied to season, with high H escape rates occurring in Southern Summer when Mars is near perihelion and the atmosphere is more turbulent (Chaffin et al., 2014; Clarke et al., 2014; Bhattacharyya et al., 2015). H escape appears to vary by at least an order of magnitude on sub-seasonal timescales, exceeding the variation predicted with state-of-the-art general circulation models (Chaffin et al., 2014; Chaufray et al., 2015). An additional factor is therefore needed to bolster H escape in Southern summer. One candidate cause for increased H escape is the presence of high altitude water vapor, detected by Maltagliati et al., (2011). This water, present at high altitude in concentrations unexpected based on the standard water cycle (e.g. Jakosky, 1985), could potentially provide H to the upper atmosphere in concentrations equaling or exceeding the H supplied by steady diffusion of long-lived molecular hydrogen (as described by (e.g. McElroy, 1972; Zahnle et al., 2008)). In this work we demonstrate that detected and plausible quantities of upper atmospheric water can produce variations of a magnitude and timescale sufficient to explain the discrepancy between model results and observations, potentially explaining the unexpectedly variable H loss rates observed.

Model Description

To perform our study, we employ a newly developed 1D photochemical model that solves the diffusion and chemical rate equations simultaneously from the surface to 200 km altitude. The inputs to the model are summarized in Figure 1. The only species that escape from the upper atmosphere are H, H_2, and O. The hydrogen species are assumed to escape thermally according to the Jeans formula while the O escape rate is fixed to 1.2×10^8 cm^{-2} s$^{-}2$. We employ standard cross sections and rate coefficients as described in Sander et al., (2011), with some changes based on the work of Deighan, (2012). We employ temperature and diffusion profiles based on the work of Krasnopolsky (Krasnopolsky, 1993; Krasnopolsky, 2010), and prescribe the ionospheric concentration of CO_2^+ based on the calculations of Matta, Withers, and Mendillo, (2013) rather than computing the ionosphere self-consistently. Finally, we prescribe the standard water vapor profile so that it has a fixed concentration of 100 ppm in the lower atmosphere, follows the saturation vapor pressure as a function of altitude, and is constant above the altitude of minimum concentration. To this water profile we add gaussian parcels to roughly match concentrations reported by Maltagliati et al., (2013), and to generalize from the observations to perturbations of larger or smaller magnitude or at different altitudes.

Equilibrium Results

The equilibrium atmosphere with the standard water profile, shown in Figure 2a, reproduces the standard photochemistry of the Mars atmosphere as reported in prior studies (e.g. Nair et al., 1994). By contrast, the equilibrium atmosphere resulting from the perturbed water profile (Figure 2b) is very different from that observed at present, having among other things a much larger O_2 concentration. This suggests that the high altitude water observed by (Maltagliati et al., 2011) is driving the Mars atmosphere away from its present toward a radically different state.

Time Response

To investigate the process of the transition induced by upper atmospheric water, we simulate the response of the atmosphere for one year following its instantaneous introduction to the standard equilibrium atmosphere. The result is described in Figure 3, which shows that most of the increase/decrease in H escape occurs in the first 10 days after water introduction/removal. The seasonal changes in escape rates could therefore be the result of upper atmospheric water concentrations varying on seasonal timescales.

To generalize our conclusions, we investigated the response of the atmosphere to a range of potential perturbations, shown in Figure **??**. The magnitude of the escape rate perturbation depends on the altitude of the parcel, increasing with parcel altitude at first due to the increasing ease of photodissociation as the water is raised above the bulk of the atmospheric CO_2 and ultimately falling as altitudes grow too large and the relative perturbation of the water vapor column grows small in an absolute sense. As the altitude of the parcel is increased, the timescale of the escape response decreases monotonically because water is more easily transported to the escape region from higher altitudes.

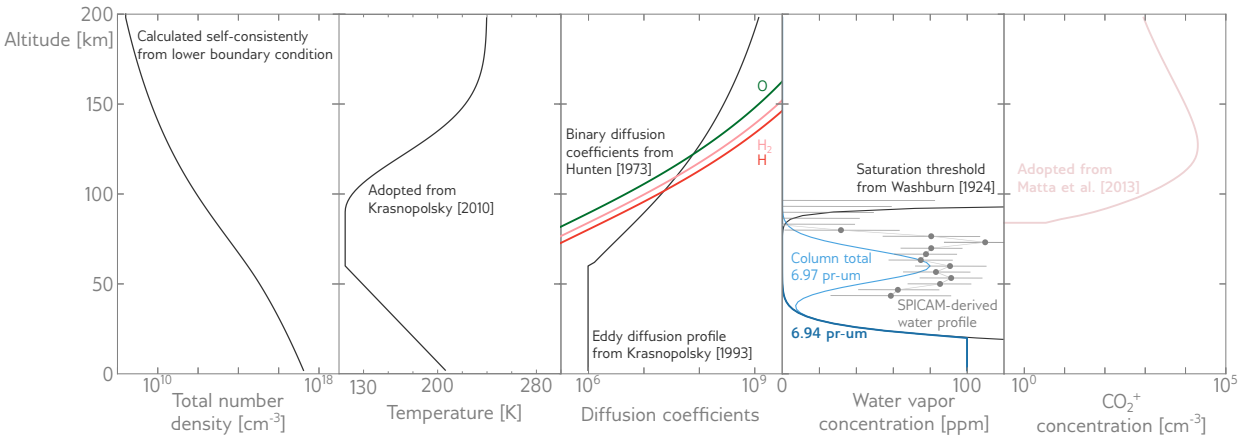

Figure 1: Important Model Inputs.

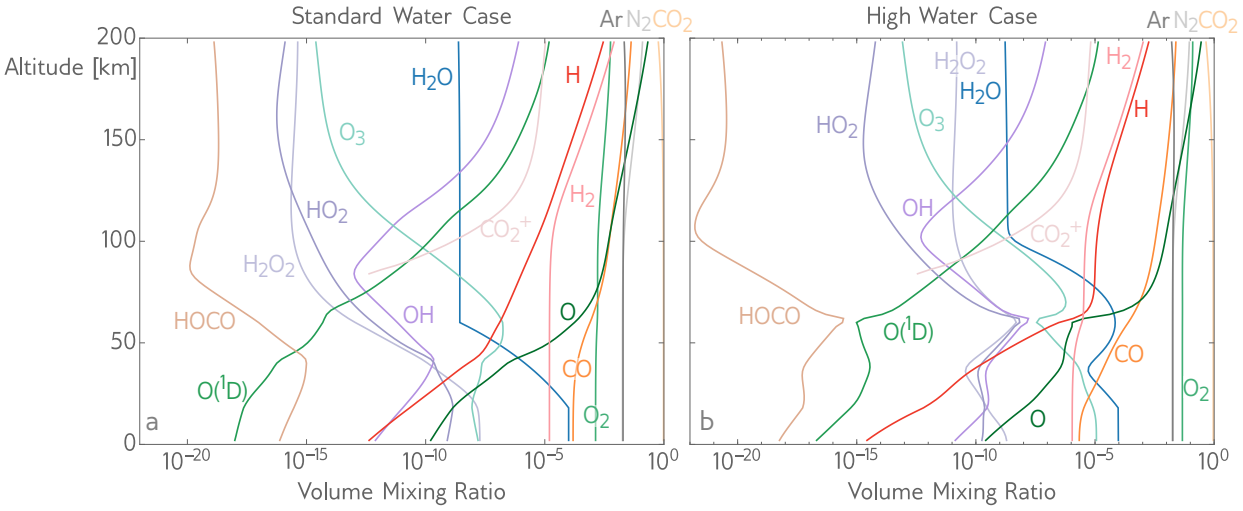

Figure 2: Equilibrium model atmospheres resulting from two assumptions about the water vapor column, with all other inputs unchanged.

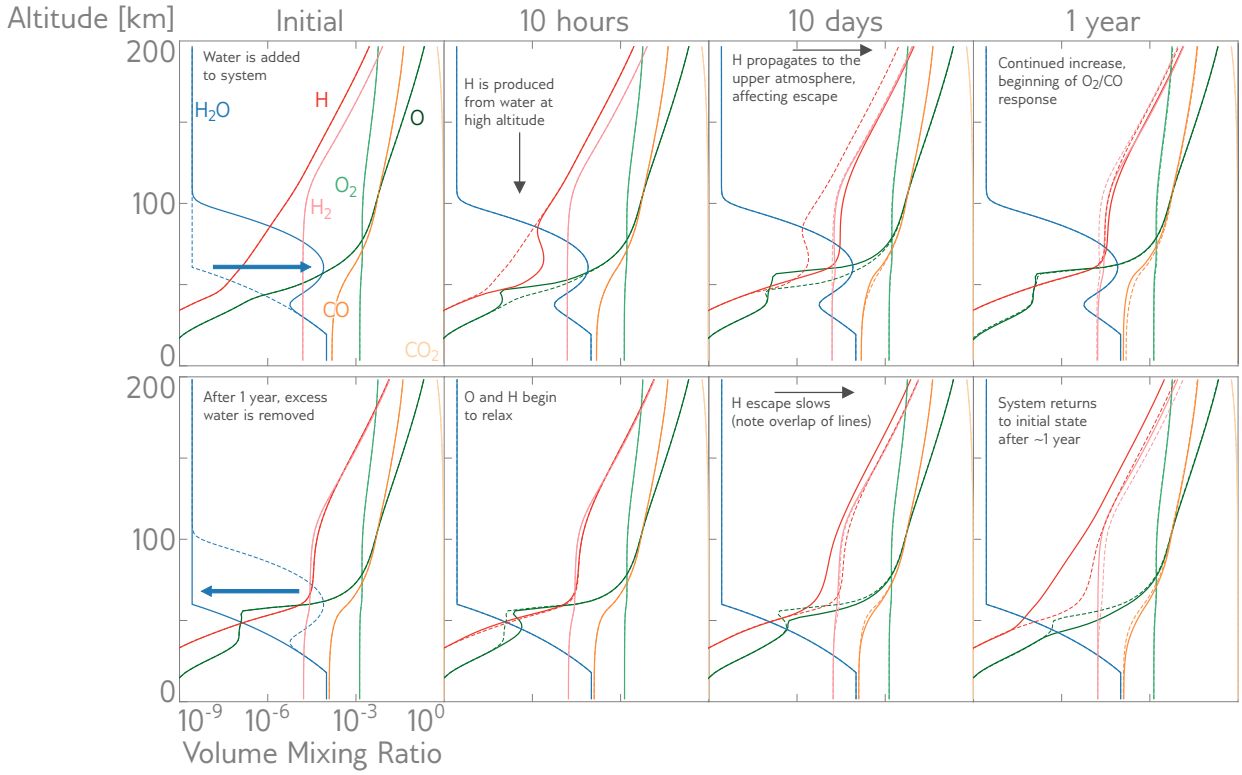

Figure 3: Time response of the atmosphere to instantaneous introduction and subsequent removal of a high altitude water parcel.

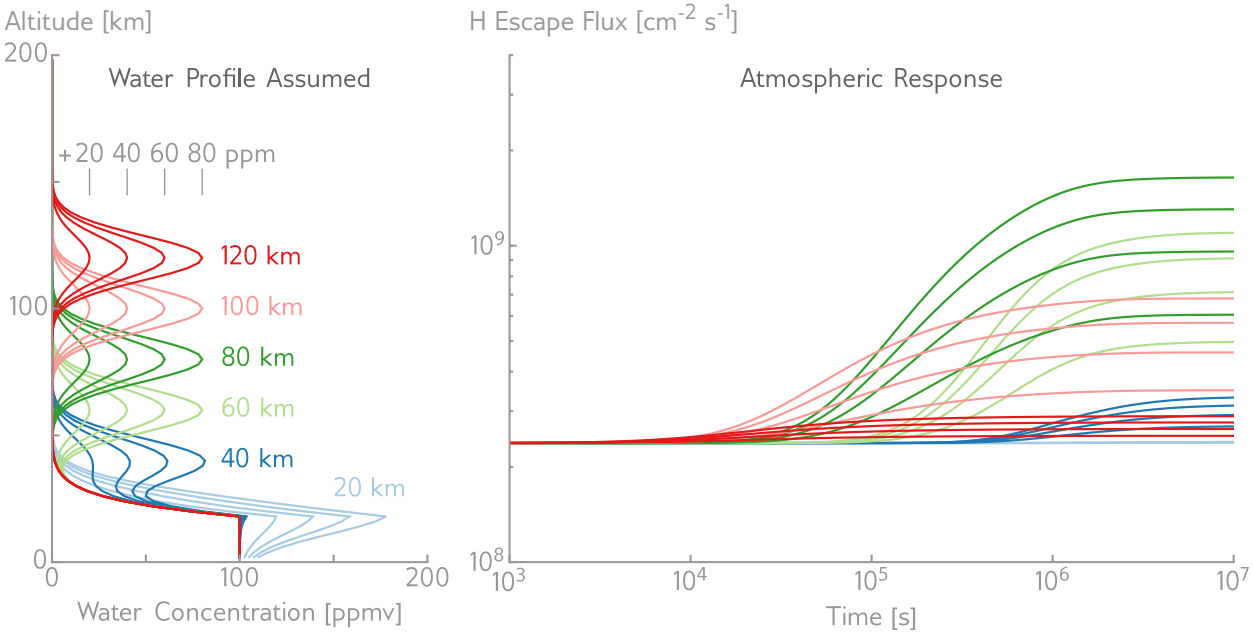

Figure 4: Response of the H Escape rate to a range of introduced water profiles. Each of the profiles shown was introduced into the standard water equilibrium atmosphere instantaneously, and the resulting perturbation to H escape was tracked for 10^7 s. Within each altitude group, higher concentrations of introduced water result in monotonically higher escape fluxes of H.

Conclusion

In this work we demonstrate that H escape from Mars is highly sensitive to the presence of upper atmospheric water. Large variations in the H escape rate presently unexplained by known factors can be explained by variation in the water column at altitude. Knowledge of the water vapor vertical distribution is therefore important not only for understanding Mars weather and climatology but also for determining its present and past H escape rate.

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