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Water vapor in the middle atmosphere of Mars during the 2007 global dust storm

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ABSTRACT

Recent observations of the Martian hydrogen corona in the UV H Ly-alpha emission by the Hubble Space Telescope (HST) (Clarke et al., 2014) and the SPICAM UV spectrometer on Mars Express (Chaffin et al., 2014) reported its rapid change by an order of magnitude over a short few months period in 2007 (MY28), which is inconsistent with the existing models. One proposed explanation of the observed increase of the coronal emission is that during the global dust storm water vapor from the lower atmosphere can be transported to higher altitudes, where its photodissociation rate by near-UV sunlight increases, providing an additional source of hydrogen for the upper atmosphere.

In this work we study the water vapor vertical distribution in the middle atmosphere of Mars during the 2007 global dust storm based on solar occultation measurements by the SPICAM IR spectrometer onboard the Mars-Express spacecraft. The vertical profiles of H_2O density and mixing ratio have been obtained for solar longitudes Ls = 255°–300° in MY28. In the Northern hemisphere from Ls = 268° to Ls = 285° the H_2O density at altitudes of 60–80 km increased by an order of magnitude. During the dust storm the profiles extended up to 80 km, with an H_2O density exceeding 10^{10} molecules/cm^3 (mixing ratio $\geq$200 ppm). Two maxima of the H_2O density were detected. The largest H_2O densities observed at latitudes higher than 60°N, over Ls = 269°–275°, do not directly correlate with the aerosol loading and likely relate to the downwelling branch of the meridional circulation that was intensified during the dust storm, and transported water from the Southern hemisphere to high northern latitudes. The second smaller maximum coincides with the high dust loading at middle northern latitudes. The comparison with geographically close observations in the quiet Mars year MY32, when the H_2O content in the Northern hemisphere did not exceed 2×10^{10} molecules/cm^3 and 50 ppm at 60 km, showed that the global dust storm was a unique event. The situation was different in the Southern hemisphere. During the dust storm the water density at 50–80 km increased by a factor of 4–5 with a mixing ratio $>$100 ppm, well correlated with the aerosol vertical extension. A somewhat weaker increase of the H_2O density by a factor of 2–3 with a mixing ratio $>$ 100 ppm was also observed during MY32 starting from Ls = 260°, suggesting a seasonal repeatability.

The observed amount of water at high altitudes in both hemispheres can produce a large increase in the H escape rate on a timescale of weeks, as was shown in the photochemical modeling by Chaffin et al. (2017). Future modeling would be necessary to separate the seasonal and the dust storm contributions to the hydrogen escape.

1. Introduction

Current Mars is a very dry planet. But there are multiple lines of evidence that early Mars was wet. Surface geology features allow one to hypothesize an ocean equivalent to a surface layer (global equivalent layer, GEL) of several hundred meters depth (e.g., Clifford and Parker, 2001). The enriched D/H isotopic ratio in the Martian water reservoirs (Owen et al., 1988; Villanueva et al., 2015; Krasnopolsky, 2015) is consistent with a loss of few meter GEL. Characterizing the loss of water from Mars throughout its history allows to distinguish between the early climate scenarios.

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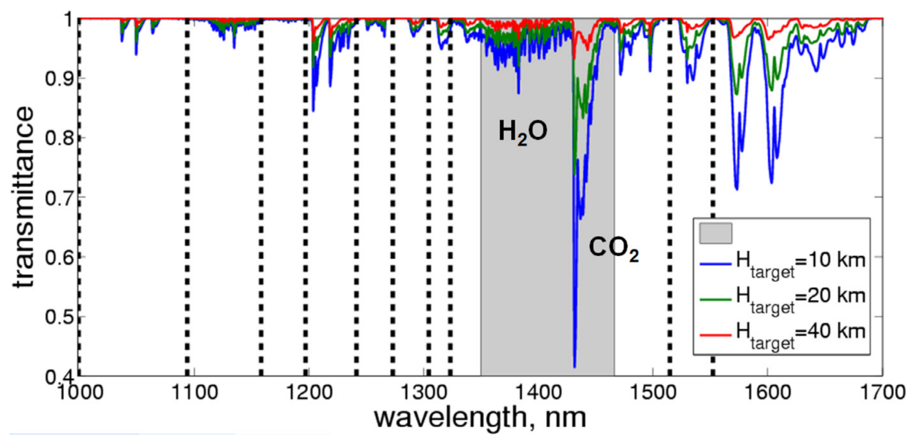

Fig. 1. A synthetic spectrum of the transmittance of the Martian atmosphere for a solar occultation geometry with tangential altitude from top to bottom: 40, 20 and 10 km in the spectral range of 1000–1700 nm. The CO_2 and H_2O bands are presented. H_2O was assumed uniformly mixed with a mixing ratio of 100 ppm up to 80 km. The spectrum has been convolved with the SPICAM IR instrumental function. Dashed lines mark the reference wavelengths used to characterize aerosols. The shaded area shows the position of the single continuous spectral "window" used in the SPICAM solar occultation observations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

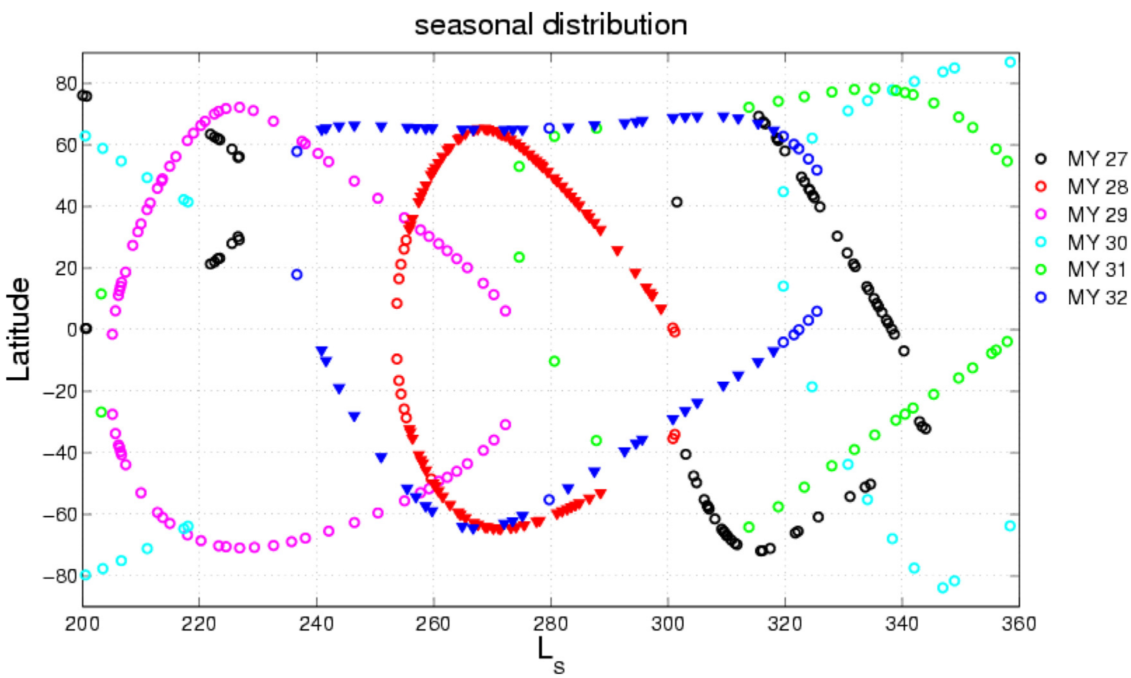

Fig. 2. Seasonal distribution of the SPICAM IR observations during the perihelion season for MY27-32. The orbits of MY28 and 32 presented in this study are marked as filled triangles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

One of the processes of water loss in the atmosphere is the escape of hydrogen atoms into space. Martian atmospheric water vapor is trapped close to the surface by condensation, and its vertical distribution is variable with season and location. In the aphelion season when the atmosphere is colder, water is confined to lowest atmospheric scale-height and blocked in the Northern hemisphere by the aphelion cloud belt (Clancy et al., 1996; Montmessin et al., 2004). The hygropause (condensation level) altitude is as low as 10–15 km. During the warmer perihelion season this altitude could reach 40–50 km (Trokhimovskiy et al., 2015). Solar near-UV radiation penetrates sufficiently deep into the atmospheres to activate the odd hydrogen cycle and to dissociate H_2O into H and O atoms (McElroy and Donahue, 1972; Parkinson and Hunten, 1972). Then H recombines into H_2 and about 20% of the hydrogen molecules formed in the cycle diffuse in the upper atmosphere (Hunten and McElroy, 1970; Hunten, 1982). The H_2 life time is hundreds of years. In the upper atmosphere the H_2 molecule can be destroyed in reactions with CO_2^+ (Krasnopolsky, 2002). The secondary H atoms diffuse to the exobase, with hotter atoms escaping into space. In this model the source of the H atoms is long-lived H_2, and no strong dependence of the hydrogen escape rate on the seasonal and solar cycle is expected.

An unexpected change in the hydrogen escape rate was first observed in 2007. Chaffin et al. (2014) analyzed 121.6 nm hydrogen Lyman-α airglow observations made by SPICAM/Mars Express ultraviolet spectrometer over the second half of 2007. The authors reported at least an order of magnitude change of the escape rate for several months from August to December 2007, depending on the assumed temperature, that was inconsistent with established models for the source of escaping hydrogen. The enhanced escape rates were associated with lower atmospheric heating and overturn during the 2007 (Martian year 28) global dust storm suggesting that hydrogen escape from Mars during the dust storms may dominate loss of water. In the same time Hubble Space