3D SIMULATIONS OF THE HYDROGEN ESCAPE ON MARS

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Introduction:

Currently, most of the water on Mars is present in different reservoirs at the surface (e.g. ice polar deposits) and in the subsurface. A small amount of water is also present in the Martian atmosphere and its variations are characterized by a strong seasonal cycle [1]. One part of the atmospheric water vapor escapes into the interplanetary medium under atomic H form. The hydrogen escape is therefore an important clue with regards to the evolution of Mars water. Thermal escape is an important source of escape for light species such as atomic and molecular hydrogen [2]. We have improved the LMD-MGCM molecular diffusion scheme to describe atomic and molecular hydrogen in the whole Martian thermosphere. This permits the model to describe the full hydrogen cycle from water vapor in the lower atmosphere up to atomic hydrogen produced below the exobase [2, 3]. The hydrogen Jeans escape as deduced from the temperature and hydrogen density at the exobase, is simulated along a full Martian year for different solar activities.

Model description:

. The LMD-MGCM model is composed of a "dynamical core" solving the continuity, momentum and energy equations of the Martian atmosphere and a "physical core" solving the sources and loss terms and the interaction with the surface and subsurface [3]. The model has also been extended to the exobase by including physical processes important at thermospheric altitudes: molecular viscosity, thermal conduction, UV and EUV heating and ionization, NLTE CO_2 infrared cooling, photochemistry of the upper atmosphere and ionosphere and molecular diffusion [4]. A coupling between this model and an exospheric model describing the thermal and suprathermal oxygen populations in the Martian exosphere has been done recently to investigate the variability of the hot oxygen escape flux [5].

Hydrogen density at the exobase:

Monthly average temperature and hydrogen density as a function of latitude and longitude/local time are displayed in Fig.1 and 2.

A large hydrogen density is observed at dawn during both equinoxes (Fig. 2a, 2c) in good agreement with the oxygen bulge at dawn noted by [5] at equinox resulting from strong convergent nightside and weak divergent dayside winds. At solstices the hydrogen density is more symmetric and maximal at nightside and minimal at dayside.

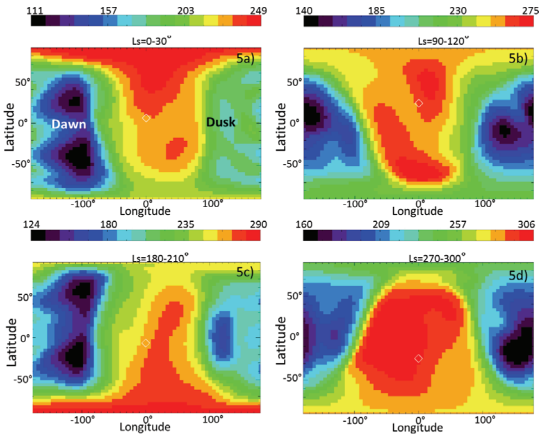

Fig. 1 :Temperature at the exobase for Ls = 0-30°, 90-120°, 180-210° and 270-300°.

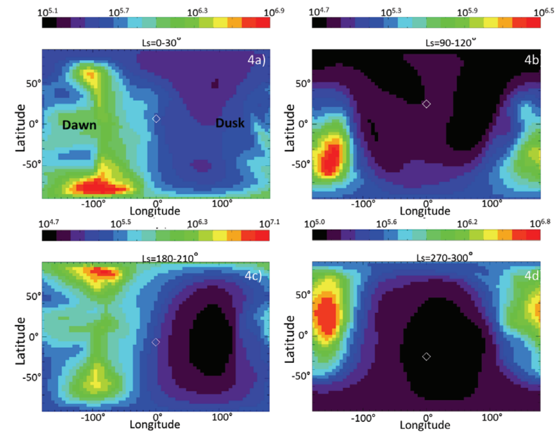

Fig. 2 : Hydrogen density (cm^{-3}) (log scale) at the exobase ($P \sim 10^{-7}$ Pa) for Ls = 0-30°, 90-120°, 180-210° and 270-300°. Noon is at longitude = 0°

Hydrogen escape

The Jeans escape is derived by integration over the full exobase. The H and H_2 escape along the Martian year with a 1 day time resolution is displayed in Fig. 2 for three different solar activities. The maximal hydrogen escape flux is obtained near Mars perihelion (Ls = 251°) for high solar activity and is equal to 4×10^{26} s^{-1}. This escape rate is three times lower than the H_2 diffusion-limited flux estimated to $1.1 \pm 0.3 \times 10^{27}$ s^{-1} at ~ 105 km, for any seasons and solar activity. As shown by the solid lines, the escape rate is well reproduced (at first order) by the simple analytic law $\Phi_{esc} = \Phi_{esc,0}\, e^{\alpha \sin(Ls-\varphi 0)}$, with a maximum close to perihelion and a minimum close to aphelion of Mars, showing that exospheric temperatures, and therefore EUV heating is the main driver of the hydrogen Jeans escape at Mars.

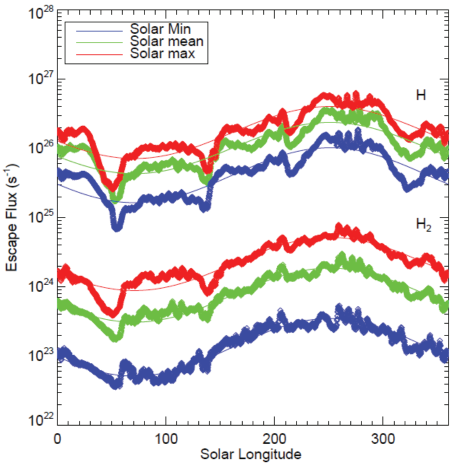

Fig. 2 Atomic and molecular hydrogen escape rates simulated for three different solar activties (F10.7 = 80, 120, 220 respectively). An analytic law $\Phi_{esc} = \Phi_{esc,0}\ e^{\alpha \sin(Ls-\varphi 0)}$ fitting the simulations is also displayed by solid lines.

Conclusion.

The thermospheric hydrogen has been simulated using the 3D LMD-MGCM. We find seasonal variations of the hydrogen escape reaching a factor ~8 in contradiction with some previous studies suggesting a constant hydrogen escape flux at Mars, limited by diffusion [6]. An exospheric coupling shows that these variations should affect, the Martian hydrogen corona and possibly the plasma environement resulting from the solar wind interaction.

References

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