

## Modeling of HDO in the Martian atmosphere

**Loïc Rossi** (1), Franck Montmessin (1), François Forget (2), Ehouarn Millour (2), Kevin S. Olsen (1), Margaux Vals (2), Anna Fedorova (3), Alexander Trokhimovskiy (3), Oleg Korablev (3) and the ACS team  
(1) Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS/IPSL), UVSQ Université Paris-Saclay, Sorbonne Université, CNRS, Guyancourt, France (loic.rossi@latmos.ipsl.fr) (2) Laboratoire de Météorologie Dynamique (LMD), Paris, France (3) Space Research Institute (IKI), Moscow, Russia

### Abstract

HDO and the D/H ratio are important in order to understand Mars past and present climate, in particular with regards to the evolution through ages of the Martian water cycle. We present here new modeling efforts aimed at rejuvenating the representation of HDO in the IPSL Mars GCM, with the perspective of comparison with the new observations provided by the Atmospheric Chemistry Suite (ACS) on board the ESA/Roscosmos Trace Gas Orbiter.

### 1. Introduction

Mars is known to have had a significant liquid water reservoir on the surface and the D/H ratio is an important tool to estimate the abundance of the early water reservoir on Mars and its evolution with time. The D/H ratio is a measure of the ratio of the current exchangeable water reservoir to the initial exchangeable water reservoir. Many observations from the ground have shown that the current ratio is five times that of the reference in Earth's oceans [3, 7, 9].

H and D atoms in the upper atmosphere are coming from  $\text{H}_2\text{O}$  and HDO, their sole precursor in the lower atmosphere. The lower mass of H over D atoms and the fact that  $\text{H}_2\text{O}$  is preferentially photolysed over HDO [2] explain the differential escape of these two elements. Finally, due to differences in vapor pressure for HDO and  $\text{H}_2\text{O}$ , the solid phase of water is enriched in deuterium compared to the vapor phase. This effect is known as the Vapor Pressure Isotope Effect (VPIE) and can reduce the D/H ratio above the condensation level to values as low as 10% of the D/H ratio near the surface [1, 4].

### 2. Modeling HDO

These fractionation processes can affect the amount of HDO with latitude, longitude, altitude and with

the season. In particular, previous models [8] have shown that an isotopic gradient should appear between the cold regions where condensation occurs and the warmer regions. This leads to a latitudinal gradient of D/H (with variations greater than a factor of 5) between the warm and moist summer hemisphere and the cold and dry winter hemisphere. Yet some observations [9, 5] also show longitudinal variations of H/D ratios which are not explained so far. It is therefore essential to model the HDO cycle and the associated processes of fractionation in a 3D general climate model (GCM).

Previous work has been done on 3D GCMs of HDO, in particular around the IPSL Mars GCM [8]. Since the GCM has considerably evolved since this first HDO introduction in the modeled water cycle, a reappraisal of HDO predictions is needed to account for the detailed microphysics that control cloud formation and thus HDO fractionation. With the TGO mission now in its mission phase, very strong and precise constraints will be soon available to evaluate the GCM prediction capability.

### 3. Contribution of ACS

The Trace Gas Orbiter, part of the ExoMars mission, is currently in orbit around Mars. Onboard is the Atmospheric Chemistry Suite, a set of spectrometers designed to study the atmosphere of Mars with a specific focus on trace gases such as methane.

ACS combines high resolving power ( $> 10,000$ ), high accuracy (ppb level) and large spectral coverage ( $0.7 - 17 \mu\text{m}$ ) to a large variety of observation modes [6].

Thanks to its solar occultation capabilities, ACS (in combination with the other spectrometer NOMAD) has already provided first vertical profiles of HDO and  $\text{H}_2\text{O}$  from a few kilometers above the surface up to 60 km, reaching precision up to 1 ppb. These observations have already showed that the dust storm had

an important effect on the distribution of water vapour and of HDO [10].

Upcoming measurements from ACS will help us further constrain the spatial and temporal variabilities and help improve our understanding of the HDO and H<sub>2</sub>O cycles.

We will describe here our work on the update of the HDO model in the IPSL Mars GCM and will attempt first comparison with the early TGO/ACS observations.

## Acknowledgements

ExoMars is the space mission of ESA and Roscosmos. The ACS experiment is led by IKI Space Research Institute in Moscow. The project acknowledges funding by Roscosmos and CNES. Science operations of ACS are funded by Roscosmos and ESA. Science support in IKI is funded by Federal agency of science organizations (FANO). L.R. acknowledges support from the Excellence Laboratory "Exploration Spatiale des Environnements Planétaires (ESEP)".

## References

- [1] Bertaux, J. L., & Montmessin, F. (2001). Isotopic fractionation through water vapor condensation: The Deuteropause, a cold trap for deuterium in the atmosphere of Mars. *Journal of Geophysical Research: Planets*, 106(E12), 32879-32884.
- [2] Cheng, B. M., et al. (1999). Photo-induced fractionation of water isotopomers in the Martian atmosphere. *Geophysical Research Letters*, 26(24), 3657-3660.
- [3] Encrenaz, T., et al. (2018). New measurements of D/H on Mars using EXES aboard SOFIA. *Astronomy & Astrophysics*, 612, A112.
- [4] Fouchet, T., & Lellouch, E. (2000). Vapor Pressure Isotope Fractionation Effects in Planetary Atmospheres: Application to Deuterium. *Icarus*, 144, 114-123.
- [5] Khayat, A.S.J et al. (2019). IRTF/CSHELL mapping of atmospheric HDO, H<sub>2</sub>O and D/H on Mars during northern summer. *Icarus*, <https://doi.org/10.1016/j.icarus.2019.04.007>.
- [6] Koralev, O., Montmessin, F., Trokhimovskiy, A., Fedorova, A. A., Shakun, et al. (2018). The atmospheric chemistry suite (ACS) of three spectrometers for the ExoMars 2016 Trace Gas Orbiter. *Space Science Reviews*, 214(1), 7.
- [7] Krasnopolsky, V. A. (2015). Variations of the HDO/H<sub>2</sub>O ratio in the martian atmosphere and loss of water from Mars. *Icarus*, 257, 377-386.
- [8] Montmessin, F., Fouchet, T., & Forget, F. (2005). Modeling the annual cycle of HDO in the Martian atmosphere. *Journal of Geophysical Research: Planets*, 110(E3).
- [9] Villanueva, G. L., et al. (2015). Strong water isotopic anomalies in the martian atmosphere: Probing current and ancient reservoirs. *Science*, 348(6231), 218-221.
- [10] Vandaele A.-C. et al., (2019). Martian dust storm impact on atmospheric H<sub>2</sub>O and D/H observed by ExoMars Trace Gas Orbiter. *Nature*, 568(7753), 521-525.