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Evolution of water vapor vertical distribution during a Martian year with SPICAM/Mars Express solar occultations

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Abstract

Observations of the water vapor vertical distribution in the atmosphere of Mars are essential to constrain the various physical processes that drive the water cycle on the planet. The SPICAM spectrometer on Mars Express retrieves by far the most extensive dataset currently available through solar occultations. We will present here the first monitoring ever of the seasonal variations of the H_2O vertical profile in the Martian atmosphere. We will focus mainly on Martian Year 29 (MY29) data. Results exhibit a significant difference with the General Circulation Model (GCM) predictions. We show that the interactions between the dust and water climatic cycles are stronger than expected.

1. Water vapor profiles on Mars

Direct observations of the vertical profile of water vapor in the atmosphere of Mars have been very sparse before the ESA Mars Express mission. Only the Auguste spectrometer onboard Phobos-2 could retrieve it, with limited seasonal and latitudinal coverage [6]. Yet, the H_2O vertical distribution gives essential information on the active processes of the Martian water cycle. Up to now, our knowledge of the water vapor profile was relying on General Circulation Models (GCM). The lack of observations, however, did not allow a thorough testing of the assumptions employed by the GCM. This lack is now filled by the SPICAM spectrometer on Mars Express.

SPICAM is a spectrometer dedicated to the observation of the Martian atmosphere simultaneously in the UV and in the IR wavelength range [1,3]. It can employ different observational modes. For the profiling of water vapor we used the infrared channel, that covers the 1 – 1.7 μm wavelength range at a spectral power R~2000, with the solar occultation mode.

During an occultation a source of light (the Sun for solar occultations) is observed at different limb altitudes outside and through the atmosphere along the line-of-sight. The atmospheric transmittance at the different altitudes is then retrieved by dividing each spectrum with the reference obtained outside the atmosphere. This self-calibration removes the uncertainties connected to the instrumental transfer function of the spectrometer and, because a reference spectrum is extracted at each observation, occultations are insensitive to instrumental aging.

SPICAM-IR allows for the simultaneous observation of H_2O, CO_2, and aerosol optical depth. The whole SPICAM dataset includes more than 700 orbits and covers more than 4 Martian years. The first results were published by [2].

We extract the local density profiles from the transmittance through an inversion procedure that employs the Levenberg-Marquardt optimization with Tikhonov regularization. The vertical resolution depends on the orbital configuration of Mars Express and varies between 3 and 7 km from orbit to orbit.

2. Results

The presentation will focus mainly on Martian Year 29. SPICAM observed two seasons of the year with a total of ~130 profiles obtained at different spatial coordinates (Fig. 1). Results on the discovery of water supersaturation in the Martian atmosphere during the first season have been presented in [4].

Here we will show the global characteristics of water vapor vertical distribution during the year.

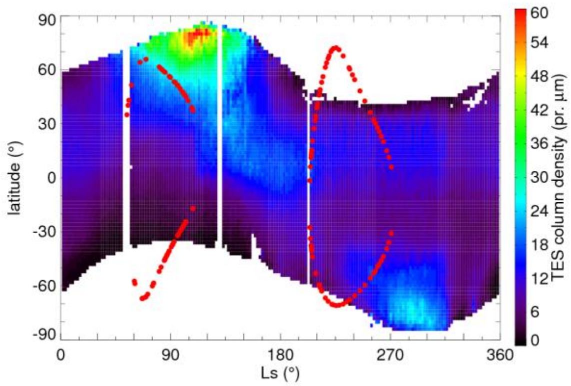

Figure 1: Distribution of SPICAM profiles as a function of Ls and latitude (red dots). The water vapor column density retrieved by the Thermal Emission Spectrometer (TES) [7] is in the background.

An important issue is the comparison of SPICAM results with the predictions made by General Circulation Models. For this purpose we used the one developed by the Laboratoire de Météorologie Dynamique (LMD), which is the most utilized GCM for Mars [5]. The comparison shows significant differences (Fig. 2). The water vapor amount in the middle atmosphere (30 – 60 km) is often underestimated by the GCM. SPICAM profiles also discover the frequent presence of detached layers of water vapor that are not predicted by the model. The frequent variations in profiles' shape seen by SPICAM indicate that the behavior of water vapor in the Martian atmosphere is more dynamic than expected.

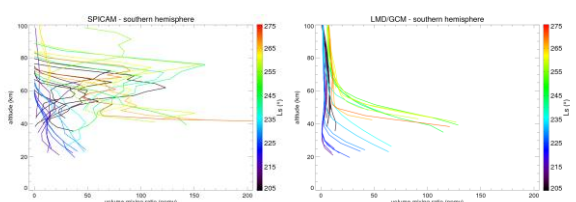

Figure 2: Southern hemisphere summer water vapor mixing ratio profiles observed by SPICAM (left) and predicted by the LMD-GCM for the same spatial and temporal coordinates (right). The color indicates the Ls.

We attribute the main cause of this discrepancy to the interaction between the water and dust climatic cycles. We believe that the GCM underestimates this connection, while we observe several evidences of the correlation between the water and the aerosol vertical distribution. An abrupt increase in both water vapor and aerosol abundance in the atmosphere, absent on the GCM, is seen thrice by SPICAM during MY29 (one example in Fig. 3). The seasonal evolution of H_2O and aerosol profiles is linked, and mutual correlation in the profiles' shape is often observed.

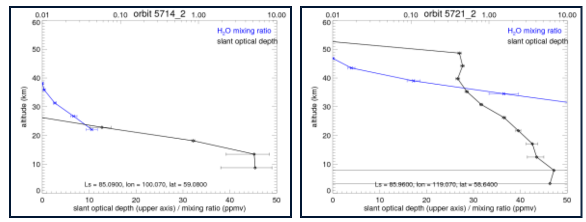

Figure 3: Vertical profiles of H_2O mixing ratio (blue) and aerosol slant optical depth (black) for two orbits acquired 1° Ls apart in the same region, near the northern summer solstice. Both components exhibit a strong and abrupt increase in abundance up to ~50 km of altitude.

The role of water ice clouds also comes out strongly from this analysis. Supersaturation, which is present in the first campaign during the northern summer solstice season and absent in southern spring, is regulated by microphysical processes associated with clouds [4]. The presence of frequent detached water vapor layers, often connected with detached aerosol layers, also points out at the clouds as an important driver that shapes the water cycle.

The analysis of SPICAM measurements in other Martian years will allow the monitoring of the vertical distribution of water vapor in other seasons not covered by MY29. We will be able to study the extension, and eventually the limits, of water-dust interactions along the year. It is known that the dust abundance in the atmosphere varies significantly between Martian years; we will study to which extent this interannual variability affects the H_2O vertical distribution.

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