CONSTRAINING THE VERTICAL DISTRIBUTION OF WATER VAPOR ON MARS: IMPLICATIONS FOR THE MARTIAN WATER CYCLE.

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Introduction: Current understanding of the vertical water vapor profile of the Martian atmosphere is incomplete due to limitations in both ground-based and orbital measurements. In situ measurements, such as those obtained by the Phoenix (PHX) Thermal and Electrical Conductivity Probe (TECP), or those obtained by the Mars Science Laboratory (MSL) Rover Environmental Monitoring Station (REMS), are limited to the surface [1-3]. In contrast, orbital data do not allow for diurnal coverage or resolution of the lower layers of the atmosphere due to geometry and the transient nature of these measurements [4]. Filling this gap is essential, as understanding the vertical distribution of water vapor provides insight into the role of regolith-atmosphere interactions. The extent to which the Martian surface plays in the diurnal exchange of atmospheric water vapor is not well known, however, there is general agreement that this interchange has an impact on the vertical water vapor profile. Previous studies have shown that water vapor is not well mixed at the surface, with the layer that exchanges diurnally with the regolith at around 0.5-1 km [2]. This indeed suggests a surface interaction that affects the vertical distribution of water vapor at the lowest layers of the atmosphere.

Understanding the near-surface Martian environment is important for in situ resource utilization, climate, and habitability. Specifically, the vertical water vapor profile is necessary in determining the stability of ground ice and water ice clouds [5]. Knowledge about the formation and evolution of water vapor will ultimately aid in a future human presence on Mars.

Objective: The main goal of this study is to determine the water vapor profile at PHX and MSL by utilizing ground-based and satellite measurements in combination with the University of Helsinki 1D Mars (SCM) model [6]. By tuning certain key SCM parameters, we match these measurements to ensure an agreement between simulated and measured values. We then simulate vertical profiles of water vapor and analyze net water transport between the atmosphere and regolith.

Data: We use in situ data from the PHX and MSL missions, as well as collocated measurements from the ExoMars Trace Gas Orbiter (TGO).

Recalibrated measurements from PHX/TECP were obtained from the Planetary Data System (PDS). The data included diurnal measurements of relative humidity (RH) and derived water vapor pressure (*e*). Air temperature at a height of 2 meters along with air pressure were obtained from the Meteorological Station (MET) instrument. Data was collected from PHX for 152 sols, from L_s 78° to L_s 148°, or during the early northern summer [7].

Diurnal ground and air temperature, pressure, and RH measurements were obtained from MSL/REMS. MSL was not able to collect reliable diurnal measurements of *e* [1]. Instead, few nighttime and daytime water vapor volumetric mixing ratios (VMR) were obtained by both REMS and ChemCam respectively, and values of *e* were calculated for each sol.

Orbital measurements from TGO were used at selected L_s where there were in situ operations overlap. TGO measurements included the tangential altitude above the Martian surface and VMR for the duration of the overhead pass.

Processed TGO measurements are currently only available between L_s 162° and 345° in Martian Year 34 (MY34), therefore there is no overlap in L_s with PHX operations. Collocated with MSL, 3 retrievals are available at L_s 233°, 242°, and 296°, corresponding to sols 2145, 2159, and 2244.

Methodology: We used SCM to simulate the vertical water vapor profile in the Martian atmosphere. The model was initially constrained using key parameters obtained from surface measurements at Gale crater such as ground temperature, surface pressure, dust aerosol opacity, surface albedo, precipitable water content (PWC), and VMR. The best-fit parameters were found by matching in situ REMS/ChemCam temperature, RH and VMR measurements to corresponding simulated values of the model output, ensuring that good agreement was found between simulations and surface measurements. After achieving a good match with in situ data, the vertical profile of water vapor for each L_s was produced.

Figure 1 shows the diurnal evolution of measured and simulated ground temperature (a), RH (b), and *e* (c) for L_s 296° of the MSL mission. The vertical water vapor profile of L_s 296° at Gale crater was produced using the set of best-fit parameters from Figure 1 and were compared to TGO measurements from the same L_s and Local Mean Solar Time (LMST). Vertical profiles were then created for various times to show how water vapor levels near the surface change throughout the day.

Results: Figure 2 shows the diurnal evolution of the vertical water vapor profile at seven hours of the day for L_s 296°, with simulated mass mixing ratio values extending from the surface up to 40 km in altitude. The model agrees with TGO measurements retrieved at 18:00 LMST (blue crosses) at a height of around 20 km, with water vapor well mixed above 4.5 km, as well as between 3.5 km and 200 m. Simulations for L_s 233° and 242° also yielded good agreement with collocated TGO data at corresponding LMST.

Below 200 m, water vapor is not well mixed. For the early morning and nighttime hours (4:00, 8:00, 18:00, 20:00, 24:00 LMST) atmospheric water vapor decreases below 200 meters, following adsorption of water onto the ground. During midday conditions (12:00 and 16:00 LMST) the amount of water vapor increases below 200 m, due to higher ground temperatures that release adsorbed water into the atmosphere. This behavior indicates that surface-atmosphere interactions drive net water transfer in the first few hundred meters of the Martian atmosphere.

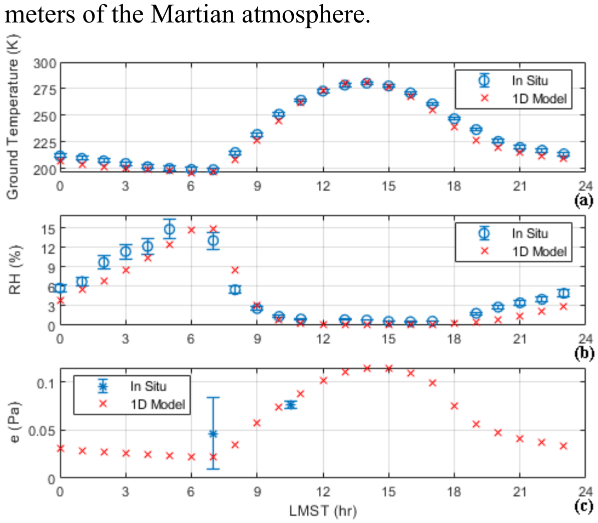

Figure 1: (a) Diurnal ground temperature (b) diurnal RH at 1.6 m (c) 1D model of water vapor pressure versus two calculated in situ measurements at 7:00 and 10:30 LMST using VMR data from REMS/ChemCam.

Conclusion: The 1D model shows that water vapor is not well mixed in the lowest few hundred meters, showing that a regolith-atmosphere interchange occurs during the early morning hours and late evening. During midday when the surface temperature is higher, simulated values show that water vapor is released from the ground into the atmosphere, eventually reaching the mixing altitude.

These results agree with PHX simulations performed by Savijärvi et al. (2020) [6], demonstrating a decrease in water vapor in the lowest 500 meters of the atmosphere for early morning and night hours, as well as an increase during midday.

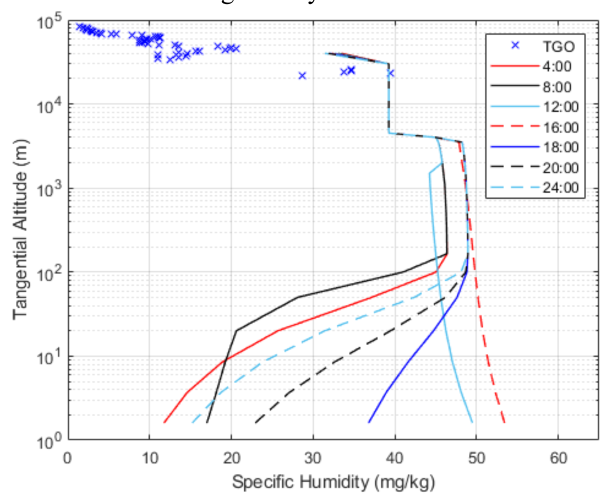

Figure 2: Simulated vertical water vapor profiles (red, blue, light-blue, black lines) at various times of day for L_s 296° using parameters obtained from REMS/ChemCam measurements at Gale crater. TGO measurements at 18:00 LMST shown in blue.

By studying the behavior of water vapor in the lowest layers of the atmosphere, we were able to provide insight into the role of the surface in diurnal water exchange. This regolith-atmosphere interchange of water vapor ultimately has implications for the Martian water cycle and present-day climate.

Future Work: We plan to perform simulations of vertical water vapor profiles for various sols apart of the PHX mission once in situ data is obtained. We also plan to complete a final paper containing an in-depth analysis using the University of Helsinki 1D model.

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