VERTICAL WATER VAPOR DISTRIBUTION AT PHOENIX

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Introduction:

The Phoenix and Mars Reconnaissance Orbiter (MRO) spacecraft participated together in an observation campaign that was a coordinated effort to study the Martian atmosphere. These coordinated observations were designed to provide near-simultaneous observations of the same column of atmosphere over the Phoenix lander. Seasonal coverage was obtained at L_s=5-10° resolution and diurnal coverage was obtained as often as possible and with as many times of day as possible. One key aspect of this observation set was the means to compare the amount of water measured in the whole column (via the MRO Compact Reconnaissance Imaging Spectrometer for Mars [CRISM; 1] and the Phoenix Surface Stereo Imager (SSI) with that measured at the surface (via the Phoenix Thermal and Electrical Conductivity probe [TECP; 2] which contained a humidity sensor). This comparison, along with the Phoenix LIDAR observations of the depth to which aerosols are mixed [3,4], provides clues to the water vapor mixing ratio profile. Commonly, water vapor is assumed to be “well-mixed,” in other words, a constant fraction of the atmospheric pressure for a given height [e.g., 5,6]. Typically, this assumption is made to an altitude at which clouds would condense given a related temperature profile.

Tamppari *et al.* [7] examined of a subset of these coordinated observations and found they indicated that the water vapor is *not* well mixed in the atmosphere up to a cloud condensation height at the Phoenix location during northern summer, and results indicated that a large amount of water must be confined to the lowest 0.5-1 km. This result was indicated by comparison of TECP near-surface humidity measurements to CRISM total column abundances, but subsequently both measurements have been refined. Nevertheless, Phoenix SSI data appear to show a diurnal variation (Fig. 1), leading to the hypothesis that water vapor exchanges diurnally with the surface and a bulk of that vapor is confined very near the surface, even in mid-day.

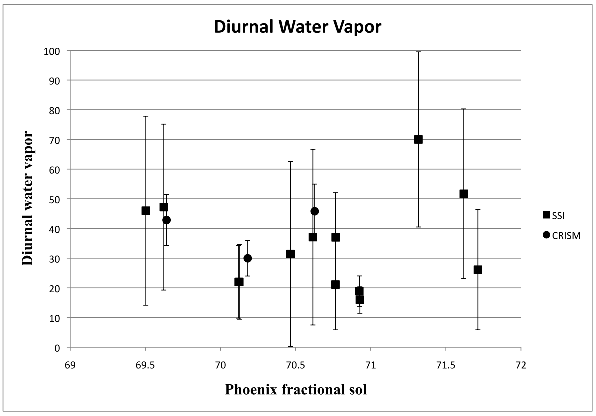

Figure 1. Diurnal water vapor measurements made by SSI (squares) and CRISM (dots) with error bars.

However, it is not known if this happens rarely or consistently throughout the Martian summer. Additionally, if water is confined near the surface, it is unknown is how deep the exchanging layer is. Analysis of additional observations taken during the Phoenix mission, combined with modeling, can shed light upon these questions.

Data Acquisition Strategy:

In order to detect water vapor using the Phoenix SSI camera, several water vapor filters were added [8]. They are: LA = 930.7 nm (broad), R4 = 935.5 nm (narrow), and R5 = 935.7 nm (narrow). The 935-nm filters are sensitive to water abundance above 5 pr microns in direct solar imaging. Because this band is weak, imaging of the horizon, opposite the sun is a more sensitive measure [9]. Other continuum filters available in the SSI were used for comparison. For each observation set, we obtained images both above the sun and along the horizon opposite the sun. The above sun images are used for calibration, and the near-horizon images are used to detect water vapor. The approach to using the above-sun and horizon images is detailed in [9]. We have modified the strategy as described further below. We found that the Titov et al. approach of using the narrow neutral density filters was ineffective due to the low response even for long integration times. However, the broader LA filter was found to be sufficiently sensitive to water.

This water vapor data set was collected throughout the Phoenix mission. There were 13 coordinated observation datasets focused on water vapor taken over the course of the Phoenix mission, spanning L_s=83-140°. Not all opportunities afforded full diurnal coverage, due to spacecraft constraints. Some opportunities included only a few observations, but others afforded 6 throughout the diurnal cycle.

Data Analysis:

We have focused on midday observations as they were more commonly taken during the mission.

We have evaluated our data using a Monte Carlo (MC) radiative transfer model to accurately capture the horizon geometry. It was found that this model did not provide a unique solution, given the natural uncertainty with a statistical model, even with a high number of trials. Because the model uncertainty was too large, we developed a hybrid DISORT-spherical model. (DISORT model [10]), which uses DISORT for a diffuse light source function and accurate geometry for the camera line of sight. Within this framework, we have evaluated a variety of profile options to model: A 2-layer model (boundary layer and free atmosphere above boundary layer), a continuous model (no discontinuity in mixing ratio at the top of a boundary layer), and a gradient model (8 layers in boundary layer; 2 layers above, with selectable scale height in each layer). Of these various models the two-layer model produced the best results.

Two-layer model. The two-layer model represents the boundary layer and the free atmosphere, with free parameters representing the water content of each and the height of the boundary. We run this model in "downhill" mode so that it will find the best solution given the constraint of total column water abundance (constrained by CRISM). We also use the SSI measured dust optical depth.

Results:

Exploring the water vapor profile space for our midday observations, the best fits occur with a large amount of the total column of water is confined below 2.5 km and sometimes very low. However, we know from LIDAR data that dust should be well mixed up to 4 km. Running vapor profiles that have water well mixed up to 4 km, and only varying the amount of water in that 4 km layer, cannot be modeled with any fidelity. Further, comparing to the standard assumption – i.e., that water is well mixed to a cloud condensation height and then follows a condensation curve – shows that that scenario also does not fit the data (Figure 2).

Given the model fits of a 'water boundary layer' fairly low in altitude, we used a water vapor profile model to determine the water vapor mixing ratios, to ensure the fits were not supersaturated when in fact no clouds were observed. We used MCS T profiles as a constraint. We assume the water in the previously determined 'water boundary layer' is well mixed, then there (usually) is a discontinuity, and water above that 'water boundary layer' is well mixed at a different mixing ratio up to a cloud condensation height and then follows the cloud condensation curve above that.

Our uncertainty metric for this two-layer model is higher than desired in many cases. In order to examine the sensitivity of the quality of the fit to uncertainties in other parameters, we varied the total column abundance of water and the total dust, independently. The uncertainty in the CRISM data is 10% [6], so we examined cases with 10% lower and higher total column water amount and sometimes varied it up to 20% to achieve a good fit. Similarly, we varied the dust amount by the uncertainties given with the measurements. In many cases, the variation of these parameters allowed for an acceptable fit to be found.

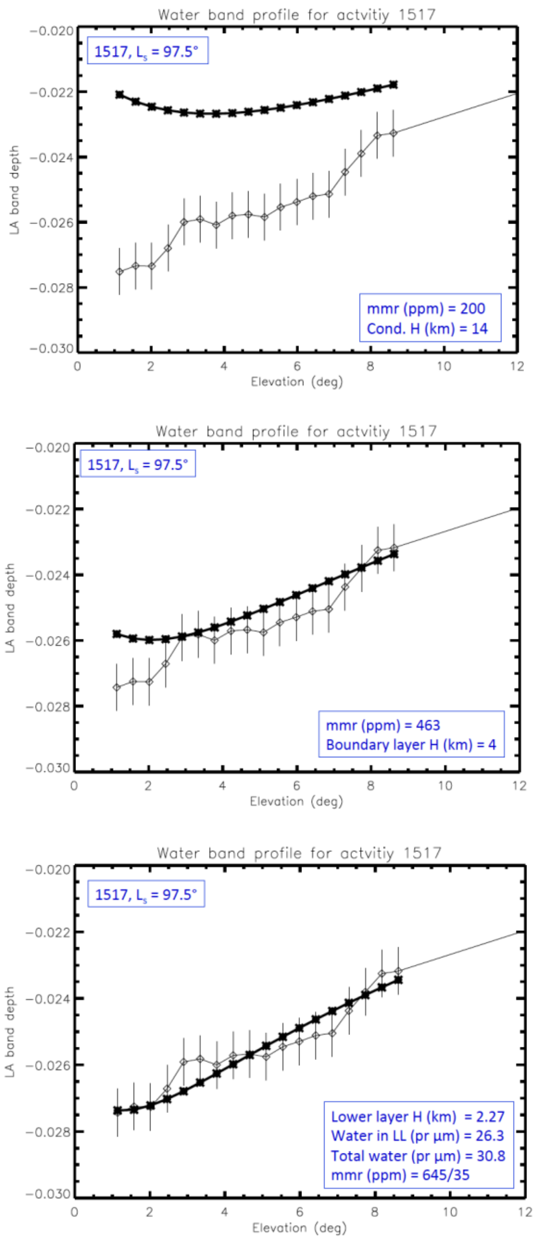

Figure 2. Model results for a midday observation at L_s=97.5° showing (top) well-mixed water vapor to a cloud condensation level, (middle) well-mixed water to 4 km, (bottom) 2-layer mod-

el. Symbols: Solid = model; Open = data.

Conclusions and Future Work:

The Phoenix data show a few percent absorption due to water vapor in the atmosphere. We are able to reproduce a few percent absorption in our DISORT/spherical model and obtain good fits to the data using a 2-layer assumption for the water vapor distribution. Our current analysis indicates that there is a large percentage of the column water vapor abundance confined near the surface and the most recent results will be presented. We will evaluate a 3-layer model in the future.

References:

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