VERTICAL WATER VAPOR DISTRIBUTION AT PHOENIX. L. K. Tamppari[1] and M. T. Lemmon[2], [1]Jet Propulsion Laboratory/California Institute of Technology, M/S 264-530, 4800 Oak Grove Dr., Pasadena, CA 91109, leslie.tamppari@jpl.nasa.gov, [2]Department of Atmospheric Sciences, Texas A&M University, College Station, TX 77843, lemmon@tamu.edu.

Introduction:

The atmospheric vertical water vapor distribution on Mars is not well known, although various models and obervations have addressed it. Observations often suffer from being limited in location (vertical and/or horizontal) and season, and various models have concluded that water vapor is *both* well mixed *and* not well mixed – "well mixed" is a constant fraction of the atmospheric pressure for a given height (e.g., [1,2]). Typically, the assumption is made that water vapor is well mixed to an altitude at which clouds would condense given a related temperature profile, and understanding the fidelity of this assumption is important. The Phoenix data provide the opportunity to examine the water vapor vertical profile for multiple times of day across the northern summer season during which the mission was active.

Understanding the vertical water vapor profile has implications to understanding the rate of exchange of vapor with the surface and subsurface and the buffering of subsurface ice. Dundas *et al.* [3] found clean ice exposed by recent craters in the northern hemisphere down to 39° N. Using ice stability modeling, they show that the presence of near-surface ice at this latitude is consistent with a long-term average of 25 pr μm, double the average column abundance today and expected assuming recent orbital cycles. However, they point out that if water vapor is confined to the lower atmosphere and not well mixed, that could explain their observations as well. Further, a water vapor vertical profile that shows a concentration near the surface could influence surface chemistry, and could limit the horizontal transport of water.

Datasets and Background:

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; [4]) and the Phoenix Surface Stereo Imager (SSI) with that measured at the surface (via the Phoenix Thermal and Electrical Conductivity probe (TECP; [5]) which contained a humidity sensor). This comparison, along with the Phoenix LIDAR observations of the depth to which aerosols are mixed [6,7], provides clues to the water vapor mixing ratio profile.

Tamppari *et al.* [8] showed that examination of a subset of these coordinated observations indicate 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. To illustrate, if the near surface TECP humidity measured during daytime is taken as well mixed to a condensation height (about 8 km per TES seasonal T data) or even to the ~4 km top-of-boundary layer measured by LIDAR, then the resulting amount of water exceeds the water column abundance measured by CRISM, indicating water cannot be well-mixed during the daytime at this season/location. Taking the TECP near-surface humidity measured at night and assuming well mixed, one derives far less water in the column than measured by CRISM or SSI, indicating that the near surface layer is depleted of water at night. Further, the total column abundance appears to change diurnally, both in CRISM data (may have been revised since [8]) and SSI data (Fig. 1-1 and 1-2). These results lead to the conclusion that water exchanges with the surface on a diurnal basis.

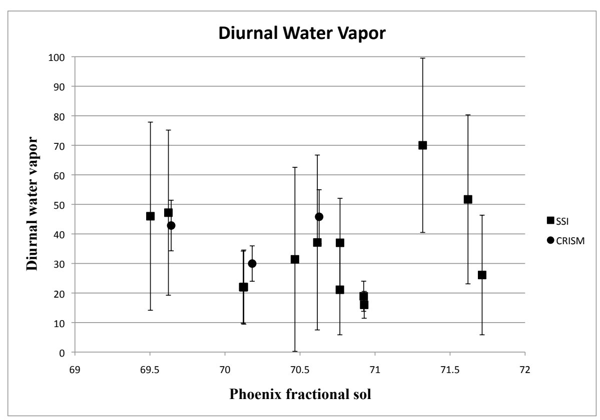

Figure 1-1. Diurnal water vapor measurements made by SSI (dots) and CRISM (squares) with error bars.

A key unknown is how deep the exchanging layer is, which is what we address with our modeling.

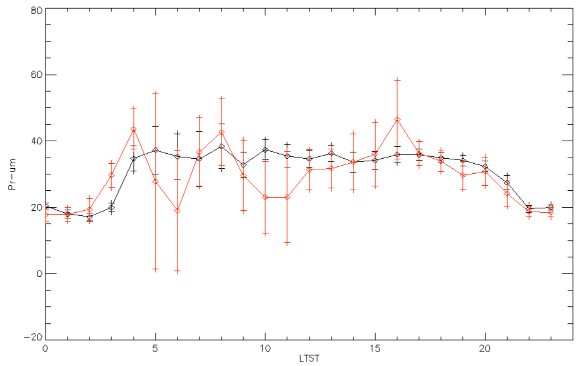

Figure 1-2. Diurnal change in water vapor column abundance as measured by SSI: averaged over the Phoenix mission (black) and for Sols 60-80 (red).

Data Acquisition Strategy:

In order to detect water vapor using the Phoenix SSI camera, several water vapor filters were added [9]. 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 [10]. 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 [10]. 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 a particular period of the Phoenix mission when we have a full complement of data sets and good diurnal coverage: Sol 70 (L_s ~108.3º). We have performed the majority of our testing 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, [11]), 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 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).

Conclusions and Future Work:

Our current analysis indicates that there is a large percentage of the column water vapor abundance confined near the surface. Improvements to the model have been made and recent analysis using this model and comparing to earlier results will be presented. In the future, we will evaluate other midday cases and compare to the Sol 70 case. Then we will evaluate data taken at other times of day (morning, evening, "night") and expand our analysis to include data taken over the course of the Phoenix mission.

References:

[1] Smith, M. D. (2002). *J. Geophys. Res.* 107 (E11), p. 5115, doi:10.1029/2001JE001522. [2] Smith, M. D. *et al.* (2009). J. *Geophys. Res.*, 114, E00D03, doi:10.1029/2008JE003288. [3] Dundas, C. *et al.* (2014). *J. Geophys. Res.*, 119, 109–127, doi: 10.1002/2013JE004482. [4] Murchie, S. *et al.* (2007). *J. Geophys. Res*., 112 (E05S03), doi:10.1029/2006JE002682. [5] Zent, A. *et al* (2009), *J. Geophys. Res.*, 114, E00A27, doi:1029/2007JE003052. [6] Whiteway, J. M. *et al.* (2008), *J. Geophys. Res.*, 113, E00A08, doi:10.1029/2007JE003002. [7] Whiteway, J. M. *et al.* (2009), *Science* 325 (5936), p. 68. [8] Tamppari, L. K. *et al.* (2010). *J. Geophys. Res.*, 115, E00E17, doi:10.1029/2009JE003415, 2010 [9] Lemmon, M.T. *et al.* (2008). *Lunar and Planetary Institute Science Conference Abstracts* 39, 2156. [10] Titov, D. V. *et al.* (2000). *Plan. and Sp. Sci.,* 48, pp. 1423-1427. [11] Stamnes, K. *et al.* (1988). *Appl. Opt*. 27, 2502.