REGOLITH CONTROL OF ATMOSPHERIC WATER VAPOR ON MARS FROM ANALYSIS OF THE PHOENIX TECP DATA.

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Introduction: One of the most important results from Phoenix was the measurement of the atmospheric humidity using the Thermal and Electrical Conductivity Probe (TECP) [1], which allows studying the water cycle in fine details, especially at the diurnal timescale. During the summer, when Phoenix performed its observations, the humidity profiles exhibits a very specific nearly Gaussian shape with a lower amplitude than described by purely atmospheric GCM models [2]. It is not clear what are the additional controls on the humidity. Several processes have been suggested, including ice – atmosphere exchange through diffusion, adsorption in the porous regolith and hydration changes of salts [1]. Indeed, Phoenix showed the presence of ~1% perchlorate in the regolith [3]. These compounds could be ideal to control the humidity through hydration-dehydration cycles. Adsorption can also control the humidity especially at low temperatures [4,5]. In this abstract we present our detailed analysis of the TECP humidity and temperature data recently released on the PDS, and a model of water vapor exchange between the subsurface and the atmosphere.

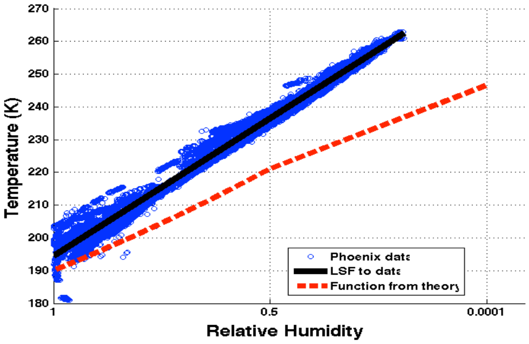

Figure 1. Board temperature versus relative humidity as measured by the TECP. The black line corresponds to a logarithm fit of the data. The red line corresponds to the theoretical line for pure sublimation of water ice (eq. 3).

Analysis of TECP data: Phoenix relative humidity R_H data was determined from the PDS for sols 0 – 150. The pressure of water (P_{H2O}) was found by computing the vapor pressure at the frost point temperature. Saturation vapor pressure from [6] was calculated using the board temperature T_b. The R_H was then calculated and plotted against the board temperature (Fig. 1). As can be seen, the data falls on a logarithmic line, i.e. $T_b = A \times \ln(R_H) + B$. A least squares fit approach was used and a slope of $A = -9.06 \pm 0.86$ was found. Since the board temperature is almost systematically higher than the real temperature by a couple of K, we also determined the change of slope associated with a board temperature having an error of ±10 K.

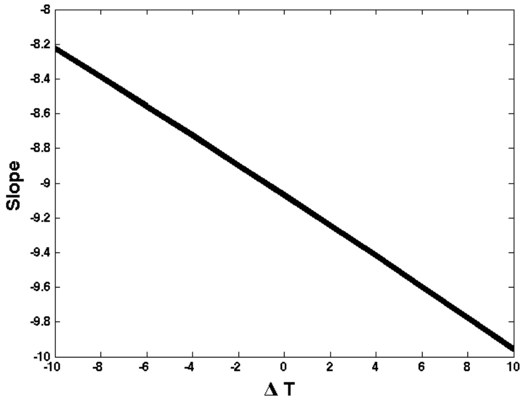

Figure 2. Expected T_b vs $\ln(R_H)$ slope as a function of temperature difference between the board and the real value.

The slope does not change significantly for a reasonable temperature, i.e. around 0.2 for a 2 K difference (Fig. 2). This line does not match thermodynamic boundaries of any salt possibly present in the regolith; thus hydration changes of salts do not seem to be controlling the humidity. In order to explain the observed relationship, a theoretical approach was taken starting from the definition of relative humidity:

$$\ln(RH) = \ln(P_{H_2O}) - \ln(P_{sat}) \tag{1}$$

where P_{sat} is the saturation vapor pressure for water ice Ih and is given by:

$$P_{sat} = P_t \exp\left[\frac{\Delta H_t}{R}\left(\frac{1}{T_t} - \frac{1}{T}\right)\right] \tag{2}$$

where P_t and T_t are the pressure and temperature at the triple point, and ΔH_t is the sublimation enthalpy at the triple point [6], which has been shown to be a weak function of temperature [7]. After substitution and rearranging, eq. 1 becomes:

$$T = \frac{\Delta H_t}{R}\left[\ln\left(R_H \frac{P_t}{P_{H_2O}}\right) + \frac{\Delta H_t}{RT_t}\right]^{-1} \tag{3}$$

Assuming a sublimation enthalpy of 51 kJ mol^{-1}, the resulting slope varies from -7.8 to -5.9 with a mean slope of -6.3 (Fig. 1). Since the slight overestimation of the board temperature is not enough to explain the difference of slope (Fig. 2), we found that a sublimation enthalpy of 74 ± 7 kJ mol^{-1} best fits the data. The resulting value is nearly 1.5 times higher than that of water ice and is in agreement with the enthalpy for adsorption water evaporation [8]. However, since the triple point pressure and temperature for adsorbed water is different than that of water ice, the corresponding enthalpy is possibly different.

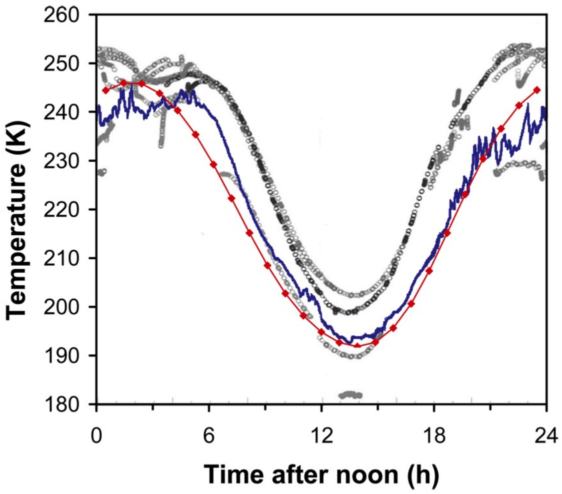

Figure 3. Comparison between the modeled temperatures (red line) and the measurements by the TECP (black and grey circles) and the meteorological station MET (blue line).

Numerical Model: From analysis of the TECP data, it appears that adsorption may affect the water cycle at the landing site. Therefore, we developed a numerical model simulating the heat and mass transfer within the regolith and planetary boundary layer (PBL) at the Phoenix landing site. The heat transfer model replicates quite well the measurements by the various instruments onboard the Phoenix lander (Fig. 3) [9]. Since equilibrium models well replicated the ice table depth [10], the ice layer is suggested to be in equilibrium with the atmosphere and the water vapor controls the ice depth. Nevertheless, this first model does not describe the humidity values themselves.

Using the modeling approach of Savijarvi [11], we simulated the diurnal and seasonal variation of P_{H2O} within the PBL assuming a constant eddy diffusion coefficient (K_H) from [12] such that:

$$\frac{d\gamma}{dt} = K_H \frac{d^2\gamma}{dz^2} \qquad (4)$$

where γ is the water mixing ratio. A 1 km atmospheric slap was modeled with temperature profiles attained from the adiabatic lapse rate and pressure profiles from hydrostatic equilibrium. Mass transfer within the regolith was modeled as diffusion advection [13] assuming the soil properties from Zent et al. [1] with an ice table at 10 cm. For these preliminary results, adsorption/desorption was not accounted for and condensation was not modeled; however, the maximum atmospheric relative humidity was set to saturation.

The model produces interesting new results and replicates many of the features described by Zent et al. [1]. Average P_{H2O} during the day is near 1 Pa (Fig. 4) in contrast to the 1.8 Pa observed and the 0.66 Pa from models not accounting for regolith H_2O exchange [14]. Average R_H values during the day are on the order of 10%, which correlate well with observations, and are seen to reach 100% during nighttime, in agreement with Phoenix results. However diurnal pressure values are not very well replicated, particularly between midnight and 6 AM, were we overestimate the pressure and during the day when our model is slightly underestimating the data. The distinctive constant P_{H2O} values during the day were also not well simulated. This may be due to the assumption of a constant K_H and not accounting for adsorption/desorption processes.

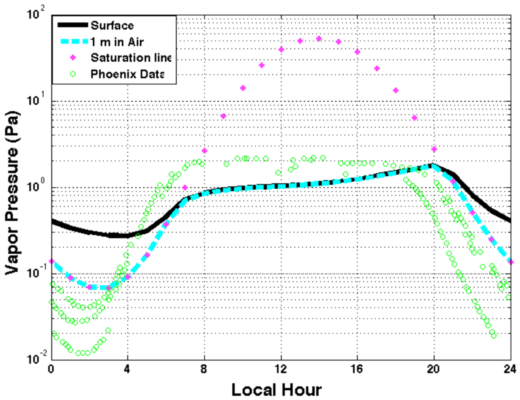

Figure 4. Comparison of modeled water vapor pressure as a function of local time (black and blue) with excerpts of the TECP measurements from [1] (green). The purple represent the water vapor saturation pressure.

Conclusions: Although we are only in the preliminary steps of the modeling, our results indicate that although diffusion is an important component of the diurnal water vapor cycle, TECP data analysis strongly suggests that adsorption is also a significant process at the Phoenix landing site. Our immediate future work will be to include the effect of adsorption in the model.

References: [1] Zent A. P. et al. (2010) *J. Geophys. Res.* 115 (E00E14). [2] Chevrier V. et al. (2009) *Geophysical Research Letters* 36 (L10202). [3] Hecht M. H. et al. (2009) *Science* 325, 64-67. [4] Chevrier V. et al. (2008) *Icarus* 196 (2), 459-476. [5] Zent A. P. et al. (2001) *J. Geophys. Res.* 106 (7), 14667-14674. [7] Feistel R., W. Wagner (2007) *Geochim. Cosmochim. Acta* 71, 36-45. [6] Feistel R. et al. (2006) *J. Phys. Chem. Ref. Data* 35, 1021-1047. [8] Möhlmann D. T. F. (2004) *Icarus* 168 (2), 318-323. [9] Rivera-Valentin, E. G. et al. (2009) Workshop on Modeling Martian Hydrous Environments, Abstract #1482. [10] Mellon, M. T. (2008) *J. Geophys. Res.* 113, E00A25. [11] Savijarvi (1999) *Q. J. R. Meteorol. Soc.* 125, 483-493. [12] Martinez et al. (2008) *Mars Atmosphere: Modeling and Observations Workshop*, Abstract #9002. [13] Ulrich, R. (2009) *Icarus* 201, 127-134. [14] Savijarvi and Maattanen (2010) *Q. J. R. Meteorol. Soc.* 136, 1497-1505.