SEASONAL RELEASE OF WATER VAPOR BY GROUND ICE ON MARS: IMPLICATIONS FOR SURFACE FROSTS AND ATMOSPHERIC WATER ABUNDANCE. Jonathan Bapst and Stephen E. Wood, Department of Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA 98195. (jnbapst@gmail.com)

Introduction: Observations from the Mars Odyssey Neutron Spectrometer (MONS) suggest substantial water ice exists beneath the Martian surface (in the upper meter or so) extending from the polar regions to mid-latitudes in both hemispheres [1,2]. The boundary between regions with ground ice and those without appears to be abrupt, as predicted [3].

Coupled thermal and vapor diffusion models have been used to study the behavior of water vapor as it diffuses through Martian regolith on intra-annual timescales [3,4]. These models show that when conditions are favorable (i.e. adequate atmospheric water abundance and sufficiently cold subsurface temperatures) pore ice will form from diffused water vapor.

Common in these models, surface vapor density is treated as a constant value which will drop to saturation vapor pressure when the surface cools beneath the frost point temperature (e.g. at night or during the winter season). When this happens there can exist a vapor density gradient such that favors transport of water vapor from the subsurface to the surface.

Our work here is aimed at estimating the amount of vapor that can be transported during seasonal transitions. We will explore various parameters (e.g. depth to perennial ice, atmospheric water abundance, geographic properties, etc.) that can affect the outward flux of vapor and its timing.

Vapor that is transported to the surface as described above would condense as frost if conditions are right (i.e. cold surface temperatures and lower vapor density at the surface than the near subsurface). The ultimate fate of that frost is sublimation and mixed into the atmosphere. This process, because of the widespread occurrence of ground ice on Mars, has the potential to influence the season water cycle on Mars.

Methodology: In order to estimate the vapor flux from the subsurface to the surface (in order to form frost and/or be mixed into the atmosphere) we focus on the upper grid points in our 1-D finite difference numerical model (similar to those described [3,4]) which allows for pore ice formation.

Vapor flux (J) is calculated based on the diffusivity of the regolith (D_o) and the vapor density gradient ($\frac{\partial \rho_v}{\partial z}$) via Fick's Law:

$$J = D_o\left(\frac{\Phi}{\tau}\right)\left(\frac{\partial \rho_v}{\partial z}\right)$$

Φ and τ are the porosity and tortuosity of the regolith, respectively.

We calculate our gradient using the surface vapor density and the vapor density just below the surface (i.e. 2nd grid point; this should capture transport between the surface and subsurface).

$$\frac{\partial \rho_v}{\partial z} = \frac{\rho_{v,2} - \rho_{v,surface}}{z_2 - z_{surface}} = \frac{\rho_{v,2} - \rho_{v,surface}}{z_2}$$

We assume $D_o = 4 \times 10^{-4}\ m^2/s$ after [5], $\Phi_{dry} = 0.40$ and $\tau = 3$. The location of z_2 is ~0.5 cm below the surface. We calculate diffusion of vapor and temperature along with ice adjustment 1000 times per sol. We ignore CO_2 frost and the effect of adsorbed water but recognize these could dramatically alter our results (see [4] for treatment of adsorbed water).

Preliminary Results: We ran our vapor diffusion model for a general case at 45°N using a prescribed atmospheric water abundance of 1 Pa (to ensure stable ground ice) and a surface albedo of 0.15. We start with an initially dry soil but conditions are such that perennial ice is stable below ~1 m depth. Due to the large fluctuations in surface vapor density our flux sign changes on a diurnal basis with vapor moving in and out of the upper subsurface layers.

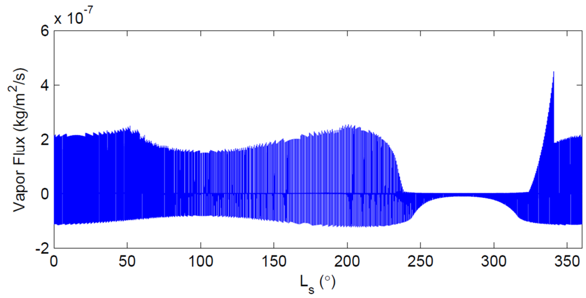

Figure 1. Vapor flux out of the subsurface (positive) and into the subsurface (negative). Variation in surface vapor density due to nighttime cooling produces changes in the sign of the flux on diurnal bases.

Due to the rapid variation in surface vapor density, it is useful to smooth out of the data (averaging over each Martian sol) to see seasonal variation. By subsequently integrating over each sol we can approximate inward/outward mass transport of vapor per sol (i.e. resetting each sol; Figure 2). We convert from kg/m² to precipitable microns for comparison to observations of column-integrated atmospheric water vapor [6]. This might also represent maximum frost thicknesses if surface frost comes and goes on a diurnal basis [7]. The sharp change at $L_s \approx 340°$ is an artifact of the model, in reality we expect this to a smoother transition as seasonal pore ice sublimates and diffuses from the near surface (and thus the steep near-surface vapor density gradients diminish).

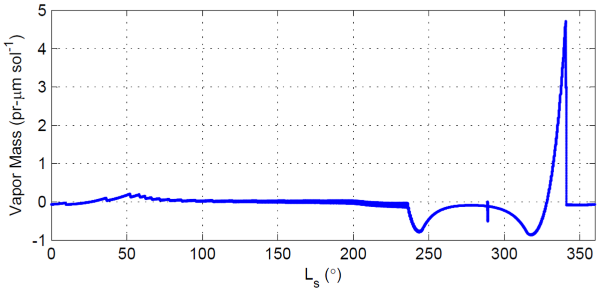

Figure 2. The integrated transport of vapor per Martian sol (using daily-averaged vapor density gradient). Note the anomalous, transient release of vapor to the surface (positive) around $L_s \approx 330°$. Integrated over that time period accumulates to 20+ pr-μm transported to the surface/atmosphere system.

Discussion: The release of vapor during late winter is an interesting result. Our explanation for this is the late-winter warming of near-surface seasonal ice, generating steep vapor gradients and thus transporting water towards the surface.

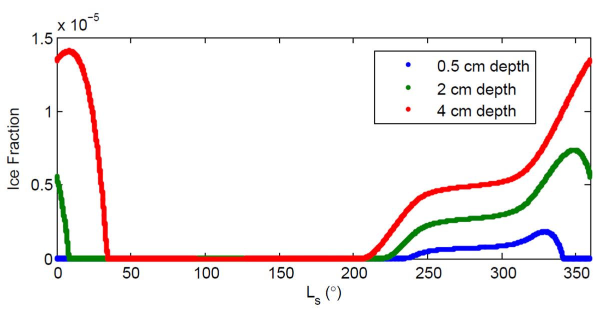

Figure 3. Near-surface seasonal ice shows growth and depletion in late winter/early summer. The depletion of ice at 0.5 cm depth (used for water vapor flux calculation of above) corresponds to the sharp decrease in flux around L_s = ~340° (see Figure 2).

Seasonal Water Frost: The possible addition of tens of precipital microns to a cold, dry winter atmosphere on Mars could result in significant surface frost. Smith *et al.*, 2002 show northern winter atmospheric vapor abundance in the mid-latitudes (and above) to be below the detection threshold. More work needs to be done, including atmospheric modeling, in order to determine the holding capacity and mixing ability of the atmosphere with respect to water vapor on these timescales. Spacecraft observations will be important in testing our model's predictions.

Apart from orbiting spacecraft, the Viking Lander 2 observed surface water frost at ~48°N [7]. Here frost was observed mostly in the late winter season. Some of this frost may have been sourced from probable ground ice in the region.

The ability for ground ice to release vapor provides a mechanism for local changes in albedo due to subsurface volatile content. This could play interesting roles in the dynamic of Martian climates, if such changes (e.g. obliquity) can strongly affect the process described here.

Seasonal Atmospheric Water Cycle: The seasonal water cycle of Mars has been observed by multiple instruments [8,9] and is relatively well replicated by general circulation models [14]. The addition of tens of microns of water into the atmosphere from ground ice sources could have a significant impact on the global water budget. Smith *et al.*, 2002 mentions a large increase in water vapor in the mid-to-high northern latitudes of Mars prior to summer solstice. This could be one possible explanation not yet considered.

References: [1] Feldman, W.C. et al. (2002) *Science,* 297, 75. [2] Boynton, W. V. et al. (2002) *Science,* 297, 81. [3] Mellon, M. T. and Jakosky, B. M. (1993) *JGR,* 98(E2). [4] Schorghofer, N. and Aharonson, O. (2005) *JGR,* 110, E05003. [5] Hudson, T. L. et al. (2007) *JGR,* 112, E05016. [6] Smith, M. D. (2002) *JGR,* 107, E11. [7] Svitek, T. and Murray, B. (1990) *JGR*, 95, B2. [8] Jakosky, B. M. and Farmer, C. B. (1982) *JGR*, 87, 2999-3019. [9] Smith, M. D. (2002) *JGR,* 107, E11. [10] Madeleine, J.-B. et al. (2009) *Icarus*, 203(2).