DRIVEN BY EXCESS? CLIMATIC IMPLICATIONS OF NEW GLOBAL MAPPING OF NEAR-SURFACE HYDROGEN ON MARS.
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Introduction: We present improved maps of near-surface WEH (Water Equivalent Hydrogen) on Mars that have intriguing implications for the global distribution of "excess" ice, which occurs when the mass fraction of water ice exceeds the threshold amount needed to saturate the pore volume in normal soils [1]: $\mathbf{W_{sat}} = \rho_{ice}P_o / [\rho_{soil}(1-P_o) + \rho_{ice}P_o] = \mathbf{25\%}$ (for ρ_{ice} = 0.92 g/cm^3, ρ_{soil} = 2.75 g/cm^3, and porosity P_o = 0.50). Our new mapping may be consistent with the widespread presence at high Martian latitudes of recently deposited shallow ice reservoirs that are not yet in equilibrium with the atmosphere.

Methodology: Following [2], we converted Mars Odyssey Neutron Spectometer (MONS) measurements of thermal, epithermal, and fast neutron counting rates [3] into a two-layer near-surface regolith model that expresses WEH concentration in terms of an upper layer of weight fraction W_{up} having thickness D overlying a semi-infinite lower layer of weight fraction W_{dn}. We have advanced upon previous mapping by refining the "crossover" approach devised by [1] through the use of tesseral spherical harmonic deconvolution in conjunction with an inverse distance-squared Gaussian weighting parameterization that calculates W_{up} from the deconvolved MONS counting rates.

Global Results: Fig. 1 shows our new WEH maps. Whereas the global crossover mapping of [1] produced numerous negative values of W_{up} that were clearly unphysical, our preferred deconvolved solution (of order N = 16) yields positive W_{up} values everywhere on Mars (Fig. 1a), ranging from W_{up} = 0.34% near Valles Marineris to W_{up} = 3.75% in Promethei Terra. Hence, we can now generate **the first global W_{up}-dependent maps of W_{dn} and D** (which have previously been calculated by assuming a constant value of W_{up}: e.g., [3]).

Our deconvolved W_{dn} maps (Fig. 1b,c) exhibit local maxima that are significantly higher than the corresponding W_{dn} values previously mapped by [2]. The most notable of these are **the W_{dn} > 90% maxima that occur throughout the 60º–70ºS band** (Fig. 1b), which tantalizingly suggest the presence of nearly pure ice (perhaps of paleoglacial origin?) buried well north of the South Polar Layered Deposits. At lower latitudes, our deconvolved solution yields (relative to [2]) significantly higher W_{dn} > 15% maxima in Medusae Fossae, Aeolis Mensae, and Arabia Terra (Fig. 1c). In addition, **the boundary of excess ice** – denoted by the dark blue W_{dn} = 25% contour in Fig. 1b – **extends much more equatorward** in our deconvolved mapping than in [2].

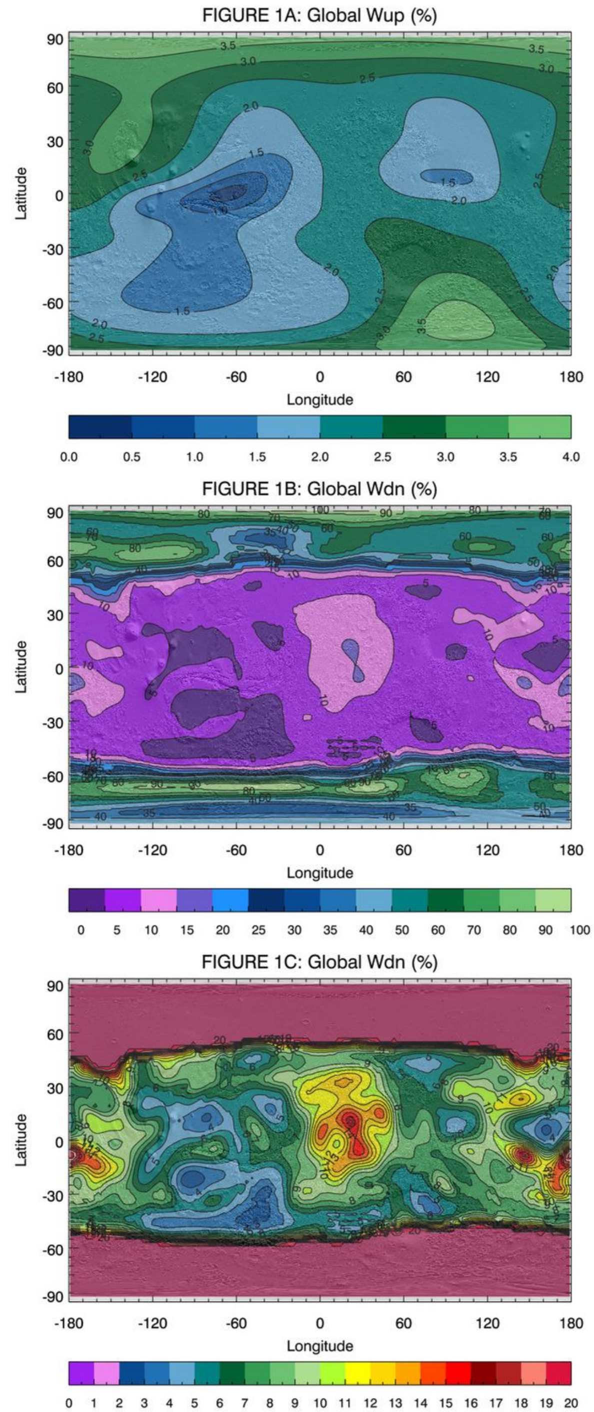

Figure 1: Maps of WEH (wt. %) corresponding to preferred deconvolved solution (order N = 16). (A) Global W_{up}. (B) Global W_{dn}. (C) Same as (B) but rescaled to highlight low-latitude W_{dn}.

Fig. 2 shows our deconvolved global depth map. The $D = 0$ dark purple contour outlines circumpolar regions where the two-layer model does not apply. Global maximum depths exceeding 50 g/cm^2 occur in both Acidalia Planitia and Noachis Terra (Fig. 2). As noted by [4], $\boldsymbol{W_{dn}}$ **and** $\boldsymbol{D}$ **are anti-correlated at high latitudes**, as depths within the 60º–70ºS and 60º–70ºN bands are generally less than D = 15 g/cm^2 (Fig. 2) wherever W_{dn} > 80% (Fig. 1b).

Ground Truth: At the Phoenix landing site, our deconvolved two-layer model solution yields $\boldsymbol{W_{dn}}$ **= 72.2%** (Fig. 3a) and D = 10.1 g/cm^2 (Fig. 2), which implies that there should should be an **excess ice layer** buried at a **depth of 7.2 cm**. But this WEH distribution is incompatible with Phoenix's *in situ* observations [5], given that the lander dug numerous trenches deeper than 7.2 cm yet **primarily detected pore ice** (90% of detections) instead of excess ice (10% of detections).

In order to reconcile these disparate MONS and Phoenix observations, we have developed a simplified **three-layer near-surface model** comprised of:
(1) an ice-poor upper layer ($\boldsymbol{W_1} = W_{up}$, $\boldsymbol{D_1} = D$),
(2) a pore-saturated middle layer ($\boldsymbol{W_2} = W_{sat}$ = 25%,
$\boldsymbol{D_2} = 60\ g/cm^2 * ((W_3 - W_{dn})/(W_3 - W_2))$, and
(3) a semi-infinite pure ice lower layer ($\boldsymbol{W_3}$ = 100%).
Note that we assume a middle layer maximm depth of 60 g/cm^2 based on our modeling of high W_{up} cases.

The results of this three-layer model can be used to compute a **minimum depth to the excess ice table**, which for the Phoenix landing site is equal to **20.1 cm** (Fig. 3b). This result is consistent with Phoenix, which only dug down to a maximum trench depth of 18.3 cm [5]. Similarly, our three-layer model results are also more consistent (relative to the two-layer model) with the **excess ice table depths implied by recent ice-exposing craters** [6] at high latitudes (e.g., Fig. 3b).

Climatic Implications: Our three-layer model is similar to that of [7], who showed that subsurface pore ice can form in two ways: "volumetric deposition" via downward diffusion, and **"vertical deposition" driven by an impermeable layer of excess ice**. Thus, if our simplified three-layer model is correct and nearly pure excess ice is ubiquitous at high Martian latitudes, then the modeling of [7] suggests that this buried ice reservoir was **likely emplaced within the past few million years** and is not yet in atmospheric equilibrium.

References: [1] Feldman W. C. et al. (2011) *JGR, 116*, E11009. [2] Prettyman T. H. et al. (2004) *JGR, 109*, E05001. [3] Maurice S. et al. (2011) *JGR, 116*, E11008. [4] Feldman W. C. (2007) *GRL*, 34, L05201. [5] Mellon M. T. et al. (2009) *JGR, 114*, E00E07. [6] Dundas C.M. et al. (2014) *JGR, 119*, 109-127 [7] Schorghofer N. and Forget F. (2012) *Icarus*, *220*, 1112-1120.

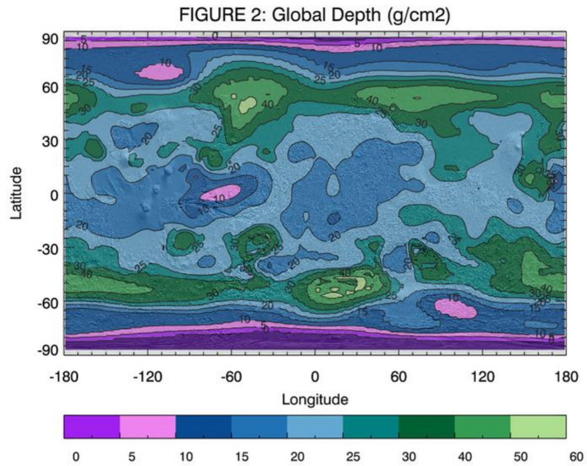

Figure 2: Deconvolved global D map: darkest purple contour corresponds to D = 0 exactly. Also, we have set D = 30 g/cm^2 in regions where $(W_{dn} - W_{up})$ < 1%.

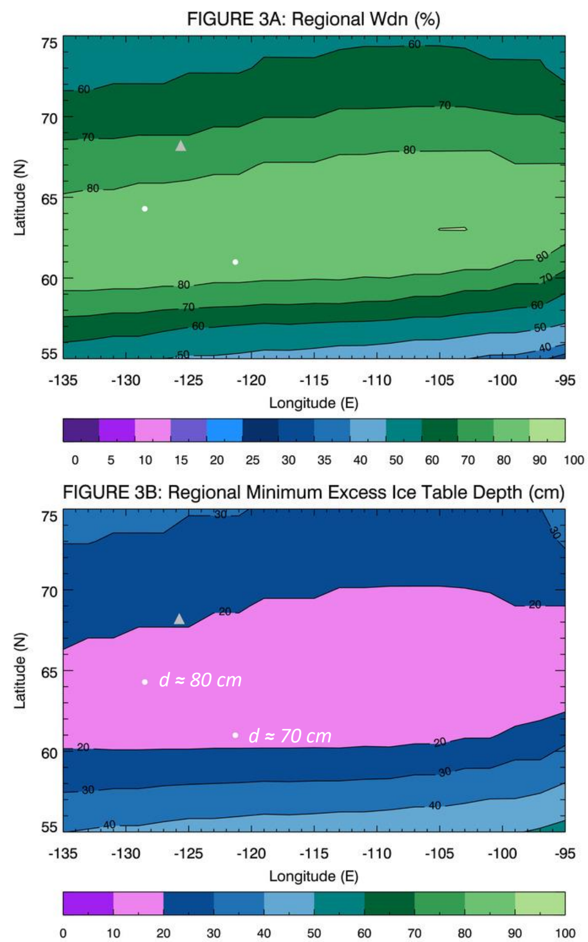

Figure 3: Maps of WEH corresponding to preferred deconvolved solution (order N = 16) for: (A) Regional W_{dn}. (B) Regional Minimum Excess Ice Table Depth. Grey triangle indicates Phoenix landing site; white circles denote recent ice-exposing craters [6].