# Explaining the Mid-Latitude Ice Deposits with a General Circulation Model

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**Introduction:** Though plausible explanations for the high latitude subsurface hydrogen features on Mars have been put forth, there still lacks a consensus on the nature of the low-latitude hydrogen features found in Arabia Terra and Daedalia Planum. While equivalent water mass fractions in these regions are low enough to potentially be explained by the presence of hydrated minerals, it still remains possible that such features are the remnants of ice deposits left from a previous period of high obliquity and which is now thermally unstable and subliming. In order to explore the thermal stability of putative ice deposits at low latitudes, we use the Geophysical Fluid Dynamics Laboratory (GFDL) Mars GCM with a newly integrated subsurface scheme to trace the deposition and sublimation rates of water ice, adsorbate and vapor across the planet at varying obliquities. In addition, these results help resolve the question of the dominant means of ice emplacement in the near surface—whether such ice is the result of buried surface deposits, or *in situ* emplaced ice due to vapor diffusion.

**Formation of Deposits:** Previous work [1,2] has suggested that the chief formation mechanism for these deposits was deposition of surface ice at high obliquity, followed by subsequent sublimation when the obliquity returned to lower values. During this sublimation process, entrained dust would be left on the surface, forming a dry, lightly indurated layer that would protect deeper ice deposits from further sublimation. The water fraction in these lower latitude deposits is significantly lower than those poleward of 60°, which is consistent with their being deposited further in the past, when obliquities were higher.

It is possible that such deposits may have been enhanced, or even completely formed by alternate methods, such as strictly by vapor diffusion [3-5], and that these features were formed in place within the regolith rather than being surface deposits subsequently buried.

Furthering the efforts in [1,2], we have added a complete subsurface vapor and heat diffusion scheme following [6]. This places a completely new reservoir into our simulations of the martian water cycle. For the first time, the effect of a regolith has been incorporated into 3-D GCM climate simulations. Water may penetrate and diffuse into the subsurface as vapor, and then remain in the gaseous phase or become adsorbed onto grain surfaces. The amount of adsorption is based upon an isotherm for basalt used previously [6-8]. If the amount of vapor within the regolith pores exceeds the saturation vapor pressure, ice is formed from the excess. The transport of vapor between the atmosphere and regolith is driven by the vapor pressure gradient between the two. In the presence of surface ice, such transport is shut off, and surface ice will be deposited or removed accordingly.

**Results:** Figure 1 shows the surface ice distribution without an active regolith. Compare this to Figure 2a, which shows identical model conditions, but with the regolith active. Figure 2b shows the total integrated subsurface water (the sum of any ice, adsorbate and vapor present). We have bookended the anticipated regolith water abundance with simulations initialized with $10^{-10}$ kg/m$^3$ and 60 kg/m$^3$ total subsurface water. In the past [6] has suggested ~2 kg/m$^3$ as an expected amount in the mid-latitudes.

**Ice-Feedback:** Of all geologic materials found in the near-surface environment of Mars, ice has the highest thermal inertia [9,10]. We should therefore expect the emplacement of ice within or on the surface to have a marked effect on the thermal properties of the soil. Indeed, such an effect has been noted before [11]. We have conducted separate investigations that include the thermal feedback due to ice. Simply, what we find is that ice will be preferentially deposited within the regolith in regions of the lowest thermal inertia within the particular latitude band where ice is most stable (depending on obliquity). The transported vapor makes its way to these regions and diffuses into the soil. Where thermal inertia is lowest, the mean annual temperature is lowest, enhancing the fractional retention of ice on the diurnal cycle.

Once this ice is emplaced, it slowly begins to raise the thermal conductivity of the region in which it is present. Over time, this value will become similar to adjacent areas, this TI-dependent behavior will be muted and the distribution of ice will become more widespread. We have yet to consider the effect of increased ice abundance on vapor diffusion, though it is likely important [3].

**Formation Timeline:** These results are consistent with the formation mechanism previously discussed in [1,2]. The chief difference is the relative times at which they dominate. It appears from these results that uptake by the regolith is sufficient to accommodate the increased vapor transport at high obliquity. Therefore, surface deposits may not immediately form. Rather, for a period of perhaps thousands of years, this water diffuses into the regolith, forming ice deposits. Once either the regolith is filled with ice, or the spatial distribution of ice chokes off the regolith at a shallow depth, ice will begin to form readily on the surface, following the method described in [1,2]. Once ice is on the surface, the regolith ceases to be the dominant sink for the atmospheric water vapor.

**Comparison to GRS Results:** When we compare our subsurface ice results to GRS maps of subsurface ice in the low latitudes, the results are encouraging. The formation of ice deposits across Mars (certainly at high latitudes, and possibly those here at low latitudes) appears undoubtedly driven by thermal stability processes. Three distinct maps of the surface—thermal inertia, GRS hydrogen abundance and our subsurface ice distribution all have similar characteristics, and lead us to believe that these deposits are formed and removed according to simple thermal principles. Along with the accepted martian obliquity history, the evidence becomes more compelling that these deposits are a result of climate forcing.

**Conclusions:** We have examined the influence of a regolith on the water cycle with a focus on high obliquity periods on Mars. Our findings show that while the regolith will almost certainly interact with the atmosphere initially, it is only a transient effect, and ice will form on the surface once the regolith is effectively isolated from the atmosphere. These low latitude deposits could conceivably be ice deposits formed at high obliquity and are certainly presently out of thermal equilibrium, but remain due to the insulating effect of a dust lag.

**References:** [1] Mischna *et al.* (2003) *JGR, 108,* E6. [2] Richardson *et al*. (2003) *LPS XXXIV,* Abstract #1281. [3] Mellon and Jakosky (1993) *JGR, 98,* 3345-3364 [4] Mellon and Jakosky (1995) *JGR, 100,* 11,781-11,800 [5] Mellon *et al.,* (1997) *JGR, 102,* 19,357-19,370 [6] Zent *et al.,* (1993) *JGR, 98,* 3319-3337 [7] Zent and Quinn (1997) *JGR, 102,* 9085-9095 [8] Houben *et al.*, (1997) *JGR 102*, 9069-9083 [9] Paige *et al.,* (1994) *JGR, 99,* 25,959-25,991 [10] Paige and Keegan (1994) *JGR, 99,* 25,993-26,013 [11] Paige (1992) *Nature, 356,* 43-45

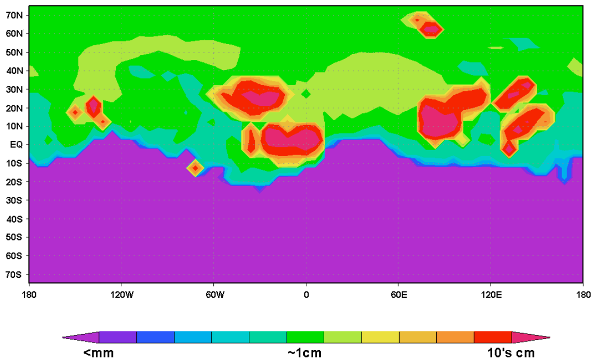

**Figure 1:** Global distribution of surface ice during northern winter at 45° obliquity *without* an active regolith. Ice preferentially deposits on regions of high thermal inertia and/or high topography.

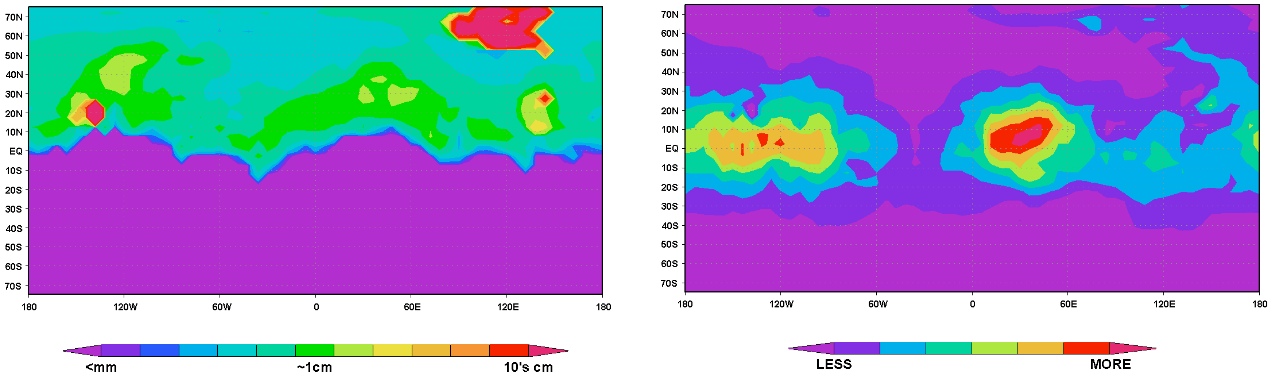

**Figure 2:** **(a)** (left) Global distribution of surface ice at 45° obliquity *with* an active regolith. Model conditions (except active regolith) are identical to Figure 1. **(b)** (right) Distribution of subsurface water (sum of ice, adsorbate and vapor) for same model run as (a). Spatial distribution is more significant that abundance, hence scale bars are qualitative. Subsurface ice is preferentially buried initially in regions of low thermal inertia