THE GLOBAL DISTRIBUTION OF MARTIAN SUBSURFACE ICE AND REGIONAL ICE STABILITY.

M. T. Mellon[1] and W. C. Feldman[2], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, 80309-0392, [2]Los Alamos National Laboratory, Los Alamos, NM.

Introduction: Ground ice (subsurface ice) in the upper several meters of the martian regolith is an important component of the global water cycle and of the martian climate. It represents a substantial reservoir of water that can dynamically exchange with the atmosphere on timescales comparable to that of oscillations in the planet's orbit [e.g., Mellon and Jakosky, 1995]. As such, the occurrence of ground ice tracks long-term changes in the martian climate. Direct and indirect measurements of the present day distribution subsurface ice on Mars can therefore be an important clue regarding the history of the martian climate.

In this work we examine latest global-scale distribution of subsurface ice inferred from Mars Odyssey measurements and compare it with theoretical estimates of ice stability under various climate conditions. Our goal is to determine, both globally and regionally, if the observed ice distribution is consistent with ground ice in diffusive equilibrium with the atmosphere, present day or otherwise, and to identify regions where diffusive equilibrium does not appear to apply.

Observations of Water on Mars: Ground ice has been inferred to be abundant, now and in the past based on the geologic record [e.g., Carr 1996]. In recent years the Mars Odyssey space craft has provided data on the gamma-ray flux and leakage-neutron flux which are directly dependent on the concentrations of subsurface hydrogen and thus water [e.g., Boynton et al., 2002; Feldman et al., 2002; Mitrofanov et al., 2002]. These observations provide us with the most direct detection of ground ice to date.

Mars Odyssey observations indicate that ground ice is pervasive at high latitudes of Mars and generally absent in the equatorial regions. They also indicate that the martian surface is best described with two layers, one of relatively dry soil above a second of ice-rich soil. While more layer structure may exist, they are not necessary to explain the data. However, a homogeneous icy soil is inconsistent with these observations.

Ice Stability: Theoretical studies starting with Leighton and Murray (1966) and continuing with numerous researchers in subsequent decades have explored the stability of ground ice on Mars from a variety of perspectives. A consistent result in all of these studies is that, with atmospheric humidity at levels similar to today, ground ice is stable against sublimation within the subsurface in middle and high latitude regions. Once more, if a dry cold soil in these regions is exposed to the atmosphere, water vapor will diffuse inward and condense in the poor space where the stability conditions are met (where the subsurface soil is colder than the condensation point of atmospheric water vapor). Conversely, ice emplaced by any means in a region where it is now unstable will sublimate and be diffusively lost to the atmosphere.

These theoretical studies also indicate that a dry soil layer should occur above an ice-rich soil layer, consistent with the observations, and consistent with naturally occurring ground ice in some terrestrial polar deserts.

The depth of this boundary between ice-rich soil and dry soil (the ice table) is controlled by diffusive equilibrium between water vapor in the soil pore space and that in the atmosphere. Any change in this equilibrium condition (changing soil temperature, erosion or deposition of soil, changing atmospheric humidity) will cause the ice table to readjust to a new equilibrium position. The time scale for this adjustment is typically 100's to 1000's of years depending on the amount of water being transported and the diffusive properties of the soil.

History of the Ice: While Mars Odyssey measurements only indicate the present day distribution of ice, this distribution can be used to infer something about the history of the ice. A number of emplacement processes may have occurred in the past (e.g., freezing of ground water, burial of snow pack, interstitial hoar frost), either in a martian climate like the present day or in a dramatically different climate. Subsequently, diffusive exchange of water with the atmosphere is theoretically expected to occur, resulting in periodic desiccation of the soil and redeposition of ice. If these processes occur then 1) the depth of the ice will be controlled by recent diffusive equilibrium regardless of the original emplacement mechanism, 2) the ice in the upper meters of regolith is unlikely to be ancient but perhaps as young as the last obliquity cycle.

Model and Data Comparison: To address these questions regarding the history of the ice and what controls its depth, we compare theoretical distributions of ice, assuming diffusive equilibrium under different climate conditions, with the latest Mars Odyssey leakage neutron flux data. Two types of comparisons are useful, a geographic boundary comparison, and a depth distribution comparison.

Geographic Comparison. Both theoretical maps of ground ice distribution and of the measured neutron flux indicate a relatively sharp boundary occurs poleward of which ground ice is abundant and equatorward of which it is "absent." When doing such a comparison, two limitations need to also be considered; 1) the neutron flux measurements have a large 600 km footprint on the martian surface, and 2) the sensitivity of the Mars Odyssey measurements decrease with burial depth and are insensitive to ice below a meter or so of soil. With these limits in mind we can compare the neutron flux boundary with the theoretical ice table depth and examine areas of agreement or disagreement.

Distribution Comparison. A specific physical relationship exists between the neutron flux and the depth of the ice table, such that a specific depth results in a specific neutron count rate, all else being equal. Therefore a comparison between the measured neutron flux and the predicted depth of the ice table at each location can be collectively examined for this relationship.

In both comparisons, the climate conditions on Mars can be varied, thus changing the theoretical ice table depth.

Results: Results of these comparisons indicate that over most of Mars, in both northern and southern hemispheres, the ground ice detected by Mars Odyssey is in diffusive equilibrium with the Mars atmosphere.

Figure 1 shows the latest map of the epithermal neutron flux. Low flux indicates the presence of abundant subsurface hydrogen, inferred to be ground ice.

Figure 2 shows a map of ice table depths derived assuming diffusive equilibrium with 20 pr um of atmospheric water vapor and assuming the measured geographic distribution of surface thermal and physical properties. In the southern hemisphere the epithermal neutron boundary closely follows the 15 cm depth contour. In the northern hemisphere the boundary similarly follows the 15 cm contour at most longitudes. However, two interesting regions occur where the boundary does not match the theoretical distribution of the ice table

Discussion: Detailed comparisons between measured neutron fluxes and theoretical ice tables for a variety of atmospheric humidity conditions indicate that 20 pr um of atmospheric water vapor results in closely matching ice-table depth distribution. Comparisons of map boundaries, as well as between count rate and ice table distributions, indicate two distinct regions of ground ice; 1) those areas in equilibrium with the atmosphere encompassing most of the martian high latitudes, and 2) two small northern regions of disequilibrium north of Tharsis and Arabia (90-170 W and 320-360W).

Details of these results and inferences about the martian climate and the regional ground ice history will be discussed.

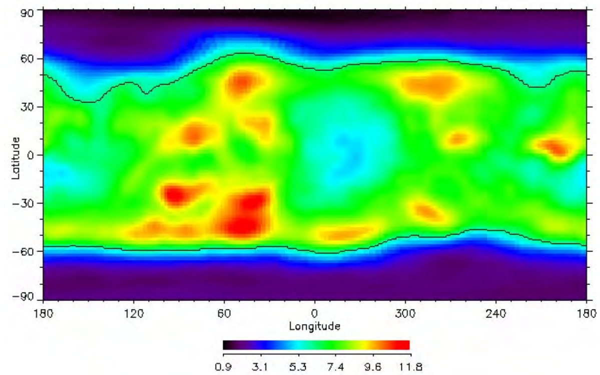

Fig 1. Epithermal neutron flux [counts per second] from Feldman et al (2004). Superimposed is a boundary at 6 counts per second, which is roughly half way between the minimum and maximum and generally marks the boundary between where ground ice is sensed and where ground ice is not sensed (not present or too deep to sense).

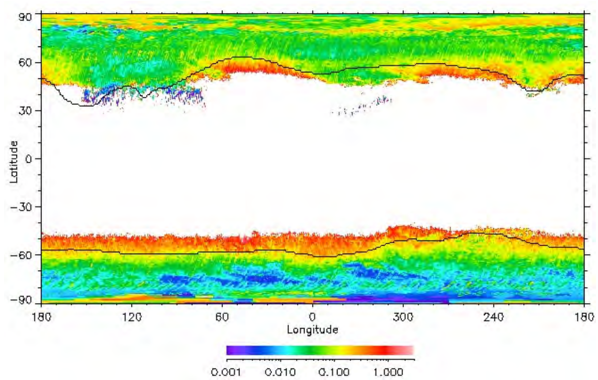

Fig 2. Map of the theoretical ice table depth [meters] with the epithermal neutron flux boundary superimposed. This maps assumes 20 pr um of atmospheric water vapor, distributed uniformly with CO2, is in equilibrium with the ground ice.

References: [1] Carr, M H, Oxford U. Press, 1996; [2] Boynton, W. V. et al., *Science, 297*, 81-85, 2002; [3] Feldman, W. C. et al., *Science, 297*, 75-78, 2002; [4] Feldman, W. C. et al., *JGR, 109*, 2004; [5] Leighton, R. B., and B. C. Murray, *Science, 153*, 135-144, 1966; [6] Mellon, M. T. and B. M. Jakosky, *JGR, 100*, 11781-11799, 1995; [7] Mitrofanov, I et al., *Science, 297*, 78-81, 2002.