MODELING DEPTH TO GROUND ICE ON MARS. M. A. Chamberlain and W. V. Boynton, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, 85721, U.S.A., mc@lpl.arizona.edu.

Introduction: Soon after the first spacecraft to Mars confirmed the surface was cold and dry, it was recognized that ice could be stable at depth below the surface [1].

Many places on the surface of Mars get cold enough to freeze water from the atmosphere in the form of frost, as seen at the Viking II Lander site [2]. Only the poles stay cold enough so that this frost does not completely sublime back into the atmosphere when the surface heats up in the summer season.

Temperatures at depth, however, do not reach the same extreme temperatures as the surface and it is possible for ground ice to be stable outside the polar regions.

Mellon and Jakosky [3] produced the first map showing the global distribution and depth to this ground ice that is stable to diffusion with the Martian atmosphere. The most convincing evidence of the ground ice so far is the hydrogen gamma ray and neutrons detected by the Gamma Ray Spectrometer (GRS) flying on the Mars 2001 Odyssey spacecraft [4]. The distribution of the ground ice, shown in the initial GRS results, was in excellent agreement with the map produced by [3] based on albedo and thermal inertia.

Presented here are some sample results from models being developed to help understand the GRS results. GRS has detected ice in such high densities in the ground that it is more likely that ice was deposited by frost or snow than vapor diffusion [5]. Though diffusion models can still determine the thickness of lag deposits that may later form over the frost or snow.

Models: The models being developed are based on those described in [3]. There are two parts to these models: a thermal model and a water-vapor diffusion model.

The thermal model finds the temperatures at different depths in the ground at different times of the Martian year. Temperatures are functions of latitude, albedo and thermal inertia. It is possible to just use the thermal model to determine a depth to stable ice. Ice is stable if the top of the "ice table" has the same average vapor density as the average water-vapor density in the atmosphere.

Water is allowed to move by the vapor diffusion model. The temperatures from thermal model are used to partition water between 3 phases: vapor, adsorbed and ice. Vapor is the only mobile phase and the diffusion of vapor is buffered by adsorbed water. The adsorbed water densities are found using the same equations in [3]. The coefficient of vapor diffusion in the ground is uncertain, a value of 0.0003 m^2s^{-1} is used here which is in the range that has been used before, [3] and [6]. The effective coefficient is reduced in these models as ice fills the pore spaces. Vapor diffusion models can have ice-poor or ice-rich starting conditions. Vapor diffusion models are run for long periods to check the depth to stable ice.

As ice distribution in the ground changes, the thermal properties of the ground change too. Thermal conductivity increases as ice fills the pore spaces. The scheme described in [7] is used here to convert ice density in the ground to thermal conductivity. Vapor diffusion models here are run iteratively with thermal models to update the temperature profiles as ice is redistributed.

Sample Results: Figures 1 and 2 show sample results of the models briefly described above.

Depth to Ice. Figure 1 shows the depth at which ice would be stable at different latitudes and obliquities. These are calculated with the thermal model and the principle that ice is stable when the average vapor density is in balance with the atmosphere.

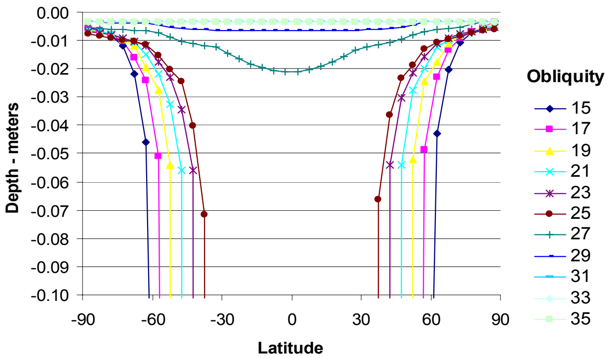
Two sets of profiles are presented showing the results for two different sets of thermophysical properties: a) bright, dusty ground (albedo = 0.30 and thermal inertia = 100 S.I. units), and, b) dark, rocky ground (albedo = 0.18 and thermal inertia = 235 S.I. units). These values are based on the distribution of IRTM results from the Viking Orbiters [8]. (TES thermal inertia values are substantially lower then Viking values and the thermal model presently used here is more consistent with the way the Viking values were derived.)

Assumptions must be made about the how atmospheric CO_2 and H_2O vary with obliquity. CO_2 pressure is calculated by energy balance at the poles, in a manner described in [1]. A relation between water vapor and obliquity from [9] is used here, which is based on the amount of insolation on the residual polar caps [10].

The distribution of ice with obliquity found here is similar to that of [9]. Both show that ice is stable close to the surface across all latitudes at times of high obliquity and that ice retreats to the polar regions when obliquity is low. The stable ice is closer to the surface in models here than [9] because the thermal conductivity of ice-cemented soil is included in models here. For the same reason that the depth to ice in recent models (e.g. [11]) is more shallow than the original model [3].

The position of perihelion in these models was moved to Ls=0 to reduce the hemispherical asymmetry, though the present eccentricity was still used.

a)



b)

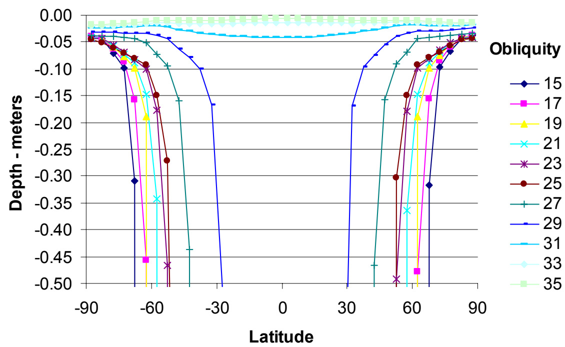
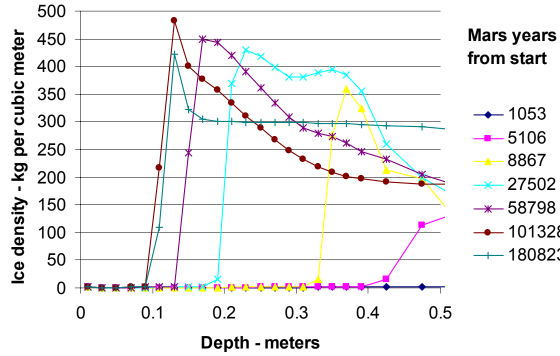


Figure 1 Depth to stable ice at recent obliquities for a) bright dusty ground, and b) dark rocky ground.

Vapor Diffusion. Figure 2 shows two model runs of vapor diffusion with the properties of dark rocky material at 62.5° N with the current Martian orbit and atmospheric water. One model run starts with an initially dry ground, the second starts ice-rich. Ice becomes stable at the same depth for each run, a depth which is also consistent with the corresponding depth in Figure 1b. The run that started dry took much longer to reach a stable depth, of the order of 100,000 Mars years, which is longer than an obliquity cycle.

Ice initially begins to form at depth. This pinches the temperature profile sending the ice deeper while making ice diffusing from the surface freeze at shallower depths. Thermal iterations were found to make the model unstable; ice would retreat from the surface intermittently.

a)



b)

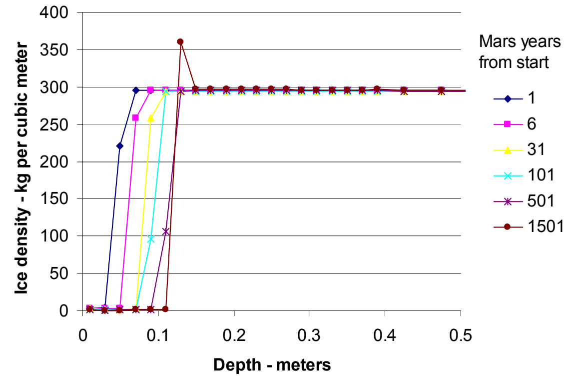


Figure 2 Profiles of ice growth produced by vapor diffusion models. The inputs for each model are the same (Lat. = 62.5 N, Alb. = 0.18, Thermal Inertia = 235 S.I., present Martian orbit), except that 2 different starting conditions are used: a) dry ground, and b) ice-rich ground. An ice density of 500 kg m^{-3} on this figure would represent part of the ground where ice had completely filled and choked the available pore space.

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