Stability of Mid-latitude snowpacks on Mars. K. E. Williams¹ and O. B. Toon², ¹Atmospheric Sciences dept. & Laboratory for Atmospheric and Space Physics (LASP UCB 392, University of Colorado – Boulder, Boulder, CO 80309-0392 kaj.williams@colorado.edu), ²Atmospheric Sciences dept. & Laboratory for Atmospheric and Space Physics (LASP UCB 392, University of Colorado – Boulder, Boulder, CO 80309-0392 btoon@lasp.colorado.edu).

Synopsis: Mid-latitude snowpacks on Mars have been postulated to exist by Christensen [1], who also suggests that runoff from melting snowpacks on slopes might be responsible for carving gullies, and suggests that such snowpacks may currently exist on the walls of Dao Valles (approx. -33.0 lat.). The snowpacks were presumably formed during the last obliquity cycle, about 74,500 years ago. In this paper we investigate the rate at which a snowpack located at -33.0 latitude on a poleward-facing slope of 21 degree inclination sublimes on Mars. Our model includes the energy and mass balance of the snowpack, and diurnal variations in insolation. Our model results indicate that a dirty snowpack would very quickly sublime under current Martian climate conditions; a 10m thick snowpack of moderate density (550 Kg/m3) and albedo (0.21) would sublime in less than 5 years. A cleaner snowpack would sublime in less than 20 years. These results suggest that the snowpack in question almost certainly could not have survived for 74,500 years. The possibility of preservation of the snowpack by immediate burial is raised, but the burial would have to be at approx. 1m deep and would have had to occur within ~5 years. In addition, snowpack temperatures never reach the melting point, raising serious questions regarding the availability of runoff for gully incision.

Introduction and Background: Gully-like features have been noted on Mars since the Mars Orbiting Camera (MOC) on board the Mars Global Surveyor (MGS) arrived in 1997 [2]. Many of the gully-like features appear to be geologically-young (last few million years) since they are not cratered and many are superimposed on surfaces which themselves are geologically young.

There have been several models proposed for the formation of these gully-like features (hereafter just referred to as gullies). Musselwhite et al. [3] propose that a liquid subsurface CO₂ reservoir may be responsible for carving the gullies. There are numerous problems with the CO₂ flow hypothesis however, including the fact that the flow-channel morphologies are inconsistent with the physics of CO₂ flow [4].

Heldmann [4] and others have argued that subsurface aquifers with impermeable boundaries may be suddenly exposed by slope failures, causing a cascade of water that could have incised some gullies. She studied hundreds of gullies and determined that most of the gullies could best be formed by subsurface fluid sources rather than snowfall or wind.

Christensen [1] has suggested an alternative model for gully formation. Christensen hypothesizes the following:

1. Water is transported from the Martian poles to mid-latitudes during periods of high obliquity.
2. Melting occurs at mid-latitudes during low obliquity, producing liquid water that is stable beneath snow.
3. Gullies are eroded by this meltwater.
4. Gullies incised into the substrate are observed where snow has been removed.
5. Patches of snow remain today where they are protected from sublimation by a layer of desiccated dust/sediment.
6. Melting could be occurring at present in favorable locations in these snowpacks.

Christensen [1] provides several photographs of a curious mantling on crater walls in the Dao Valles region located ~33 deg. South by 93 deg. east. He suggests that this mantling (fig. 1) is a remnant snowpack and that several gullies can be seen protruding from this mantling, suggesting that they therefore could be the result of the snowpack snowmelt.

Figure 1. Proposed snowpack in Dao Valles. This is a portion of MOC image M09-2875 and covers an area approx. 2.5x4.0 km. This spot is located at approx. 33.3S, 92.9E. (Malin et al, 2000)

The object of our research is twofold: First to determine whether a mid-latitude poleward slope (such as
the slope in fig. 1) is really cold enough to preserve a snowpack for 74,500 years, and secondly if a snowpack were to survive 74,500 years and suddenly become exposed to current climate conditions whether melting is ever achieved.

**Results:** Our model is a standard thermal model where a surface energy balance is:

\[(1 - A)S = \varepsilon \sigma T^4 - k \frac{\partial T}{\partial z} - AH + SH + L \frac{\partial M}{\partial t}\]

Where \(A\) is surface albedo, \(S\) is the incoming shortwave insolation, \(\varepsilon\) is the IR emissivity of the material, \(T\) is temperature, \(t\) is time, \(z\) is depth, \(k\) is the thermal conductivity of the material, \(L\) is the latent heat of the material and \(M\) is mass of material. \(AH\) is an atmospheric heating term and \(SH\) is the sensible heating term. This equation is then coupled with the general heat conduction equation:

\[\rho C_p(T) \frac{\partial T(t, z)}{\partial t} = \frac{\partial}{\partial z} (k(T) \frac{\partial T(t, z)}{\partial z} + F(t, z))\]

The specific heat capacity term \(C_p(T)\) and the thermal conductivity term \(k(T)\) are allowed to vary with temperature \(T\). The \(F(t, z)\) term is a general heating term that allows for heating within layers. The results of the two research questions addressed in this study are now presented:

**Persistence of a snowpack.** The model was run with both low and high albedo, as well as varying amounts of dust, slope, aspect and angle. Latitude was fixed at -33.0 deg. The snowpack density was fixed at 550 Kg/m3, ambient atmospheric pressure at 8.75 mb and 15 prum of atmospheric water (constant) was included. The results show that if the albedo was as low as 0.21 and the snow contained 1000ppmw dust then a 10m snowpack on the slope in question lasted 4 yrs 75 days. If the albedo was increased to 0.36 and dust decreased to 100ppmw the snowpack lasted 18 yrs 90 days (all Mars years). Model runs for a flat surface indicate that the snowpack lifetime was shortened even further to 3 yrs 111 days and 14 yrs 60 days, respectively. Approximately 74,500 BP the eccentricity was higher (~0.12), but the obliquity has not been higher than the present value (~25.19) for that same time period [5]. However, model runs with this higher eccentricity merely shortened the snowpack lifetime even more. This is expected since higher eccentricity results in more vigorous heating.

**Melting potential of current snowpack.** None of the model runs produced melting of any kind. The highest temperature reached was for a very dusty snow with low albedo (0.21) in which case the highest temperature reached was ~260K.

**Discussion and Conclusion:** Our model runs show that a 10m snowpack deposited 74,500 BP at mid-latitudes on a slope as in fig. 1 would have sublimed very quickly. It is possible that the addition of a radiative transfer component in our model would raise ice temperatures near the surface, perhaps even to the melting point (such as found in the work of Clow [6]). However, if that were to occur then the snowpack would have disappeared even more quickly. Therefore under either scenario an exposed 10m snowpack would never survive for 74,500 years.

There is a scenario where the snowpack could survive: immediate burial by a substantially thick dust lag. Modelling by Mellon et al [7][8] has shown that on a similar slope the snowpack could stay stable if buried by at least 1 m of dust. Such a burial would have to occur very quickly (within a few years of snow deposition) in order for the snowpack to be preserved. However, if lag deposition were to occur quickly (for example, via a slope failure) this would be expected to be a highly localized phenomenon, and probably not extensive enough to blanket large tracts of snowdrifts. In addition, for melting to occur there must also be a rapid exposure of the preserved snowpack. If the snowpack is exposed too gradually, for example by the lag being blown off the snowpack surface, then the snowpack would sublime from beneath the lag.

In sum, a 10m snowdrift on a poleward slope at mid-latitudes, deposited within the last 74,500 years, would have sublimed very quickly unless it was immediately buried by at least 1m of dust. Melting is unlikely to occur in either a buried snowpack or an exposed one. Runoff is even less likely.