The Role of Mid-Latitude Ground Ice in North Polar Layered Deposits Formation.

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Introduction:

The climatic conditions which govern the formation of the North Polar Layered Deposits (NPLD) on Mars are influenced by interactions with vast mid-latitude ground ice deposits. Deciphering the paleoclimate record depends on understanding the behavior of the water sources and how they interact with each other and with the NPLD [1]. Both theoretical and observational work show that shallow subsurface ice is abundant in the mid-high latitudes For example, Haberle [2] showed that subsurface ice affects the seasonal CO_2 cycle by storing heat during summer and releasing it at winter, altering the seasonal cover. The ground ice changes the thermal inertia from ~200 J m^{-2} K^{-1} $s^{-0.5}$ without subsurface ice to ~2000 J m^{-2} K^{-1} $s^{-0.5}$ when ice is present [3] and allowing more heat to be stored. In this work we explore how subsurface ice grows and recedes as function of changes in orbital elements and how it, in turn, affects the NPLD accumulation and chemical composition.

Methods:

Our methods rely on linking two models that simulate aspects of the climate on two timescales— seasonal changes by a global climate model, and millennial changes by an ice evolution model.

1. Global Climate Model (GCM): we use the LMD-GCM to simulate and track the martian water cycle [4, 5]. Ice can precipitate in clouds or condense directly on the surface. The ice cap albedo is set to 0.4 to reproduce TES water vapor distribution. The model's spatial resolution is 64x64 (or 128x128 in select cases) with 28 vertical layers that span 100 km in altitude and 18 layers in the subsurface that span to ~30 m in depth. The dust opacity is set 0.15. Surface ice initially resides in the tropics or in the pole, depending on the orbital configuration and the history. We allow the model run for 7 Mars years to reach steady state.

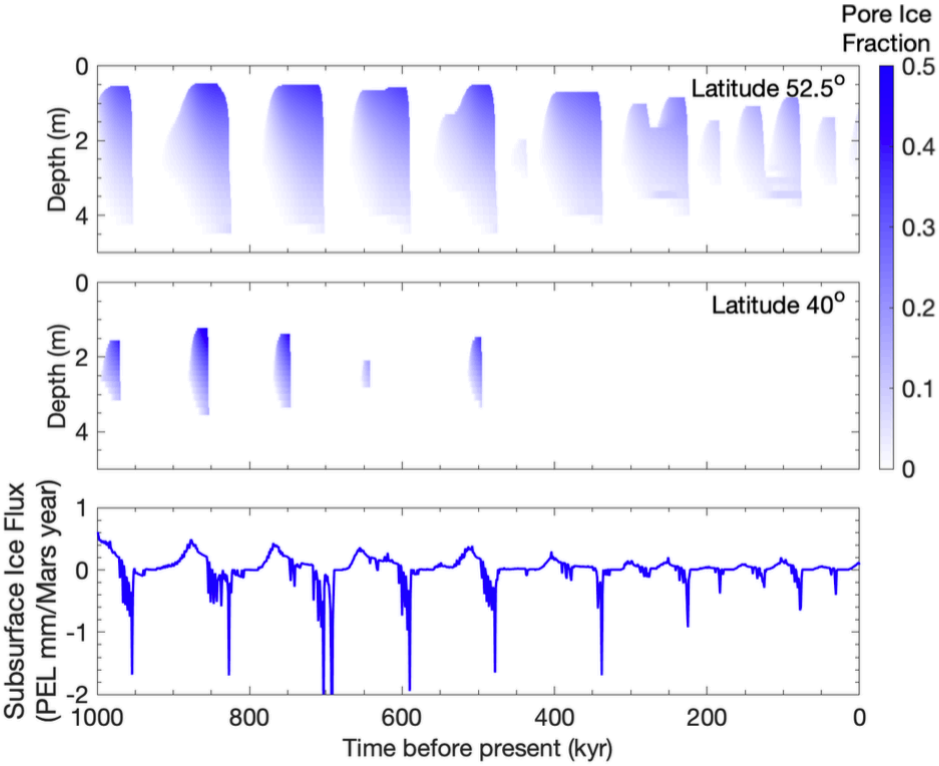

Figure 1: (a) Pore ice evolution over the last million years as predicted by the MSIM model at latitude 52.5°. Note both the obliquity and precession timescales control the ground ice growth and retreat. (b), same as for (a), but at latitude 40°, near the margin the ground ice sheet at past climates. (c) Ice flux into the subsurface integrated from latitudes 40° to 80°. The flux is plotted in units of Polar Equivalent Layer (PEL), that is the equivalent depth of accumulation over an area the size of the current NPLD. For this simulation we assume 40% porosity.

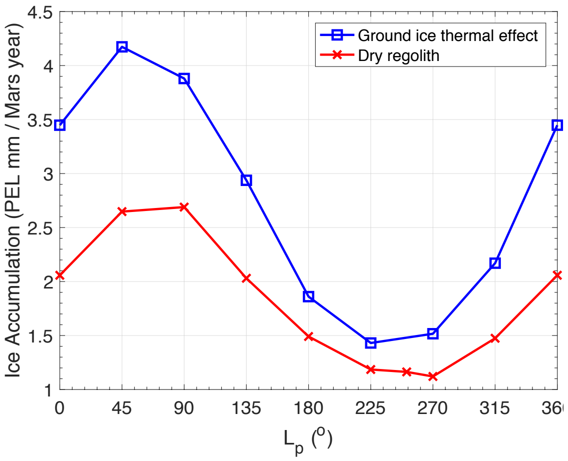

Figure 2: Ice accumulation at the North Pole as a function of L_p, for today's orbital parameters. Note the ~50% decrease in polar accumulation when ground ice is included in the model.

2. Mars Subsurface Ice Model (MSIM): our 1D MSIM model [6] calculates the diffusive flux of vapor and ice deposited at the subsurface over thousands of years, based on near surface humidity and local properties. The relevant inputs are obtained from the GCM runs.

Results:

Subsurface ice can affect the NPLD physical stratigraphy via several mechanisms. It acts as a water source, as well as a heat reservoir altering the energy budget [2]. The subsurface ice could also affect the polar chemical stratigraphy by changing the times and hence condensation temperature at which ice accumulates at the pole or by supplying water molecules with a different isotopic value [1]. We test and quantify these effects as follows. To test if ground-ice acts as a significant source we ran MSIM for the last 4 Myr with changing orbital elements based on Laskar [7]. We track the evolution of the ice (Figure 1a,b), and integrate the subsurface flux over the midlatitudes that participate in the exchange (c). We find the magnitude of the flux to be of order mm's year, comparable to the polar accumulation rates computed in previous work [1, 8].

To isolate the effect of the subsurface ice on the polar accumulation through changes in the thermal balance, we constructed the GCM to have ice in the tropical region and ran simulations with the following orbital elements $\epsilon = 25,\ e = 0.093$ and a range of L_p values, where L_p is the solar longitude at perihelion. We ran two sets of simulations, one with no subsurface ice and one where the thermal inertia in the subsurface was set to mimic the presence of an ice sheet extending from 30° to 80° latitude in both hemispheres at a depth of 5 cm. Figure 2 summarizes the results from both sets of simulations, and shows the presence of a massive ice sheet close to the surface reduces the flux by ~50%. This effect is due to a change in the heat distribution preventing the high latitudes from becoming humid during the summer. Vos [9] showed that the temperature in the northern high latitude summer is a an important determinant of NPLD accumulation when vapor is available from lower latitudes.

Discussion: Our results indicate that the subsurface ice affects the NPLD, acting both as significant vapor source, and altering the accumulation rates due to thermal effects (reduction of ~50%). As noted, the subsurface ice will further affect the chemical stratification of the polar deposits due to various effects [1].

References:

[1] Vos, E., et al. (2019) Icarus, 3241-7. [2] Haberle, R.M., et al. (2008) Planetary and Space Science, 56(2): p. 251-255. [3] Mellon, M.T. and B.M. Jakosky (1993) Journal of Geophysical Research: Planets, 98(E2): p. 3345-3364. [4] Forget, F., et al. (1999) Journal of Geophysical Research: Planets, 104(E10): p. 24155-24175. [5] Montmessin, F., et al. (2004) JGR, 109(E10): p. E10004. [6] Schorghofer, N. (2010) Icarus, 208(2): p. 598-607. [7] Laskar, J., et al. (2004) Icarus, 170(2): p. 343-364. [8] Levrard, B., et al. (2007) JGR, 112(E6): p. E06012. [9] Vos, E., et al (2019) Ninth International Conference on Mars, Abst. 2089