Paleo-evolution of Martian subsurface ice and its role in the polar caps evolution. E. Vos1,2, O. Aharonson2,3, N. Schörghofer3, F. Forget1, L. Lange1, E. Millour1,1 Laboratoire de Météorologie Dynamique/IPSL, CNRS, Paris, France, 2Weizmann Institute of Science, Rehovot, Israel, 3Planetary Science Institute, Tucson, Arizona (Eran.Vos@lmd.ipsl.fr)

Summary: Mars harbors ice deposits on the surface and in the subsurface, which exchange with each other on various timescales. Here, we seek to investigate the SubSurface Ice (SSI) pore-filling evolution over the last few Myr and its role in the polar cap’s evolution. We couple two models, the Mars LMD Planetary Climate Model (PCM) [1], which calculates the atmospheric and surface evolution on short timescales, and the dynamical version of the Mars Subsurface Ice Model (MSIM) [2], which calculates the evolution of the SSI on long timescales. The model result shows that the SSI latitudinal boundary fluctuates over more than 25° and 10° in obliquity and precession cycle, respectively. At locations where the SSI is continuously stable over orbital cycles, we suggest layering caused by a sublimation front at the SSI top boundary. The amount of ice lost from the SSI in the obliquity drop about 5 Myr ago is at least ~95 m of polar equivalent layer (PEL) ice [3].

Introduction: The distribution of the present SSI is observed and calculated using several methods including: The Phoenix lander that removed a few centimeters of regolith to expose stable subsurface ice at latitude 68° [4], the Mars Odyssey Neutron Detector [5], fresh craters [6] and more confirm SSI is present down to latitude 35°. However, models suggest that the present equilibrium SSI is expected at about ±55° [7, 8]. Previous modeling work showed that the SSI distribution changes in response to obliquity and that for higher obliquity, the SSI extended towards the equator [9]. Ice can be emplaced in the subsurface in two ways. First, it may be emplaced as a surface layer that subsequently partially sublimates, leaving behind a lag. Alternatively, it may be directly deposited from atmospheric water vapor in the subsurface pores [10, 11]. Our objectives here are threefold: First, to quantify the evolution of the pore-filling subsurface ice over the last few Myr. Second, to quantify the contribution of the SSI to the NPLD growth. And third, to evaluate the indirect effects of the SSI on the physical and chemical evolution of the PLD.

Methods: We use two models; the first is the Mars PCM [1] with the complete water cycle that includes treatment of surface ice, atmospheric vapor, and ice clouds and has been described in detail previously [12]. We use the PCM to calculate the mean annual atmospheric humidity at each grid cell for different orbital configurations [13]. The choice of parameters is identical to that published in previous work [12]. The second model is the dynamic MSIM [2], which is a 1D thermal-diffusion model for long-term SSI volume changes. MSIM receives as input the humidity and the orbital parameters [13]. The model calculates the time-average sublimation and accumulation rates at every vertical grid point. The thermal properties depend on the ice content and are periodically updated. This asynchronous coupling between a thermal model with a small time step and an ice volume evolution model with a large time step makes integrating over millions of years possible. At each 1 kyr time step, we update the orbital configuration and the humidity at each grid cell and calculate the SSI evolution. We initialized the model 10 Myr ago with pores empty of ice. To simplify the modeling, an assumption is made: subsurface ice is assumed to reside in pore spaces rather than in the form of massive ice. Hence, our model results apply only to the period since the last glaciation. Put differently, the calculated subsurface pore-ice volume changes represent a maximum since massive ice sheets compete with the availability of regolith pore space.

Results: Figure 1 shows the model results for the evolution of the SSI for latitudes 60°, 55°, and 50°N. The ice table’s depth and the depth-dependent pore-filling fraction change with time. Earlier than 4.5 Myr ago, the obliquity was overall higher, the atmosphere was more humid and the mid-latitude SSI was more stable. At high latitudes, where the SSI is stable, the depth of the ice table is several centimeters, and only slightly varies. Closer to the SSI margin, the depth to the ice table increases rapidly to more than a meter and is substantially affected by changes in humidity and orbital configuration. The pore-filling rate at the upper few meters is higher, and the ice fraction shows large variations that mirror the obliquity cycles, except at times when the obliquity is almost constant, from 2.7 to 2.2 Myr ago and from 0.4 Myr ago to the present. At these times, smaller variations in the SSI due to changes in Lp are seen. An interesting feature emerges when the SSI experiences an abrupt increase in the stability depth. For example, just before 3 Myr ago at latitude 60°, the SSI stability depth increases substantially over several kyr. In subsequent time, the orbital configuration allows the SSI to refill the empty pores above ~2 m depth, but a record of the ice-table retreat event appears in the form of a layer of increased ice density which persists for long timescales (> 1 Myr). We suggest that such layering in the SSI can persist and be observable in the high latitudes.
Figure 1: SSI evolution at latitudes 60°N, 55°N, and 50°N.

and, if found, would be a signature of past events of rapid retreat in the ice table.

The extent to which subsurface ice is a significant source of water vapor is an important question for understanding the NPLD growth. Having calculated the evolution of the SSI, we examine its bulk changes that represent its exchangeable volume. In the top panel of Figure 2, we plot this quantity integrated between latitude -80° and 80°. The maximum in the SSI integrated volume over the last 5.5 Myr reaches plus 98 m PEL at periods of high obliquity. The typical SSI flux is < 1 mm/yr PEL. These values are of the same order of magnitude as previous estimates of the NPLD accumulation rate when a tropical source is available [12]. The instantaneous fluxes of ice from the SSI and equatorial surface reservoirs may be comparable. However, the SSI can only contribute ~ 95 m PEL, far from the ~2000 m current height of the NPLD. The rest of the net PLD accumulation must be sourced from reservoirs such as surface or buried glaciers.

The lower panel of Figure 2 shows the power spectrum of the flux for two time windows: 2-1.5 Myr ago, during which the dominant frequency is 120 kyr (obliquity cycle), and 0.5 Myr ago to the present, during which the dominant frequency is 50 kyr (precession cycle), with an amplitude lower in order of magnitude than the earlier window, which now emerges in the absence of obliquity variations [3].