**A 120,000-YEAR SIMULATION OF MARS UNDERGOING AN OBLIQUITY CYCLE UP TO 45° AND BACK** E. Vos[1], F. Forget[1], J.B. Clement[1], L. Lange[1], E. Millour[1], [1] Laboratoire de Météorologie Dynamique/IPSL, CNRS, Paris, France (Eran.Vos@lmd.ipsl.fr)

**Introduction** Mars has several ice deposits; the North Polar Layered Deposits attract the most interest due to many exposures of a stratigraphy of alternating layers[1]. These layers are believed to indicate variations in polar ice/dust accumulation rate [1, 2]. At present, surface ice is stable only in the polar regions. But there are remnants of glaciers in the tropics and mid-latitudes. The NPLD dust-rich layers are formed either at low levels of ice accumulation or by sublimation, leaving behind lag layers[1]. During the last 5 Myr, Mars' obliquity value has varied between 45° and 15° [3], leading to a significant change in insolation and, as a result, migration of ice. Higher obliquity values lead to NPLD loss, while lower values lead to accumulation, given that a source is present [4, 5]. The loss of ice is a function of the atmospheric humidity, ice depth, and the ice temperature (which is a function of the orbital configuration, the albedo, and the thermal inertia [6]). Previous work [7] showed that the atmospheric humidity is controlled by orbital configuration and can change by more than two orders of magnitude between small and large obliquity values [6, 7].

Here, we calculate the migration of ice from (to) the NPLD as the obliquity rises (decreases) for a full obliquity cycle (120 kyr), starting at present-day to 45° and back to 25° using a new approach, asynchronous coupling between the Mars Planetary Climate Model (PCM) [8] and the Planetary Evolution Model (PEM) [9], which smartly extrapolates the tendencies from the PCM.

**Methods** In this work use two models, the first is the PCM [10] which has a time step of several minutes, with the complete water cycle that includes treatment of surface ice, atmospheric vapor, and radiatively active water ice clouds as described in detail previously [10–13]. In addition, we use the subsurface scheme [6] that calculates the interaction between the subsurface ice (SSI) and the atmosphere or surface water frost (if present). The second model we use is the PEM, which smartly extrapolates the tendencies from the PCM with a time step of one year and can run for thousands of years unless it meets one of its stopping criteria [9]. The asynchronous coupling between the models allows us to accurately calculate the changes in the atmosphere-surface interaction using the PCM and extrapolate them for longer times using the PEM until a stopping criterion is met, then we call the PCM again to get new tendencies for the PEM and continue the cycle until the simulation time has reached (in our case 120 kyr). This new approach allows to calculate the migration of ice on orbital timescales without losing the important processes occurring on the diurnal and seasonal timescales.

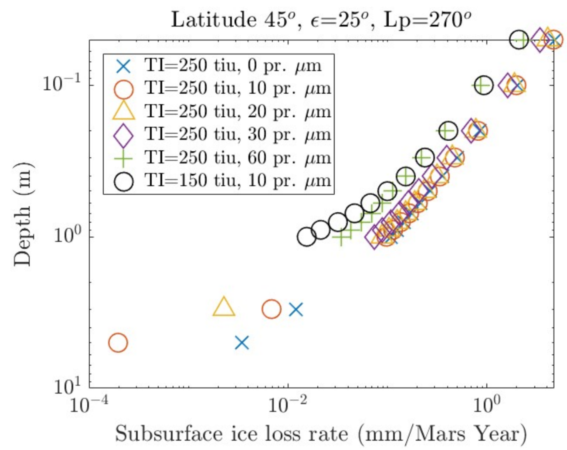


Figure 1: Example of subsurface ice loss rate at 45° N modeled by the 1D PCM as a function of depth and atmospheric humidity and dry-soil thermal inertia, for present-day obliquity and eccentricity, and $L_p$ of 270°.

**Results** We wish to run a long, 120 kyr, simulation of ice migration as the orbital elements evolve. So far, studies that used a GCM to calculate the long-term migration of ice have assumed that the ice is placed on the surface, leading to much larger loss rates, or reduced the flux based on parameterization, which gives inaccurate results [2, 4]. Here, due to our latest model developments of the subsurface ice scheme [6] in the PCM we can accurately calculate the loss of ice as it get buried. Figure 1 shows the subsurface ice loss rate at 45° N modeled by the 1D PCM as a function of depth and atmospheric humidity. The SSI loss rate at a depth of 5 cm for present-like configuration is ~4.5 mm/Mars Year (MY). There is a strong decrease in flux for greater depths and larger atmospheric water content; a lower surface thermal inertia value also results in a smaller loss rate. 30 centimeters of burial depth is enough to decrease the flux below 1 mm/MY, even for low atmospheric content.

At the conference, we will show the results from our 3D simulations of the migration of ice for a full obliquity cycle starting at present-day, going to 45° and back to 25°. We could also see the thickness of the lag layers that are growing at different locations as obliquity evolves and compare it to observations.

**References:** **[1]** Hvidberg, C. *et al.* Reading the climate record of the martian polar layered deposits. *Icarus* **221,** 405–419 (2012). **[2]** Vos, E., Aharonson, O. & Schorghofer, N. *Icarus* **324,** 1–7 (2019). **[3]** Laskar, J. *et al. Astron. Astrophys.* **428,** 261–285 (2004). **[4]** Levrard, B., Forget, F., Montmessin, F. & Laskar, J. *J. Geophys. Res. Planets* **112** (2007). **[5]** Vos, E. *et al.* Stratigraphic and Isotopic Evolution of the Martian Polar Caps From Paleo-Climate Models. *J. Geophys. Res. Planets* **127,** e2021JE007115 (2022). **[6]** Vos, E., Forget, F., Clément, J.-B., Lange, L. & Millour, E. The Martian Mid-Latitude Subsurface Ice is the remnant of a past ice sheet. **[7]** Et al., E. V. Paleo-evolution of martian subsurface ice and its role in the polar physical and isotopic layering. *J. Geophys. Res. Planets* (2023). **[8]** Forget, F. *et al. J. Geophys. Res. Planets* **104** (1999). **[9]** Clément, J.-B. *et al. A New Long-Term Planetary Evolution Model to Simulate the Formation of Polar Layered Deposits on Mars* in *8th International Conference on Mars Polar Science and Exploration* (2024), LPI–Contribution. **[10]** Forget, F. *et al.* Improved general circulation models of the Martian atmosphere from the surface to above 80 km. *J. Geophys. Res. Planets* **104** (1999). **[11]** Madeleine, J.-B. *et al.* Recent Ice Ages on Mars: The role of radiatively active clouds and cloud microphysics. *Geophys. Res. Lett.* **41,** 4873–4879 (2014). **[12]** Navarro, T. *et al.* Global climate modeling of the Martian water cycle with improved microphysics and radiatively active water ice clouds. *Journal of Geophysical Research: Planets* **119,** 1479–1495 (2014). **[13]** Naar, J. *et al. Recent ice ages on Mars by destabilization of the Northern Polar Cap at 35° obliquity* in *EGU General Assembly 2024* (2024), EGU24–10784.