**DISCOVERY OF BURIED PERENNIAL ICE AT LOW LATITUDES ON MARS.** M. Vincendon[1], J. Mustard[1], F. Forget[2], M. Kreslavsky[3], A. Spiga[4], S. Murchie[5], J.-P. Bibring[6], [1]Department of Geological Sciences, Brown University, Providence, RI, USA. (mathieu_vincendon@brown.edu) [2]Laboratoire de Météorologie Dynamique, Université Paris 6, Paris, France. [3]Earth and Planetary Sciences, University of California - Santa Cruz, CA, USA. [6]Department of Physics & Astronomy, Open University, Milton Keynes, UK [5]Johns Hopkins University/Applied Physics Laboratory, Maryland, U.S.A. [6]Institut d'Astrophysique Spatiale, Université Paris Sud, Orsay, France.

**Introduction:** Perennial water ice has been observed on Mars as exposed polar cap, continuous permafrost down to 60° latitude and more sporadic occurrence of permafrost or buried glaciers down to 40° latitude [e.g. 1, 2, 3, 4]. At lower latitudes, geomorphologies implying the past presence of ice have been reported [e.g., 5, 6]. This ice could be still locally preserved today, in agreement with modeling predictions of subsurface temperatures below pole facing slopes [7]. It is however not possible yet to directly detect these potential perennial water ice reservoirs. First, ice is not stable through the entire year if exposed at those latitudes, which prevents direct observation by near-IR imaging systems such as OMEGA and CRISM. Second, the vertical resolution of radar sounding systems such as MARSIS or SHARAD (10 m for the latter) is too low for shallow subsurface ice. Third, the spatial resolution of neutron or gamma ray measurements by MARS ODYSSEY instruments is too low (100s of km) to resolve these deposits. Finally, the restricted number of possible deposits dramatically reduces the probability of recent crater impact observation by HIRISE.

**Methodology:** The presence of ice in the shallow subsurface strongly increases its thermal inertia, which significantly impacts surface temperatures [8, 9]. Surface temperatures then modify the capability of gaseous species ($CO_2$ and $H_2O$) to condense. In this work, we study the distribution of seasonal ice at low to mid-latitudes using OMEGA and CRISM. We then analyze these observations within the framework of a new modeling approach developed from the global circulation model of the LMD [10]. Comparison between modeling predictions and observations are used to study the properties of the subsurface and reach conclusions about the distribution of subsurface ice.

**Observations:** The OMEGA and CRISM dataset are probed to highlight occurrences of surface ice equatorward of 45°S and 50°N (the approximate limits of the seasonal caps), where ice is observed on pole-facing slopes only [11, 12]. The ice thickness detection limit (or grain size as we are sensitive to photon path length in spectroscopy) is a few tens of microns for $CO_2$ ice and a few microns only for $H_2O$, but for the latter clouds complicate surface ice detectability. OMEGA and CRISM have been observing Mars for about 3 and 1.5 Mars years respectively, providing a detailed spatial and temporal coverage of mid-latitudes. $H_2O$ and $CO_2$ frost can be mapped as a function of $L_S$ with limited observational bias (Fig. 1). Ice is observed in local fall and winter. $H_2O$ is detected poleward of 13°S and 32°N, while $CO_2$ is observed in the southern hemisphere only, down to 34°S (Fig. 2).

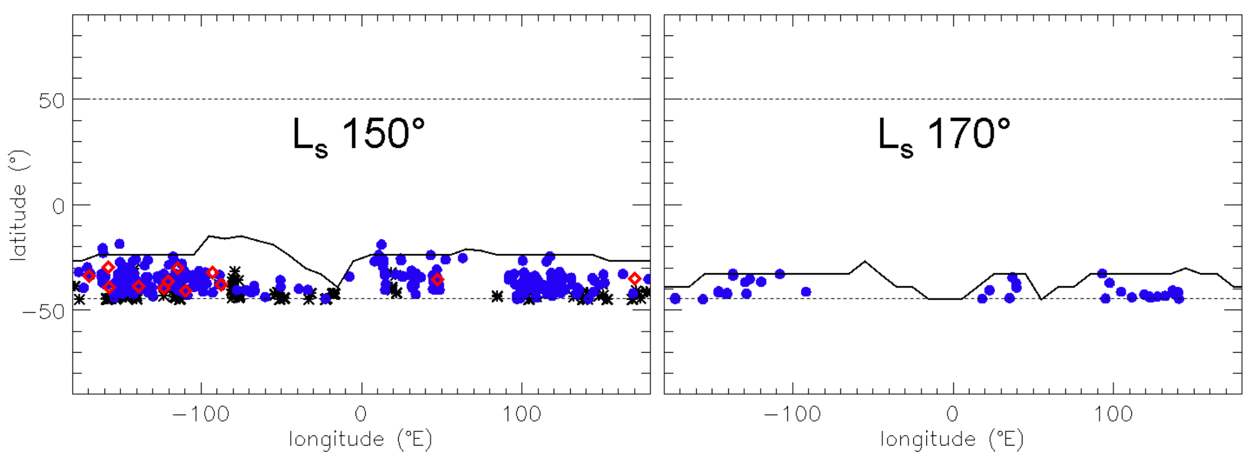


*Figure 1: Examples of maps of seasonal water frost detections by OMEGA (black stars) and CRISM (blue dots and red diamonds, low and high spatial resolution modes respectively). We looked for ice between 50°N and 45°S only (dotted lines). Two periods are shown: $L_S$ 150° ± 10° and $L_S$ 170° ± 10° (southern winter). The equatorward limit of frost stability predicted by our model is shown with a solid line. It corresponds to the limit on a steep slope (30°) with average surface properties. A good agreement is observed between model predictions and observations.*

**Model:** We use a local 1D energy balance code derived from the LMD GCM to model the seasonal condensation of $CO_2$ and $H_2O$ ice on pole facing slopes. While $CO_2$ is always largely available in the martian atmosphere, the amount of water vapor is low and depends on location and season. It has therefore been necessary to develop a new modeling approach for $H_2O$ by coupling the 1D code with outputs (amount of water vapor / water ice precipitations) from the 3D version of the GCM.

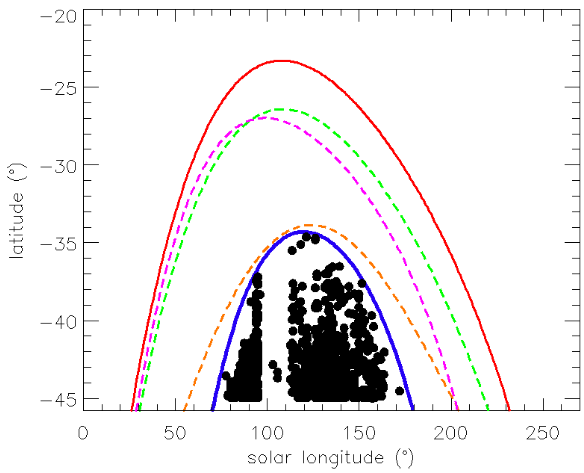


*Figure 2: Latitude / season diagram of observed $CO_2$ ice deposits (black dots) and model prediction of the ice stability limit for various hypotheses (lines). The model result with the basic parameterization of the GCM is shown in red line (the stability limit is over-predicted). Predictions for a very high aerosols loading (winter optical depth of 0.5) or a very dark ice (albedo of 0.25) are shown in green and purple dashed lines respectively. The only way to obtain a good model fit is to use a high surface/subsurface thermal inertia: the dashed orange line corresponds to a single layer with $I = 1180\ kgK^{-1}s^{-5/2}$; the thick blue line corresponds to a subsurface water ice layer (I = 2120) covered by a dry regolith layer (I = 250) with a latitude dependent thickness (6 cm at 45°S, 13 cm at 35°S).*

**Discussion and Conclusion:** The predicted formation of $H_2O$ ice as a function of time and place is in good agreement with observations (Fig. 1). On the contrary, a strong mismatch was initially obtained for $CO_2$ in the southern hemisphere (Fig. 2). Contrarily to $H_2O$ ice, $CO_2$ ice is strongly sensitive to subsurface thermal properties. A detailed analysis of modeling assumptions and parameters uncertainties show that subsurface water ice is required on pole facing slopes (Fig. 2). Water ice needs to be present within the first meter of the subsurface down to about 25° latitude (Fig. 3). Our study provides the first observational evidence for perennial subsurface ice that could be linked with previous ice ages equatorward of 40° latitude. This result is of significance for the future robotic and human exploration of Mars, as it put the prospect for perennial water ice at low latitudes where mild conditions are.

**References:** [1] Kieffer, H. H. et al. (1976), *Science*, 194, 1341-1344. [2] Mellon, M. T. et al. (2004), *Icarus*, 169, 324–340. [3] Plaut, J. J. et al. (2009), Geophys. Res. Lett., 36, L02203. [4] Byrne, S., et al. (2009), *Science*, 325, 1674-167. [5] Mustard, J. F. et al. (2001), *Nature*, 412, 411–414. [6] Head, J. W. et al. (2003), *Nature*, 426, 797–802. [7] Aharonson, O., and N. Schorghofer (2006), *J. Geophys. Res.*, 111, E11007. [8] Haberle, R. M. et al. (2008), *Planet. Space Sci.*, 56, 251-255. [9] Bandfield, J. L. and W. C. Feldman, W. C. (2008), *J. Geophys. Res.*, 113, E08001. [10] Forget F., et al. (1999), *J. Geophys. Res.*, 104, 24155–24176. [11] Schorghofer, N. and K. S. Edgett (2006), *Icarus*, 180, 321–334. [12] Carrozzo, F. G. et al. (2009), Icarus, 203, 406–420.

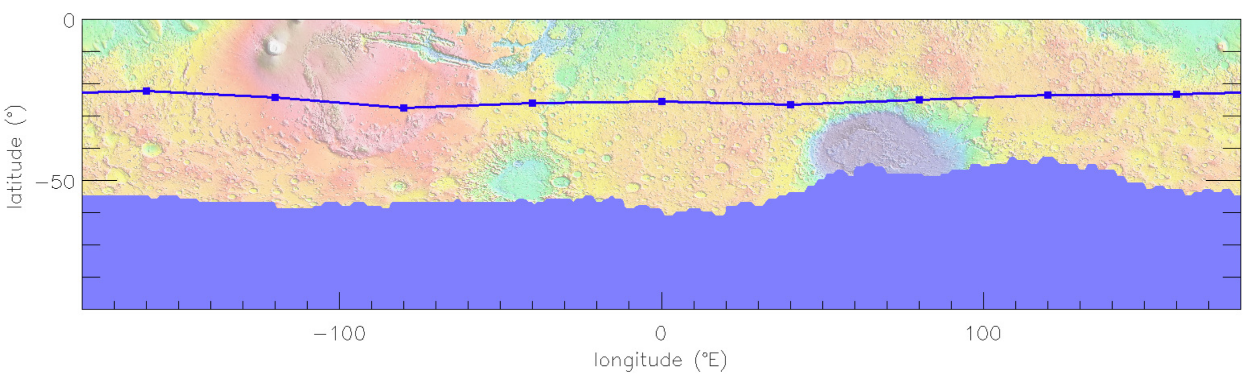


*Figure 3: Map of subsurface water ice in the southern hemisphere. The blue-filled area is from [2] (Mars Odyssey) and corresponds to flat surfaces. Our derived local limit for pole facing slopes is shown as a blue line (about 25°S).*