

A GCM RECENT HISTORY OF NORTHERN MARTIAN POLAR LAYERED DEPOSITS: CONTRIBUTION FROM PAST EQUATORIAL ICE RESERVOIRS. B. Levrard^{1,2}, F. Forget³, J. Laskar¹ and F. Montmessin⁴, ¹Astronomie et Systèmes Dynamiques, IMCCE UMR 8028, Observatoire de Paris, 77 Avenue Denfert-Rochereau, 75014 Paris, blevrard@imcce.fr ²Laboratoire des Sciences de la Terre, UCBL1/ENS Lyon UMR 5570, 43 boulevard du 11 Novembre 1918, 69622 Villeurbanne Cedex, blevrard@ens-lyon.fr, ³Laboratoire de Météorologie Dynamique, IPSL, Paris VI, 4 place Jussieu, 75005 Paris, francois.forget@lmd.jussieu.fr; ⁴ NASA Space Science Division MS 245-3, NASA/Ames Research Center, Mofett Field, California, 94035, USA.

Introduction: Polar layered deposits are exposed in the walls of the troughs cutting the north polar cap of Mars. They consist of alternating ice and dust layers or layers of an ice-dust mixture with varying proportions and are found throughout the cap. Layers thickness ranges from meters to several tens of meters with a ~ 30 meter dominant wavelength [1,2]. Although their formation processes is not known, they are presumed to reflect changes in ice and dust stability over orbital and axial variations. Intensive 3-D LMD GCM simulations of the martian water cycle have been thus performed to determine the annual rates of exchange of surface ice between the northern cap and tropical areas for a wide range of obliquity and orbital parameters values. These rates have been employed to reconstruct an history of the northern cap and test simple models of dust-ice layers formation over the last 10 Ma orbital variations.

Model description: We use the 3-D water cycle model simulated by the 3-D LMD GCM [3,4] with an intermediate grid resolution (7.5° longitude x 5.625° latitude) and 25 vertical levels. The dust opacity is constant and set to 0,15. No exchange of ice with regolith is allowed. The evolution of the northern cap over obliquity and orbital changes (eccentricity, Longitude of perihelion) has been recently described with this model in [5,6]. High summer insolation favors transfer of ice from the northern pole to the Tharsis and Olympus Montes, while at low obliquity, unstable equatorial ice is redeposited in high-latitude and polar areas of both hemisphere. The disappearance of the equatorial ice reservoir leads to a poleward recession of icy high-latitude reservoirs, providing an additional source for the cap accumulation during each obliquity or orbital cycle. Furthering the efforts in [5], a quantitative evolution of ice reservoirs is here investigated for various astronomical conditions.

Polar ice annual loss rates (PIALR): the sensitivity of the annual polar ice rates has been determined from 12 equilibrated simulations at various obliquities and orbital parameters leading to an unstable northern cap [5]. Because the most intense cap sublimation occurs at the beginning of the summer when the permanent

cap is exposed, we expect that the summer solstice insolation is, at first order, a good forcing function for the (PIALR) variations. However, high summer insolation correspond to shorter summers (summer solstice at perihelion, for example). We found that, at first order, the summer solstice insolation divided by the martian orbital speed at summer solstice is well correlated with the PIALR. Fig.1 illustrates the marked exponential correlation between the PIALR and this new insolation forcing [7].

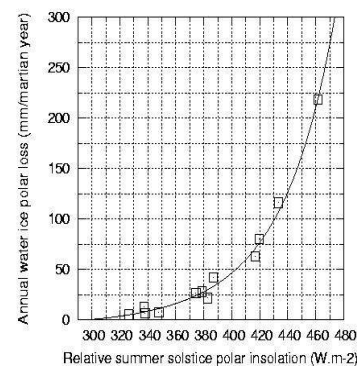


Figure 1: Correlation between the PIALR and the modified summer solstice insolation. The best least-square fit (solid line) exhibits a critical insolation close to 300 W.m^{-2} above which the northern cap becomes unstable.

Polar ice annual accumulation rates (PIAAR): Below the critical insolation, equatorial ice reservoirs become unstable. The PIAAR have been determined from 6 equilibrated simulations for various obliquities (30° , 25.19° , 20° and 15°) and extreme orbital configurations ($e=0$ and $e=0.0934$ with $L_p=90^\circ$ and $L_p=270^\circ$). Interestingly, the PIAAR have been found nearly insensitive to obliquity and orbital changes and range between 1.4 and 2.0 mm/yr for decreasing obliquities. These rates appear also insensitive to the equatorial reservoir size. This can be explained by the fact that, in these conditions, most of the equatorial ice is deposited first in high-latitude areas. In this context, the PIAAR have been considered as a simple function of the obliquity.

Recent Evolution of the Northern polar cap:

Considering the previous annual accumulation/loss ice rates, the thickness of the polar cap has been computed over the recent 10 Ma insolation and obliquity changes [8] with a 500 yr step. For each orbital condition, the accumulation/loss rate is interpolated from the PIAAR and PIALR values. The evolution of the surface reservoir has been divided in three budgetary elements shown in Fig.2. The evolution of the tropical water (30°S-30°N) has been determined from the previous simulations and interpolated for an arbitrary orbital condition. The exchange between the high-latitude reservoirs and the tropical budget is determined to ensure the global ice mass conservation at each step.

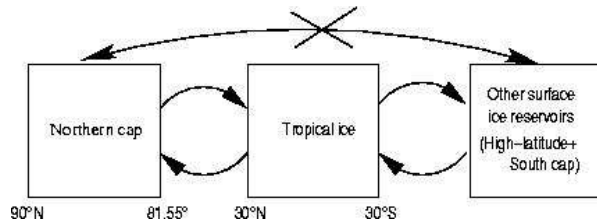


Figure 2: Cartoon illustrating the three-box surface ice reservoirs considered. No exchange is allowed between the Other Surface Ice Reservoirs (OSIR) and the northern cap although this exchange is possible when the equatorial reservoir disappears. This choice allows to detect the occurrence of these periods.

Influence of a dust lag deposit: A common presumption is that polar water ice contains a small fraction of dust, which could form a thick lag deposit protecting deeper ice deposits from further sublimation at higher insolation periods. To incorporate a such mechanism, we considered that, when a thickness H of ice has sublimed, the PIALR are reduced by a factor f .

In our standard model, characteristic values $H=10$ m and $f=10$ have been used. However, the total dust thickness is not predicted by our model.

Results: An exemple of the evolution of the surface ice reservoirs is shown in Fig.3, starting with a current 3 km-thickness northern cap. In this case, polar ice rapidly goes to the equator in the high mean-insolation period (5-10 Ma ago) and the onset of the polar cap begins around 4 Ma during the transition towards a lower mean-insolation period (0-5 Ma). As predicted in [5], high-latitudes deposits could have been formed during this transition, when the equatorial reservoir progressively disappears. We predict that a maximal global equivalent layer (GEL) of 100 m could have been deposited in high-latitude areas. After this transition, the northern cap grows without major erosional periods and each "oscillation" corresponds to the formation of a dust-ice layer.

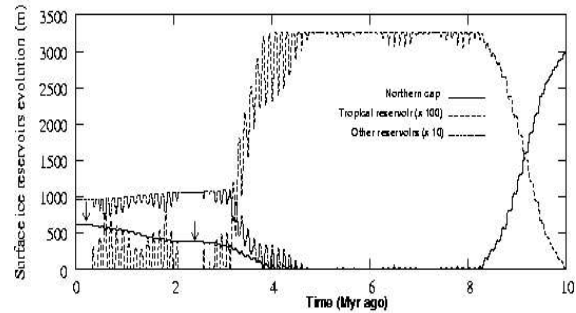


Figure 3: Evolution of the surface ice reservoirs thickness following the three-box cartoon described in Fig.2 and for our standard dust lag model. The thickness indicates the equivalent ice thickness uniformly distributed on the whole surface of the reservoir. For more clarity, the ice thicknesses of the tropical reservoir and of the OSIR have been multiplied respectively by 100 and 10.

About 620 meters of ice accumulates from the equatorial ice reservoir. A statistical analysis shows that this corresponds to the formation of 27 ice-layer with a 22.0 m averaged thickness and a 13.8 m standard deviation. These properties are not changed for moderate changes in H and f parameters. This is very close to the thickness observed in polar layering [2,8]. No accumulation of polar ice from equatorial ice occurs during the recent low-amplitude obliquity variations (0-500 ka and around 2.5 Ma ago), while transient equatorial reservoirs are predicted during the recent summer insolation peaks (0.5-2.2 Ma).

Discussion: Our standar model suggests that most of the present northern cap thickness does not come from the contribution of past equatorial ice reservoirs, but more likely from the poleward recession of northern icy high-latitude deposits during the intervals (0-500 ka and around 2.5 Ma). This has to be compared to geological observations. However, other surface (South polar cap) or subsurface (regolith) ice reservoirs may have participated in its formation.

Critical insolation values are also probably very sensitive to surface (polar albedo, thermal inertia) and atmospheric properties (atmospheric dust content, CO₂ pressure..) and must be investigated in details. This could significantly changes the surface ice reservoirs history.

References:[1] Howard, A.D et al. (1982), *Icarus*, 50, 161-215. [2] Milkovich, S.M and Head, J.W (2004) *LPSC*, 35, 1342 [3] Forget, F. et al. (1999) *JGR*, 24,24155-24176,[4] Montmessin, F. et al. (2004) *JGR*, 109. [5] Levrard, B et al. (2004), *Nature*, 431, 1072-1075.[6] Montmessin, F. et al. (2004) *LPSC*, 34 [7] Levrard, B et al. (2005), *GRL*, in preparation.[8] Laskar, J. et al. (2002), *Nature*, 419, 375-377.