SPECULATIONS ON ORBITAL FORCING OF SUBLIMATION FROM THE POLAR CAPS M. H. Hecht, Jet Propulsion Laboratory, California Institute of Technology (michael.h.hecht@jpl.nasa.gov)

Introduction: Calculation of the periodic variations in the martian orbital parameters by Ward [1] and subsequent refinements to the theory [2,3] have inspired numerous models of variation of the martian water cycle. The limitations of models such as this can not be overstated. Albedo, for example, has a much greater influence on temperature than orbital forcing, and seems to be linked to insolation, possibly via its influence on dust transport [4]. To make further progress, either new constraints must be identified, or additional clues must be obtained from remote sensing and *in situ* exploration.

The MGS and Odyssey missions have provided us with several such critical pieces of information. The discovery of what can only be described as an ice sheet underlying a lag deposit over enormous areas of both hemispheres is one such clue [5], along with indications from surface features of recent, wide-scale modification by water [6]. Another is the observation of mantling of gullied slopes, presumably a vestigial layer of frost and snow protected by a similar lag deposit [7]. More speculative, perhaps, are suggestions from analysis of MOLA data of a net seasonal increase in thickness of the northern cap [8], or correlation of PLD structures with orbital variations dominated by precession of the L_s of perihelion [3]. Speculative implications of these new data are summarized in the sections below.

Critical oscillations: Most orbital forcing models have focused on variations in planetary obliquity (on both a short-term, 110 kyr time scale and larger oscillations occurring over millions of years) [9-11]. The fastest mode of variation, perihelion precession, has generally been deemphasized because it does not change the integrated annual insolation. But as a result of this precession, the asymmetry in peak summer insolation between the poles exceeds 50% today, with the maximum cycling between poles every 25.5 kyrs. Variations in planetary eccentricity also play a role, defining the magnitude of the excursions associated with this perihelion precession.

Fanale, for example, concluded that precession of the longitude of perihelion may be sufficient to increase water removal from the poles by factors of 50-100 [9]. He calculated the peak vapor pressure at the North Pole by assuming a surface of pure water ice or CO_2 ice with distinct optical properties, incorporating only radiative balance and latent heat of CO_2 deposition. It was further assumed that the zonal humidity was proportional to that peak water vapor, which was in turn a simple function of the ice surface temperature. This assumption is reasonable because the energy deposited as sunlight into the polar cap must ultimately be accommodated in the form of sublimation. If advection or vertical transport is insufficient to remove the generated water vapor, for example, it will recondense as fog, pumping heat into the atmosphere and either generating convective currents or increasing the saturation vapor pressure.

Figure 1 shows the results of calculations using a protocol similar to Fanale's, but with the critical addition of tracking latent heat of water condensation and sublimation. All three curves represent an extrapolation back only 150 kyrs. Rather than extrapolating back far enough to reflect large changes in obliquity, the obliquity was forced to specific values. Thus one curve represents the calculated obliquity, a second holds the obliquity at the current value of 25°, and the third holds the obliquity at 40°. The data is expressed in terms of the amount of heat from insolation that is converted to sublimation under these circumstances. It can be seen that, at constant obliquity, the sublimation rate can increase by a factor of 100 with the passage of only 20 kyrs. Changing the obliquity from 25° to 40° adds another factor of only approximately 5.

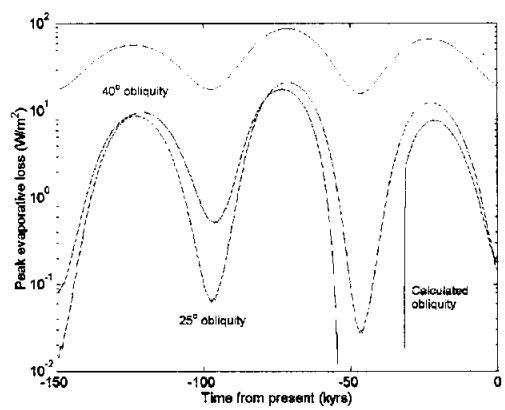


Figure 1: Calculated peak evaporative loss at the North Pole of Mars, expressed as an evaporative heat measure over 150,000 years. The calculation balances radiation, latent heat of CO_2 and H_2O, and insolation using orbital parameters from Ward [1], albedo and emissivity values suggested by Fanale et al [9]. To show the relative effect of precession and obliquity, the three curves represent calculated obliquity and obliquity fixed at 25° or 40°.

Lag deposits and ice cap evolution: Odyssey results suggest that the vast majority of ice on Mars is sequestered beneath either a lag deposit of dust or a buffer layer of CO_2. The reason for this seems straightforward – the water table will retreat to a depth such that the annual thermal wave does not result in temperatures above the dewpoint [12]. In other words, the boundary of the cryosphere will tend to adiabatically adjust to the changing heat balance. The southern hemisphere is currently favored by summer perihelion, and not surprisingly exposed water is scarce. To the extent that cap evolution can track climate change, the boundary of the exposed northern polar cap would represent the latitude above which the surface temperature doesn't exceed the frostpoint.

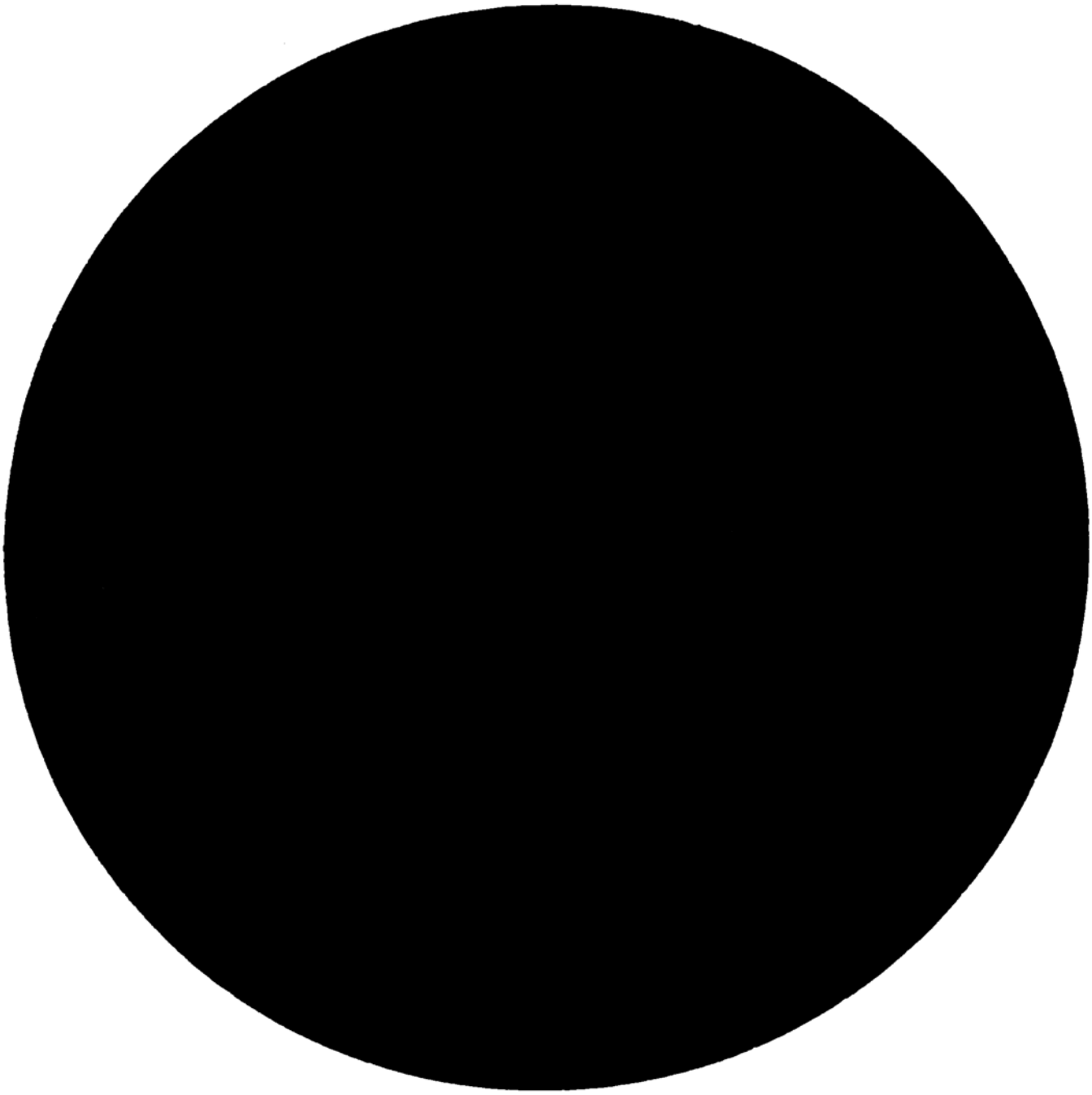
The appearance of the PLD and the apparent high resurfacing rates of the cap itself [13] suggest that the age of the cap isn't geologically great. There are few polar features suggestive of flow, implying that the cap periodically retreats by other processes, presumably sublimation and transport to lower latitudes or the opposing hemisphere. The time scale for disappearance and reconstruction of the cap has never been resolved, but could range from many millions of years to the rapid 51,000 year cycle of precession.

As the northern hemisphere warms up due to orbital precession, two things may occur. The boundaries of the cap may be encouraged to retreat to higher latitude, and measurable amounts of water may be seasonally removed from the polar cap. If formation of a lag deposit halts the surface erosion of the cap, then further erosion may be limited to the scarps and slopes at the edges of the cap, effectively eroding the cap from the outside. Only by vigorous removal on the perimeter, where gravitational forces remove the residue, could the cap be substantially modified on the timescale suggested by the geological record. Supporting such a view is the observation that as ice sublimates, surface facets will tend to grow normal to the sun direction, maximizing further erosion [14]. We might imagine, therefore, that as the summers become hotter in the north over the next 20,000 years, the diameter of the northern cap will become smaller, with material being vigorously removed from the edges and redeposited on top. Indeed, if the net increase in thickness of the cap suggested by the MOLA data were verified, it would not be inconsistent with such a mechanism. It is also not unreasonable that the cap would bifurcate into two regions – a high latitude, actively growing region with thermally stable exposed ice, and a lower latitude region with suppressed growth, where a lag deposit protects the ice from further erosion.

Conclusions: Models of peak seasonal sublimation from the north polar cap suggest that the important cycle of water injection may be 25.5 or 51 kyrs, depending on whether one or two poles are involved. If the process is limited by hemispheric depletion of available dust-free water, the result may be periodic pulses of water injection. The tendency of the surface to form lag deposits above ice layers is consistent with an equilibrium water table determined by the frostpoint. As temperatures warm, this stability level will retreat below the surface at higher latitudes, encouraging polar cap retreat. The ability of the cap to shrink from the surface may also be limited by lag formation, suggesting that the cap grows and shrinks from the perimeter, with the sublimed material being transported from perimeter to top surface. Favorable geometries with respect to the sun would make this an efficient form of water transport.

References: [1] Ward W.R. (1974), *J. Geophys. Res. 79*, 3375-3386. [2] Laskar J. (1990), *Icarus 88*, 266-291. [3] Laskar J., Levrard B., Mustard J.F. (2002), *Nature 419*, 375-377. [4] Kieffer H.H., Zent A.P. (1992), in *Mars*, ed. H. H. Kieffer et al., 1180-1218. [5] Boynton, W. et al. (2002), *Science* **297** 81-85. [6] Kreslavsky M. and Head J. (2000), JGR 105, 26695. [7] Christensen P.R. (2002), *Nature* ***422***, 45-48. [8] Smith, D. E., M. T. Zuber, G. A. Neumann (2001), *Science* **294**, 2141. [9] Fanale F.P. et al. (1986), *Icarus 67*, 1-18. [10] Carr, M.H. (1982), *Icarus 50*, 129-139. [11] Hecht M. H. (2002), *Icarus 156*, 373-386. [12] Leighton R.B., Murray B.C. [1966], *Science 153* 136-144 [13] Herkenhoff, K. E. and J. J. Plaut (2000), *Icarus* **144**, 243-253. [14] Ingersoll A.P., Svitek T., Murray B.C. (1992), *Icarus 100*, 40-47.

Acknowledgements: This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under ~~funding from NASA.~~ a contract with the National Aeronautics and Space Administration. Useful discussions with Frank Carsey are greatly appreciated.

Remove or Correct wording

End of File