**LATE NOACHIAN ICY HIGHLANDS: SCENARIOS FOR TOP-DOWN MELTING AND VOLUMES OF MELTWATER.** James L. Fastook[1] and James W. Head[2], [1]University of Maine, Orono, ME 04469, fastook@maine.edu, [2]Brown University, Providence, RI 02912.

**Introduction**: Given reasonable supply limits on the amount of water available to grow Late Noachian Icy Highland (LNIH) ice sheets under a lapse-rate-dominated climate with an ice-stability elevation predicted by GCM results for a denser Martian atmosphere, ice sheets are found to be exclusively cold-based [**1**], incapable of producing the large volumes of liquid water from either basal or surface melting that would be necessary to form the fluvial (valley networks) and lacustrine (open-basin lakes - OBL) features and deposits known to have existed in this region. We investigate how such water might be released by short-lived top-down climatic warmings due to large meteor impacts (e.g., [**2**]) or periods of intense volcanism (e.g., [**3**]). For the minimum estimate of the magnitude of meltwater required, we assume that all the OBLs were filled simultaneously, and adopt as our target the total volume of all of the filled OBLs measured by [**4**], ~0.42 $Mkm^3$, a value less than 10% of the current (1X) surface/near-surface ice volume [**5**].

**Results:** Short-lived warmings are handled through our relatively simple climate parameterization, where a shift in the base temperature produces a uniform shift of the global temperature field. At the same time, the mass balance as a function of elevation is modified by a combination of a specified lapse rate (2.4 K/km) and a positive-degree-day calculation [**6,7**] of 1.08 mm/PDD.

Our transient event is represented by a 2000 year sinusoidally-varied base temperature, begun after 1 million years of steady growth for the 5X supply, 55 $mW/m^2$ case, with warming amplitudes ranging from +10 to +19 K. The temporal variation of the base temperature is shown in Figure 1a.

We assess separately the response to the shift of the sublimation-dominated ice stability line and to the melting-dominated PDD calculation. Response to the shift of the ISL is immediate for any warming, since we raise the ISL by ~400 m/K of warming, but, because sublimation is capped at 5 mm/yr, once the ISL is above the highest terrain, the rate of loss reaches a plateau. This is apparent in Figure 1b showing the volume response for warmings of 10 to 19 K. During the warming event the loss due to raising the ISL ranges from 0.17 $Mkm^3$ for +10 K to 0.23 $Mkm^3$ for +19 K, presumably due to sublimation in the now larger ablation region.

Since the PDD calculation does not produce any melting until the warmest point on the ice sheet is within half the seasonal amplitude (40 K, from [**8**]) of the melting point, the volume change for the PDD calculation only, shown in Figure 1c, displays no loss for +10 and +12, and only 5.4 X $10^{-3}$ $Mkm^3$ for +14 K. A warming of +16 K begins to show an effect (0.06 $Mkm^3$), but only at a value of +17 K warmer is the effect comparable to the effect of shifting the ISL by a similar amount (0.17 $Mkm^3$). However, once the mean annual temperature of a significant number of ice sheet points are within half the seasonal amplitude of the melting point, mass loss by melting accelerates rapidly, with +18 and +19 yielding melt amounts of 0.45 and 0.99 $Mkm^3$.

Figure 1d shows volumes with both effects active, suggesting that there is no synergy in their combination. Our assumption is that the shifting ISL increases the area of mass loss by sublimation, whereas the PDD calculation of melting reflects the amount of liquid water released onto the landscape. With our minimum target volume of ~0.42 $Mkm^3$ [**4**], we conclude that a 2000 year transient warming of approximately +18 K would release sufficient meltwater to fill all of the open-basin lakes. **[3]** have shown that episodic warming of a LNIH climate by punctuated volcanism could raise the global mean annual temperature by 26 K, clearly bringing the lower latitudes to temperatures exceeding 273 K for several months of the year.

Given the uncertainty in the duration of climate warming due to meteor impacts or volcanic eruptions, climatic events with a 2000-year duration may not be

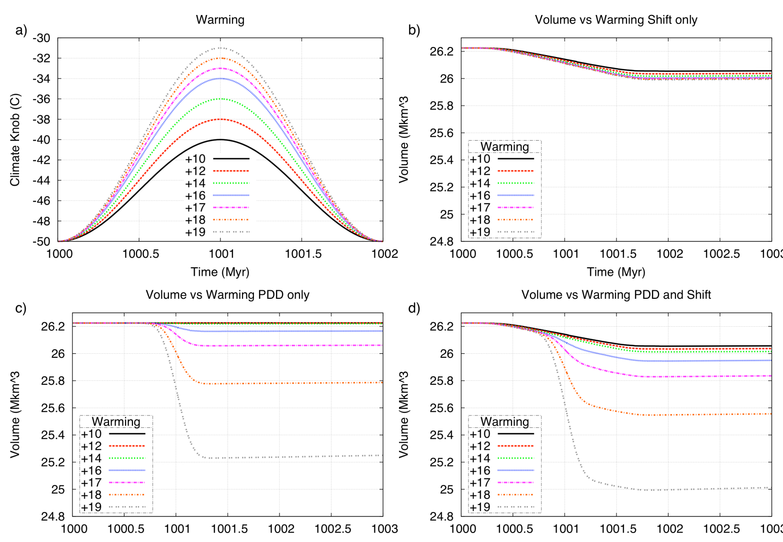


Figure 1: a) Temporal variation of base temperature, b) raising the ISL only, c) PDD melting only, d) combined effect of both.

typical. We thus investigate the amount of melting one might obtain from a single-year melting event. This value can be used as a baseline for assessing the plausibility of durations of warming derived from other perspectives to account for the observed fluvial and lacustrine features. Extracting and calculating temperature from our parameterization for all points above the 1000 m ISL, we impose various degrees of warming by offsetting the base temperature in the parameterization. We apply a seasonal swing of 40 K, similar to the magnitude seen in the McMurdo Dry Valleys, where the mean annual temperature is 253 K and where seasonal melting is known to occur [**9,10**]. Applying this seasonal cycle we count PDDs and compute a melting for each point for various PDD factors ranging from high albedo snow (1.05 mm/PDD) to low albedo ice (2.55 mm/PDD). Averaging these and multiplying by the area of our ice sheet we obtain a potential mass loss for a single year with warmer temperatures. In Figure 2, the top x-axis shows the amount of warming applied, and the bottom x-axis, the average temperature of the points above the ISL that defines the boundaries of the cold-climate ice sheet. Also shown is the target volume of 0.42 $Mkm^3$ [**4**], representing the total volume of all open-basin lakes. With a snow surface it is difficult to obtain our target volume in a single year, requiring a warming of +40 K that brings the average temperature to an unreasonable 285 K. For a lower albedo PDD factor, such as one for an ice surface, our target volume is reached in a single year with a warming just under +30 K, resulting in an average temperature very close to the melting point. It is worth noting that the presence of dark impurities in the ice could reduce the albedo further, resulting in larger PDD factors [**11-13**], resulting in larger melt amounts for lower warmings. However, too much debris on the surface can have the opposite effect of armoring the surface and lowering melt rates [**14**].

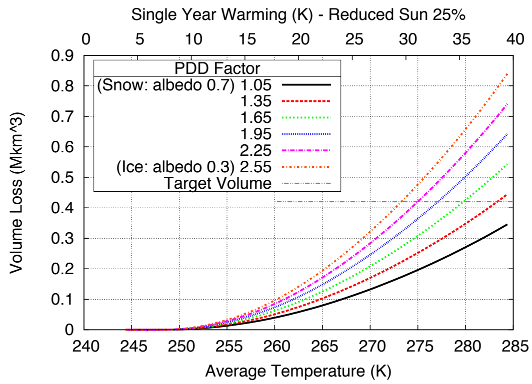


Figure 2: Volume loss for a single-year event for various PDD factors. The target volume fro the open-basin lakes is shown by the horizontal dashed line.

**Conclusions:** Scenarios for a single year of warming of the LNIH glacial scenario are sufficient in some cases (e.g., the dusty ice scenario) to produce a volume of meltwater comparable to our minimum estimate of the total volume of all open-basin lakes. More extended periods of top-down melting associated with punctuated warmings could produce even greater volumes, and specific spin-axis/orbital parameter conditions could produce even longer periods characterized by seasonal melting, despite mean annual temperatures well below freezing, as in the case of the McMurdo Dry Valleys on Earth [**10**]. We conclude that the LNIH glacial scenario provides a huge reservoir of potential meltwater, and a ready source for abundant and volumetrically significant meltwater that may be sufficient to account for the observed valley networks and open-basin lakes, under several plausible top-down melting scenarios (e.g., peak seasonal temperatures above 273 K, [**10**]; spin-axis/orbital parameter perturbations under specific conditions, [**15**]; large impact events, [**2**]; punctuated volcanic eruptions, [**3**]). Estimates of the volume of material eroded to form the valley networks, permitting estimation of the volume of water necessary to carve them, have been made (e.g., [**16-19**]; recent estimates [**20**] suggest that values approximately 10 times the current (~34 m GEL) surface/near surface water inventory on Mars could account for their erosion and formation. In general, episodes of punctuated heating and melting of the LNIH ice sheet, cycled through the valley network system over extended periods, could readily account for their formation. Not yet determined is the detailed mechanism of top-down heating and melting, the predicted regional valley network patterns and associated landforms, and their comparison to the observed valley-network distribution and patterns. Preliminary comparisons of the global distribution of valley networks and open basin lakes with the LNIH (+1 km ELA) distribution of snow and ice shows a close correlation [**10**], but more detailed studies are required to compare the nature of valley networks with the predictions of "warm and wet" and "cold and icy" climate models."

**References:**
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