

**LATE NOACHIAN ICY HIGHLANDS: SPATIAL DISTRIBUTION OF TOP-DOWN MELTING AND VOLUMES OF MELT-WATER FOR SINGLE-YEAR WARMING EVENTS.** James L. Fastook<sup>1</sup> and James W. Head<sup>2</sup>, <sup>1</sup>University of Maine, Orono, ME 04469, [fastook@maine.edu](mailto:fastook@maine.edu), <sup>2</sup>Brown University, Providence, RI 02912.

**Introduction:** We present here the next level of detail for the general calculation of top-down melting on supply-limited ice sheets for the Late Noachian Icy Highlands (LNIH) [1], in this case looking specifically at the spatial distribution of meltwater produced by Positive-Degree-Day melting at the ice sheet surface that results from a single-year warming. Knowledge as to where this meltwater is produced in relationship to the existing valley networks (VN) and open-basin lakes (OBL) can provide insight into possible mechanisms for their formation, as well as climatic conditions necessary to produce the required volumes of water thought to have fed the VN and OBL.

Reasonable supply limits on the amount of water available to grow LNIH ice sheets range from 1 to 5 times the present available water [2]. Using a lapse-rate-dominated climate with an ice-stability elevation predicted by GCM results for a denser Martian atmosphere [3], ice sheets are cold-based [4] and incapable of producing the large volumes of liquid water necessary to form VN or OBL, features and deposits known to have existed in this region. We investigate how such water might be released by surface melting during short-lived climatic warmings due to large meteor impacts (e.g., [5]) or periods of intense volcanism (e.g., [6]). 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 [7],  $\sim 0.42 \text{ Mkm}^3$ , a value less than 10% of the current (1X) surface/near-surface ice volume [2].

**Results:** With our relatively simple climate parameterization, short-lived warmings are handled by shifting the base temperature, which produces a uniform shift of the global temperature field. Simultaneously, the mass balance as a function of elevation is adjusted by a combination of a specified lapse rate (2.4 K/km) and a posi-

tive-degree-day factor [8.9] of 1.05 mm/PDD.

Here we investigate the distribution and amount of melting one might obtain from a single-year melting event, using our target value of  $0.42 \text{ Mkm}^3$  to assess plausible scenarios. Extracting and calculating temperature from our climate parameterization for all points that are ice covered for our 1X, 2X, and 5X ice sheet simulations, we impose various degrees of warming by offsetting the base temperature in the climate parameterization. We impose a seasonal swing of 40 K (+/-20), analogous to that observed in the McMurdo Dry Valleys, where the mean annual temperature is 253 K and where seasonal melting is known to occur [10-11]. 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) [9]. Summing these over the area of our simulated ice sheets we obtain potential mass losses for a single year with warmer temperatures for various warmings and PDD factors.

Figure 1 shows volume losses for our three supply-limited ice sheets as a function of warming. Also shown is the target volume of  $0.42 \text{ Mkm}^3$  [7], representing the total volume of all open-basin lakes. Clearly, with a snow surface (PDD factor of 1.05 mm/PDD, the bottom solid line in each figure) it is difficult to obtain our target volume for any of the simulated ice sheets. The 2X ice sheet reaches the target, but only PDD factors typical of an ice surface, and even with that, it requires unreasonably large warmings (36, 38, and 41 C for PDD factors of 2.55, 2.25, and 1.95 mm/PDD respectively). For the 5X ice sheet, an ice surface PDD factor of 2.55 mm/PDD obtains the target volume loss with the least warming, 31 K, yielding an average temperature for the ice sheet surface close to the melting point. These results are summarized in Table 1, which also includes the average melt, temperature over the ice sheet, and number of PDDs, as

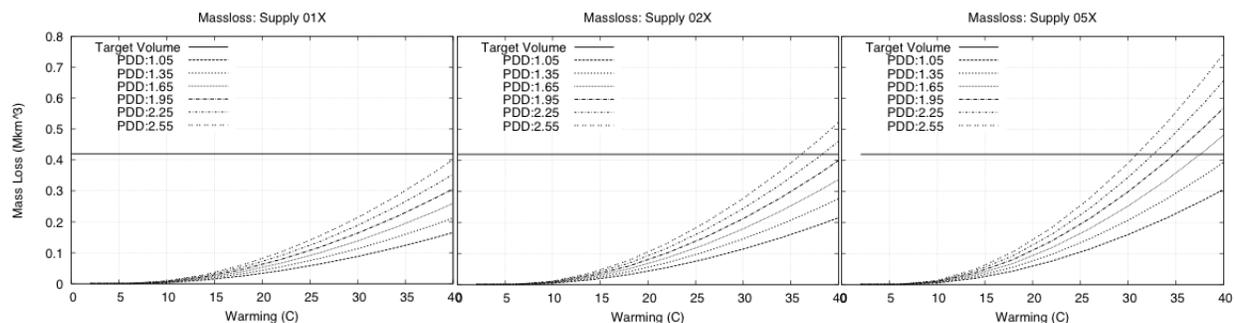


Figure 1: Showing volume loss during a single-year warming event for the 1X, 2X and 5X supply-limited model ice sheets for various PDD factors ranging from 1.05 mm/PDD (snow) to 2.55 mm/PDD (ice) as a function of the warming. Also shown is the target volume of the OBL,  $0.42 \text{ Mkm}^3$ .

Supply	Warming (C)	PDD factor	Average Melt (m)	Average Temperature (K)	Average PPD	Area (Mkm <sup>2</sup> )	Volume Loss (Mkm <sup>3</sup> )
1X	41	2.55	23.13	284.3	9071	18.3	0.423
2X	36	2.55	17.33	279.2	6799	24.0	0.415
2X	38	2.25	17.21	281.2	7648	24.0	0.412
2X	41	1.95	17.58	284.2	9016	24.0	0.422
5X	31	2.55	12.04	273.8	4721	35.1	0.422
5X	33	2.25	12.24	275.8	5442	35.1	0.429
5X	35	1.95	12.11	277.8	6209	35.1	0.424
5X	37.5	1.65	11.93	280.3	7234	35.1	0.418
5X	41	1.35	11.88	283.8	8799	35.1	0.416

Table 1: Summarizing the scenarios from Figure 1 that achieve the target volume for various warmings and PDD factors.

well as the area of the ice sheet and the volume lost.

Figure 2 shows the distribution of mass loss for the scenario that achieves the target volume with the least required warming, the 5X ice sheet with a PDD factor of 2.55 mm/PDD, typical of a low albedo ice surface. It is worth noting that the presence of dark impurities in the ice could reduce the albedo further, resulting in larger PDD factors [12-14], resulting in larger melt amounts for less warming. However, too much debris on the surface can have the opposite effect of armoring the surface and lowering melt rates [15]. Where [6] suggests a warming of 26 C due to volcanic activity, we might ask what PDD factor is necessary to achieve our target volume in a single year, and whether these values are reasonable. The 1X supply requires a PDD factor of 7.0, 2X requires 5.38, and 5x requires 3.85 mm/PDD. Of these, only the 5X case is possible given our assumption of a 25% reduction in the solar intensity during the Noachian, and even this requires a low but not unreasonable albedo less than 0.2 [16].

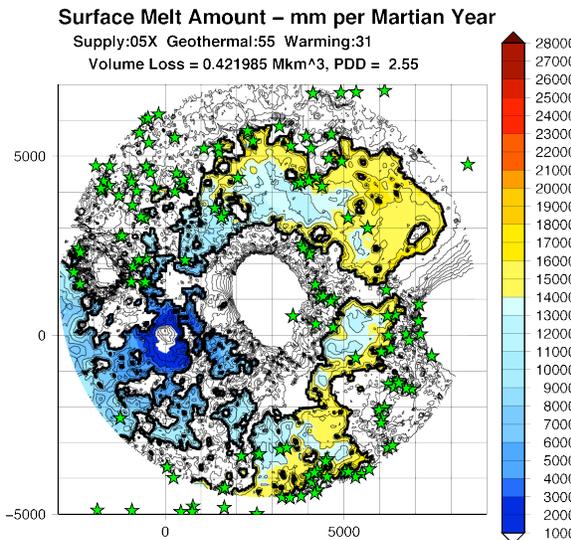


Figure 2: Showing the distribution of surface melt across the 5X ice sheet in mm/Martian year. The South Pole is at grid coordinate 0,0.

**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. Water melted on the surface of the ice sheet will in general flow down local surface slopes to the nearest margin. While our treatment does not at this point allow us to predict the exact flux delivered to the ice sheet margin, one would expect from Figure 2 that the largest delivery would be along the yellow margin, where surface melting is in the 14-17 m range. Figure 2 also includes all of the OBL cataloged by [7] (green stars). There are major clusters of lakes just outside the margin (e.g. the clusters near grid (4000,-4000), (7000,0), (4500,1000), and several others. Lakes are very rare within the boundaries of the ice sheet (only two near grid (5000,3000), two more near (3200,-3200), and one near (5250,-750); the rest inside the ice sheet are within ~100 km of a margin).

We conclude that the LNIH glacial scenario provides a huge reservoir of potential meltwater, and that this meltwater would be delivered in locations that could account for many of the observed valley networks and open-basin lakes under several plausible top-down melting scenarios. 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. These preliminary comparisons of the distribution of open basin lakes with the LNIH supply-limited ice sheets show a close correlation [11], 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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