INSOLATION-DRIVEN BOUNDARY CONDITIONS FOR DEBRIS-COVERED GLACIERS ON MARS AND EARTH.

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Introduction: Debris-covered glaciers (DCG) play a unique but important role in the long-term preservation of ice on Mars and Earth. This ice preservation stores information about paleoclimate [1] and it stores significant volumes of water that contribute to hydrological resources in alpine communities on Earth and are strong candidates for *in situ* resource utilization on Mars due to their large volume, high ice concentration, and relatively low latitude [2,3]. The supraglacial debris layer is a key component of DCG on both Earth and Mars. It provides a thermal boundary that shields water ice in regions where it would ablate at the ground surface.

While the supraglacial debris plays a significant role in the preservation of the ice in DCG, the lack of radar sounding detections of the debris/ice interface on Mars leaves many key properties—including the thickness—of this debris layer poorly constrained [4]. Vapor diffusion models constrained by gamma ray spectrometer data indicate depths to ice stability greater than one meter at the mid-latitudes [5], but the theoretical vertical resolution of the Shallow Radar (SHARAD) instrument is approximately 10 m in geologic media [6].

Multiple glacier flow models inverting surface slope with SHARAD-derived basal topography indicate heterogeneities in yield stresses and flow parameters between the pole- and equator-facing slopes of a DCG in Mars' southern hemisphere [7, 8, 9]. This trend may also be observed on Earth; change-detection measurements show that a pole-facing DCG in Alaska flows approximately half the speed of its equator-facing neighbor [10]. Here, we test the hypothesis that topography causes significant variation in solar radiation received between equator- and pole-facing slopes, which may be sufficient to drive variations in surface temperature, ice accumulation, viscosity, or depth to stable ice in either martian or terrestrial regimes.

Method – Annual Insolation Ratios: We calculated the apparent horizon from the perspective of individual DCG using Shuttle Radar Topography Mission (SRTM) data for Earth (~10 m/pixel) and Mars Orbiter Laser Altimeter (MOLA) data for Mars (~400 m/pixel). We reconstructed a horizon for each Alaskan DCG lobe shown in Figure 1a and each martian point of view in Figure 1b—one equator- and one pole-facing slope at each location. Next, we compared this horizon with the astronomical coordinates of the sun over one orbit and estimated the amount of radiation obstructed by the horizon in comparison with a flat surface at the same latitude. Using this method, we expanded our analysis to include a northern hemi-

sphere site on Mars (Deuteronilus Mensae) and two lower-latitude sites on Earth (Absaroka Mountains, Wyoming, and San Juan Mountains, Colorado).

Since annual solar path depends on the planet's spin axis obliquity, and Mars' obliquity varies with high amplitude [11], we estimated the variation in insolation at present day obliquity (25°) and high obliquity (40°). Our estimations produce relative insolation ratios (Q_{rg}/Q_{flat}) at localized coordinates, therefore we do not consider deviations in orbital distance or absolute heat flux.
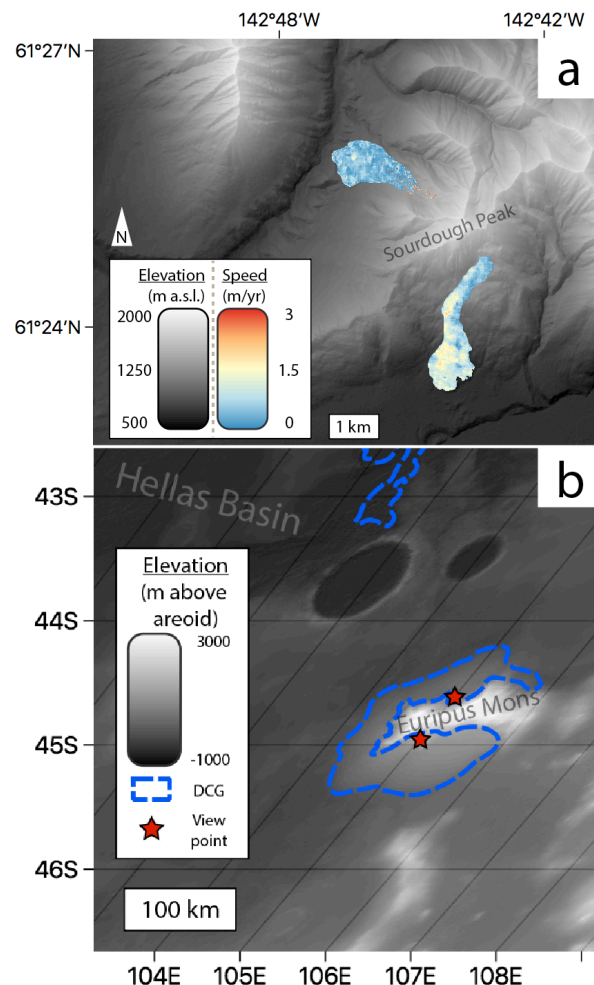
Figure 1: a) Hillshaded SRTM 1/3'' elevation data published with the U.S. National Elevation Dataset along with repeat photogrammetry change detection measurements of two DCG in the Wrangell Mountains, Alaska. The equator-facing DCG flows approximately twice as fast as the pole-facing DCG [10]. **b)** Locations used to plot apparent horizons on Euripus Mons, Mars, on hillshaded MOLA data with the DCG mapped in [2] and modeled in [7, 8, 9].

Sourdough, Latitude 61°N

Equator-Facing: Q_{rg}/Q_{flat} = 0.91

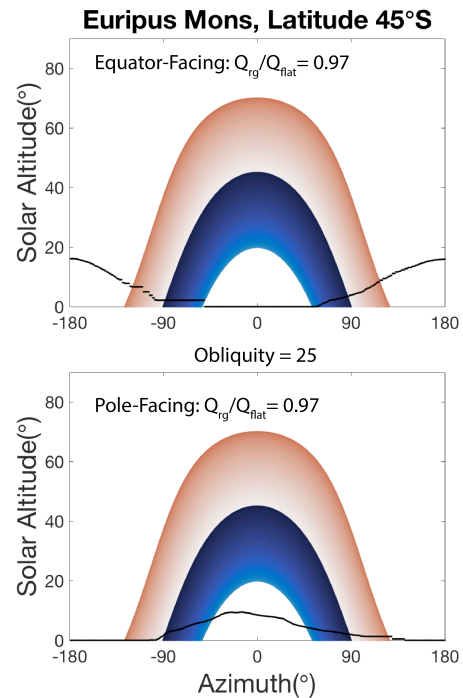Pole-Facing: Q_{rg}/Q_{flat} = 0.83
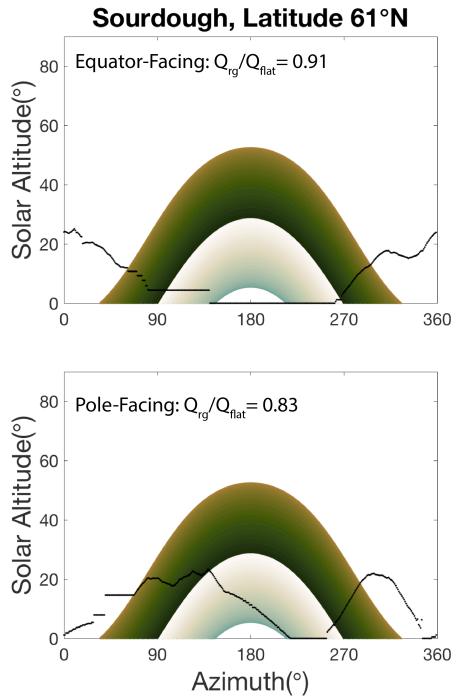
Figure 2: Annual sun path versus apparent horizon comparison for two DCG in Alaska. Relative annual insolation is calculated by subtracting insolation contribution if solar altitude angle is lower than horizon; time step is one minute.

Result – Extreme Topography Required: Figure 2 shows that for the Alaskan case, the equator-facing DCG receives 91% of the radiation of a flat horizon at that geographic location, while the pole-facing DCG receives 83%. These results suggest a measureable difference in solar radiation between the neighboring DCG, and future work should consider this difference in heat flux when modeling glacier strain rate or viscosity at these sites. Additionally, each of the Absaroka and San Juan sites result in insolation ratios below 75% of the flat surface value. This may indicate that significant topographic obstruction is needed for DCG preservation at lower latitudes on Earth.

Conversely, neither Euripus Mons nor Deuteronilus Mensae have discernible radiation differences between the equator- and pole-facing slopes at the current obliquity (Figure 3), and has a 1% difference at high obliquity. While the martian DCG abut significant massifs or mesas, the low average surface slopes of ~2° and wide lateral extent ensure that the line of sight that produces the apparent horizon remains at a low altitude angle, therefore obstructing weaker sunlight in comparison with the terrestrial analogs, where surface slopes typically exceed 10°.

Discussion – Accumulation vs. Insolation: While the results for the terrestrial sites show that extreme topographic relief between two DCG can cause insolation differences that may explain observed differences

in present-day flow, the martian sites did not display this same variability. This implies that observed differences in glacier properties are not a product of the insolation regime of the present day. Rather, it suggests that the differences must have been caused by local variations in ice accumulation at the time of glaciation.

Euripus Mons, Latitude 45°S

Equator-Facing: Q_{rg}/Q_{flat} = 0.97

Obliquity = 25

Pole-Facing: Q_{rg}/Q_{flat} = 0.97

Figure 3: Sun path/horizon plot for Euripus Mons, Mars at the current obliquity.

Slope aspect is not a robust indicator of current depth to ice stability for the largest DCG on Mars. However, the higher-resolution terrestrial results indicate that extreme topography in regions of ice accumulation may contribute to local variation in surface temperature, which could vary the evolution of neighboring DCG in cirques on Mars and Earth. More analyses are needed to model and understand fine-scale variations in the supraglacial debris layer, flow parameters, and glacial emplacement history on each planet.

References: [1] Mackay S. L. and Marchant D. R. (2017) *Nature Comms., 8,* 14194. [2] Levy J. S. et al. (2014) *JGR Planets, 119,* 2188-2196. [3] Petersen E. I. et al. (2018) *GRL, 45,* 11595–11604. [4] Baker D. M. H. and Carter L. M. (2019) *Icarus, 319,* 745-769. [5] Aharonson O. and Schorghofer N. (2006) *JGR Planets, 111,* E110077. [6] Seu R. et al. (2007) *JGR Planets, 112,* E05S05. [7] Karlsson N. B. et al. (2015) *GRL, 8,* 2627-2633. [8] Parsons R. and Holt J. W. (2016) *JGR Planets, 121*, 432-453. [9] Schmidt L. S. et al. (2019) *J. Glaciology*, 1-11. [10] Meng T. M. et al. (2019) *LPSC 50*, Abstract #3197. [11] Laskar J. et al. (2004) *Icarus, 170*, 343-364.