AN ANALYSIS OF SEASONAL TEMPERATURE VARIATION IN THE ANTARCTIC MCMURDO DRY VALLEYS: IMPLICATIONS FOR EARLY MARTIAN CLIMATE AND VALLEY NETWORK FORMATION.

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Introduction: The climate of the Antarctic McMurdo Dry Valleys (MDV) is hyperarid and hypothermal, with mean annual temperatures (MAT) ~255 K. Despite the cold and arid climate, fluvial features such as gullies, lakes, and ponds persist [1,2]. Although MAT are far below the 273 K melting point of water, seasonal and diurnal temperature variations induce short-lived periods of atmospheric heating >273 K, producing ice-melting and subsequent runoff, forming these fluvial and lacustrine features [1-3].

For early Mars, recent climate models have predicted a "cold and icy" climate, with MAT ~225 K [4,5]. Under these conditions, the MDV may be a useful analog: there is evidence of stable liquid water conditions on the Noachian surface (fluvial valley networks and lakes) despite the unusually cold climate (MAT<<273 K). Thus, it is possible that peak annual or peak seasonal temperature (PAT/PST) variations on early Mars could produce transient periods with temperatures >273 K, and associated melting and runoff, similar to the general conditions that we observe in the MDV [1,6]. Here we investigate the range of PST durations in the MDV and the factors that influence this, as a terrestrial process analog to early Mars.

There are two goals for this study: 1) characterize the conditions permitting formation and sustenance of the gullies, lakes, and ponds in the MDV and 2) discuss possible forces driving formation of fluvial features on a "cold and icy" Mars and the necessary duration of heating to produce sufficient meltwater and runoff for formation.

Factors Influencing MDV Climate: Warm conditions in an MDV-like environment are likely linked to changes in incident solar radiation. Temperatures are higher in Antarctica during the sunlit summer season than they are during the dark winter season [1]. If temperatures are >273 K for a portion of the summer season, then top-down glacial melting and runoff are possible.

Incident solar radiation, however, is not the only factor that raises temperature transiently in the MDV. Short-lived changes in temperature can be caused by katabatic wind events—moving of air masses off the ice sheet and on to the ice-free ocean and continents. Katabatic winds occur when there is a strong pressure gradient force, usually related to a large ice sheet, and gravitational influence, usually related to slopes. Accordingly, primary locations for katabatic events are the Antarctic ice sheet, especially during the winter season of darkness, and the current Mars polar caps.

On the Antarctic ice sheet, the ice interacts with the air above, cooling it and creating a dense, high pressure region. Off the ice sheet, there is no ice to interact with the air, leaving the air at a warmer temperature and producing a less dense, lower pressure region. A pressure gradient force develops from high to low pressure, and gravity forces the air downslope. The end result is a powerful wind moving downslope and off the ice sheet at maximum speeds comparable to hurricane winds (~120 km/h) and circulating air across the landscape. Thus, katabatic winds can distribute cold air from above the ice-covered regions to ice-free regions and warm air from above the ice-free regions to ice-covered regions, causing short-lived variations in temperature.

Variation in summertime temperature, soil moisture, and relative humidity produce three microclimate zones in the MDV, all of which are critical to an understanding of seasonal temperature variation: upper stable zone (USZ), inland mixing zone (IMZ), and coastal thaw zone (CTZ). Most fluvial activity that results in surface erosion occurs in the IMZ and CTZ [1-3].

Factors Influencing Cold and Icy Early Mars Climate: In contrast, the martian fluvial features are located in the equatorial region, and the effects of solar insolation and katabatic winds are different. In equatorial regions, sunlight follows a diurnal cycle. Thus, while conditions would still be warmest in the summer season, there will also be strong diurnal temperature variation. Equatorial katabatic winds may have been present off the edges of the Noachian ice sheet, but would likely have had different speeds than MDV katabatic winds due to the differences in slope, pressure, and temperature. Thus, it is important to constrain the influence of solar insolation and katabatic winds on MDV temperature variation before applying the PAT/PST concept to Mars.

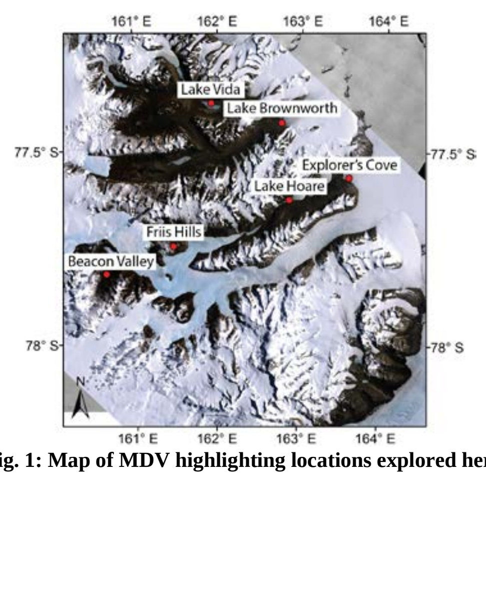

Fig. 1: Map of MDV highlighting locations explored here.

Methods: To determine seasonal temperature variation throughout the MDV, we chose six different locations, two from each microclimate zone (see Fig. 1): Friis Hills (77.75°S, 161.47°E; USZ), Beacon Valley (77.82°S, 160.65°E; USZ), Lake Vida (77.38°S, 161.93°E; IMZ), Lake Hoare (77.63°S, 162.87°E; IMZ), Lake Brownsworth (77.43°S, 162.77°E; CTZ), and Explorer's Cove (77.57°S, 163.58°E; CTZ). We utilize Long Term Ecological Research (LTER) meteorological station temperature data [www.mcmlter.org] to produce temperature time series for 11 years, from 2000 to 2010, at each location. At Friis Hills, temperature data was only available from 2011-2014, inclusive, so we use this time period for our analysis at this location. Temperature measurements are made at 3 m above the surface, an elevation comparable to temperatures at the surface, and observations are made every 15 minutes.

We 1) determine the percentage of each year during which the temperature exceeds 273 K and 2) over the 11 years, calculate the average percentage of the year >273 K and the range of percentages of the year >273 K. This provides a guideline for conditions required to produce enough melt to form fluvial/lacustrine features in a cold and arid environment. The results can be applied to early Mars as an analog for how much seasonal variation in temperature is required to form similar features on Earth.

Additionally, one of the locations, Lake Hoare, has corresponding LTER lake level data [www.mcmlter.org]. We searched for a correlation between changes in lake level and periods when temperature exceeded 273 K to determine whether enough meltwater is produced annually to increase lake level or if durations are only of sufficient duration to sustain the lake [1,7].

Results: This analysis provides insight into seasonal temperature variation in various locations in the MDV. The results from this analysis are shown in Table 1. As expected, temperatures almost never reach 273 K in the USZ, where fluvial features are not observed. However, the IMZ and CTZ are characterized by ~4% of the year >273 K. The warmest years at Lake Vida and Lake Hoare (IMZ) experienced 6% and 7% of the year >273 K, respectively. The warmest years at Lake Brownsworth and Explorer's Cove (CTZ) experienced 8% and 18%, respectively. Thus, as a guide to the interpretation of formation of similar fluvial features on early Mars, we conclude that ~4% of the year is required to experience temperatures >273 K to produce the necessary scale of fluvial activity. To form larger features, a longer duration may be required.

Zone	Location	Average (%)	Maximum (%)
USZ	Friis Hills	0	0
USZ	Beacon Valley	0.14	0.5
IMZ	Lake Hoare	3.7	6.9
IMZ	Lake Vida	3.9	5.7
CTZ	Lake Brownworth	2.2	8.2
CTZ	Explorer's Cove	4.7	18.4

Table 1: Average and maximum percentage of year >273 K.

Katabatic winds. In some cases, temperatures approach or exceed the melting point of water during the dark winter season; for example, temperatures are temporarily ~273 K at Lake Hoare in 2007 (Fig. 2). These conditions are not due to incident solar radiation and are likely related to the circulation of air by katabatic winds. This increase in temperature lasts only 15-30 minutes and does not correspond to any lake level changes, implying that significant meltwater is not produced. Thus, we conclude that katabatic winds are a negligible force in the MDV and likely also the analog martian environment, implying that seasonal/diurnal temperature variation is the driving force for melting and fluvial activity.

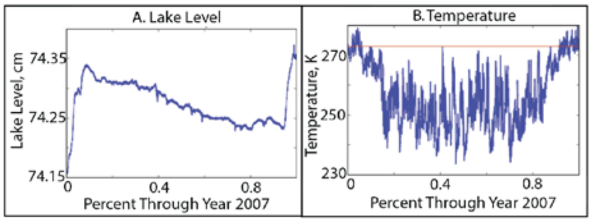

Fig. 2: Lake Hoare, 2007. (A) lake level, (B) temperature time series. Horizontal red line is shown at 273 K.

Lake Hoare: changes in lake level. Our study shows that lake level does not vary significantly annually from 2000 to 2010. Variations are typically less than a centimeter, with levels slightly decreasing throughout the winter and increasing throughout the summer (Fig. 2), corresponding to seasonal changes in solar insolation (and summer runoff). Peak summer temperatures are sufficient to produce enough meltwater to sustain the lake from year to year without complete freezing, but there is insufficient meltwater annually to drastically increase lake level.

Conclusions: The similarities between the MDV and a "cold and icy" early Mars implies that MDV conditions may be a good process analog for conditions on early Mars. We have analyzed seasonal temperature variations at six locations in the MDV in order to determine the relationship between the percentage of the year >273 K and the formation of fluvial/lacustrine features in the cold and arid MDV. We find that on average ~4% of the year is spent with temperatures >273 K, a duration sufficient to cause fluvial activity and sustain Antarctic lakes. The MDV driving force for melting/runoff is solar insolation, with katabatic winds having a negligible effect. We are currently testing this analog by using early Mars climate models to assess seasonal variability in temperature and determine under what conditions VN and lake areas on Mars experience ~4% of the year >273 K [6].

References: [1] Marchant and Head (2007), Icarus 192, 187-222. [2] Head and Marchant (2014), Antarctic Sci 26, 774-800. [3] Dickson et al. (2007) LPSC 38, 1678; [4] Wordsworth et al. (2013), Icarus 222, 1-19. [5] Wordsworth et al. (2015), JGR 120, 1201-19. [6] Palumbo and Head (2017), LPSC 48, 2107. [7] Chinn (1993), AGU Antarctic Res 59, 1-51.