EARLY MARS CLIMATE HISTORY: EXPLORING THE POSSIBILITY OF TRANSIENT MELTING THROUGH PEAK SEASONAL TEMPERATURES. A. Horan[1] and J. Head[1]. [1]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence, RI 02908 USA (Ashley_Horan@brown.edu).

Introduction: Ancient fluvial features on the surface of Mars, including valley networks (VN) [1] and open- and closed- basin lakes [e.g. 2, 3], are indicative of liquid water flow on the surface of the southern highlands during the Late Noachian and Early Hesperian [4]. Is the formation of these features possible through transient warming and thus not require continuous temperatures above the melting point of water? Models have suggested that under the influence of a younger Sun, emitting approximately 75% the present luminosity [5], early Mars would be forced into a cold steady state with temperatures consistently below the triple point of water [6, 7]. In these models, greenhouse gases and CO_2 clouds are incapable of producing the additional warmth necessary for rainfall and runoff [6-13] when staying within reasonable source and sink constraints; strong greenhouse gases on Mars include those which absorb in the infrared region of the martian atmospheric window, predominantly between 800 and 1200 cm^{-1} [6]. It is likely that orbital parameter variations differed in the Noachian from the current values with potential large variations in obliquity; Laskar et al. [14] predict an average obliquity over the past 4 Gyr of 41.80 degrees. Adjusting orbital parameters, however, also does not induce a large enough temperature increase [6].

With models incapable of producing relatively continuous natural clement conditions [6, 7], we consider the possibility of a “cold and icy” planet with periods of punctuated warmth, permitting transitory rainfall or snowmelt and runoff. Recent general circulation models (GCMs) [6,7] show that when atmospheric pressure exceeds tens to hundreds of millibar, an altitude-dependent temperature effect is induced and H_2O preferentially accumulates in the highlands, producing a “Late Noachian Icy Highlands” (LNIH) scenario [15]. In this context, Wordsworth et al. [16] studied where precipitation would occur under a natural “cold and icy” LNIH scenario versus a gray-gas forced “warm and wet” scenario, finding that snow accumulation under a cold climate correlates much better with the known valley network distribution. However, melting of the surface snow accumulation must occur for incision of the valley networks [17, 18]. There are several end member options for transient atmospheric warming on early Mars including (1) periods of intense volcanism releasing high concentrations of sulfur dioxide into the atmosphere [13], (2) impact cratering induced warming [19-21], and (3) the possibility of transient melting from peak seasonal temperatures elevating above 273 K [e.g. 15]. Punctuated volcanism could raise temperatures enough to permit snowmelt and runoff on the surface from the inceased SO_2 in the atmosphere. However, the period of warmth would be relatively short-lived as the SO_2 would convert into aerosols and bring planetary cooling [13]. Impact cratering induces extremely hot conditions and intense precipitation through a hydrologic cycle which could last hundreds of years [19, 20]; the rainfall and runoff produced by this mechanism may be too intense and globally-distributed to produce the delicate and widely-spaced valley network features and patterns [1]. The focus of this work is to use the Laboratoire de Meteorologie Dynamique (LMD) GCM to test the hypothesis [e.g. 15] that peak seasonal daytime temperatures producing transient snowmelt and subsequent runoff in the equatorial regions could explain the nature and distribution of valley networks.

Methods: We employ the 3-D LMD GCM for early Mars to test for transient melting under the conditions of peak warm-season temperatures. Other researchers [6, 22] use different methods to predict a maximum early Mars CO_2 concentration of around 1000 mbar. For the purpose of this study we focus on a 600-1000 mbar atmosphere with obliquities ranging between 25 and 55 degrees, specifically testing 600 mbar, 800 mbar, and 1000 mbar atmospheres each at obliquities 25, 35, 45, and 55 degrees. We search for regions with substantial snow accumulation which also have peak temperatures above the melting point of water, allowing for snowmelt and runoff at these locations. In regions where snow accumulation is well correlated with the valley network distribution [16], transient melting of snow and ice accumulation may be responsible for valley network formation as the process repeats yearly in similar locations over long periods of time, as is observed in the Antarctic Dry Valleys (ADV) [15]. We also apply our results to place constraints on the parameter space necessary to produce transient melting in the appropriate regions for observed valley network incision.

We collect model data every hour to ensure that our values represent the maximum temperatures reached. Although peak seasonal melting can form fluvial features in the McMurdo Dry Valleys [15], it is possible that these temperatures on Mars may not last for more than a few hours yearly which could be insufficient to cause the necessary scale of melting and erosion [17]. We are currently assessing melt volume calculations to determine if the peak temperatures last long enough to provide sufficient melting [17, 22] and analyzing temperature versus time plots at specific valley network locations to determine the yearly time duration of heating.

Results and Discussion: Figure 1 shows contour plots for peak seasonal temperatures under the conditions of a 1000 mbar CO_2 atmosphere and obliquities 25, 35, and 45 degrees. Although the mean annual temperatures are well below 273 K (approximately 225 K, [6, 15]), the temperature distribution shows peak seasonal temperatures above the 273 K occurring in the southern uplands in equatorial and southern-most regions. The valley network distribution [1] (Figure 2) projected onto martian topography provides insight into the distribution and shows the correlation to equatorial regions of peak temperatures exceeding 273 K. Figure 3 (from [16]) gives the snow and ice accumulation patterns under a "cold and icy" scenario. In this work, we compare the snow and ice accumulation distribution for each of the tested parameter spaces with the regions of peak seasonal temperatures above 273 K, capturing the relative relationship between these areas and the valley network distribution.

The results show evidence that peak summertime temperatures can exceed 273 K in areas of long-term snow and ice accumulation in equatorial regions of the southern uplands, allowing for transient melting and corresponding latitudinally with the known valley network distribution [1]. We conclude that transient melting over long geologic timescales could occur through small amounts of yearly melting and erosion during the warmest hours of the martian summer season [15]. However, preliminary results suggest that the periods of heating may be short lived and thus another mechanism of transient atmospheric warming would be required for valley network incision, such as impact cratering [19-21] or volcanism [13]. Our ongoing work includes comparing our results, melt durations and volumes with previously calculated values [17, 22] to address this issue.

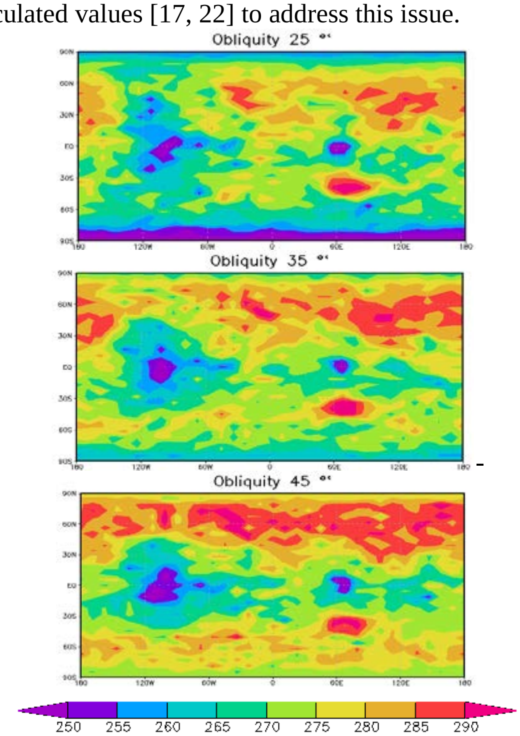

Figure 1, above. Maximum summertime surface temperature distribution after 5 model years. Pressure is 1000 mbar and obliquity is 25 degrees (top), 35 degrees (middle), and 45 degrees (bottom). Note the influence of obliquity on the maximum temperature distribution: warmer temperatures strengthening at higher latitudes, cooling near equator.

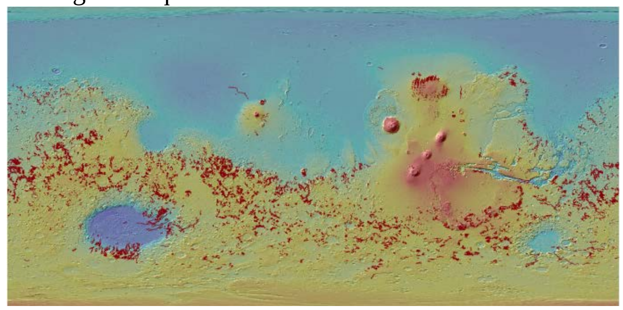

Figure 2, above. Valley network distribution [1] martian topography (red lines).

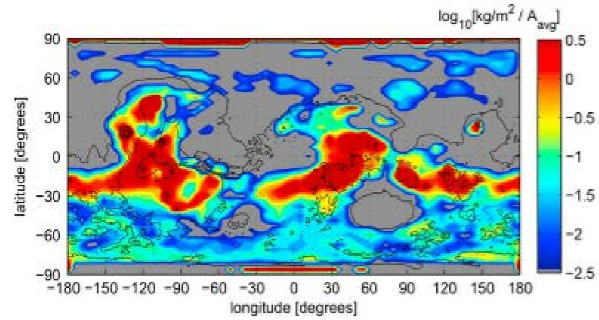

Figure 3, above (from [16]). Ice and snow accumulation after five model years. Obliquity is 41.8 degrees, pressure is 0.6 bar CO_2, and H_2O sources at poles. Note correlation between regions of peak seasonal temperatures above 273 K, ice accumulation, and valley network distribution.

References: [1] Hynek et al. (2010), M.R.T. *J. Geophys. Res. Planets115*, E09008. [2] Fassett and Head (2008a), *Icarus* **195**, 61–89. [3] Goudge et al. (2015), *Icarus* **260**, 346-367. [4] Fassett and Head (2008b), *Icarus **198***, 37–56. [5] Gough (1981), *Sol Phys.*, **74**, 21-24**.** [6] Forget et al. (2013), *Icarus* **222,** 81-99. [7] Wordsworth et al. (2013), *Icarus* **222(1),** 1-19. [8] Kuhn and Atreya (1979), *Icarus* **37**, 207-213. [9] Kasting et al. (1992), In: R.M. Haberle & B.M. Jakosky (Ed.), Martian Surface and Atmosphere through Time. Pp. 84-85. [10] Segan and Chyba (1997), *Science* **276**, 1217-1221. [11] Johnson et al. (2008), *J. Geophys. Res. Atmospheres* **107**, 8022. [12] Wolf and Toon (2010), *Science* **328**, 1266. [13] Halevy and Head (2014), *Nature Geosci. Lett*. [14] Laskar et al. (2004), *Icarus* **170**, 343-364. [15] Head and Marchant (2014), *Antarctic Science* **26**, 774-800. [16] Wordsworth et al. (2015), *J. Geophys. Res. Planets 120*, 1201-1219 . [17] Fastook and Head (2015), *Planet. Space Sci.* **106**, 82-98. [18] Rosenberg and Head (2015), *Planet. Space Sci.* **117**, 429-435. [19] Segura et al. (2002), *Science* **298**, 1997-1980. [20] Segura et al. (2008), *J. Geophys. Res.* **113**. [21] Toon et al. (2010), *Earth Planet. Sci.* **38**, 303-322. [22] Scanlon et al. (2013), *Geophysical Res. Lett.* **40**, 4182-4187. [23] Bouley et al. (2015), *LPSC* **46**, 1887.