SEASONAL SNOWMELT VERSUS IMPACT-TRIGGERED RUNOFF IN MARS' GEOLOGIC RECORD OF SURFACE LIQUID WATER. E. S. Kite[1] and M. Manga[2], [1]Caltech, Division of Geological and Planetary Sciences, Pasadena CA 91125 USA (ekite@caltech.edu), [2]University of California - Berkeley, Earth and Planetary Science, Berkeley CA 94720 USA (manga@seismo.berkeley.edu).

Introduction: Impacts triggered some fluvial activity on Mars [1]. However, sulfate-bearing sedimentary rocks show cyclic bedding indicating deposition over Myr, inconsistent with impact-induced transients [2]. Major uncertainties remain about the mechanisms coupling impact energy to fluvial runoff, and how much thicker the atmosphere must be to allow Early Mars snowmelt. Therefore there is no consensus about the climatic conditions corresponding to most of Mars' geologic record of surface liquid water, including the classic highland valley networks [3-4], shallow-floored ancient craters [5-6], and the fans that modify relatively young craters [7]. Were these produced by short-lived (10^{-3} yr - 10^{2} yr) or prolonged (>10^{3} yr) wet intervals? We are working to reduce the uncertainties through:- (1) development of a global, orbitally-integrated seasonal-melting model, and gathering data to constrain it; (2) building both idealized and 3D models for impact-triggered fluvial runoff. Resolving these problems is essential for understanding the divergence between Mars' environmental deterioration and Earth's long-term climate stability, as well as whether Early Mars' surface environment had the right physical boundary conditions to sustain life.

Our approach is to relate pre-modern, but still relatively young, geomorphic features to inputs of water and energy. These include Late Amazonian Mojave Crater, the Aeolis-Zephyria rivers, and the largely Hesperian sulfate-bearing sedimentary rocks. The plan is to develop calibration points and a climate trajectory to support subsequent work on the Noachian.

Seasonal melting as a water source for prolonged wet events: The main difficulty in melting snow on Early Mars is retreat of water ice to planetary cold traps. (Melting is also suppressed at low paleopressures by evaporitic cooling [8], but this is less important for P > 50 mbar). For example, modern orbital conditions, flat topography, a Faint Young Sun, snowpack albedo 0.28, and $P(CO_2)$ = 146 mbar produce a large cold trap in the Northern Hemisphere. If melting is to occur, warm-season snow must occur on >43% of the planet (Fig. 1a). However, rare orbital conditions can eliminate cold traps, forcing seasonal melting (Fig. 1b).

Strong sensitivity to orbital forcing, plus the knowledge that the sedimentary rock record could have formed in a small fraction of Mars history [2], requires the use of an orbitally integrated model. If the rock record is a wet-pass filter, recording only a subset of orbital conditions most favorable for melt, then using modal orbital conditions is neither sufficient nor appropriate.[1]

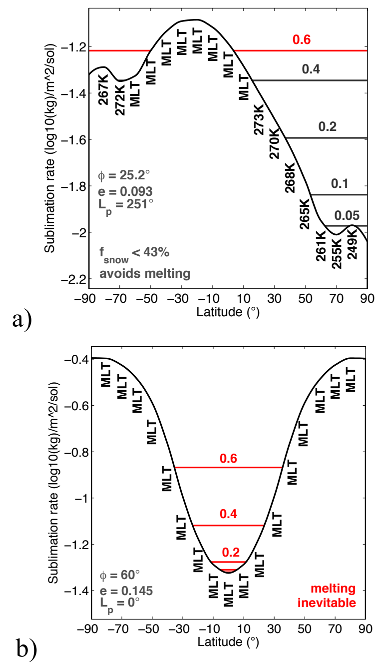

Fig. 1. *Eliminating cold-traps with unusual orbital conditions: results from a 1D model. Sublimation rates are annual averages, for a hypothetical snowpack that persists through the year. Temperatures are annual maxima. Horizontal lines show the latitude range with warm-season snow, labeled according to the fraction of planet surface area with warm-season snow. Horizontal lines are gray if no melting occurs anywhere on the planet, red if some melting occurs. For example, the horizontal line '0.2' in (a) shows that warm-season snow is only found N of ~40N at this snow coverage fraction, and doesn't exceed 270K anywhere. (a) current orbital conditions; (b) optimal orbital conditions.*

We have built a 1D model of snowpack energy balance and melting and run it for a range of paleopressures, orbital conditions, latitudes, seasons, and freezing-point depressions relevant to Early Mars. The model assumes that warm-season snow is only present in orbitally-determined cold traps. For each candidate past climate, we then sum over the pdf of orbital states and compare to data (Fig. 2)

The main weakness of the 1D approach is that we cannot track precipitation. Also, results are only meaningful for P <~ 200 mbar, because do not account for meridional heat transport. Nevertheless, interesting patterns emerge from preliminary runs targeting the distribution of sedimentary rocks:- (i) the basic pattern of sedimentary rock distribution [9] – low elevation and equatorial lati

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1. For GCM users we suggest {$e \sim 0.15$, obliquity ~ 50°, $L_p \sim 0$} as orbital conditions that are favorable for melting, and are likely to have been reached at least once during Mars' history [14].

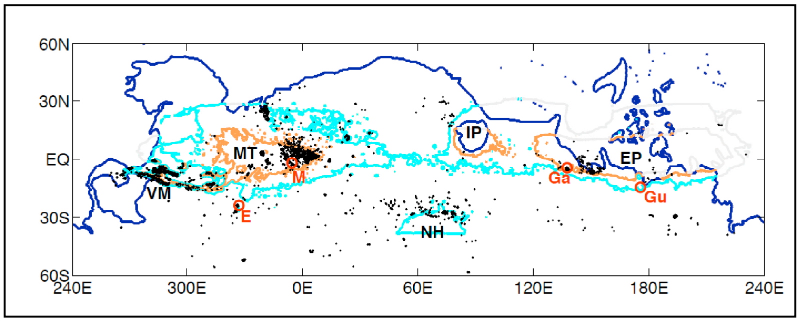

Fig. 2. *Output from global snowmelt model. Dark blue line is edge of mask for young terrain. Cyan and orange contours correspond to less frequent and more frequent melting, respectively. Black dots are sedimentary rock locations [9]. VM = Valles Marineris, MT = Margaritifer Terra, NH = Northern Hellas, EP = Elysium Planitia. M = Meridiani Planum, E = Eberswalde, Gu = Gusev, Ga = Gale.*

tude, plus Hellas – is easily reproduced; (ii) the distribution of sedimentary rocks on Mars is most consistent with a Hesperian paleoclimate that only marginally allowed melting even under the most favorable orbital conditions. Warmer paleoclimates produce a broader sedimentary rock distribution than is observed; (iii) Gale Crater is strongly favored for snowmelt with almost all parameter choices, so MSL will be a decisive test of the snowmelt model; (iv) although sulfates in Terby and Hellas are well fit by the model, (v) the large alluvial fans near 25S (including Eberswalde) are *not* satisfactorily fit by the model, so either the model contains faulty assumptions or another mechanism produced these fans.

If the large alluvial fans were not snowmelt-fed, alternatives water sources include ice melting and impacts. (Unlike snow, ice location can lag orbital forcing, allowing out-of-equilibrium melting).

Impact-triggered fluvial activity and transient wet events: Of many mechanisms that could connect impact energy to fluvial activity - hydrothermal activity, ballistic plume rainout, ejecta-on-ice, liquefaction, ejecta dewatering, e.t.c. – impact-induced precipitation is particularly interesting. This is because impact-induced precipitation could produce regional-to-global scale geomorphic effects that would be hard to distinguish from prolonged climate-driven runoff.

3D simulation of impact-induced precipitation is difficult because of the wide range of temperatures and pressures [10]. Our approach is to modify MRAMS [11] to simulate rapid water vapor injection just after formation of ~150km diameter craters in volatile-rich targets. Surface temperature and ice distribution initial conditions are supplied by CTH shock hydrocode output [5]. Initial tests simulated atmospheric response to idealized lakes and outflow channel vapor release [12,13]. Precipitation occurs as snow. Preliminary results for Mojave Crater are shown in Fig. 3. Impact-induced precipitation is challenged by the existence of fans in Mojave secondaries - e.g., DTM at http://gps.caltech.edu/~kite/stereo3/#YoungFans These secondaries are too small to seed their own impact-storm cells, suggesting that at least these fans result from ejecta dewatering.

Once snow reaches the ground, melting will chill the contact between snow and hot rock. Melting will be outcompeted by further accumulation unless erosion can mine heat from deeper within the shock-heated layer. Similar arguments apply to the source region for Eberswalde fan, if this was formed by hot ejecta landing on pre-existing ice [7].

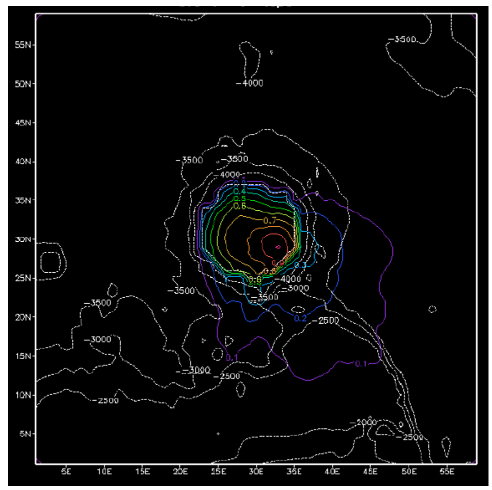

Fig. 3. *Preliminary output from a Mojave impact-induced precipitation simulation using MRAMS. Colored contours are total snow precipitation (g/cm^2) 16 hours after impact. 1 grid unit = 2.9 km. Crater is ~60km across.*

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