Global Constraints on Rainfall on Ancient Mars: Oceans, Lakes, and Valley Networks.

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Introduction: The last five decades of Martian exploration have shown evidence for standing surface liquid water in Mars' ancient past [1]. The Viking, Mars Global Surveyor (MGS), and Mars Reconnaissance Orbiter (MRO) spacecraft have all observed valley networks in the equatorial and southern tropical regions of Mars [2][3]. As well, recent observations by the MRO HiRISE camera show geomorphological features that have been interpreted as lake strandlines/shorelines [4].

These observations led to extensive research into possible mechanisms for sustaining surface liquid on ancient Mars while also explaining how the current Martian climate could be so hostile to the existence of surface liquid water. Mechanisms include: a once thick CO2 atmosphere that was slowly removed by the solar wind and/or entrainment into the subsurface (as carbonates or CO2-H2O clathrates) [5]; a relatively thin CO2 atmosphere periodically injected, perhaps by volcanism, with additional greenhouse gases such as SO2 [6]; or a temporarily clement climate generated by the impact of moderate or large sized impactors [7][8].

However, the existence and distribution of precipitation depends on more than achieving global mean temperatures above the freezing point of water. The actual global abundance and distribution liquid water in a warmer Martian atmosphere is equally important and has not been previously investigated. Understanding the constraints on precipitation due to atmospheric dynamics and topography will provide insight into the current geological evidence for surface liquid water. We present here the results of our investigation into the patterns of precipitation and evaporation for the types of climates that might have existed during ancient Mars [9].

Modeling Methods: As a first order assessment of the global constraints on precipitation in a warm, Martian paleoclimate, we used an Earth climate model modified to have a Martian topography. The Community Atmosphere Model (CAM) already includes a hydrological model that couples the ocean, land, and atmosphere reservoirs of water. We merely changed the topography in the model to match current Mars topography and thus capture the likely distribution of water in a Martian paleoclimate. For a first order study this is a valid simplification since the large scale atmospheric dynamics are similar on Earth and paleo-Mars due to their similar rotational rates. We refer to this type of simple climate model modification as "Mars as Earth", or Mearth.

Using the Mearth model, we run simulations with varying global abundances of water. The initial distribution of this water is determined by the climate scenario we are investigating. The Mearth model is then run for 10 Mars year allowing us to determine a mean state of precipitation and evaporation.

Results: We investigated four scenarios: (1) a paleo-Mars with no ocean but a globally saturated regolith; (2) a northern hemisphere ocean filled to the -4.5 km altitude, with respect to the Martian geoid; (3) a northern hemisphere ocean filled to the -3 km altitude, with respect to the Martian geoid; and (4) a distribution of lakes resulting from valley network activity [2].

Scenario (1) showed no signs of extensive precipitation. Instead, the equatorial and mid-latitudinal regions were slowly de-hydrated as the water in the regolith moved to the cold polar regions. Essentially, the polar regions were "cold-trapping" the water. Since this scenario has a low global abundance of water, the water carrying capacity of the polar regions was never exceeded and thus there is insufficient water in the equatorial and mid-latitudinal regions to produce precipitation.

In scenarios (2) and (3) the presence of the ocean provides sufficient global abundance of water to generate globally distributed patterns of precipitation. The zonal and meridional location of the precipitation is closely controlled by the location of the ocean relative to the intra-tropical convergence zone (ITZC). In the larger ocean case, Scenario (3), a sufficient amount of water reaches poleward such that the conditions for monsoonal flow during the southern summer are achieved. This leads to a precipitation distribution that is very similar to the observed distribution of valley networks.

Finally, Scenario (4) shows that an ancient Mars consisting of just valley network lakes, i.e. no ocean, does not generate significant global prcipitation. As shown in Figure 1, the lakes annually experience net evaporation. This evaporated water is cold trapped in either the Olympus Mons region or the polar regions. Once cold trapped, the water is no longer active in the climate system. The lakes simulation results in a similar end state as the globally saturated regolith simulation, Scenario (1).

Conclusion: A minimum global abundance of surface liquid water is required to create the amount and distribution of precipitation seen in the geological evidence. The lakes associated with the valley network system are insufficient to generate global precipitation patterns that would sustain the valley networks. An ocean is required to inject sufficient water into the climate system to develop global distribution of precipitation and surface liquid water.

References:

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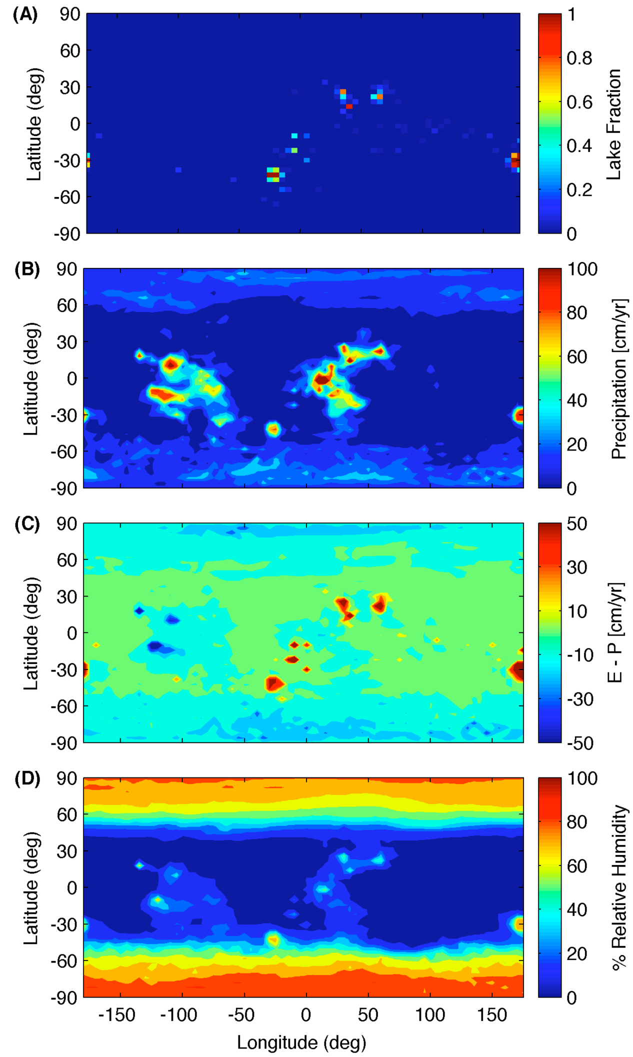

Figure1. Results from the valley network simulations. The lake fraction for each GCM grid cell, **(A)**, is derived from the valley network and lakes map from Fassett and Head (2008) [2]. This lake fraction map is used as the input for the lake simulation. The annual mean precipitation, **(B)**, shows rainfall over the surface liquid water and in the cold regions, i.e. Olympus Mons and the polar caps. Elsewhere the planet sees very little rain. The annual mean evaporation, **(C)**, however, shows a strong peak of net evaporation over the lakes and a peak in net precipitation over the poles and Olympus mons. The rest of the planet sees an E-P of approximately zero. Finally, the annual mean relative humidity, **(D)**, shows the concentration of atmospheric water vapor over the polls.