MODELING MORE COMPLEX EARLY MARTIAN ATMOSPHERES AND DETERMINING THE RESULTING PRECIPITATION AND EROSION RATES

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The early Mars climate problem remains one of the most interesting ones in planetary science. In particular, the high degree of fluvial surface erosion, as exemplified by modified craters and large winding ancient valley networks, suggests that early Mars may have exhibited a more Earth-like climate in the past. However, climate models have always struggled to simulate the warmer and wetter conditions that were apparently required to explain these observations, given that early Mars (˜3.8 Ga) received less than 1/3 the solar insolation that reaches our planet today. One possibility is that warm climate conditions on early Mars were maintained by a multi-bar CO_2-rich atmosphere (with H_2O vapor), mirroring conditions that may have been true during the early days of Earth and Venus. However, climate models have repeatedly shown that a dense CO_2 atmosphere alone is insufficient to generate warm conditions.

This inability of climate models to warm planets using the conventional greenhouse gases (i.e. CO_2 and H_2O) had prompted us and other groups to consider additional warming from secondary absorbers, such as H_2 and CH_4. Both CO_2-H_2 and CO_2-CH_4 atmospheres have been shown to generate above-freezing mean surface temperatures, which are high enough to explain the existence of geological features that were most likely carved by running water.

However, these previous calculations were performed by single-column radiative convective climate models that can only compute mean-averaged planetwide properties and are unable to spatially resolve atmospheric and surface parameters. Such models are also unable to evaluate the effects of oceans on climate, or compute precipitation and the resulting erosion rates to compare with those inferred from observations. On the other end, 3-D models, although quite complex, are very expensive computationally and are unable to explore parameter space as fully and completely as can simpler models. For best results, 3-D models also require a level of knowledge about the planet that, although available for present Earth, is simply unavailable for early Mars, which necessarily results in making many assumptions that cannot be tested or verified as with any other model.

Here, I present my advanced 2-D non-grey energy balance model, which provides a nice compromise between complexity and speed for this problem. It contains 36 latitude bands, clouds, topography, the ice-albedo feedback, and accurate radiative transfer directly computed from detailed single-column climate modeling calculations. Ocean sizes can be varied and planetary parameters, including eccentricity and obliquity can be computed. A typical simulation takes less than a minute. I present some preliminary results (Figure 1).

We will present simulation results for CO_2-H_2 and CO_2-CH_4 atmospheres of various H_2 (0 -20%) and CH_4 (0- 10%) concentrations, pressures (0 –3 bar), while varying ocean size given various literature estimates. From these simulations, we will compute atmospheric and surface temperatures as a function of latitude, yielding precipitation rates, and the resultant erosion rates as a function of latitude. These latitudinal erosion rates will be compared against those inferred for observations. Should such erosion rates be too high, we can conclude that the resultant climates are too wet/warm. Likewise, should they be too low, the climates are not wet enough. Thus, for the first time we will be able to constrain realistic atmospheric compositions using a relatively complex model that may satisfy the available atmospheric and geologic constraints, providing a glimpse into what the ancient atmosphere could have actually been like. We will also discuss the implications of our results and give hypotheses that can be tested by upcoming and future missions searching for ancient geology and even life.

Keywords: early Mars, life, climate, atmospheres, erosion

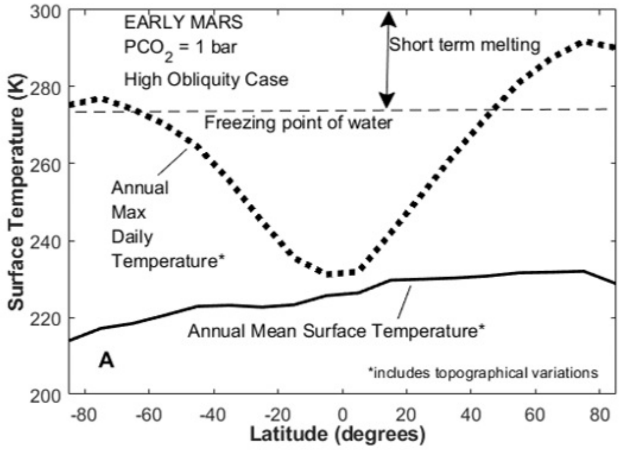

Figure 1: Computed surface temperatures per latitude band, which agrees well with the similar 1-bar case from the 3-D model of Wordsworth et al. 2015 Fig.1.