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Ancient Martian Climate with ROCKE-3D

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Abstract

We present simulations of the ancient Martian climate with the Resolving Orbital and Climate Keys of Earth and Extraterrestrial Environments with Dynamics (ROCKE-3D) general circulation model. We evaluate the efficacy of CO_2-H_2 and CO_2-CH_4 collision-induced absorption (CIA) in producing temperate conditions on Mars during the late Noachian-early Hesperian period near 3.7 Gya. We additionally study the fate of liquid water if it was on the surface during that time period in history.

Geologic evidence indicates that ancient Mars supported widespread surface liquid water approximately 3.5-4 Ga (e.g., [1], [2]). For nearly as long, climate modeling has attempted to find a self-consistent mixture of atmospheric gases with realistic atmospheric pressures that could support a hydrological cycle that is consistent with the geologic evidence (see [3] for an overview). Despite those efforts, substantial doubt remains about the feasibility of a "warm and wet" climate that could have existed for sufficient time to produce the geologic evidence during the period of the faint young Sun.

Recently, [4] and [5] (among others) have shown that H_2, in combination with CO_2 and CH_4, can produce efficient CIA that provides substantial warming at plausible surface pressures (i.e., <2 bar, see [6]) with modest H_2 mixing ratios. Using the CIA tables provided by [5], we evaluate the ability to generate temperate climactic conditions on ancient Mars using the ROCKE-3D GCM.

We conduct a series of ROCKE-3D GCM [7] simulations in two broad groups that we term "dry" and "wet." The "dry" group consists of simulations that are run without open liquid water initialized on the surface, while the "wet" group is initialized with some amount of surface liquid water as either lakes or fully-dynamic oceans.

The dry simulations are conducted to evaluate what mix of pressure and gases can produce global surface temperatures above the freezing point of water. A range of pressures (from 0.5-2 bar) and H_2 mixing ratio (0-10%) are evaluated. The wet simulations are all conducted with a surface pressure and gas mixture that is supportive of surface liquid water and is initialized with planetary water inventories from 10-500 m global equivalent layers.

Both modern topography and a plausible paleotopography (following [8]) is used to evaluate the effect of the Tharsis emplacement and true polar wander on the climate state. We employ a stellar spectrum that is appropriate for 3.8 Ga. All simulations are run until radiative and hydrological equilibrium are reached.

We find that global mean surface air temperatures are only above freezing for high pressure (1.5-2 bar) and/or H_2 mixing ratios of at least 3%. Using modern topography, the high elevations of Tharsis Montes remain below freezing, even with 2 bar surface pressure and 10% H_2. At 1 bar surface pressures, only the lowest elevation areas (e.g., Hellas Planitia) experience any above-freezing temperatures during the year, but remain below freezing on an annual average basis (Figure 1).

Including CH_4 in the atmosphere (at 1%) produces a weak tropopause and distinct stratosphere (defined as warming temperatures with altitude), which also reduces cloud cover. Intriguingly, simulations without CH_4 have increased cloud cover which serves as a more effective hygropause than the CH_4-induced stratosphere, which may be relevant for ancient Martian water loss to space.

The wet simulations that employ modern topography show that water is cold-trapped onto the Tharsis plateau, leaving comparatively little water (relative to the initial planetary inventory) in an active hydrological cycle. What water is available falls as both rain and snow onto Tharsis and near the planetary topographic dichotomy. The initial water inventory is not predictive of the location or amount of precipitation. However, planetary obliquity is important, with 0° obliquity showing increased amounts of precipitation, with some of it falling in locations congruent with valley network formations (e.g., [2]) (Figure 2).

We will also present ongoing simulations with paleotopography and dynamic oceans.

Figure 1: Percent of sols with above freezing daily average surface air temperatures for 10 ROCKE3D simulations with surface pressures and CO_2 and H_2 mixing ratios identified in the panel title. All simulations incorporate dry soil. The black line encloses the areas with 100%.

Figure 2. Annual total liquid precipitation (mm) for 6 simulations initialized with surface liquid water as lakes as shown in the panel title.

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