PROGRESS IN CLIMATE/GROUNDWATER MODELING OF ANCIENT MARS.

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Introduction

While evidence exists for a more complex hydrology during parts of ancient Mars evolution, the timing and duration of these past climates is still debated [1]. The Viking, Mars Global Surveyor (MGS), and Mars Reconnaissance Orbiter (MRO) spacecraft all observed valley networks in the equatorial and southern tropical regions of Mars [2, 3] and lake strandlines/shorelines [4]. Evidence for persistent late stage hydrology in Gale Crater over geologically long time periods (10^4-10^7 yrs) raises questions regarding the nature of hydrology and climate on Mars [5]. Mudstone layers on the crater floor provide evidence for a past lake within Gale Crater [5] and fan deposits suggest younger surface hydrology [6].

Understanding these various observations requires investigation of both the climate hydrology and groundwater hydrology of ancient Mars. A number of groups have investigated the various climate conditions for ancient Mars [7, 8, 9, 10, 11]. As well, the groundwater hydrology of Mars has been investigated by a few groups in the last decade [12, 13, 14, 15, 16]. These investigations, however, have mostly treated the atmospheric and subsurface regimes as entirely separate and disconnected.

We are developing a modeling system that combines the climate modeling and groundwater modeling of the Martian hydrology. We are applying this system to the late Noachian and early Hesperian eras on Mars, with the aim of improving our understanding of the evidence for surface and subsurface water in the Martian geological history. Here we discuss our previous work and our ongoing endeavor to combine the climate and subsurface domains.

Groundwater modeling

Recently, Horvath et al. (2016) studied the potential hydrology of Gale Crater [17]. They used a finite-difference approximation of the groundwater flow equation to simulate subsurface hydrology coupled to an analytical representation of the surface run-off. The model predicted both the patterns of surface and subsurface flow, as well as the distribution of ponded water. Due to uncertainties in modeling the ancient Martian climate [1, 11], Horvath et al. (2016) used the evaporation potential and precipitation rates from Earth-based observations provided by the North American Land Data Assimilation Systems (NLDAS) in order to force their ground water model [17]. They used a semi-arid Great Plains climate from central Kansas, an arid climate from Arizona, and a marine climate from Seattle as proxies for a range of possible hydrological conditions on ancient Mars. The simulations using the driest scenario created no lakes within Gale Crater, while the wettest scenario created an over-abundance lakes. The Horvath et al. (2016) results suggest a much wetter ancient Mars once existed at the time of the Gale crate lake, in fact, an ancient Mars that was comparable in aridity to present-day Kansas.

Previous atmospheric modeling

We have previously investigated the distribution of rainfall on early Mars for a variety of conditions using an Earth GCM, with the Martian surface topography as the bottom boundary (the Mars as Earth, or MEarth model) [18]. Though the use of Earth-like conditions to simulate rainfall in an early Mars is a simplification, it allowed us to investigate the possible patterns of atmospheric circulation and rainfall. Where the Horvath et al. (2016) focused on Gale Crater, our previous work focused on the global affects of precipitation [17, 18]. This work demonstrated that in the presence of an northern lowlands ocean, there would be widespread precipitation at rates of 1 m/yr, in a pattern that approximately matches the distribution of valley networks [18]. This result, however, does not match the arid conditions and low erosion rates observed in the rock record from the Noachian-Hesperian transition [19].

For an Earth-like climate without an ocean, the model predicted drastically lower precipitation rates, and the areal distribution of precipitation was much more restricted. The model predicts a regional zone of orographically driven precipitation over Tharsis and high-latitude precipitation in the cold arctic and subarctic regions. Outside of these regions, the next largest zone of precipitation predicted by the MEarth model occurs at the southeastern edge of Arabia Terra, with mean rates of $\sim$40 cm/yr. This precipitation belt results from upslope flow as winds from the inter-tropical convergence zone travel up Arabia Terra. Interestingly, this predicted region of precipitation is ideally situated to recharge the aquifers of Arabia Terra thereby driving a sustained flux of groundwater upwelling at Meridiani Planum [20].

To achieve these patterns of precipitation in an ocean-free Mars either a shallow groundwater table or widespread pooling of water in lakes and ponds is required to provide a source of water in order to sustain surface and near surface water in the tropics and mid-latitudes [18]. Ultimately, the available water will be 'cold-trapped' in the polar regions. Therefore, liquid water on an early arid Mars would have a limited time to erode the surface or recharge aquifers in the tropics and mid-latitudes. However, times of high orbital obliquity or transient perturbations from impacts or volcanic eruptions could mobilize the cold-trapped water, potentially resetting early Mars' hydrological system [21, 22].

The next step in atmosphere-subsurface modeling

Clearly, the use of Earth-like precipitation levels [17] or Earth-like climate conditions [18] are not realistic and fail to accurately capture the potential hydrological conditions on ancient Mars. Therefore, we are developing updated versions of the models from Soto et al. (2010) and Horvath et al. (2016) in order to improve our understanding of the ancient Martian hydrology and climate [17, 18]. These models will be run together, though not necessarily coupled, in order to improve our understanding of the paleo-hydrological conditions on Mars.

To simulate an ancient Martian climate, we use the Mars Weather Research and Forecasting (MarsWRF) GCM [23]. This version of MarsWRF includes a correlated-k radiative transfer scheme designed for use in Martian paleoclimate studies [24]. To achieve warmer climate conditions than will be generated by the current state of the model, we added a gray infrared absorption factor. Although this is an non-physical means of achieving warm temperatures, it has been shown to be a useful method for exploring a range of warm climate conditions on early Mars by circumventing the question of the specific greenhouse mechanism responsible for the warming [11]. We implemented a moist convection scheme to handle multiple forms of precipitation of water, including rainfall and snow. With this version of MarsWRF, we explore the range of paleoclimate conditions, from cold-dry to warm-wet.

The climate modeling produces precipitation and evaporation maps that are used in the groundwater modeling. Just like in Horvath et al. (2016), we use a hydrological model solves the groundwater flow equation using finite difference methods while using an analytical solution for the surface run-off calculations [17]. This time, the subsurface hydrology model is forced using the results from our MarsWRF simulations. We also accounted for a range in sub-surface properties, focusing on the effects of aquifer permeability. This model incorporates a horizontally uniform aquifer permeability ranging from 10^{-9} cm^2 (comparable to a consolidated bedrock aquifer) to 10^{-6} cm^2 (comparable to a fractured aquifer) and and assumes a simple exponential decrease with depth of the permeability to simulate the closure of pore space.

We will present current results from this new climate/groundwater modeling and show how the two components of the hydrological system interact in the arid conditions of the Noachian-Hesperian transition. We will also discuss our future plans for this type of modeling.

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