EXPLORING POST-IMPACT CLIMATE CONDITIONS FOR EARLY MARS WITH THE AMES GCM.

K. E. Steakley, J. R. Murphy, *Astronomy Department, New Mexico State University, Las Cruces NM, USA (steakley@nmsu.edu)*, **M. Kahre, R. Haberle,** *NASA Ames Research Center, Mountain View, CA, USA*.

Introduction

Numerous valley networks (VNs) have been identified and studied in the martian southern highlands which are thought to have formed roughly 3.5-3.75 Gya (Hynek et al., 2010). Hynek et al. (2010) argue that drainage densities and high stream number of VNs imply they formed from precipitation and runoff and rough estimates of their formation timescales range from 10^2 to 10^4 years or longer (Barnhart et al., 2009; Rosenberg & Head, 2015). Estimates of the amount of water required to form these networks include >12 mm/year of liquid precipitation (Andrews- Hanna & Lewis 2011) and a global equivalent layer of 3-100 m of water (Rosenberg & Head, 2015).

Climate models have struggled to reproduce warm and wet conditions on early Mars (Forget et al., 2013) especially considering the decreased solar luminosity 3.8 Gya to 75% of its current value (Gough 1981). Multiple potential heating mechanisms have been suggested and are being explored for early Mars including impacts (Segura et al., 2002), volcanism (Kerber et al., 2015), hydrogen and CO_2 release via climate cycling (Ramirez et al., 2014; Batalha et al., 2016), and methane release via obliquity changes (Kite et al., 2016). Alternatively, an icy highlands scenario has been suggested (Wordsworth et al., 2013) in which water ice accumulates in the southern highlands in a primarily cold environment and seasonal or periodic melting forms fluvial features. Here, we explore impacts as a potential heating mechanism for early Mars.

Prior studies with 1D and 3D atmosphere models have implied that comet and asteroid impacts might be capable of inducing significant rainfall and sustaining above-freezing temperatures for years (Segura et al., 2002; Segura et al., 2008; Colaprete et al., 2003). Colaprete et al. (2003) found with the Ames Mars Global Climate Model (MGCM) that an impactor roughly 12 km in size could produce up to 400 cm of rainfall in some locations over 100 sols. Despite some promising results, the parameter space of impactor sizes and surface pressures has not been fully explored with a 3D GCM.

The Ames GCM for early Mars

We use the NASA Ames Research Center Mars Global Climate Model (MGCM) with a solar luminosity of 75% of its current value and a surface pressure of 150 mbar. Rather than use the existing microphysics package of the MGCM which includes CO_2, water, and dust cycles that can be coupled, cloud formation via nucleation and growth, and a moment scheme for transport and radiation, we incorporate a simpler hydrological cycle into the MGCM. This hydrological cycle includes three tracers for CO_2 clouds, water vapor, and water clouds which could be liquid or ice similar to Wordsworth et al. (2013). It includes condensation to form clouds in the event that a grid box becomes supersaturated (Manabe et al., 1965), precipitation of water from those clouds in the event that the water cloud to atmospheric mass ratio exceeds a threshold of 0.001 kg/kg (Wordsworth et al., 2013), and sublimation of water from the surface. We account for latent heat exchange in cloud condensation and surface sublimation. It is assumed that precipitation falls to the surface instantaneously with no evaporation. We have also incorporated the effect of collisionally induced CO_2 absorption in the infrared as described in Wordsworth et al. (2010). Physical processes that still require development in the model are cloud particle sedimentation, radiative effects of liquid water clouds and a Manabe moist convection scheme.

Simulating an impact

The conditions produced following an impact are described in multiple papers (Segura et al., 2002; Colaprete et al., 2003; Segura et al., 2008) and begin with the assumption that surface material and the incoming asteroid are vaporized or melted on impact. That hot material, including water, is excavated, leaving behind a crater. It is ejected into the atmosphere and transported globally, heating its surroundings. The molten rock eventually falls to the surface, forming a debris layer that continues to radiate heat. Our initial conditions aim to represent this point after impact when shock waves have dissipated and water vapor and energy are distributed globally within the atmosphere. We estimate the global atmospheric temperature and atmospheric water vapor mixing ratio increases for a range of impactor sizes in Table 1. We assume that impactors are 12.5% water by volume (roughly the value used in Segura et al., 2008) and have impact velocities of 8 km/s (roughly the median impact velocity at Mars according to Sleep & Zahnle, 1998). Resulting crater diameters are calculated by the Dence et al. (1977) crater relations, which are then used to estimate the amount of water stored in Mars' regolith that is excavated from the crater based on the methods described in Segura et al. (2002). Bulk temperature increases of the atmosphere are estimated assuming that 30% of the impact energy (½mv^2) is converted into thermal energy using a specific heat capacity for CO_2 of 0.763 kJ/K/kg. We aim to model these initial conditions to determine whether these amounts of water vapor produce a significant enough greenhouse effect to be able to sustain the imposed warmer temperatures and how water clouds influence that greenhouse effect.

Diam (km)	L_{H2O} (cm)	dT 150 mb (K)	dT 1 bar (K)
0.05	2.27E-04	3.88E-06	5.82E-07
0.1	9.10E-04	3.10E-05	4.66E-06
1	0.0611	0.0310	0.0047
6	1.45	6.71	1.01
8	2.42	15.90	2.38
10	3.59	31.05	4.66
30	25.87	838.23	125.73
50	66.35	3881	582.11
100	251.43	31046	4657

Table 1 . Estimated initial GCM conditions after impacts of various sizes. Columns show impactor diameter (km), global equivalent thickness of water an impactor delivers (cm), temperature increase in a 150-mbar atmosphere (K), and temperature increase in a 1 bar atmosphere (K)

Expected results

We present preliminary 3D GCM results of the effects of some of these post-impact conditions on early Mars climate scenarios. In our first attempt, we follow the initial conditions of Colaprete et al. (2003) with an isothermal atmospheric temperature of 300K, an isothermal subsurface temperature of 350K, and 5 pr-cm of water distributed evenly globally as water vapor (corresponding to an atmospheric mass mixing ratio of 0.01237). This initial test resulted in significantly less precipitation in the first 100 sols than Colaprete et al. (2003), but this was performed without the radiative effects of water vapor or water clouds. Thus far, our simulations result in atmospheric temperature decreases which cause cloud formation and the rainout of most of the water initially injected into the atmosphere.

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