TESTING EARLY MARS IMPACT DELIVERY OF REDUCING GREENHOUSE GASES WITH THE NASA AMES MARS GLOBAL CLIMATE MODEL.

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Introduction: Reducing greenhouse gases H_2 and CH_4 have been shown to be capable of warming early Mars by increasing opacity due to collision induced absorption (CIA) with CO_2 molecules [1, 2, 3]. Theoretical calculations of CO_2-H_2 and CO_2-CH_4 CIA by Wordsworth et al. [2] show that mean annual surface temperatures could have exceeded 273K for early Mars in 1.25 - 2 bar CO_2 atmospheres with molar concentrations of H_2 and CH_4 between 2 and 10%. Turbet et al. [4] present laboratory measurements of CIA over a subset of the wavelengths presented in Wordsworth et al. [2]. They find that measured opacities are lower by a factor of 1.6 and 1.7 for H_2 and CH_4 respectively, but support the findings of Wordsworth et al. [2] that CIA between reducing gases and CO_2 is more significant than between those gases and N_2 (as in [1]).

Impacts have been suggested as a mechanism for potentially delivering reducing gases including H_2 and CH_4 to early Mars [5, 6]. It is thought that impact degassing could have maintained a reducing atmosphere for the early Earth rich in CH_4, H_2, H_2O, N_2, and NH_3 [7, 8, 9]. Haberle et al. [5, 6] calculate the quantities of H_2 that could be delivered to early Mars by impacts and show that for large impactors (>100 km), they exceed quantities required to support above-freezing mean annual surface temperatures in a 1-bar atmosphere according to Wordsworth et al. [2]. They estimate that the cumulative durations of above-freezing surface temperatures due to impact degassing of H_2 during the mid to late Noachian could have been on the order of 10^5 – 10^6 years [6]. The impact hypothesis for warming early Mars has the advantage over other mechanisms that there is ample evidence of crater formation during the Noachian, but is problematic for explaining some geologic observations because the largest craters pre-date the end of valley network activity and the formation of alluvial fans [10].

Previous assessments of potential post-impact greenhouse warming for early Mars have focused only on the water and energy delivered to by impacts and show that although they are capable of inducing periods of above-freezing temperatures and high rainfall rates, these effects are short lived, on the order of a few years at most following an individual impact [10, 11, 12, 13]. Here, we use a 3-D global climate model (GCM) to simulate post-impact scenarios similar to those explored in Steakley et al. [10] now accounting for H_2 delivered by these impacts to test whether this extends the duration of warm and wet conditions. We examine the global distributions of rainfall and warm surface temperatures that follow an impact and assess whether such an environment is consistent with geologic evidence of fluvial activity such as crater degradation [14], valley network formation [15], and/or the formation of nontronite-rich clays [16].

Initial Conditions: In the early, extremely hot stage of a post-impact environment, reduced iron from an impactor and water (from both an impactor and water that is excavated from the planet subsurface during crater formation) can react to produce FeO and H_2. Here we estimate the amount of H_2 that could be produced from Fe and H_2O given a few simple assumptions. We assume the impactor is an iron rich H-type ordinary chondrite that is 30% iron by mass [17] and has a density of 3.4 g/cm^3. Assuming all of this iron is used to make H_2 ($Fe + H_2O \rightarrow FeO + H_2$), we estimate the atmospheric molar concentration of H_2 that would be produced by an impact. Other compounds (e.g., CH_4) would likely be degassed during this process, however, for this study we focus exclusively on the maximum amount of H_2 that could be produced. Given these assumptions, minimum impact diameters of roughly 83 km and 101 km in 2- and 1- bar atmospheres respectively could produce molar concentrations (of 0.03 in a 2-bar atmosphere and 0.1 in a 1 bar atmosphere) high enough to maintain surface temperatures > 270K [2]. It is therefore feasible that impactors of the larger sizes explored in Segura et al. [11, 12] and Steakley et al. [10] could have delivered planetwide warming quantities of hydrogen if they impacted atmospheres with large enough surface pressures.

Here, we simulate a 100-km diameter impactor in an atmosphere with a surface pressure of 2 bar. Following the post-impact initial conditions described in Segura et al. [12], the simulation is initialized with a vertical atmospheric temperature profile following the moist adiabatic lapse rate with a near-surface temperature of 700K. Initially, there is a hot (1500K) subsurface layer that is 2.23 m deep to represent a global debris layer formed from the impact and a well-mixed atmospheric water vapor content equivalent to a 1.75-m thick layer of water if it were evenly distributed on the surface. We also initialize the model with a fixed molecular concentration of hydrogen of 0.05 to represent the quantity produced following a 100-km diameter impactor that is 30% iron by mass. On the timescales over which we run our simulation (10 Mars years), the escape rates of hydrogen from the atmosphere (on the order of 10^{11} molecules cm^{-1} s^{-1} [2, 5]) are negligible.

Early Mars Global Climate Model: We utilize the NASA Ames Legacy early Mars Global Climate Model (eMGCM), which is supported by the Agency's Mars Climate Modeling Center. This version of the model uses an Arakawa C-grid dynamical core: ARIES version 2 [10]. A 2-stream radiative transfer scheme with correlated-k's accounts for gaseous CO_2 and H_2O absorption. We incorporate the Wordsworth et al. [2] coefficients for CO_2-H_2 CIA (adjusted by a factor of 1.6 as per Turbet et al. [4]) into the eMGCM radiation treatment in addition to existing coefficients for CO_2-CO_2 CIA. The radiative effects of liquid and ice H_2O cloud particles are also accounted for [10]. Physical treatments of water cloud microphysics in the eMGCM include bulk H_2O cloud condensation and sublimation when the atmosphere is supersaturated or sub-saturated (with condensed cloud mass distributed equally between a constant number of spherical particles; 10^5 condensation nuclei per kg of CO_2), precipitation when cloud mass mixing ratios exceed 0.001 kg of H_2O per kg of CO_2, gravitational sedimentation, and moist convection [10]. In these simulations, the CO_2 cycle is excluded such that CO_2 does not condense onto the surface nor condense to form clouds. Dust exists as condensation nuclei for H_2O clouds but is not radiatively active, is not lifted from the surface, nor advected through the atmosphere. To represent the faint young Sun approximately 3.8 Gya, solar flux is decreased to 75% of its present day value [18]. Constant values are used for surface thermal inertia (250 J m^{-2} $s^{-1/2}$ K^{-1}) and surface albedo (0.2 for regolith, 0.5 if surface ice is present, 0.07 if liquid surface water is present). Mars' present day topography is used.

Expected Results: We will present preliminary 3-D eMGCM simulation results for the post-impact scenario of a 100-km diameter impactor in an atmosphere with a surface pressure of 2 bar. Results from a simulation that only accounts for the H_2O and energy delivered by this impact will be compared with results from a simulation that additionally accounts for the H_2 delivered by this impact. We will explore whether including the CO_2-H_2 CIA extends the duration of warm and wet conditions that follow an impact and examine annual rainfall and surface temperature distributions to assess whether this environment would support the formation of observed Noachian fluvial features.

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