

THE EFFECT OF IMPACTS ON THE EARLY MARTIAN CLIMATE. A. Colaprete¹, R. M. Haberle¹, T. L. Segura³, O. B. Toon³, K. Zahnle¹, NASA Ames Research Center, Moffett Field, MS 245-3, Mountain View, CA 94035, tonyc@freeze.arc.nasa.gov, ²Program in Atmospheric and Oceanic Sciences, Laboratory for Atmospheric and Space Physics, University of Colorado, Campus Box 392, Boulder, CO, 8030.

Introduction: The first images returned by the Mariner 7 spacecraft of the Martian surface showed a landscape heavily scarred by impacts. Mariner 9 imaging revealed geomorphic features including valley networks and outflow channels that suggest liquid water once flowed at the surface of Mars. Further evidence for water erosion and surface modification has come from the Viking Spacecraft, Mars Pathfinder, Mars Global Surveyor's (MGS) Mars Obiter Camera (MOC), and Mars Odyssey's THEMIS instrument. In addition to network channels, this evidence includes apparent paleolake beds, fluvial fans and sedimentary layers. The estimated erosion rates necessary to explain the observed surface morphologies (Craddock and Maxwell, 1993; Golombek and Bridges, 2000) present a conundrum. The rates of erosion appear to be highest when the early sun was fainter and only 75% as luminous as it is today. All of this evidence points to a very different climate than what exists on Mars today. The most popular paradigm for the formation of the valley networks is that Mars had at one time a warm ($T_{\text{average}} > 273$), wetter and stable climate. Possible warming mechanisms have included increased surface pressures (Pollack et al, 1987), carbon dioxide clouds (Forget and Pierrehumbert, 1997) and trace greenhouse gasses. Yet to date climate models have not been able to produce a continuously warm and wet early Mars (Haberle, 1998). The rates of erosion appear to correlate with the rate at which Mars was impacted (Carr and Waenke, 1992) thus an alternate possibility is transient warm and wet conditions initiated by large impacts. It is widely accepted that even relatively small impacts (~10 km) have altered the past climate of Earth to such an extent as to cause mass extinctions (Toon et al., 1997). Mars has been impacted with a similar distribution of objects. The impact record at Mars is preserved in the abundance of observable craters on its surface. Impact induced climate change must have occurred on Mars.

Impacts: The impacts of asteroids and comets larger than 100 km in diameter have left more than thirty craters on Mars (Kieffer et al. 1992). Collisions of such large, energetic objects result in the production of meters thick debris layers that are global in extent (Melosh 1989; Sleep and Zahnle, 1997). For example, an object with a diameter of 100 km will result in a global melt/vapor debris layer approximately 10 cm thick (Melosh 1989; Sleep and Zahnle, 1997). This

debris layer will be very hot having temperatures in excess of 1000 K.

In addition to the heat introduced by the impact, a substantial amount of vaporized water, both from the impactor itself and from the target material is injected into the atmosphere. Following the impact, the thermal pulse that travels downward into the regolith may release additional water from subsurface reservoirs adding to the total liquid water amount at the surface. Water vapor is an excellent greenhouse gas and works to trap the impact generated heat within the atmosphere. The heat from the debris combined with the additional greenhouse afforded by the injected water vapor could result in periods of warmth. Segura et al. (2002) demonstrated that asteroids with diameters larger than 100 km could warm the surface of Mars for several years to decades. However, numerous valley networks have been dated to periods after the majority of these large ($D > 100$ km) objects had impacted Mars.

The simulations conducted by Segura et al. (2002) were limited to 1D and thus only considered impacts which would have a thick (> several cm) global debris layers. There are, however, more than 1000 craters with diameters larger than 60 km on Mars. A 60 km crater would result from an impactor with a diameter of approximately 6 km. While these smaller impactors do not have thick global debris layers, they do have dramatic regional effects that are similar to those proposed by Segura et al. (2002).

GCM Simulation: The obvious limitation of the 1D calculations of Segura et al. (2002) is the absence of dynamics and the ability to model smaller impacts that do not have thick global debris layers. An accurate assessment of the effects of impacts on the climate will need to include the transport of both heat and water vapor. Reported here are the results of post impact climate simulations using the Ames Mars General Circulation Model (MGCM). A hydrological cycle has been incorporated into the Ames MGCM that includes the formation of clouds, precipitation, and surface and regolith reservoirs. In these simulations, impacts by objects as small as 4 km in diameter can be simulated.

Each simulation is initialized to represent the conditions just following an impact. After a period of simu-

lation time, an impact debris layer and atmospheric thermal plume is emplaced at any location in the model. The impact debris layer thickness and extent, and the thermal plume temperature and extent, is defined as a function of impact diameter. Regolith water abundance and distribution can be specified for each simulation. If regolith temperatures rise above freezing water is allowed to diffuse to the surface at a fixed rate. Infiltration of the subsurface by surface water is not currently modeled. Both water clouds (wet and cold microphysics) and carbon dioxide clouds are modeled. Water and CO₂ cloud radiative effects are included. In this presentation results are shown for an early Mars atmosphere containing 300 mbars of CO₂ and a solar flux that is 75% current levels.

Results: Two key simulation results include the total precipitation and the total liquid water at the surface. Total precipitation is defined as either snow or rain. The total liquid water (TLW) at the surface is a measure of any water at the surface that is warmer than 273 K. This water may be in the form of surface melt (e.g. melting snow or ice) or large bodies of water (e.g. seas or lakes). Figure 1 shows an example of the total precipitation resulting from a 20 km diameter impactor (no cloud radiative effects). Following impact surface temperatures can rise well above freezing for several years even for impacts smaller than 10 km in diameter.

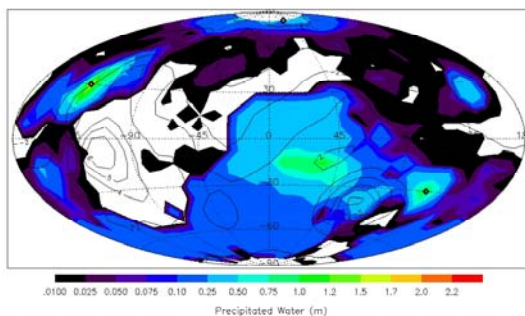


Figure 1 The total integrated rain following the impact of a 20 km diameter impactor. In this simulation the regolith water abundance as assumed to be 20% (by mass) and to be uniformly distributed.

A range of impact sizes has been modeled so that the total amount of resulting precipitation as a function of impact diameter can be parameterized. Using this parameterization it is possible to estimate the total integrated precipitation and TLW that has occurred over the history of Mars based on the observed crater record (Figure 2). Based on these results it is likely that impacts have been a significant, and possibly the dominant source of erosion during Mars distant past.

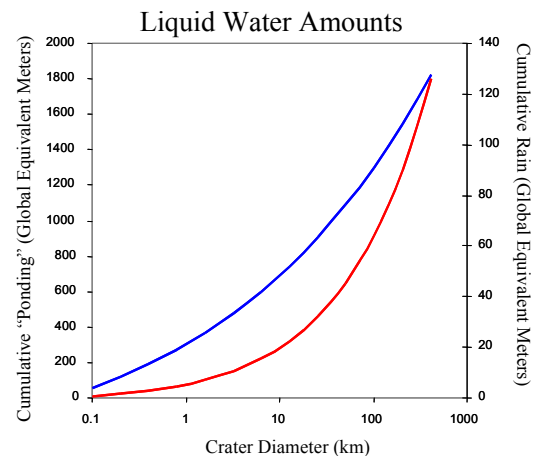


Figure 2 Total precipitation and total liquid water amounts assessed from a series of simulations for a range of impact diameters and the observed Martian crater record. These results do not include the radiative effects of clouds.