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Effects of meteorites and asteroids bombardments on the atmospheric evolution on Mars

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Abstract

Early in its history, Mars probably had a denser atmosphere with sufficient greenhouse gases to sustain the presence of stable liquid water at the surface. Previous studies have showed that asteroids and comets impacts could affect the atmospheric evolution not only by causing atmospheric erosion but also by delivering material and volatiles to the planet. Here, we investigate the atmospheric loss and the delivery of volatiles with the help of a simplified semi-analytic model that takes into account the impact simulation results.

1. Introduction

In its early history, Mars probably had a denser atmosphere which might have provided conditions favorable for the presence of liquid water on the surface, an essential prerequisite for the beginning of life and its further evolution [8]. By bringing volatiles and by removing part of the Martian atmosphere, impacts by asteroids and comets could have influenced its evolution [1].

In order to compute the atmospheric mass evolution due to impact erosion and delivery, we use an analytical model which incorporates the results from impact simulations and impactor flux estimates given in the literature [3] [7] [9] for an exponentially decaying impact flux [6].

2. Impact model

The mass of atmospheric gas escaped and delivered can be calculated by numerical models (hydrocodes), in which equations of motion and state are solved over discretized space and time. Among the difficulties of modeling impact processes with hydrocodes there are the choice of an appropriate equation of state and a proper modeling of the vapor cloud dynamics.

Based on the results of hydrocode simulations, analytical models such as the "tangent plane model" have been developed for computing the long term atmospheric mass evolution.

The tangent plane model considers a minimal impactor mass, the critical mass, m_{crit}, that can remove all the atmospheric mass above the plane tangent to the impact surface (m_{tan}) (for example, Melosh and Vickery, 1989). It is specified that

$$m_{crit} \geq m_{\tan} = \frac{m_{atm} H}{2R} \qquad (1)$$

with m_{atm} as the atmospheric mass of the planet, $H = \frac{R_{pg} T}{m_{mol}\, g}$ the atmospheric scale height of the planet, with R_{pg} the perfect gas constant, T the temperature, m_{mol} the molar mass of the atmosphere, g the gravity of the planet, and R as the planet radius.

5. Equations

The escaped and delivered atmospheric mass rates are:

$$\frac{dM_{atm}(t)}{dt} = \frac{dM_{del}(t)}{dt} - \frac{dM_{esc}(t)}{dt} \qquad (1)$$

$$\frac{dM_{esc}(t)}{dt} = \frac{\partial N_{cum}(>m_{crit}(t),t)}{\partial t} 4\pi R^2 \left[m_{\tan}(t) f_{vit}\, f_{obl}\right] \qquad (2)$$

$$\frac{dM_{del}(t)}{dt} = \frac{\partial N_{cum}(>m_{crit}(t),t)}{\partial t} 4\pi R^2 \left(\frac{b}{1-b}\right)\left[m_{crit}(t) y_{imp}\, f_{vap}\right] + \frac{\partial N_{cum}(>m_{crit}(t),t)}{\partial t} 4\pi R^2 \left[m_{crit}(t) y_{imp} (1 - f_{vit}\, f_{obl}) g_{vap}\right] \qquad (3)$$

where $\frac{\partial N_{cum}(>m_{crit}(t),t)}{\partial t}$ is the impact flux of mass greater than the critical mass, and f_{vel}, f_{obl}, y_{imp}, f_{vap} and g_{vap} the factors of velocity, obliquity, volatiles content, vaporization for $m < m_{crit}$, and for $m > m_{crit}$ and $v < v_{min}$ for erosion respectively.

The efficiency of impact erosion and delivery is determined by the value of the critical mass, parameterized by $n = m_{crit}/m_{tan}$. Increasing n decreases the escaped atmospheric mass rate and increases the delivered atmospheric mass rate. Following the value of n, impacts can remove atmospheric or deliver volatiles to it. Figure 1 gives atmospheric mass evolution for two extremes values of *n*: *n* = 10 and *n* = 2400.

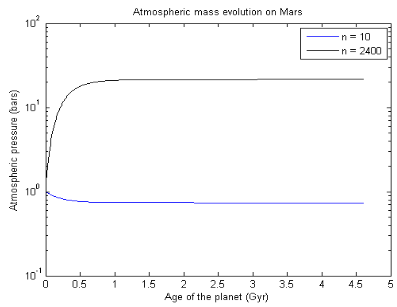

Figure 1: Evolution of the surface pressure P on Mars as a function of time t, assuming an initial surface pressures: P(t= 0) = 1 bar. The calculations are made for the tangent plane model, with different values of n (see legend on the figure). Calculations are made following an exponential decaying impact flux.

Impacts cause atmospheric erosion only for little *n* values (*n* = 10). Even with *n* = 10, erosion by impacts is not sufficient to explain a surface pressure high enough to support liquid water at the Martian surface.

6. Summary and Conclusions

In this paper we considered the impacts of meteorites and comets on Mars and their influence on atmospheric mass evolution by erosion and delivery of volatiles. Our results suggest that impacts can erode more easily the primitive atmosphere of Mars, if its initial surface pressure was lower compared to Earth. Since other escape mechanisms are omitted and most of the parameters used in present study are far from being exact, the present solutions are representative, and should not be considered as actual atmospheric evolutions of the planet. Nevertheless they provide insight to the atmospheric evolution by comparing the influences of initial conditions and of the main physical parameters of Mars. The next step of this work will be to consider impact fluxes of comets and asteroids (separately) related to the early history of the solar system including the late heavy bombardment, using numerical simulation output of the solar system [2] [4] [5].

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