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Effects of giant impacts on the mantle and atmosphere of terrestrial planets at medium and long time scales.

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Abstract

Our main interest is to understand how surface conditions change during a planet's evolution and which mechanisms are most important. Therefore, we investigate how the coupled evolution of Venus' atmosphere and mantle is modified by giant impacts. We focus on volatile fluxes in and out of the atmosphere: atmospheric escape and degassing. We link those processes into a coupled model of mantle convection and atmospheric evolution. Feedback of the atmosphere on the mantle is included via surface temperature. As large impacts are capable of contributing to atmospheric escape, volatile replenishment and energy transfer, we estimate their effects on the evolution of Venus.

1. Introduction

The study of terrestrial planets' surface conditions and their evolution with time is necessary to understand how and when a planet becomes habitable. Recently, perception of the importance of interactions between interior and exterior has led to better understanding of the evolution of planets [1, 2, 3]. Due to its activity and dense atmosphere, Venus is a perfect place to test models. While it has similar general characteristics to Earth, conditions at its surface are very different, with an average surface temperature of around 740 K, due to its 92 bar CO_2 atmosphere. The solid part of the planet could still be active [4, 5]. Additionally, it is generally thought that, based on crater counting, the surface of Venus is relatively young. Our understanding of the formation and early evolution of the solar system and observation of its terrestrial bodies shows that impacts are unavoidable. Giant collisions, in particular are suspected to have strong effects on the surface conditions of terrestrial planets. We want to understand how they can affect a Venus-like planet.

2. Model

The model can be separated into four different parts.

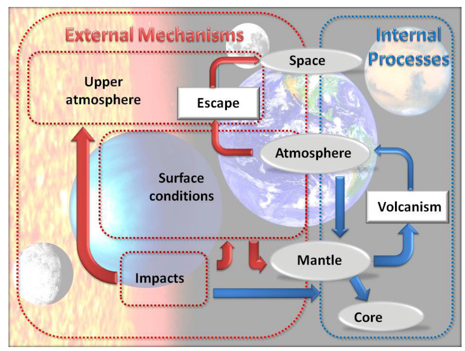

Figure 1: basic layout of the model.

(i)Internal processes are dependent on mantle dynamics. We use a variation of the StagYY code designed for Venus [6]. Physical are depth-dependent. The phase transitions in the olivine system and in the pyroxene-garnet system are included. The assumed rheology is Newtonian diffusion creep plus plastic yielding. Degassing is calculated when melting occurs and we use a wide range of possible lava compositions (10-300 ppm for water, 5-5000ppm for CO_2).

(ii)Atmospheric escape modeling involves two different aspects: hydrodynamic escape (0-500 Myr) and non-thermal escape mechanisms (dominant post 4 Ga). Hydrodynamic escape is the massive outflow of light volatiles into space occurring when the solar energy input (Extreme UV and solar wind) is strong. Post 4 Ga escape from non-thermal processes is comparatively low. It is also powered mainly by EUV. Mechanisms include sputtering, ion pick-up, plasma clouds and dissociative recombination. Constraints include present-day measurements by the ASPERA instrument and recent numerical simulations.

(iii) Surface conditions are calculated from the greenhouse effect of main gases from the atmosphere: water and CO_2. We use a one-dimensional radiative-convective grey atmosphere model modified from [1]. Surface temperature is thus calculated and used in the mantle convection model as a boundary condition.

(iv)Impacts can bring volatiles and erode the atmosphere. Mantle dynamics are modified by the large amount of energy brought to the mantle. A thermal anomaly created by the impact is used and can lead to melting. Volatile evolution due to impacts is heavily debated so we test a broad range of impactor parameters (size, velocity, timing) and test different impact erosion factors.

3. Results

We are able to produce models leading to present-day-like conditions through episodic volcanic activity consistent with Venus observations (eruption rates, present-day state, possible resurfacing events). Changes in water vapor partial pressure lead to variations in surface temperatures of up to 200 K during, which have been identified to have an effect on volcanic activity. We note a clear correlation between low temperature and mobile lid regime.

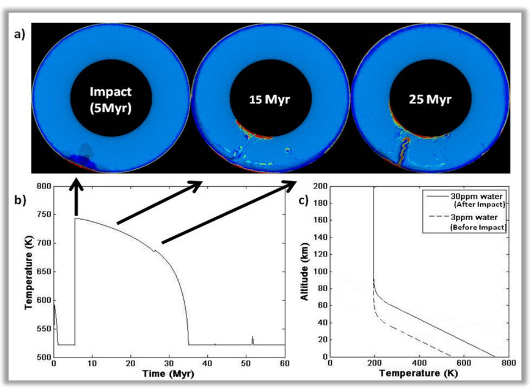

Figure 2: short term effects of a large impact.

We observe short term and long term effects of the impacts on planetary evolution. Single impact atmosphere erosion affects evolutions only in a marginal way, even for massive (up to 800 km) impacts. For volatile balance, smaller (less than 50 kilometer scale) meteorites have a negligible effect. Larger ones (from 100 km up) generate melt both at the impact and later on, due to volcanic events they triggered. A significant amount of volatiles can be released on a short timescale.

Truly massive impacts (400+ km) can even have global and billion years scale consequences, especially when they occur at specific times.

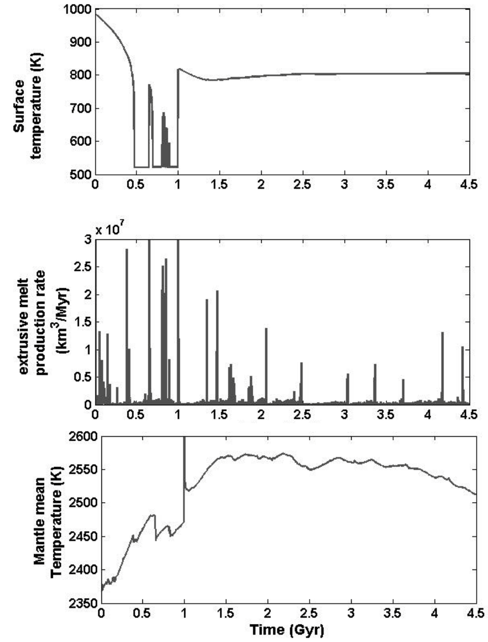

Figure 3: Long term evolution of Venus with a 400 km impact 3.5 Ga ago.

Early impacts can deplete much of the initial volatile content of the mantle, leading to low later degassing if the mantle is not replenished (subduction).

Later impact can counteract the effect of atmosphere escape by releasing volatile into the atmosphere at a larger rate than volcanism in a single event. The resulting high surface temperatures affect directly mantle convection pattern and can prevent mobile lid regime from initiating, with profound consequences for volatile exchanges and mantle evolution.

References

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