EPSC Abstracts
Vol. 9, EPSC2014-52, 2014
European Planetary Science Congress 2014

Large impacts and the evolution of Venus; an atmosphere/mantle coupled model.

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Abstract

Our main interest is to understand how surface conditions on a planet change over time together with mantle dynamics and other processes, common to most terrestrial bodies. To this end, we investigate how the coupled evolution of the atmosphere and mantle on Venus is modified by the occurrence of large impacts. We focus on mechanisms that deplete or replenish the atmosphere: atmospheric escape and volcanic degassing. These processes are linked to obtain a coupled model of mantle convection and atmospheric evolution, including feedback of the atmosphere on the mantle via the surface temperature. Large impacts are capable of contributing both to atmospheric escape and to volatile replenishment; we estimate their effects on the evolution of Venus.

1. Introduction

Habitability is normally considered to require the existence of liquid water at or near the surface. The study of terrestrial planets' surface conditions and their evolution with time is therefore necessary to understand how and when a planet becomes habitable or ceases to be. Recently, increasing perception of the importance of interactions between interior and exterior has led to better understanding of planets. In particular, feedbacks between the different layers of the planet have become the focus of studies [1, 2, 3, 4] and been identified as important mechanisms. Due to its activity and dense atmosphere, Venus is a perfect place to test these models. Venus has similar general characteristics to Earth. Conditions at its surface are very different, however, with an average surface temperature of around 740 K, due to the strong greenhouse effect of its 92 bar CO_2 atmosphere. The solid part of the planet is still active, as evidenced both by indirect clues [5] and by direct recent observations [6]. Additionally, it is generally thought that, based on crater counting, the surface of Venus is relatively young.

2. Model

The model we use can be separated into four different parts illustrated on figure 1.

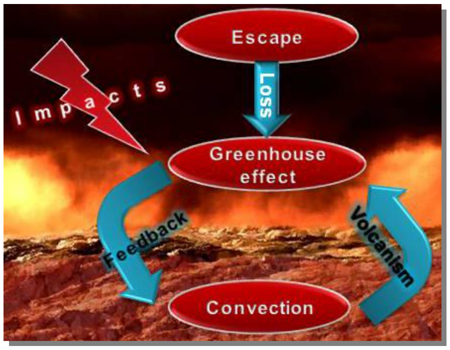

Figure 1: basic layout of the model.

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 from the atmosphere into space occurring when the solar energy input (Extreme UV and solar wind) is strong. We model it following [7] and take into account the effects on oxygen loss and noble gases fractionation. 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.

Surface conditions are calculated from the greenhouse effect of main gases from the atmosphere: water and CO2. 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.

For mantle dynamics, we use a variation of the StagYY code designed for Venus [8]. Physical properties like density, thermal expansivity and thermal conductivity 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 CO2).

Impacts can bring volatiles as well as erode the atmosphere. Mantle dynamics are modified since the impact itself can also bring large amounts of energy to the mantle. A 2D distribution of the thermal anomaly due to the impact is used and can lead to melting. Volatile evolution due to impacts (especially the large ones) is heavily debated so we test a broad range of impactor parameters (size, velocity, timing) and test different assumptions related to impact erosion going from large eroding power to recent parameterization [9].

3. Results

We are able to produce models leading to present-day-like conditions through episodic volcanic activity consistent with Venus observations, including eruption rates, present-day activity, mainly young surface and possible resurfacing events. Without any impact, CO_2 pressure only slightly increases due to degassing. On the other hand, water pressure varies rapidly due to volcanic events and corresponding degassing. These changes lead to variations in surface temperatures of up to 200 K during late evolution, which have been identified to have an effect on volcanic activity. We observe a clear correlation between low temperature and mobile lid regime.

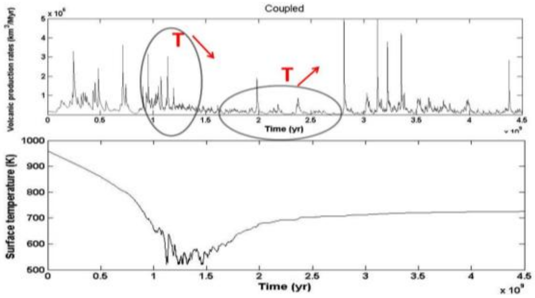

Figure 2: Feedback of surface temperature on volcanic activity in the coupled model.

We observe short term and long term effects of the impacts on planetary evolution. While small (less than kilometer scale) meteorites have a negligible effect, large ones (up to around 100 km) are able to bring volatiles to the planet and generate melt both at the impact and later on, due to volcanic events they triggered due to the changes they make to mantle dynamics. A significant amount of volatiles can be released on a short timescale. Depending on the timing of the impact, this can have significant long term effects on the surface condition evolution. Atmospheric erosion caused by impacts, on the other hand, and according to recent studies seems to have a marginal effect on the simulations, although the effects of the largest impactors is still debatable.

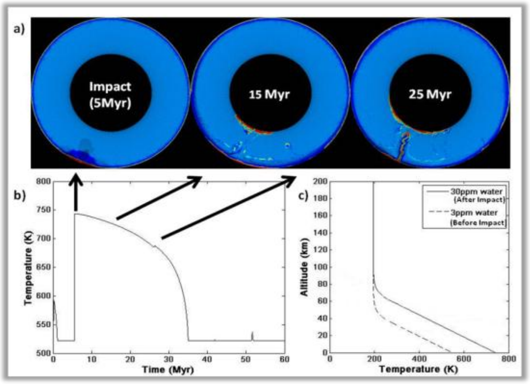

Figure 3: short term effects of a large impact.

References

[1] Phillips, R.J., Bullock, M.A., Hauck II, S.A. Climate and interior coupled evolution on Venus. Geophys. Res. Lett. 28, 2001. **[2]** Gillmann, C. and Tackley, P., Atmosphere/mantle coupling and feedbacks on Venus, JGR Planets, 2014. **[3]** Noack, L., D. Breuer & T. Spohn, Coupling the Atmosphere with Interior Dynamics: Implications for the Resurfacing of Venus, Icarus 2012. **[4]** Lenardic, A., Jellinek, A.M., Moresi, L.-N. A climate induced transition in the tectonic style of a terrestrial planet. EPSL 2008. **[5]** Bullock, M.A., Grinspoon, D.H., The recent evolution of climate on Venus. Icarus 150, 2001. **[6]** Smrekar, S. E., E. R. Stofan, N. Mueller, A. Treiman, L. Elkins-Tanton, J. Helbert, G. Piccioni, and P. Drossart Recent Hotspot Volcanism on Venus from VIRTIS Emissivity Data. Science 328, 2010. **[7]** Gillmann, C., E. Chassefière & P. Lognonné, A consistent picture of early hydrodynamic escape of Venus atmosphere explaining present Ne and Ar isotopic ratios and low oxygen atmospheric content, EPSL, 286, 2009. **[8]** Armann, M., and P. J. Tackley, Simulating the thermochemical magmatic and tectonic evolution of Venus's mantle and lithosphere: Two-dimensional models, J. Geophys. Res., 2012. **[9]** Shuvalov, V., Atmospheric erosion induced by oblique impacts. Met. & Planet. Sc. 44, 2009.