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Coupling of Interior Dynamics Models with Global Atmosphere Models and its Application to Venus

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Abstract

In the present work, we have coupled a 2D convection model with a 1D gray atmosphere model to study the interaction between the interior dynamics and the atmosphere evolution. We have applied this model to Venus and identified a self-consistent mechanism for a temporal surface mobility.

1. Introduction

The atmospheric and climatic evolution of a planet is mainly controlled by the solar flux and the amount of greenhouse gases in the atmosphere. The latter can change significantly with time due to the release of greenhouse gases from the planetary interior as a consequence of partial melting and the associated volcanic degassing. In fact, a positive feedback process can operate by the release of greenhouse gases to the atmosphere via mantle melting, leading to an increase in the surface temperature which on the other hand may result in an increase of the mantle temperature and then in an increase of the partial-melting rate [1]. The coupling between the interior and the atmosphere, however, is not well understood and here we present a preliminary study of a coupled atmosphere-interior evolution for Venus with a 2D convection model and a gray radiative-convective atmospheric model.

2. Computational Model

We have used the 3D spherical simulation code GAIA [2] including partial melt production and coupled it with the atmosphere module CIDGA using a gray greenhouse model for varying H_2O concentrations. This way, not only the influence of mantle dynamics on the atmosphere can be investigated, but also the re-coupling effect, which the surface temperature has on the mantle dynamics. So far, we consider one-plate planets without crustal and thus volatile recycling. Phillips et al. [2001] already investigated the coupling effect of the surface temperature on mantle dynamics by using simple parameterized convection models for Venus. In their model a positive feedback mechanism has been observed, i.e., an increase of the surface temperature leads to an increase of partial melt and hence an increase of atmospheric density and surface temperature, leading to a positive run-away effect, which destabilizes the climate of the planet.

3. Results

Applying our model to Venus, we show that an increase of surface temperature leads not only to an increase of partial melt in the mantle; it also strongly influences the style of mantle convection. As a consequence, the positive feedback process as suggested by [1] is not predicted in our model for all cases. In particular when the surface temperature reaches a critical value, i.e., about 800-900 K depending on the rheology, for which convection turns from a stagnant lid regime in a sluggish-like regime, see Figure 1.

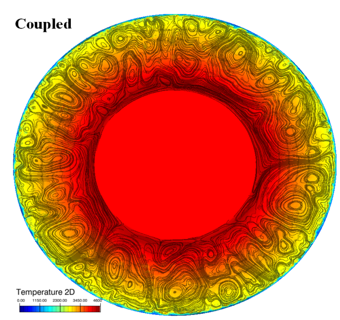

Figure 1: Snapshot of temperature slice for a steady state simulation with a coupled atmosphere model. The increase in the surface temperature allows for a mobilization of the lid (no plate tectonics!).

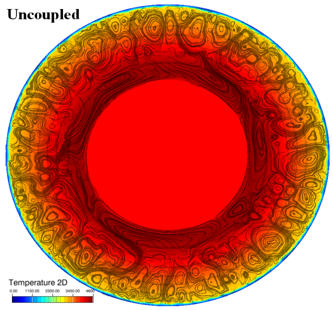

Figure 2: Snapshot of the temperature for a steady state simulation after 4.5 Ga. Here, the change in the surface temperature is not included in the mantle convection model. A constant surface temperature of 737 K is used.

At the time of surface mobilization, the mantle cooling is enhanced resulting in a smaller melt production and consequently a decrease in the surface temperature - a negative feedback mechanism starts to regulate the concentration of greenhouse gases in the atmosphere.

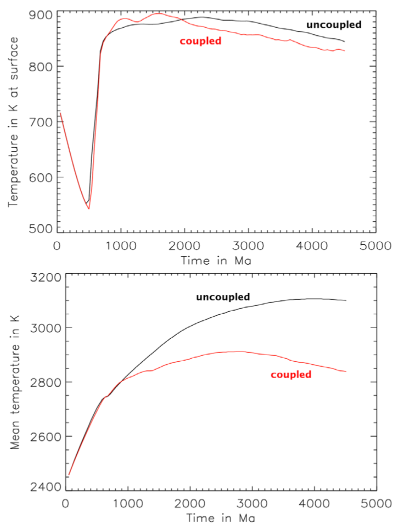

Figure 3: Surface temperature (top) and mean mantle temperature of Venus for the coupled and the uncoupled case. After the lid begins to mobilize for the coupled model, the mantle cooling is very effective, and the mean mantle temperature sinks.

4. Summary and Conclusions

This simple model indicates that the young surface of Venus could be explained with a strong variation in surface temperature. High degassing rates lead to a mobile surface (not plate tectonics, which would need a cold and stiff crust) and thus new material at the surface. This resurfacing event appears (and disappears) self-consistently when coupling the thermal evolution of Venus with an atmosphere model.

References

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