CIDGA Coupling of Interior Dynamic Models with Global Atmosphere Models

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Introduction

Climate models and surface temperatures mostly depend on the solar heat flux and the composition of the atmosphere. The latter can be influenced by interior processes of the planet like volcanism, that releases greenhouse gases such as H_2O and CO_2 into the atmosphere, and plate tectonics, that recycles the atmospheric CO_2 into the mantle. A higher concentration of greenhouse gases in the atmosphere results in a higher surface temperature, which might influence the convection pattern in the mantle of the planet and hence influence surface processes (Phillips et al., 2001). This feedback relation between mantle convection and atmosphere is still not very well understood, since until now mostly either the interior of a planet or its atmosphere was investigated. 2D or 3D mantle convection models to the author's knowledge haven't been coupled to the atmosphere so far.

The 3D spherical simulation code GAIA developed by the Joint Planetary Interior Physics Research Group of the University Münster and IfP DLR Berlin (Hüttig et al., 2008) has been extended by the atmosphere module CIDGA using a gray greenhouse model.

Model

The atmospheres of a terrestrial planet can be devided into a convective layer directly above the surface (the troposphere) and a radiative layer. For both layers, the temperature profile is calculated for the greenhouse gas H_2O.

In the convective layer, the temperature T_c decays linearly with altitude z along the dry adiabatic lapse rate $\varGamma_d$,

$$\frac{dT_c(z)}{dz} = -\varGamma_d. \tag{1}$$

In the radiative layer, the temperature T_r depends on the effective temperature T_e and the optical thickness τ, which is taken to be wavelength-independent.

$$T_r(z) = \left(1 + \frac{3}{4}\tau(z)\right)^{1/4} T_e. \tag{2}$$

The optical thickness depends on the time-dependent amounts of particles of the different greenhouse gases, which define the partial pressures P_i, and on the absorption coefficients k_i, which do not change with time (Phillips et al., 2001),

$$\tau(z) = \frac{H}{k_B T_{Surf}} \left(\sum_i k_i P_i\right) e^{-z/H}, \tag{3}$$

where H is the scale height, k_B the Boltzman constant, and T_{surf} the surface temperature.

Results

With CIDGA, not only the influence of mantle dynamics on the atmosphere can be investigated, but also the recoupling effect, that the surface temperature has on the mantle dynamics. (Phillips et al., 2001) already investigated the coupling effect of the surface temperature on mantle dynamics by using simple scaling laws for the amount of partial melt and the mantle convection. In this model, an increase of surface temperature leads to an increase of partial melt and hence an increase of atmopshere density and surface temperature.

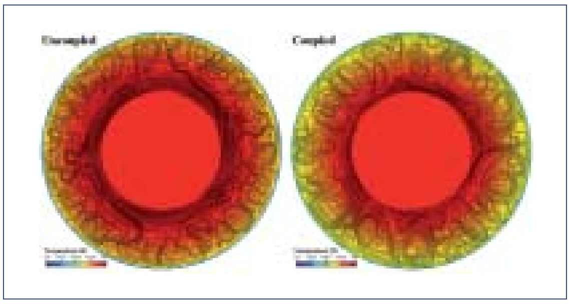

Fig. 1. – Temperature snapshots of Venus after 2.3 billion years. The mantle of the uncoupled case (left) is warmer than for the coupled case (right), since the isolating effect for the coupled case is strongly reduced.

Investigating the thermal evolution of Venus (Fig. 1), it has been shown that an increase of surface temperature leads not only to an increase of partial melt in the mantle, but also to a strong decrease of lid thickness and hence its isolating effect. The mantle temperatures and with this the amount of partial melt decrease much faster than when the change in surface temperature has not been considered for the mantle convection. This result was quite unexpected, leading to the conclusion, that the surface temperature has a much stronger effect on mantle dynamics than previously thought and is not predictable.

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References

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