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Numerical investigations on the relationship between hot plumes and coronae on Venus

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Introduction

The ESA Venus-Express mission has provided data on the composition of Venus atmosphere [1] and on the surface brightness [2]. It has recently been proposed that climate changes on Venus could induce a transition from plate-tectonics to stagnant-lid convection [3]. High values of the surface brightness are correlated with three hot-spots in the Southern Hemisphere: Themis, Dione and Imdr [4]. Analysis of gravityy/topography data shows that they have deep compensation depths, thin elastic lithosphere, or both, implying the presence of a plume. Coronae, which are circular geological features unique to Venus [5], are present in these areas. As a preliminary step to a better understanding of the relationship between internal dynamics and atmospheric evolution, this study investigates the relationships that may exist between hot plumes of the convective mantle and the characteristics of hotspots and coronae.

Description of the numerical runs

Numerical runs describing convection processes in a 3D spherical shell are performed with the OEDIPUS code [6]. This code uses the cubic-sphere projection which divides the sphere into 6 different volumes of equal geometry. Only one cube is used. The finite-difference formulation allows us to investigate the behaviour of a fluid having a strongly temperature-dependent viscosity. The viscosity obeys the relation: $\nu=\nu_0.\exp\{-avis.\theta\}$ where ν_0 is the surface viscosity, avis is a coefficient and $\theta=(T-T_0)/\Delta T$ is the non-dimensional temperature where T_0 is the surface temperature and ΔT is the temperature difference across the spherical shell. This viscous lawequation gives a good representation of the viscosity variations in the convective fluid if the viscosity follows an Arrhenius-type law. The larger is the value of avis, the larger the activation energy.

It is assumed that convection operates in the whole mantle. The effect of phase transitions and mineral transformations is not taken into account. In this first set of runs, volumetric heating is not taken into account in order to favour the formation of hot plumes at the core/mantle boundary.

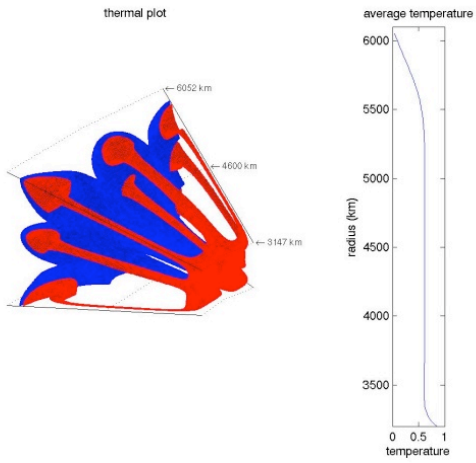

Figure 1: Geometry of the hot plumes (red) forming at the core/mantle boundary. The figure has been rotated to help visualize the plumes. The horizontally-averaged temperature versus depth is represented on the right side.

Convection is driven by the temperature difference across the mantle. Hot plumes form at the core mantle boundary and cold plumes form at the cold thermal boundary layer below the stagnant lid (Fig. 1). Different viscosity contrasts have been investigated as well as different temperature differences across the mantle. For each run, the number of plumes, the mean diameter of the

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plumes, and their vertical velocity are determined at mid-depth. Mean temperature (Fig. 1) and heat-flux are also calculated.

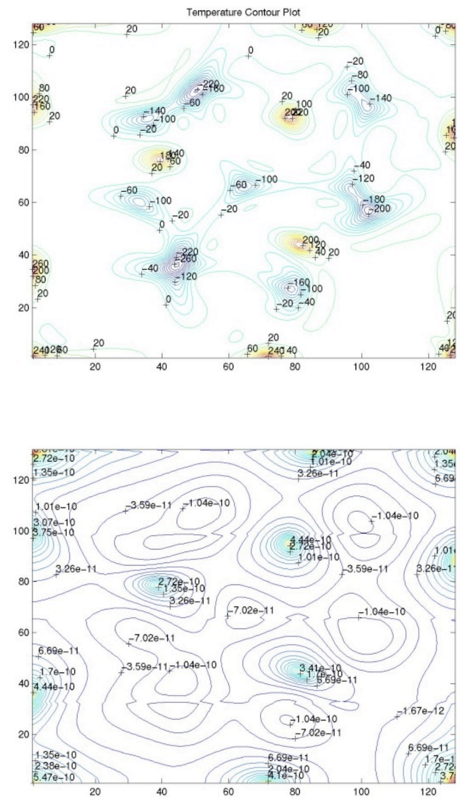

Figure 2: Example of a temperature (top) and velocity (bottom) field at mid-depth. These plots are used to determine the characteristics of the plumes.

Results and implications for Venus internal dynamics and evolution

In the numerical runs performed to date, the number of plumes varies between 4 and 8 depending of the value of the Rayleigh number and on the activation energy for the viscosity. This number of plumes is quite small. The diameter of the plumes is equal to several hundreds of kilometres (Fig. 2), which is much larger than the characteristics of the coronae. The velocities within the plume (Fig. 2) allow us to determine the flux of material which is transported towards the surface.

Several other parameters are being investigated at present time. First, the relationship between the thickness of the lower thermal boundary layer and the width of the plume would provide a means to extrapolate the present results to more realistic values of the Rayleigh number. Second, the characteristics of the lower thermal boundary layer (thickness, temperature difference and heat flux) are being compared with scaling laws issued either from isoviscous spherical runs or Cartesian simulations for fluids having a temperature-dependent viscosity. Third, the temperature profiles within the plumes are being compared with the solidus of mantle material to evaluate the amount of volcanism that could erupt on Venus surface. Fourth, the shear stress along the conductive lid is compared with the yield strength of the lithosphere to assess the conditions that would allow the lithosphere to break.

Conclusions

These first experiments are being used to assess how scaling laws based on either 'Cartesian-coordinates & fluid with complex viscosity' or 'spherical geometry & isoviscous fluid' are modified by this more realistic geometry. They will be used to extrapolate the present results to cases which may be closer to Venus conditions. This approach should allow us to better assess the correlation that may or may not exist between the upwelling plumes and the coronae. It will enable us to choose between the different models proposed for coronae [7]. The effect of surface temperature on the internal dynamics and the behaviour of the stagnant lid will be also assessed.

References

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