

**THE EVOLUTION OF SURPRISINGLY STATIONARY PLUMES WITHIN VENUS.** S. D. King, G. T. Euen, Department of Geosciences, Virginia Tech, Blacksburg, VA 24061 ([sdk@vt.edu](mailto:sdk@vt.edu)).

**Introduction:** We have previously shown that the pattern of the initial condition can persist in a stable convective planform for more than 2.5 Gyr in stagnant-lid, spherical-shell convection calculations. This stable pattern of plumes is unexpected because vigorously convecting planetary interiors are thought to retain no memory of the initial conditions [1]. The spacing of the plumes matches the spherical harmonic degree 8 order 6 pattern that is theorized to be a stable pattern for vigorous stagnant-lid convection.

*Stability comes from the lithosphere.* The topography on the base of the stagnant lithosphere (i.e., the lithosphere-asthenosphere boundary) is responsible for the spatial stability of the plumes in these calculations. In calculation with a constant-thickness, high-viscosity lithosphere and otherwise identical parameters, the initial (8,6) spherical harmonic pattern is maintained for a significantly shorter time than was the case for the temperature-dependent stagnant lithosphere case (<1 Gyr). This is still longer than the current surface age of Venus. The stronger the lithosphere, the more long-lived and stable the plume pattern is. This plume stabilizing mechanism differs from the Earth where plumes are thought to be anchored in a more highly viscous lower mantle and possibly coupled with compositionally-distinct Large Low Shear Velocity Provinces (LLSVP).

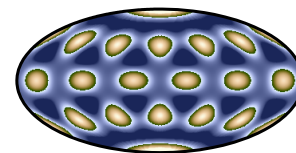
*Method.* The equations of the conservation of mass, momentum, and energy for incompressible fluid in a spherical shell are solved using CitcomS (version 3.3.1) with a 64 x 64 x 64 element mesh for each of the 12-cubes within the spherical shell [2]. The Rayleigh number, defined by the radius of the planet and not the mantle thickness, is fixed at  $3.18 \times 10^8$ . Free-slip boundary conditions are applied to both the surface and the core-mantle boundary and the surface temperature is held constant at 460 °C, while the initial core-mantle boundary temperature is 3980 °C (including a 0.3 °C/km adiabatic gradient added for the calculation of core thermodynamics and rheology). The calculations use an initial mantle potential temperature of 2282 °C. A single temperature perturbation of 20 °C in the form of a single spherical harmonic is added at the middle depth of the spherical shell. The calculations use a temperature-dependent, yield-stress rheology [3] with core boundary condition based on analytical models of core cooling similar to the formulation described in King [4].

**Model Results:** The initial pattern of plumes is a degree 8 order 6 pattern (Figure 1). As the calculation

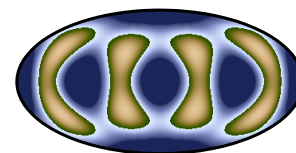
progresses, the mantle cools as the abundance of radiogenic elements in the mantle decreases and the temperature at the core mantle boundary decreases as the core cools and the stable degree 8, order 6 pattern transitions to a cubic pattern (degree 4, order 4) as the equatorial plumes wane and the off-equatorial plumes grow into a pattern with four equatorial, cylindrical downwellings each surrounded by six plumes. The individual plumes then merge forming rising sheets. As the mantle continues to cool, the sheets break down and two large upwellings plateaus develop.

**Application to Venus:** The geoid of Venus differs significantly from Earth in that the spectral power is not dominated by the longest wavelengths [c.f., 5] and there is a strong correlation between geoid and topography on Venus up to degrees 40 [e.g., 6]. That is the case in each of the temporal stages of these calculations. The pattern of dynamic topography, which closely follows the major convective upwellings, is illustrated in the figure below.

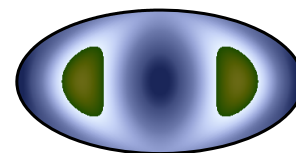
Figure 1:  
Dynamic Topography  
initial state



intermediate state



final state



**References:**

- [1] Yuen et al. (1993) *JGR Planets*, 98, 5355–5373.
- [2] Zhong, S., et al. (2000) *JGR*, 105, 11,063–11,082.
- [3] H. J. van Heck and Tackley, P. J., (2008) *GRL*, 35, L19312.
- [4] King (2018) *JGR Planets*, 123, 1041–1060.
- [5] Wieczorek, M. A. (2015) In: *Treatise on Geophysics*, v, 10, pp. 153–193, Elsevier.
- [6] Pauer, M. et al. (2006) *JGR*, 111, E11012.