CONSTRAINTS ON THE GLOBAL LITHOSPHERIC THICKNESS OF VENUS IN THE ISOSTATIC STAGNANT LID APPROXIMATION. C. P. Orth and V. S. Solomatov. Department of Earth and Planetary Sciences, Washington University in Saint Louis, St. Louis, MO 63130 USA (corth@epsc.wustl.edu)

The Isostatic Stagnant Lid Approximation: The Venusian topography can be supported by a variety of mechanisms. Here we focus on long-wavelength topography and assume that the stagnant lid overlaying the convective mantle is in isostatic equilibrium - the isostatic stagnant lid (ISL) approximation. This approximation ignores any contribution of dynamic, elastic, and transient effects on the long-wavelength topography. Instead, the ISL approximation requires the stagnant lid to be in perfect isostatic equilibrium. This includes both the lithosphere and the crust embedded in the upper part of the lithosphere. This approximation has been systematically tested in two-dimensional numerical calculations. It has been shown that in the stagnant lid regime of temperature-dependent viscosity convection the dynamic support associated with convective motions inside the mantle is small and that topography and geoid anomalies are largely caused by density variations in the upper viscous layer (in the stagnant lid [1, 2, 3, 4]).

We consider a spherical harmonic representation of the Venusian geoid and topography (namely MGNP180U, [5] and shtjv360.a02, [6]; respectively) truncated to degree and order 20 to correspond to the scale of the expected convective cells (~2,000 to 3,000 km). This truncation limits the isostatic stagnant lid approximation to the long-wavelength topography and geoid and does not consider the wavelengths where the elastic effects are important.

In the ISL approximation, the primary support mechanism for the long-wavelength topography is thermal isostasy due to the convective thinning of the lithosphere by mantle convection. However, on Venus, variations in lithospheric thickness alone are insufficient to explain the observed topography and geoid because it would require thinning of the lithosphere beyond that expected for stagnant lid convection and in some places even through the entire lithosphere. Therefore, crustal thickening is required to restrict the lithospheric thinning to values consistent with those expected for stagnant lid convection. The requirement of thickened crust is consistent with previous works (e.g. [7, 8]).

The errors associated with the ISL approximation are on the order of 10-30% depending on various factors such as the assumed mantle rheology. Although these errors are large, they are comparable to and even smaller than other uncertainties in the dynamic models of Venus. The main advantage of the ISL approximation is that it allows inversion of gravity and topography data assuming a convective planet but avoiding costly three-dimensional convection calculations. To reduce the errors due to the ignored contribution from mantle convection beneath the stagnant lid we improve the ISL approximation by taking into account the contribution from the mantle by using the constraints from two-dimensional convection calculations on the correlation between the stagnant lid thickness and the amplitude of mantle thermal anomalies. In particular, the lateral temperature variations associated with convective motions where regions of rising material have a slightly higher temperature than the ambient mantle temperature and regions of sinking material have a slightly lower temperature. For a given rheology, this correction substantially reduces the errors and at least theoretically can eliminate the errors completely, at least in a statistically average sense (meaning that this approximation can be as good as the actual three-dimensional model).

Calculation of the Global Lithospheric Thickness: Under the assumptions of the ISL approximation we calculate the geoid directly from the density variations within the crust, lithosphere, and mantle. We begin with an initial average lithospheric thickness and determine the lithospheric variations assuming complete compensation by thermal isostasy. We then add minimal regions of thickened crust to limit the thermal thinning of the lithosphere to values expected for stagnant lid convection. The lateral mantle temperature profile is then varied as a proxy for the temperature variations within a convecting mantle.

The model geoid is then calculated using a direct three-dimensional integration over the sphere rather than the HOT (Haxby-Ockendon-Turcotte) approximation [7] (the latter predicts a substantially thinner lithosphere). The lithospheric thickness and mantle temperature variations are used to calculate the lateral variations in the radial temperature profile for either the plate cooling (which is more appropriate for a nearly steady-state thermal lithospheric structure) or half-space cooling (which corresponds to a transient cooling and a small contribution from sublithospheric convective instabilities) models of temperature distribution. The deviation in the temperature from a reference temperature profile corresponding to zero topography leads directly to the calculation of the density anomaly. The component of the geoid anomaly associated with the crustal, lithospheric, and mantle density structure is then calculated from a spherical harmonic representation of the density anomaly on each of n radial layers

[8]. The component associated with the topography is calculated from the Bouguer gravity anomaly and added to the geoid anomaly from the lithosphere. The resulting total geoid anomaly is then compared to the observed geoid anomaly and the initial global average lithospheric thickness is adjusted to minimize misfit (Figure 1).

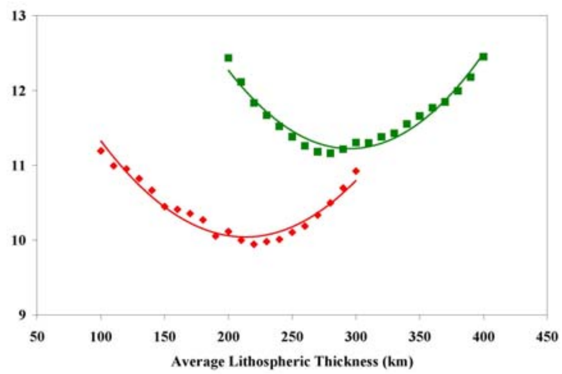

Figure 1: Normalized r.m.s. deviation between the observed and calculated geoid. The red diamonds are the ISL calculations with zero contribution from the mantle. The green squares are the ISL calculations which take into account the contribution from the mantle temperature variations (the maximum effect is shown). The lines are quadratic fits.

Results: Assuming an average crustal thickness of 50km, the minimization of the misfit between the observed and calculated geoid results in a global average lithospheric thickness of ~200 km for the case with no mantle temperature variations. For the case with mantle temperature variations the global average lithospheric thickness increases to ~300 km (Figure 1). Also, both the surface area of the regions of thickened crust and the maximum crustal thickness decreases with increasing average lithospheric thickness. With an average lithospheric thickness of 200 km only 12% of the crust is thickened with a maximum thickness of 80 km (slightly less than the expected depth of the basalt-eclogite phase transition) (Figure 2) compared to only 3% of thickened crust with a maximum thickness of 65 km for a 400 km average lithospheric thickness.

Conclusions: Most of the Venusian topography can be explained by the thermal isostasy associated with the lithospheric thickness variations. The magnitude of these variations is consistent with that expected for the stagnant lid convection regime with the viscosity parameters corresponding to diffusion creep. Only limited, if any, crustal thickness variations are required to explain the observed geoid. The inclusion of mantle temperature variations results in a thicker global average lithospheric thickness.

Future work includes statistical analysis of the lateral distribution of temperature within the mantle to improve the accuracy of the ISL approximation. We will also need to test the ISL approximation in fully three-dimensional convection calculations. The models need to explore the effects of chemical stratification within the mantle and consider different assumptions regarding the lithospheric models, including the effects of radiogenic heating and different degrees of thermal equilibrium.

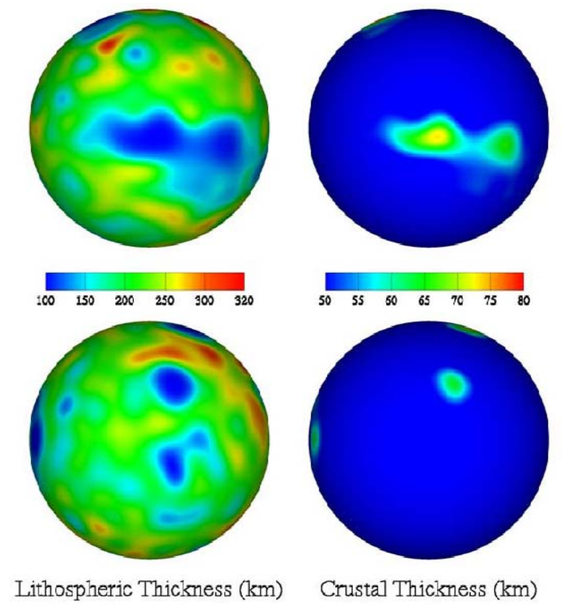

Figure 2: Lithospheric thickness (right) and crustal thickness (left) for the best-fit ISL model with zero mantle contribution. The average lithospheric thickness is 200 km. The top hemispheres are centered at 90° East and the bottom hemispheres at 90° West.

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