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On the origin of Venus' unusual gravity spectrum

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Despite obvious differences in the present state of the terrestrial planets and the Earth's Moon, e.g. in their tectonic mode (plate tectonics, episodic resurfacing, stagnant lid, ...), al these bodies feature a gravity spectrum that is dominated by the spherical harmonic degree 2. The only exception is Venus, which features a degree 3-dominance and a much stronger correlation between geoid and topography at long wavelength than e.g. Earth.

Taking this as motivation, we analyze Venus' gravity spectrum in more detail. We use a dynamic model to predict synthetic gravity spectra for a Venus-like planet and compare them to the observed spectrum provided from satellite missions in sufficient detail. It is known that the viscosity structure of a planetary mantle has a strong impact on the spectrum, such that we can in turn use the misfit between observed and predicted spectrum as a constraint for the viscosity profile, which also shapes the structure of mantle flow.

First, we test different prescribed viscosity structures inferred from mineral physics. While the match between observed and predicted spectrum is a matter of improvement, these models reproduce Venus' strong geoid-topography correlation. Furthermore, these models support the idea of no, respectively, a small viscosity contrast between upper and lower mantle – in contrast to Earth.
Second, we test self-consistently calculated viscosity structures based on an Arrhenius law, which include lateral viscosity variations. These cases lead to a stable degree 3-structure as observed, if convective vigor is sufficiently high. However, comparison of viscosity structures with and without lateral variation indicates that the long-wavelength components of the spectrum are basically insensitive to the lateral variations, which do not improve the fit between observed and predicted spectra. In order to further address this discrepancy, we test models that include a crustal layer and spatial variations in its thickness in the next step.