LONG-WAVELENGTH TOPOGRAPHY AND GRAVITY ANOMALIES OF MARS AND THEIR IMPLICATIONS TO THE FORMATION OF THARSIS RISE. S. Zhong, Department of Physics, University of Colorado, Boulder, CO 80309 (szhong@anquetil.colorado.edu).

Introduction

The Maritan gravitational field is dominated by long-wavelength anomalies that are closely related to the Tharsis Rise [1] where successive tectonic activities and volcanism are concentrated. An understanding of the origin of the long-wavelength topography and gravity anomalies is important for the formation of the Tharsis Rise and the thermal evolution of Mars. Two different mechanisms have been proposed to explain the long-wavelength anomalies associated with the Tharsis Rise [2, 3]. First, the gravity anomalies are explained as a result of loading of the Tharsis volcanic rocks on ~100-km thick elastic lithosphere with insignificant contribution from the deep interiors [2]. Second, the gravity and topography of the Tharsis are interpreted as dynamic effects of mantle convection [3].

Mantle convection models with an endothermic phase change (i.e., the spinel to perovskite phase change) indicate that a single thermal plume may develop in the Martian mantle [4]. This single thermal plume may not only provide the necessary concentrated heat for the successive volcanism in the Tharsis region, it also produces topographic uplift and geoid anomalies that can account for ~50% of the observed geoid of the Tharsis Rise [5]. However, because of the lack of constraints on Martian mantle structure, in practice, most models of gravity and topography only consider surface loads on elastic lithosphere with a crust [1].

In this study, we show that mantle convection models with a purely viscous rheology [5] may significantly overestimate the geoid. We argue that the proposed single plume may not produce the observed geoid to topography ratio at long-wavelengths, provided that current Martian elastic lithosphere is thicker than 100 km.

Geoid to Topography Ratio

We have computed the geoid to topography ratio (G/T ratio) and degree correlation using the MGS data [6, 7]. The degree correlation is reasonably high at low harmonic degrees except at degree 4 (Fig. 1). The G/T ratio is greater than 0.1 from degrees 2 to 4, but it drops to about 0.05 at degree 5 and remains about the same at higher degrees (Fig. 1).

Dynamic Response of Mars

While a thin elastic shell model is used for surface loading problems [2, 1], mantle convection models predict dynamic topography and geoid using an instantaneous mantle flow with a purely viscous rheology [5]. Here we have extended our previous viscoelastic formulation [8] to include internal loading. Our model for a self-gravitating planet can be degenerated into either elastic shell or purely viscous flow models. Our model in its elastic plate limits is superior to the thin elastic shell model because it does not use the thin plate approximations [5].

For viscous response, loads at the surface are always completely compensated and do not produce any geoid anomaly [9] (Fig. 2). In our calculation, a 150-km thick high viscosity (10^9 times more viscous than the mantle) lid is included at the surface. However, this viscous lid does not support any stress when loaded at its surface. Therefore, a high viscosity lid does not mimic the effects of an elastic plate on loading. For this model, only loads below 270 km depth produces G/T ratio > 0.15 at low degrees (Fig. 2c).

When a more realistic viscoelastic rheology is used with the same viscosity structure as for Fig. 2, the dynamic response is quite different. The topographic compensation is now incomplete for surface loads, particularly at relatively short wavelengths (Fig. 3). This results in significant reduction (~ 2 times over a large depth range) in the geoid at low degrees (Fig. 3). For loads within or immediately below the lithosphere, the resulting geoid kernel and G/T ratio are negative (Fig. 3). Only loads below 550 km depth can produce G/T ratio greater 0.15 at low degrees. The difference between viscous and viscoelastic responses decreases as the lithospheric thickness decreases. However, the elastic plate thickness inferred for the Tharsis region is > 150 km [1].

Discussions

Internal loads may be controlled by thermal structure from mantle convection. Considering the thermal structure from the single plume model [5], the long-wavelength structure that is relevant to the low degree gravity is derived from the part of the plume that spreads out right below the lithosphere. The thickness for this spreading layer is likely smaller than 200 km [10]. However, our results show that only the loads ~400 km below the base of lithosphere may produce G/T ratios at low degrees that are consistent with the observations (Fig. 3). Although plume-related concentrated heat may be needed below the Tharsis region, the low degree gravity anomalies of the Tharsis Rise may be largely induced by surface loading.

References

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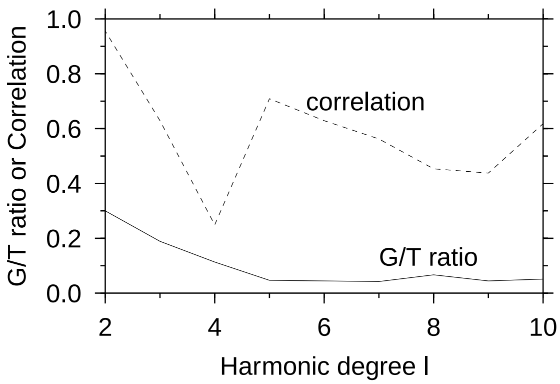

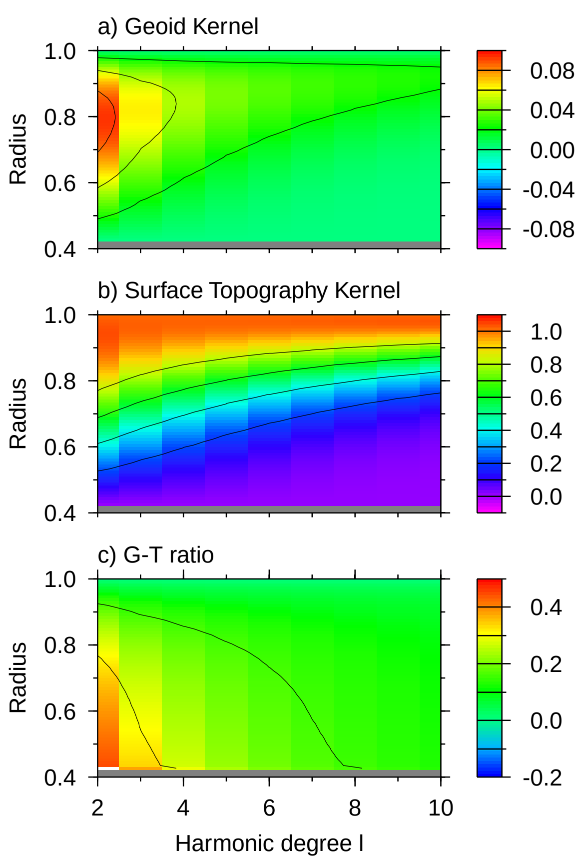

Figure 1 (top left). Degree correlation between topography and geoid and the ratio of geoid to topography for Mars.

Figure 2 (bottom left). Geoid and topography kernels and corresponding geoid to topography ratio. The rheology is purely viscous with a 150-km thick high viscosity lid at the surface. The contour level s are 0.02, 0.05, and 0.08 for 2a, 0.2, 0.4, 0.6, and 0.8 for 2b, and 0.15 and 0.3 for 2c.

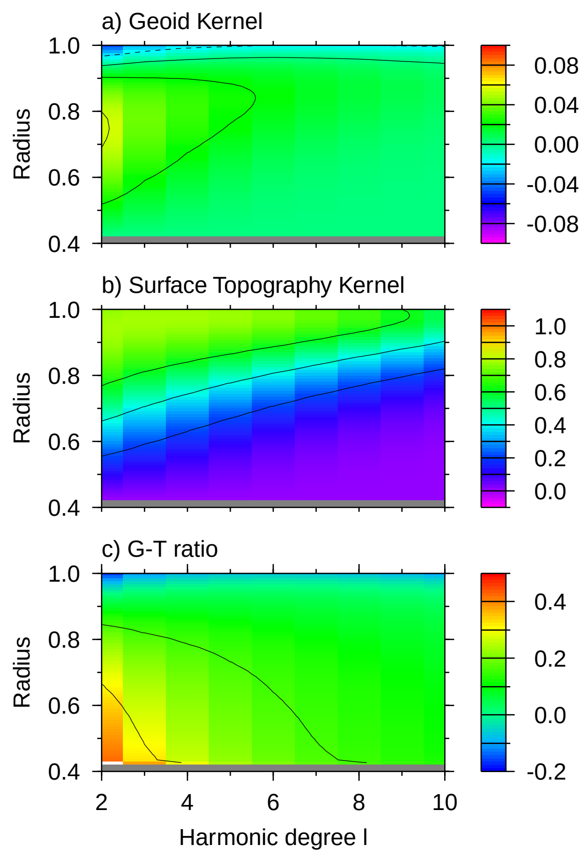

Figure 3. Geoid and topography kernels and corresponding geoid to topography ratio. The rheology is viscoelastic with a 150-km thick high viscosity lid at the surface. The results are for 10^9 years loading, which is long enough to eliminate any transient effects. The dashed contour in 3a is -0.02, and otherwise contour levels are the same as Figure 2. Note in 3a the largest contour level is for 0.05.