The changing gravity field due to a superplume under the Tharsis Region

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Context

The Tharsis Region has been an interest of study for many years due to its large impact on the long wavelength gravity field and topography of Mars.

Figure 1. Topography of Mars from the Mars Orbiter Laser Altimeter data. The colorbar range is limited to ±5 km in order to show the global topographic features. The location of the InSight lander is indicated with a black star.

The leading theory on the origin of the volcanic region is a combination of both isostatic flexure of a thickened crust and a small contribution due to a (possible) large superplume residing in the upper mantle. The isostatic balance, on which previous studies have relied, does not adequately explain the long-wavelength gravity field spectra. These long-wavelength signals contribute to large scale features in the mantle. We consider the presence of a dynamic mass anomaly below the Tharsis Region. This could help explain the geological surveys of the relative young lava flows. By looking at mantle dynamic models we can explore the effect of a superplume that is actively rising in the mantle and changing the geoid over time.

Methods

After rotating Tharsis so that it comes to be under the North pole of an otherwise perfectly spherically symmetric planet, we ran a series of instantaneous axisymmetric Newtonian finite element models of Mars with varying plume and subsurface structural variables constrained by InSight. We run the model for 50 years, thereby accounting for the total duration of satellite data acquisition. The deformation in the model allows us to calculate the change in dynamic topography and gravity anomaly.

We use 4 different density and viscosity profiles in our numerical experiments: one from Steinberger et al [1], two from Samuel et al [2], and one consisting of 4 layers:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Density (kg/m³)</th>
<th>Viscosity (Pa.s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3200</td>
<td>3700</td>
</tr>
<tr>
<td>2</td>
<td>3600</td>
<td>3500</td>
</tr>
<tr>
<td>3</td>
<td>4000</td>
<td>3000</td>
</tr>
<tr>
<td>4</td>
<td>4500</td>
<td>1000</td>
</tr>
</tbody>
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Figure 2. Left: geometry of the axisymmetric model. Right: FEM setup example with (A) Mesh representation with zoom in on upper right corner (h=80 km) (B) 4-layer homogeneous density distribution and (C) viscosity distribution.

Figure 3. Left: Aspect mesh; Right: ASPECT mesh next to Fieldstone mesh.

With a maximum dynamic topography of 2091 km for Aspect and 2252 km for Fieldstone, this corresponds to a peak error of 2.6%. Further away from plume center the discrepancy does not exceed ±5 m or an error of 0.2%.

Figure 4. Dynamic topography at the surface. Fieldstone results are shown in blue and Aspect in orange. The difference between both is shown in red. Angle theta is given in radians.

Figure 5. The surface changes due to a rising mantle anomaly underneath the Tharsis Rise.

The gravitational signal is mostly related to the dynamic topography changes, as can be seen in the following figure.

Figure 6. The gravity change after one year due to a rising mantle anomaly underneath the Tharsis Rise.

Conclusions

Our preliminary results show dynamic topography rates of a few centimetres per year and gravity rates in the order of 0.1-10μGal per year. These gravity rates should fall within the precision of the Mars Reconnaissance Orbiter gravity field estimates, but are masked by other geological surface mass changes. Our results show that with longer and dedicated gravity observations, we should be able to observe the large scale mantle dynamics of Mars.

References

[3] https://geodynamics.org/resources/B