University of Copenhagen
MSc program in Geology–Geoscience

Geodynamics – shaping Earth's surface

Isostasy and elasticity of Earth's lithosphere

Exercise 2: Isostacy and elasticity in orogenic plateaus

The build–up of large orogenic plateaus, such as Tibet or the Central Andeas, is the result of the convergence between tectonic plates. Over time–scales of million years, crustal material is squeezed horizontally in the process of tectonic subduction, and therefore accumulates (i.e., builds up) vertically. Figures 1 and 2 show elevation and satellite–measured free–air gravity anomaly of the Tibetan Plateau area, respectively.

Based on the file `EX2_ISOSTACY.ipynb` (Jupyter Notebook), perform the following exercises:

1. Select a point in the middle of the Tibetan Plateau where the free–air gravity anomaly is close to zero, but not exactly zero. Make a theoretical prediction of the thickness of its roots, assuming fully isostatic conditions (i.e., no elasticity), a crustal density of 2700 kg/m^3, a mantle density of 3300 kg/m^3, and a standard crust of thickness 35 km.
2. Consider now the scenario where isostatic equilibrium is not achieved by a buoyant root (Airy compensation), but rather a mass deficit in the mountains and crust itself, i.e. the Tibet and the crust beneath are much lighter than regular crust. What would have to be the density in this case? Assume a full depth of compensation ($W = 35km$). Is that density value reasonable, or even plausible for rocks? (for reference: $\rho_{granite} = 2600\ kg/m^3$, $\rho_{shale} = 2500\ kg/m^3$, $\rho_{sediments} = 2000\ kg/m^3$)
3. Consider now the possibility that the Tibetan Plateau is not isostatically compensated, but rather supported by the elastic strength of the lithosphere. What would have to be the elastic thickness of the lithosphere in this case? Estimate this for a support going North–South (its widest) and East–West (its narrowest). Is that value within the range of know lithospheric thicknesses? Even if it is not, what qualitative implication does this near–zero gravity anomaly have on the mantle?

Notes:

⇨ The thickness of the roots as a function of gravity anomaly is given by:

$$h_r = \frac{1}{(\rho_m - \rho_c)} \cdot \left[\rho_c h_m - \frac{\Delta g}{2\pi G}\right]$$

where ρ_m is the density of the mantle, ρ_c is the density of the crust, h_m is the height of the mountains, Δg is the free-air gravity anomaly, and G is the gravitational constant.

⇨ The Pratt compensation density as a function of depth of compensation is given by:

$$\rho_{c2} = \rho_c \left(\frac{W}{W + h_m}\right)$$

where ρ_{c2} is the density of the mountains/crust, ρ_c is the density of the reference crust, W is the depth of compensation, and h_m is the height of the mountains.

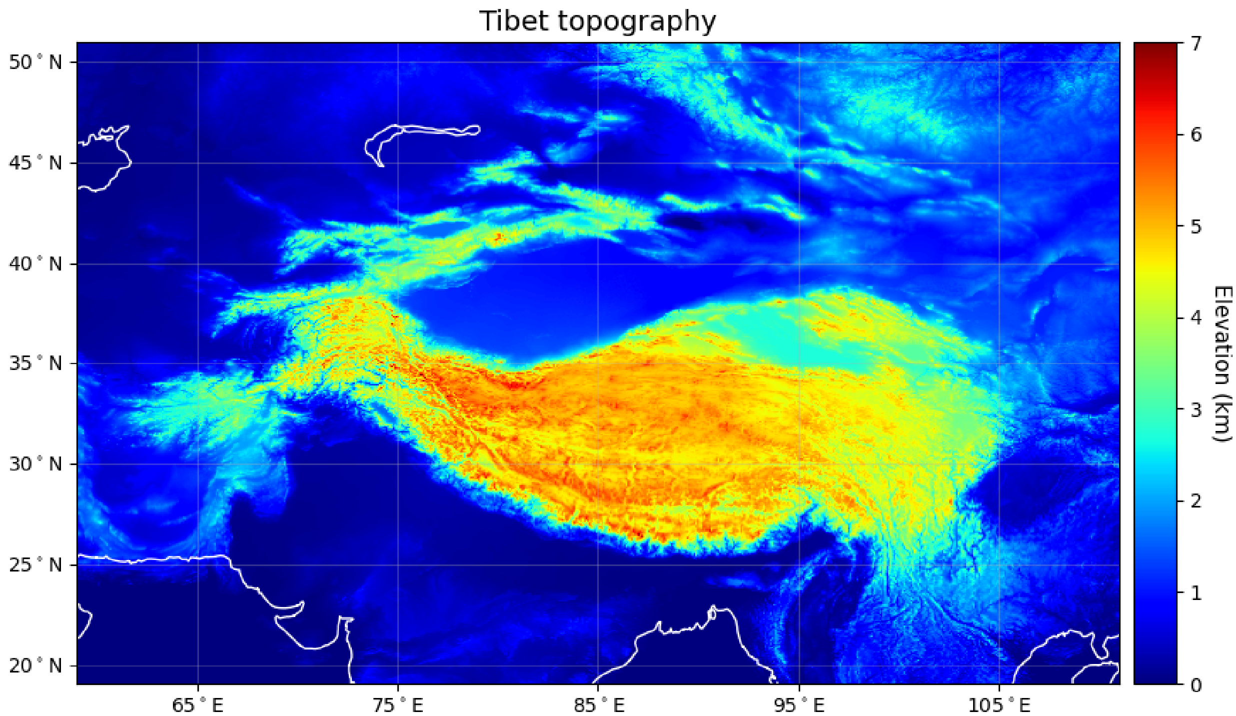

Figure 1: Elevation (m) of the Tibetan region. Coastline is in white.

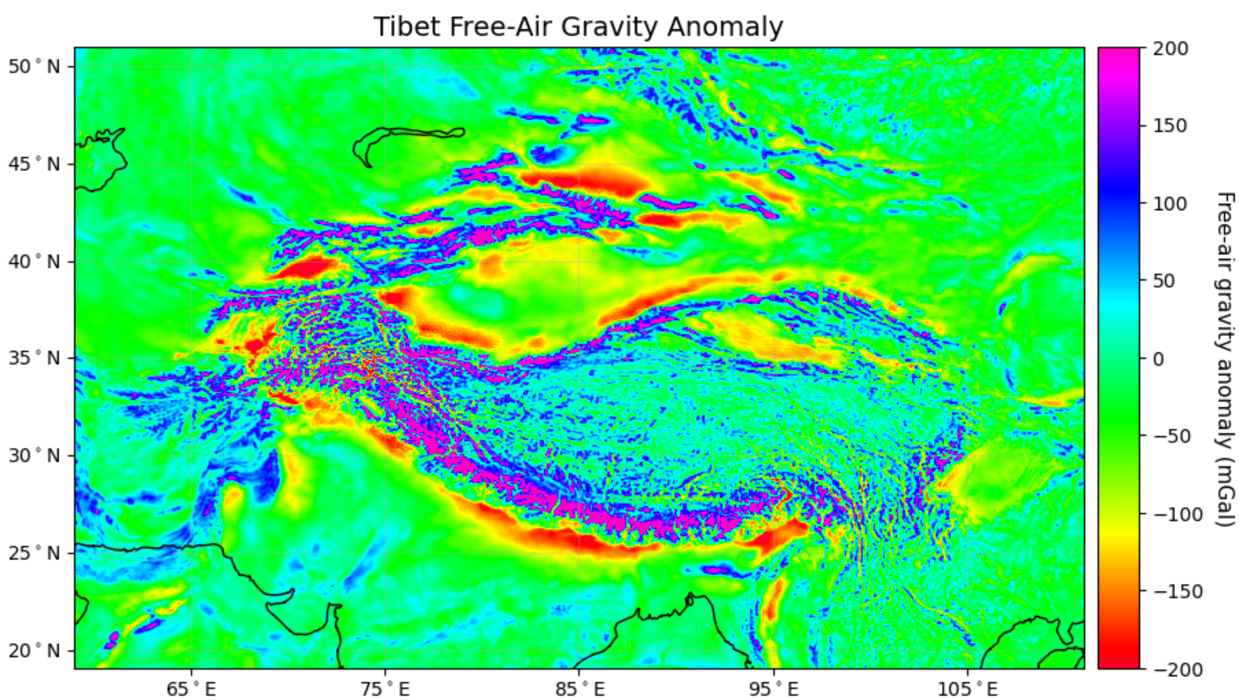

Figure 2: Gravity anomaly ($mGal = 10^{-5}\ m \cdot s^{-2}$) of the Tibetan region. Anomaly is computed as local gravitational acceleration minus the global average ($g = 9.8\ m \cdot s^{-2}$). Coastline is in black.