Introduction to Geophysics

Assignment: Bouguer Anomaly Corrections and Crustal Root Modeling

In this assignment, you will apply gravity corrections to compute the Bouguer anomaly at a mountain station, and investigate why the Himalayas exhibit strong negative Bouguer anomalies despite their large topographic mass.

Problem 1: The Bouguer anomaly corrections at the top of a mountain range

A gravity station is located at the summit of a mountain range of height h and average rock density ρ. The observed gravity g_{obs} is recorded at 06:00 local time. In this problem, you will apply a series of standard corrections — tidal, free-air, and Bouguer — to compute the Bouguer anomaly at this station.

Given information

A gravity station is located on the top of a mountain with:

- Elevation above sea level: $h = 8848$ m
- Observed gravity at 06:00 local time, after tidal correction:
$$g_{\text{obs}} = 977792 \text{ mGal}$$
- Normal gravity:
$$g_{\text{nor}} = 979325 \text{ mGal}$$
- Rock density:
$$\rho = 2670 \text{ kg/m}^3$$

Use the following formulas and constants:

(1) Free-air correction

$$C_{FA} = 0.3086\, h \qquad (\text{mGal},\ h \text{ in m})$$

(2) Bouguer correction

$$C_B = 2\pi G \rho h$$

(3) Bouguer anomaly

$$\Delta g_B = g_{\text{obs}} - g_{\text{nor}} + C_{FA} - C_B$$

(4) Tidal correction

Assume that the Earth-tide effect at this station varies as

$$g_{\text{tide}}(t) = 0.18 \cos\left[\frac{2\pi(t-6)}{12.42}\right] \text{ mGal}$$

where t is local time in hours.

The corrected observed gravity is

$$g_{\text{obs}} = g_{\text{obs}}^{\text{raw}} - g_{\text{tide}}(t)$$

so equivalently

$$g_{\text{obs}}^{\text{raw}} = g_{\text{obs}} + g_{\text{tide}}(t).$$

Questions

1. Compute the difference $g_{\text{obs}} - g_{\text{nor}}$.
2. Compute the free-air correction C_{FA}.
3. Compute the Bouguer correction C_B.
4. Compute the Bouguer anomaly Δg_B.
5. If gravity is measured at 12:00, 18:00, and 24:00 local time at the same station, what raw gravity values would be recorded?

Remark

The corrections above give a positive Bouguer anomaly, but real Bouguer anomalies in the Himalayas are often strongly negative. This indicates that an additional mass deficiency exists at subsurface, commonly interpreted as a low-density crustal root. This effect is treated in Problem 2.

Problem 2: A low-density cylindrical root causing the large negative anomalies of the Himalayas

Gravity observations over the Himalayas reveal large negative Bouguer anomalies, commonly ranging from about -180 mGal to below -550 mGal. However, the Bouguer anomaly computed in Problem 1 is positive, which contrasts with these observed negative values. One major explanation is the presence of a low-density crustal root beneath the mountain belt.

In this problem, you will model this root as an idealized finite vertical cylinder with a density lower than the surrounding crust. Given the observed gravity deviation Δg_{root}, you will estimate the density of the root. Treat the given anomaly as exact.

Given information

Assume the crustal root is a finite vertical cylinder with:

- Radius $a = 100$ km,
- Top depth $z_t = 20$ km,
- Thickness $H = 50$ km,
- Root density ρ_{root},
- Rock density $\rho = 2600$ kg/m^3,
- Gravity deviation caused by a low-density root $\Delta g_{\text{root}} = -500$ mGal.

Let the density contrast be

$$\Delta\rho = \rho_{\text{root}} - \rho.$$

For a finite vertical cylinder, the vertical gravity anomaly directly above its center is

$$\Delta g_{\text{root}} = 2\pi G \Delta\rho \left[H + \sqrt{z_t^2 + a^2} - \sqrt{(z_t + H)^2 + a^2} \right],$$

where z_t is the depth from the observation point to the top of the cylinder, H is the cylinder thickness, and a is the cylinder radius.
Thus, the density contrast is

$$\Delta\rho = \frac{\Delta g_{\text{root}}}{2\pi G \left[H + \sqrt{z_t^2 + a^2} - \sqrt{(z_t + H)^2 + a^2} \right]}.$$

Since the root is low density,

$$\Delta\rho < 0.$$

Questions

1. Compute the density of the low-density root ρ_{root}.
2. Keeping Δg_{root}, ρ, z_t, and H fixed, determine how ρ_{root} would change if the cylinder radius were increased to 150 km.
3. Compute the sum of Δg_{root} and Δg_{B}. Does the result fall within the observed range of approximately -180 mGal to below -550 mGal?

Remark

This cylindrical model is a highly simplified model. Its purpose is to illustrate how a subsurface low-density body can produce a negative gravity anomaly. In reality, the observed anomalies are influenced by crustal thickening, lateral density variations, complex root geometry, and regional isostatic compensation. Therefore, the density obtained here should be interpreted as an equivalent model value rather than the exact physical density of the real crustal root.