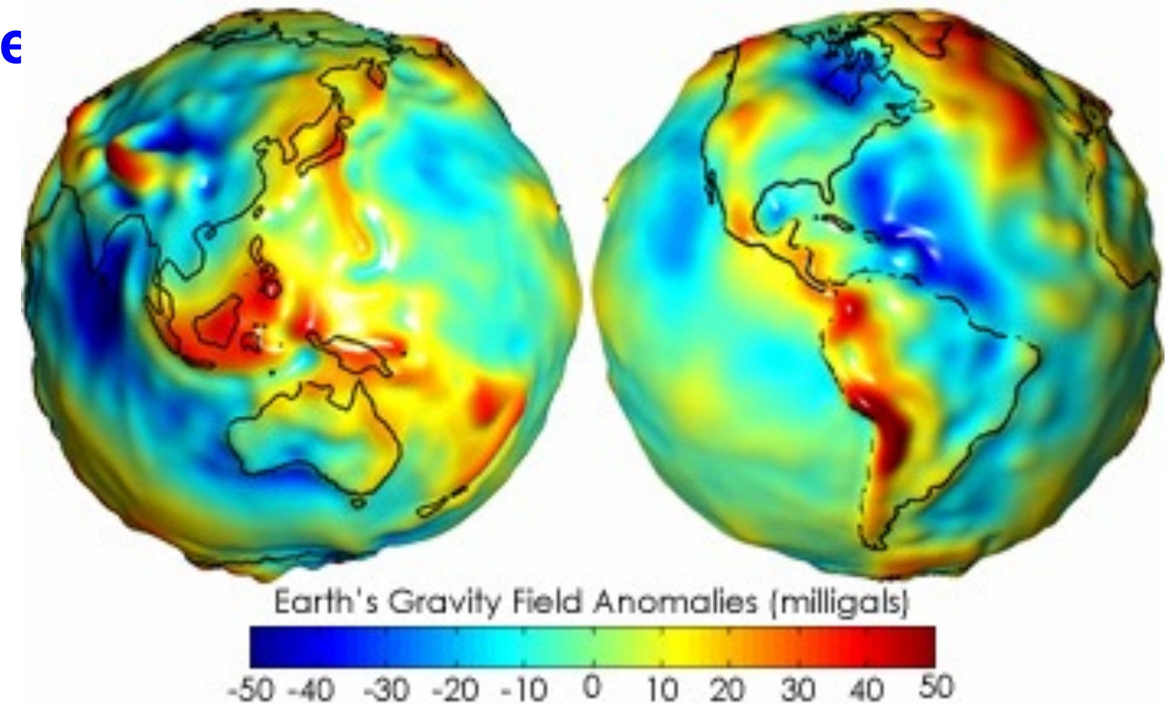
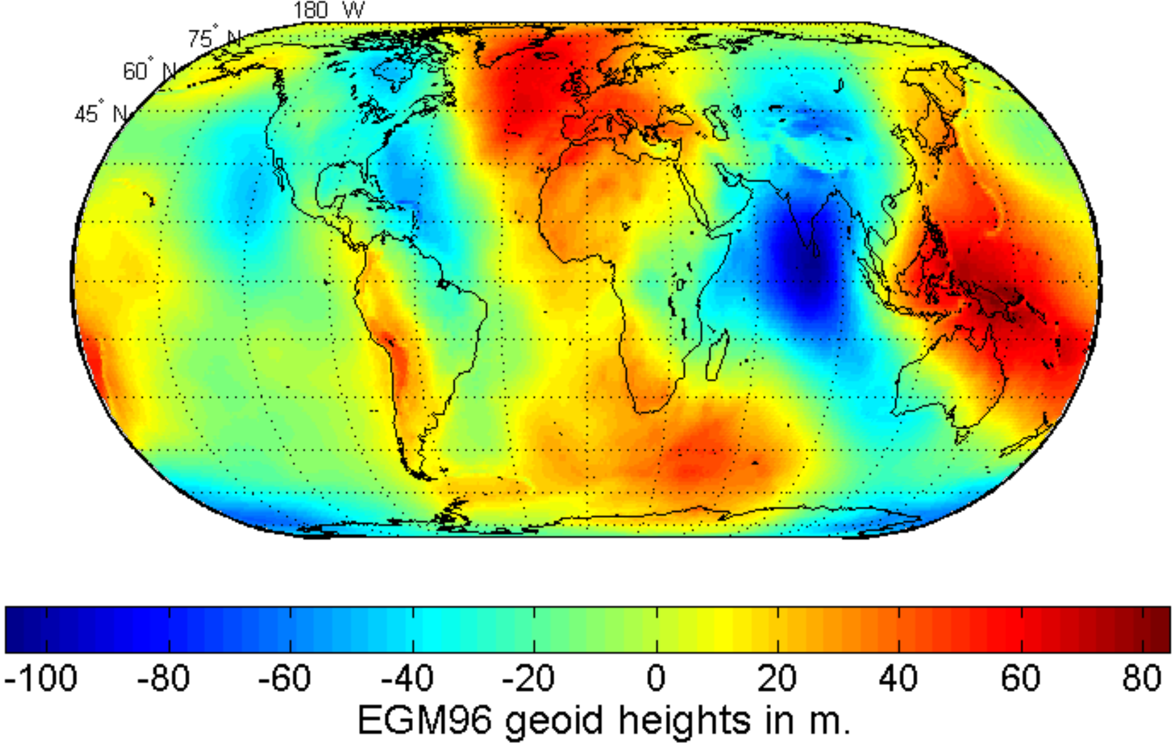
Lithosphere & Asthenosphere Composition & Evolution

GEO-DEEP9300

Gravity Studies





Clint Conrad
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Measurement of Gravity

Measurement of Absolute Gravity:

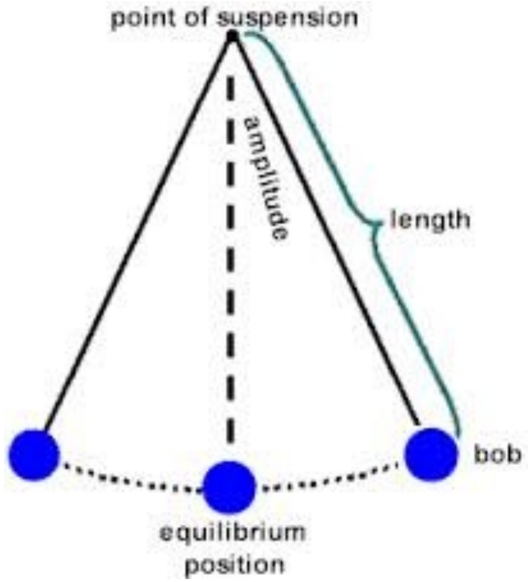
Pendulum Method: Measure the period $T = 2\pi\sqrt{\frac{I}{mgh}} = 2\pi\sqrt{\frac{L}{g}}$

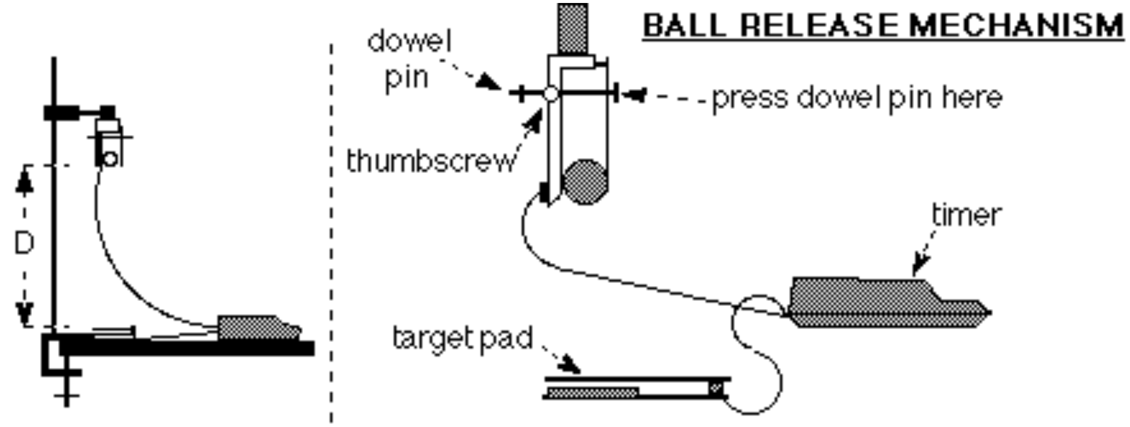
To measure 1 mgal variation, the period must be measured to within 1μs.

Free-fall Method: Measure the fall of a mass: $z = z_0 + ut + gt^2/2$

To measure 1 μgal variation, time must be measured to within 1ns.

Rise-and-fall Method: Measure time T for a thrown ball to rise and fall a height z: $z = g(T/2)^2/2$. Then $g = \frac{8(z_1 - z_2)}{(T_1^2 - T_2^2)}$. μgal precision; not portable.



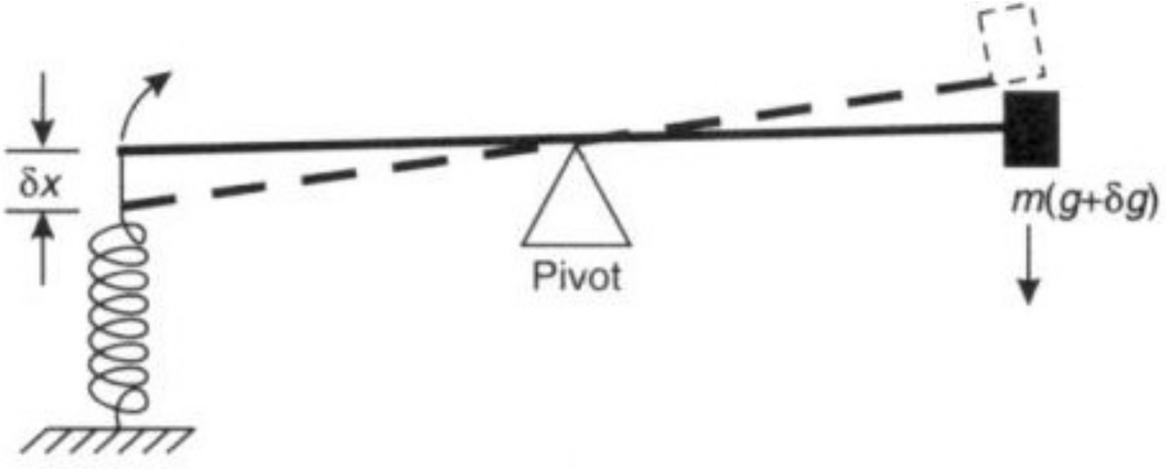


Measurement of Relative Gravity

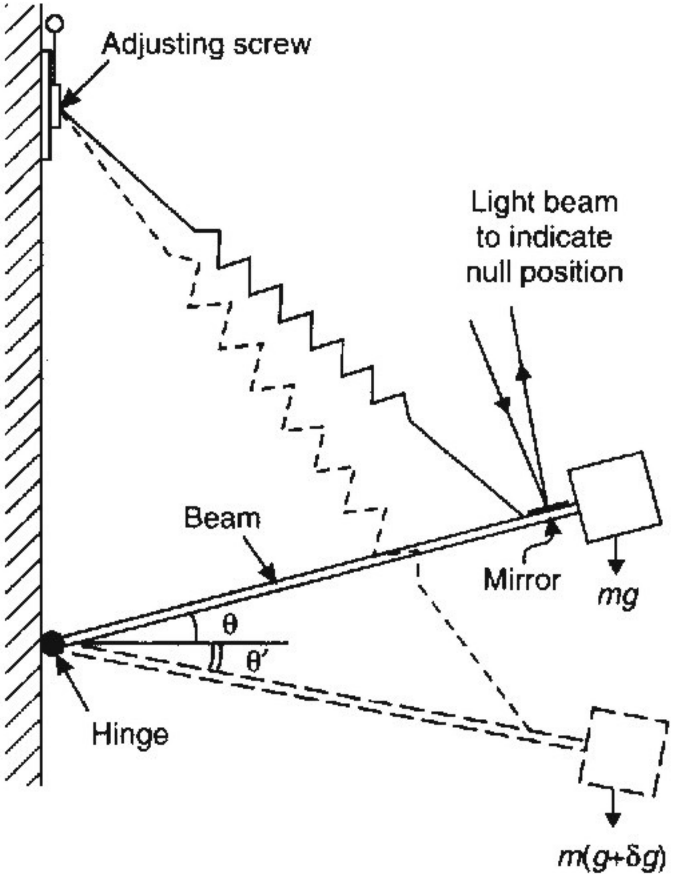
Stable Gravimeter: Measure Δs, the change in a spring's length:

$$\Delta g = \frac{k}{s} \Delta s$$

→ Useful for measuring *changes* in gravity (not absolute gravity)



Measurement of Relative Gravity



$$\Delta g = \frac{k}{m} s$$

Unstable Gravimeter:

Uses a spring with built-in tension

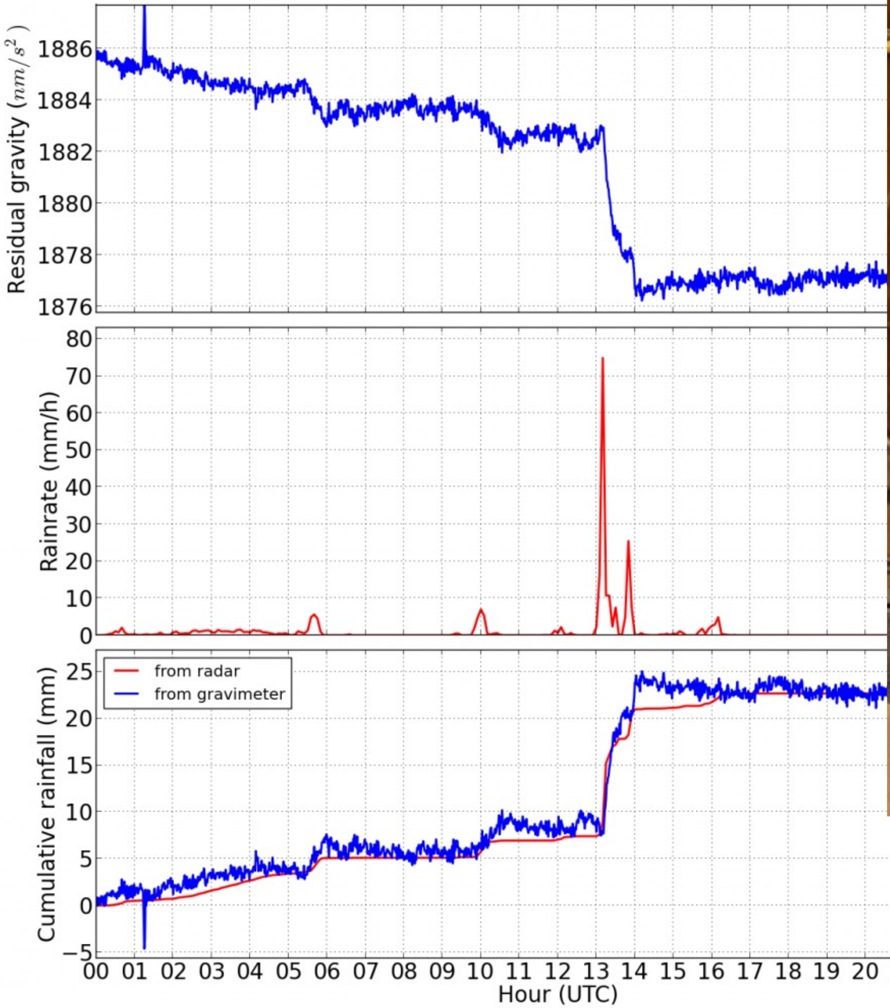
Usage: Adjust spring length using a calibrated screw.

Sensitivity: 0.01 mgal for a portable device.

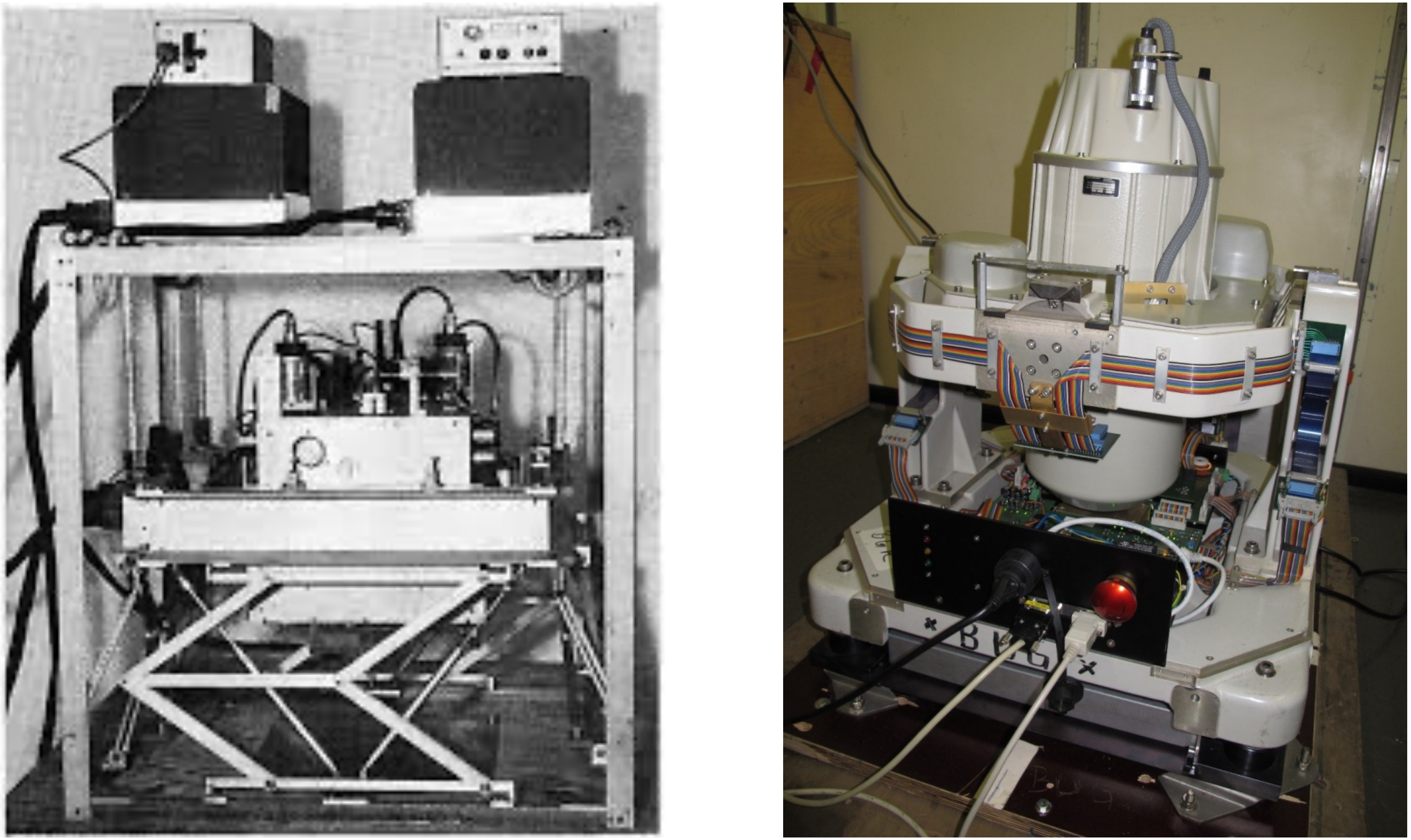
Superconducting Gravimeter:
Suspend a niobium sphere in a stable magnetic field of varying strength

Sensitivity: 1 ngal (not portable)

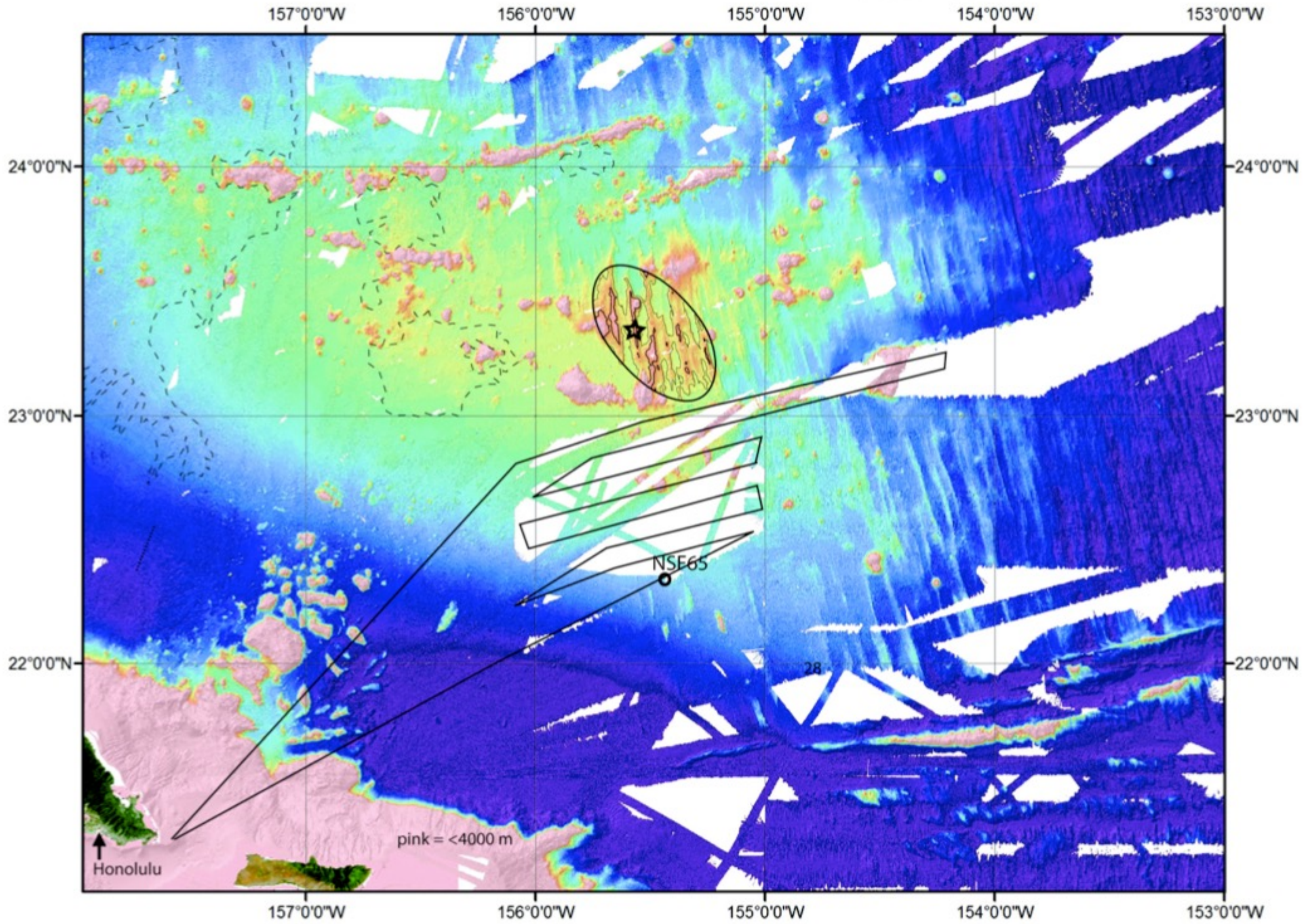
25 years in the Royal Observatory of Belgium



← Can detect cumulative rainfall

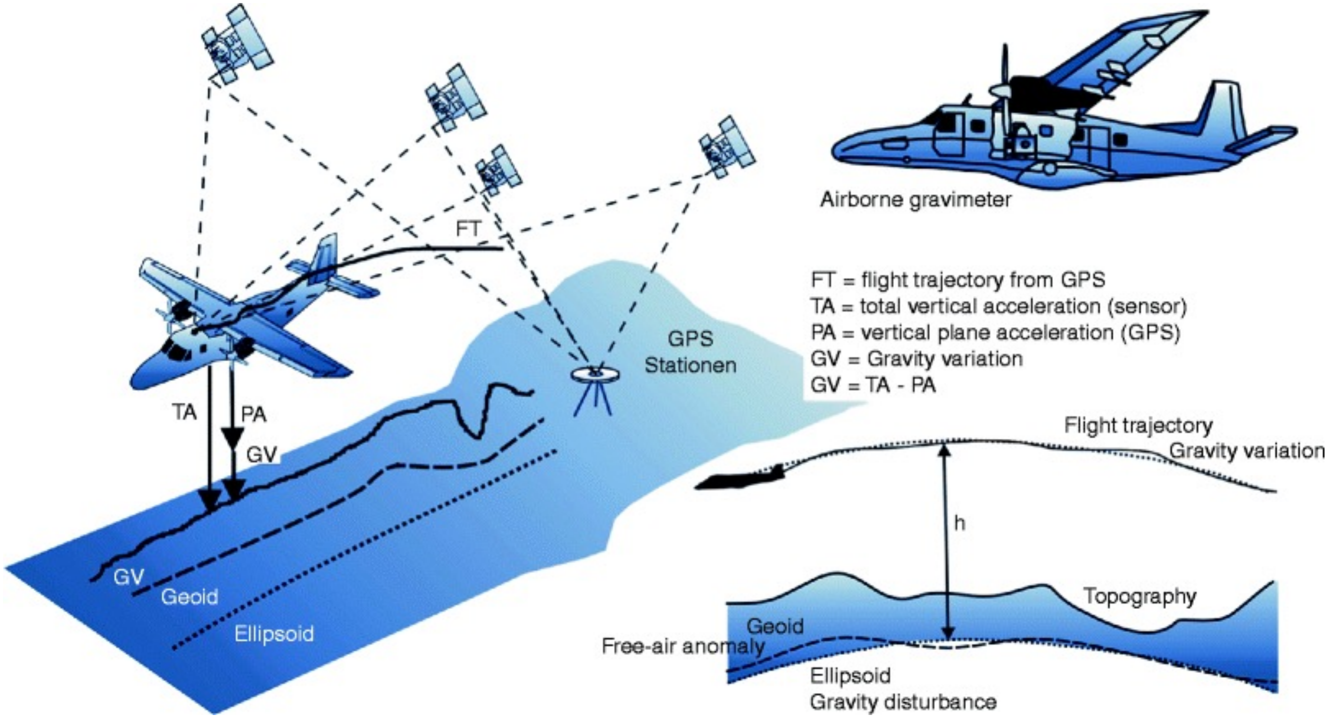


Shipboard Gravimeter (stabilized for ship’s movement)



Star = N. Hawaiian Arch Mohole Site: 23°20′N, 155°34′W, 4050-4100 m, 81 Ma, 56 mW/m2, 36 mm/yr HSR, 90 nm to Honolulu airport

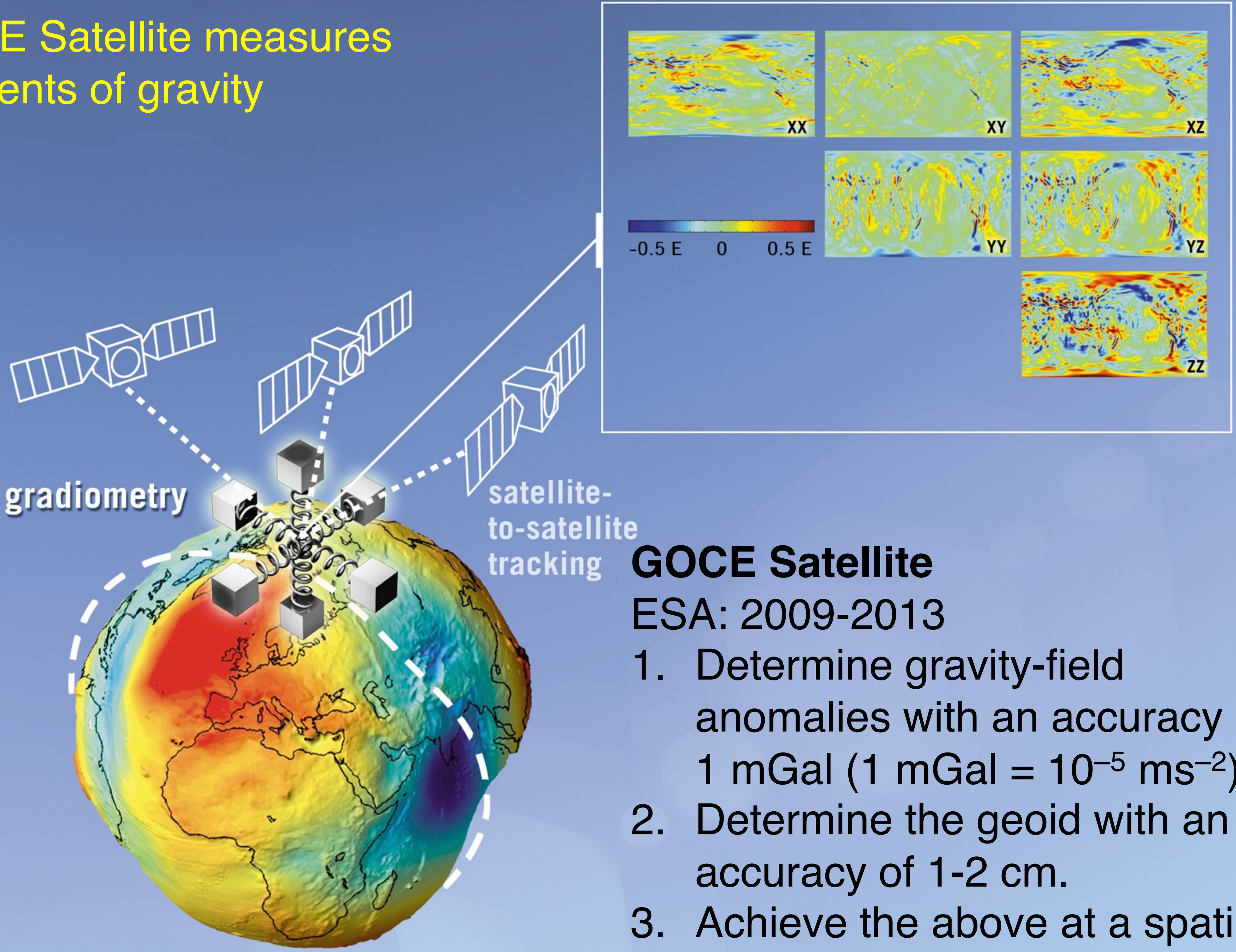
Within Oval, bold lines = 4100 m, fine lines = 4200 m.
Dashes outline arch volcanism



Airborne Gravimeter (also stabilized, tracked for location)

Sensitive to ~1 mGal

GOCE Satellite measures gradients of gravity

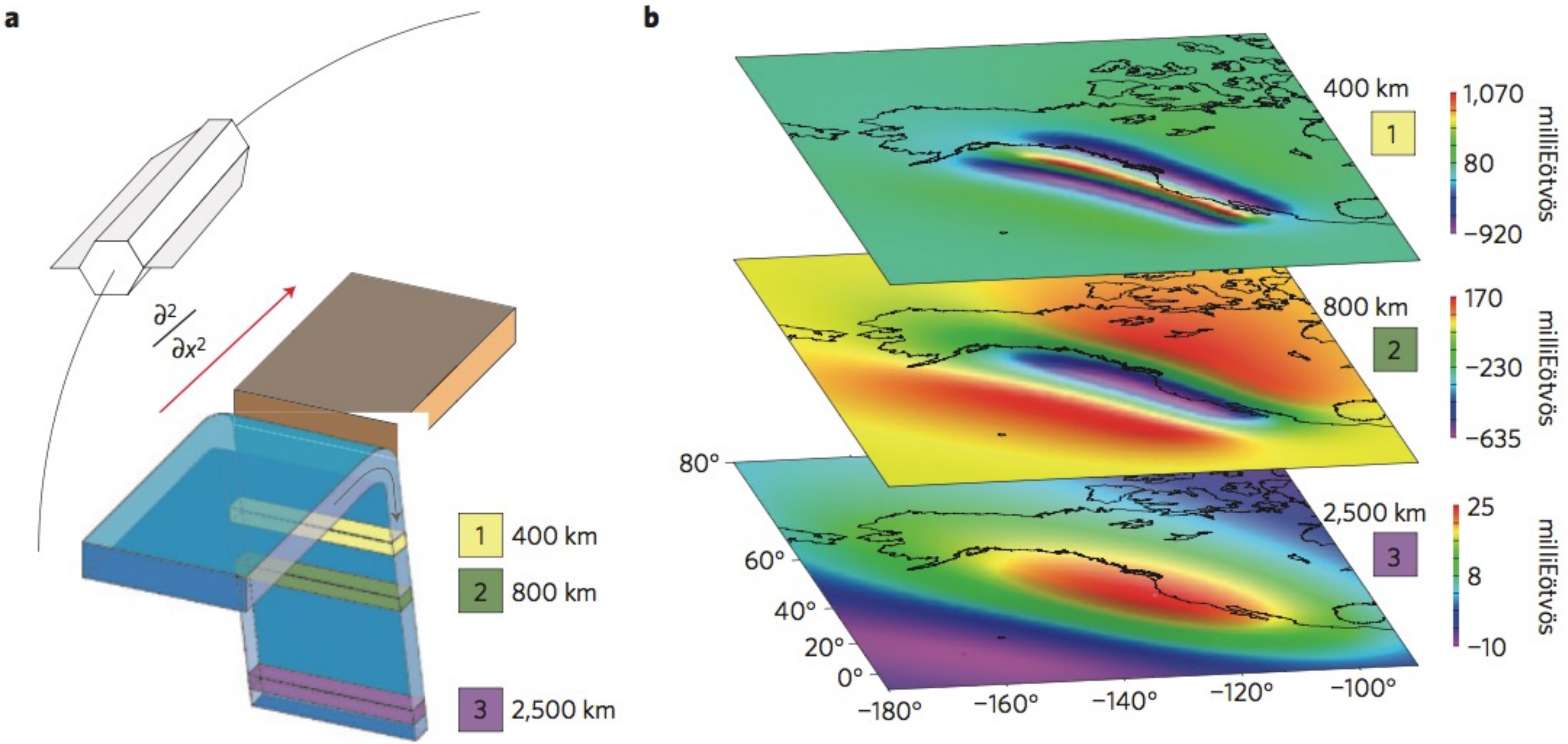


GOCE Satellite

ESA: 2009-2013

1. Determine gravity-field anomalies with an accuracy of 1 mGal (1 mGal = 10^{-5} ms^{-2}).
2. Determine the geoid with an accuracy of 1-2 cm.
3. Achieve the above at a spatial resolution better than 100 km.

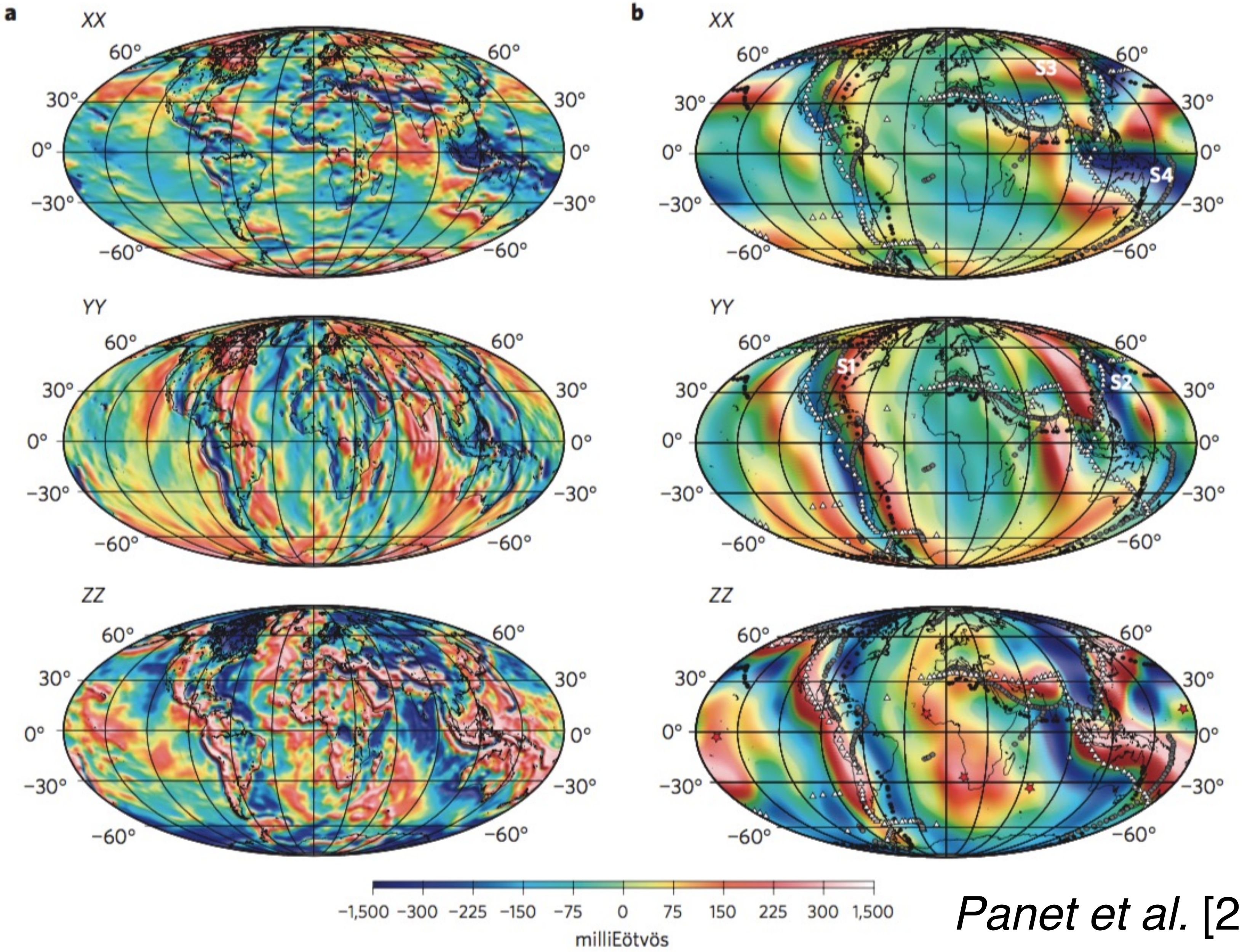
Gravity Gradients from a Satellite



Panet et al. [2014]

Gravity Gradients from GOCE

Measured from GOCE   Predicted from Tectonic Model



Panet et al. [2014]

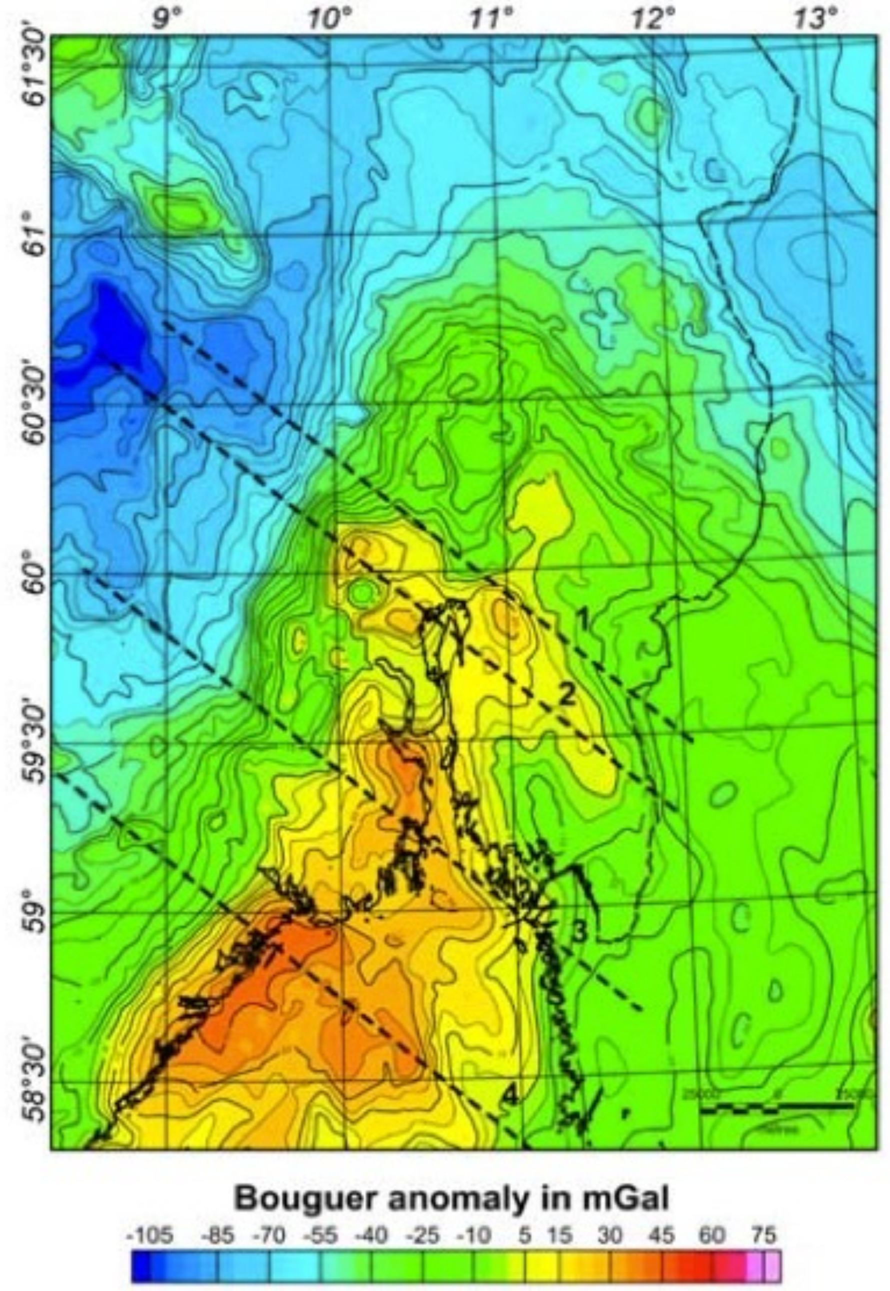
Gravity Corrections:

To observe the gravity anomaly of a subsurface structure, we need to correct a gravity measurement for:

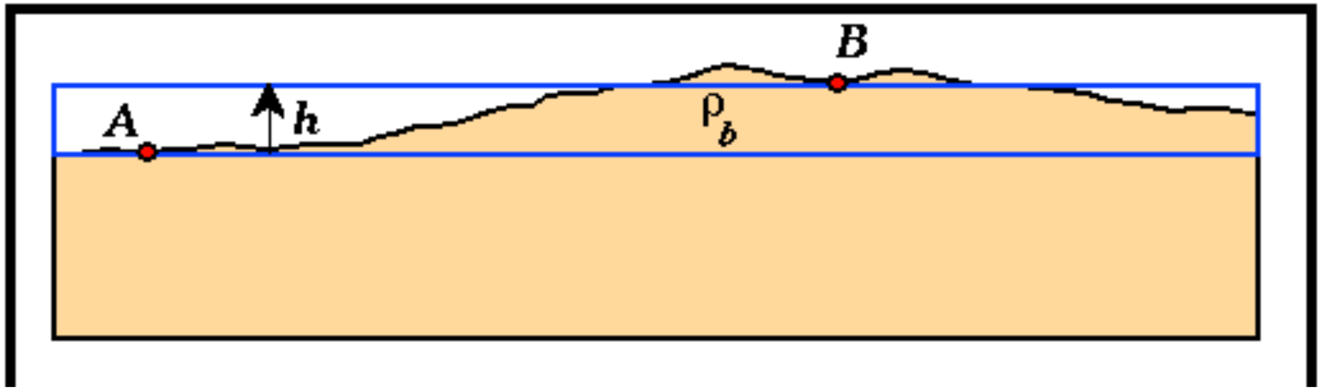
- → Instrument Drift
- → Tidal effects
- → Movement of the gravimeter (Eötvös correction)
- → Position on the Earth (Latitude correction)
- → Nearby Topography (Terrain correction)
- → Elevation (Free-air correction)
- → The mass of rocks below (Bouguer correction)
- → Geoid height

Gravity Survey of the Oslo Graben

Ebbing et al. [2007]



Corrections due to Topography

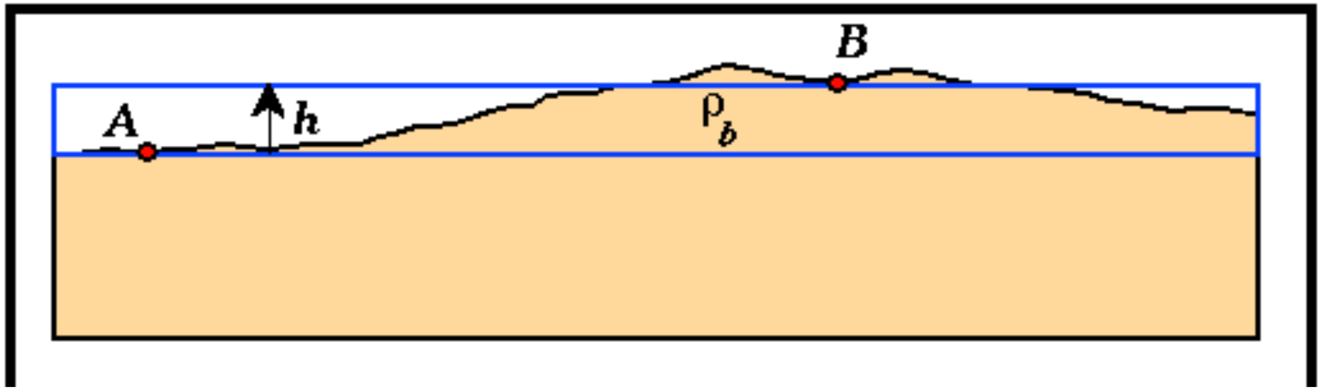


Free-Air Correction

Add a correction that accounts for the smaller gravity at elevation B relative to elevation A.

$$\Delta g_{FA} = h \times 0.3086 \text{ mgal/m}$$

Corrections due to Topography



Free-Air Correction

Add a correction that accounts for the smaller gravity at elevation B relative to elevation A.

$$\Delta g_{FA} = h \times 0.3086 \text{ mgal/m}$$

Bouguer Plate Correction

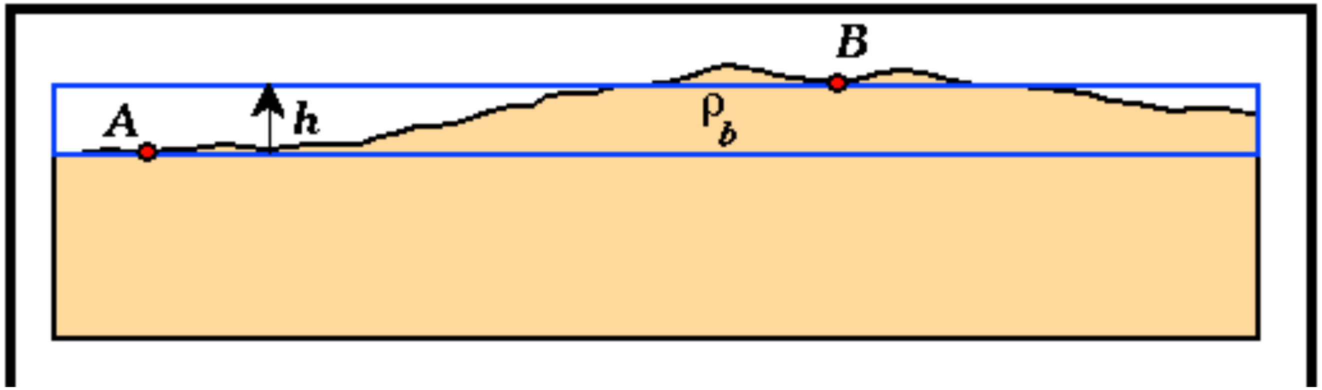
Subtract a correction that accounts for the extra gravity at B due to the extra mass of the rock layer below.

$$\Delta g_{BP} = 2\pi G \rho_b h$$

$$\Delta g_{BP} = h \times 0.1173 \text{ mgal/m}$$

for a density of 2800 kg/m^3

Corrections due to Topography



Free-Air Correction

Add a correction that accounts for the smaller gravity at elevation B relative to elevation A.

$$\Delta g_{FA} = h \times 0.3086 \text{ mgal/m}$$

Terrain Correction

Corrects for nearby topography. Small but always positive (why?)

Bouguer Plate Correction

Subtract a correction that accounts for the extra gravity at B due to the extra mass of the rock layer below.

$$\Delta g_{BP} = 2\pi G \rho_b h$$

$$\Delta g_{BP} = h \times 0.1173 \text{ mgal/m}$$

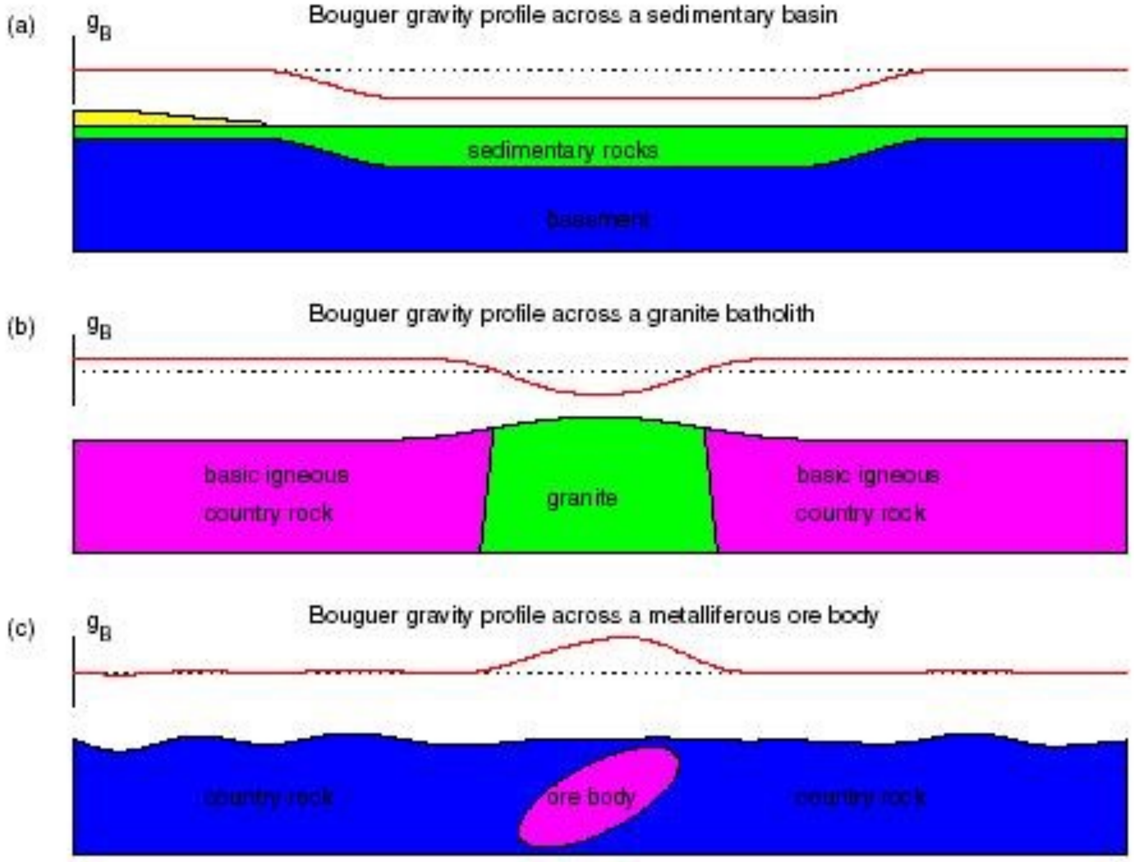
for a density of 2800 kg/m^3

Gravity anomalies over uncompensated topography (short λ)

Free-air anomaly (apply the free-air correction only):
$g_{FA} > 0$ because of the topography's excess mass

Bouguer anomaly (apply free-air and Bouguer plate corrections):
$g_{BP} \sim 0$ because Bouguer corrects for excess mass.

Bouguer anomaly can sense uncompensated density variations at depth

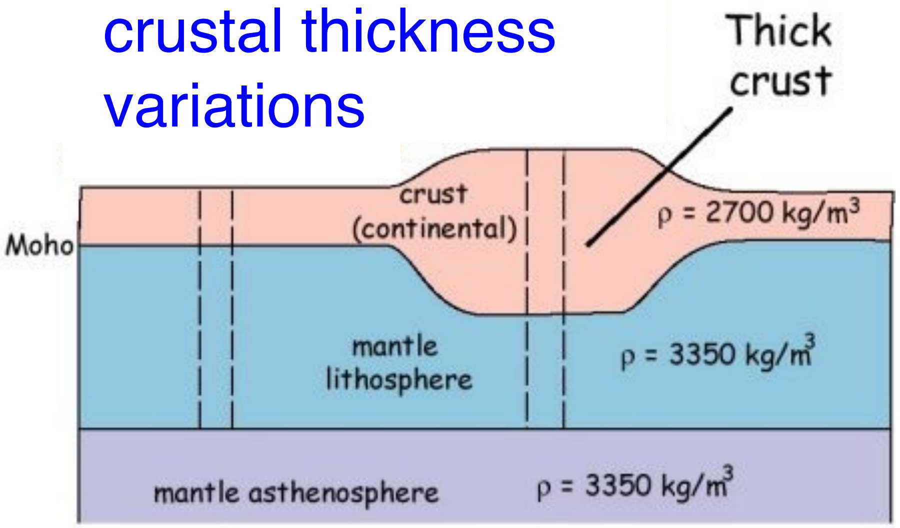


Isostatic Compensation:

Excess mass in topography is compensated by mass deficit at depth

Airy Isostasy:

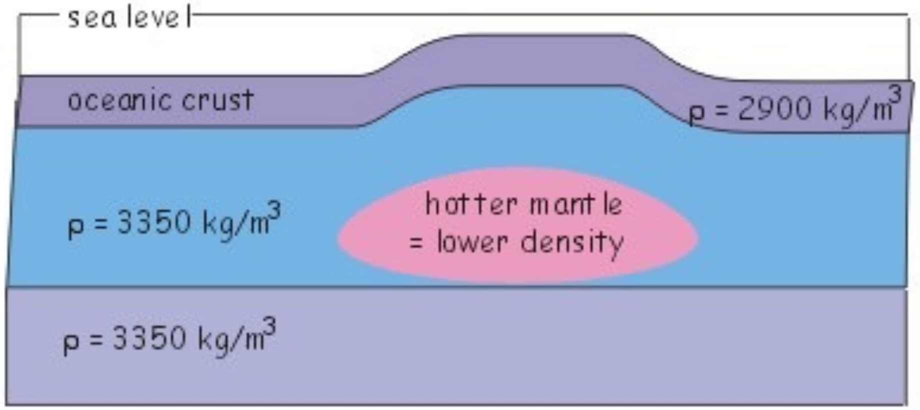
Compensation of topography with crustal thickness variations



Examples:
Mountain ranges, continents

Pratt Isostasy:

Compensation of topography with density variations

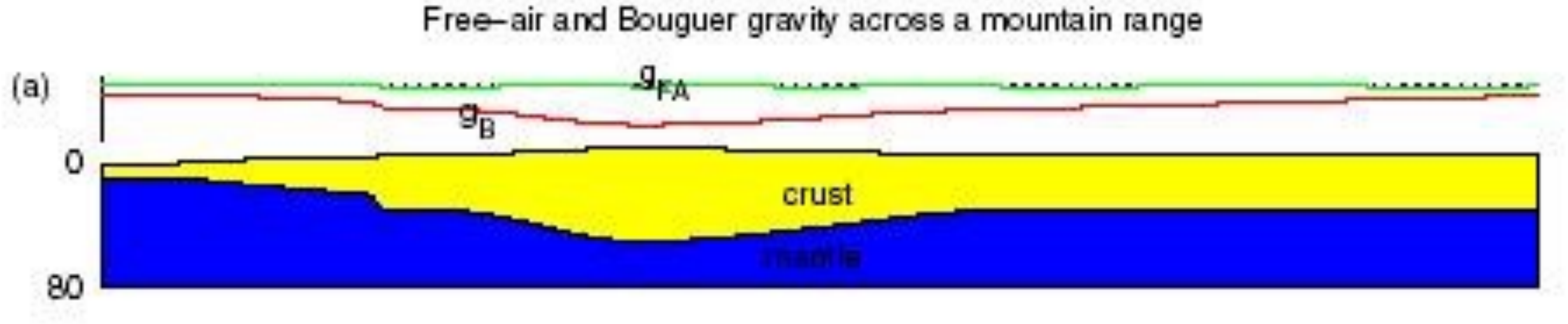


Example:
Mid-ocean ridges

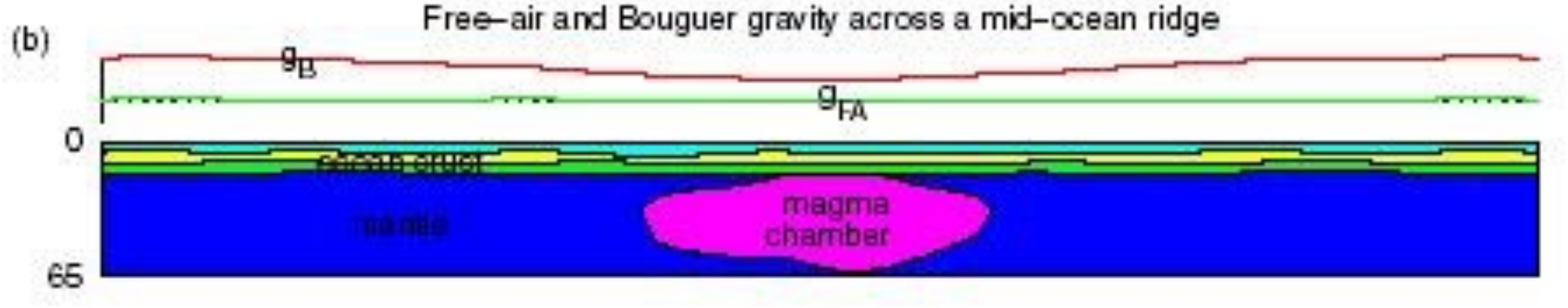
Compensated topography (Long-wavelengths)

Free-air anomaly (apply the free-air correction only):
$g_{FA} \sim 0$ because topography is compensated (no excess mass)

Bouguer anomaly (apply both free-air and Bouguer plate corrections):
$g_{BP} < 0$ because Bouguer removes additional mass.

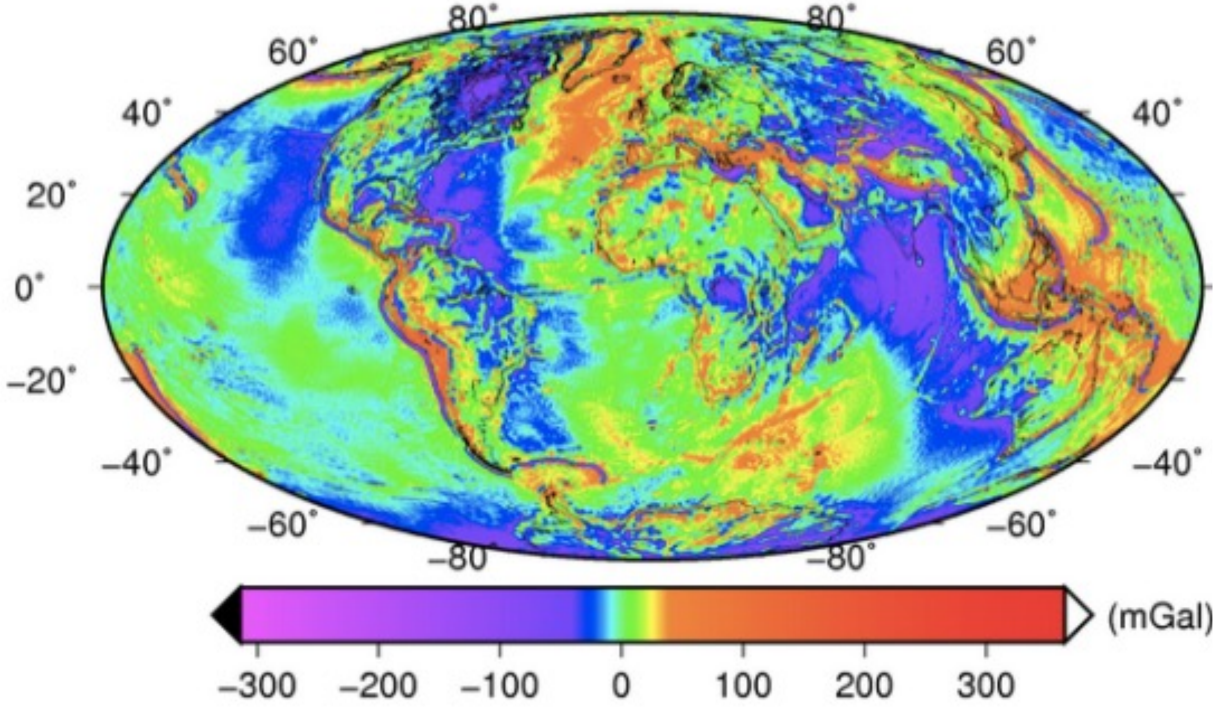


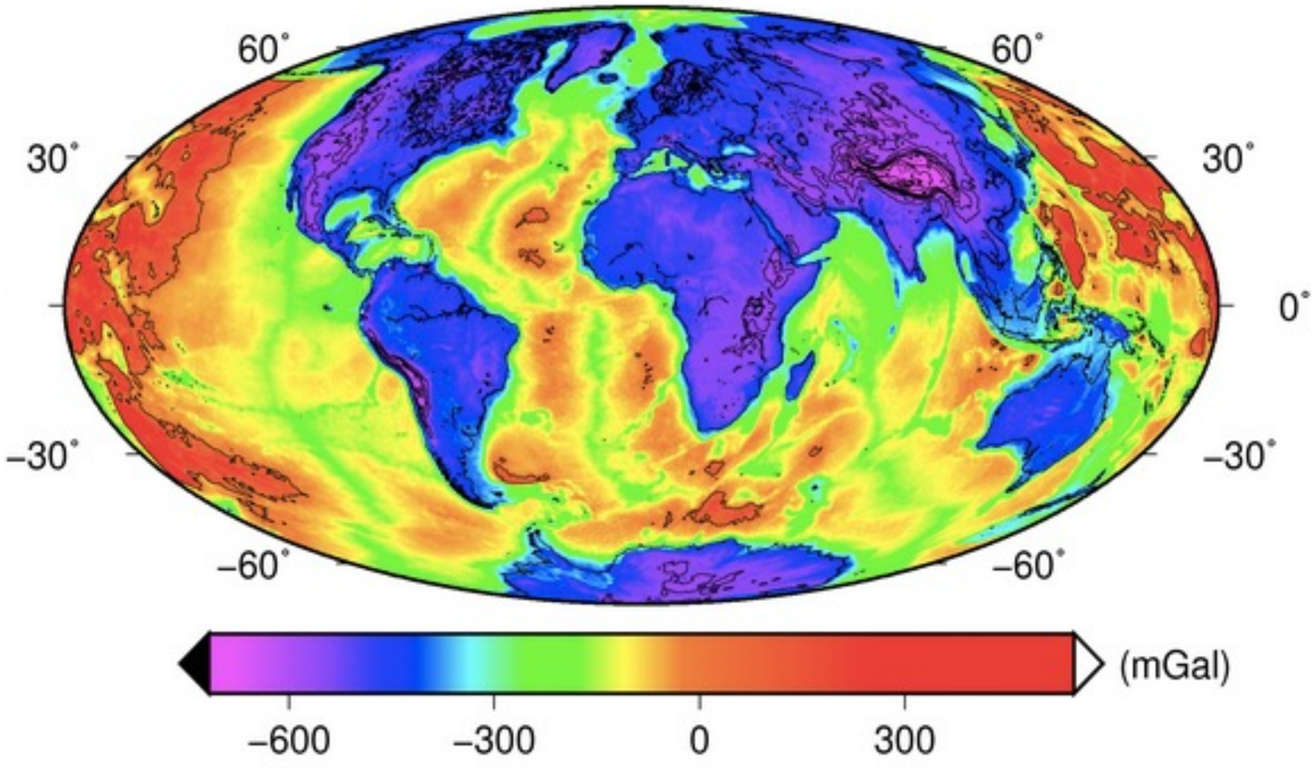
Airy



Pratt

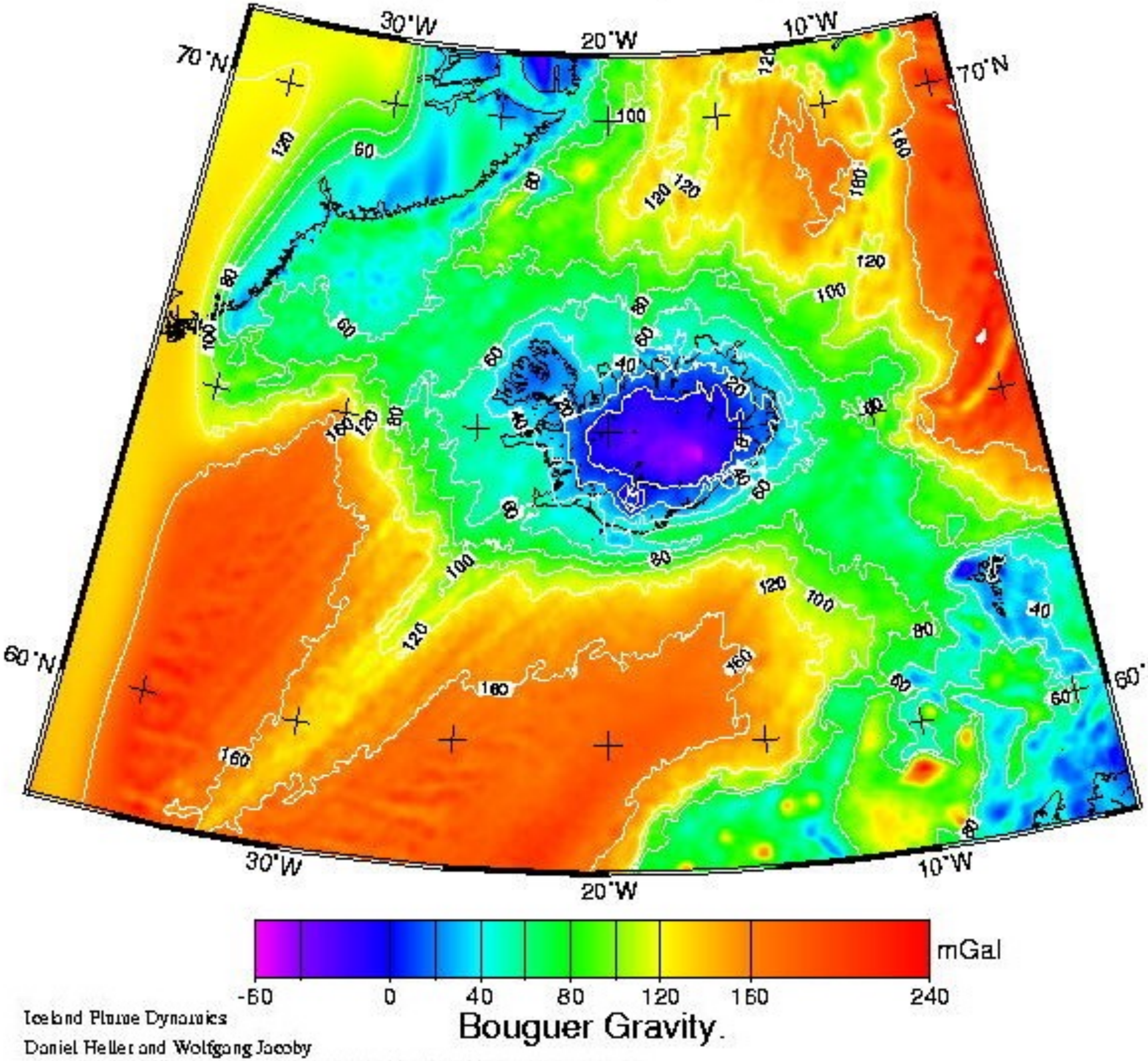
Free Air Anomaly →





← Bouguer Anomaly

Iceland
Bouguer Gravity Map

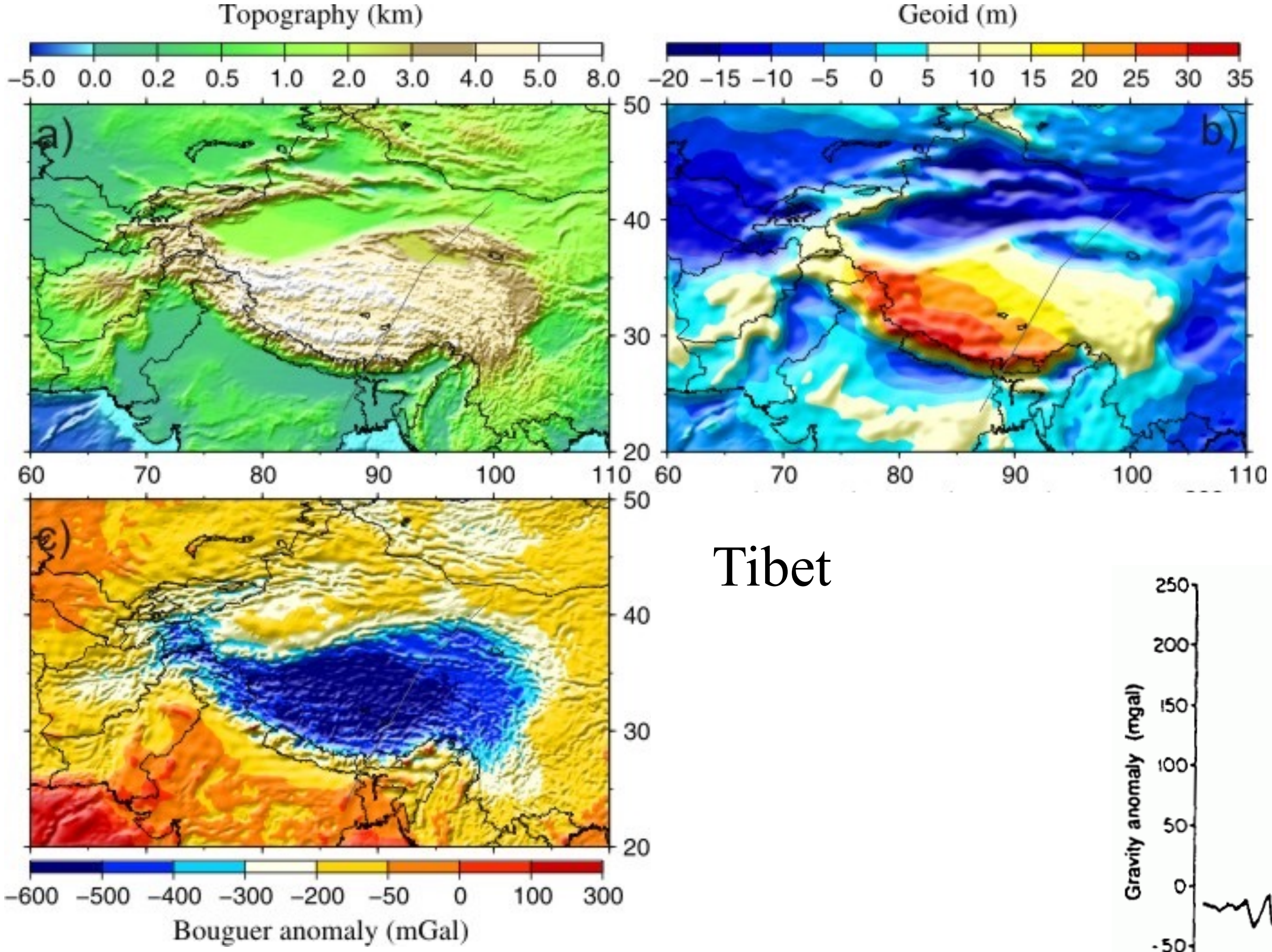


Iceland Plume Dynamics

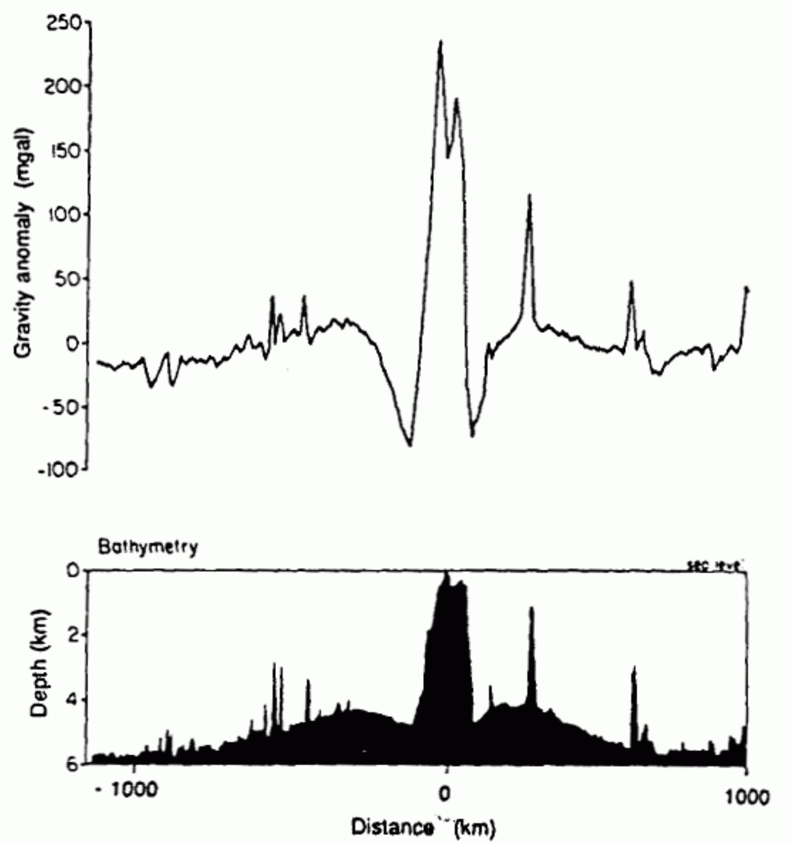
Daniel Heller and Wolfgang Jacoby

Inst. for Geoscience - Geophysics - Johannes Gutenberg University of Mainz

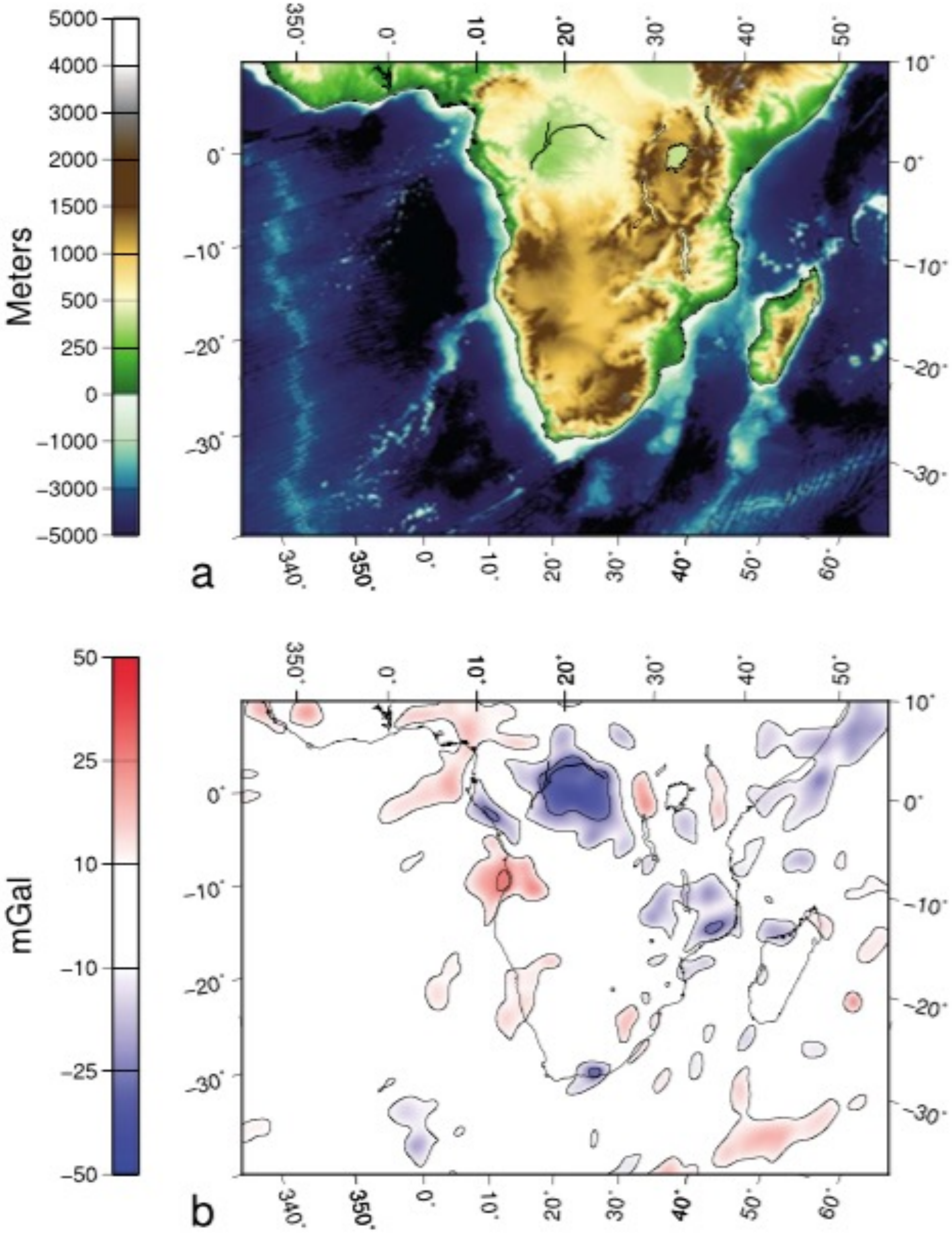
GMT Jul 10 09:34

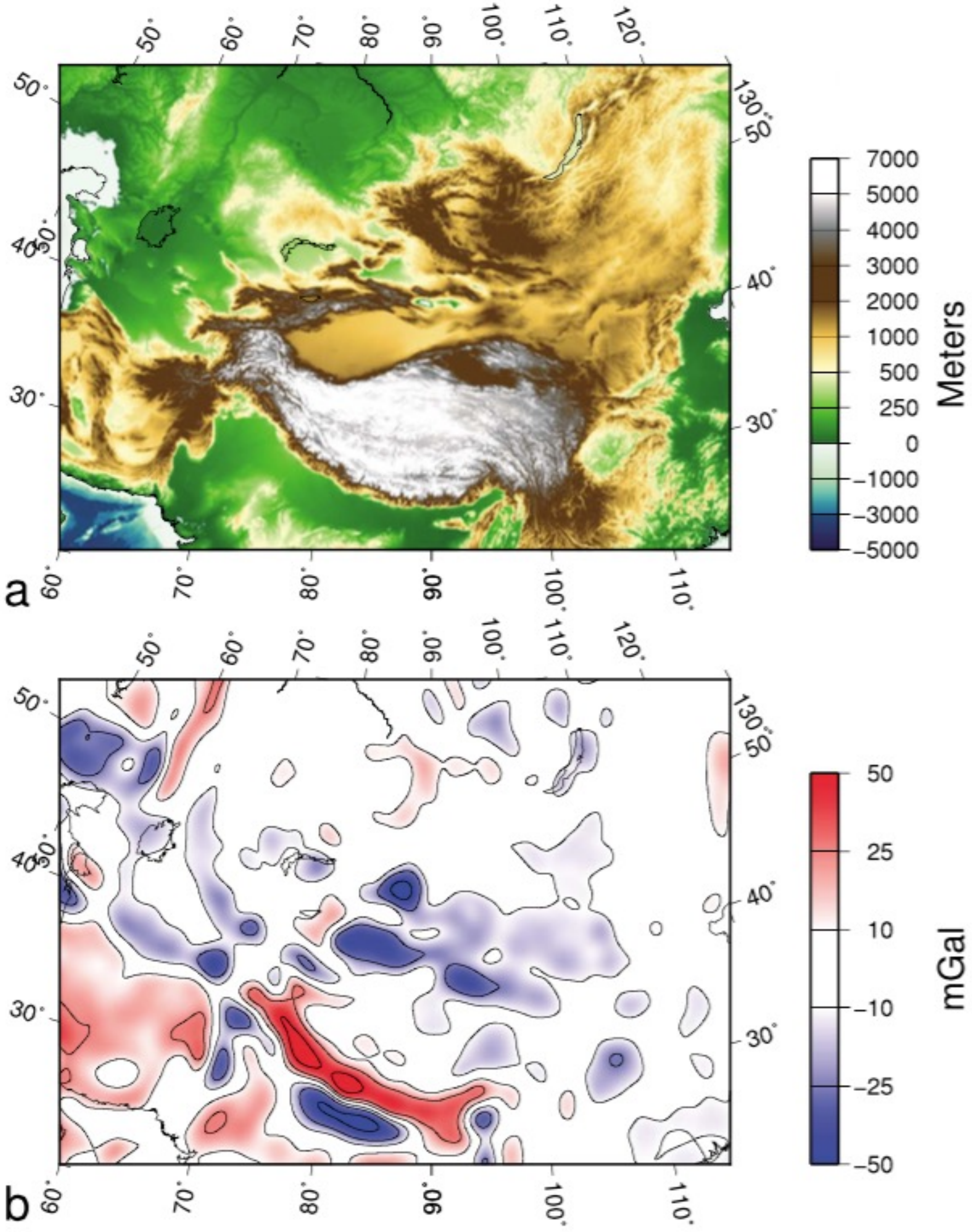


Tibet



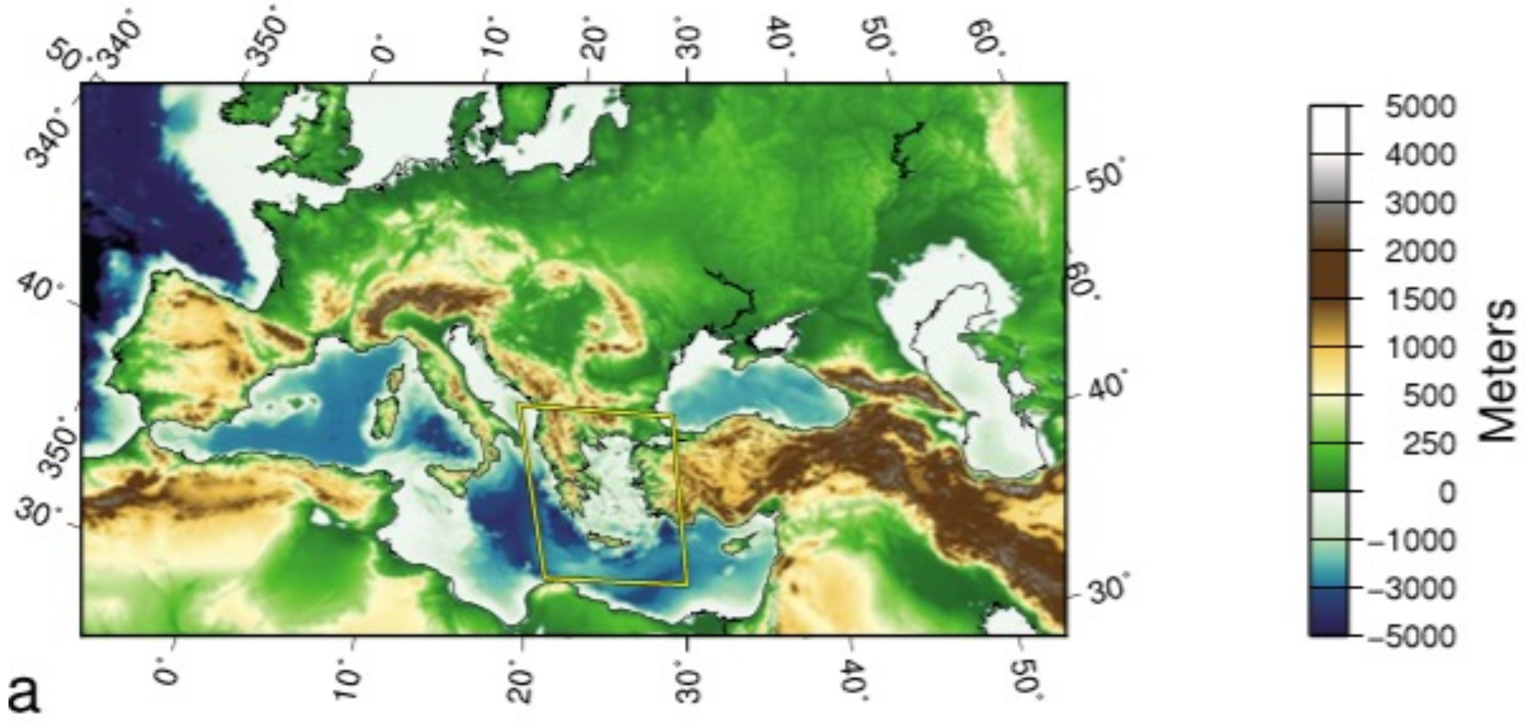
Free-air gravity across the Hawaiian ridge



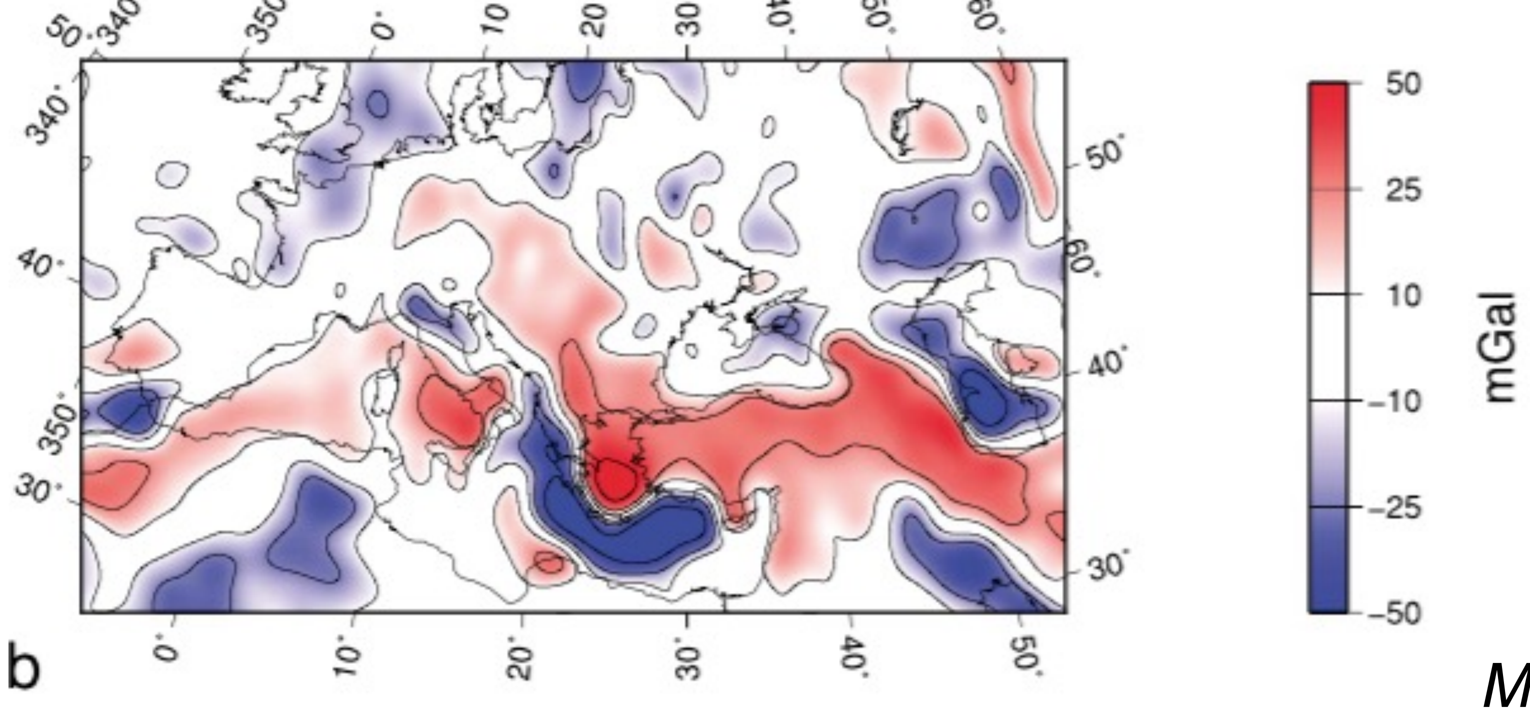


Free-Air Gravity Anomalies

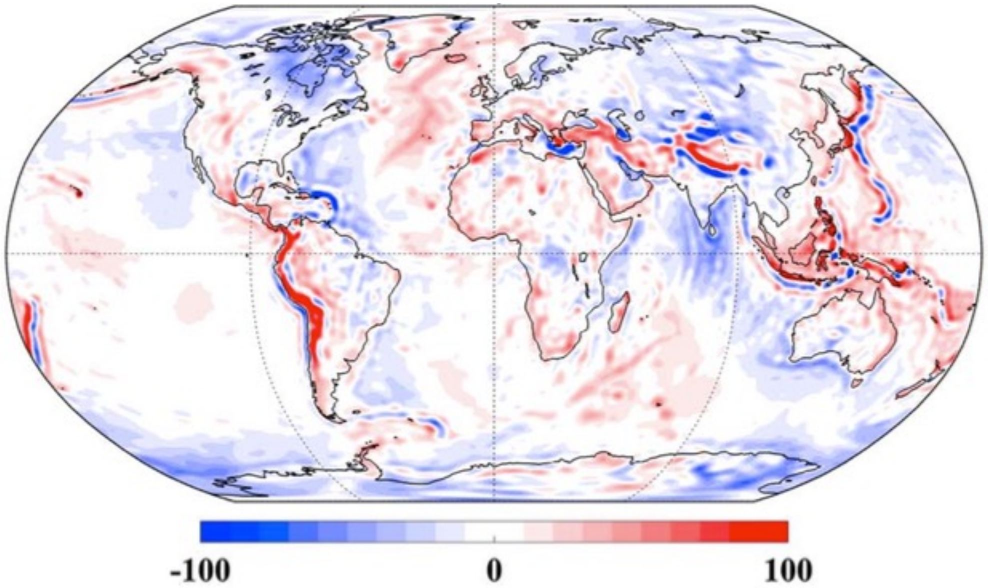
Molnar et al. [2015]



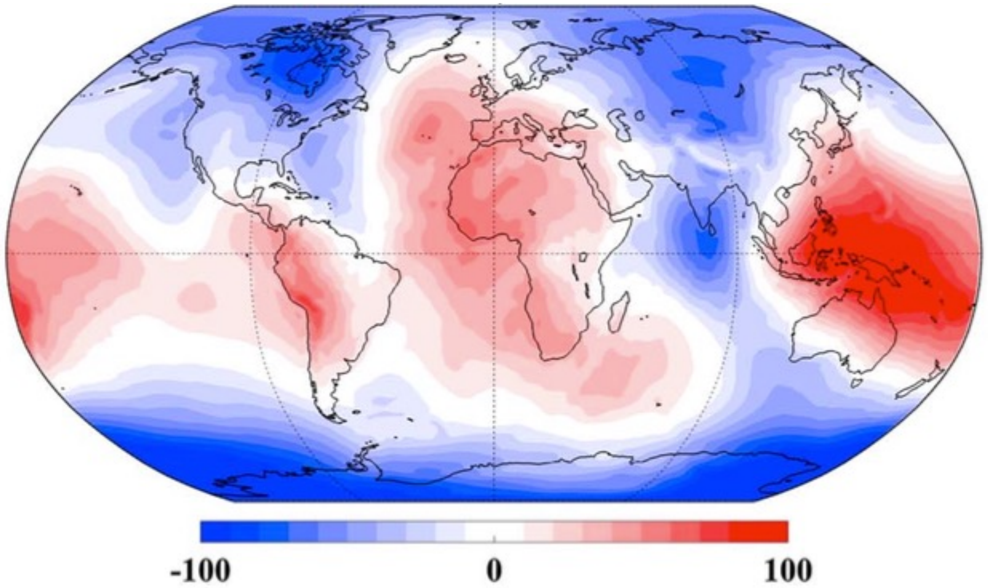
Free-Air Gravity Anomalies



Molnar et al. [2015]



Free-Air Gravity Anomaly (mgal)



Geoid Anomaly (m)

The free-Air Gravity Anomaly still has long-wavelength structure: Why?

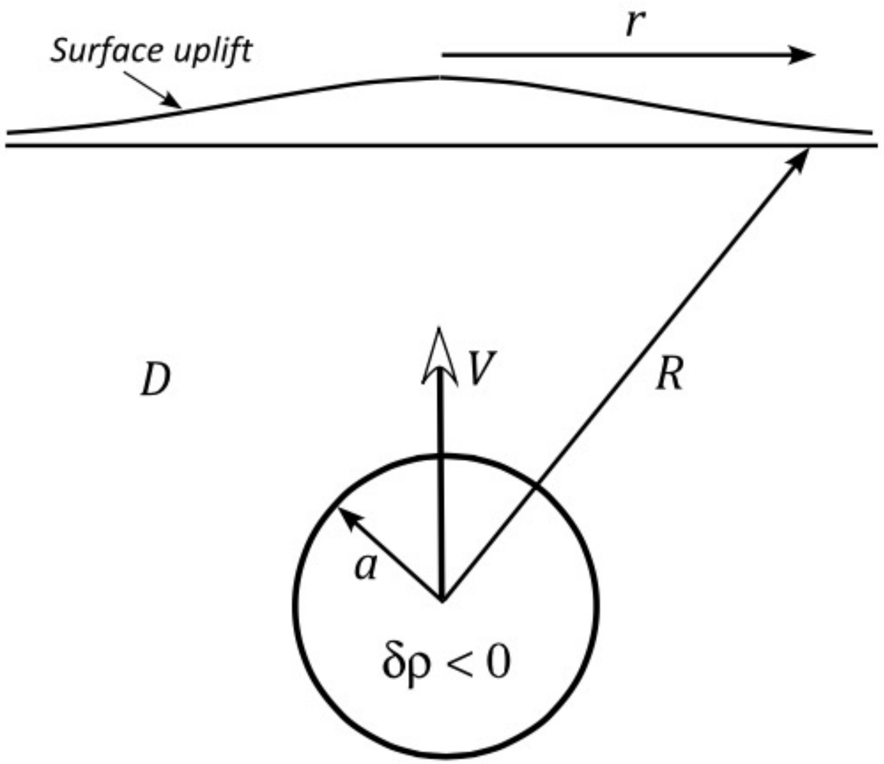
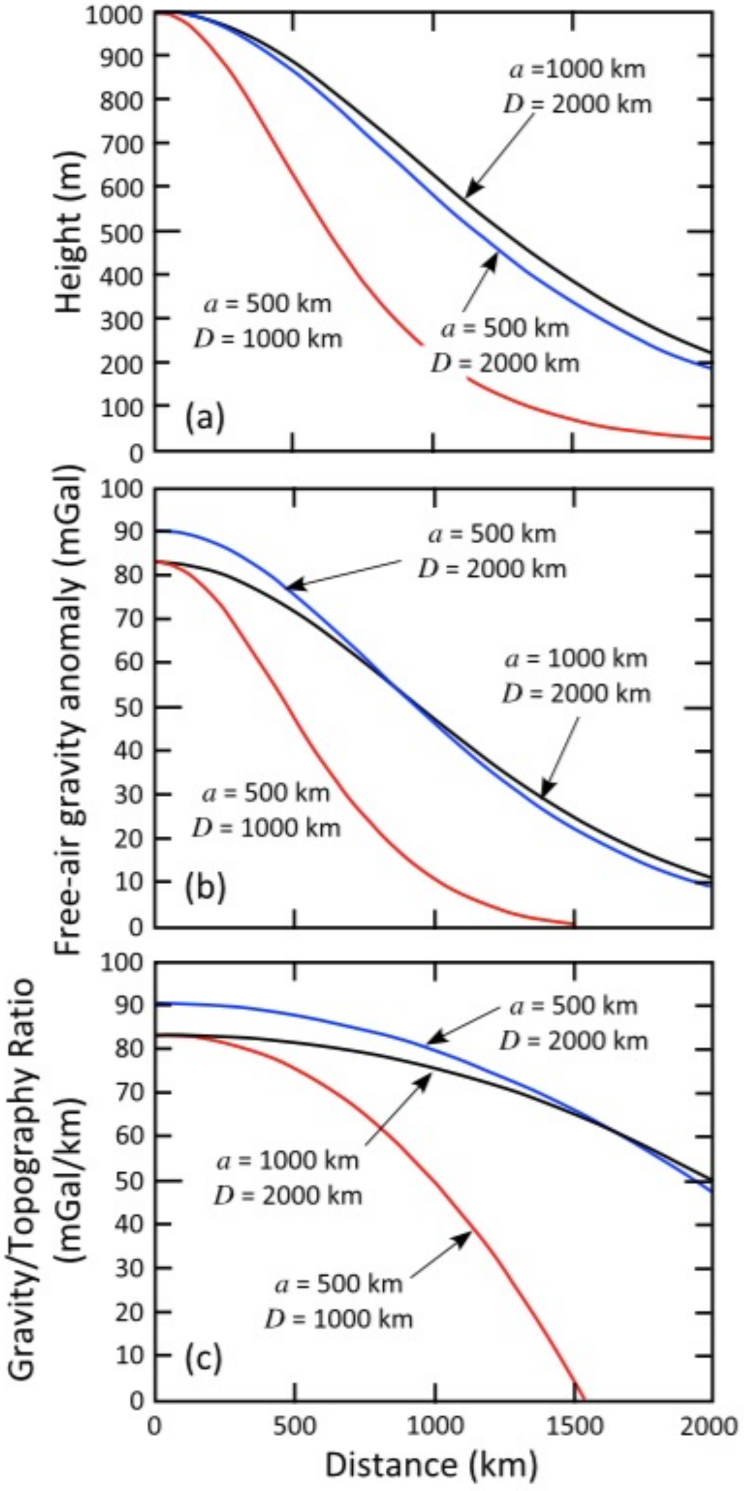
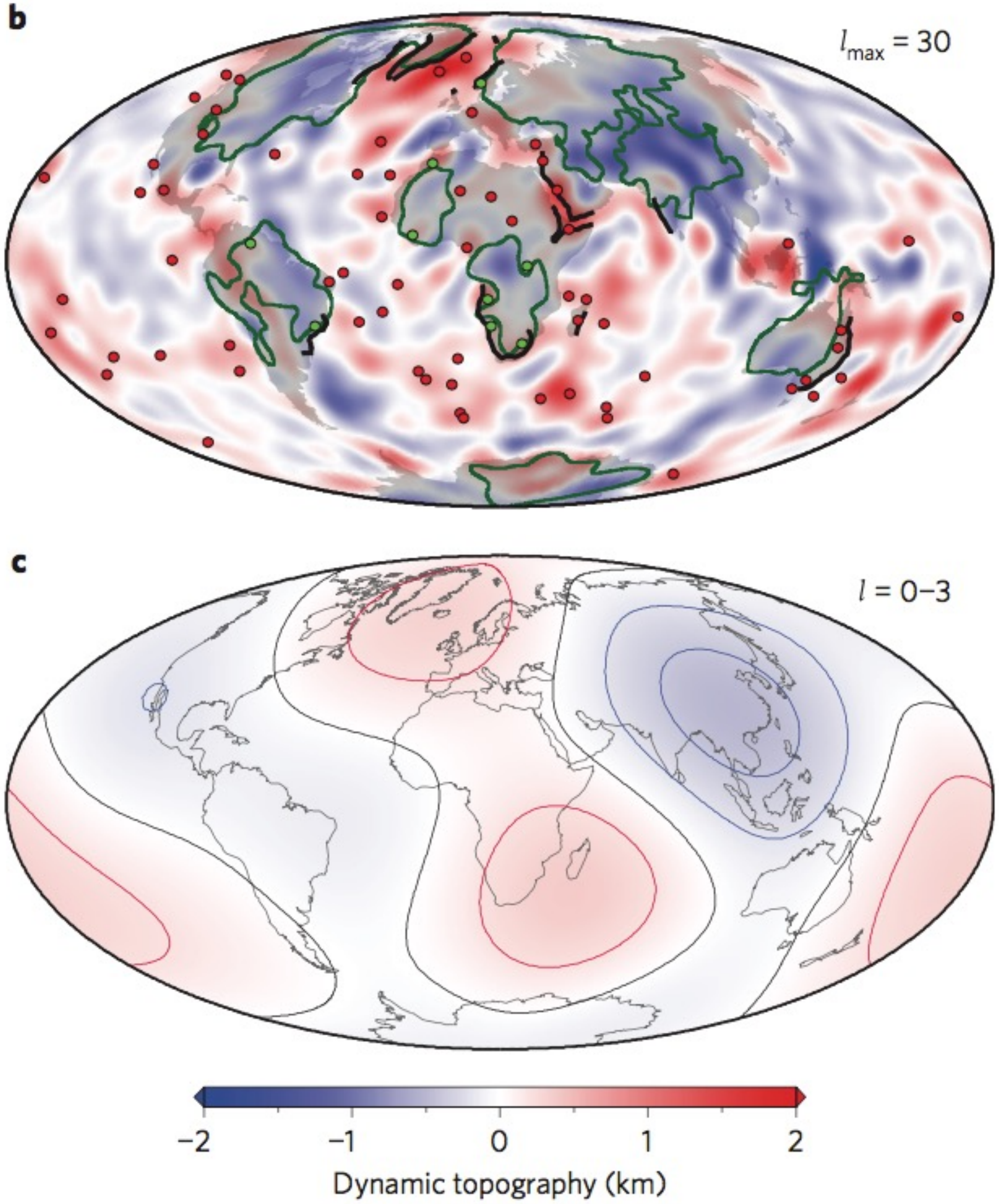


Figure A4. Coordinate system used calculating surface defections above a rising sphere, following *Morgan* [1965a].



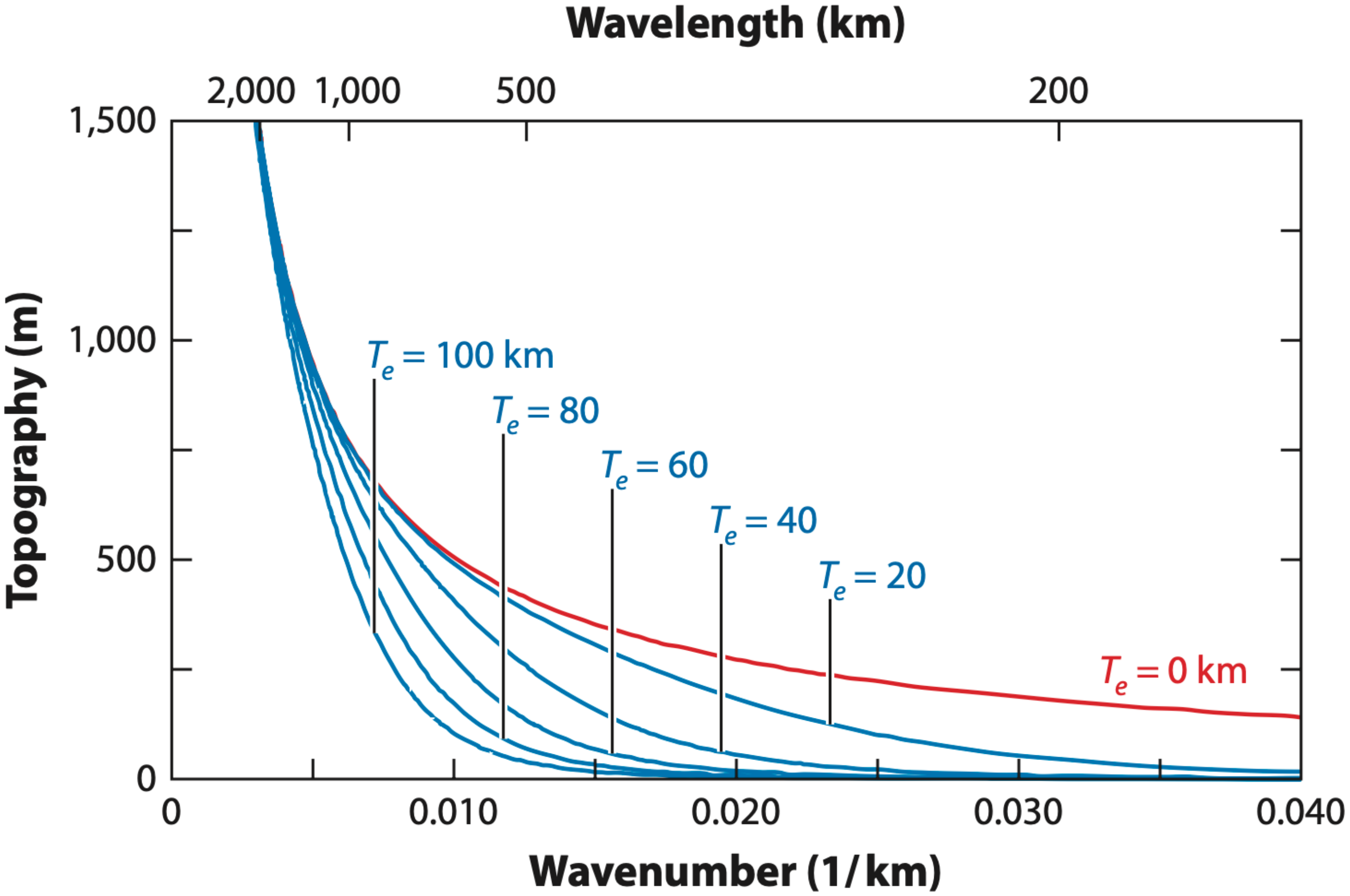
Dynamic Topography above a rising sphere: The surface deflection is NOT compensated!

Molnar et al. [2015]



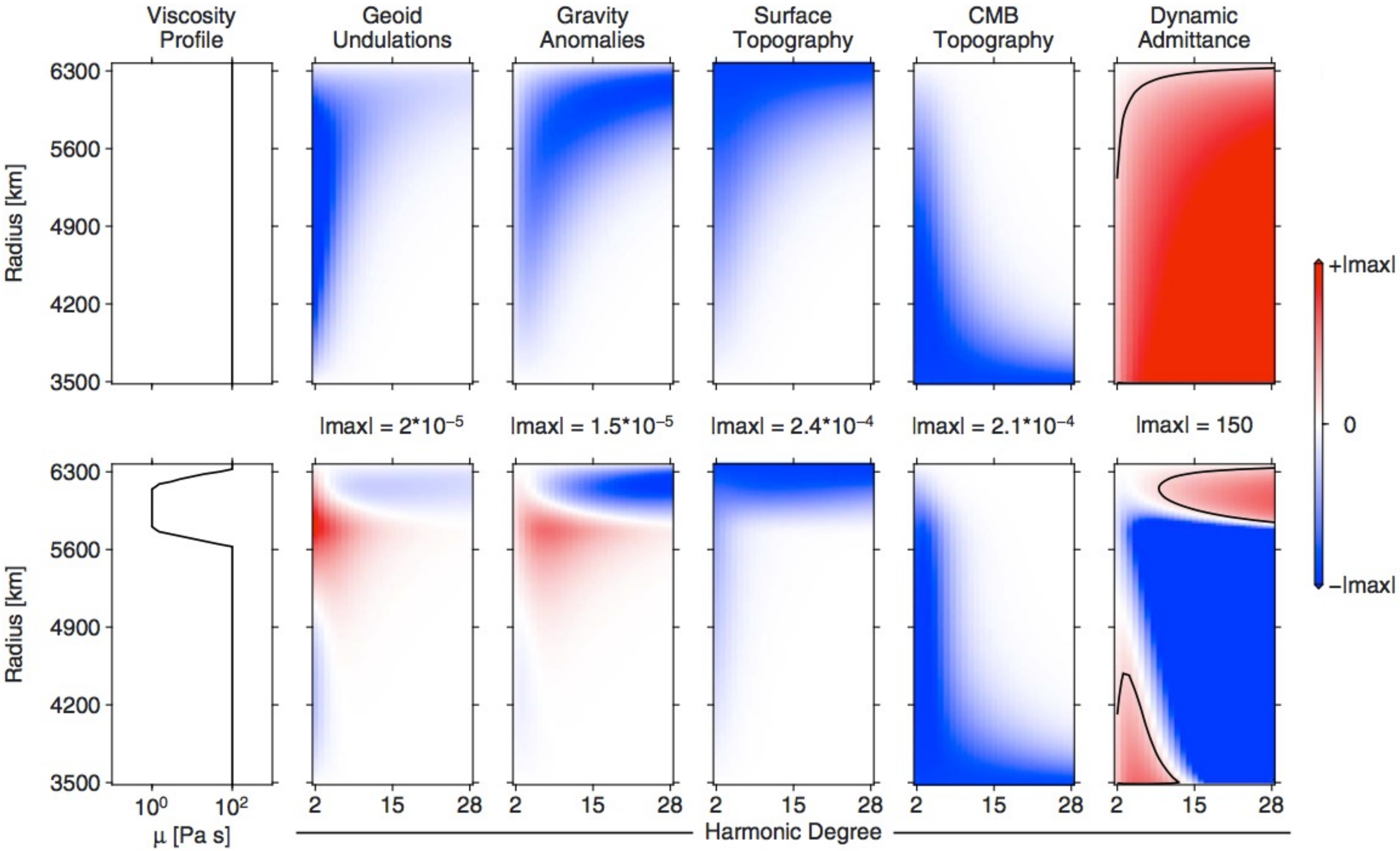
Can we measure dynamic topography using the observed gravity to topography ratio?

Hoggard et al. **[2016] use an** ***admittance*** **of**
Z = 50 mgal/km



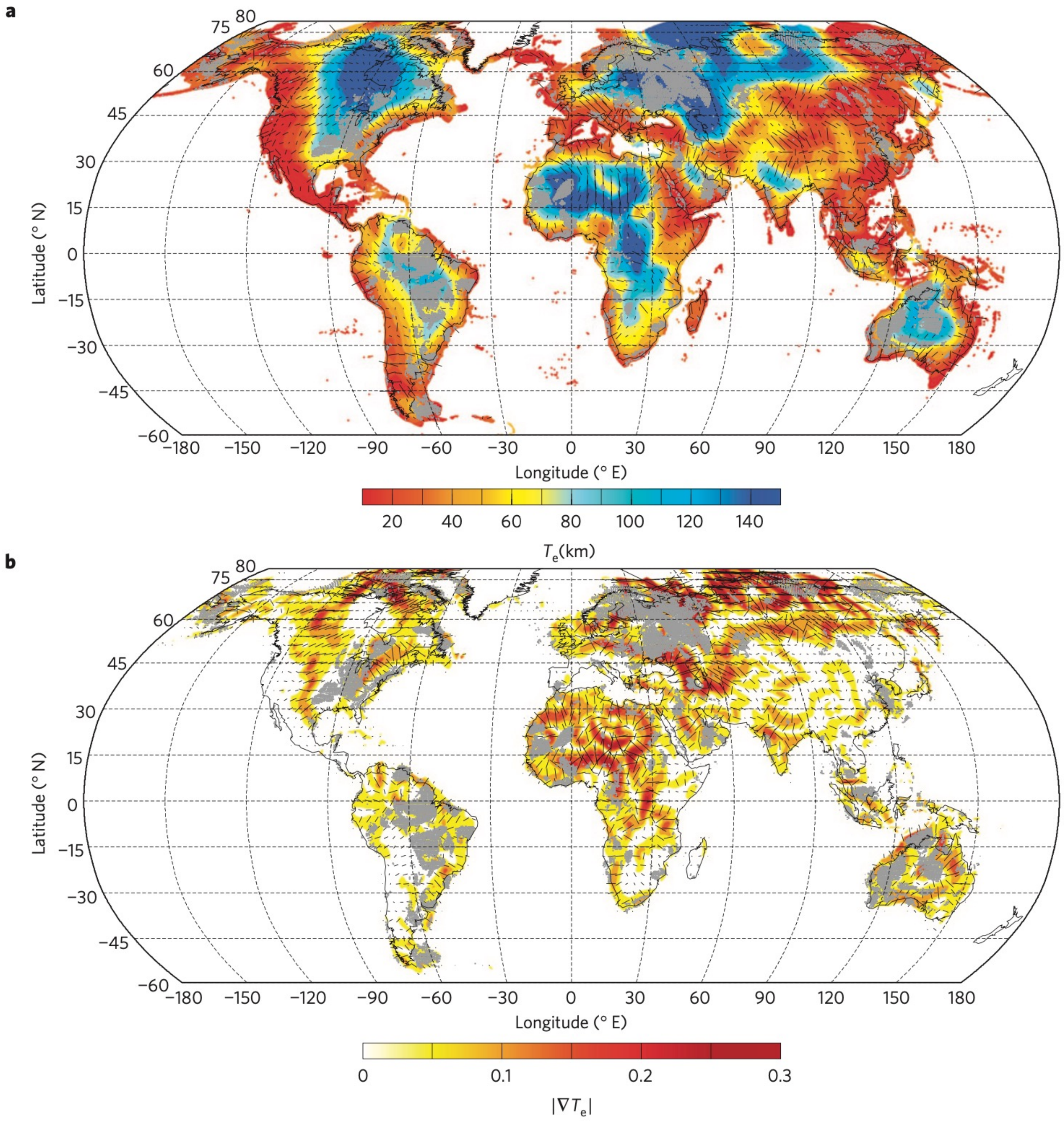
Effect of elastic thickness on (observed) dynamic topography

Watts [2013]



How do gravity and geoid anomalies relate to depth anomalies?
Its complicated…. (and still a research topic)

Colli et al. [2016]



Global effective elastic thickness over continents calculated from the coherence between Bouguer gravity and topography using a wavelet transform

Audet & Burgmann [2011]

Conclusions

→ Gravity and the geoid tell us about density heterogeneity at depth.

→ Interpretation depends on:
- Isostatic compensation of topography
- Wavelength of anomaly
- Viscosity structure

→ Gravity interpretation may be non-unique!

Topography

Bouguer Gravity