Gravity Surveying

Measurement of gravity and interpretation

Measurement of gravity

Absolute measurements

- Large pendulums

$$T = 2\pi \sqrt{L/g}$$

- Falling body techniques

$$z = \frac{1}{2} g\, t^2$$

For a precision of 1 mgal

Distance for measurement 1 to 2 m

z known at 0.5 µm

t known at 10^{-8} s

Relative measurements

- Gravimeters
- Use spring techniques
- Precision: 0.01 to 0.001 mgal

Relative measurements are used since absolute gravity determination is complex and long!

Gravimeters

LaCoste-Romberg mod. G

Scintrex CG-5

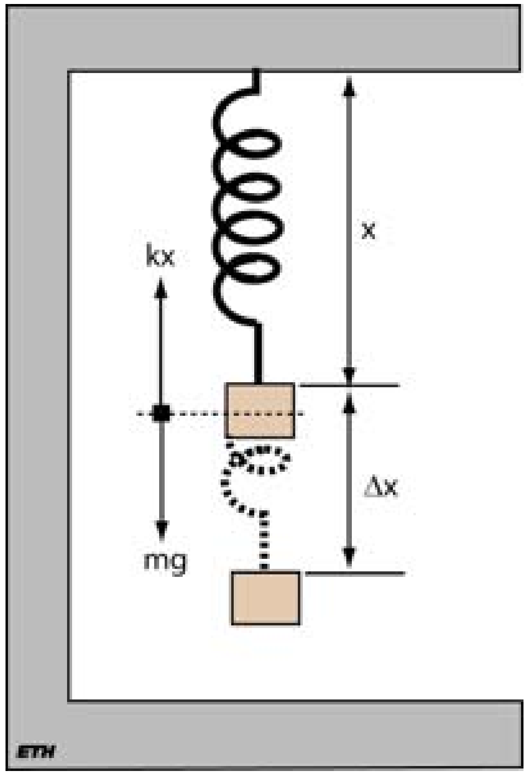
Source: P. Radogna, University of Lausanne

Stable gravimeters

$$\Delta g = \frac{k}{m}\Delta x$$ Hook´s Law

$$g = \frac{4\pi^2}{T^2}\Delta x \quad \text{with} \quad T = 2\pi\sqrt{\frac{m}{k}}$$

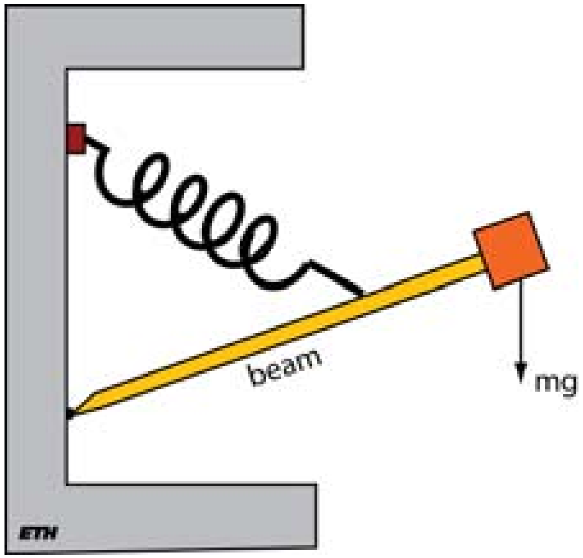
For one period



k is the elastic spring constant

Problem: low sensitivity since the spring serves to both support the mass and to measure the data. So this technique is no longer used…

LaCoste-Romberg gravimeter



This meter consists in a hinged beam, carrying a mass, supported by a spring attached immediately above the hinge.

A „zero-lenght“ spring can be used, where the tension in the spring is proportional to the actual lenght of the spring.

- More precise than stable gravimeters (better than 0.01 mgal)
- Less sensitive to horizontal vibrations
- Requires a constant temperature environment

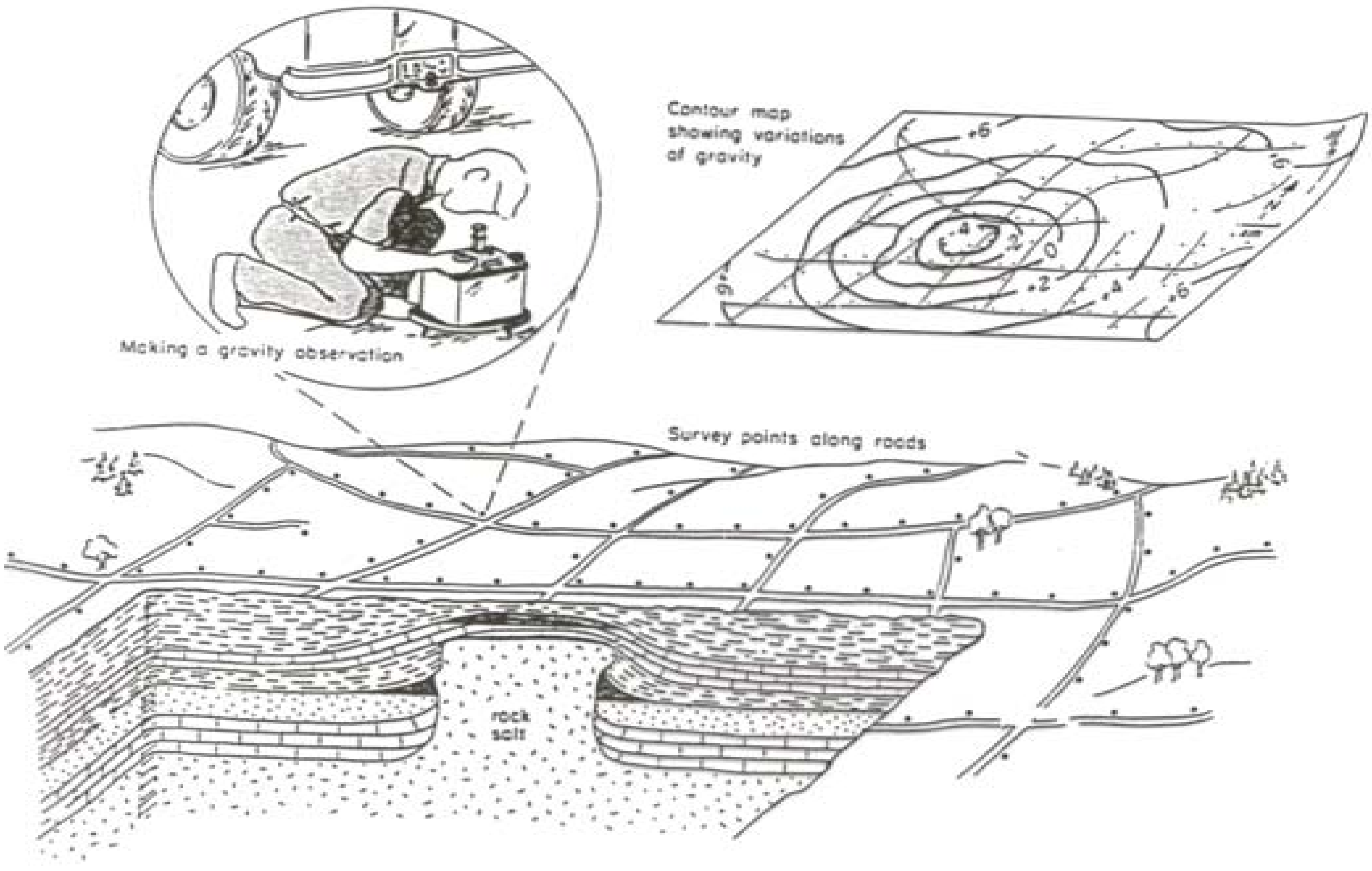
CG-5 Autograv

CG-5 electronic gravimeter:

CG-5 gravimeter uses a mass supported by a spring. The position of the mass is kept fixed using two capacitors. The *dV* used to keep the mass fixed is proportional to the gravity.

- Self levelling
- Rapid measurement rate (6 meas/sec)
- Filtering
- Data storage

Gravity surveying



Factors that influence gravity

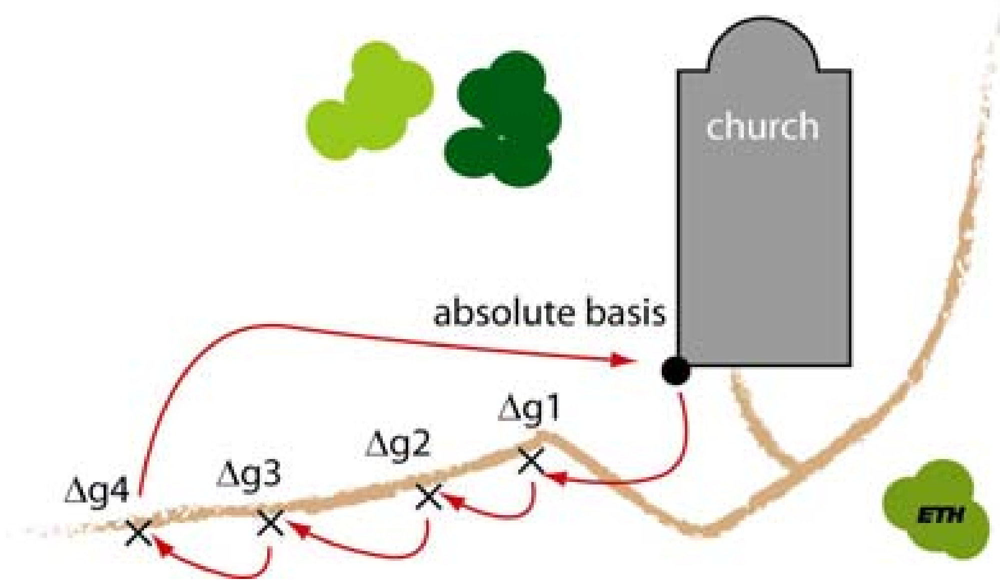
The magnitude of gravity depends on 5 factors:

- Latitude
- Elevation
- Topography of the surrounding terrains
- Earth tides
- Density variations in the subsurface:

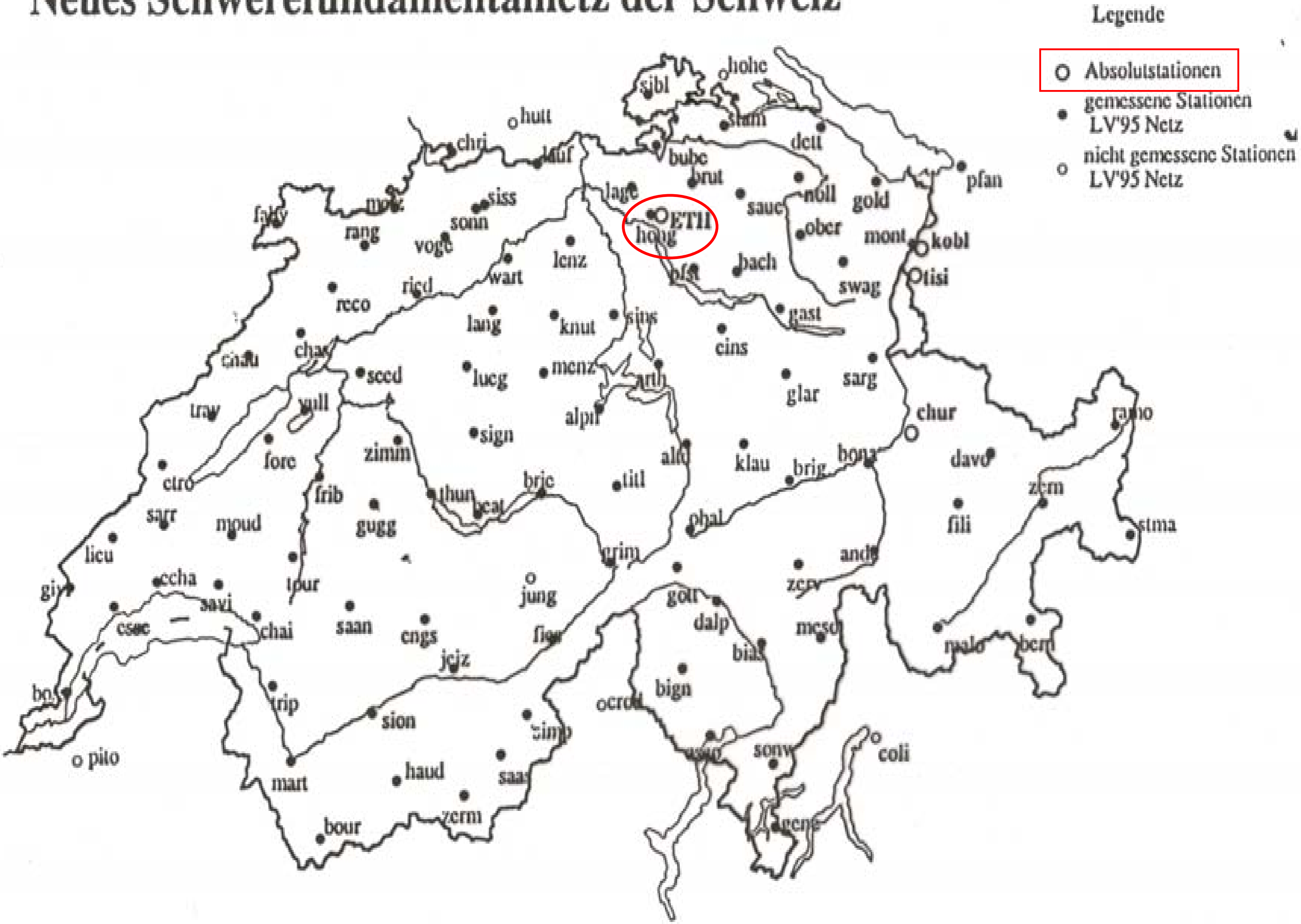
  this is the factor of interest in gravity exploration, but it is much smaller than latitude or elevation effects!

Gravity surveying

- Good location is required (about 10m)
- Uncertainties in elevations of gravity stations account for the greatest errors in reduced gravity values (precision required about 1 cm) (use dGPS)
- Frequently read gravity at a base station (looping) needed



Neues Schwerefundamentalnetz der Schweiz



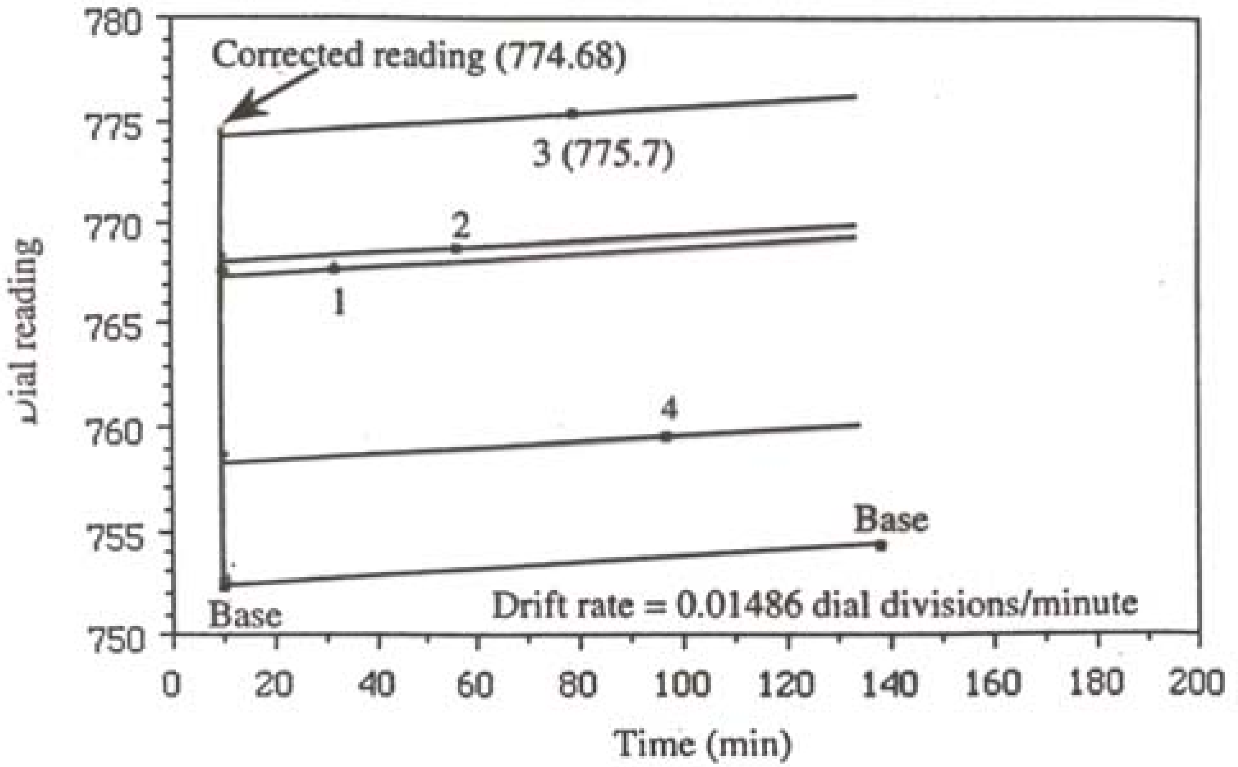
Observed data corrections

g_{obs} can be computed for the stations using Δg only after the following corrections:

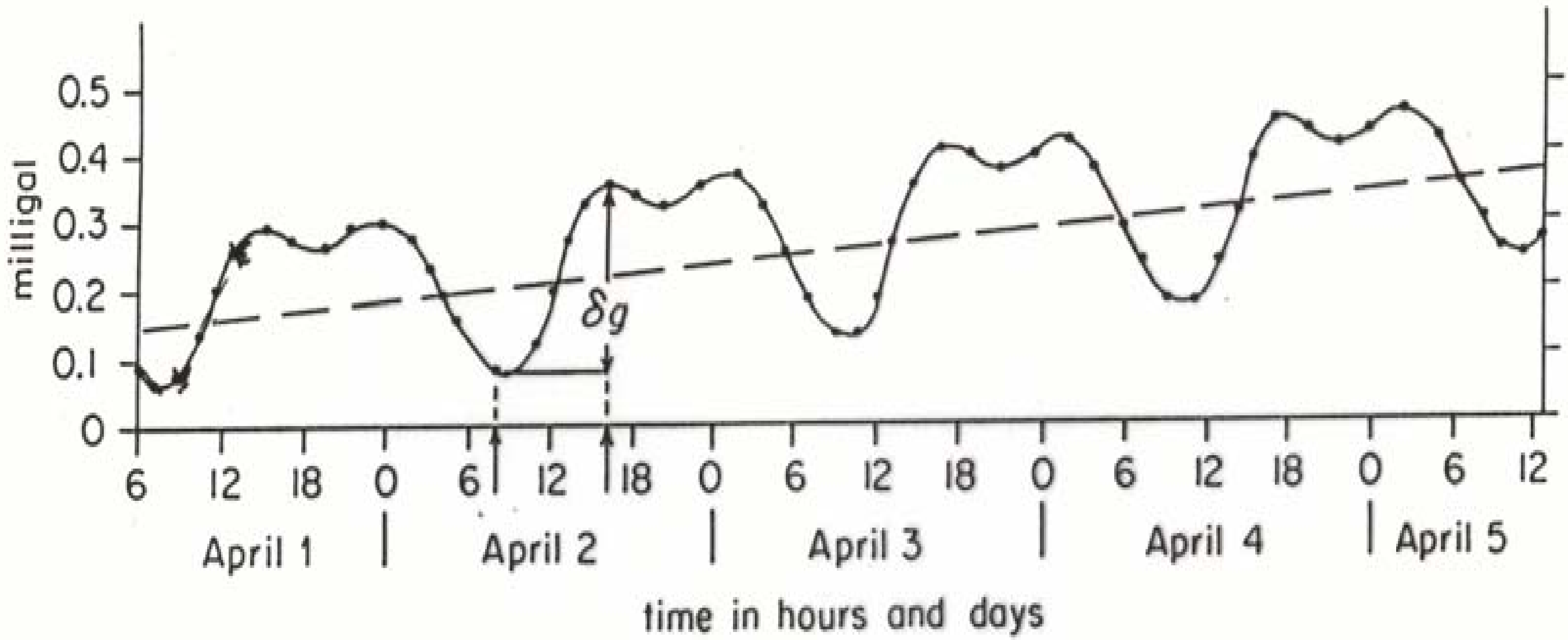
- Drift correction
- Tidal correction
- Distance ground/gravimeter („free air correction“ see below)

Drift correction on observed data

Gradual linear change in reading with time, due to imperfect elasticity of the spring (creep in the spring)



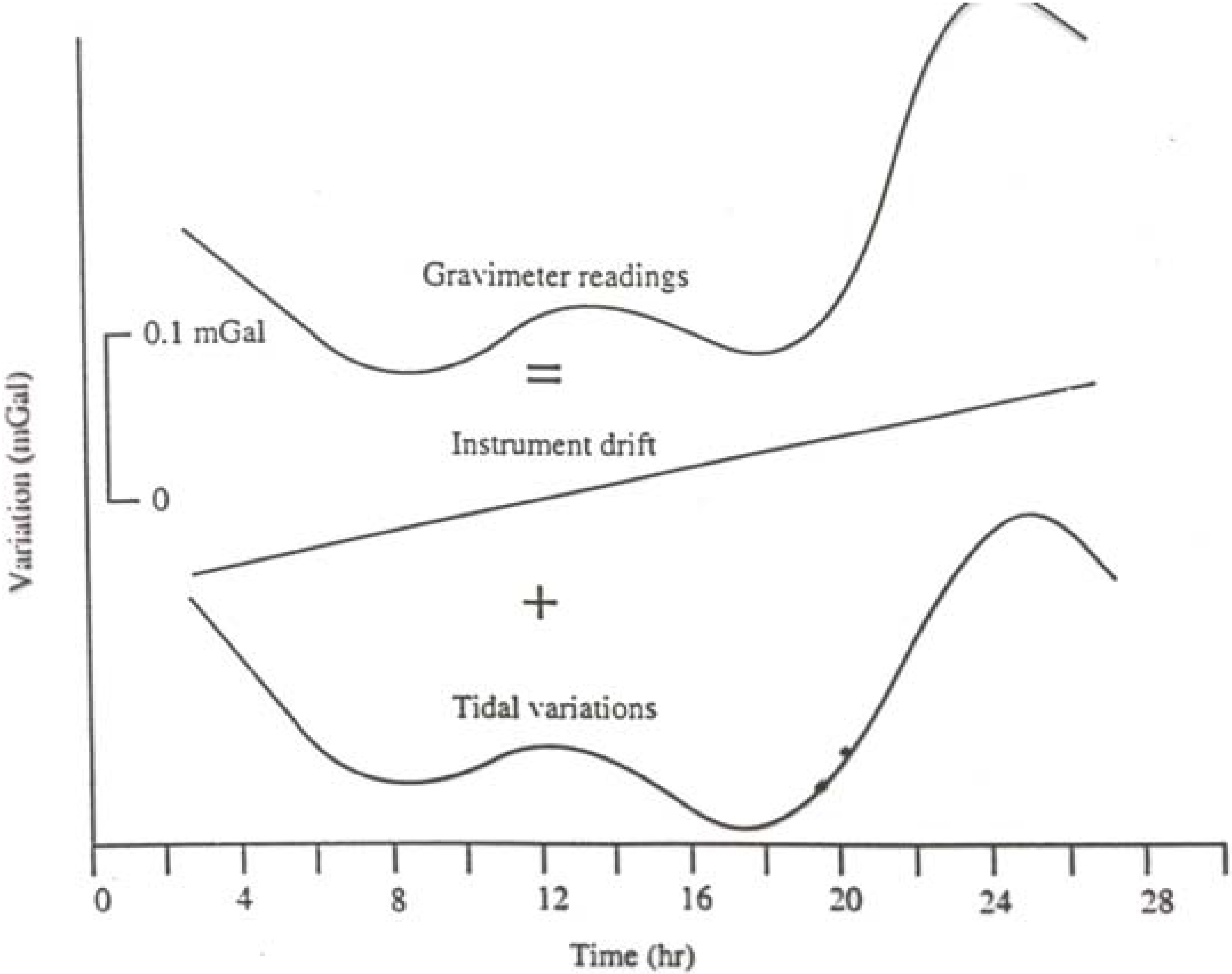
Tidal correction on observed data



Effect of the Moon: about 0.1 mgal

Effect of the Sun: about 0.05 mgal

After drift and tidal corrections, g_{obs} can be computed using Δg, the calibration factor of the gravimeter and the value of gravity at the base



Gravity reduction: Bouguer anomaly

$$BA = g_{obs} - g_{model}$$

$$g_{model} = g_{\phi} - FAC + BC - TC$$

- g_{model} model for an on-land gravity survey
- g_{ϕ} gravity at latitude ϕ (latitude correction)
- FAC free air correction
- BC Bouguer correction
- TC terrain correction

Latitude correction

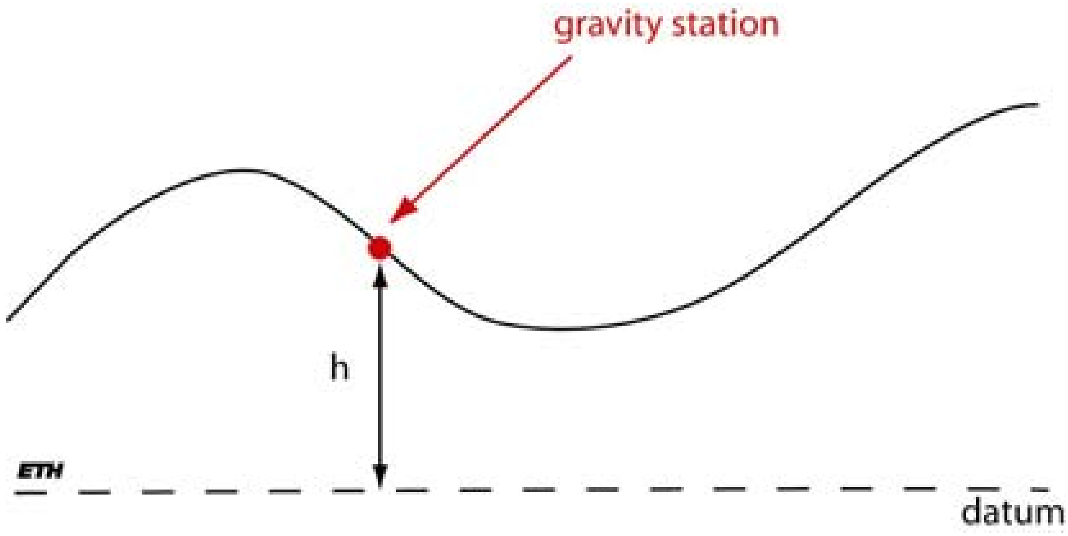
$$g_{\phi} = g_{equator}\left(1 + \beta_1 \sin^2\phi + \beta_2 \sin^4\phi\right)$$

- β_1 and β_2 are constants dependent on the shape and speed of rotation of the Earth
- The values of β_1, β_2 and $g_{equator}$ are definded in the Gravity Formula 1967 (reference spheroid)

Free air correction

The *FAC* accounts for variation in the distance of the observation point from the centre of the Earth.

This equation must also be used to account for the distance ground/gravimeter.



Free air correction

$$g = \frac{GM}{R^2}$$

$$\frac{dg}{dR} = -2\frac{GM}{R^3} = -2\frac{g_N}{R}$$

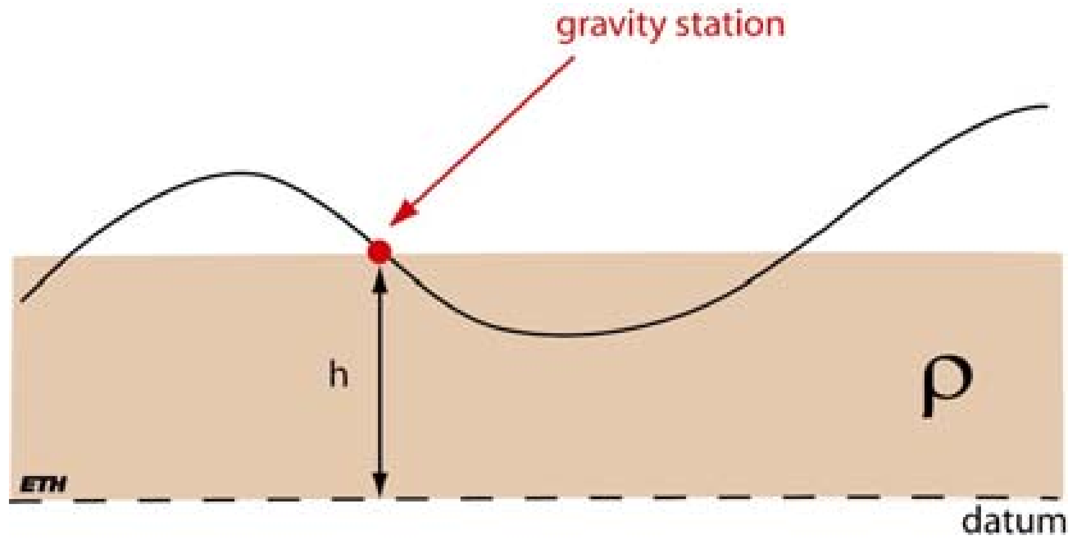
$$\Delta g_{Höhe} \approx 2\frac{g_N dR}{R} \approx 0.3\,\mathrm{mgal} \cdot dR$$

$$FAC = 0.3086\,h \quad (h \text{ in meters})$$

Bouguer correction

- The *BC* accounts for the gravitational effect of the rocks present between the observation point and the datum
- Typical reduction density for the crust is ρ =2.67 g/cm^3

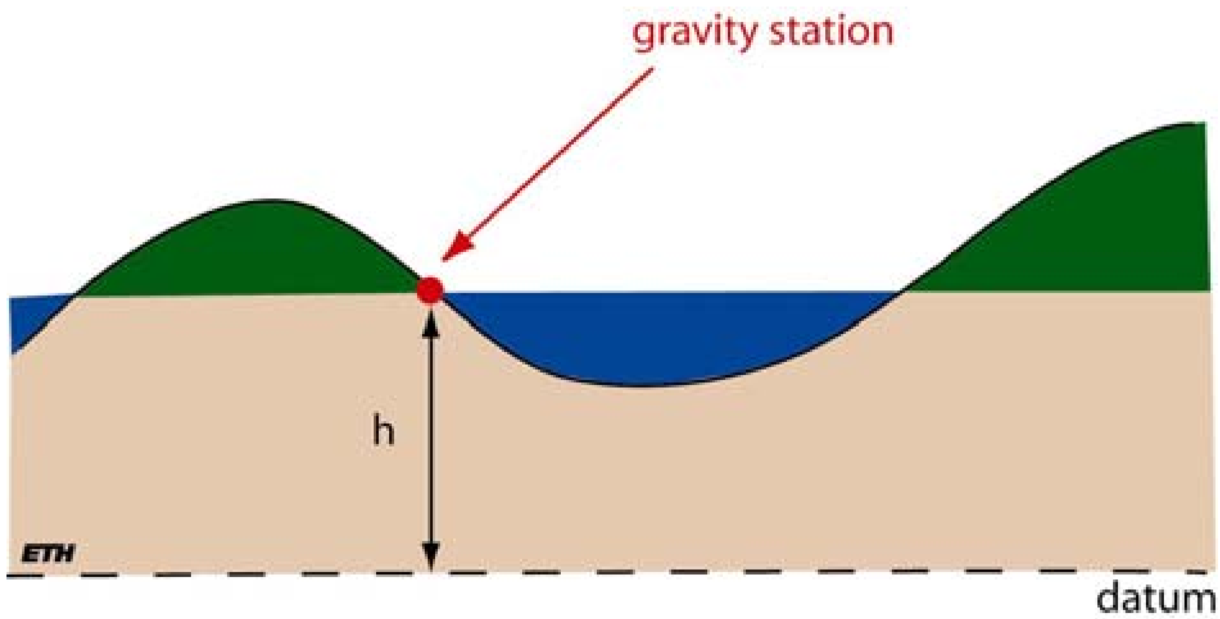
$$BC = 2\pi\, G\, \rho\, h$$

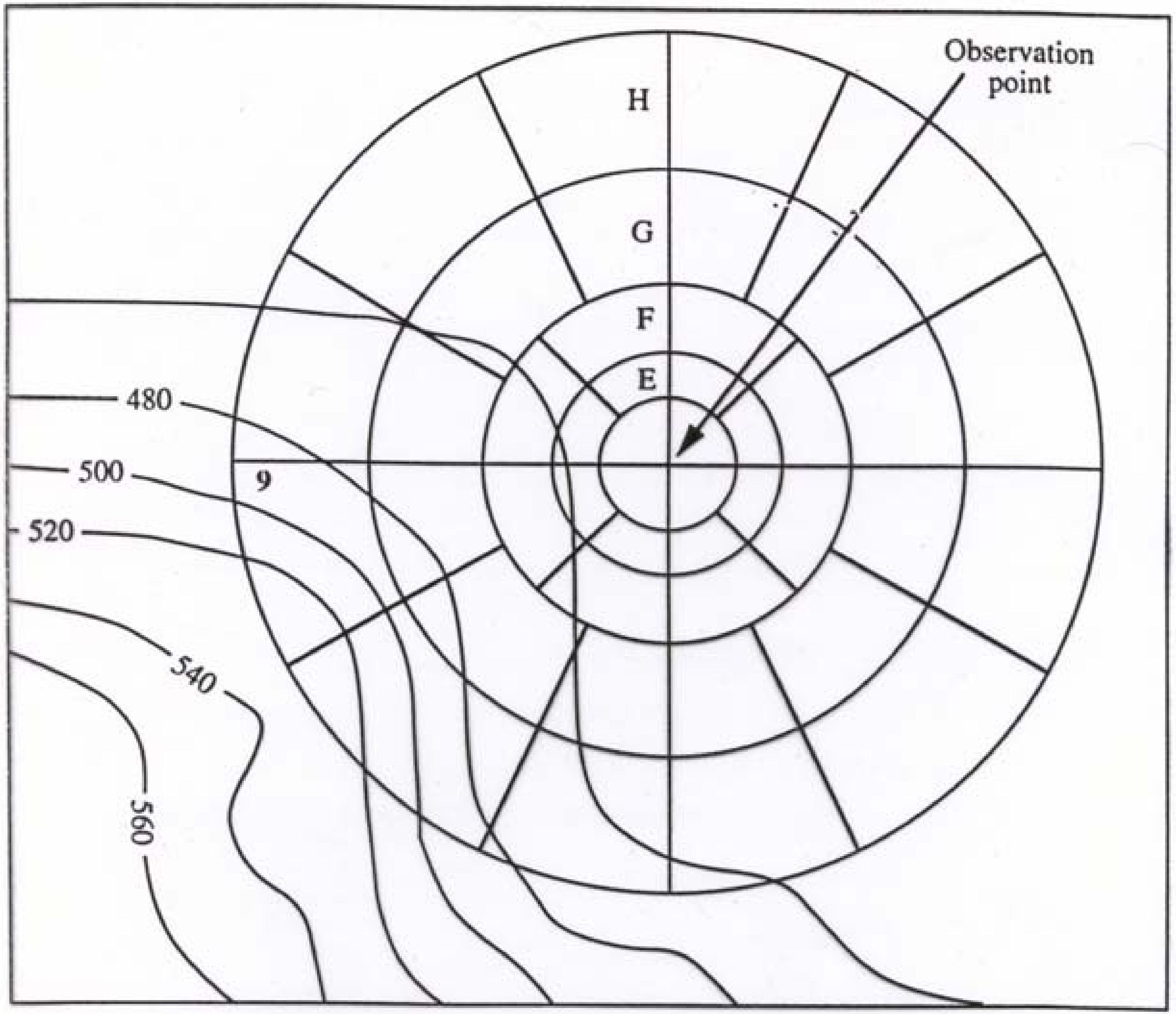


Terrain correction

The *TC* accounts for the effect of topography.

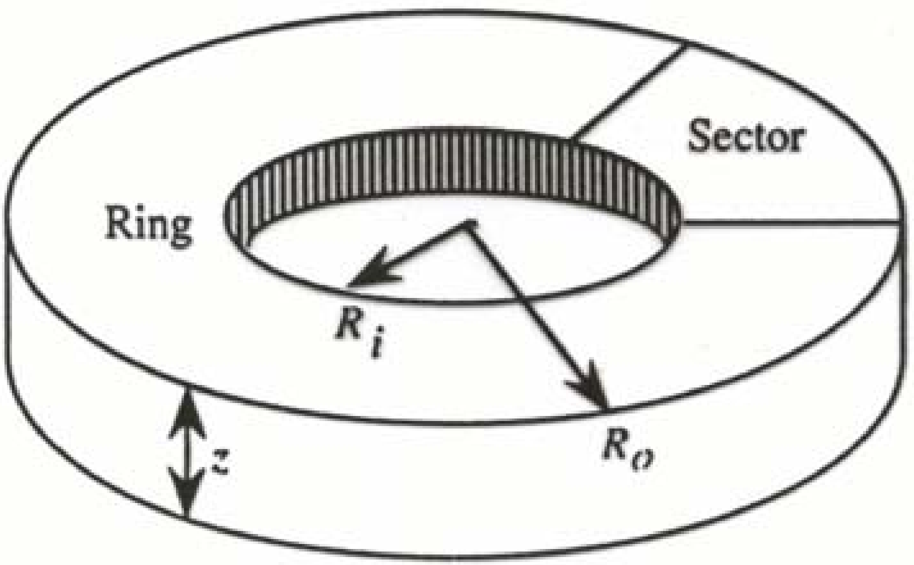
The terrains in green and blue are taken into account in the *TC* correction in the same manner: why?



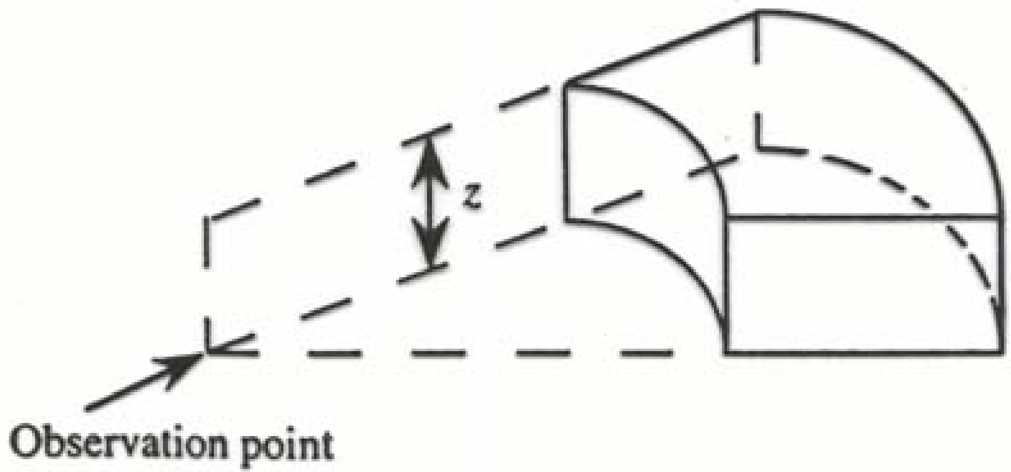


Observation point
H
G
F
E
9
480
500
520
540
560

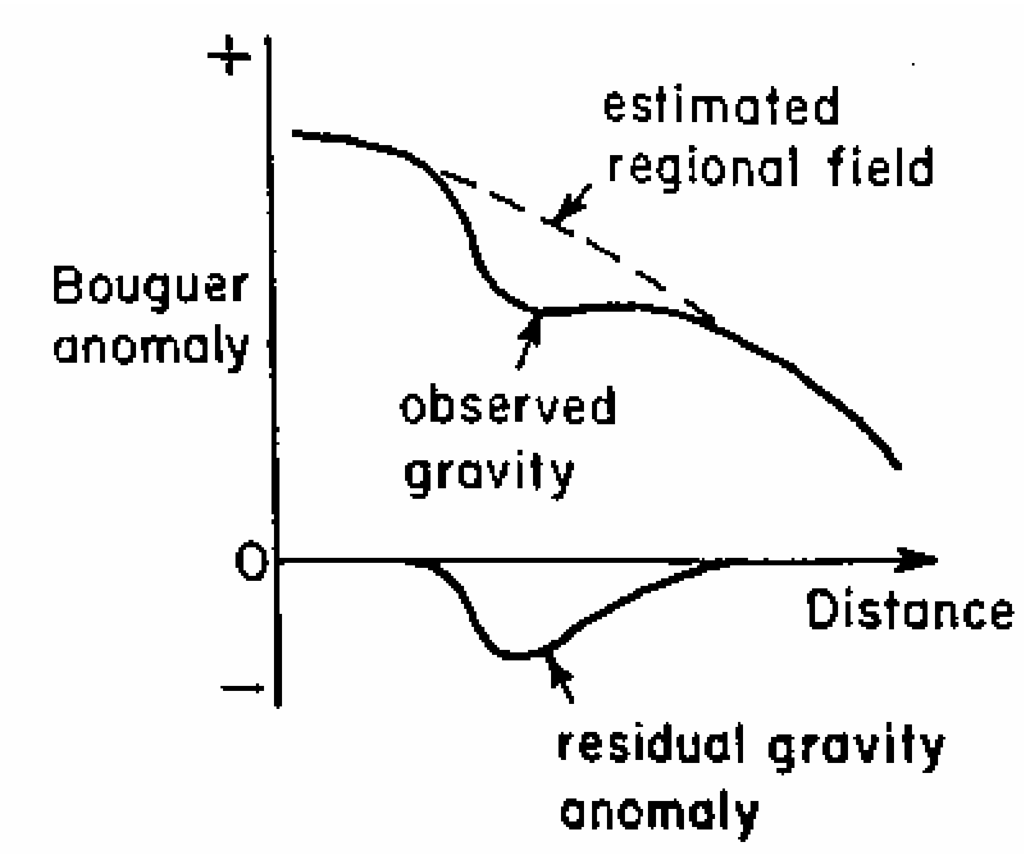
(a)



(b)

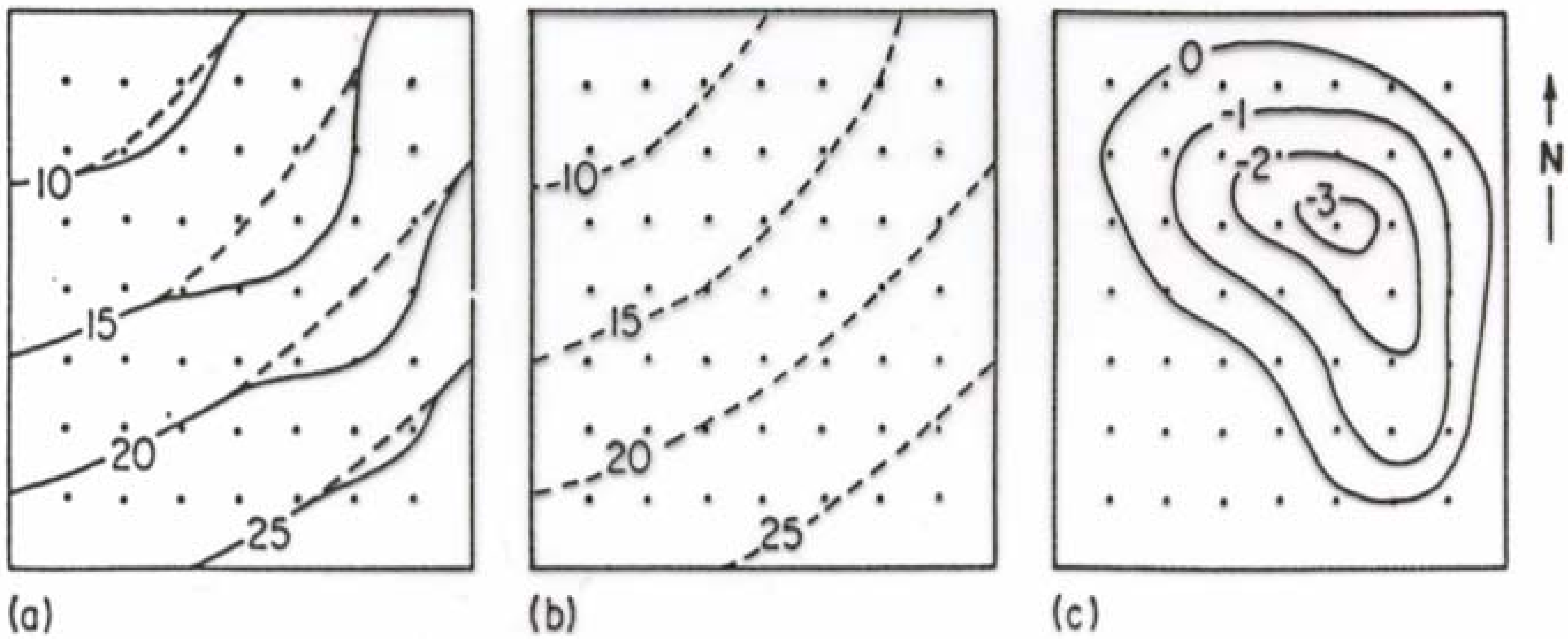


Residual gravity anomaly

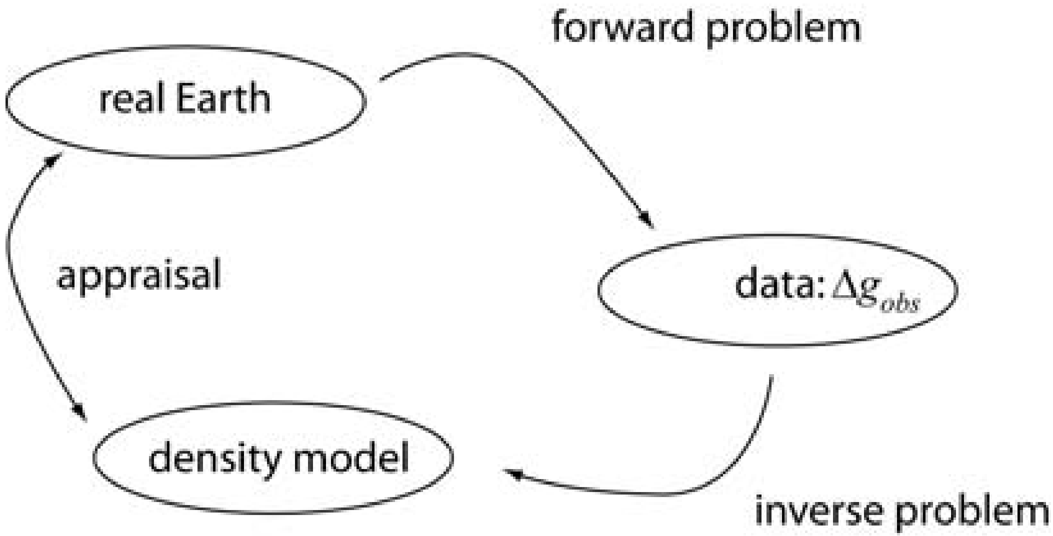


The regional field can be estimated by hand or using more elaborated methods (e.g. upward continuation methods)

Bouguer anomaly



Interpretation: the inverse problem

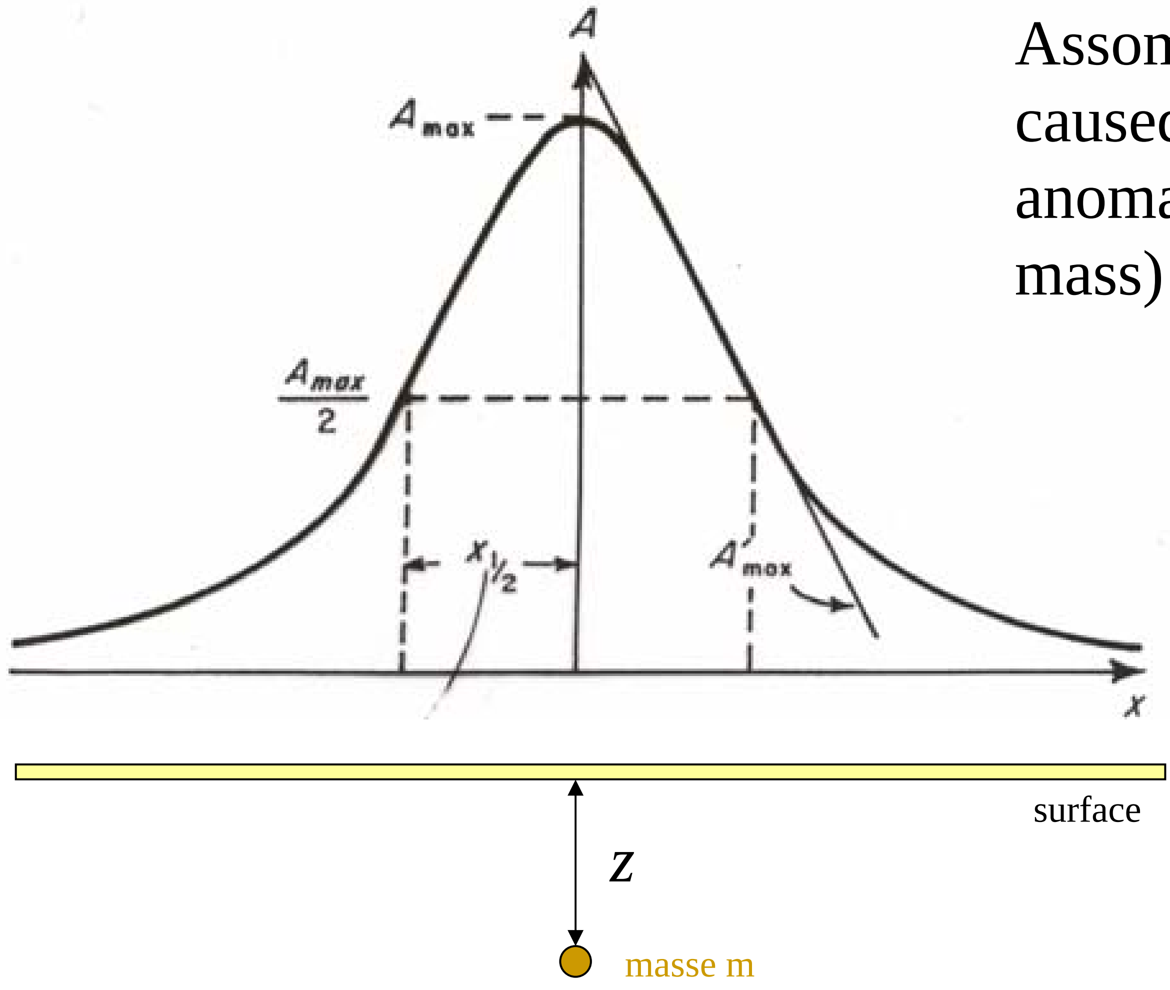


Two ways of solving the inverse problem:

- „Direct“ interpretation
- „Indirect“ interpretation and automatic inversion

Warning: „direct“ interpretation has nothing to do with „direct“ (forward) problem!

Direct interpretation



Assomption: a 3D anomaly is caused by a point mass (a 2D anomaly is caused by a line mass) at depth=z

$x_{1/2}$ gives z

Direct interpretation

Geometry	*Formula*	*Depth*
Ball	$$\Delta g = \frac{4\pi G R^3 \Delta\rho}{3z^3} \frac{1}{\left[1+\left(x^2/z^2\right)\right]^{3/2}}$$	$z = 1.305 x_{1/2}$
Horizontal cylinder	$$\Delta g = \frac{2\pi G R^2 \Delta\rho}{z} \frac{1}{\left[1+\left(x^2/z^2\right)\right]}$$	$z = 1.0 x_{1/2}$
Vertical cylinder	$$\Delta g = \frac{\pi G R^2 \Delta\rho}{\left(x^2+z^2\right)^{1/2}}$$	$z = 0.58 x_{1/2}$

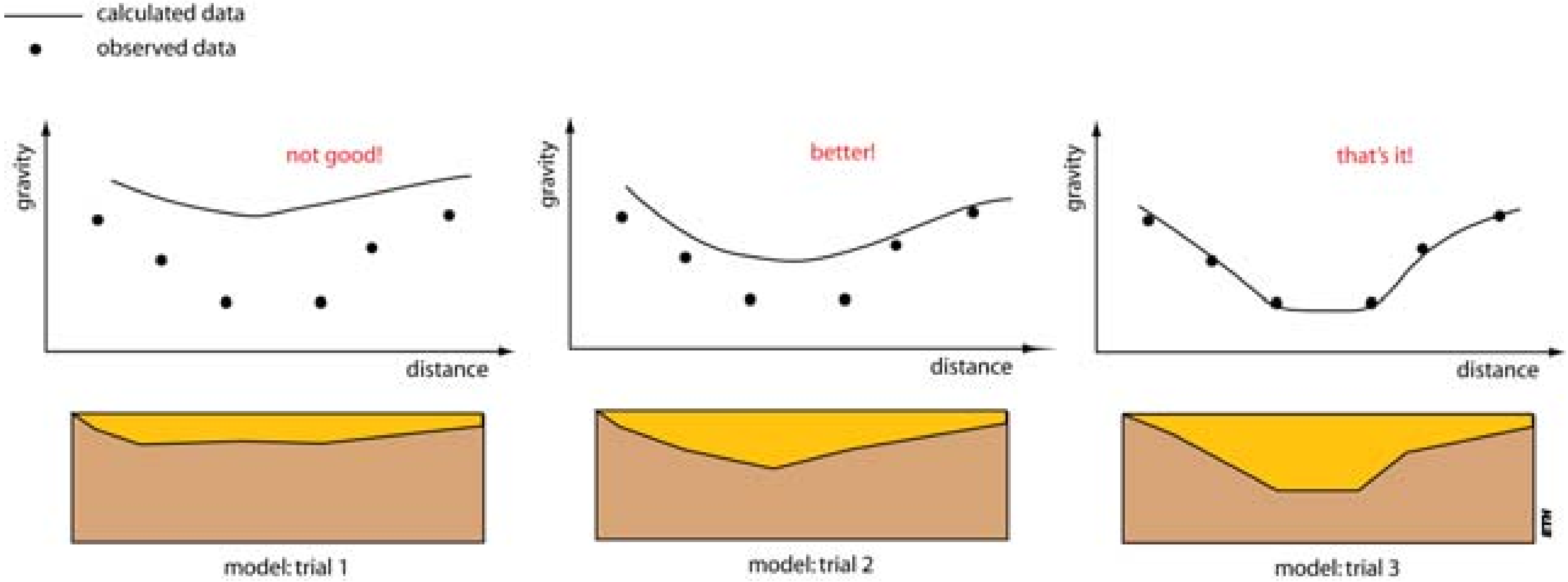
Indirect interpretation

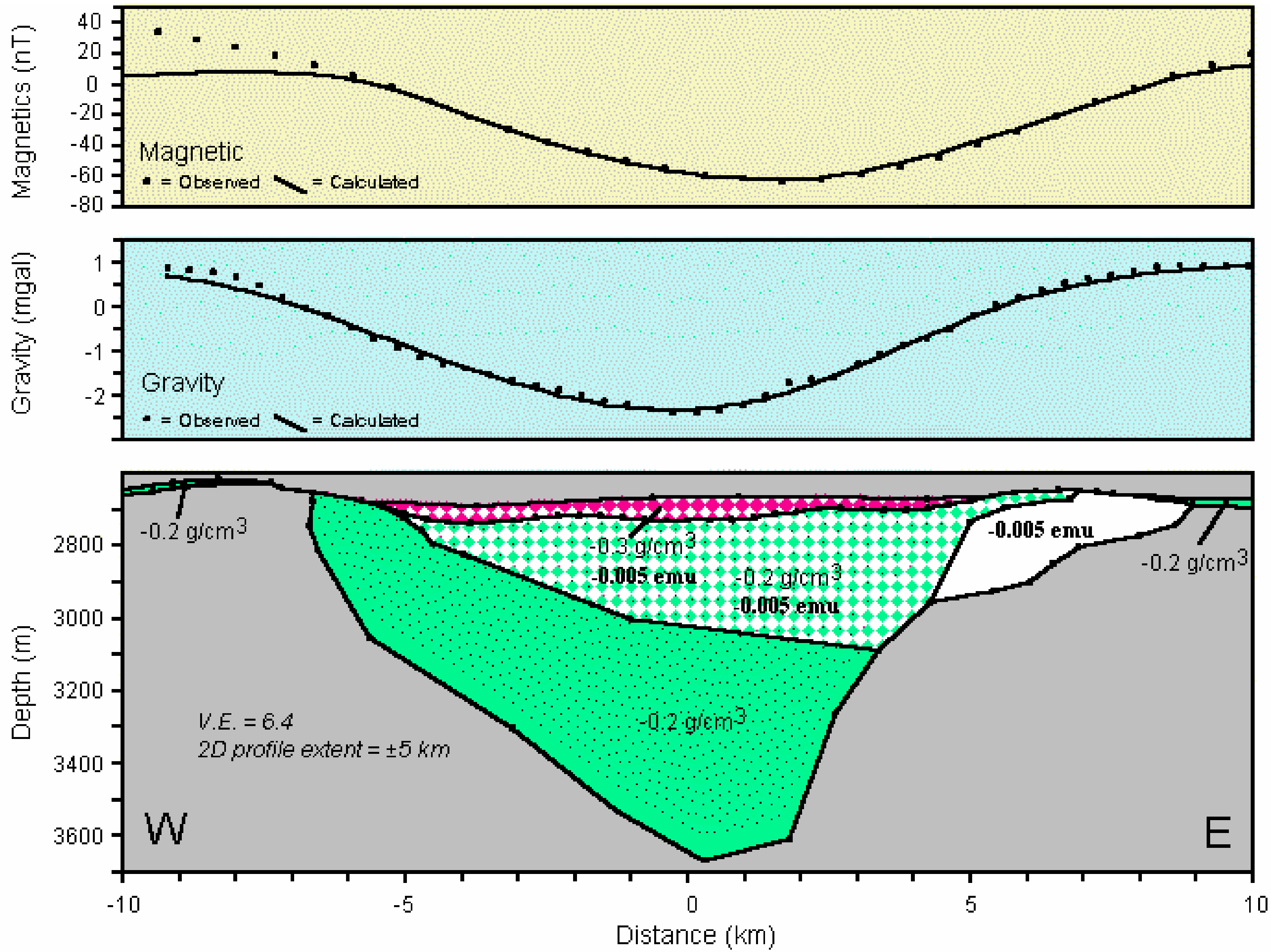
(1) Construction of a reasonable model

(2) Computation of its gravity anomaly

(3) Comparison of computed with observed anomaly

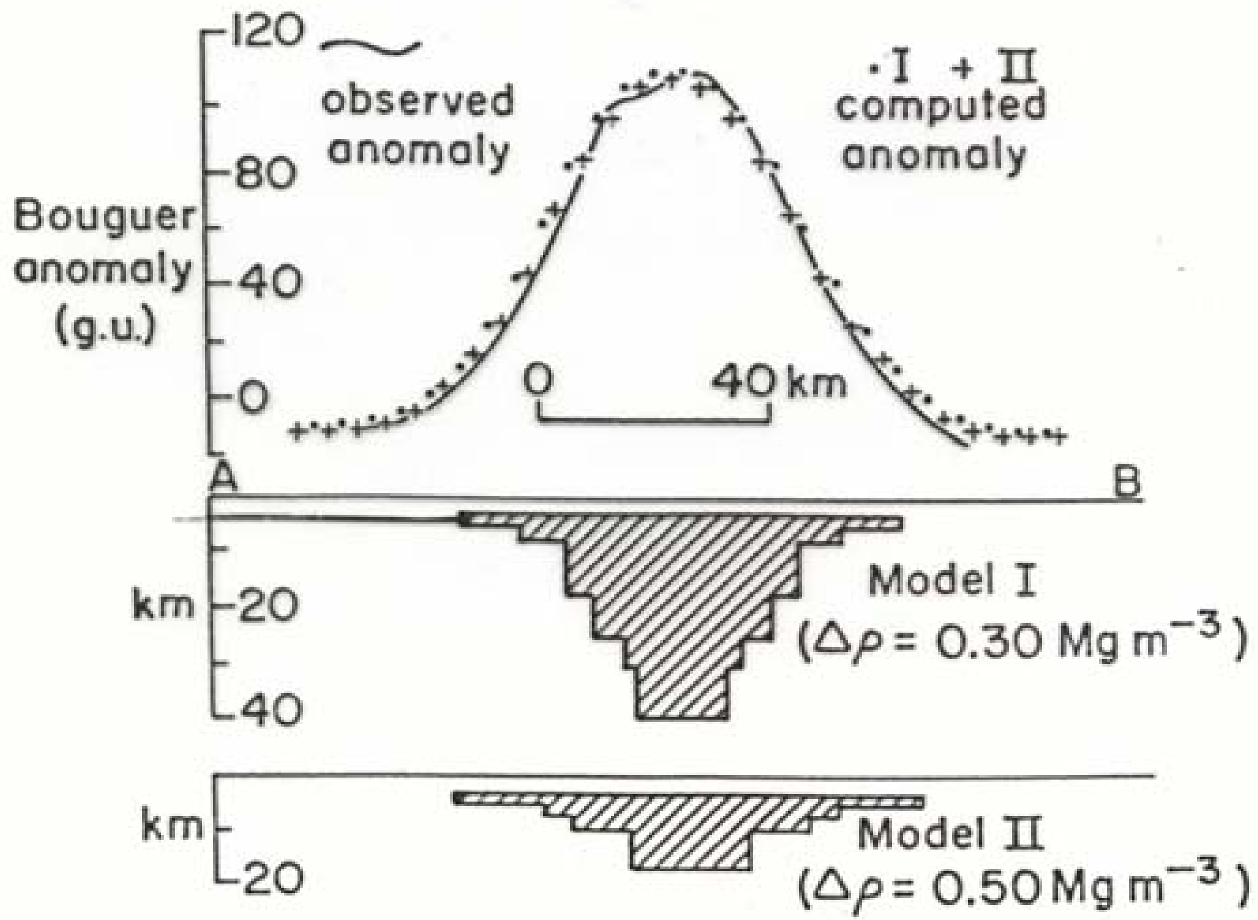
(4) Alteration of the model to improve correspondence of observed and calculated anomalies and return to step (2)





Magnetics (nT)
40
20
0
-20
-40
-60
-80
Magnetic
= Observed = Calculated
Gravity (mgal)
1
0
-1
-2
Gravity
= Observed = Calculated
Depth (m)
2800
3000
3200
3400
3600
-0.2 g/cm3
-0.3 g/cm3
-0.005 emu
-0.2 g/cm3
-0.005 emu
-0.005 emu
-0.2 g/cm3
-0.2 g/cm3
V.E. = 6.4
2D profile extent = ±5 km
W
E
-10
-5
0
5
10
Distance (km)

Non-unicity of the solution



Automatic inversion

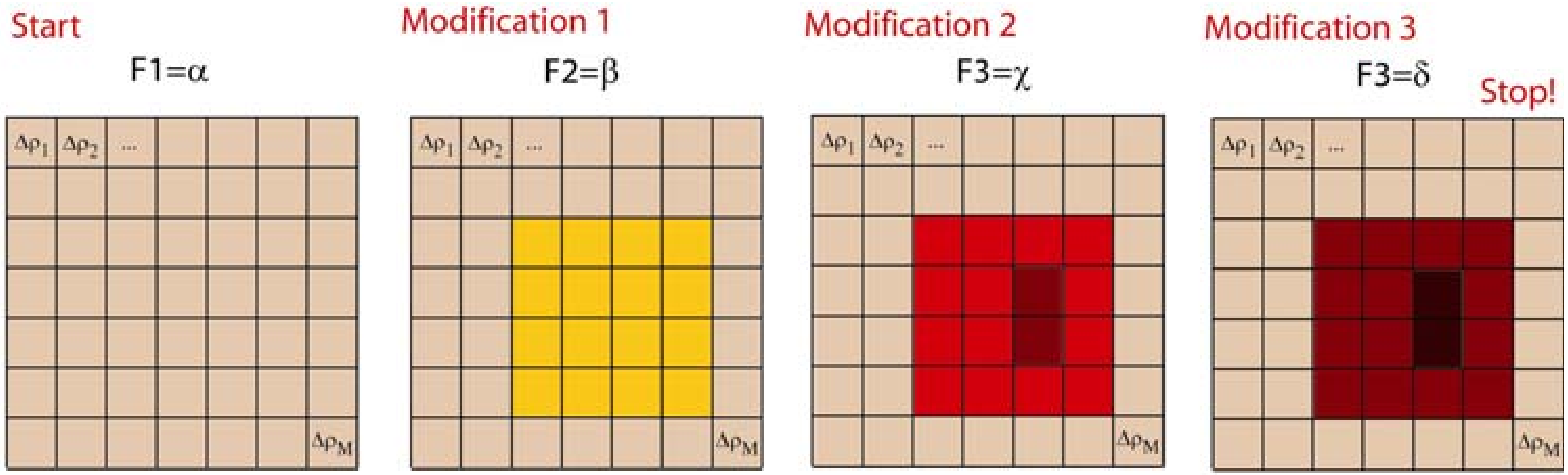
Automatic computer inversion with a priori information for more complex models (3D) using non-linear optimization algorithms. Minimize a cost (error) function *F*

$$F = \sum_{i=1}^{n} \left(\Delta g_{obs_i} - \Delta g_{calc_i} \right)$$

with *n* the number of data

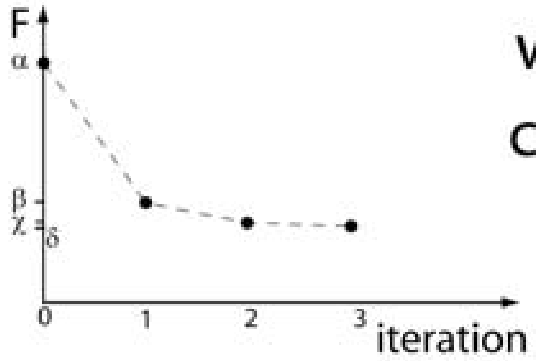
Automatic inversion is used when the model is complex (3D)

Automatic inversion



with $\alpha > \beta > \chi > \delta$

convergence and stop if $\chi \cong \delta$



Mining geophysics