Geophysics 325
B.5.1 Measuring devices for gravity exploration

B5.1.1 Absolute measurements of gravity

Reversible pendulum and free fall devices can be used, but they are generally slower than relative gravimeters. Applications include studies of absolute gravity in evaluating earthquake hazards due to the Cascadia subduction zone.

http://www.pgc.nrcan.gc.ca/geodyn/abs_grav.htm

Absolute gravity instruments manufactured by Micro-g-solutions. Details can be found at http://www.microgsolutions.com/

B5.1.2 Relative measurements of g

Since we have seen that it is the **differences** in gravity that define anomalies, we do not need absolute gravity measurements everywhere. Often **relative** gravity measurements can be made over a survey area, and then tied to an absolute value by using the relative gravimeter at a location that was previously surveyed with an absolute gravimeter.

(a) Portable pendulum

A simple pendulum of length l will swing with a period T when the acceleration of gravity is g. The period T is defined as

$$T = 2\pi\sqrt{\frac{l}{g}} \qquad (1)$$

This can re-written as

$$g = aT^{-2} \qquad (2)$$

where a is a constant. The pendulum is then moved to a location where the acceleration of gravity is $g+\delta g$. What will be the corresponding change in period *$(T+\delta T)$?*

Differentiating equation (2) with respect to T, we obtain

$$\frac{dg}{dT} = -2aT^{-3} \qquad (3)$$

Substituting for *a* this gives

$$\frac{\delta g}{g} = \frac{-2\delta T}{T} \qquad (4)$$

Thus if *dg* is 1 mgal and *g* = 1,000,000 mgals then we must look for a change in period of 0.5 parts-per-million. This can be achieved by timing many swings of the pendulum.

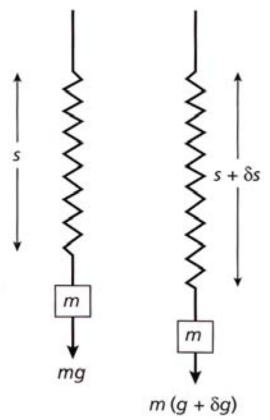
Will a short or long value of T be preferred?

Applications:

(a) Used by Gulf R&D in 1930s; 1-second period, thermostat, vacuum

(b) used in late 1950s, early 1960s by George Woolard at airports, seaports, large cities, to establish worldwide gravity network

(b) Mass-on-a-spring gravimeters



The figure shows the results of measurements at two locations. On the left the acceleration of gravity is given by *g* and the spring has extended a length *s*. The spring constant is *k*. Hooke's Law tells us that

$$mg = ks \qquad (5)$$

At the second location the acceleration is given by $g+\delta g$ and the spring stretches a distance $s+\delta s$. Again Hooke's Law gives

$$m(g+\delta g) = k\,(s+\delta s) \qquad (6)$$

Subtracting (6) from (5) gives

$m\delta g = k\delta s$ (7)

Thus the **change** in the acceleration of gravity is given by

$\delta g = k\delta s/m$

What values of *k* and *m* are required to give the maximum value of δs for a given δg? Are these values mutually compatible?

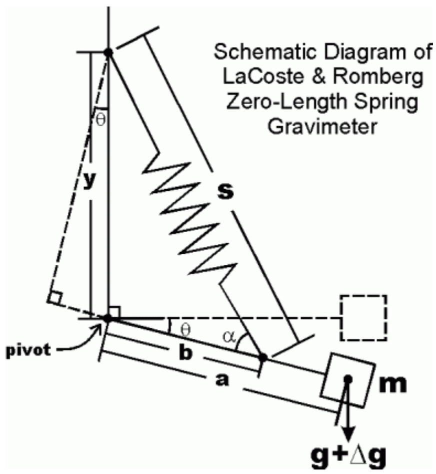
What extension will result for a change of 1 mgal?

The text book provides pictures of the following gravimeters. All use various engineering features to give maximum sensitivity for a given δg

●Ideal stable gravimeter (Telford Figure 2.10)

●Unstable gravimeter (Telford Figure 2.11)

●LaCoste-Romberg gravimeter. (Telford Figure 2.12).



Force on mass is given by $F = k(s-z)$ where z is unstretched length. Taking moments about the pivot gives:

$mga \cos\theta = k(s-z)b \sin\alpha$

$mga \cos\theta = k(s-z)by \cos\theta / s$

Rearranging gives:

$$g = \frac{k}{m}\frac{b}{a}(1-\frac{z}{s})y$$

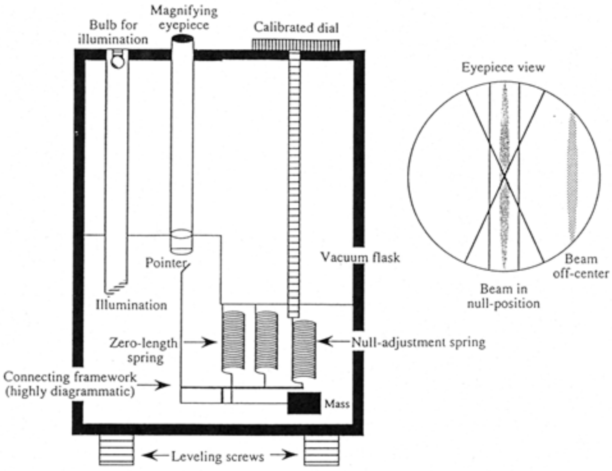
The sensitivity is given by

$$\frac{dg}{ds} = \frac{k}{m}\frac{b}{a}\frac{z}{s^2}y$$

The spring is designed with a length *z*, that is **as short as possible**, to increase sensitivity (zero length spring)

In this instrument the mass is restored to the original position by applying a known force. This avoids effects arising from variations in the spring constant as a function of extension. This type of instrument can achieve 0.01 mgal accuracy.

●Worden gravimeter (Telford Figure 2.14, Burger Figure 6.1). This gravimeter can also achieve ~ 0.01 mgal accuracy.



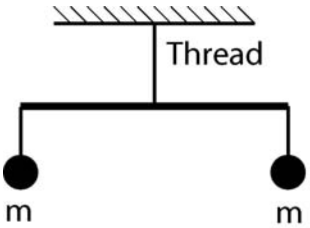
See http://planet.gcn.ou.edu/gravmag/measure/relative.html for more details

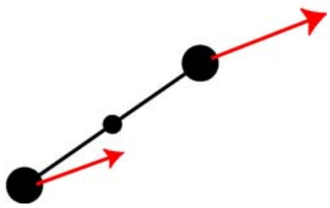
B5.1.3 Gradient measurements (dg/dx)

Locations A and B are separated by a distance Δx and the acceleration of gravity has values g_A and g_B . The horizontal gravity gradient can be defined as $\frac{dg}{dx} = \frac{g_B - g_A}{\Delta x}$

Gravity gradients give additional information about subsurface structures and are especially sensitive to the edges of targets (B6)

Cavendish torsion balance

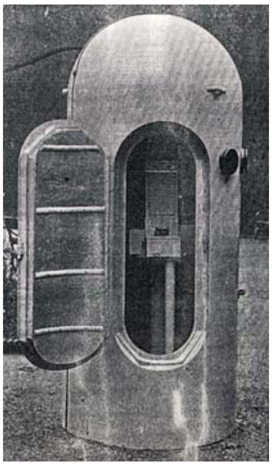




The differential attraction of a distant mass will result in the beam pointing towards the mass. This is resisted by the (known) torsion coefficient of the thread.

Eötvös torsion balance

This used masses hung at **different levels** to give sensitivity to vertical gradients. The instrument was widely used in the 1920's and is credited with the discovery of a number of salt domes in Europe, Texas and Louisiana.



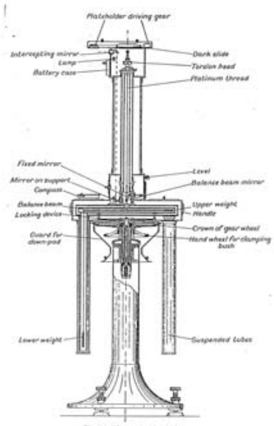
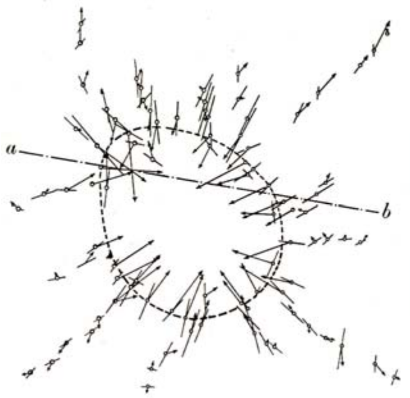
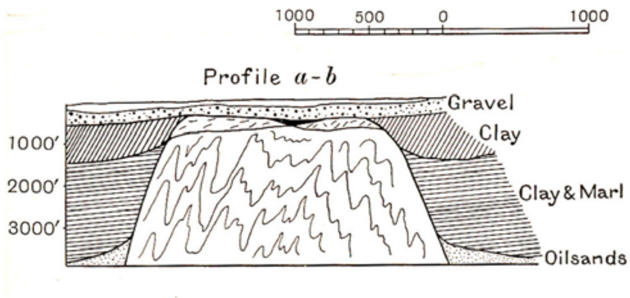


Fig. 66. Eötvös Torsion Balance.



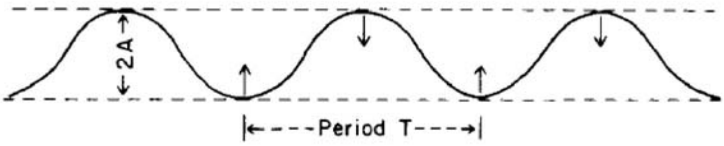


B5.1.4 Airborne and marine gravity surveys

These measurements need to account for the **motion** of the measurement location. This should include both short term **accelerations** (waves and turbulence), as well as the effect of the steady **velocity** of the ship/plane (Eötvös correction)

Airborne gravity surveys

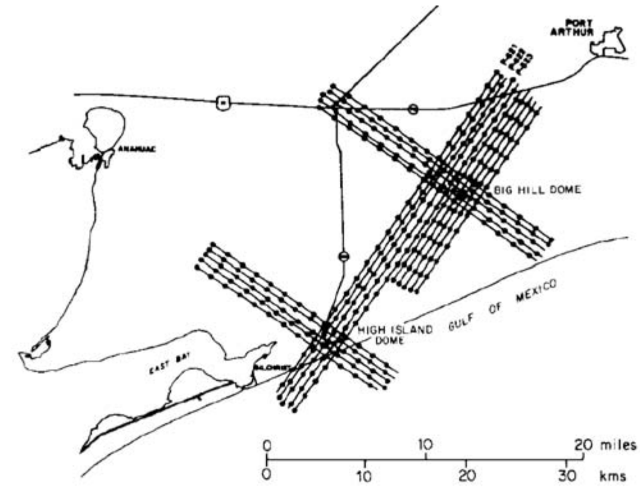
See paper : S. Hammer, Airborne gravity is here, *Geophysics*, 48, 213-223, 1983.

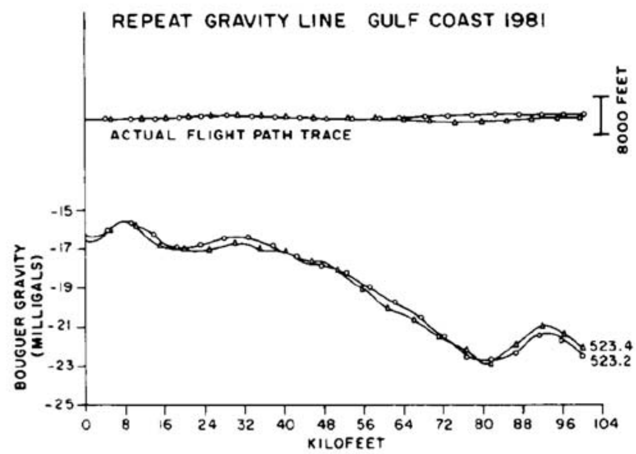


$$\pm a_{max} = 4\pi^2 A/T^2 = 592{,}176/T^2 \text{ mgals}$$
$$A = 15 \text{ cms}$$

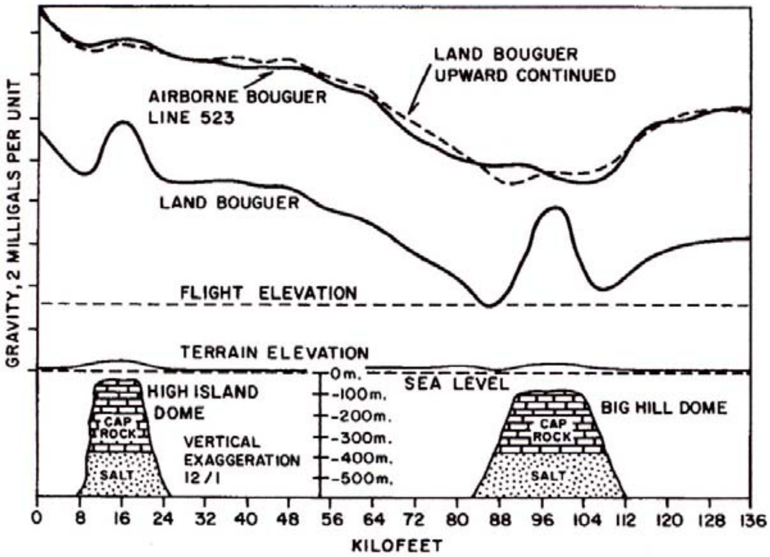
Period T	1"	5"	10"	30"	1'	1 hr	12 hrs
2a mgals	1,184,353	47,374	11,844	1,316	329	0.091	0.0006

Even small vertical oscillations produce accelerations that are large compared to typical gravity anomalies.





Note that a grid of lines is flown. The cross-over points allow the consistency of the data to be evaluated. Repeating the same line gives another way of testing the data. Accuracy is typically around 1 mgal for airborne work.



Ground (land) gravity data must be projected to aircraft elevation to allow for an objective comparison of the two data sets. This uses a mathematical technique called **upward continuation**, and details of this will be described in Geophysics 437.

Note the good agreement of the airborne and upward continued ground data.

Note the broad (long wavelength) gravity low associated with the low density salt dome. A shorter wavelength gravity high is observed above the salt dome owing to the high density cap rock.

Why is the effect of the cap rock **not observed** in the airborne gravity data?

Marine gravity surveys

Gravity can be measured on a moving ship, when the gravimeter is placed on a gyroscope stabilized platform. Measurements are averaged for several minutes (i.e. several waves). If accurate gravity data is needed, a gravimeter can be lowered to the seafloor.

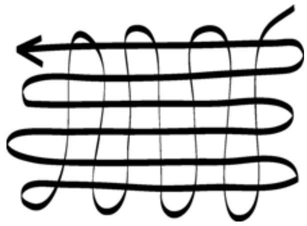
Measurements have also been made in submarines. Data can be accurate to a few mgal.

B.5.2 Survey procedures for gravity exploration

- often several survey crews needed for each gravimeter crew.

- Gravity data is usually collected on a two dimensional (2-D) grid. Repeat measurements are made at points where lines intersect to estimate repeatability.

  Differences at cross-over points are usually due to data errors, not changes in subsurface density.



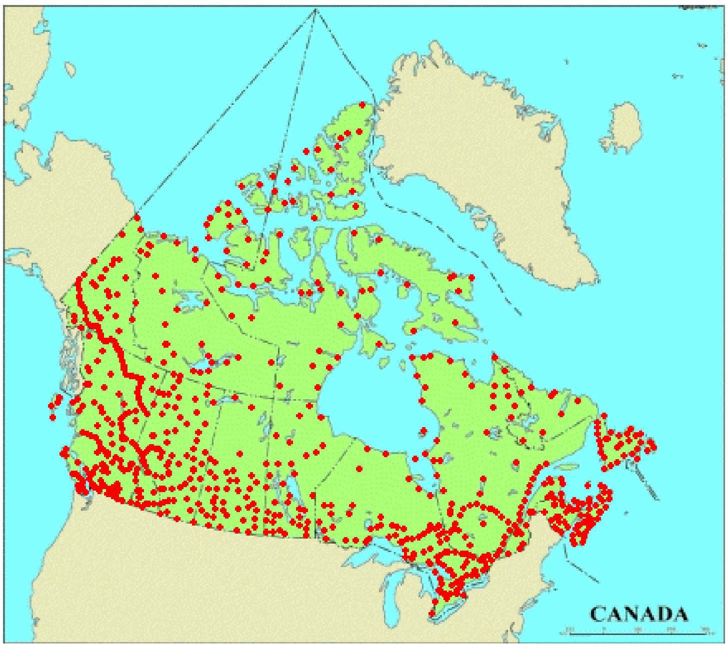
- Set up a series of base stations to allow instrument drift to be removed. These can be chosen to minimize driving time during the survey. Usually a base station is visited several times per day.

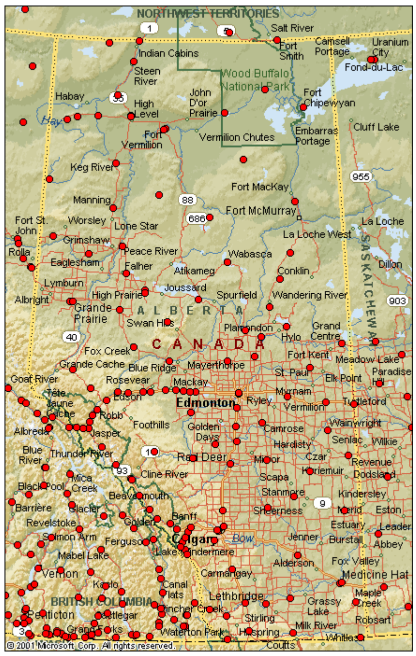
- Airborne surveys cover ground quickly, but effect of motion needs to be corrected. Also, the data are collected further from the target than in a ground survey.

- Tie measurements to absolute values at pre-surveyed stations. In the United States the network is the IGNS71. In Canada absolute values of gravity are specified at Canadian Gravity Standardization Net (CGSN).

  A typical station description is attached. Next time you visit the Edmonton airport, why don't you see if you can find the station?

  http://www.geod.nrcan.gc.ca/aboutus/gravity/grvstds_e.php





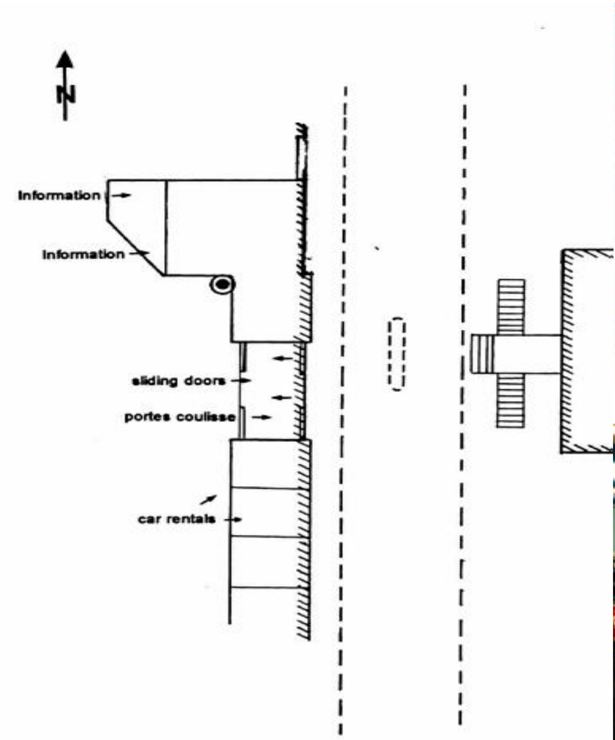
Canadian Gravity Standardization Network (CGSN)

STATION IDENTIFICATION (IGNS71)	STATION COORDINATES (SCALED)
EDMONTON **ALB** **9500-1993** **Gravity: 981117.890 mgal** **Last Inspection: 08/1996**	**Latitude :** N 53° 18' 29" **Longitude :** W 113° 35' 1" **Elevation :** 723 m

STATION INFORMATION AND LOCATION

The station is located in the Terminal of the Edmonton International Airport at Nisku. It is on the floor, in the corner, E of the Information counter on the ground floor of the terminal building. The station is monumented by an aluminum disc.

SKETCH:



DISTANT VIEW:

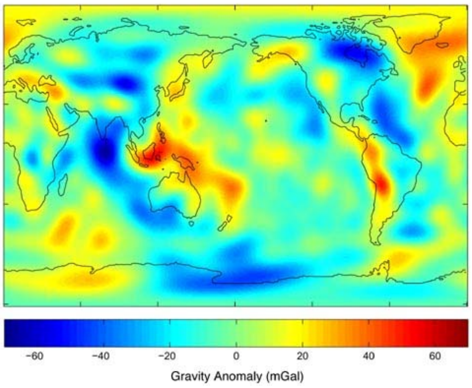
CLOSE-UP VIEW:

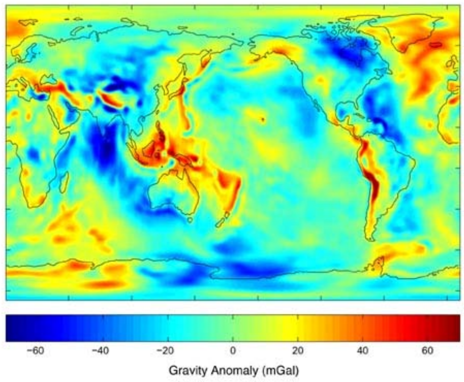
● satellite gravity : Cannot actually measure acceleration while the satellite is in free fall. However several techniques can be used to determine variations on gravity from a satellite.

(1) From detailed observations of orbit perturbations, the gravity field can be inferred.

GRACE mission : Gravity recovery and Climate research experiment

http://www.csr.utexas.edu/grace/ and http://www.csr.utexas.edu/grace/gravity/



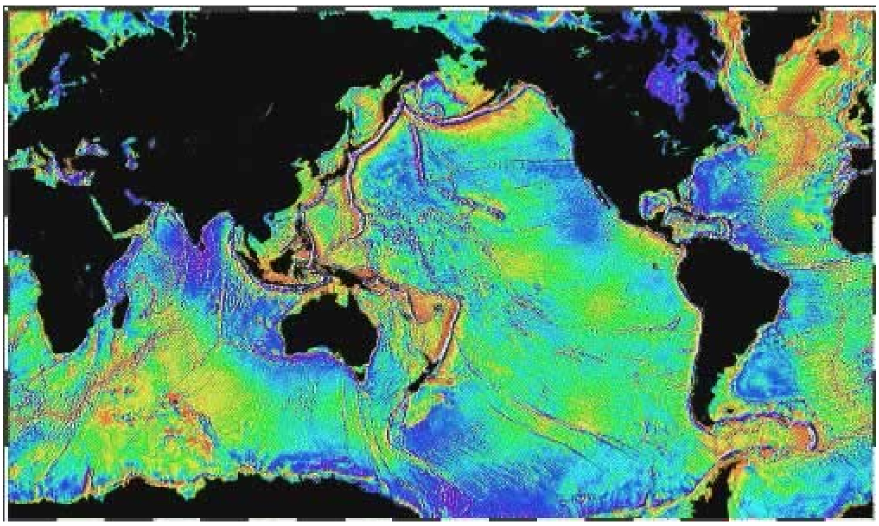


Note the big improvement (right) compared to all previous data (left). Short wavelengths and more detail has resulted from 1 year of GRACE data using twin satellites.

(2) By measuring the **altitude** of the satellite above the Earth's surface with radar, subsurface density structure can be inferred. This is only effective over the oceans (why?)

Remember how the geoid (the equipotential at sea level) responds to excess/deficit masses.

Reference: Sandwell, D. T., W. H. F. Smith, Marine gravity anomaly from Geosat and ERS 1 satellite altimetry, Journal of Geophysical Research, v. 102 , No. B5, p. 10039-10054, 1997.



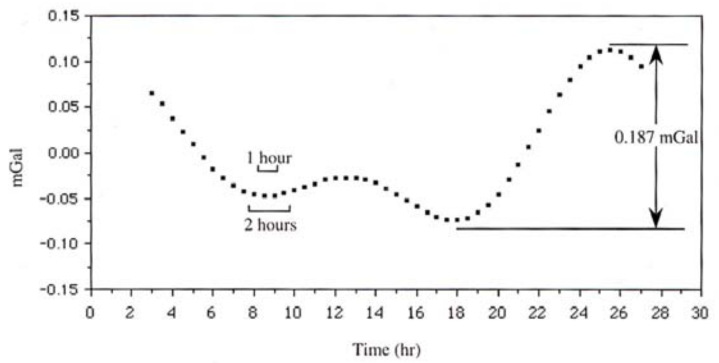
http://topex.ucsd.edu/marine_grav/mar_grav.html

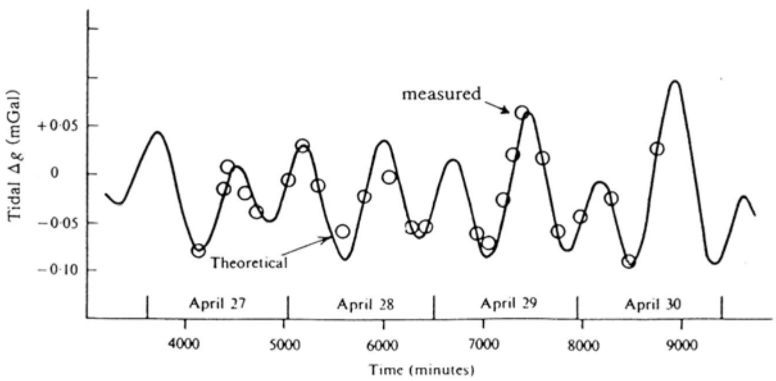
B.5.3 More corrections – temporal variations

Tidal effects

● gravitational pull of the sun and moon varies. Also effect as Earth and ocean moves.

● Can be calculated and removed quite accurately (Telford 2-6, Burger 6-9)



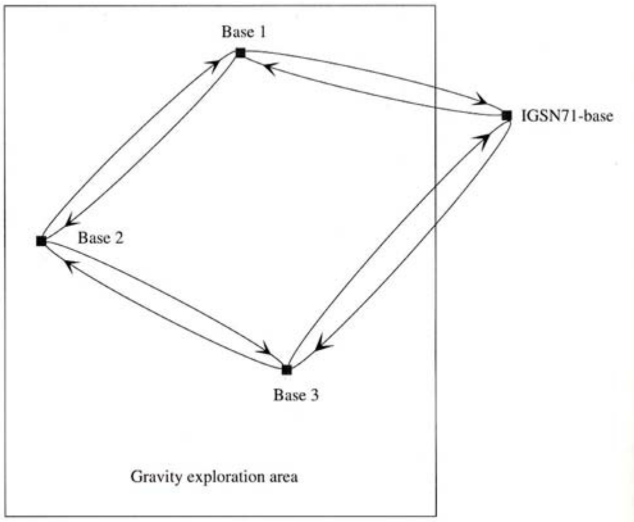


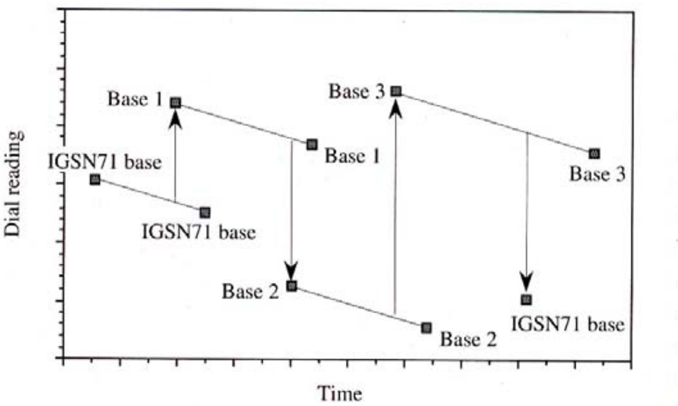
● Peak to peak value of 0.5 mgal, or 0.05 mgal per hour

Instrument drift

● The springs in a gravimeter **stretch** noticeably over time, typically 0.5 mgal per month

● Drift can be removed by re-occupying base stations in a series of loops as shown in Burger figures 6-11 and 6-12





Sources of error in gravity measurements

(a) Vertical position 0.3 mgal per m

(b) Horizontal position 0.0008 mgal per m north-south

(c) Inadequate or incorrect terrain corrections ~ 1 mgal or more

(d) Instrument drift 0.5 mgal per month

(e) Incorrect Bouguer density

e.g. change in elevation = 100 m, density error 0.1 g cm $^{-3}$ gives an error of 0.42 mgal