Gravity surveying: a brief introduction

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Abstract

This is an introduction to gravity surveying for absolute beginners. Students should read it before the Edinburgh/Paris Sud/Münster geophysics field course. It explains what gravity measurements can tell us about the subsurface, how a gravity survey is done and how the data are processed. It does not explain the details of using a gravity meter: these will be explained by the teaching staff on the field course.

1 Introduction

Everything is gravitationally attracted to everything else. And the gravitational attraction of an object is proportional to its mass. So if the rocks below you at a given place are denser, then the gravity there will be slightly larger. The changes in gravity from place to place are small: gravity, g, at the Earth's surface is about $9.81\,\mathrm{ms}^{-2}$, but the local variations are a tiny fraction of this; often we are measuring differences of $10^{-6}\,\mathrm{ms}^{-2}$. If you can measure how g changes from place to place, you can learn something about how the density of the rocks below you varies: see Figure 1.

2 Measuring gravity

It is possible to build an instrument that measures g directly. Such an instrument is called an *absolute gravity meter* and is large, unwieldy and expensive. For field surveys it is more usual to use a *relative* gravity meter. These are cheaper, smaller and more robust. But they do not measure the absolute value of g. They can only measure the differences in g between one place and another. Relative gravity meters are essentially a mass hung on a spring: if you go to somewhere where gravity is a bit larger, the spring stretches a bit more. The extra stretch is tiny: to measure it, we pull on the spring with a micrometer screw to restore the mass to the original position. Levers are used to make the system more sensitive and the whole mechanism is enclosed in a temperature-controlled box to prevent changes in temperature from affecting the results.

3 Measuring altitude

Although g is affected by differences in the rock density below the ground it is affected a lot more by the height of the ground surface. This means that in order to see the small differences in g caused by the density changes, you have to measure the height differences for each of your gravity measurements. For small-scale surveys (1 km long, say) the heights need to be measured to an accuracy of ± 1 cm. GPS can not provide this level of accuracy: the altitudes must be surveyed in the traditional manner, using a theodolite and a levelling stave. The process is shown in Figure 2.

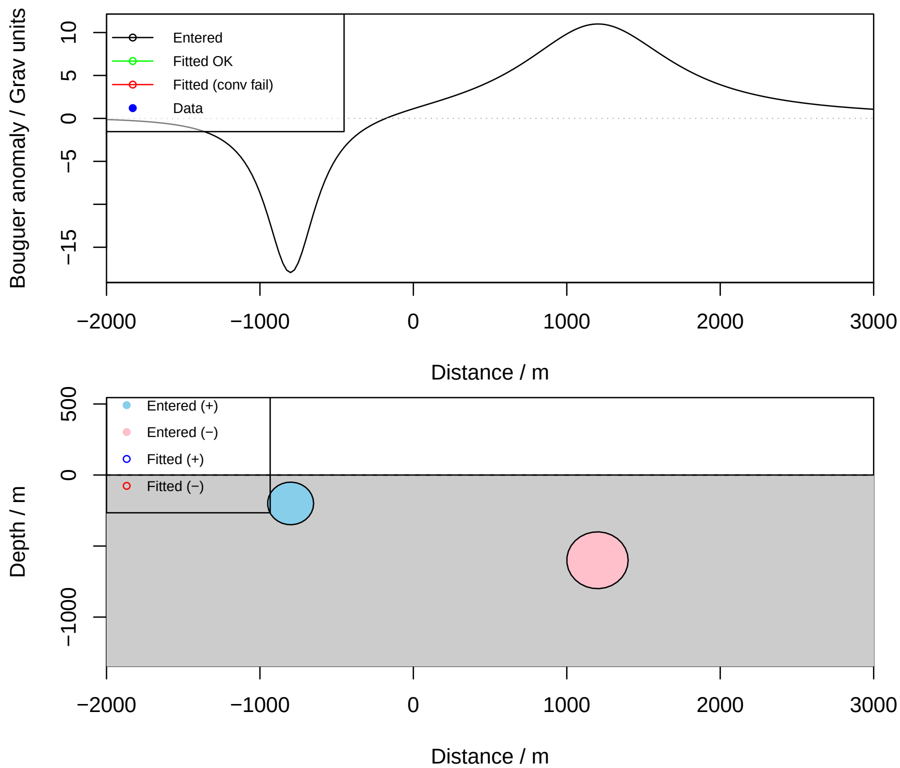

Figure 1: Gravity surveying: the basic idea. The lower panel shows a cross-section through the ground. The circles represent denser (right) and less dense (left) regions. The upper panel shows the gravity that might be measured at the surface.

4 Reducing the data

The number which is read from the gravity meter is simply the number of turns of the micrometer screw from the end position. To convert this into a useful value for interpretation it is necessary to apply several corrections to it.

4.1 Taking differences

As the instrument is only a relative instrument, we subtract the reading for the first measurement point from all of the other measurements.

4.2 Applying the calibration constant

Each gravity meter has its own calibration table which converts micrometer dial turns into physical units. The traditional unit for gravity is the milligal (mgal: 10^{-5}ms^{-2}); the modern tendency is to work in "gravity units" (gu: 10^{-6}ms^{-2}). The calibration constant varies slightly with number of dial turns. Figure 3 shows an example.

4.3 Applying the drift correction

If left at the same place, the measurement recorded by a relative gravimeter tends to change slowly (or *drift*) due to fluctuations in temperature etc. We correct for this my making a measurement at the same location at the beginning and end of the day. By recording the time of every measurement and assuming that the drift in the instrument

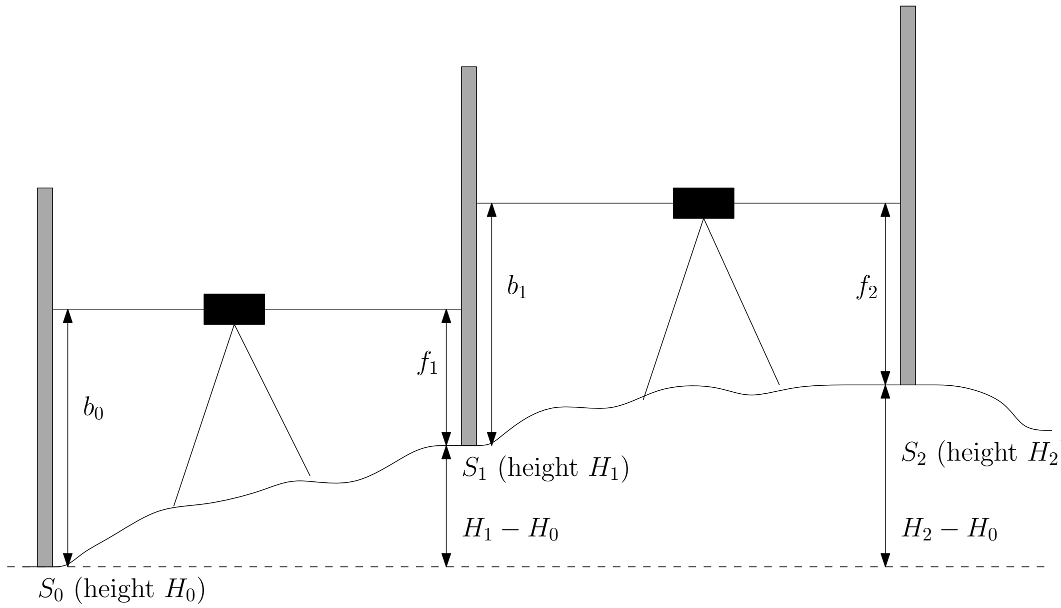

Figure 2: Use of a theodolite (black) and levelling staves (grey) to measure the altitude of stations S_1 and S_2 with respect to the base station S_0. The theodolite is a telescope that looks exactly horizontally. The staves are giant rulers, marked in cm. The backwards and forwards readings b_i and f_i are read by looking the staves through the theodolite. The heights are given by $H_1 = H_0 + b_0 - f_1$, $H_2 = H_0 + b_0 - f_1 + b_1 - f_2$ etc.

is linear in time we can correct our measurements to account for the drift, as shown in Figure 4

4.4 Applying the height correction

If a gravity meter is moved upwards (away from the Earth) then the value of g which it measures will decrease. Measured values must be corrected for this effect; this is called the free air correction. The usual reason that a gravity meter is at a different altitude is that the ground is higher. The correction for the gravity of this extra mass of ground is called the Bouguer plate correction. To make it, a value for the typical density of rock must be assumed. As the free air and Bouguer plate corrections are both proportional to height they are often combined into a single height correction. Gravity values with the height correction applied are called Bouguer anomalies. For a typical rock density of 2.67 tonnes / m^3, the height correction is about 1.97 gu (0.197 mgal) for every m of height.

4.5 Applying the latitude correction

Gravity varies with latitude λ according to the *normal gravity formula:*

$$g_n = g_e(1 + \beta_1 \sin^2 \lambda + \beta_2 \sin^2 2\lambda)$$

For a small scale survey we often approximate this formula by a linear or quadratic fit using either latitudes or grid Northings. At the latitude of Derbyshire (53 °N) the latitude correction is approximately 7.834 gu (0.7834 mgal) for each km north of the base station. At the latitude of Bermuthshain, Germany (50.47 °N) it is 7.999 gu (0.7999 mgal)

Milligal Values for LaCoste & Romberg, Inc. Model G Gravity Meter #275

COUNTER READING*	VALUE IN MILLIGAL	FACTOR FOR INTERVAL	COUNTER READING*	VALUE IN MILLIGAL	FACTOR FOR INTERVAL
000	000.00	1.05115			
100	105.12	1.05108	3600	3786.12	1.05337
200	210.22	1.05104	3700	3891.46	1.05347
300	315.33	1.05100	3800	3996.81	1.05356
400	420.43	1.05095	3900	4102.16	1.05365

Figure 3: Section of the calibration table for a Lacoste-Romberg gravity meter. The important number is the one labelled FACTOR FOR INTERVAL — we multiply the counter reading by this to get a value in physical units. (We would also multiply by 10 to get the answer in gu rather than mgal.)

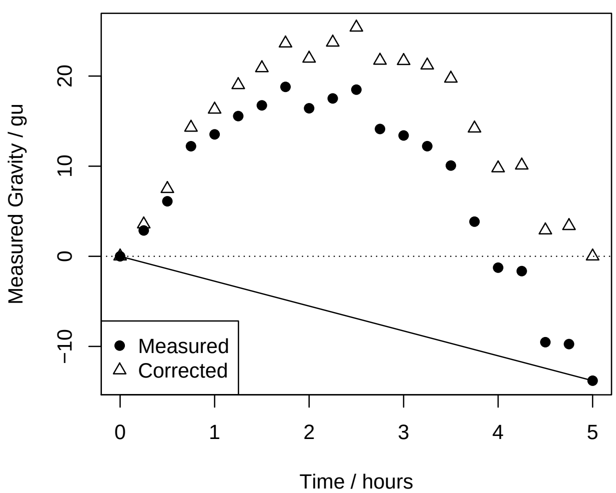

Figure 4: Applying a correction for instrumental drift to relative gravity measurements. Each point is supposed to be a measurement at a different location. But the first and last points were measured at the *same place*, so gravity there should not change. The measured drift will include the effect of the gravity tides (daily amplitude about 1 gu) as well as the instrument drift. Serious people correct for the tide separately but we will lump it in with the drift correction.

for each km north of the base station. At Montalivet-les-Bains, France it is 8.1397 gu (0.81397 mgal) for each km north of the base station.

4.6 Applying the terrain correction

This correction accounts for the fact that a nearby mountain pulls upwards on the gravity meter, reducing the measured value. And a nearby valley fails to pull downwards on the meter, again reducing its value. This is by far the most tiresome correction to apply as we need to consider all of the terrain surrounding the measurement point. If the terrain is sufficiently smooth then this correction is often not carried out.

5 Modelling the results

Once you have reduced your measurements to Bouguer anomalies, they must be interpreted. The usual way to do this is to construct a model of the sub-surface density variations which reproduces the measured gravity. Figure 1 shows an example of this. It is important to understand how under-constrained the problem is: there are many possible arrangements of density which could match a set of measurements.