Gravity Measurements–Making Corrections and Calculating Anomalies

After completing this practical you should be able to:

• Use Excel to perform basic calculations using formulae.

• Use formulae to automatically calculate results for a series of data values.

• Use Excel to plot simple x-y scatter graphs of the results of formulae calculations performed on a series of data.

• Understand the scientific rationale for, and calculate, the standard corrections to observed gravity measurements including;

1. Calculating a **standard theoretical gravity value** for a given location on Earth.
2. Calculating the **Free Air correction**.
3. Calculating the **Free Air anomaly**.
4. Calculating the **Bouguer correction**.
5. Calculating the **Bouguer anomaly**.

Required Formulae (please read accompanying pages of Chapter 8, Lillie, 1999)

Reference theoretical gravity formula 1967 (see page 226, Chapter 8)
$gt = ge * (1 + 0.005278895 * Sin^2(lat) + 0.000023462 * Sin^4(lat))$

Free Air correction (see pages 226-228, Chapter 8)
$FAC = -(dg/dR)*h = 0.308*h$ (mGal)

Bouguer correction (see pages 229-231, Chapter 8)

On Land, $BC = 2*\pi*G*rhoc*h$ (m.s^{-2})…multiply by 10^5 for answer in (mGal)

At Sea, $BC = 2*\pi*G*(rhow-rhoc)*hw$ (m.s^{-2})…multiply by 10^5 for answer in (mGal)

Free Air anomaly (see pages 227-228, Chapter 8)
$gFA = (go – gt) + FAC$

Bouguer anomaly (see pages 232-234, Chapter 8)
$gBA = gFA – BC$

lat = latitude of gravity station
ge = standard 1967 theoretical gravity value at equator, 978031.85 mGal
hw = depth of water below marine gravity station, m
h = height of gravity station above ellipsoid, m
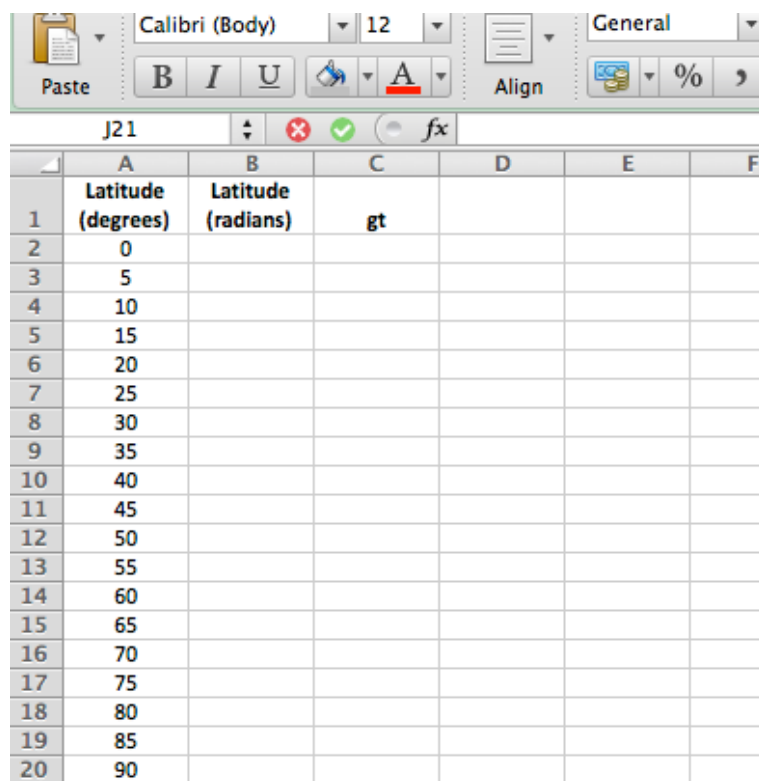rhoc = Standard Bouguer crustal density is 2670, kg.m^{-3}
rhow = Sea water density is 1030, kg.m^{-3}
G = Gravitational constant, is 6.67 x 10^{-11} N.m^2.kg^{-2}

Task 1.
Calculate the theroretical gravity value (in mGal) using the 1967 Reference Gravity
Formula (page 226 of notes) for a series of points on Earth, 5 degrees of latitude apart,
from the equator to the north pole (so every 5 degrees from 0 degrees latitude North to 90
degrees latitude North).

TIP: Setup one column within Excel to store the latitude values (in degrees) and a second
column to store the values of latitude converted to Radians. You will need to convert your
angles of latitude in degrees to angles in radians using the RADIANS function (see Excel
notes/guide below). Then use the standard theoretical gravity formula to calculate the
theoretical gravity value for each latitude and store the result in a third Excel column (see
example in figure below).

	A	B	C	D	E	F
1	Latitude (degrees)	Latitude (radians)	gt			
2	0					
3	5					
4	10					
5	15					
6	20					
7	25					
8	30					
9	35					
10	40					
11	45					
12	50					
13	55					
14	60					
15	65					
16	70					
17	75					
18	80					
19	85					
20	90					

Task 2.
Plot a a simple x-y scatter graph using Excel which illustrates how the theoretical gravity
values calculated in Task 1 vary with latitude, i.e. plot gt on the y-axis and values for
latitude (degrees) on the x-axis.

Task 3.
Calculate (using the Excel AVERAGE function) an average theoretical gravity value for the
Earth (the average of the gt values from Task 1) and the difference in gravity (in mGal)
between the poles and the equator.

Task 4.
Show that an approximate value for dg/dR (the rate of change of gravity with distance from
the centre of mass of the Earth) is about -0.308 mGal/metre. Use the average gravity

value you determined in Task 3 and a mean radius for Earth, R, of 6367000m and the formula (from page 227 of notes);

$$dg/dR = -2*(average\ g)/R$$

Note that the rate of change of gravity with increasing distance is negative (i.e. the further away from the centre of mass of the Earth you are the smaller g is going to be).

Task 5.
A gravity measurement was performed on land at the following field site;
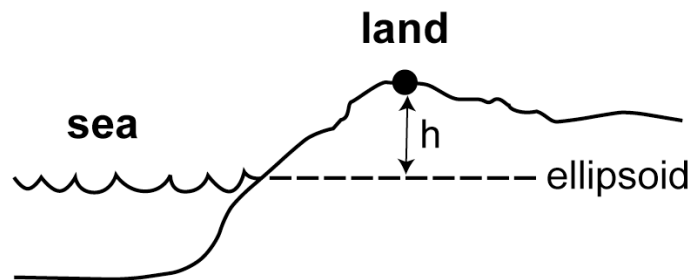

Terrain is undulating, low relief.   Latitude: 48.1195 N   Longitude: 3.5678 W
Elevation (ellipsoid height), h, 487.9 m, and observed gravity (go) is 980717.39 mGal

1. Calculate the Free Air correction, FAC.
2. Calculate the Bouguer correction, BC.
3. Calculate the Free Air anomaly, gFA.
4. Calculate the Bouguer anomaly, gBA.

Task 6.
If the gravity station was at sea level (i.e. part of a marine gravity survey), and the depth of water, h_w, beneath the site was 487.9 m, then assuming all other parameters are the same as in Task 5;
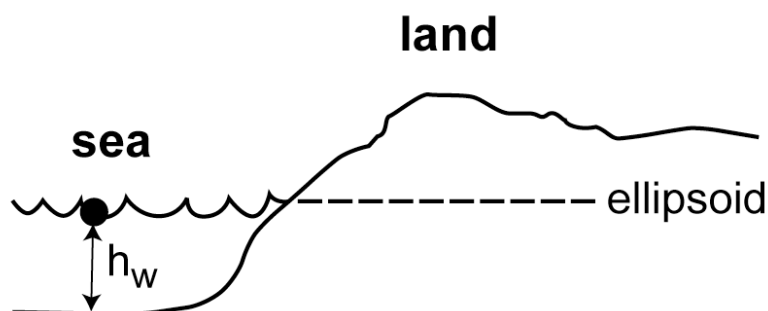
1. Calculate the Free Air correction, FAC.
2. Calculate the Bouguer correction, BC.
3. Calculate the Free Air anomaly, gFA.
4. Calculate the Bouguer anomaly, gBA.

Units of acceleration/gravity: 1 Gal = 1 cm.s^{-2} mGal = Gal x 10^{-3} = m.s^{-2} x 10^{-5}

Quick Guide to Syntax used in Excel Formulae

Operation	Excel Syntax	Comment
Addition	x+y	x plus y
Subtraction	x-y	x minus y
Multiplication	x*y	x times y
Division	x/y	x divided by y
Power	x^y	x raised to the power of y
Sine	SIN (x)	angle x in radians*
Cosine	COS (x)	angle x in radians*
Tangent	TAN(x)	angle x in radians*
Sum	SUM(A2:A10)	of cells from A2 to A10
Average	AVERAGE(A2:A10)	of cells from A2 to A10
Pi	PI()	Note empty brackets ()
Degrees->Radians	RADIANS(A2:A10)	Converts to radians

*The radian is a measurement unit of angle (like degrees). It is the SI derived unit of angle. It is defined as the angle subtended at the centre of a circle by an arc of circumference equal in length to the radius of the circle. Angle measures in radians are often given without any explicit unit. When a unit is given, it is sometimes abbreviated rad.

This is a very terse list of the most basic operations available for building formulae in Excel. To explore further options (and to see the syntax used) using the main menu go to **Insert->Function…** and look through some of the options.

Formulae are entered in the formula bar edit field at the top of the workbook page. If this is not showing then switch it on by selecting **View->Formula Bar** from the main menu. To enter a formula in a cell, rather than a simple value, begin the formula definition with an equals sign, i.e. =.

Examples of Excel formulae:

Convert angle in degrees in cell A2 to angle in radians [note pair of empty brackets (), this is the correct syntax];

= **A2** * (**PI**()/180)   OR   try using   = **RADIANS** (**A2**)

Calculate the theoretical gravity value in mGal for a given latitude using the theoretical gravity formula (truncated to first two terms) referring to latitude value (in radians) in cell B2. The reference gravity value in the formula (i.e. 978031.85 mGal) is the gravity value for the equator (i.e. zero latitude);

= 978031.85 * (1 + ((0.005278895 * (**SIN(B2)**)^2)) + (0.000023462 * (**SIN(B2)**)^4))

In formulae, like the one above, which have variables that vary for a series (here it is latitude that is varying) and some variables that can be treated as constants (like the reference gravity value above) it is useful to be able to define variables by a word and assign a value to them. Then the formulae can be rewritten by referring explicitly to your defined variable by its name. This avoids odd or unexpected things happening when you apply the formulae across a series of data. It also allows you to set up a complex set of formulae for a series and then experiment with different values for the assigned variables.

To assign a named variable do the following;

1. Select a cell in a clear area of your work sheet (e.g. to the right of your series of columns) and type the name that you want to assign to the variable, e.g. we might want to define a variable to hold the gravity value at the equator, and call it **ge.**
2. Select an adjacent cell (e.g. on the right) by clicking once in the empty cell.
3. Using the main menu go to **Insert->Name->Define**
4. Enter the name of your variable if it is not listed already and click **Add** (note that the cell this variable name refers to is the cell you selected above).
5. Click **OK**

You can now use the variable you have defined, i.e. **ge**, explicitly in your formula (i.e. use the word '**ge**' in this example as shown below instead to a specific value as we did above) and it will refer to the value that you entered in the cell to which the variable refers (the cell to the right of the name **ge**).

To change the value of the variable all you need to do is change the value in the reference cell, this will automatically update any formula in the current workbook that makes use of the variable **ge**. So you can right the new formula like this;

= **ge** * (1 + ((0.005278895 * (**SIN(B2)**)^2)) + (0.000023462 * (**SIN(B2)**)^4))

Useful short-cuts to using Excel formulae for a series of cells:

To automatically fill a set of cells (e.g. within a column) with a series of numbers;

1. Enter the value you want your series to start with in the first cell.
2. Select the cells you want to create the series in, starting with the first cell (click and drag over the range of cells you want to select).
3. Using the main menu select **Edit->Fill->Series…**
4. Enter values for the series increment etc that you want.

To automatically apply a formula to a series of cells within a column;

1. Enter the formula for the first cell in the column.
2. Select the range of cells you want to apply the formula to, starting with the first cell in the column (the one you have just entered the formula for).
3. Using the main menu select **Edit->Fill->Down**

4. The formula will be applied to each cell you have selected in the column, with the reference cells being incremented automatically (note some times you may have to click on a cell first and then the green 'OK' arrow in the formula bar to activate the calculation).