Applying Corrections to Gravity Survey Data

GOPH 547

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Abstract

Ground gravity surveys are a geophysical technique where an absolute and relative gravimeter are used in conjunction to extract raw gravity data. A gravity anomaly is defined as the difference between the observed gravity and the value predicted from a model. In order to properly assess the raw surveyed data, various corrections need to be applied to the measured gravity values. The purpose of this investigation is to apply corrections to the supplied data set so that the local subsurface geology is more accurately represented. The software Matlab was employed to do such corrections with which figures and results were then plotted, showing clear distinctions between raw vs corrected gravity data.

Background and Theory

The following equation formed arguably the foundation of this exercise and was employed as Matlab function;

$$g_z = -\frac{\partial U}{\partial z} = Gm\frac{z - z_m}{r^3} \qquad (1)$$

representing the gravity effect. Contributed by a number of physicists, most notably Newton in his *Principa Mathematica* (1687), the equation describes the gravity effect, the component of g that is directed toward the Earth's centre of mass, itself derived from taking the negative gradient of the gravitational potential (U)[1].

Using the above formula to get gravity values, the data is corrected initially to the theoretical value of gravity, which leaves results being only dependant on the local effects. This is done by using the International Gravity Formula (IGF);

$$\text{IGF: } g_t(\theta) = 9.780327[1 + 0.0053024\sin^2(\theta) - 0.0000058\sin^2(2\theta)] \qquad (2)$$

which results in normally corrected gravity.

The next corrections to be applied were the time dependant corrections, specifically tidal and instrument drift corrections. Tidal drift arises due to variations in tidal effects over the

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1 Karchewski, B. (2017). GOPH 547 - Gravity and magnetics. Retrieved from https://d2l.ucalgary.ca/

duration of the survey. This is mainly due to changes in the location of the moon and sun. Tidal forces can be represented as a function of the rotation of Earth;

$$\Delta g_{tide,i} = \Delta g_{tide,ref}(\theta, \varphi, t_i) \tag{3}$$

where the variables represent latitude longitude and time. Instrument drift arises due to variations in internal variables within the gravimeter itself over the duration of the survey (for example the spring stiffness possibly changing).

$$\Delta g_{drift,i} = \frac{g_{ref,2} - g_{ref,1}}{t_{ref,2} - t_{ref,1}}(t_i - t_{ref,1}) \tag{4}$$

Finally, a set of elevation and terrain corrections are applied. The elevation corrections can be divided into two; free air and Bougeur plate correction. Essentially what the free air correction does it put all of the survey points/data points onto the same elevation, accounting for minor variations in elevations such as bumps and hills. Uniforming the elevation of each survey point to a reference datum results in the free air correction. This correction is represented by the following;

$$\Delta g_{FA,i} = -\frac{2GM_e \Delta Z_i}{{R_e}^3} \approx -0.3086 \text{mGal/m} \tag{5}$$

The next elevation correction to be applied is the Bougeur plate correction. This corrects for gravity effects caused by any material between the gravimeter and the reference datum. A uniform slab of infinite length and thickness t is assumed. This accounts for the presence of average density material (used 2.65 g/cm^3) in the elevation change. What this elevation correction does is assumes a uniform plate of material 'over-correcting' for the free air present between hills and 'under-correcting' for density present in hills. This is represented by;

$$\Delta g_{BP,i} = 2\pi G \rho_B \Delta Z_i \approx 0.04193 \rho_B \text{mGal/m} \tag{6}$$

The final correction applied in the laboratory is known as the terrain correction. The terrain correction is essentially a further refinement of the Bougeur correction where it refines the idea by account for upward pulls of hills and the lack of downward pull of valleys. This accounts for the effects of rapid lateral changes in density (e.g. cliffs) which is finally represented as;

$$\Delta g_{terr,i} = -\sum_m \frac{GM_m |Z_{im} - Z_{datum}|}{{r_{im}}^3} \tag{7}$$

After theoretical/normal gravity correction, along with time dependant corrections and elevation plus terrain corrections are applied, the processed data can then be plotted in contour plots, figures and graphs and be used for geophysical interpretation of the subsurface local geology or anomalies that may be present.

Method and Algorithm

Questions 1 - 7 involved fairly basic Matlab operations which revolved around preparing the gravity survey data for subsequent corrections that are necessary when interpreting geophysical data properly. To begin, raw relative gravity of time variations and tidal variations were plotted. Contour plot of the surveys raw terrain data was also produced. These introductory figures served as a reference point for one to look back at once corrections were applied, to compare and contrast the regions being changed slightly.

Questions 8 - 9 involved performing first corrections known as theoretical/normal gravity corrections. The IGF equation (2), itself based on the Somigliana equation[2], was employed for this part of the implementation to obtain normal gravity. A latitude of 49.1286°N was used. To elaborate a little further on one of the parts, a for loop is employed to sum all the values for theoretical and then subtracted from the raw data to correct for it.

The next section in the Matlab implementation involved performing time dependant corrections. This was necessary because the gravity survey was taken over a substantial period of time (2500 hrs). Tidal drift is corrected by subtracting the values of tidal variations (dg_tide) from all readings. Instrument drift is corrected for by applying linear interpolation over each loop (details in comments).

The last section of the algorithm deals with elevation and terrain corrections. This is performed by first calculating the free air correction between the survey point and the reference datum using equation 5. This is fairly straightforward applying a loop and the previous equation for all pojnts. Then the Bouguer plate correction is performed using equation 6 which is similar in fashion to the above free air correction, employing a for loop and apply equation to all indices.

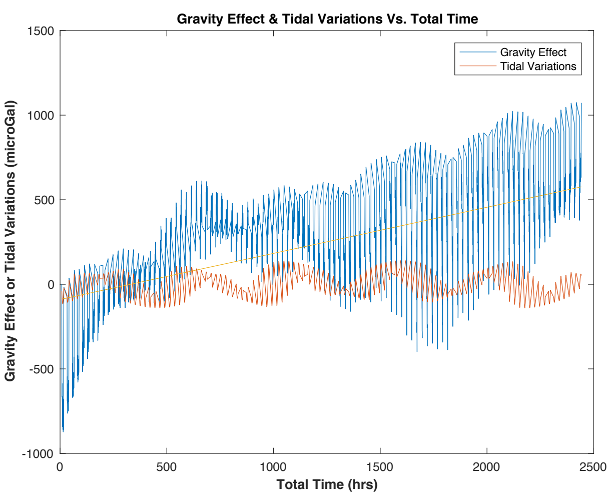
The most complicated correction to apply was the terrain correction. Three nested for loops were used inside a main for loop. Starting from the inside the nest, terrain correction equation 7 was used for a j2 index, n2 number of times where n2 was a variable created (size of Zt). The second nested for loop repeated such for i2 index the same n2 number of times. The

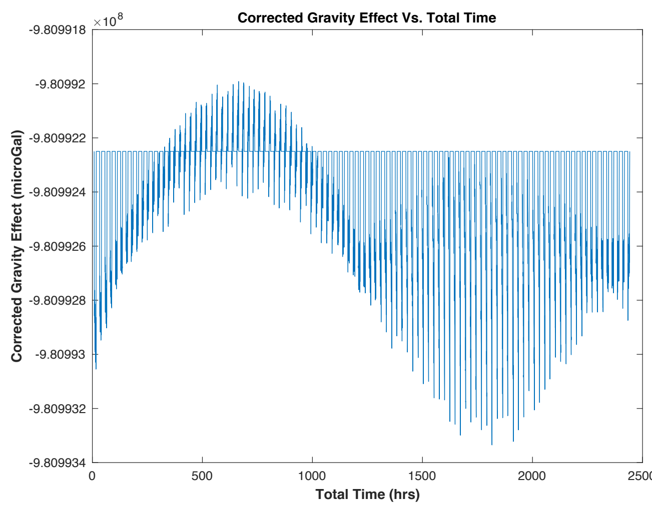
[2] https://en.wikipedia.org/wiki/Clairaut%27s_theorem#Somigliana_equation

third nested for loop then saves local centre of mass relative to datum as corresponding values from XT, YT, etc in a row vector. The enclosing for loop then outputs our final dg_terr which is used to apply terrain corrections. This method of looping over every gravity survey point, and then looping again over every terrain survey point is necessary to perform the terrain correction. The final correction is applied by calculating the regional correction which is the average of all gravity effects in the corrected gravity and then subtracting this from the corrected gravity at each survey point[3].

For question 22, I am not too confident with my Matlab implementation. The value of the anomaly I outputted as 5.2925x10^12 kg which is roughly 12 orders of magnitude smaller than the mass of the Earth, though it still seems too big.

Results and Discussion





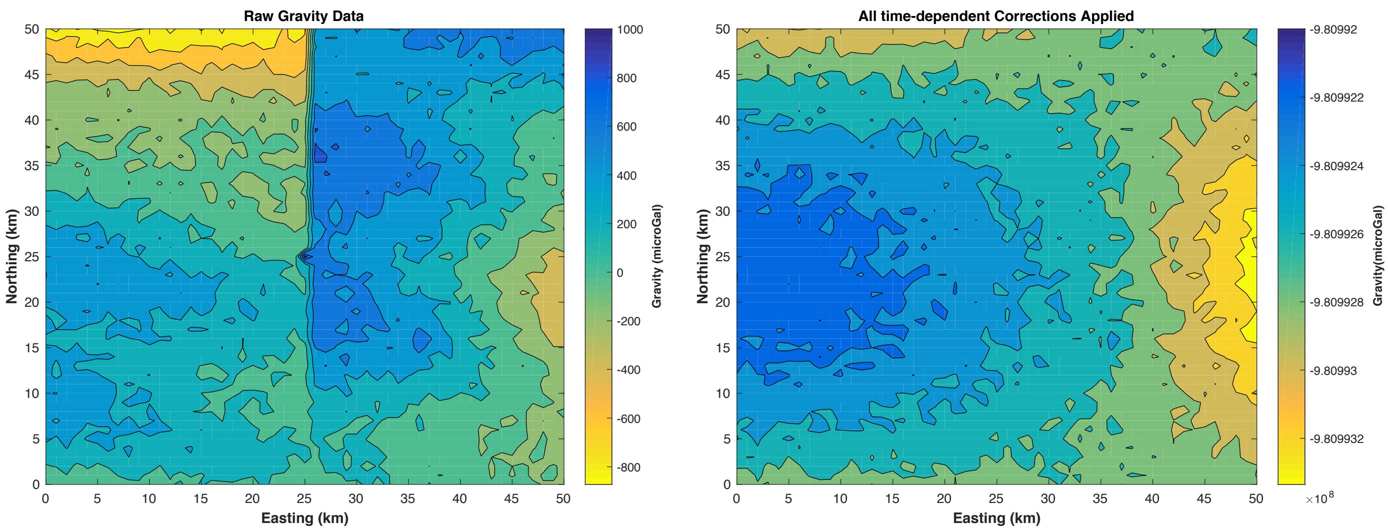
Figures 1 and 2: Variations in gravity effect and tidal variations, variation in gravity effect after corrections after eliminating time dependencies.

To begin, the first figure shows a clear graph of how the relative gravity and tidal effects vary over the duration of the survey. Since the survey was over a significant period of time, this is important to take a note of. From these results, it is determined that the relative gravity seemed to have gradually decreased during the first 500 hours of the survey. It then seemed to have changed course, steadily increasing instead for the remaining days of the survey duration. A line of best fit is plotted via polyfit function in Matlab which shows that, in general, the relative gravity was gradually increasing. A suggestion for next time may be to use a quadratic fit, as a parabola may have modelled the data more accurately. From the same figure, it is also

[3]Karchewski, B. (2017). GOPH 547 - Gravity and Magnetics. Retrieved from https://d2l.ucalgary.ca/d2l/le/content/169330/viewContent/2406931/View?ou=169330

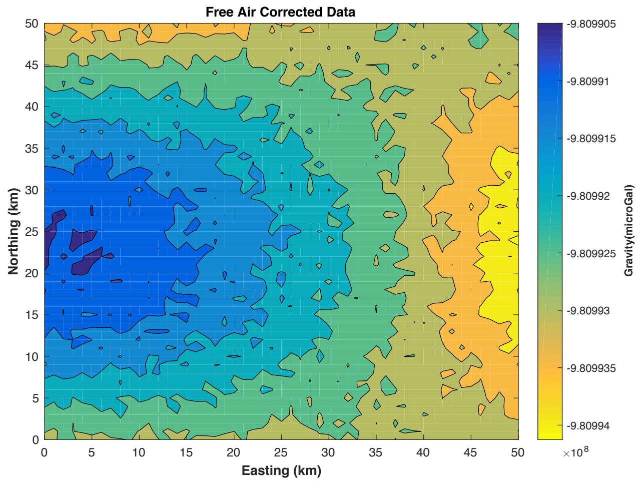
evident that the tidal effect varies over the survey duration, following a sinusoidal function. This intuitively makes sense because the tidal effect is dependant on the rotation of the Earth along with, most notably, the placement of the moon.

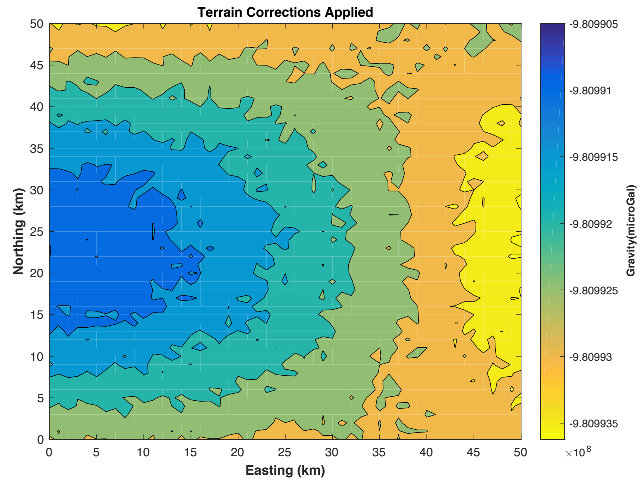
The graph in figure 2 shows results of the corrected gravities variation after accounting for time dependant variances (after tidal and instrument drift). From this graph one can verify that at each base station, each survey point has been corrected to zero. One can see that the relative gravity no longer gradually increases or decreases with time, but just osculates around x-axis, therefore this data is no longer time dependent.

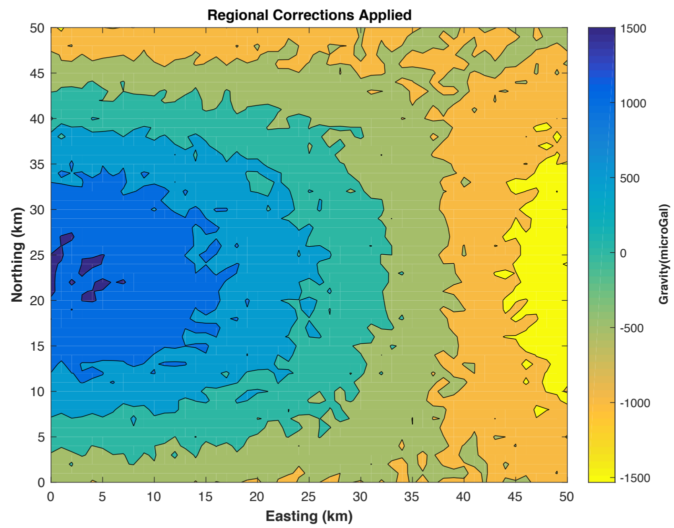


Figures 3 and 4: raw gravity contour plot vs normally corrected and tidal/instrument drift corrected contour plot

Figure 4 depicts the very 'first' of the gravity data in its raw form. A contour function in Matlab is used to produce the plot of the raw data. In the raw data, the measured gravity is just Δg values relative to the first data point. From here, normal gravity correction, tidal correction and instrumental drift corrections are applied which produce the next figure. Although not all figures are shown, the distinct vertical 'bar' evident in the figure 3 is solely due to instrument variances. Correcting for normal gravity and tidal correction did not get rid of the vertical bar in the other figures, though after applying the instrument correction it disappears.

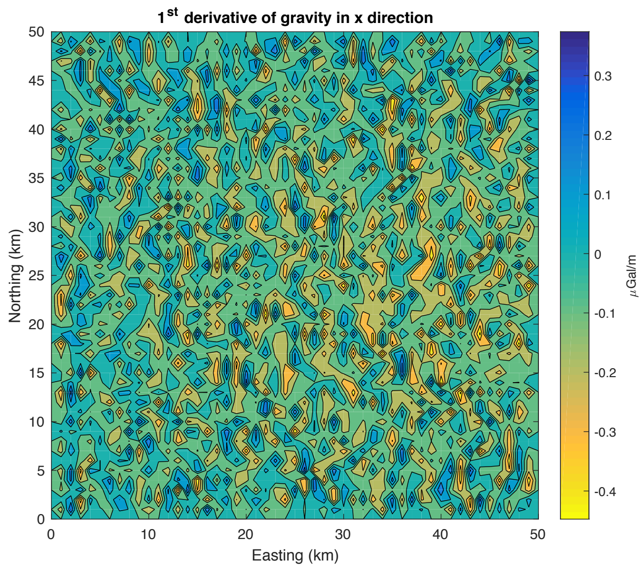


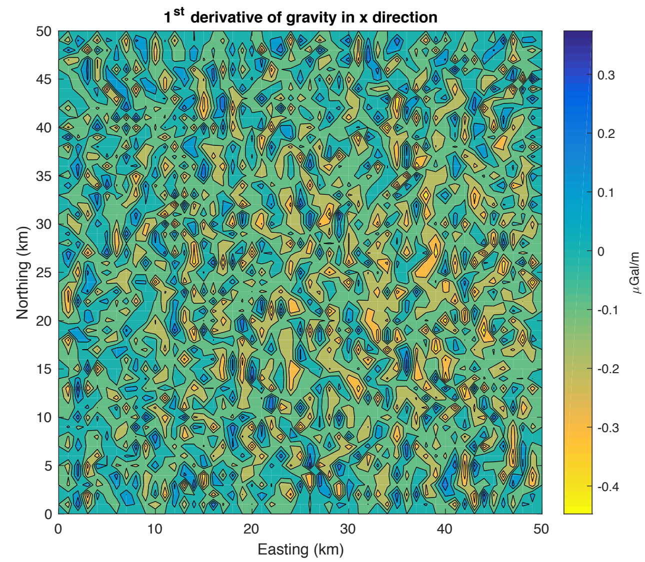


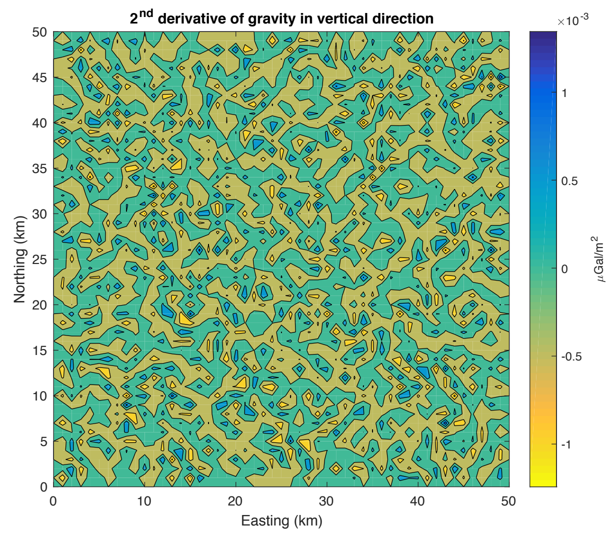


Figures 5, 6 and 7: applying free air corrections to time drift corrected data, contrasting with terrain corrected data. Finally applying regional correction to create presentable data for geophysical interpretation

After applying free air correction, some anomalies finally appear! Three strong anomalies are present quite clearly in the free air corrected data with precise locations given. However, after applying our terrain corrections, these anomalies seem to disappear once again. This may be to the terrain correction being too aggressive or perhaps applying a Bouguer over/under-correction to cause the anomalous bodies to disappear. However, once we apply regional corrections, the bodies appear once more and we have fairly clear target locations within the subsurface.







Figures 8, 9 and 10: applying free air corrections to time drift corrected data, contrasting with terrain corrected data. Finally applying regional correction to create presentable data for geophysical interpretation

For question 22, I am unsure if my implementation was correct. The charts produced by evaluating first second derivatives seem to produce fairly meaningless charts, although it may be because I am simply not interpreting them correctly/I am not learned enough to interpret them yet. Regardless, the implementation for the excess mass calculation, which seems to possibly be reasonable, is the mass being 5.2925x10^12 kg.

Conclusion

This investigation into gravity corrections highlighted importance of performing corrections on measured gravity data. The process of refining our data was clearly seen in the figures. From the raw gravity data, after applying instrument drift corrections, the produced graph looks a lot cleaner and easer to interpret. Further, after applying free air corrections, we can finally see localized gravity anomalies within the subsurface, there being 3 in total. Regional corrections also helped us see this and in our final graph/figure (being the regional correction), we have a strong estimate as to where the position of these anomalies may be within the subsurface so that further steps may be taken. Refining and correcting our model to better understand local subsurface geology is a fundamental goal of applied geophysics.

References

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