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High Precision Terrain Corrections for Next Generation Airborne Gravity Data

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SUMMARY

Next generation airborne gravity systems are expected to deliver significant improvements in measurement precision and resolution. In rough terrain a major component of the measured data will be the effects of the terrain beneath the aircraft, and corrections are routinely applied to remove most of these terrain effects. In order to fully utilise the higher precision data, advances in estimating these terrain effects will be necessary.
This paper will describe some of the steps necessary to improve estimation of terrain effects and demonstrate the expected improvement in target recognition.

Key words: Airborne gravity, gravity gradient, terrain effects.

INTRODUCTION

Currently, several next generation airborne gravity gradiometer systems are under development and they are expected to deliver a significant improvement in data precision and resolution. For example, the VK1c system, currently under development by Rio Tinto, at the University of WA, aims to measure gravity gradient to a precision of 1 Eo at intervals of 1 second, equivalent to about 60m at normal survey air speed.
In rough terrain, a major component of the recorded signal will be the effect of the terrain beneath, and around the aircraft, and this is routinely estimated and removed as a "terrain correction" to facilitate target recognition. In order to fully utilise the anticipated new, higher quality data, better methods of estimating the terrain effects may be necessary.
This paper will describe some of the shortcomings in current terrain corrections when applied to high resolution airborne gravity gradient data and methods which have been developed to improve the estimate of terrain effects in rough terrain.
Examples of simulated data will be used to demonstrate the possible improvements in target recognition, by applying more accurate terrain corrections.

Terrain Correction Methods

The application of terrain corrections to gravity data has been a standard step in processing measured data since gravity surveys began (Gannett, 1906). Historical gravity measurements were made with ground based, stationary instruments, measuring either gravity or gravity gradient at a defined location, where both the elevation and the surrounding topography could be accurately mapped. Airborne gravity, or gravity gradient measurements are made on a moving platform and the measurement is usually averaged or integrated over a finite time interval (usually 1 second), which is equivalent to approximately 60 metres for a fixed-wing aircraft. Any calculation of the terrain effect component of the measurement should also be integrated over this same interval. In relatively flat terrain, and with the precision and resolution of current systems, it may be adequate to calculate the terrain effect at defined locations and simply assume a linear variation between them. In the future we anticipate that more precise terrain corrections will be desirable and the method described in this paper was developed to test this expectation.

Spatial integration of the terrain response

Figure 1a illustrates a conceptual flight path over rough terrain, in two dimensions. There may also be lateral variations in the flight path and topography, which could materially affect the calculated terrain correction and these are of course included in the computation, but not illustrated here. Most current methods would calculate the terrain effect only at the points indicated and possibly interpolate assuming a linear change in terrain effect between points.
Figure 1b illustrates a linear interpolated terrain effect (the area under the trapezoidal curve) and additional samples taken over the areas of rough topography and splined to better approximate the detailed topography. Although only illustrated here in two dimensions, in general the additional samples would be located along the actual flight path, including lateral variations. A more accurate terrain effect at the measurement point (shown in 2D) would be the area under the red curve. The errors introduced by using only a linear interpolation can easily exceed 10 Eö.
The additional sub sampling of the terrain effect calculations is only necessary in areas of such steep topography, or rapid changes in flight path and specific criteria may be used in advance to determine where it is necessary, and to avoid unnecessary additional computations. One such criterion is the rate of change of the terrain effect initially computed for the

one second spaced locations and it has been used in the following example. In this example, a 4 x 8 km survey with a 100 m line spacing and a nominal clearance of 80 m over varied topography is used to show the effect of integrating the terrain effect. **Figure 2** shows the topography, the terrain response as calculated at 60 m stations along each line, and the effect of integrating the signal along 60 m spatial windows.

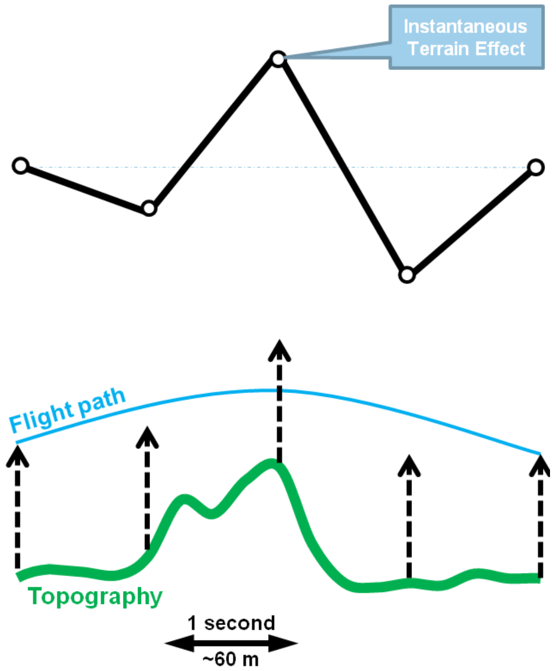

Figure 1a – Instantaneous terrain effect calculated at uniform, discrete points along a flight line. Deviations from an ideal terrain clearance are indicated by the arrows.

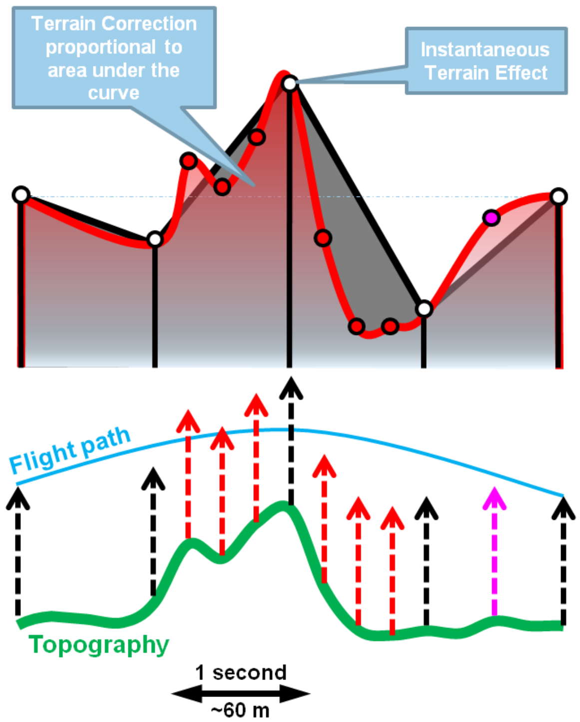

Figure 1b - Sub-sampled, integrated terrain effect. In areas where the terrain response changes rapidly, the response is subsampled (pink and red arrows).

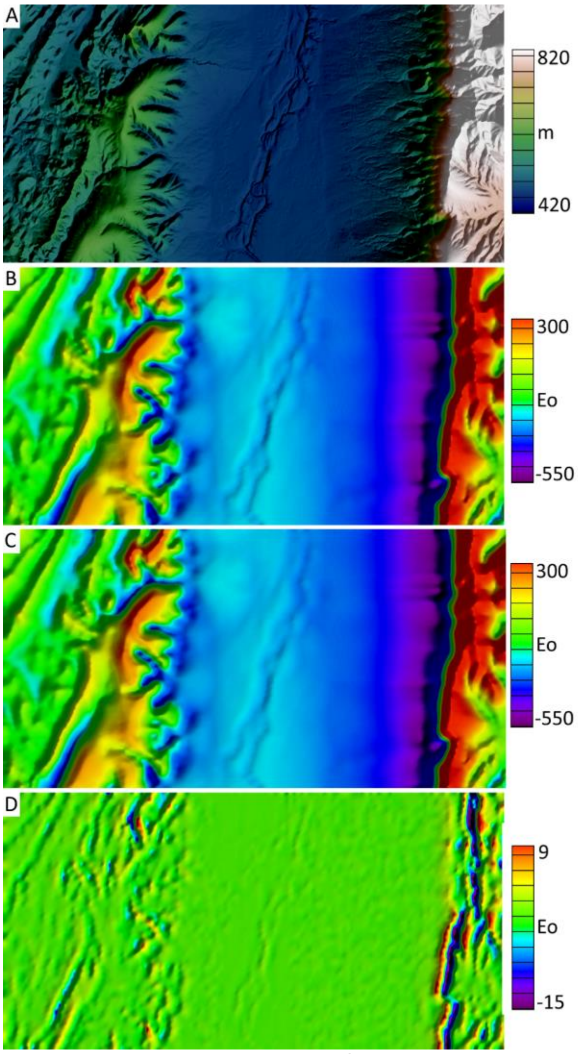

Figure 2 – A: The topography of the survey area. B: The vertical gravity gradient of the topography at discrete, 60 m intervals. C: The vertical gravity gradient of the topography integrated over 60 m intervals. D: The effect of integrating the vertical gravity gradient of the terrain (Figure 2C minus Figure 2B).

Figures 2B and **2C** appear highly similar, suggesting that the effect of spatial integration is subtle when viewing the full range of the terrain's gravity gradient response. However, spatial integration is shown to locally introduce errors of up to 15 Eö in this example (**Figure 2D**).

Figure 3 shows the effect of spatial integration of the terrain signal with simulated noise characteristic of current and next generation airborne gravity gradiometer systems.

This suggests that the effect of spatial averaging on terrain corrections would not typically be discernable through the inherent noise and long wavelength low pass filter exhibited in current airborne gravity gradiometry systems. However, it becomes important to account for the integration of the terrain signal when considering terrain corrections for the highly accurate next-generation systems.

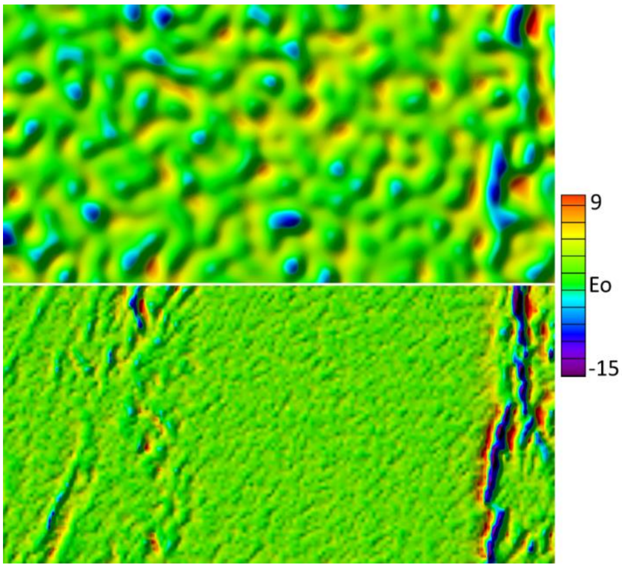

Figure 3 – The effect of spatial integration plus simulated current generation survey noise of 15 Eo/rootHz (upper) and next-generation survey noise of 1 Eo/rootHz (lower).

Computational efficiency

Integrating the gravity gradient of the terrain along the flight significantly increases the computational workload when compared to calculating the terrain effect at discrete points. It is possible to sample the flight path at fine increments and use the calculated gravity gradient at these points to account for the effects of spatial averaging. However, this may result in unnecessary amounts of computations (e.g. in areas where the gravity gradient does not vary significantly).

To increase the computational efficiency, it is important to minimise the number of integration calculations. One way to do this is to determine the minimum number of points along each flight line so that, when cubic splines are fitted between them and integrated across, the spatial integration effects are below some desired threshold. To assist in determining the number and location of the required data points at which to determine the gravity gradient of the terrain, the along-line rate of change of either the observed gravity gradient or the terrain response (calculated at discrete points) can be used; where the gravity gradient changes significantly within some window, the less appropriate a discrete evaluation of the terrain response becomes for that window.

Figure 4 demonstrates how the along-line derivative of the gravity gradient of the terrain is transformed into a map of the required data point density.

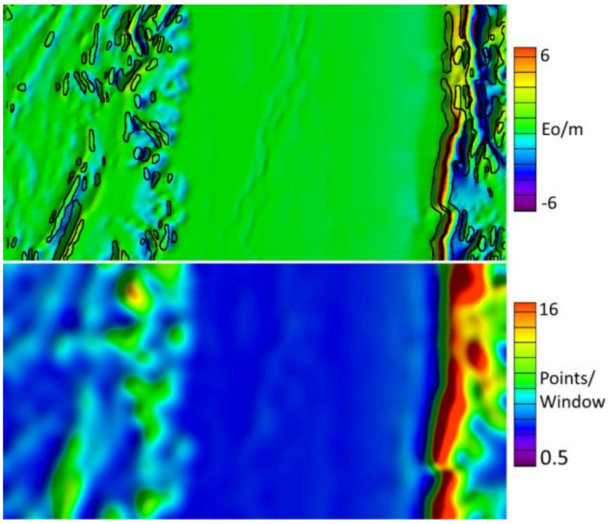

Figure 4 – Upper: The along-line derivative of the gravity gradient of the topography. The contours are of the effect of spatial integration at ±2 Eö. Lower: The transformed map of the required data point spacing for a target spatial averaging error of 0.5 Eö.

As seen in **Figure 4**, the along-line derivative of the terrain effect is highly correlated to the effect of spatial integration. By low-pass filtering the magnitude of the along-line derivative of the terrain effect, a metric for the required number of discrete data points per sampling window (60 m in this case) can be obtained. In this example, if the densest data point separation had been used for the entire survey, ten times as many calculations would have been required than if the optimised data point separation was used.

CONCLUSIONS

Integrating the gravity gradient of the terrain along the flight path of an airborne gravity gradiometry survey has been shown to be a necessary part of terrain corrections for the upcoming generation of highly accurate gravity gradiometers. It has been shown that the effect of spatial integration does not generally need to be considered in the data processing workflow of current instruments. A method of increasing the computational efficiency of the spatial integration by using the along-line derivative of the measured signal or the terrain response has been introduced. The spatial integration method described in this paper can also be applied at other stages of the gravity gradiometry data processing workflow, including 3D inversion.

ACKNOWLEDGMENTS

REFERENCES

Gannett, H., 1906, Manual of topographic methods, Washington Government Printing Office

Li, Y et. al., 2010, Terrain correction and its effect on 3D inversion of airborne gravity gradiometry data: Abstracts from the ASEG-PESA Airborne Gravity 2010 Workshop