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Results from SGL's AIRGrav airborne gravity system over the Kauring airborne gravity test site

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SUMMARY

A Sander Geophysics AIRGrav airborne gravity system was flown over Geoscience Australia's Kauring airborne gravity test site. Comparisons with both Geoscience Australia ground data and airborne gravity gradiometer data acquired by CGG using the Falcon system are presented. A series of band pass filters of the vertical gravity and vertical gravity gradient are employed to highlight performance at different wavelengths. While the Falcon system is best suited to the shortest wavelengths present at the Kauring test site, the AIRGrav system is also able to resolve relatively short wavelength features. This is due to noise reduction through the oversampling present with tight line spacing, combined with the unique characteristics of the AIRGrav system. Additional results with wider line spacing more commonly employed in airborne gravity surveys are shown using data acquired over both the Kauring test site and Papua New Guinea.

Key words: airborne gravity meter, airborne gravity gradiometer, gravity resolution, AIRGrav, Kauring.

INTRODUCTION

The relative performance of airborne gravity (AG) systems and airborne gravity gradiometer (AGG) systems is a recurring subject. In the broadest terms, AGG systems are best suited to shorter wavelength shallower features while AG systems hold an advantage at longer wavelengths and deeper targets. There is a wide range of opinion on what exactly 'shorter' and 'longer' wavelengths mean. A theoretical limit on airborne gravimeters based on GPS noise (van Kann 2004) is often cited to imply a practical limit on the order of 5-10 km resolution for AG systems in general, despite published AIRGrav airborne gravity data sets being available at 1.5-2 km resolution that accurately reproduce ground data and have low internal noise estimates (Sander et al., 2004). Note that 'resolution' in this context means the half-wavelength of the filter used.

In addition to this broader question, the characteristics of specific AG and AGG systems vary. Side-by-side testing provides the most direct comparison of instruments, eliminating variability created by different survey design and flying conditions. For example, a side-by-side test of AIRGrav and Canadian Microgravity GT-1A gravimeters was conducted which demonstrated the AIRGrav system was able to acquire higher quality data and was able to do so in a wider range of flight conditions (Studinger, Bell, and Frearson, 2008). The practical difficulties in arranging these kinds of tests make them rare.

Repeatability tests are more commonly used as they are relatively easy to perform. The noise characteristics of the AIRGrav system were examined using 100 repeat lines acquired over 10 years in Elieff and Ferguson (2008) and compared with noise estimates from survey data. Both consistently show accuracies in the 0.1-0.3 mGal range for spatial resolutions of 1.4-4.5 km, depending on survey design.

The gravity test site at Kauring in Western Australia is an excellent additional tool for the analysis of airborne gravity and gradiometer systems because of the high quality independently acquired ground gravity data at the site (Howard, Grujic, and Lane, 2010). Airborne data acquired at the Kauring test site are compared here with the ground data using a series of band pass filters to qualitatively illustrate performance as a function of wavelength. The dense line spacing typically employed for surveys targeting smaller spatial anomalies allows for additional noise reduction through averaging in an oversampled area that can extend the reach the AIRGrav system into wavelengths well below theoretical GPS limits. With more typical widely spaced lines on the order of 1 km, only a modest amount of spatial filtering equivalent to a few kilometres resolution produces high quality gravity data because the accuracy of GPS derived accelerations improves rapidly at longer wavelengths. This is demonstrated using Kauring data and another recently acquired data set over Papua New Guinea.

METHOD AND RESULTS

The Kauring gravity test site consists of detailed ground data sampled in the inner-most 5x5 km region (the “AGG area”) and semi-detailed 500m stations in a wider 20x20 km region (the “AG” area). The inner AGG area has been flown by the Falcon system with 50 m line spacing (Christensen, 2013). The AGG area was also flown by AIRGrav at 50 m line spacing, with the entire AG area covered by 200 m line spacing. AIRGrav data were acquired using a draped flying surface with a minimum clearance of 80 m in normal daytime turbulence conditions. Figure 1 shows free air gravity grids from ground and AIRGrav measurements to provide an overview of the Kauring site as well as to give a general idea of the relative resolutions of the ground gravity areas and the AIRGrav grid. A 600 m (AGG area) / 1000 m (AG area) half-wavelength low pass filter was employed for the AIRGrav data.

A detailed view of the AGG area is shown in Figure 2 using Bouguer vertical gravity gradient (G_{DD}) grids. The sharp, shallow round anomaly at the centre of the appropriately named AGG area presents an ideal target for an AGG system. Not surprisingly, the Falcon AGG system reproduces these shortest wavelengths well. The AIRGrav grid, with a 600 m half-wavelength low-pass filter for the AGG area, does not detect the smallest anomalies but longer wavelength anomalies are imaged clearly.

Band Pass Filtered Grids

A series of band pass filters in Figures 3-5 corresponding to 500-1000 m, 1000-2000 m, and 2000-4000 m resolution (ie., filter half-wavelengths) illustrate the performance with increasing wavelength. At 500-1000 m and 1000-2000 m using the Bouguer vertical gradient grids (G_{DD}), the AIRGrav system captures the gravity field with improving accuracy.

Moving to 2000-4000 m it is more appropriate to use the entire AG area due to the small size of the AGG area relative to these wavelengths. This is displayed using Bouguer gravity (g_D) grids in Figure 5 instead of the gravity gradient (G_{DD}) used in Figures 2-4. Also shown is the longer wavelength signal after a 3333 m low pass filter. In this area the ground station spacing is less dense and the AIRGrav data are collected using wider 200 m line spacing. Falcon data are not available for the entire AG area, nor would it make sense to include it here since Falcon relies on external data sources for the long wavelength field (Dransfield, 2010). For the Kauring test site the Gravity Anomaly Grid of the Australian Region (GAGAR09) was used beyond a 2500-5000 m half-wavelength transition band for the Falcon data set (Fugro, 2012).

The standard deviations of the airborne-ground differences for the grids shown in these figures are given in Table 1. Note that these are not instrument noise estimates. The ground gravity grid has not been upward continued in these comparisons, nor has any attempt been made to correct for processing differences present in each data set.

Area	Resolution	Falcon	AIRGrav
AGG	500-1000 m	3.6 Eö	7.7 Eö
AGG	1000-2000 m	2.6 Eö	4.3 Eö
AGG	2000-4000 m	n/a	0.09 mGal
AGG	> 3333 m	n/a	0.09 mGal
AG	2000-4000 m	n/a	0.18 mGal
AG	> 3333 m	n/a	0.18 mGal

Table 1. Standard deviations of the differences between airborne and ground for the grids shown in Figures 3-5.

The AIRGrav system is able to collect data at short wavelengths because it is essentially limited by the spectrum of GPS position noise. The instrumental errors in the gravimeter, such as those induced by flight dynamics, are comparatively small. The random GPS noise can be averaged through oversampling and grid filtering, extending the reach of the system into shorter wavelengths. In addition, advanced processing techniques have enabled noise reduction in individual lines below older theoretical GPS limits (Elieff and Ferguson, 2008).

Wider Line Spacing

Relatively tight line spacing of 50m (AGG area) / 200m (AG area) was used for AIRGrav acquisition over the Kauring test site. For longer wavelength data this is unnecessary. Gravity accuracy improves substantially at longer wavelengths so only a modest amount of oversampling will produce accurate data.

To demonstrate this, the AIRGrav data covering the AG area were divided into five subsets of 1000 m spaced lines and the accuracy estimated using difference grids to measure repeatability. The accuracies are 0.41 mGal (1000-2000 m band pass), 0.22 mGal (2000-4000 m band pass), and 0.14 mGal (3333 m low pass) standard deviation, all using 1000 m spaced lines. For a survey targeting 3 km resolution, for example, 1000 m line spacing is expected to produce a final filtered grid with 0.1-0.2 mGal accuracy.

SGL has flown over 100,000 km of AIRGrav surveys in Papua New Guinea. The Bouguer vertical gravity gradient for a small subsection of this data with the same parameters of 1000 m line spacing and 3000 m half-wavelength resolution covering approximately 30x30 km is shown in Figure 6. The accuracy was estimated with the method from Sander et al. (2002) using subsets of 2000 m spaced lines. The final grid has 0.15 mGal accuracy, in agreement with the data acquired at the Kauring test site.

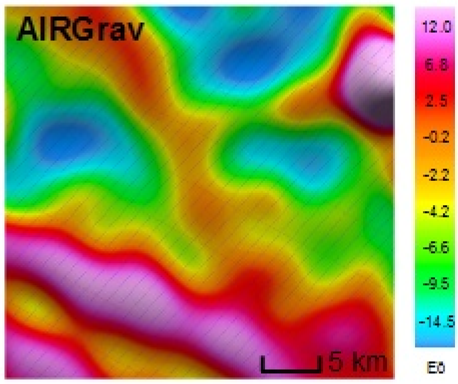

Figure 6. Bouguer vertical gravity gradient from a survey in PNG with 1000 m flight lines superimposed. A 3000 m half-wavelength filter is applied to the grid.

CONCLUSIONS

The AIRGrav system is capable of obtaining accurate gravity grids at resolutions of a few kilometres using relatively wide 1 km line spacing. Tighter line spacing significantly extends AIRGrav's utility into shorter wavelengths through oversampling noise reduction, as is evident from the 500-2000 m resolution data acquired over the Kauring test site. A wide range of factors go into survey design: accuracy and resolution requirements, instrument capabilities, sensor types (such as simultaneous acquisition of other geophysical data), cost, pre-existing data sets, etc. It would be unwise to suggest a simple rule for where the short wavelength cross-over occurs between AGG and AG systems, nor should it be based on a theoretical limit for a single line that does not reflect the actual survey designs being employed.

ACKNOWLEDGMENTS

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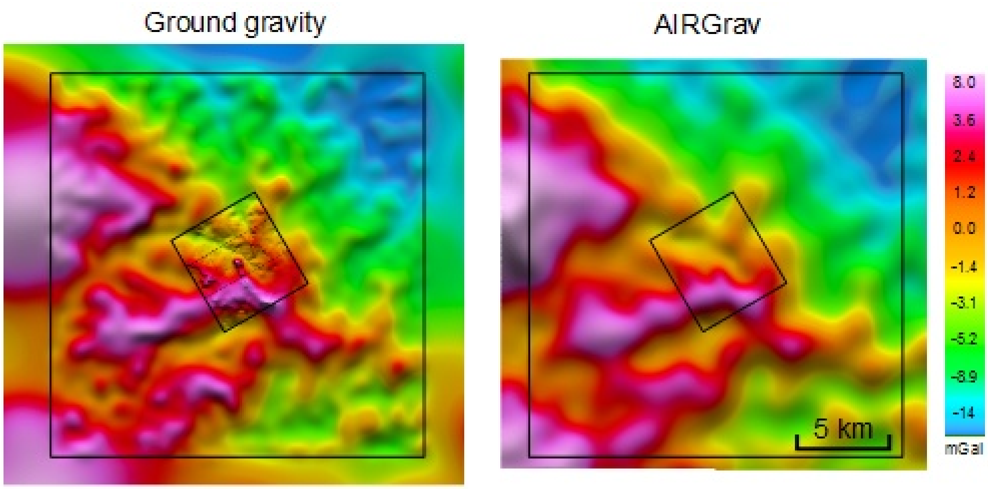

Figure 1. Free air g_D (vertical gravity) from ground measurements (left) and AIRGrav (right) at the Kauring test site. The outer square is the 20x20 km AG area, the inner square is the 5x5 km AGG area.

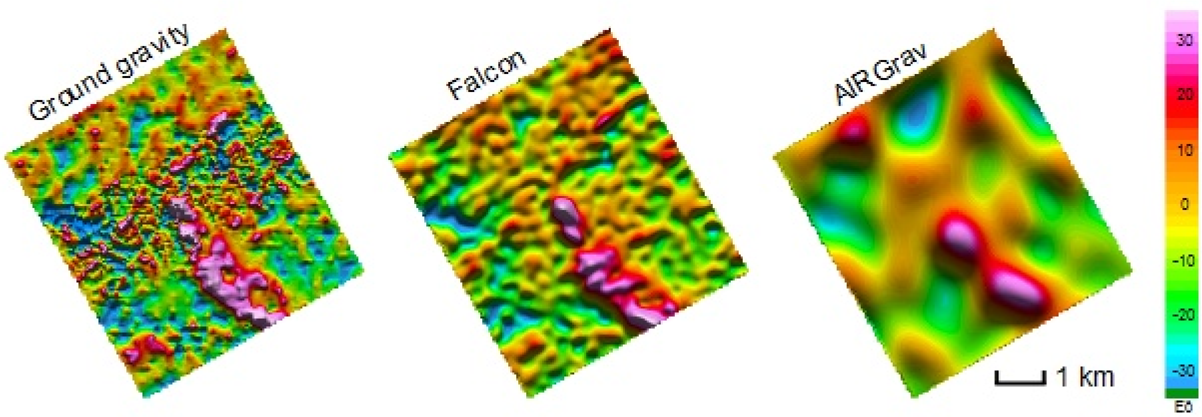

Figure 2. Bouguer G_{DD} (vertical gravity gradient) grids from ground gravity, Falcon, and AIRGrav (left to right) in the AGG area

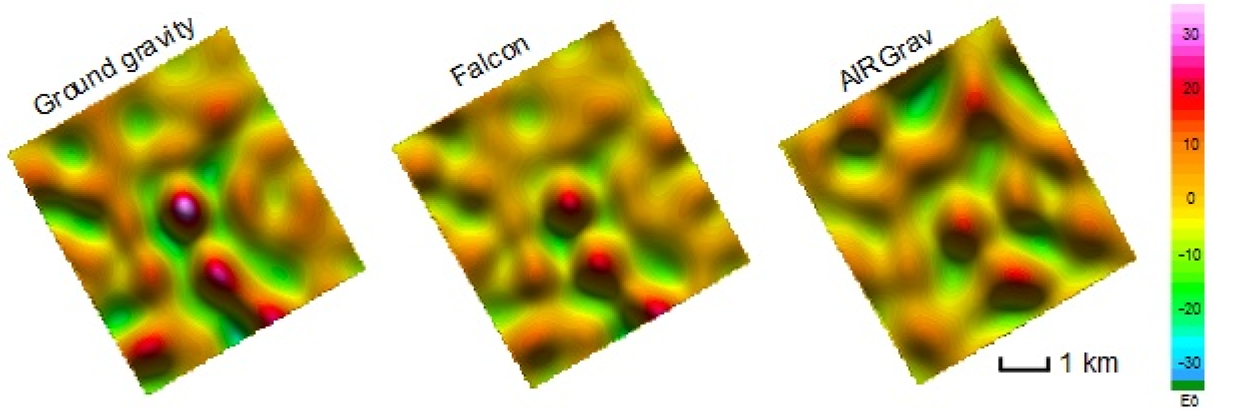

Figure 3. 500-1000m resolution band pass of Bouguer G_{DD} (vertical gravity gradient) grids from ground gravity, Falcon, and AIRGrav (left to right) in the AGG area.

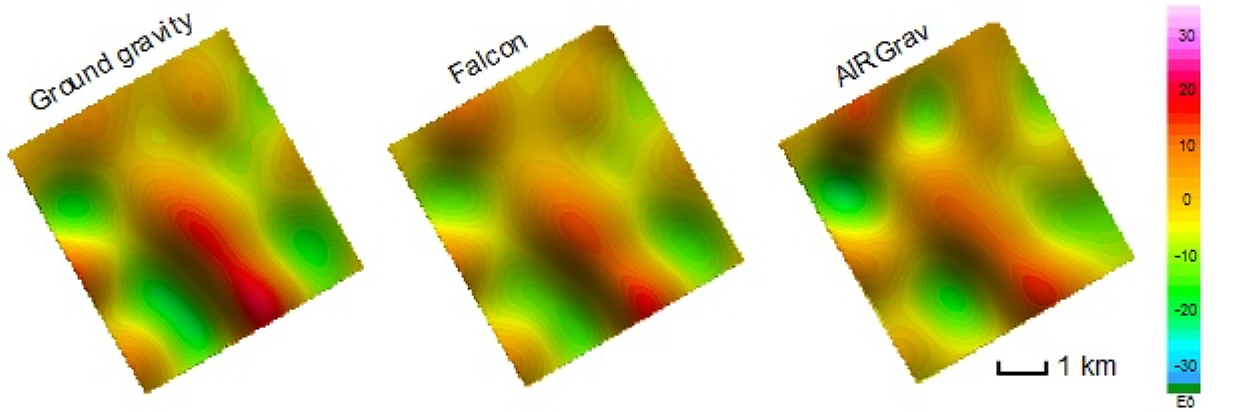

Figure 4. 1000-2000m resolution band pass of Bouguer G_{DD} (vertical gravity gradient) grids from ground gravity, Falcon, and AIRGrav (left to right) in the AGG area.

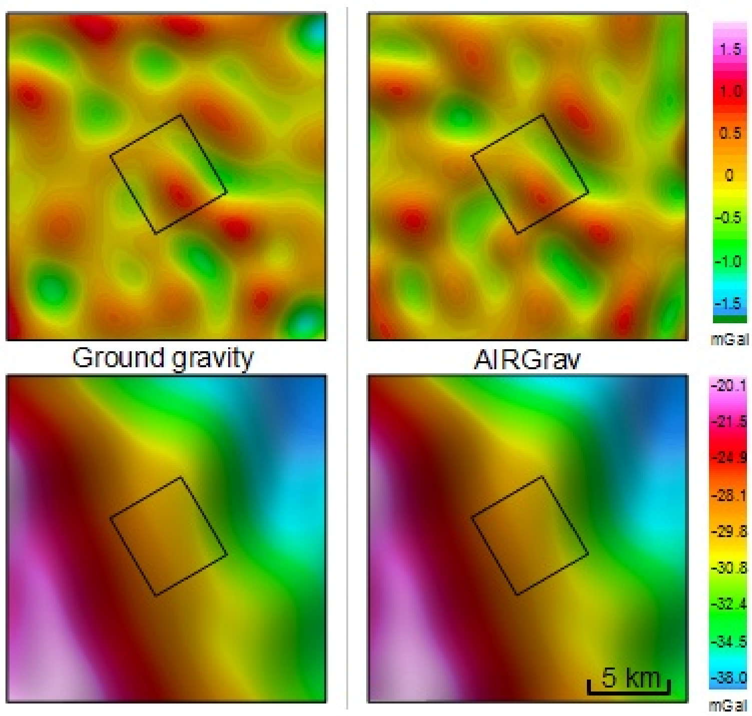

Figure 5. Bouguer g_D (vertical gravity) grids from ground gravity (left) and AIRGrav (right). Top row is 2000-4000m resolution band pass, and bottom row is 3333m half-wavelength low pass filtered (the cut-off used by Falcon for Kauring where it relies on an external regional gravity data source to conform the g_D grid).