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Regional airborne gravity surveys in Western Australia: Considerations for the end user

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SUMMARY

Regional airborne gravity surveys are being acquired over much of the State of Western Australia by the Geological Survey of Western Australia (GSWA) and Geoscience Australia (GA) to provide coverage where existing ground gravity coverage is sparse. The acquisition and processing of these surveys poses several challenges.

The data acquired by Sander Geophysics (SGL) using the AIRGrav system in Western Australia during 2018 was done so without control lines for reasons of cost efficiency, relying on the ground gravity to provide the necessary levelling corrections. Methodologies have been developed to achieve effective levelling under these circumstances, although the final result varies depending on the methodology used. Data acquired on earlier surveys with control lines are being used to compare and contrast to data acquired without them. Ongoing power spectrum analysis suggests a way in which the different methods may be judged objectively.

Horizontal components of gravity are also acquired by AIRGrav. Levelling these components is a challenge under all circumstances. The relationships between the components expressed in potential field theory allow the different components data to be compared and checked for consistency.

Digital elevation model (DEM) data acquired during the surveys provide a means for checking other sources of DEM typically employed for applying terrain corrections. The impact of inaccurate DEM data on the corrected gravity data overall is small but can be locally significant. Data quality of the regional surveys is high, but the end user should be aware of the limitations posed by the choices made in data acquisition and processing.

Key words: AIRGrav, airborne gravity

INTRODUCTION

The Geological Survey of Western Australia (GSWA) and Geoscience Australia (GA) are engaged in a state-wide reconnaissance gravity mapping program to provide a new generation of data at a nominal 5 km wavelength resolution to replace the earlier 22 km resolution coverage of the State (Howard et al., 2018). The multi-year project proceeds as a series of regional surveys undertaken by private company suppliers contracted through open tenders. By 2015, ground surveys (helicopter-assisted for the most part) had provided data over 65% of the area of the state, mainly in the south and west. Most of these surveys were at a station spacing of 2.5 km (Figure 1).

Since 2016, a series of fixed-wing airborne gravity surveys have been implemented to provide rapid and uniform coverage over large areas in the north and east of Western Australia where access issues severely affect the ability to conduct ground data acquisition efficiently.

As part of the airborne campaign, the Sander Geophysics' (SGL) AIRGrav system was employed in 2016 in the north part of Western Australia (Kimberly East Block), again in 2018 over a further six blocks (Kimberley Basin in the north, and Little Sandy East and West, Warburton East and West, and Great Victoria Desert in the central part of the state) and has been engaged on a further two blocks in the northwest for 2019 (Pilbara NW and Pilbara SE) (Figure 1).

Within these areas, with little exception, the existing ground gravity points are spaced at 11 km. For the airborne surveys, traverse lines were flown at a spacing of 2.5 km apart at a nominal survey altitude of 160 m and a target speed of 50 m/s. Perpendicular control lines were flown for the Kimberley East survey in 2016, but for none of the survey blocks flown subsequently. The line spacing is designed to retain a minimum signal wavelength of 5 km in the gravity data, for a nominal spatial resolution of 2.5 km half-wavelength equivalent to the 2.5 km station spacing of the recent ground surveys.

Analysis of the 2016 and 2017 airborne surveys led GSWA and GA to drop the use of control lines for the 2018 campaign, yielding a saving of 10% in total line kilometres. The basis for this decision was that the lower resolution ground gravity could be used to provide a long wavelength levelling adjustment to the airborne data, recognising that the final result would be dependent on the levelling methodology employed.

The AIRGrav system measures horizontal gravity components in addition to the vertical components. Even if control lines are acquired, they are not as effective at levelling the horizontal components, and the regional ground gravity does not provide measured horizontal gravity components that can be used as for levelling the vertical gravity data. Therefore, the global gravity field model (EGM2008, Pavlis et al., 2008) is used to provide a long wavelength correction to the airborne horizontal gravity components.

A significant by-product of the SGL surveys is the generation of a digital elevation model (DEM) calculated from a combination of laser altimeter and GPS data. Due to the wide line spacing, this DEM is not suitably high resolution to provide terrain corrections for the airborne gravity, but it can be used to ground truth other sources of elevation data such as the widely available Shuttle Radar Topography Mission (SRTM) data from NASA. A comparison of these two DEMs reveals significant artifacts in the SRTM data related to both the mode of acquisition of the SRTM data and the variable nature of the terrain surface. The impacts of these artifacts on terrain corrected gravity is small but not completely insignificant and are a challenge to mitigate.

METHOD AND RESULTS

Levelling AIRGrav data

For all airborne gravity surveys up until those flown in Western Australia in 2018, SGL has used a tried and trusted levelling procedure that involves two steps:

1. A single shift is applied to the data from each flight based on data acquired on the ground before and after the flight as compared to an established local calibration value.
2. Individual lines are adjusted using zero or gently sloping corrections (normally <1 mGal/hour) based on averages of all intersections along the line.

For the data acquired in 2018, various methods were investigated to leverage the ground gravity data (Bates et al., 2019) using the publicly available state-wide gravity grid that has an approximately 20 km full wavelength resolution in the area of these surveys (Brett, 2017; Figure 2). The method finally employed was the one that retained the most short wavelength data possible from the airborne data whilst removing the levelling artifacts which we termed difference decorrugation**,** as follows:

1. Calculate a difference channel along each profile between the unlevelled airborne data and the ground data.
2. Apply a zero order DC correction by subtracting the mean difference calculated in step 1.
3. Recalculate and grid the residual difference.
4. Decorrugate (Minty, 1991) the residual difference grid, designed to keep only the short wavelengths in the direction perpendicular to the survey lines that are due to the changes in level from one line to the next, and all wavelengths parallel to the lines.
5. Sample the decorrugation grid along each profile.
6. Apply a low pass filter to the extracted data to remove any short wavelengths along the profile that are signal and isolate only the long wavelength levelling issues along each profile.
7. Apply the low pass filtered correction to the unlevelled airborne data.

An example of this approach is illustrated in Figure 3 for the Kimberley Basin. The Bouguer gravity data from Kimberley Basin levelled using difference decorrugation are shown juxtaposed with the data from Kimberley East levelled in the traditional way using control lines. The average corrections for Kimberley Basin are 0.02 mGal indicating essentially no bias was introduced, and the standard deviation of the corrections is only 0.64 mGal. A grid of the corrections appears to show only line parallel level shifts; no apparent loss of signal can be seen (Figure 4). The two datasets were combined as one and gridded with no further adjustments and filtered with a 5 km full wavelength low pass filter designed to retain the nominal resolution of the data. The resultant single grid is seamless.

Notwithstanding this result, experimentation is underway to re-level the Kimberley East data using the difference decorrugation method. Although the results of the two methods appear very similar it is hoped that the presence of control lines will allow refinement of the specific parameters employed when levelling without control lines and may lead to improvements in the method.

Power Spectra

Although the method of difference decorrugation yields satisfactory results, other approaches were tested and as indicated above we anticipate the method may yet be refined. The computation of power spectra of the resultant grids provides a mechanism to quantify the effect of a levelling method on the data, and the differences between alternate levelling methods.

Overall, the objective of levelling is to retain maximum signal power (proportional to the square of the amplitude) whilst correcting the data sufficiently to remove obvious level shifts. One might expect that the impact of the levelling process on the signal will be uneven in directions parallel and perpendicular to the survey lines. The largest corrections should occur in the direction perpendicular to traverse lines.

One alternate levelling method tested was that of direct decorrugation or "micro-levelling" (Minty, 1991).

Figure 5 shows the averaged 1D-power spectra from rows and columns, separately, of grids made from the two methods applied to the Kimberley Basin data. These power spectra are provided for illustration purposes only but show how we can take a quantitative approach to define the best method to level the data under various conditions.

Horizontal Components

Horizontal components are processed differently from vertical components. After accounting for the Coriolis effect and terrain, the data must be levelled. However, horizontally oriented accelerometers are more sensitive than vertical accelerometers to small tilts of the gyro-stabilized gravimeter platform. A tilt of 10 arc seconds changes the gravity reading of a vertical accelerometer by about 0.001 mGal and a horizontal accelerometer by about 50 mGal. Small residual off-level platform errors result in long wavelength levelling errors in the horizontal gravity components. These are corrected using an earth gravity model to adjust the long wavelengths.

East and north gravity components are calculated using EGM2008 for each point along the aircraft flight path. A slowly varying curve is fitted to the difference between the uncorrected AIRGrav horizontal component and the EGM. This was applied as long-wavelength levelling correction. Residual levelling artifacts are corrected using a decorrugation approach.

The vertical gravity is processed without reference to the EGM2008 model, but the long wavelength signal can be compared to it to check for consistency. The horizontal gravity incorporates long wavelengths from the EGM2008 model so by definition they are consistent with it. They can then be verified for consistency with the vertical gravity in the shorter wavelengths using the simple Laplacian formula as follows:

$$g_{xx} + g_{yy} + g_{zz} = 0$$

OR

$$g_{xx} + g_{yy} = -g_{zz}$$

where,
g_{xx} is the first derivative of the x or east component in the x direction
g_{yy} is the first derivative of the y or north component in the y direction
g_{zz} is the first derivative of the z or vertical component in the z direction

Therefore, the g_{zz} derivative calculated from the vertical component can be compared to the g_{zz} derivative calculated from the two horizontal components (see Figure 6 for an example).

Terrain Corrections

Using data from the Little Sandy Desert West Block acquired in 2018, a comparison was made between SRTM data and the DEM derived from the airborne survey data. Differences between the two were mostly +/-1 m,but show a pattern that strongly suggests that there are artifacts in the SRTM that relate to the flight path of the space shuttle and the scanner used when acquiring the data (Figure 7). Some attempt was made to "correct" the SRTM data, but in the end the procedure was considered too subjective. Nevertheless, to get a handle on the potential impact of such artifacts, adjustments were made to the SRTM using the survey DEM and data were re-corrected for terrain effects. The resultant change in the gravity signal was as follows:

- Minimum: -0.88 mGal
- Maximum: +0.82 mGal
- Average: -0.03 mGal
- Standard Deviation: +0.14 mGal

Thus, although the changes are small overall, they have the potential to be above the noise level of the airborne gravity (typically less than 0.3 mGal) in places.

All DEMs have sources of error, one of which is how the particular altimeter employed interacts with the surface of the earth. An example of this can be found over Lake Disappointment, an ephemeral lake in the eastern part of the Little Sandy Desert West Block. Profiles of SRTM, and terrain calculated using survey laser altimeter data and survey radar altimeter data (each combined with survey GPS) from across this lake are shown in Figure 8. A number of small islands can be identified where the DEM calculated from the survey radar data tends to overestimate the distance from the aircraft, something that is not uncommon over areas of damp or unconsolidated ground, due to penetration of the radar energy into the ground. As a result, the islands appear to be lower than the surrounding lake. On the other hand, the SRTM seems high compared to the terrain calculated from survey laser data in these same places. Overall the laser data predicts a flatter and more consistent aspect to the islands than the other two DEMs. Over the lake water the DEMs from survey radar and laser data are quite flat and generally consistent with each other, but higher than the SRTM. It is clear that there are important differences in the DEM sources, and whilst one might be drawn toward the more consistent looking version, in the absence of a detailed land survey it is difficult to say which is more accurate, and it can even be allowed that each may be more accurate under different circumstances. Whilst the differences seen in this example will have only a small impact on the AIRGrav data, the effect on data such as a ground gravity point will be more profound due to the proximity of the station to the topography.

CONCLUSIONS

Various methods to level airborne gravity data using pre-existing ground gravity data have been experimented with, and a method based on decorrugation of the difference between the two types of data appears to be the best based on removal of artifacts with minimal corrections, with no apparent loss of signal. Notwithstanding this, experiments are ongoing with data for which control lines are available, plus power spectrum analysis, to further refine the method. In the end, no one method can really be said to be perfect, and understanding the limitations will help the end user to interpret the data appropriately.

Horizontal gravity components have been computed and levelled using the EGM2008 model data since the ground gravity does not provide equivalent data for levelling purposes. The horizontal data is transformed to derive a vertical equivalent derivative and is verified against the measured version for consistency.

Errors and inconsistencies in the digital elevation model data used to correct for terrain effects are recognized, and whilst they are difficult to fully account for and are generally not significant, their impact on the gravity data can be kept in mind when interpreting the data.

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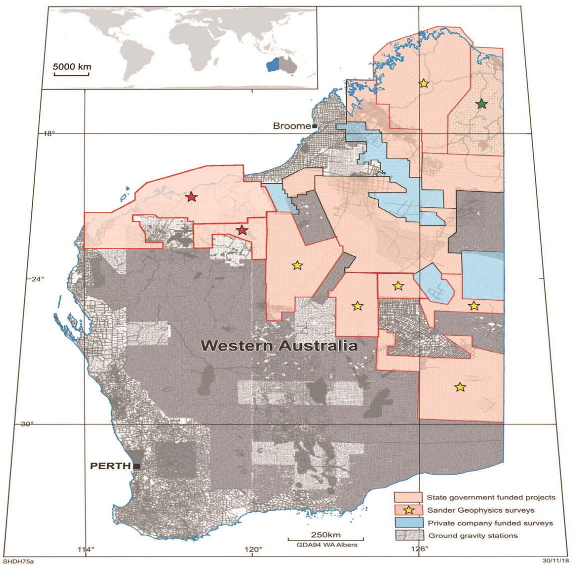

Figure 1. Location of the Geological Survey of Western Australia and Geoscience Australia's large-scale reconnaissance gravity mapping project in Western Australia. Ground gravity stations are shown in grey, and airborne survey blocks are in colour. The airborne surveys flown by Sander Geophysics over several years are marked with a star (green for 2016, yellow for 2018, red for 2019).

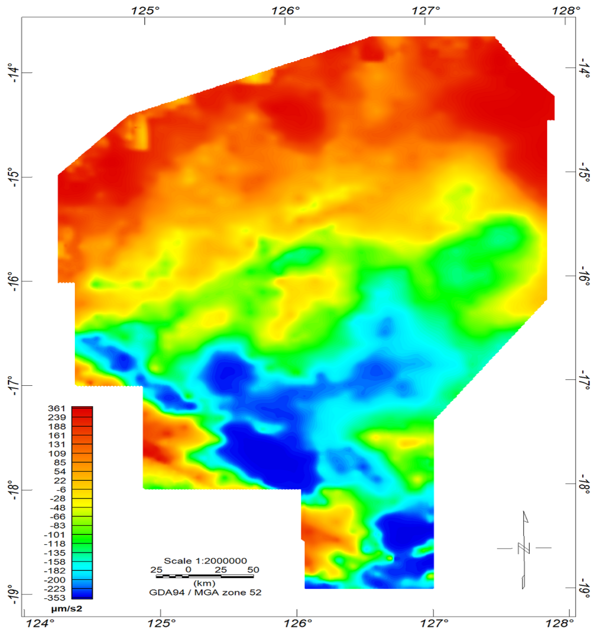

Figure 2. Ground Bouguer gravity data for the Kimberley Basin Block extracted from the continent-wide gravity grid at approximately 20 km wavelength resolution (Brett, 2017).

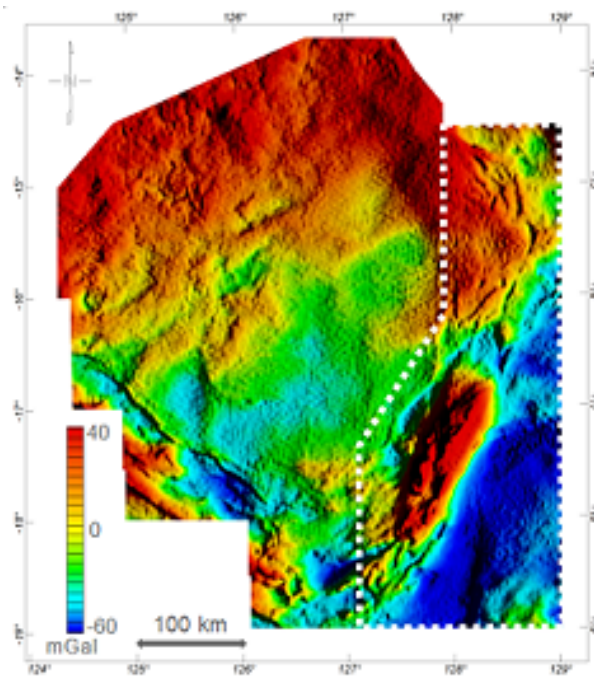

Figure 3. Airborne Bouguer gravity data of the Kimberley Basin Block levelled using difference decorrugation adjacent to Kimberley East Block data levelled with control lines (surrounded by the dashed line), low pass filtered (2.5 km half wavelength mid-point), with a sun shade from the east.

Figure 4. A grid of the levelling corrections applied to the Kimberley Basin survey data using the difference decorrugation method.

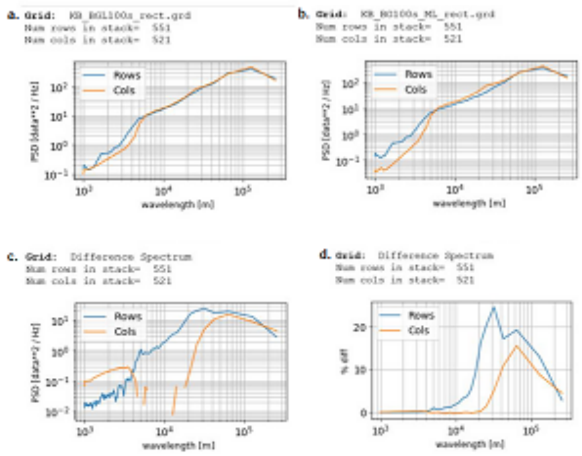

Figure 5. Log-log average 1D power spectra plots of grid rows and columns of (a) difference decorrugated levelling and (b) direct decorrugated or "micro-levelled" gravity from the Kimberley Basin data. Differences between the two spectra sets in (c) log-log, and (d) semi-log plots. Grid columns are in the line direction (North-South), grid rows are perpendicular (E-W).

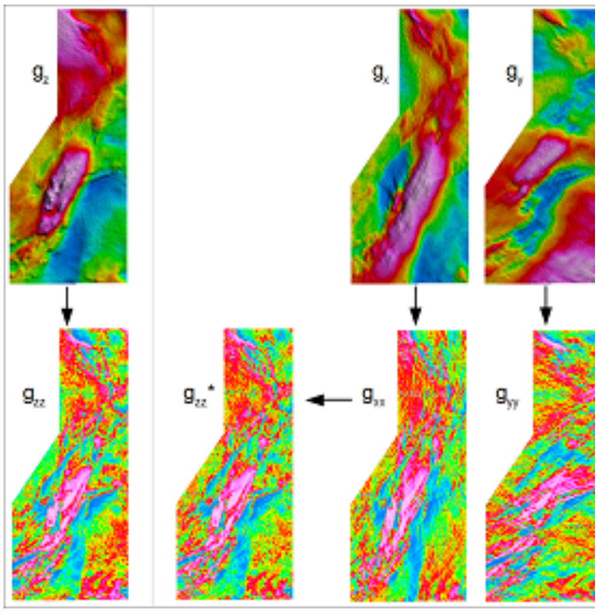

Figure 6. The vertical (g_z) and horizontal components (g_x and g_y) of the airborne gravity from the Kimberley East survey (Howard et al., 2018). Derivatives g_{zz}, g_{xx} and g_{yy} are derived directly from the component data as shown. g_{zz^*} is derived through summation of g_{xx} and g_{yy} and compared to g_{zz} to check for consistency.

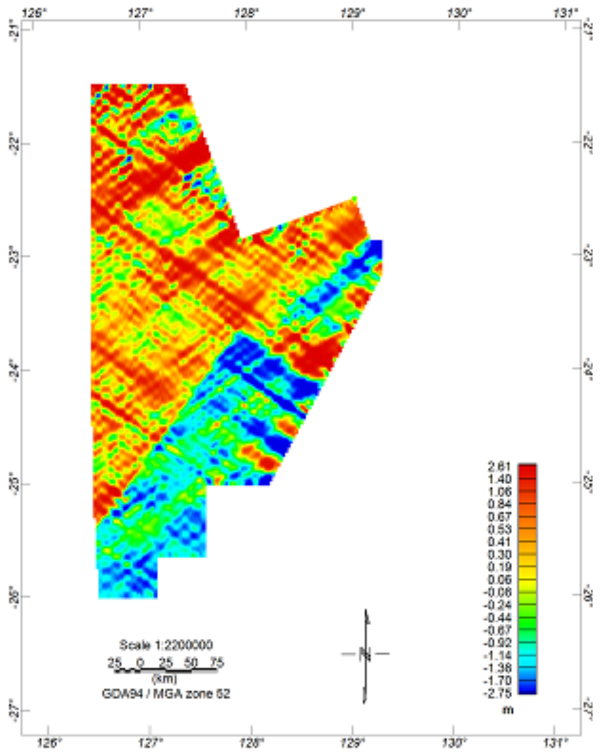

Figure 7. The difference in the terrain calculated from laser and GPS survey data from the Little Sandy Desert West Block compared to the SRTM.

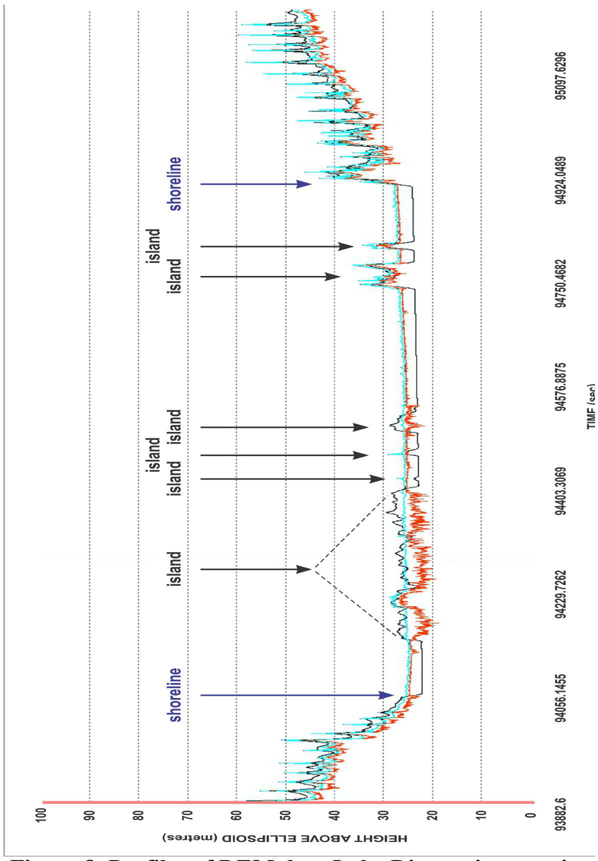

Figure 8. Profiles of DEM data Lake Disappointment in the Little Sandy Desert West Block. The black trace is the SRTM, the light blue trace is the terrain calculated from survey laser altimeter data, and the red trace is terrain calculated from survey radar data.