Measurement of noise in airborne gravity data using even and odd grids

Stephan Sander, Stephen Ferguson, Luise Sander and Veronique Lavoie, Sander Geophysics, Ottawa, Canada and R.A. (Bob) Charters, GEDCO, Calgary, Canada discuss a significant benefit provided by a new gravity instrument developed by Sander Geophysics.

Gravity has been measured from aircraft in flight since the late 1950s (Thompson & LaCoste 1960). Recent improvements in GPS processing, and a new gravity instrument, the AIRGrav system (Argyle *et al*. 2000), have resulted in significantly reduced noise levels in airborne gravity data. In this paper we present a methodology to quantitatively calculate noise levels of airborne gravity data sets by dividing the flight lines into two equal data sets (the 'even' and 'odd' lines), gridding and filtering the separate data sets, and measuring the difference between the resultant grids. The data is low-pass filtered before the noise level is measured, and noise levels are calculated for specific filter lengths. We also present an example of this noise calculation performed on an AIRGrav data set from the foothills region of Alberta, Canada, along with an interpretation of the data (Peirce *et al*. 2002; Sander *et al*. submitted).

AIRGrav airborne gravity data is generally acquired along survey lines spaced between 50 and 3000 m, flown in a grid pattern over the survey area. After normal gravity corrections, data is gridded and filtered to remove high frequency GPS and gravity acquisition noise. On many AIRGrav surveys, SGL over-samples the gravity field to increase the accuracy and resolution of the resultant data. Noise from the over-sampled gravity data cancels in a manner similar to the stacking of seismic data. The over-sampled gravity data can be used to calculate the noise level on a gravity grid by dividing the data set into two independent data sets covering the same area, and calculating the RMS difference between them. As the data sets cover the same area, the geological signal will cancel, leaving only the noise of the two data sets. The RMS noise measured on the difference grids will be twice the noise level of the combined grid, as explained below.

In this case 'noise' means the errors between lines or individual readings within the data set. The method would not measure systematic errors common to the entire data set. Systematic errors could occur if the entire data set was levelled to some predetermined value, or if the same erroneous elevation model was used for terrain corrections for both the odd and even data sets.

Each of the even and odd data sets is an independent data set, separately levelled, gridded and low-pass filtered to create even and odd grids. Each data set contains a geological component and a noise component. The geological component in each data set is identical, i.e. they are both measured over the same survey area and the geological signal is well sampled on each of the odd and even data sets. The noise component is assumed to be white, containing all frequencies in equal proportion. Tests with AIRGrav airborne gravity data sets indicate that, except for the highest frequencies, which would have been filtered out of realistic gravity grids, the remaining noise is very close to white.

Qualitative evaluation

The reliability of the data can be qualitatively evaluated by looking at the combined grid, and the even and odd grids. If the same anomalies appear on the two independent odd and even data sets, a data user can be reasonably confident that the anomaly is real. Differences between the data sets represent noise on the data.

Quantitative evaluation – difference grid

A difference grid is created by subtracting the odd grid from the even grid. The measured noise level is the RMS noise of the difference between the subsets of the data having even and odd line numbers.

For each element (i, j) of the grids:
Signal of the odd grid … $s_o(i, j)$
Signal of the even grid … $s_e(i, j)$
Noise of the odd grid … $n_o(i, j)$
Noise of the even grid … $n_e(i, j)$
Noise of the difference grid … $n_d(i, j)$
Then,

Each element (i, j) of the difference grid

$$= [s_o(i, j) + n_o(i, j)] - [s_e(i, j) + n_e(i, j)]$$
$$= n_o(i, j) - n_e(i, j)$$
$$= n_d(i, j)$$

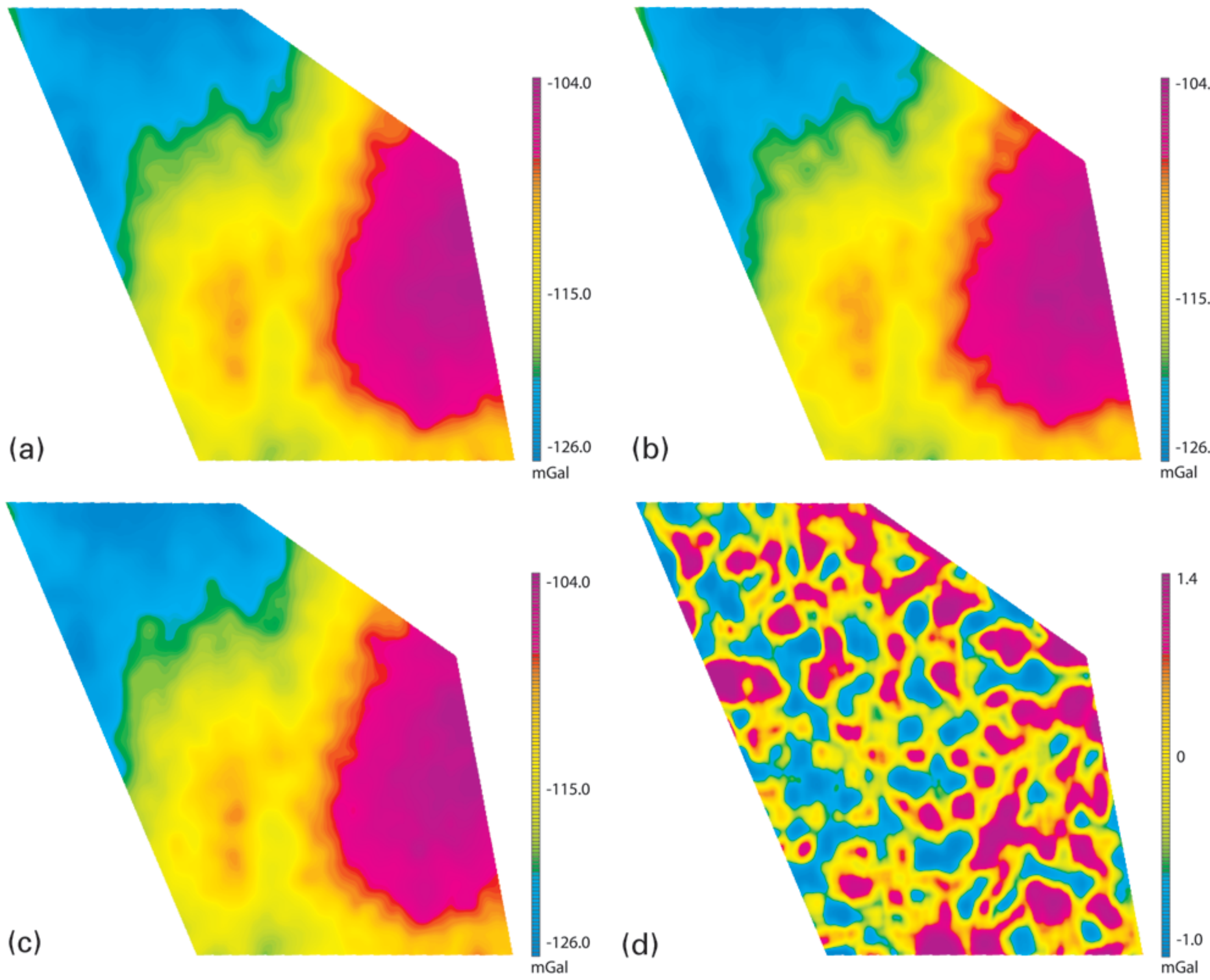

Figure 1 (a) Bouguer gravity grid of all lines combined from a 250 m line spacing AIRGrav survey over the Turner Valley region of Alberta Canada. (b) Bouguer gravity grid of the even numbered lines. This is half the data set used for the grid in (a). (c) Bouguer gravity grid of the odd numbered lines. This is half the data set used for the grid in (a). (d) Difference grid of the odd minus the even grids in (b, c).

The geological gravity signal cancels in the difference grid, as the real geological signal is represented on both the even and odd grids. This assumes that the signal is adequately represented on each grid, as would be the case on a close spacing AIRGrav survey. Both $n_o(i, j)$ and $n_e(i, j)$ are assumed to be uncorrelated white noise, so the noise power of the data sets add together, i.e.

$$\begin{aligned} N_d &= \text{RMS value of } n_d \\ &= \overline{[n_d^{\,2}\,(i, j)]}^{\,0.5} \\ &= \overline{[n_o^{\,2}\,(i, j) + n_e^{\,2}(i, j)]}^{\,0.5} \end{aligned}$$

Note: the bar notation above represents the average, so $\overline{[n_d^{\,2}\,(i, j)]}$ is the average value of $n_d^{\,2}\,(i, j)$.

Combined grid of the entire data set

As the normal product of an AIRGrav survey, all of the survey data are gridded and filtered together, and forms a combined data set. This grid contains all the data from both the odd and even grids. Unlike the difference grid above, the combined data set is an average of the even and odd data sets.

On the combined grid, the geological component remains unchanged, and the noise on the combined data is an average of the power addition of the even and odd data sets.

Then,

Each element (i, j) of the combined grid

$$= [s_o(i, j) + n_o(i, j) + s_e(i, j) + n_e(i, j)]/2$$

$$= [s_o(i, j) + s_e(i, j)]/2 + [n_o(i, j)]/2 + [n_e(i, j)]/2$$

The noise on the combined grid is $n_c(i, j)$

$$n_c = [n_o(i, j)]/2 + [n_e(i, j)]/2$$

again for uncorrelated white noise,

$$N_c = [(\{\overline{n_o(i, j)}\}/2)^2 + (\{\overline{n_e(i, j)}\}/2)^2]^{0.5}$$
$$= [\{\overline{n_o^2(i, j)} + \overline{n_e^2(i, j)}\}^{0.5}]/2$$

combining with the equation for the noise on the difference grid above we get

$$N_c = N_d/2$$

So, the RMS difference measured on the even minus odd grid, N_d represents twice the noise level of the combined data set, N_c.

Example data

An example follows. Data are from an AIRGrav survey flown over the Turner Valley region of Alberta, Canada, in the summer of 2001 (Peirce *et al.* 2002; Sander *et al.* submitted). The data set consists of over 12 000 line km of airborne gravity data flown on 250 m spaced east–west lines, and 1000 m spaced north–south lines. The north–south extent of the data set is 60 km. The data were processed through all the normal stages of gravity processing, including a full Bouguer correction. The combined (Fig. 1a), even (Fig. 1b) and odd (Fig. 1c) grids were each low-pass filtered with a half wavelength cut-off of 2 km. The RMS of the difference grid (Fig. 1d) was 0.6 mGal, so the RMS noise on the combined grid (Fig. 1a) was 0.6/2 = 0.3 mGal.

Figure 2 is an interpretation of the AIRGrav data and the aeromagnetic data acquired at the same time. Colours are the first vertical derivative of the Bouguer gravity, with the warm colours representing gravity highs. The grey shades are the shadow of the first vertical derivative of the aeromagnetic data. The western side of the data set is dominated by north–south trending faults associated with the foothills region. The eastern side of the area consists of flat lying sediments. Gas and oil producing areas are outlined by solid and dotted lines, respectively. The long north–south trending field in the centre of the area is the Turner Valley field, first discovered in 1914. The Turner Valley field, and the Quirk Creek Field, in the north-west of the area are generally associated with gravity highs. East-west trending lineaments, marked with dashed lines, were determined by joining terminations on the aeromagnetic data. The same lineaments also mark changes in the gravity signal, and offset the Turner Valley field.

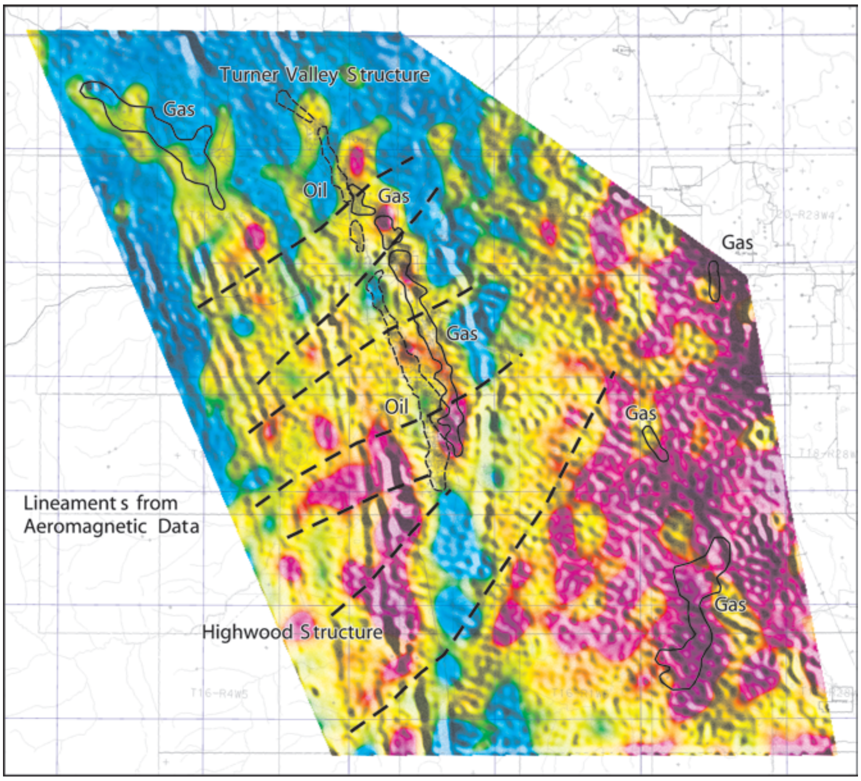

Figure 2 Interpretation map of the survey area shown in (a). Colours are the first vertical derivative of the Bouguer gravity data and the grey shades are the shadow of the first vertical derivative of the aeromagnetic data.

Summary

A quantitative analysis of noise in airborne gravity data has been developed and demonstrated. The analysis involves creating two separate Bouguer gravity grids, one using only odd numbered lines (the 'odd' grid) and the other using only even numbered lines (the 'even' grid), and subtracting the odd grid from the even grid. The RMS noise of the difference grid is twice the RMS noise of the combined grid created using the complete data set. The noise in a real AIRGrav data set, flown in a foothills environment, is shown to be 0.3 mGal RMS. Gravity anomalies of less than 2 mGal can be seen on the data set, and correlate with known oil and gas fields.

Acknowledgements

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References

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