# Learnings from the Gawler Craton airborne survey quality control

**Matthew Hutchens**
*Geoscience Australia*
*Symonston, ACT*
*matthew.hutchens@ga.gov.au*


## SUMMARY

The Geological Survey of South Australia (GSSA) designed the Gawler Craton Airborne Survey (GCAS) to provide high resolution magnetic, gamma-ray and elevation data covering the northern portion of the Gawler Craton. In total, 1.66 million line km were planned over an area of 295,000 km$^2$, covering approximately 30% of the state of South Australia.

The survey design of 200 m spaced lines at a ground clearance of 60 m can be compared with the design of existing regional surveys which generally employed 400 m line spacing and a ground clearance of 80 m. The new survey design results in ~2 x the data coverage and ~25% closer to the ground when compared to previous standards for regional surveys in South Australia.

Due to the enormous scale of the survey, the data were acquired using four contractors who employed ten systems to fly the sixteen blocks.

To standardise the data from the multitude of systems, Geoscience Australia (GA) employed a comprehensive set of technical specifications. As part of these specifications the contractors were required to fly each of the ten systems over a series of test lines termed the "Whyalla Test Lines" (Whyalla).

The final GCAS data provide truly impressive high resolution regional scale products. These will allow more detailed geological interpretation of the prospective Gawler Craton.

A laser altimeter was added to the list of required survey equipment. Deficiencies in the technical specifications relating to laser altimeters were identified. Standards and procedures specific to laser characteristics will need to be considered on future surveys.

Analyses show that weaknesses in current standards and procedures are still evident. The weaknesses identified allow room for improvements to be made for future surveys.

Gamma-ray processing results raised the most serious concerns, with repeatability not achieved. Changes to standard procedures may need to be considered.


**Key words:** airborne, magnetic, gamma-ray, elevation, Gawler Craton

## INTRODUCTION

Many geoscientists consider the airborne magnetic and gamma ray (aMagRad) technique to be 'mature' in Australia. This implies that the technique, in its current form, delivers repeatable high quality data. I assess that position with reference to results from the GCAS. I suggest that while very good, there are still possible improvements to be made and present supporting evidence from observations made while performing quality control (QC) of GCAS data.

Acquisition of aMagRad data in Australia has become routine since the first survey was conducted in 1947 (Doyle, 1987). Commonwealth and State/Territory governments began routinely commissioning semi-detailed (500 m line spacing or better) airborne surveys to attract investment from resources industries from approximately 1990 (Denham, 1997). Furthermore, the technique still arguably provides the best value for money of any of the current airborne geophysical survey techniques.

The GSSA commissioned one of the first very large scale regional multi-block surveys with the South Australian Exploration Initiative (SAEI) starting in 1992. The GSSA has recognised the correlation between aMagRad data availability and mineral discoveries, with the availability of higher resolution data appearing to coincide with new discoveries (Katona, 2018).

Australian geophysicists have been applying similar aMagRad acquisition and processing principles to government funded regional surveys since they were standardised by the Australian Geological Survey Organisation (AGSO) 20 plus years ago (Horsfall, 1997, Luyendyk, 1997, Minty, 1997, Minty et al., 1997). Some changes have been made since then, most notably 1. Improved accuracy of positioning, 2. Laser altimeters being added to the survey equipment 3. Faster sampling rates of some magnetometers 4. Routine application of Noise Adjusted Single Value Decomposition (NASVD) to the gamma ray data (Hovgaard and Grasty 1997). These standards are imposed on contractors by means of technical specifications set out in the procurement process.

Laser altimeters provide superior distance measurement accuracy when compared to radar altimeters. For radar altimeters typically used for aMagRad, such as the KRA 405, typical altitude accuracy is published as 0.91 m or 4% (whichever is greater) for altitudes less than 150 m (Honeywell, 2016). Laser altimeters used during GCAS such as the Renishaw ILM-500-R have a typical published point to point distance accuracy of 0.1 m for returns from a good reflector (Kodak White Card), with no accuracy value published for poor reflectors (Renishaw, 2019).

GCAS presents a unique opportunity to assess aMagRad acquisition and processing procedures due to the multitude of systems employed to acquire data with identical technical specification requirements. Four contractors were commissioned to acquire the data, employing ten different systems in total. The contractors were required to fly the "Whyalla Test Lines" prior to the survey, employing all systems intended to be used for GCAS acquisition. The results provided a direct comparison of systems and processing performance.

I make observations about the acquisition and processing of the new laser altimeter data below. I comment on the strengths and weaknesses of current airborne magnetic and gamma-ray survey design, acquisition, processing. I raise concerns regarding the gamma-ray results.

## METHOD AND RESULTS

Geophysicists working on behalf of GA and GSSA including myself have assessed (i) Survey Design (ii) Technical specifications (iii) Pre-survey calibration and test line data for all ten systems (iv) Raw survey data from all sixteen blocks (v) Final processed deliverables for ten blocks (at the time of writing).

I have assessed the increased resolution of the resulting grid images from the GCAS survey design compared to the previous standard. A survey flown with 400 m spaced lines over an entire 1:250,000 map sheet (1.5° of longitude x 1° of latitude) at South Australian latitudes will yield a grid image with a resolution of approximately 1835 x 1420 pixels when gridded at 1/5 of the line spacing. At 200 m line spacing the grid size increases to approximately 3670 x 2840 pixels when gridded at 1/5 of the line spacing. The increase in resolution from the new survey design is 4 x with >10 million pixels in new grid images covering a 1:250,000 map sheet representing a significant improvement.

I performed forward modelling to assess the increase in magnetic anomaly amplitude generated by near-surface dyke and pipe sources at the lower ground clearance. The modelling suggests an increase in anomaly amplitude of ~20%.

The gamma-ray data should have reduced relative statistical noise due to the lower survey height, and hence higher count rates. This was partially offset where acquisition speeds were above the nominal ground speed of 70 $ms^{-1}$.

Navigation and positioning systems accuracy has improved dramatically over the last few decades. Global Navigation Satellite System (GNSS) receivers have been employed for regional aMagRad acquisition since at least 1991 (R. Brodie, pers. comm., 9$^{th}$ April 2019). Contractors commissioned for GCAS all employed GNSS systems capable of typical horizontal position accuracy <1 m and vertical position accuracy <3 m. The increased accuracy of the GNSS systems resulted in a very close match between planned and actual flight paths. It is unfortunate a tracking video is no longer standard on our surveys. Videos have been very useful for evaluating ground conditions at the location of anomalies in various data streams.

Manufacturers publish laser altimeter performance for good reflectors. However, the ground surface is likely to be a poor reflector. Contractors were not required to report the mode of operation selected for the laser altimeter during acquisition nor any data indicating the quality of returns. This resulted in questionable returns being included in the supplied data and derived products.
Laser based point to point distance measurements are directional. The point to point distance is measured along the vector coincident with the laser beam. This is in contrast to a radar altimeter, which emits a spreading wavefront of radio waves and records the return from the nearest reflector.

The directional nature of laser altimeters results in a larger height reading than the true height, which requires correction using aircraft orientation information. However, since the Contractors were not required to measure the aircraft orientation, they were unable to correct the heights for the directional effect. Furthermore, they were also not required to provide the position on the ground from where the return was generated. This resulted in different altitude profiles from the radar and laser altimeters, most notable in locally varying terrain, as shown in Figure 1. Contractors were required to create digital elevation models from laser altimeter data using the same processing applied to radar altimeter data. Thus, in order to fully capitalise on the higher fidelity of laser altimeters, there is a need to update the acquisition and processing procedures.

Magnetic data were acquired at either 10 Hz or 20 Hz. The average sample spacing achieved by the 20 Hz systems was approximately 3.5 m. This provided very high resolution line data allowing more options for signal processing.

Raw magnetic intensity profiles acquired by all systems appear very similar to the naked eye. Differences were observed in the very high frequency component, considered noise when the wavelength is shorter than that which could be generated by the nearest real source (a source at or protruding from the ground). A high-pass filter such as a 4$^{th}$ difference spatial filter was routinely applied to magnetic profiles to identify 'spikes' in the profiles with the average dynamic range of the 4$^{th}$ difference giving an indication of high frequency noise content.

Average spectra of a moving window across all data provides a complete statistical picture of the frequency content of line data. An example of such a spectrum of magnetic line data from GCAS is shown in Figure 2. The spectrum shows features indicative of filtering. The filtering in this case was a result of settings and options chosen by the contractor and occurred prior to data being output by the digital acquisition system. This resulted in apparently less noise in the 'raw' magnetic data supplied but came at the expense of maximum short wavelength resolution.

The very long magnetic wavelengths were checked against Australia Wide Airborne Geophysical Survey (AWAGS) data (Milligan et al., 2009). Geophysicists can be confident the GCAS magnetic data has been levelled for use in compilations such as the magnetic maps of South Australia and Australia with only 'DC' adjustments required.

Portions of the medium to short magnetic wavelengths were cosmetically treated using line and micro-levelling. Micro-levelling in particular needed to be carefully applied to minimise the removal of short wavelengths along the line. In some cases, there appeared to be short wavelengths associated with geology removed by micro-levelling.

All contractors were required to fly Whyalla with each system intended to be employed on GCAS prior to the commencement of survey acquisition. The Whyalla Test Lines are described in Figure 3. The contractors were required to supply both raw and final processed elevation, magnetic and gamma-ray data from the test flights. The main purpose of Whyalla was to assess the calibration of spectrometers used to acquire airborne gamma-ray data. The section of the range over water was designed to allow background values to be calculated.

Minty Geophysics (Minty) compared the airborne gamma ray data acquired over the Whyalla Test Lines. Minty processed the raw counts into mean equivalent ground concentrations of potassium (K), Uranium (U) and Thorium (Th) over the test range for comparison. The system specific calibration coefficients stated by the contractors were used. The results are presented in Table 1.

The Whyalla gamma-ray results highlighted the difficulty in conversion of gamma ray counts to equivalent ground concentrations. Even with rigorous calibration procedures performed pre-survey and checked during acquisition, the range of calculated values is large. The standard deviations of the sample set of calculated Whyalla K, U and Th mean ground concentrations are equivalent to 15%, 36% and 6% of the mean of all systems values respectively. In the case of System A, the calculated U value is more than 2 standard deviations from the mean of all systems.

System I was used to acquire data over the Whyalla Test Lines twice during GCAS. The different mean values of K, U and Th along the calibration range, calculated from each run, indicated the error that is present in all equivalent ground concentration calculations. Statistical count errors are propagated through the corrections into final values. Calculated U values are also affected by the presence of varying levels of atmospheric radon.

The two main causes of the large variation in calculated equivalent ground concentrations of radioelements appear to be errors in pre-survey calibration range ground concentrations used to calculate system sensitivities and radon estimation (Paterson, 2013). Paterson showed that questionable estimates of the ground concentration of radioelements at Carnamah used to calibrate airborne systems can propagate errors of >20% into later survey data and that radon backgrounds can vary greatly over the course of a typical calibration (or survey) flight.

Contractors routinely performed NASVD on acquired airborne gamma-ray data to produce smoother profiles and images with less speckle. GA prefers NASVD to be applied on a flight by flight basis which is in opposition to the Contractors' usual approach of whole survey application. Geophysicists have varying opinions on the minimum number of spectra required as input for statistical validity. Generally, the flight by flight approach resulted in greater noise reduction. Variable noise reduction from flight to flight resulted in the appearance of banding in grid imagery in some cases requiring further cosmetic processing.

GSSA geophysicists discovered that some false anomalies were generated by application of NASVD. An example of a false Th anomaly is presented in Figure 4. False anomalies were less likely to be generated when NASVD was applied by survey, but still occurred in some cases. GA now recommends caution be used when interpretation is made using NASVD processed gamma-ray data, particularly quantitative assessments based on radioelement ratios.

Contractors were required to supply gridded images of final processed elevation, magnetic and gamma-ray products. GA did not specify a required gridding algorithm. This resulted in contractors choosing different algorithms. Where a spline algorithm was used, a directional bias (perpendicular to line direction) was imposed on the resulting grid images.

**Table 1. Mean equivalent ground concentration results from the Whyalla Test Lines. System I flew the lines twice. Only the U range mean from system A falls more than 2SD away from the mean of all systems.**

| System | K mean (e%) | U mean (ePPM) | Th mean (ePPM) |
|---|---|---|---|
| A | 0.411 | **1.27** | 3.56 |
| B | 0.339 | 0.707 | 3.65 |
| C | 0.477 | 0.743 | 3.76 |
| D | 0.465 | 0.449 | 3.88 |
| E | 0.502 | 0.652 | 3.67 |
| F | 0.591 | 0.31 | 3.97 |
| G | 0.409 | 0.8 | 3.3 |
| H | 0.531 | 0.83 | 3.87 |
| **I** | **0.423** | **0.619** | **3.29** |
| J | 0.487 | 0.723 | 3.81 |
| **I** | **0.432** | **0.467** | **3.43** |
| MEAN of all systems | 0.461 | 0.688 | 3.654 |
| SD of all systems | 0.068 | 0.251 | 0.235 |

## CONCLUSIONS

The new survey design resulted in high resolution data coverage of a large percentage of South Australia. Improvements were not only achieved by the closer line spacing but also by the decreased ground clearance.

Contractors employed GNSS navigation and positioning systems with high positional accuracy resulting in very consistent data coverage that closely matched the survey plan.

The technical specifications regarding laser based altitude data and associated products will need to be reviewed and improved to realise the full potential of the new equipment.

Magnetic processing did sometimes lead to short wavelengths suspected to represent geology being removed from survey data. This highlighted the need for careful application of the standard procedures and checking of results during QC.

More concerning issues resulting from radiometric processing were identified. In particular NASVD and conversion to equivalent ground concentrations were found to introduce error. Some of these errors have implications for further assessment and interpretation of final gamma ray products.

GA will endeavour to address these findings to continue improvement of data quality and repeatability from future aMagRad surveys.

## ACKNOWLEDGEMENTS

I thank Brian Minty from Minty Geophysics for his continual assistance in the assessment of airborne gamma-ray data. I thank Richard Lane and Ross Brodie from Geoscience Australia for their guidance. The Gawler Craton Airborne Survey was funded by the Government of South Australia. This abstract is published with the permission of the CEO, Geoscience Australia

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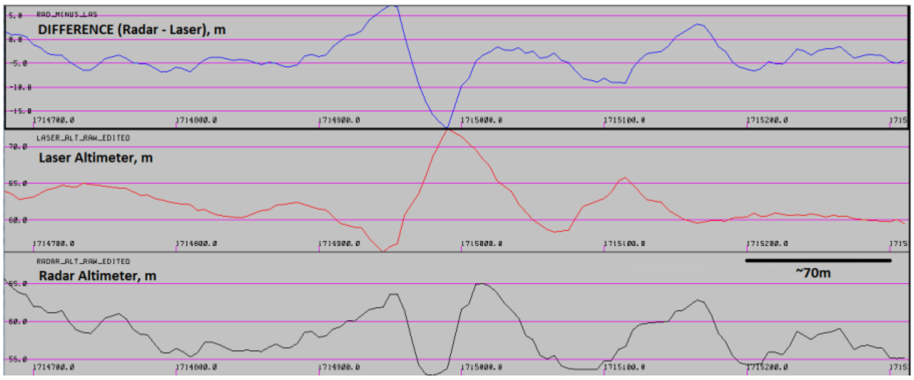


**Figure 1. Radar altimeter versus Laser altimeter responses in locally varying terrain. The responses are locally different by >10 m.**

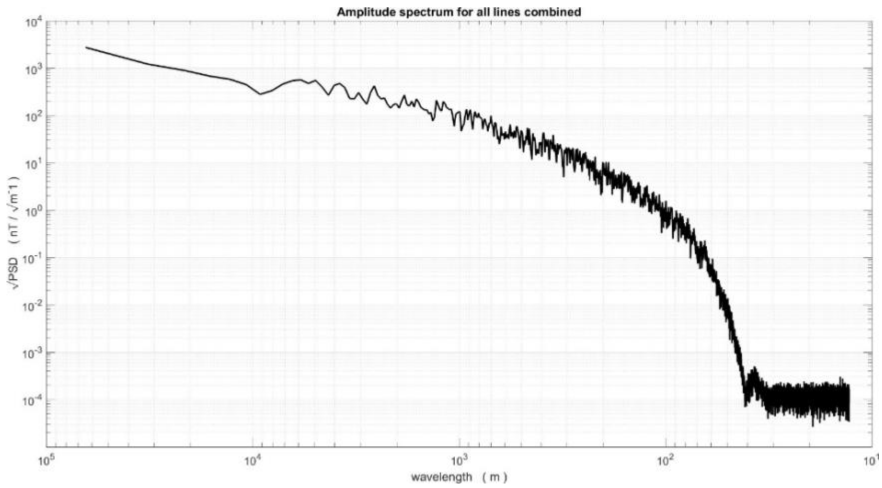


**Figure 2. Amplitude spectrum of a single long line of raw magnetic data collected using one of the systems employed on GCAS. The sharp drop of the curve at ~50 m and subsequent 'bounce' are indicative of filtering of wavelengths <50 m.**

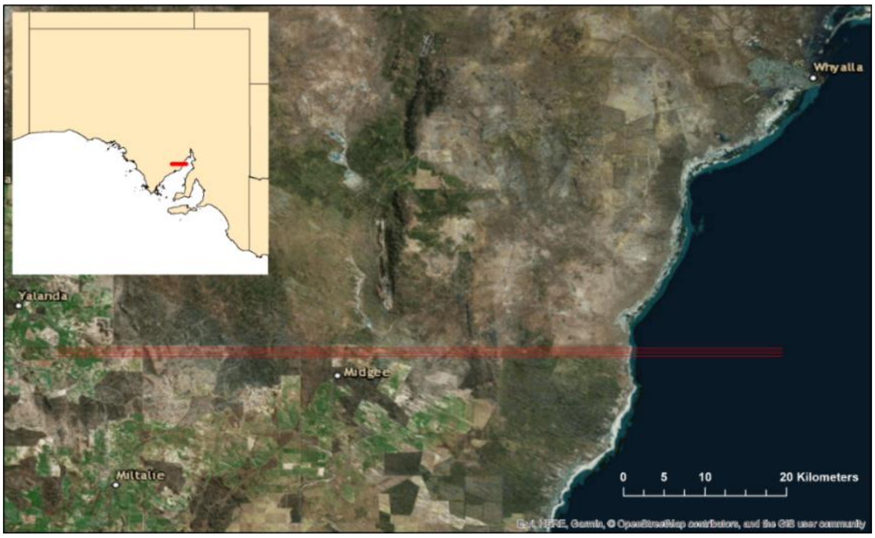


**Figure 3. The location of the Whyalla Test Lines. There are seven E-W lines spaced 200 m apart. The lines are ~75 km long with the eastern portion extending over the Spencer Gulf.**

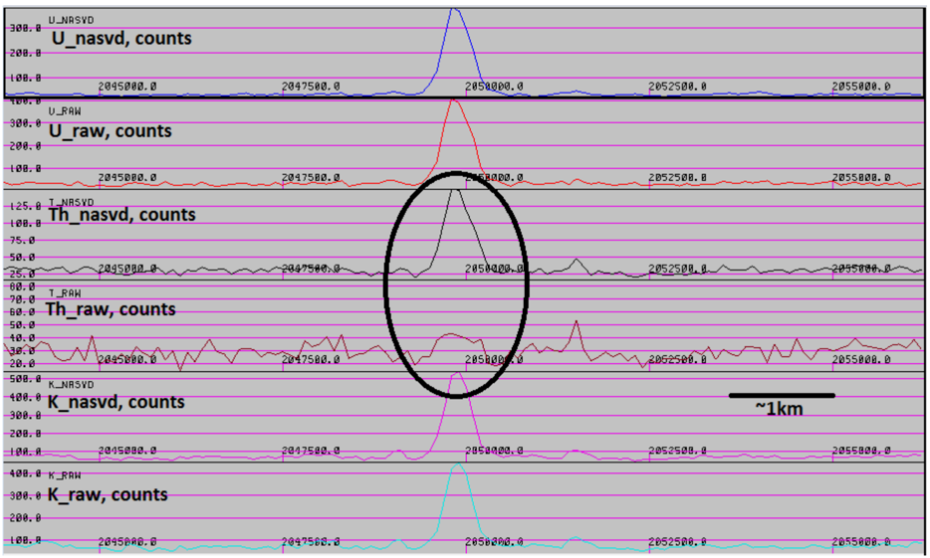


**Figure 4. Profiles of raw and NASVD adjusted radioelement window counts from a line of GCAS data: from top to bottom, Uranium (U) NASVD, U raw, Thorium (Th) NASVD, Th raw, Potassium (K) NASVD and K raw. An example of a false Thorium (Th) anomaly generated by the application of NASVD can be seen within the black ellipse. False Th anomalies were generated when a strong U anomaly was measured in the absence of a strong coincident Th anomaly.**