Quality control in airborne geophysics

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SUMMARY

Onshore exploration technology continues to evolve with the arrival of new airborne instrumentation systems. Central to this has been the need to also evolve quality control processes that ensure useable signal is being captured during the surveying process, even though the true value add occurs at a later time. Gravity gradiometry is now well established, and able to provide independent mapping detail to wavelengths of less than 400 m. Airborne electromagnetic data is also starting to provide cross-sections that are reflecting actual geology bodies in terms of dips and thicknesses.

The quality control (QC) technology applied across the industry is not uniform, and sometimes inappropriate for new datatypes being acquired. Government contract specifications can help. Also improved software tools being generally available and having trained operators, is an emerging requirement. This critical aspect includes fit for purpose geophysical gridding.

Key words: Survey design, quality control, potential fields, gradiometry, electromagnetics

INTRODUCTION

Quality control of airborne geophysics surveys is a complex subject. The disciplines have continuously developed over more than 60 years. The primary check on quality is that of common sense and the measured field providing an accurate geological basis for interpretation at the required scale and resolution. Of the common geophysical exploration techniques, gravity, magnetics, inductive electromagnetics (EM) and radiometrics have long histories of successful development of airborne systems and applications. Horsfall (1997) outlines equipment calibration and field data quality checking procedures that have not altered much since then for magnetic and radiometric surveying.

All members of an airborne survey crew have a role to play in delivering a quality outcome. The skill of the pilot always contributes, as the specifications for the flight path and minimization of influences such as turbulence are critical. The field technician's role involves making sure the acquisition system and the instruments are running and producing useable data. At the start and end of each flight and each day, repeat lines might be required to be acquired, to check the instruments remain working within specifications. The survey processing engineer typically has access to each flight of data and standard post-processing steps are undertaken to verify the data. This process is usually performed over time series data. De-spiking and trimming to the required survey line-specifications are the next steps. This data can then have progressive grids created, so that any variations from flight to flight, or day to day become apparent. A diligent independent quality assurance process is then also added to the process, with the aim of reproducing the preliminary results, and making requests for re-flights, if the data is out of specifications. A contractor should not be allowed to demobilize and leave the survey until a formal process of verifying a viable and in-specification data set has been achieved.

Influence of Government Regulations

Some Government's require all exploration geophysics datasets to vest back with the government, after an exclusive period. This then sets up a long-term archive and repurposing activity. Australia can be seen to be at the forefront of this style of activity, resulting in continental scale compilation at survey resolutions, of gravity, magnetics, radiometrics and emerging airborne electromagnetics (AEM). Other jurisdictions, such as the USA, leave the data in the hands of individuals, and consequently lag, in an obvious way, any attempts at upscaling their geological mapping and making predictions about what lies "UNDERCOVER". There is typically a lag of many years between an initial geophysical survey and follow up drilling, ground sampling for geochemical purposes, and detail structural geology studies. So, airborne geophysics is the common path finder. As there are many competing requirements, and engineering products, there is a spread of quality produced by the available systems. Good practise is stated in terms of flying height, speed, topographic drapes, and line spacings. These requirements vary from one physical parameter to another - see Reid (1980). Clifton (2016) builds on this original work and develops the arguments for flight line spacing and direction, to create survey data that is better suited for the purpose of deducing near surface buried bodies, in terms of detectability. The goal posts have shifted towards not just a surface mapping outcome but finding out more about the features in the top 1000m below the topography. Consequently, when designing a new geophysics airborne acquisition system, no one system design is optimal for all cases.

Also, commercial competition has proven to be very important as an evolutionary driver, in that the value for money proposition drives one aspect of the technology versus the requirement for highest quality and a multi-sensor system to illuminate the unknown and lead to a better geology interpretation.

When a new technology emerges and is championed by an exclusive development partner, e.g. magnetic tensor gradients, the progress of the development can struggle to progress as fast as a more competitive environment is capable of (FitzGerald, 2013).

METHOD AND RESULTS

Field Acquisition Issues

Before a survey is undertaken, a process of survey design is undertaken, that is affected by the weather, availability of aircraft, and fuel, Initial test flights are undertaken, to verify the airborne systems are functioning, and often to verify by repeat lines, that a viable signal is being acquired. Calibration ranges may be involved. During acquisition, the flights are required to meet strict guidelines as to height above ground, deviation from the original flight plans, speed and accelerations of aircraft, turbulence of the aircraft, a continuous recording history for each instrument recording and remaining within operational specifications. If a vector or tensor gradient is being measured, or a secondary field, the rotational state of the instrumentation system is critical, if a useful signal is to be acquired.

Gravity gradient acquisition systems all derive from the original Lockheed Martin GGI pack. Figure 1 shows a Falcon survey from Brazil being subjected to a noise review.

In the case of AEM surveys, increasingly, both X and Z components of the B field decay curve responses are a deliverable. For such systems, calibration of both X and Z, so that they are consistent with each other, lag distances, rotational state of the bird, non-saturation of the sensors in the instrumentation, are all important.

The Human Factor

Survey design standards have been continuously improving to account for arising issues. Airborne geophysics surveys are one of the prime techniques available to illuminate the near surface geology, even if indirectly. The various government agencies in Australia are collectively spending more than $100M annually.

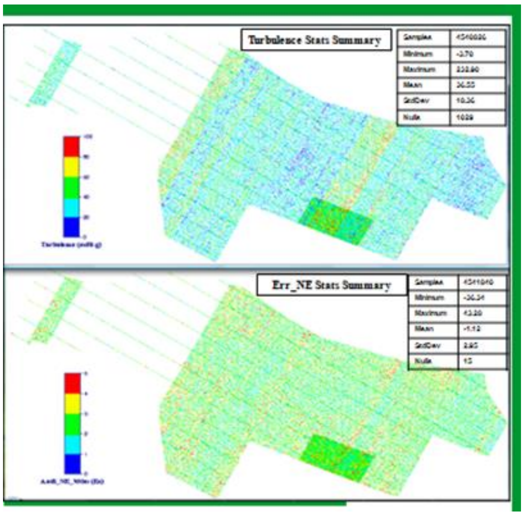

Figure 1. Falcon Gravity Gradient field data from Brazil, in 2014 being subject to Quality Control check. A Frobenius Norm filter is used to check noise levels

Government led initiatives are up to date with QA/QC developments and provide generally robust results.

The private sector, especially in minerals, is not always as organized, as the activity of running a survey is not as common an activity in any one company.

Post-Acquisition

Most of the work done after flying and before final data delivery involves a correction for systematic errors or adjustments for known factors, such as magnetic compensation, altitude corrections, spike removals, radon corrections, de-striping, de-corrugation or cross-over analysis.

Terrain

Terrain effects are commonly the dominant component of any raw airborne geophysics survey. It follows that a terrain dataset at the appropriate resolution should be available, before assessing the quality of the survey.

Gridding

Gridding of an acceptable final version of the measured field, after all the conditioning steps and production of a residual anomaly estimate, to reveal how the local geology is influencing the measures, is the principal deliverable to clients. This follows from the reality that the ultimate client is usually an interpreting geologist, not a geophysicist. The very act of gridding, immediately rejects, or does not use around 80% of the acquired data, due to the fact that flight line data is aliased in the direction of acquisition, and poorly sampled between the lines. Honouring the 20% of the data that is being used while a representation of the field in the grid is created is critical. The common practice is just 4 cells between lines. As an aid, the physics that the measured field is known to obey, can be used to constrain the gridding algorithms – hence the popularity of minimum curvature and bi-cubic splines for potential field components or scalar measures. It is a limitation of the minimum curvature smoothing convolution operator, that the 11, 25, and 49 terms that might be used here in various flavours of the implementation, are first order errors, second order, or third order errors, when judged from a finite difference perspective. The actual width of this operator, each time it is applied, needs at some point, to access original observations that are being honoured, to constrain the curvatures to observations. It is for this reason, as much as anything else, that scalar airborne surveys have come to use 4 cells between lines.

A grid contains the summary information content of a survey, whereas, an image is a reduction of that information, using a look up table colour stretch. The colours and their transitions do not signify a change of geology, or a boundary, but an arbitrary assignment, so the eye can better detect the information content.

Higher Dimension Signal Observations

Gradient gridding and tensor gridding change this processing practise quite a bit, as greater than 70% of the measured signals can make it into the grid, producing a higher resolution grid of the field. In this case, the quality control issue shifts even more critically, to the gridding algorithm and its ability to honour locally all the trends that have been measured. The technical objective here for instance, is to produce from magnetic gradient tensor data, a grid with a cell size that is one tenth of the line spacing, while honouring the observations. This leads to twice the resolving power, as a minimum, to traditional TMI surveys. For instance, a 5 m cell size or less can routinely be achieved with this technology. Figure 2 shows a model study of a dyke like structure, buried below the surface, with a quite ambiguous TMI signal, when sampled along four lines that cross it. If a tensor magnetic gradient signal is acquired, or in this case calculated (Holstein et al., 2009), most of the ambiguity disappears, and the challenge then is to push the resolution to the upmost. A sensor may have up to 6 degrees of freedom, in its trajectory through space. The three rotational states have not been routinely measured with the required accuracy, nor corrected for. This has now become a requirement for these high rate, higher dimensional acquired signals. Of course, the presence of noise, and non-ideal flying directions, also can be investigated, once this framework is available.

AEM gridding poses a significant QA/QC challenge. Typically, the Magnetic B field component decay curves of the secondary response are the primary survey deliverable.

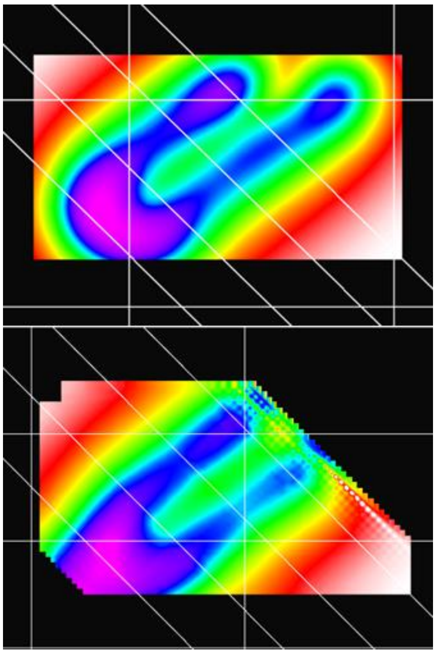

Figure 2. Magnetic Tensor gridding, synthetic data trials. (a) top, is the forward model of a highly folded dyke body and its magnetic tensor default visual enhancement "Cube Root of the Determinant", without any noise. The four flight lines, at right angles to its strike, are shown. Sample observation are made back to the flight lines. (b) A tensor grid is created, in this case with 12 cells between each pair of lines, recovering the correct geology object signature. The top edge is unconstrained, so some artefacts are coming in.

As it is easy to do, grids of these early time and late time values can be generated. These grids are not directly interpretable as a geological response, but rather an indication of local coherence between soundings. It is the cross-sections of the log conductivity, after an inversion, that has more geological significance, and that is what the geologist needs.

Inversion

The 2.5D inversion technique has a place to play in quality control for AEM surveys. The method is very exact and reports all difficulties with the delivered data from a contractor with ease. Figure 3 shows an example where the quality of the survey data is being tested. In particular, the inversion requires correct calibration of X and Z channels, accurate compensation for bird motion, validation of the noise model, and a lack of late time correlated noise. When the data is not processed correctly, any, or all these factors are easily detected.

If 1D inversion or CDI production is all that is attempted by the team checking the delivered AEM data, there is much less quality control being applied for a coherent, and properly calibrated signal. The characteristic "pants-leg" artefacts from 1D, often are interpreted as an anticline by a geologist, when in fact they often reflect a steeply dipping conductor, or an off-end effect associated with a fault.

Longer Term Factors

As geophysical surveys have been acquired over more than 50 years, there are generations of workers and instruments that make for a non-homogeneous patch work of spatial coverage, which in turn, has an impact on regional dataset quality. Regional surveys abut each other, and further quality control issues, which were never anticipated at the onset, emerge. Each of the geophysical signal types seems to have its own unique issues, once this scenario is discussed.

Gravity

Older gravity stations, set out on up to a grid of 11 km, have issues with XY location, and of more concern, the height, as a barometric pressure method was used historically. This means the elevation estimate in older datasets has much larger errors that typically cannot be fixed, compared to more modern survey observations. This means merging older data of this nature, with a modern airborne gravity survey, is almost a pointless exercise, except there may be no choice.

Radiometrics

In the earlier times, calibration of the crystals, and the processing coefficients used, may either be lost, or poorly executed. At times, flight lines need to be reoccupied, with a view to re-establishing what coefficients might have been used, to produce the "final" 256 channel data, and the standard four channel products. Unless this process is followed, there is almost no chance of harmonizing the old survey data with a next generation.

Magnetics (TMI)

This is also not without its issues. What was the diurnal correction applied, what trends were removed from the survey data? are there enough overlaps between surveys, to figure out an adjustment, that the physics of the situation might find acceptable i.e. first order trend and a DC shift. The push to mix poor survey data with high quality modern surveys, to create the illusion of a coherent continental coverage does a dis-service for the interpreting geologist, as Clifton (2016) points out. East-west flown lines with a spacing of greater than 200m have a poor chance of being able to characterize near surface magnetic sources in the geology.

Practical implementations of these Quality Control adjustments show up in the GridMerge tool, Minty (2011) where routinely, more than 5000 prior TMI surveys are re-adjusted, and remerged to make a new coherent representation of the magnetic field.

CONCLUSION

The critical step of ensuring high quality geophysics data is both acquired and then reduced via established processing methods to a coherent and consistent representation of an element of a field cannot be taken for granted.

2.5D AEM inversion provides an exacting quality control check on survey data, as all aspects of the components of the B field measured signal are rigorously tested for coherence.

Airborne gravity and gravity gradiometry also require a high level of quality control procedures, especially involving terrain factors.

An emerging magnetic tensor gradient survey technology presents even further challenges for quality control, as many of the established short-hands and rules of thumb no longer apply.

QA/QC procedures applied across the industry are not uniform, and sometimes inappropriate for new. Government contract specifications can help. Also improved software tools being generally available and having trained operators, is an emerging requirement.

In time, consistent, coherent, regional compilations of airborne geophysical data open up a new range of applications for these data. Large regional anomalies can now be better appreciated and interpreted. A significant benefit is the ability to apply quantitative modelling and data processing techniques to large areas. These methods have the potential to provide significant new insights into the geology, and prospectivity of continental scale compilations.

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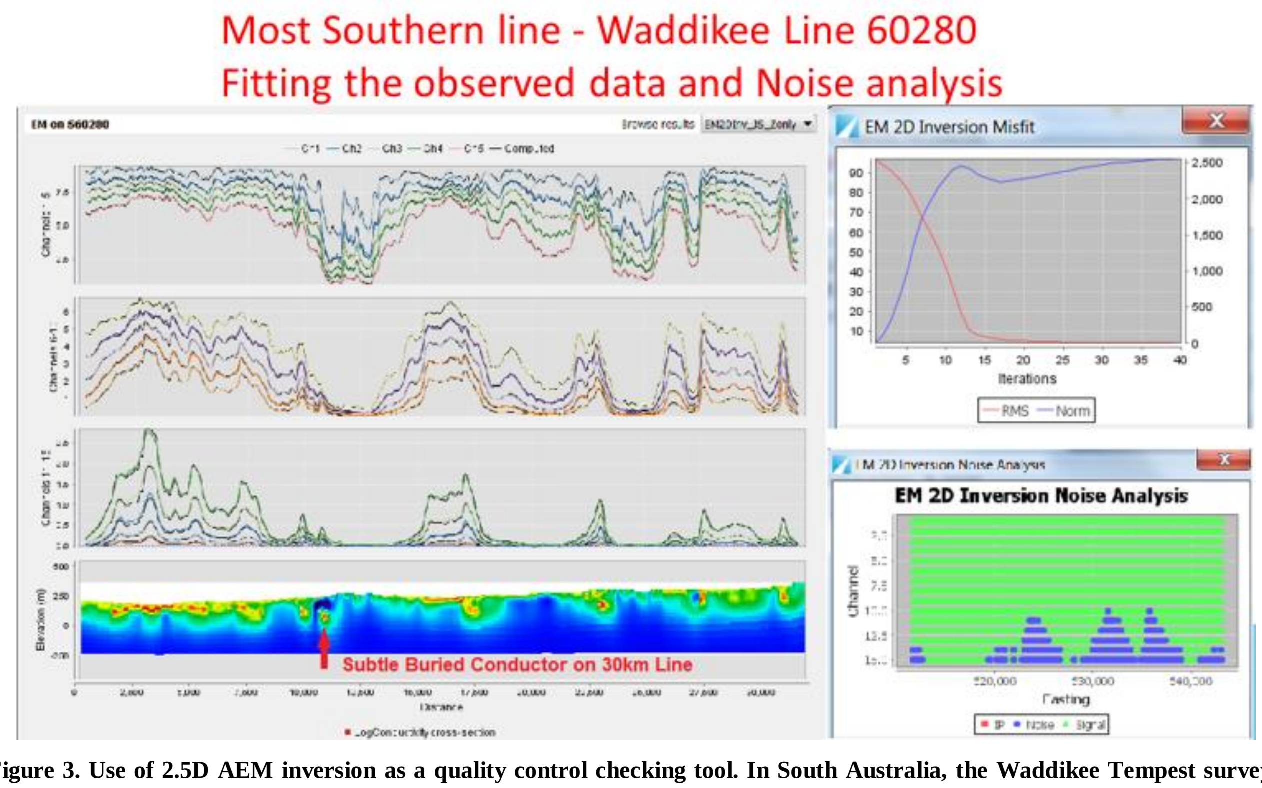

Figure 3. Use of 2.5D AEM inversion as a quality control checking tool. In South Australia, the Waddikee Tempest survey shows what portion of the measured signal is useable and what is below the noise floor.