Ten things the textbooks don't tell you about processing and archiving airborne gamma-ray spectrometric data

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Grant, J.A., 1998: Ten things the textbooks don't tell you about processing and archiving airborne gamma-ray spectrometric data; in Current Research 1998-D; Geological Survey of Canada, p. 83-87.

Abstract: Techniques used for acquiring and processing (correcting) airborne gamma-ray spectrometry data are well documented. However, these publications have not addressed some of the more subjective aspects of this process, such as filtering, presentation, and archiving of the data. This paper discusses some of the often overlooked, but important issues related to the proper handling of airborne gamma-ray spectrometry data.

Résumé : Les techniques utilisées pour l'acquisition et le traitement (correction) des données dérivant des levés aéroportés de spectrométrie du rayonnement gamma ont fait l'objet de nombreuses publications. Toutefois, aucune d'entre elles ne décrit certains des aspects parmi les plus subjectifs de ce processus, notamment le filtrage, la présentation et l'archivage des données. Le présent article aborde quelques-uns de ces aspects souvent négligés mais importants relativement au traitement adéquat des données susmentionnées.

INTRODUCTION

Techniques used for acquiring and processing (correcting) airborne gamma-ray spectrometry (AGRS) data are well documented (IAEA, 1991; Grasty and Minty, 1995). However, these publications have not addressed some of the more subjective aspects of this process, such as filtering, presentation, and archiving of the data. Consequently, there are few standards in this area. On several occasions, on reviewing airborne gamma-ray spectrometry display products and digital data produced by other organizations, it has become apparent that some questionable procedures have been followed. The following discussion outlines the principles and preferred techniques followed by the Airborne Geophysics Section, Mineral Resources Division.

1. Use correct names for variables and units

The recommended short and long names and their corresponding units are listed in Table 1.

It is important to note that the term "equivalent" must be used for uranium and thorium, because these element concentrations are computed from counts collected in windows that measure radiation from ^{214}Bi and ^{208}Tl respectively, assuming that these daughter products are in radioactive equilibrium within the U and Th decay series. The term "equivalent" does not apply to the potassium window, because the recorded counts are a direct measurement of ^{40}K.

Note that the units label for eU/K and eTh/K is "X 10^{-4}", reflecting the fact that eU and eTh are both measured in parts per million and K is measured in per cent.

Occasionally, the term "background radiation" is encountered, presumably to represent some form of "exposure" or "natural air absorbed dose rate" measure of "normal" radioactivity. This is an ambiguous term. The word "background" should not be used unless it is fully qualified (i.e. "cosmic background", "aircraft background", "atmospheric background", etc.) because it can be confused with radon (it is quite reasonable to create a map of radon) or the backgrounds that are removed from the raw counts as a normal part of the data processing.

2. Noise level

All values of magnetic total field carry equal weight – there is no lower level that is treated as noise (any "noise" exists in the resolution of the measurement of the field). However, airborne gamma-ray spectrometry data has a "noise level" that is tied directly to the nature of the Poisson distribution of the counts in the statistical process being measured, in that the proportion of noise increases with decreasing count rates.

A "rainbow" spectrum of colours that might be suitable for displaying a magnetic total field or magnetic residual grid image might not be appropriate for use with airborne gamma-ray spectrometry data, particularly if low values are assigned a dominant colour. Low values of airborne gamma-ray spectrometry data should be displayed with colours that emphasize this "noise level" (i.e. grey, blue).

A variety of methods can be used to remap or convert grid data values to colours, two of which are linear and equal-area (histogram-equalized) mapping. An equal-area colour scheme is usually not appropriate for use with airborne gamma-ray spectrometry data because it gives undue emphasis to low "noise values". We prefer a linear mapping of colours within the range [0, max] where "max" is the maximum data value of about 90% of the data (i.e. excluding spurious or unusually high anomalous values).

Table 1. The primary variables.

Short name	Long name	Units
K	Potassium (measures ^{40}K)	%
eU	Equivalent uranium (measures ^{214}Bi)	ppm
eTh	Equivalent thorium (measures ^{208}Tl)	ppm
Total count	Total count	μR/h
Exposure	Natural air absorbed dose rate from geological sources (13.08*K + 5.43*eU + 2.69*eTh)	nGy/h
eU/K	Equivalent uranium/potassium	X 10^{-4}
eTh/K	Equivalent thorium/potassium	X 10^{-4}
eU/eTh	Equivalent uranium/equivalent thorium	

3. Negative values are important – don't discard them

Gamma-ray spectrometry data is a measure of a statistical process characterized by a Poisson distribution (as opposed to a measurement of a potential field). Any statistical set of data will have values that lie outside the expected range of values. Although measured count rates will always be greater than or equal to zero, it is normal to see a few negative values in the computed K, eU, and eTh concentrations. Although this may not seem "reasonable", it is a perfectly valid representation of the statistical data set and is a natural reflection of the correction process that includes background subtraction and application of stripping corrections. Negative values must never be set to zero, or this information will be lost and will bias subsequent statistical analysis. The number and size of these negative values is a measure of the correctness of the calculations that have been applied to the count rates (backgrounds, stripping, and sensitivities). If a significant proportion of the data for the entire survey is negative, perhaps the calibration of the equipment is incorrect. Similar observations for a particular region of the survey or set of flight lines on a particular day might indicate anomalous radon concentrations or unsuitable conditions for collecting data.

The negative airborne gamma-ray spectrometry values must:

a) remain in the archival data set,

b) carry equal weight as positive values and be treated as legitimate values during gridding and computation of eU/eTh, eU/K, and eTh/K ratios, and

c) be drawn as negative values in stacked profile plots (see Fig. 1)

4. The gridding algorithm should be tailored to the statistical nature of the data

Most map products require the data to be interpolated onto a regular grid. Many of the popular gridding algorithms (i.e. splining) are suitable for potential surface data (i.e. magnetic, gravity), but are not necessarily suited to airborne gamma-ray spectrometry data, because of the inherent statistical variations of the airborne gamma-ray spectrometry data. A suitable gridding algorithm is one which takes the average of all data points lying within a circular or elliptical area, weighted inversely by distance from the grid point. The data is implicitly filtered by this algorithm during the gridding process: it is not necessary to filter the data first (as is required for the splining technique).

5. Ratios must be calculated carefully

The diagnostic ratios of the three radioelements (eU/eTh, eU/K, and eTh/K) are frequently plotted as profiles. Due to statistical uncertainties in the individual radioelement measurements, some care should be taken in the calculation of these ratios to avoid dividing "noise" by "noise", resulting in very small and very large meaningless values.

Each airborne gamma-ray spectrometry reading is assumed to be a sample counted over a homogeneous half space that represents a "Poisson source". It is well known that the mean and variance of a Poisson population are equal, therefore the standard deviation is the square root of the mean value.

When computing ratios of stripped and corrected data it is necessary to ensure that both numerator and denominator are positive. In addition, some smoothing is necessary to prevent wild swings in the lowest concentration areas. The method of computing ratios is as follows:

a) In order to remove areas that could be expected to have a mean concentration of 0 in both the numerator and denominator, a test was devised to eliminate points sampled "over water". It was observed early in the development of the GSC's Skyvan system, that whenever the system passed over a "large" body of water, the measured concentration of potassium fell below 0.25%. This value is used in all ratio computations as an indication of a sample probably "over water"; all three ratio values are set to 0 if "over water".

b) Progressively sum the element concentrations of adjacent points on either side of the data point until the total accumulated concentration of both the numerator and denominator exceed a threshold or minimum value. Then calculate the ratio by dividing the accumulated sums. This imparts a measure of smoothing to the computed ratio, as well as ensuring that the two values are statistically significant.

After some examination of profiles of airborne gamma-ray spectrometry data obtained with the first Skyvan acquisition system, it was observed that areas that had concentrations less than 1% K, 1 ppm eU, and 4 ppm eTh had ratio profiles that varied wildly. A running average was applied to the numerator and denominator in an attempt to smooth each variable before computing the ratio, however this technique was rejected because it resulted in rather nondescript-looking ratio profiles. A better sort of "adaptive filtering" was required that would have the most effect on the low concentration areas while leaving the responses in higher concentration areas relatively unchanged. A somewhat heuristic decision was made that a ±10% error (66% of the time) in each of the numerator and denominator would be acceptable for computation of the ratios and would result in an error of ±20% (66% of the time) in the computed ratio. The 10% error is equivalent to 100 counts. For the first Skyvan acquisition system (sensitivities: 50 cps/% K, 9 cps/ppm eU, and 7 cps/ppm eTh), 100 cps is equivalent to 2% K, 10 ppm eU, and 15 ppm eTh, so those are the minimum threshold values required for the numerator and denominator from which the ratio is computed. This requirement ensures that the error associated with the calculated ratios is similar for all data points.

Grid ratios

The gridded eU/eTh, eU/K, and eTh/K ratios are not created by gridding the ratios computed from the line data. Instead, the eU, eTh, and K variables are gridded and the grid ratios are computed by dividing the grids of the individual variables. The numerator and denominator are accumulated by summing the values of each ring of cells that surround the grid cell for which the ratio is being computed. It is normal to insist on greater "smoothness" for grid images than is acceptable in profiles. Thus a similar heuristic decision was made for gridding the airborne gamma-ray spectrometry variables: the equivalent of at least 500 counts (5% error) needs to be accumulated in both numerator and denominator before dividing to obtain the ratio. This results in an error in the computed ratio of ±10% (66% of the time).

The threshold values used depend on the sensitivity of the acquisition system: for the Skyvan system, a 500 cps minimum value is equivalent to summed values of 10% K, 55 ppm eU, and 71 ppm eTh, so those are the minimum threshold values required for the numerator and denominator.

6. Decorrugation, microlevelling

A variety of techniques have been developed to try to remove streaks or lineations in grid images along flight lines (i.e. decorrugation, microlevelling). The "noise" in airborne gamma-ray spectrometry data is usually caused by fluctuating background values (changing weather, terrain, ground moisture content, radon pockets, etc.) between adjacent flight lines. These techniques are suitable for geophysical data types that are a measure of a single variable (i.e. magnetic data), but care must be taken when they are used with airborne gamma-ray spectrometry data.

The line data is the primary data set and the grids are just one of several views of that data. If techniques are applied to the grids to improve their appearance, there must be a corresponding mechanism to direct those corrections back to the set of line data from which the grid images were created. It must always be possible to create a grid image from the primary archival line data set, simply by routinely gridding the archival line data. There is little value in creating a polished, smoothed "airbrushed" grid image if it can never be reproduced (i.e. with a different projection or cell size) without applying the (possibly iterative and subjective) process again.

Complicating matters is the cross-coupling that exists between the count rates of the K, eU, and eTh variables: in particular the ^{40}K potassium window includes significant scattered counts from uranium and thorium decay series. This coupling is removed by applying the stripping ratio corrections after the backgrounds have been subtracted. The decorrugation corrections that are applied to a single airborne gamma-ray spectrometry grid are in effect modifying the background values of that variable in order to level the data. But for airborne gamma-ray spectrometry line data, a change in the background count rate for one variable can result in changes in the computed concentrations of all three variables, the degree of which depends on the sensitivities. This interdependence makes it difficult to correct any of the K, eU, or eTh grid images individually without applying related corrections to the other two grid images.

7. Line data is the primary archival data set, not grid data

The primary archival data set is the line (point) data, to which the following processing has been applied:

- subtraction of backgrounds
- stripping corrections
- attenuation correction (for variations from survey flying height)
- conversion of counts to equivalent ground concentration using sensitivities

It is particularly important to note that the archival data set is never filtered, however it may be filtered on the fly for presentation purposes (stacked profiles) or implicitly by a gridding algorithm.

Grids are considered secondary and are merely one of several possible "views" of the archival set of data. We do not archive grids – they are generated on demand from the archival line data to suit the requirements of individual clients, i.e. region, projection, and cell size.

8. Never archive filtered data

Airborne gamma-ray spectrometry data represents a measure of a statistical process and is completely different from magnetic or gravity data that represents a relatively smooth potential surface. By its very nature, statistical data is not "smooth", therefore smoothing techniques that might be applied to potential field data should not necessarily be applied to airborne gamma-ray spectrometry data. That which is considered "noise" in potential field data is treated as "information" in airborne gamma-ray spectrometry data. Smoothing airborne gamma-ray spectrometry data reduces the resolution of the data and effectively discards potentially useful information. The stacked profile section shown in Figure 1 contrasts the normal "noisy" character of airborne gamma-ray spectrometry data (potassium, 1 sample/s) with the relatively smooth nature of magnetic total field data (5 sample/s).

Once a filter has been applied to a set of data, the effect can never be removed. Therefore, the primary archival line data set must consist only of unfiltered K, eU, eTh components. The filtering that is applied implicitly during the computation of the eU/K, eU/eTh, eTh/K ratios, is acceptable for the archival data set.

Filtering should be a dynamic process that is applied and removed subjectively to the data during interpretation or presentation (i.e. viewing or printing stacked profiles). But routine filtering to make the final archival digital data set "look nice" can destroy a significant part of the signal contained in the data, leaving it less useful for interpretation. Furthermore, subsequent gridding of this filtered line data results in a dual application of filters, because interpolation is essentially a low-pass filtering operation in itself. Filtering may be applied during the gridding process, either explicitly (if splining) or implicitly (inverse distance-weighted averaging), but any line data that is prefiltered for gridding should be treated as temporary data that exists only for that purpose and it should be discarded when the gridding process is complete.

9. Ternary radioelement map

The primary archival data set is considered to be the line data for the primary variables (K, eU, eTh), from which other variables (eU/K, eTh/K, eU/eTh, exposure) are derived. The primary grid products are considered to be individual images (maps) of the primary variables (K, eU, eTh) plus a ternary radioelement map.

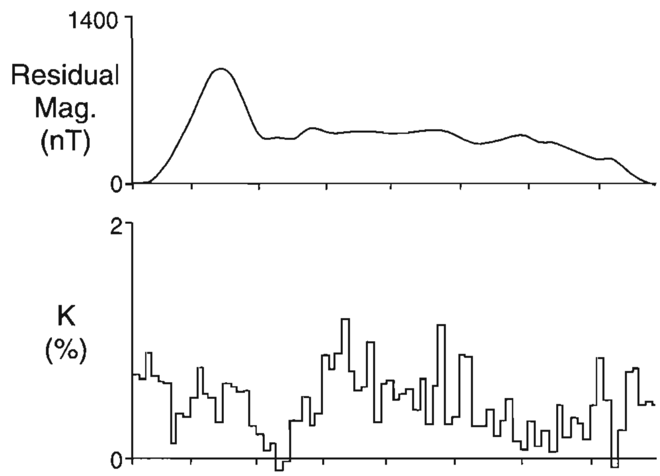

Figure 1. *Comparison of 'point-to-point' plotting method for non-airborne gamma-ray spectrometry data (5 sample/s) with the preferred "step" or "histogram" method for airborne gamma-ray spectrometry data (1 sample/s).*

The ternary radioelement map can not be created simply by assigning each of the K, eU, and eTh variables to a colour (i.e. red, green, blue or cyan, magenta, yellow). The values must be normalized to account for the natural relative abundance of potassium, uranium, and thorium. To ensure that the resultant map is not dark and muddy, a special equalization process is applied to limit the saturation of the colours (Broome et al., 1987). Furthermore, it has been found that, although the (red, green, blue) colour model might be appropriate for video display, it creates a relatively 'dark' image when printed. The Airborne Geophysics Section uses the CMY (cyan, magenta, yellow) colour model (for eU, K, and eTh respectively) for the printed map because the information is more visible.

The Airborne Geophysics Section creates a special 8-bit image file (TER.BIL –Ternary Band-Interleaved by Line), following the procedure described above. It can be displayed directly by ESRI ArcView and by SurView (Grant, 1992) and appears as a CMY image. Note that the file contains the RGB equivalents of the CMY values because ArcView uses only the RGB colour model.

10. Stacked profile presentation

Magnetic field, VLF, and EM data is acquired by taking an instantaneous measurement of each variable at each sample interval (typical sampling rates are 1, 2, 5, or 10 samples per second), therefore it is appropriate to plot the stacked profile trace as a simple point-to-point line. However, airborne gamma-ray spectrometry data is acquired by accumulating a sum of counts during the sample interval (typically 1 second). Therefore, it is recommended that the airborne gamma-ray spectrometry data be plotted using a "step" or "histogram" method, where each data value is represented by a horizontal line for the duration of the sample interval (see Fig. 1). This not only graphically illustrates the counting interval (in a spatial sense), it also portrays the statistical fluctuations in the data (even if a minimal presentation filter is applied).

ACKNOWLEDGMENT

I would like to thank John Carson for his valuable comments in the discussion of these issues.

REFERENCES

Broome, J., Carson, J.M., Grant, J.A. and Ford, K.L.
1987: A modified ternary radioelement mapping technique and its application to the south coast of Newfoundland; Geological Survey of Canada, Paper 87-14.

IAEA (International Atomic Energy Agency)
1991: Airborne Gamma Ray Spectrometer Surveying; IAEA Technical Report 323, International Atomic Energy Agency, Vienna.

Grant, J.A.
1992: SurView – A Microsoft Windows 3.x application to view geophysical survey data; Geological Survey of Canada, Open File 2661.

Grasty, R.L and Minty, B.R.S.
1995: A guide to the technical specifications for airborne gamma-ray surveys; Australian Geological Survey Organisation (AGSO) Record 1995/60.

Geological Survey of Canada Project 880029-ZZ