Merging radiometric grids using histogram matching

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Abstract

Large-scale compilations of airborne geophysical data are an important part of regional-scale mineral exploration and in most cases, the compilation involves merging datasets of varying quality, acquired over a long period of time. Merging radiometric datasets involves the additional complication that many older surveys were flown with uncalibrated spectrometer systems. Conventional grid merging is based on calculation of base-level shift and scaling factors for each grid with the grid edges feathered. However, even after these corrections, soil moisture differences between surveys acquired over a long period of time and at different seasons when soil moisture content varied introduce scaling errors into the estimated radioelement concentrations. An alternative method based on histogram matching is suggested as an improvement on existing methods. Source code in Matlab format is available from the server at www.iamg.org.

1. Introduction

Large-scale compilations of airborne geophysical data are an important part of regional-scale mineral exploration. In most cases, the compilation involves merging datasets of varying quality, acquired over a long period of time. Minty (2000) and Minty et al. (2003) discuss the requirements for continental-scale compilation of airborne geophysical data. A major problem in merging radiometric datasets is that many older surveys were flown with spectrometer systems which had not been calibrated (Minty, 2000; Clifton, 2004), making comparison between adjacent areas difficult. Minty (2000) suggests a holistic approach to grid merging, where a number of grids are adjusted in a least-squares sense rather than piecemeal. Base-level shift and scaling factors are calculated for each grid and then the edges are feathered. The merged grids allow comparison of radiometric signatures from one area to another.

However, even with modern calibrated spectrometer surveys, soil moisture differences between surveys introduce scaling errors into the estimated radioelement concentrations. Conventional grid merging does not cope well when the grids being merged have quite different statistical properties. An alternative method based on histogram matching is suggested as an improvement on existing methods.
methods. This provides coherent radioelement images for regional-scale radiometric interpretation and recognition of large-scale geochemical domains.

2. Grid merging by histogram matching

Merging radiometric data grids by using a base-level shift and a scaling factor can give excellent results when the difference between two surveys has this form. However, in practice the relationship between the two datasets may be more complicated, and can take on any form. Histogram matching makes no assumptions about the statistics of the datasets or of the relationship between them. It is a technique that is commonly used in remote sensing applications (Richards, 1993, p. 103). Fig. 1 illustrates the procedure involved in matching the histograms of two datasets. Firstly, the cumulative histograms of the datasets are calculated (Figs. 1C and D). Each data value of the dataset that is to be adjusted is replaced by the data value in the second dataset that has the same cumulative histogram value. To avoid discretization problems due to the binsize used in the histogram calculation, histogram values are interpolated at actual data value locations. The arrows on the figure show how a data value of +2.8 is mapped to a new value of −1.5. When the technique is used to merge radiometric grids, the histogram matching function can be calculated from any overlapping region of the surveys, then applied to the entire survey. If there is no overlap, then the histograms of the entire surveys can be used, assuming that radiometric signatures are similar. The method should not be used when the two grids are from different geological environments. Ideally,

![Fig. 1. (A) Histogram of dataset 1, which is to be matched to; (B) histogram of dataset 2, which is to be modified; (C) cumulative histogram of dataset 1; (D) cumulative histogram of dataset 2; and (E) histogram of dataset 2 after matching.](image-url)
back calibration, involving flying special control lines should be used.

3. Airborne gamma-ray spectrometry

The main sources of natural gamma radiation are potassium ($^{40}$K) and the decay series of uranium ($^{238}$U) and thorium ($^{232}$Th). Potassium is measured directly by the 1.46 MeV energy peak of $^{40}$K but $^{238}$U and $^{232}$Th are measured indirectly using spectral peaks of daughter products assuming that the decay series are in equilibrium. $^{238}$U is monitored using the 1.76 MeV peak of $^{214}$Bi, a daughter product low down in the $^{238}$U decay series. $^{232}$Th is measured using the gamma-ray spectral peak at 2.62 MeV of $^{208}$Tl, a daughter product of $^{232}$Th.

The gamma-ray spectrometer data undergo a series of corrections to convert raw count rates into

Fig. 2. (A) Standard grid merge radiometric ternary image, K = red, eTh = green, eU = blue. Black = low in all three radioelements (lakes). White = high in all three radioelements. (B) Histogram-matched grid merge radiometric ternary image, K = red, eTh = green, eU = blue. Black = low in all three radioelements (lakes). White = high in all three radioelements.
radioelement concentrations. These involve noise filtering, removal of aircraft and cosmic background, radon background removal, channel interaction correction (stripping), height correction, and conversion into apparent ground radioelement concentrations (Minty, 1997).

Over 95% of gamma radiation is emitted from the upper 30 cm of the soil or bedrock profile so the observed gamma radiation depends fundamentally on the properties of the surface materials. Soil moisture content is one of the major contributors to the intensity variations in gamma radiation (Grasty, 1997). Grasty showed that the gamma-ray flux from potassium and the thorium decay series showed an expected decrease with increasing soil moisture. However, the gamma-ray flux from the uranium decay series was highest in the spring when the ground was water saturated and even covered with snow. These results are explained through the build-up of radon and its associated gamma-ray—emitting decay products in the clay soil of the calibration range with increasing soil moisture. Similar results were found from airborne measurements over other clay soils. However, measurements over sandy soils such as coarse-textured drift showed that the count rates from all three radioelements increased with decreasing soil moisture. This difference between soil types was attributed to the lower radon emanation of the more coarse-grained sandy soils compared to finer-grained clay soils. There is seasonal variation in gamma radiation, and gradual soil warming and drying result in increasing levels of gamma radiation with maximum gamma radiation values reached at maximum soil temperatures in midsummer. The use

![Figure 3](image-url)  
*Fig. 3. Frequency histograms of radioelements for north and south grids prior to merging and final histogram-matched merged grid.*
Fig. 4. (A) Standard grid merge radiometric ternary image, $K = \text{red}$, $e\text{Th} = \text{green}$, $e\text{U} = \text{blue}$. Black = low in all three radioelements (lakes). White = high in all three radioelements. (B) Histogram-matched grid merge radiometric ternary image, $K = \text{red}$, $e\text{Th} = \text{green}$, $e\text{U} = \text{blue}$. Black = low in all three radioelements. White = high in all three radioelements.
of radiometric ratios such as K/Th can help to minimize soil moisture effects at the expense of increased noise levels. Dense vegetation can also lead to reduced gamma radiation flow.

4. Geological survey of Finland (GTK) gamma-ray spectrometer surveys

The Geological Survey of Finland (GTK) have acquired high-resolution radiometric data over 85% of Finland, flown with 200 m line spacing at a nominal flight height of 30 m (Hyvonen et al., 2005). The radiometric data were acquired over a long period of time and at different seasons when soil moisture content varied so that radiation levels show a high degree of variation. Merging GTK grids using conventional grid merging methods based on matching the means (base-level shift) and variances (scaling factor) gave unsatisfactory results for some areas, even though individual surveys were fully calibrated.

The concentration of radioactive elements in soil is determined by the source rock and controlled by soil formation and glacial processes. The maximum concentrations are associated with soils developed from felsic bedrock and clay. The glacial dispersion in Finland varies from a few hundred metres to over 1 km and the usefulness of gamma-ray surveys in mineral exploration and geological mapping depends on the nature of the glacial debris and dispersion. In many cases, the radioactivity of the underlying bedrock can still be identified, but in other cases the radioactivity pattern of the underlying bedrock can be obscured completely.

Fig. 2 shows a comparison of merging two grids from the Karelia Craton in Eastern Finland.
The northern grid is part of a survey flown in spring 1976 using a DC-3 platform, flown east–west at a nominal elevation of 30 m with 200 m line spacing. The southern grid is part of a survey flown in summer 1987 using a Twin Otter platform, flown east–west at a nominal elevation of 30 m with 200 m line spacing. The north–south overlap between the two 50 m mesh grids is only 600 m, providing 7200 data points for histogram generation. In this case, the more recent data, flown at the best time of year were selected as the control dataset. Fig. 2a is a K, eU, eTh RGB ternary image, produced by conventional grid merging of the individual radionuclide grids. Conventional grid merging has been unsuccessful in matching radionuclide distributions with clear differences remaining between the northern and southern grids. Fig. 3 shows basic statistics of the north and south grids showing the differences in radionuclide concentrations. Fig. 2b shows the results of grid merging using histogram matching. The image in Fig. 2b is clearly superior to that in Fig. 2a, providing continuity across the join of the two grids. Fig. 3 shows basic statistics of the histogram-matched merged grid. Comparison of the histogram-matched data with a summer 2001 high-resolution infill survey shows excellent correlation, suggesting that histogram matching has performed well.

5. Northern territory, Australia grid merging

Radiometric data from the Northern Territory, Australia were used to test the histogram matching algorithm in an arid area where differences in soil moisture content should show less variation than in Finland. In this example, the problem is to merge data acquired at different times where one grid in uncalibrated, with data in counts per second, and the other in ground concentration units. In this case, the ground concentration unit eastern grid was selected as the control dataset. The two grids overlap from west to east. The eastern grid is part of a survey flown in 1981 at an elevation of 100 m along north–south flight lines with 500 m line spacing. The survey was flown using a Nomad platform with a detector volume of 50 l. The western grid is part of a survey flown in 1995 at an elevation of 100 m along north–south flight lines with 500 m line spacing. The survey was flown using a Shrike Aerocommander platform with a detector volume of 33 l. The two grids have an overlap of 3 km, providing 15,000 data points for histogram generation, a larger data overlap than in the case of the Finnish data. However, even here, the histogram matching provides a better result than conventional grid merging. Fig. 4 shows the results of merging the two grids. Fig. 4a, an RGB ternary image produced by conventional merging shows significant striping along the north–south flight lines in the overlap area. Fig. 4b, produced by histogram matching has removed the flight line striping in the overlap area and also provided better balance, especially in potassium (red). Fig. 5 shows basic statistics of the west grid in counts per second, the east grid in ground concentration units and the merged grid in ground concentration units. Clearly, the distributions are non-Gaussian and the grids being merged have quite different statistical properties.

6. Conclusions

A new method of merging airborne radiometric datasets, based on histogram matching, has been introduced. The method allows the statistical relationship between the datasets being merged to take on any form. Matlab source code for the method is available from the IAMG server at www.iamg.org/CGEditor/index.htm.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.cageo.2007.05.012.

References


