Inverting airborne gamma-ray spectrometry data of Maricá calibration range, Brazil

Jessica Derkacz Weihermann [a], Saulo Pomponet Oliveira [a], Francisco José Fonseca Ferreira [a] , Adalene Moreira Silva [b]
[a] Federal University of Paraná, [b] University of Brasília

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Abstract

We present an inverse analysis of the Maricá Calibration Range data, located in Rio de Janeiro - Brazil. As a gamma-ray detector does not admit a fixed field of view, there is significant overlap between successive fields of view. For this reason, standard height and sensitivity corrections may lead to incorrect estimates of the concentrations of the radioelements, thus a practical solution is to invert the data. By inverting the airborne gamma-ray spectrometric data we obtained smoothed results compared to the conventional procedure, especially in potassium and uranium channels.

Introduction

The airborne gamma-ray spectrometry (AGRS) processing is a tool for geophysical–geological mapping to aid both mineral exploration and the gathering of lithological information (e.g., Davis & Guilbert, 1973; Grasty, 1979; Charbonneau, 1991; Graham & Bonham-Carter, 1993; Dickson & Scott, 1997, Gnojek et al., 2018).

The gamma-ray spectrometry method measures the relative abundance or concentration of potassium (K), uranium (eU) and thorium (eTh) in rocks and weathered materials up to 30–45 cm deep by detecting the gamma radiation emitted by the natural radioactive decay of these elements (Dickson & Scott, 1997; Minty, 1997; Wilford et al., 1997; Wilford, 2002; IAEA, 2003). The main sources of gamma radiation are derived from the disintegration of potassium 40 (^{40}K), uranium 238 (^{238}U) and thorium 232 (^{232}Th) series.

As the spectral windows of K, U and Th overlap due to Compton scattering, each spectral window will also contain some effect from the other two radioelements. To suppress this effect is necessary to apply the stripping correction, which makes use of spectral ratios called stripping ratios. They are calculated experimentally using concrete calibration pads containing known concentrations of K, U and Th. The calibration process usually consists of four concrete pads with known concentrations of potassium, uranium, and thorium. Ideally, three of these pads should provide pure potassium, uranium, and thorium spectra so that the interfering effects of these elements can best be determined. A fourth low-radioactivity pad is required to remove the effects of background radiation from the surrounding ground, the equipment, cosmic radiation, and radon decay products in the air (Grasty et al. 1991). They are exposed one at a time to the aircraft, being positioned right below the crystal pack being tested (Fig. 1).

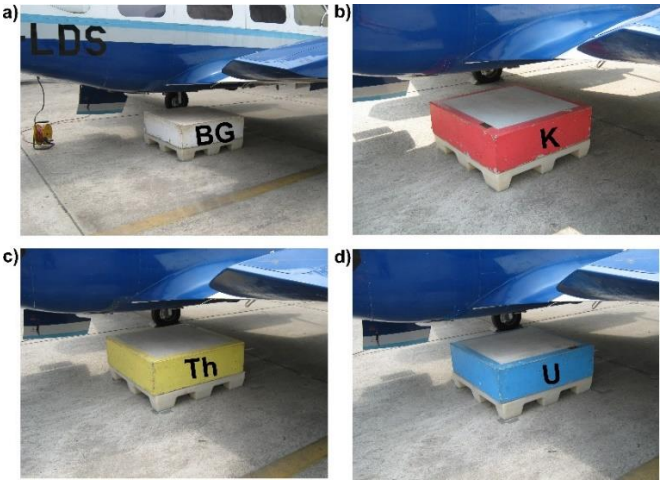

Figure 1 – *Calibration pads. a) Background; b) Potassium, c) Thorium and d) Uranium (Modified from CPRM, 2011).*

The airborne measurements are made at an established height, and the elemental count rates should be converted to estimates of the elemental concentrations on the ground by a ‘sensitivity factor’, depending only on the primary radiation and the nominal height above the ground level (IAEA, 2003).

A gamma-ray detector does not have a fixed field of view since it can receive radiation from any angle (Grasty et al., 1979), which can result in significant overlap between successive fields of view. The sensitivity correction is applied on a point-by-point basis, despite the fact that the ‘field of view’ of an airborne detector can be a circle of up to 700 m diameter on the ground, depending on the height of the detector (Minty & Brodie, 2015).

An alternative to suppress this overlap is to invert the airborne data to elemental concentrations on the ground, considering the attenuation of gamma-ray signal with the increase of the source-detector distance (flight height), the radioelement sources distribution in ground and the detector response (Minty & Brodie, 2015).

Classical AGRS inversion techniques (e.g. Kogan, 1971; Tammenmaa et al., 1976; Gunn, 1978; Crosley & Reid, 1982; Schwarz, 1992) are being revisited to contemplate the detector field of view and signal attenuation (Billings et al., 2003; Minty & Brodie, 2015; Druker, 2017).

Inversion Methodology

In the case of airborne gamma-ray spectrometry, an elementary source is considered as a radioactive rod (Fig.

2). It is also convenient to admit the gamma-ray source as infinite, both laterally and in depth.

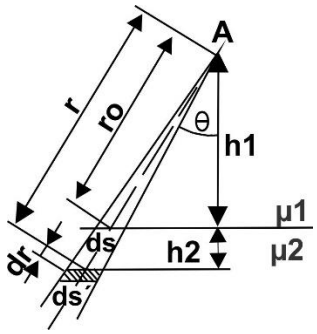

Figure 2 – *Schematic representation of a gamma radiation of a rod (Modified from Kogan, 1971).*

Following Kogan (1971), the intensity of a prismatic source of cross-sectional area [a,b] x [-w,w] is found by integration of the intensity due to an elementary rod as follows:

$$J = J_0 \frac{h}{2\pi} \int_a^b \int_{-w}^{w} \frac{\exp(-\mu_1 r)\, ds}{r^3} \qquad (1)$$

where $J_0 = q/2\mu_2$ is the intensity on the surface, and q is the source activity, μ_1 and μ_2 are linear attenuation coefficients in the air and earth, h is the flight line, r is the distance between the detector and ground, and ds is the element surface area.

We use the inversion methodology of Minty & Brodie (2015):

$$\emptyset = \emptyset_d + \lambda \emptyset_m \qquad (2)$$

where $\emptyset_d$ is a data misfit term, $\emptyset_m$ is a model roughness term, and λ is the regularization factor. The data misfit is defined as the L_2 norm:

$$\emptyset_d = [Gm - d]^T [Gm - d] \qquad (3)$$

where d are the observed data (elemental count rates), and m is the vector of unknown parameters (concentrations estimates in the ground). G is the sensitivity matrix.

The model roughness is defined as:

$$\emptyset_m = m^T L^T L m \qquad (4)$$

where L is the second-order finite difference operator. The model vector m that minimizes the misfit ∅ corresponds to solution of the linear system $(G^T G + \lambda L^T L)m = G^T d$. To find the best lambda value (λ = 0.5), we have found the inflection point of the L-curve, as in Minty & Brodie (2015).

The regularization parameter reduces overfitting, which decreases the variance of estimated regression parameters, in addition to control the impact on bias and variance.

Application to the airborne strip data

We applied the inversion to the data collected from the LDS aircraft during the dynamic calibration range in the Maricá Calibration Strip (Fig. 3). These data were acquired in 10/17/2010, as a part of the airborne geophysical Project ‘’Paraná- Santa Catarina’’ (CPRM, 2011).

Calibration of airborne systems is usually determined by flying over "test strips". A test strip is an easily and repeatedly navigated strip of land that is used to measure the response of an airborne gamma-ray spectrometer to changes in detector height (height attenuation coefficients) and to sources of known elemental concentrations (sensitivity coefficients). Guidelines for the establishment of a calibration range is provided by IAEA (1991).

The test strip was flown at different heights over the Maricá calibration range and Maricá lagoon, eight flights were made at 330, 400, 500, 600, 700, 800 feet and two additional at 330 feet, which correspond to the airborne flight height. Flights over a nearby body of water at the same height serve as estimates of background (CPRM, 2011). The reason why lines were flown at different altitudes is to calculate the attenuation coefficients, which are used for the height correction. The background-corrected and stripped window count rates are employed to estimate the attenuation coefficients for each radioelement. The ground concentrations on the calibration range are measured using a portable gamma-ray spectrometer at the same time as the airborne calibrations are flown. This enables the system “sensitivity coefficients”, which are used to convert airborne count rates to elemental concentrations on the ground, to be estimated.

To apply equation 1, we used h = 100 m (flight height at 330 feet), the air linear attenuation was determined by the ratios between on-board and ground measurements on tests conducted on the dynamic calibration range. For the ground linear attenuation and source activity we used values available for concrete, the cross-sectional area (ds) is the detector field of view. Figure 4 shows the comparison between airborne and inverted airborne data of K, eTh and eU.

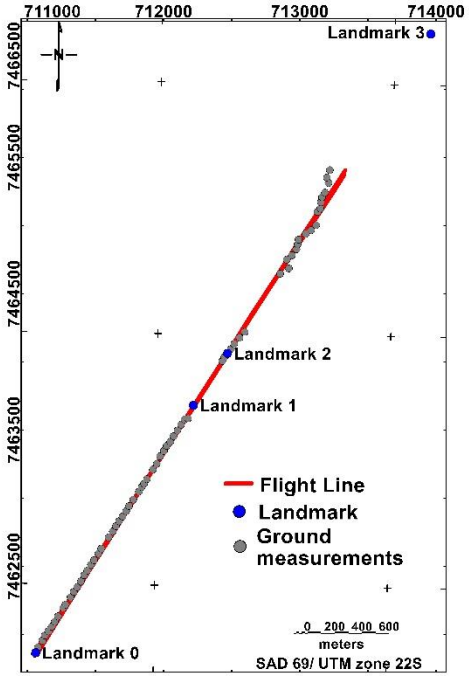

Figure 3 – *Maricá dynamic calibration range (Modified from CPRM, 2011).*

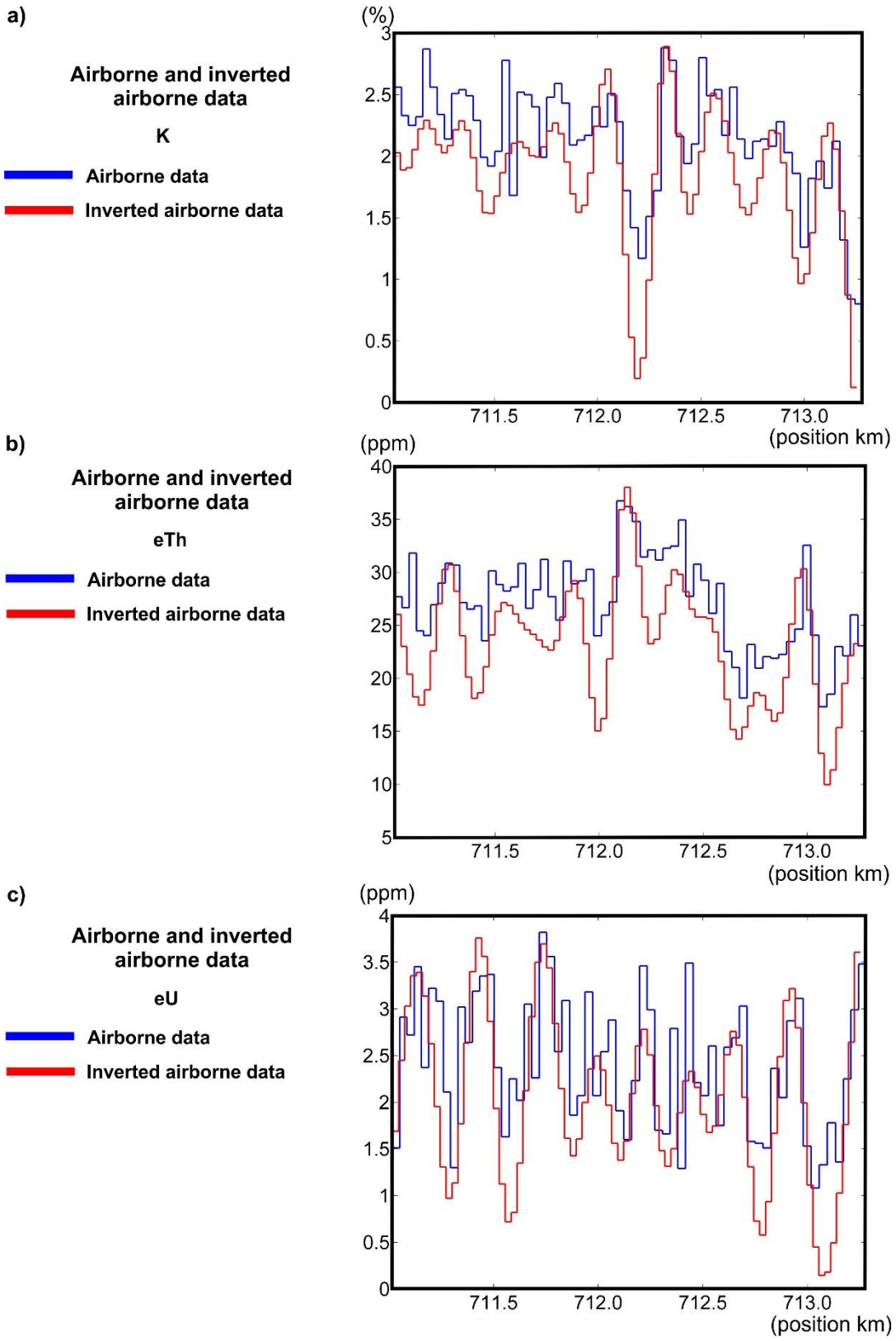

Figure 4 – *Comparison between airborne data corrected using conventional processing and inverted elemental counts to ground concentrations of K (a), eTh (b) and eU (c).*

The inverted results showed good consistency with the conventional processing of airborne data, especially in eU, which tends to have more errors. Clearly the inversion method is smother than the conventional one, and contemplates practically all the curves. In Figures 5, 6 and 7 are showed the comparison between airborne, inverted airborne and ground data for K, eTh and eU, respectively.

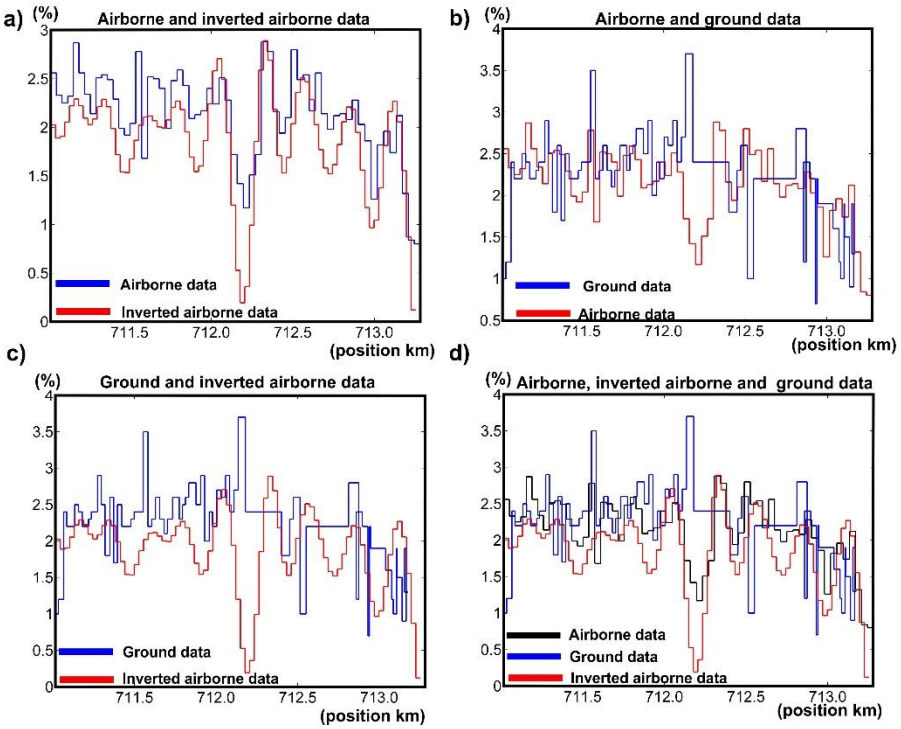

Figure 5 – *Comparison of potassium data. Airborne and inverted airborne (a). Airborne and ground (b). Ground and inverted airborne (c). Airborne, inverted airborne and ground data (d).*

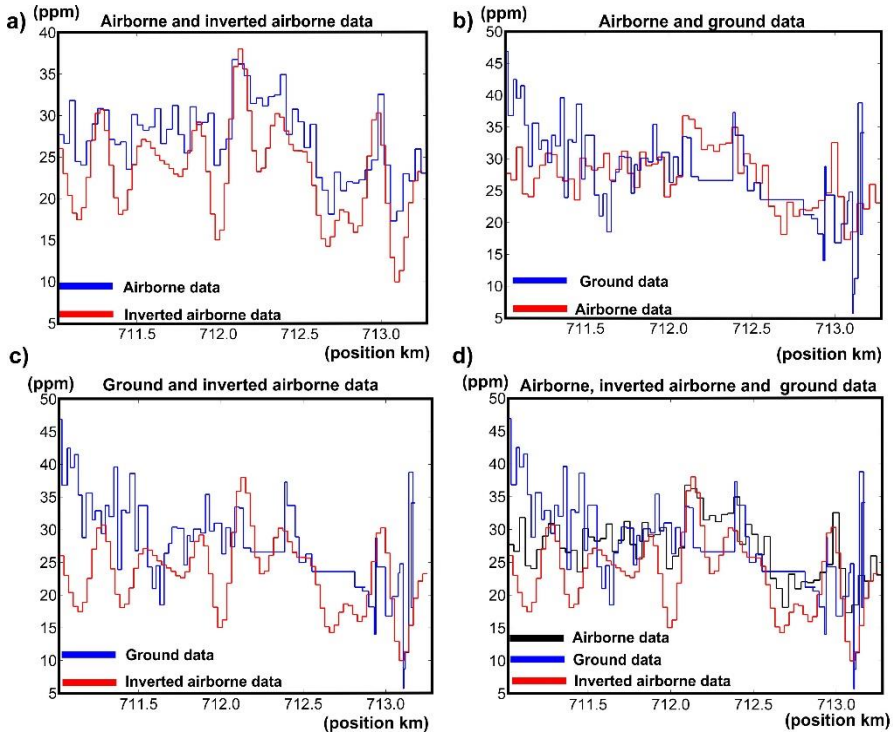

Figure 6 – *Comparison of thorium data. Airborne and inverted airborne (a). Airborne and ground (b). Ground and inverted airborne (c). Airborne, inverted airborne and ground data (d).*

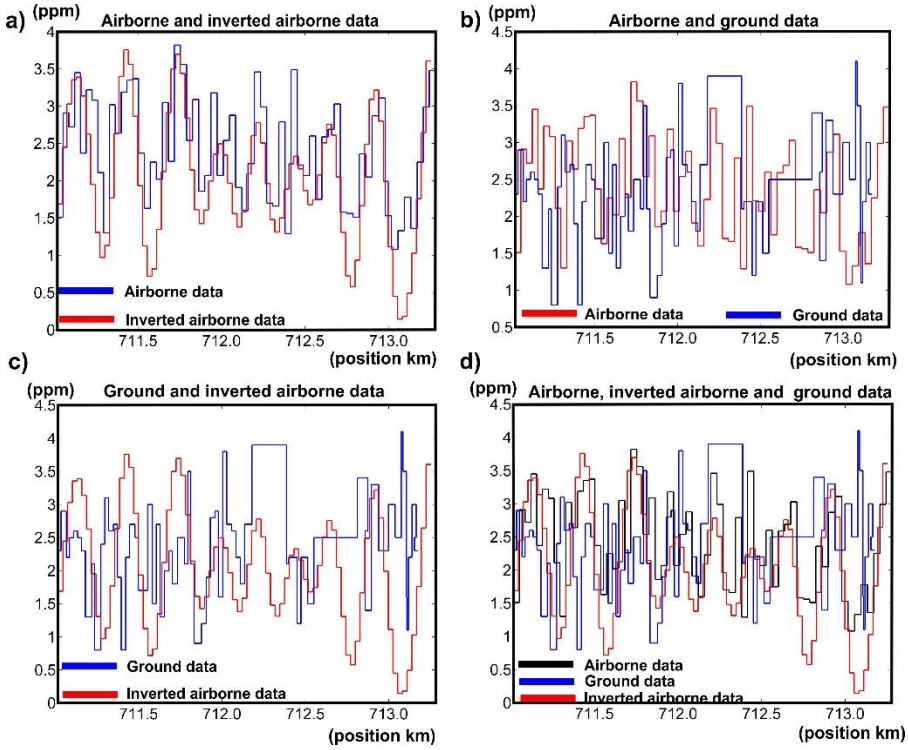

Figure 7 – *Comparison of uranium data. Airborne and inverted airborne (a). Airborne and ground (b). Ground and inverted airborne (c). Airborne, inverted airborne and ground data (d).*

The inversion responses of the radionuclides (K, eTh and eU) showed compatibility with both airborne and ground data. Note that in almost every comparison the inverted concentration is lower than the conventional one, which could possibly be explained by the correction of the successive overlays of gamma-ray spectrometric readings.

Considering that uranium is known by its disequilibrium, its response to the inversion method is a great improvement as it has the better correspondence among the other radionuclides (K and eTh). The uranium results were outstanding, considering that it is the radioelement which produces more errors and noise.

Conclusions

The inversion methodology is an improvement towards the conventional methods, as it suppresses the overlapping problem and tends to smooth out the data. As inversion uses a forward model that follows physical principles to infer the values of the parameters that characterize the system, it should provide good results. The inversion procedure applied in this work could be tested in airborne gamma-ray spectrometry survey data, which should suppress the flight height variations, especially in mountainous regions. The field of view overlap should also be suppressed, reflecting in smoother results. Our results were satisfactory and showed consistency between inverted and conventional data.

Acknowledgments

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