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On background radiation gradients – the use of airborne surveys when searching for orphan sources using mobile gamma-ray spectrometry

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ABSTRACT

Systematic background radiation variations can lead to both false positives and failures to detect an orphan source when searching using car-borne mobile gamma-ray spectrometry. The stochastic variation at each point is well described by Poisson statistics, but when moving in a background radiation gradient the mean count rate will continually change, leading to inaccurate background estimations. Airborne gamma spectrometry (AGS) surveys conducted on the national level, usually in connection to mineral exploration, exist in many countries. These data hold information about the background radiation gradients which could be used at the ground level.

This article describes a method that aims to incorporate the systematic as well as stochastic variations of the background radiation. We introduce a weighted moving average where the weights are calculated from existing AGS data, supplied by the Geological Survey of Sweden. To test the method we chose an area with strong background gradients, especially in the thorium component. Within the area we identified two roads which pass through the high-variability locations. The proposed method is compared with an unweighted moving average. The results show that the weighting reduces the excess false positives in the positive background gradients without introducing an excess of failures to detect a source during passage in negative gradients.

1. Introduction

In mobile gamma-ray spectrometry, systematic changes in the background components can be a great challenge, e.g. when searching for orphan sources (Aage and Korsbech, 2003; Cresswell and Sanderson, 2009; Kock et al., 2010). The possibility to use airborne gamma spectrometry (AGS) records as background estimates at the ground level has been suggested (IAEA-TECDOC-566, 1990). In a study conducted in areas with highly variable background levels comparing terrestrial and airborne spectra, a strong correlation between terrestrial and AGS measurements was shown (Kock and Samuelsson, 2011). Areas with high variability are also expected to cause more false positives (type I errors) than more homogeneous areas. Thus, background estimations based on AGS data should be useful in high-variability areas, where the data is expected to correlate well.

Statistical hypothesis testing is a common way to indicate increased levels of radioactivity (Currie, 1968; Hjerpe et al., 2001; Strom and MacLellan, 2001). Ideally, a method should have a false alarm rate close to the predefined rate, α, and high power, $1-\beta$, where β is the probability of a false negative (type II error). Different methods exist that can be used when searching for orphan sources, e.g. (Aage and Korsbech, 2003; Cresswell and Sanderson, 2009; Kock et al., 2010; Hjerpe and Samuelsson, 2003; Méray, 1994). Strom and McLellan compared false alarm rates of eight statistical tests and found that many of these deviated from the predefined false alarm rate (Strom and MacLellan, 2001). In a recent study we incorporated the information from the spectral distribution of the gamma counts and found that this increased the true positive rate, i.e. power, of the test (Kock et al., 2012).

Apart from the random fluctuations, which can be modelled using statistical techniques, there is also the problem of different fields of view between the ground based system and an airborne system. The photon fluence can be mathematically expressed as a function of height and radionuclide distribution in the ground (ICRU Report 53, 1994) and the detector response can be modelled or simulated (Billings and Hovgaard, 1999). The problem has also

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been studied in field studies and exercises, cf. e.g. (Kock and Samuelsson, 2011; Sanderson et al., 2003; Hovgaard and Scott, 1997). However, it should be recognized that uncertainties introduced by unknown radionuclide distributions, topography and geology as well as shielding materials can lead to problems when comparing measurements conducted at the ground level to an airborne survey.

When entering an area with a positive background radiation gradient without any *a priori* knowledge one would expect an excess of false positives, compared to the predefined level of significance, α. Trying to assess the background while moving in the gradient by means of, for example, a moving background (MB) (Hjerpe and Samuelsson, 2003), would mean that the background estimate is always too small compared to the background acquired at the current position. Analogously, while moving in a negative gradient, i.e. decreasing levels of background radiation, one would expect an increase in the number of false negatives, i.e. a lower power of the test, $1-\beta$.

One method to estimate the height of a peak is to use a trapezoidal formula (Ramirez and Wielopolski, 1994). This method, which is mostly applied to high-resolution spectra, uses a background region on either side of an isolated peak and assumes a linear background under the peak (Gilmore, 2008). The trapezoidal method can also be used in mobile gamma-ray spectrometry to estimate the net counts in a region of interest (Kock and Samuelsson, 2011). Another common technique, mostly used with low-resolution spectrometers, is the spectral windows method where a stripping matrix is used to subtract the contributions from K, eU and eTh (ICRU Report 53, 1994; IAEA Technical Report Series 323, 1991). Both methods estimate the background from the spectrum itself, which can be problematic in mobile gamma-ray spectrometry considering the short sampling times needed to attain good spatial resolution. The alternatives are to estimate the background from the latest n samples, e.g. by means of a moving average (Cresswell and Sanderson, 2009; Kock et al., 2010; Hjerpe and Samuelsson, 2003), or to use a previously measured set (Hjerpe et al., 2001).

Many countries have AGS capabilities, cf. (Sanderson and Ferguson, 1997; Zhang et al., 1998; Grasty, 1995; Bristow, 1983; Martin et al., 2006; Toivonen, 2004), and have conducted baseline surveys, often in connection to mineral exploration. This work aims to explore the use of existing AGS measurements, which incorporate the systematic variations, along with statistical methods that handle the stochastic fluctuations. When searching for orphan sources, the combination of these methods could be used to avoid or at least reduce the number of additional false positives while in a positive gradient, and potentially increase the power of a test while in a negative gradient.

2. The survey area

An area (9×9 km^2, centre N 56° 15.379′, E 14° 13.769′) in the southern part of Sweden (Scania, *sv.* Skåne) with strong gradients in the background radiation was identified by studying AGS data supplied from the Geological Survey of Sweden (SGU). The area is rural, covered by forest with a few small villages and dwellings connected with asphalt or gravel roads. Several small lakes as well as part of a larger lake (Immeln) are within the bounds of the area. However, the lakes are too far away from any road (>200 m) to influence the measurements of this study. The general topography is flat, but some hills rise as high as 30–40 m above the surroundings.

As can be seen in Fig. 1, the variations are largest in the eTh and eU components, while ^{40}K activity shows a more modest variation. An area extending in the north-northeast direction located in the middle of the figure shows increased eTh concentrations up to a factor 6–7 times those of the surroundings. The chosen area is well suited to test methods that account for systematic changes in the background radiation, since it has such a distinct subarea with elevated background radiation levels. The chosen area is also crossed by a number of roads, making it suitable for car-borne gamma spectrometry (CGS) surveys. In Fig. 2, two excerpts from the roads within the area are marked, henceforth referred to as 'route I' and 'route II'. Both pass through the area with increased eTh levels extending in the north-northeast direction of the area.

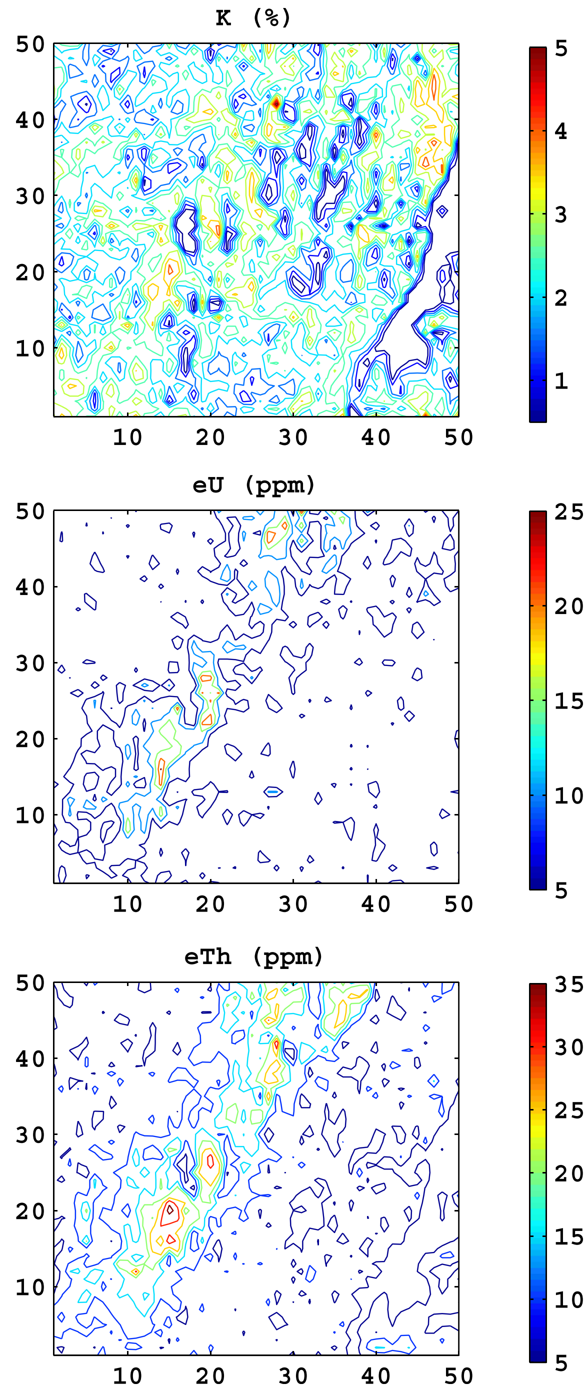

Fig. 1. Contour plots of interpolated AGS data on a 50×50 grid (cell size 180×180 m^2).