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High resolution observations of ^{137}Cs in northern Britain and Ireland from airborne radiometric data

Cathy Scheib* & David Beamish

British Geological Survey
Keyworth
Nottingham NG12 5GG
UK
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SUMMARY

This study presents high-resolution airborne geophysical estimates of the distribution of 137Cs across three areas of northern Britain and Ireland. The radiometric spectra were acquired as part of a program of modern resource and environmental surveying. The largest survey area considered covers the whole of Northern Ireland. All three data sets display some clustering on high ground together with regional scale banding features. The two main banding directions are approximately NNW-SSE and NW-SE. Our interpretation of the regional scale features is in relation to existing knowledge of the wet deposition model of the Chernobyl release of 1986. The airborne estimates, obtained at 200 m flight line intervals, add significant detail in relation to the meteorological and atmospheric interactions involved in the fallout from the Chernobyl plume over Western Europe.

Introduction

Airborne radiometric or gamma-ray surveys were historically most commonly used as part of mineral exploration surveys. A new generation of regional and national scale High Resolution Airborne Resource and Environmental Surveys (HiRES) are being conducted in the UK as part of revised priorities in the geosciences. The surveys employ a 'three-in-one' measurement system comprising magnetic, radiometric and active electromagnetic sensors. A flight line spacing of 200 m has been adopted with a nominal survey altitudes of 56 m (244 m above elevated structures).

The radiometric spectra are routinely processed to provide information on the naturally-occurring radionuclides potassium, thorium and uranium. This information, along with 'Total Count' derived from the whole spectrum, is then used in resource, environmental, soil, land-use and health (e.g. radon) assessments. The recorded spectra also contain information on man-made radionuclides, such as ^{137}Cs. The purpose of the present study is to report on three HiRES surveys whose radiometric spectra have been processed to provide estimates of the distribution of ^{137}Cs across northern areas of the UK and Ireland. Our largest data set is from the Tellus survey of Northern Ireland (> 82,000 line-km), comprising over 1.2 million data points. The ^{137}Cs estimates obtained from two further survey areas in the Republic of Ireland and in southern Scotland are also presented.

The Chernobyl reactor accident of April 26, 1986 introduced a specific spatial variability into the distribution of ^{137}Cs across the Northern Hemisphere. Distinct local patterns of enhancement were formed which reflected air mass trajectories and the incidence of precipitation at the time that the Chernobyl atmospheric plume passed overhead (Clark and Smith, 1988). Our interpretation of the features observed lies within the framework of existing models of the interception of the Chernobyl plume of April- May 1986 by a series of discrete rainfall events. Our observations appear to provide significant detail in relation to this existing model of large-scale 'wet-deposition'. Finally, since ^{137}Cs is also used as a tracer for studying rates of erosion, the ^{137}Cs data from areas of high ground have been examined in relation to detailed DTM information.

^{137}Cs processing

The ^{137}Cs concentrations in kBq m^{-2} were estimated by applying a least-squares method to the 256-channel data using the Praga3^{TM} full spectrum processing extension of Geosoft Oasis Montaj^{TM} software. The least-squares fitting process applied uses a set of model detector responses (weighted least-squares fitting algorithms) to find contributions of individual nuclides to the input spectrum and was designed primarily for the processing of man-made radiation data. The software allows visual browsing of the raw and processed spectra to achieve parameter optimisation. Peak location averaging tools which track spectral drift ruled out any problem with spectrometer stability.

256-channel spectra, along with accurately known positional information, radar altimeter height information and temperature data were quality checked and combined in season/ survey specific databases. Spectra were initially energy calibrated within the software using photopeaks of natural radionuclides from an average input spectrum. Season-specific stripping ratios were used during the fitting process; aircraft and cosmic background parameters were removed and height correction was completed.

^{137}Cs results for Northern Ireland

The ^{137}Cs estimates are obtained at the same sampling rate as the radiometric data i.e. at about 60 m intervals along flight lines and at 200 m line separations. The exponential height attenuation corrections applied to the data set are only valid up to a flying height of about 160 m for ^{137}Cs due to the exponential depth distribution assumption used. Although corrected for height, the ^{137}Cs data have been masked at survey altitudes > 160 m. The Cs data set is also masked at the coast, together with the main inland water body of Lough Neagh. This reduced data set comprises 1 195 148 data values with a range from -4.15 to 9.88 kBq m^{-2}. The mean of the data set is 2.03 kBq m^{-2} and the distribution is close to normal. The statistics are consistent with figures obtained from ground-based inventories. The data, in conventional geophysical terms, possesses high variance with low signal-to-noise attributes.

The resulting Tellus ^{137}Cs data set is shown in Figure 1 as a colour-scale image draped on a digital terrain model to reflect some of the spatial terrain aspects of the distribution observed. The high-fly areas are indicated by cross-hatch zones showing towns with a population greater than 1000 people.

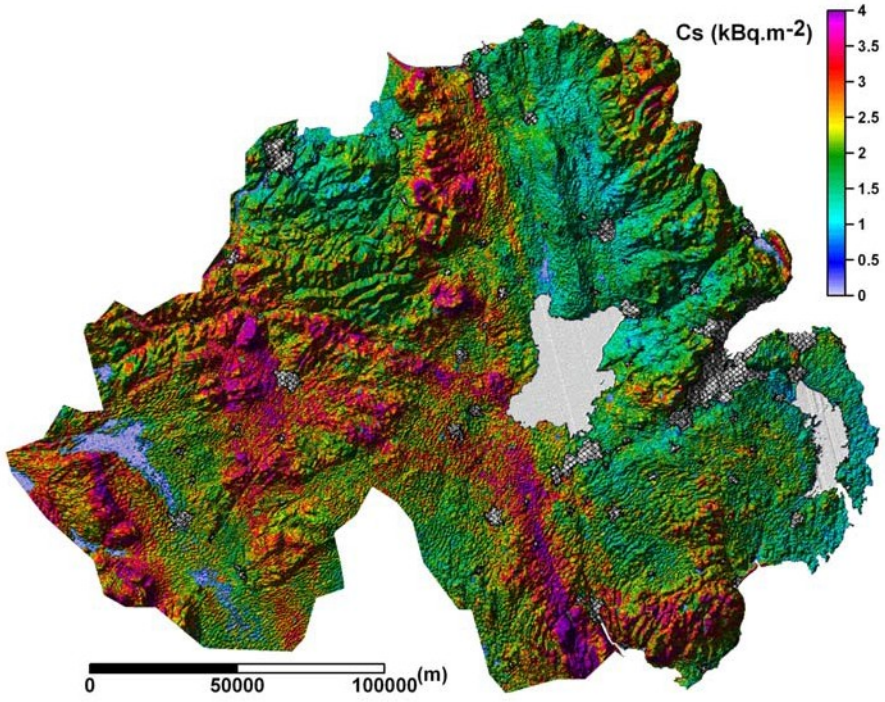

Figure 1. The ^{137}Cs distribution obtained from the Tellus survey of Northern Ireland. A continuous colour image derived from 100 x 100 grid cells is shown draped on a base DTM. The distribution is cut to the coast. Centres of population (>1000 people) are shown shaded with cross-hatch.

The high amplitude zones display both clustering on high ground together with regional scale banding. The banding is observed to occur in two distinct directions which are approximately NNW-SSE and NW-SE and cut across both high and low topographic features. In detail there are also a number of high amplitude clusters, including some extensive coastal zones, which warrant further investigation.

The banding along the NNW-SSE direction is close to the survey line direction of 345° and this has prompted a series of further investigations into the validity of the processed data. The estimates obtained, as above, have been compared to independent results from orthogonal tie-line survey data obtained in the western area. The main banding features in both NNW-SSE

and NW-SE directions are verified. A further feature of the banding, that of the sharp (or high gradient) edges of the band distribution, is also confirmed. An independent ground investigation of our results was undertaken in September 2007 by the University of Stirling Environmental Radioactivity Laboratory. A principal aim was to investigate the airborne estimates by performing in situ gamma spectrometry (IGS) with a germanium detector along transects crossing the main banding directions. Soil coring was also employed to provide additional information on the ^{137}Cs distribution to a depth of 45 cm. The data comparisons indicated that the IGS measurements provided slightly higher estimates of the ^{137}Cs inventory than the airborne measurements (Tyler et al., 2008). This difference is in part due to the fact that the airborne procedure assumes an exponentially decreasing model for the depth distribution. The soil coring provides information on this distribution and it was noted that soil cores along three of the profiles indicated significant departures from the simple exponential model (e.g. the development of subsurface maxima) (Tyler et al., 2008). Despite the wide differences in the fields of view of the IGS and airborne measurements, the overall comparison of the two data sets indicated a good level of correspondence and again supported the existence of banded features..

Further Cs results

The ^{137}Cs results from two other surveys, in the Cavan area of the Republic of Ireland (1503 km^2) and in Ayshire, Scotland (1000 km^2) are shown, in conjunction with the Tellus results in Figure 2. Survey acquisition parameters were identical apart from the E-W flight line direction used in the Ayrshire survey. The colour range is from 0 to 4 kBq m^{-2} and the higher levels found in SW Scotland together with a prominent NNW-SSE band on the high ground in east of the area can be noted.

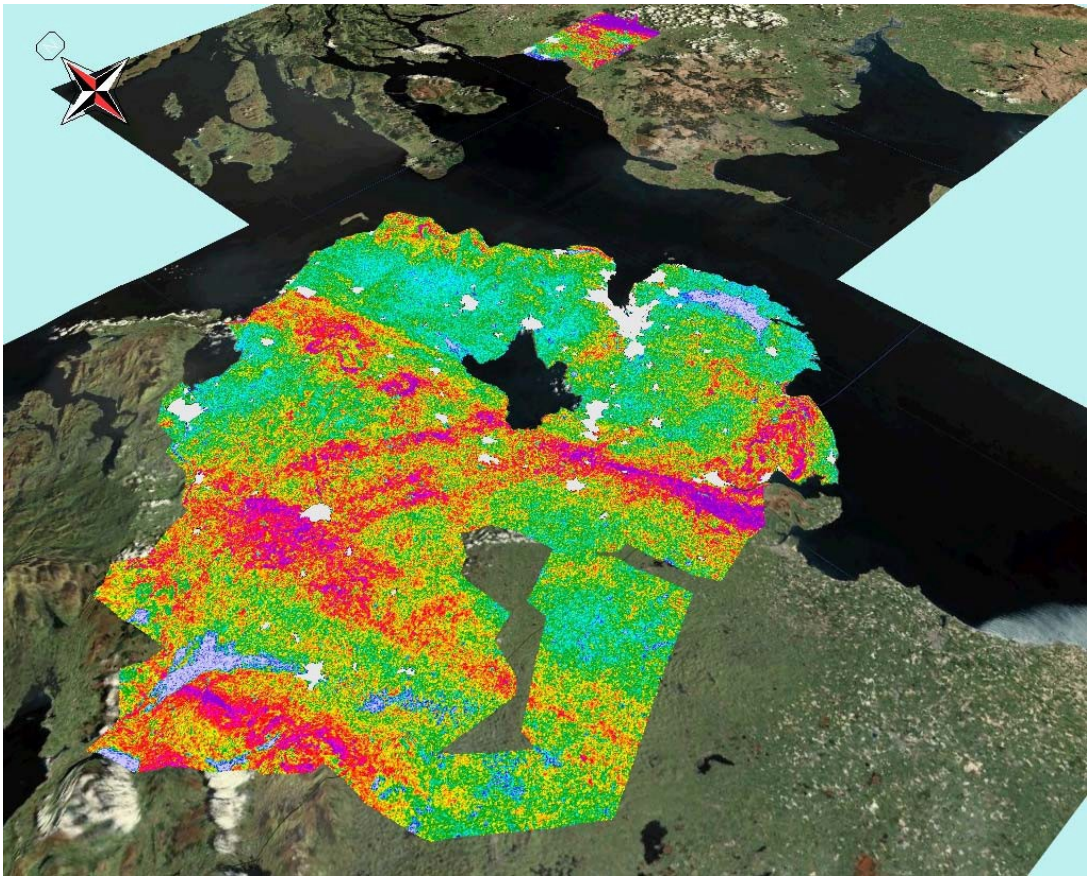

Figure 2. Perspective view of the ^{137}Cs distribution for all three survey areas discussed in the text. The colour range (grey to purple) is from 0 to 4 kBq m^{-2}.

Interpretation

The three sets of high resolution ^{137}Cs survey results presented here constitute what we consider to be some significant, detailed and extensive observations of the pattern of ^{137}Cs distribution over northern parts of the UK and the Republic of Ireland. The contributions will result from a combination of nuclear weapons testing and the Chernobyl accident of April 1986. The northern portions of Britain and Ireland are known to have received combinations of rainfall during the passage of the Chernobyl plume (Clark and Smith, 1988). Smith and Clark (1989) provide a detailed description and analysis of the atmospheric debris (the Chernobyl plume) that crossed Britain a week after it was emitted and was repeatedly intercepted by rainfall events that resulted in selective wet-deposition. The majority of wet deposition occurred over two days (02 to 04 May 1986) and Clark and Smith (1988) provide maps of the rainfall that intercepted the plume and thus an estimate of total deposition that resulted from atmospheric washout. Our data compare favourably with these interpretations.

Much of the rain affecting the Chernobyl plume over Britain came from deep convective storms. These left narrow footprints of rainfall elongated alongwind, with similar footprints associated with the resulting deposition. Our observations appear to provide previously unknown detail in relation to existing knowledge of along-wind deposition from the Chernobyl plume.

In addition, our high resolution ^{137}Cs results contain detailed information that can be used in a range of studies such as quantifying erosion and sedimentation rates. It is known that following fallout deposition, ^{137}Cs is strongly bound to the upper horizons in soil. Subsequent redistribution occurs primarily through erosion and sedimentation (Mabit et al. 2008). The ^{137}Cs data from areas of high ground have been examined in relation to detailed DTM information. The results appear consistent with existing erosional model concepts in which reduced ^{137}Cs inventories are associated with convex slopes (e.g. hilltops) and are increased in rapidly eroding areas associated with depressions and run-off. We would argue that the correspondences observed indicate the detailed integrity and utility of the airborne estimates.

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References

Clark, M.J. and Smith, F.B., 1988. Wet and dry deposition of Chernobyl releases. Nature, 332, 245-249.

Mabit, L. Benmansour, M. and Walling, D.E., 2008. Comparative advantages and limitations of the fallow radionuclides 137Cs, 210Pbex and 7Be for assessing soil erosion and sedimentation. Journal of Environmental radioactivity, 99, 1799-1807.

Smith, F.B. and Clark, M.J., 1989. The transport and deposition of airborne debris from the Chernobyl nuclear power plant accident with special emphasis on the consequences to the United Kingdom. Meteorological Office, Scientific paper No. 42, HMSO, 56pp.

Tyler, A., Scheib, C., Bradley, S., Jones, D. 2008. Ground Reference Data Collection: Validation of the Tellus Airborne Gamma Spectrometry Survey of Northern Ireland. University of Stirling; Environmental Radioactivity Laboratory. ERL Project Reference: P030 0507 Date: 18/12/08.