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European Calibration and Coordination of Mobile and Airborne Gamma Spectrometry

(ECCOMAGS)

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Introduction

Airborne Gamma Spectrometry (AGS) utilises highly sensitive radiation spectrometers mounted in low-flying aircraft to record variations in terrestrial radiation fields. The combination of high fields of view (10^4-10^5 m^2), rapid measurement (1-10s per measurement) and high detector mobility (30-50 m s^{-1}) results in area sampling rates (10^7-10^8 m^{2}hr^{-1}) which are many orders of magnitude higher than can be achieved using conventional ground-based measurement methods. In recent years the number of AGS teams in Europe has increased and the techniques and instrumentation have advanced considerably, including developments in software systems making it possible to analyse survey data in real time or near real time. The ability of the method to map deposition rapidly over large areas has been established by work conducted individually by AGS teams in Europe and elsewhere. The ability of teams to work together producing compatible results despite diversity of equipment and methods, and to produce results which are quantitatively traceable to ground-based measurements, was the focus of this project. As a result of the ECCOMAGS project, the validity of the AGS method, which has vital importance of emergency response, can now be clearly demonstrated.

Objectives

The main aims of the ECCOMAGS project, building on collaborative links established under the Fourth Framework Programme, were to conduct an international AGS intercomparison exercise and to coordinate AGS work through specific workgroups and network activities.

Whereas other regional scale radiometrics exercises had examined source location, and the relationships between carborne gamma spectrometry (CGS) and AGS systems, the ECCOMAGS exercise was aimed at validation of protocols for quantitative deposition and dose-rate mapping using AGS. Documentation of measurement protocols and predefinition of comparisons were important parts of exercise design. Establishing traceability of AGS to ground-based methods required a significant contemporary set of ground-based measurements in the study areas. An additional aim was to demonstrate the ability of AGS teams to cooperate in the rapid mapping of a large area through a composite mapping task.

The second objective of the project was to maintain and develop the coordination and communication in AGS and mobile gamma spectrometry research based on the cooperative links established under the previous Concerted Action. Two areas where several different teams within Europe are already conducting research which could benefit from coordination of effort were identified: investigation of different methods of spectral analysis and the use of other platforms, specifically unmanned aircraft, for mobile spectrometric measurements. Workgroups studied the potential for cooperation in each of these areas.

Results

Prior to project start-up three possible areas for the exercise venue were identified, from which the UK venue in SW Scotland was selected. The area provided a varied range of environments with significant variations in ^{137}Cs deposition levels and dose-rates. More than 150 people, from 18 institutions and 10 European countries, participated in the exercise which took place in May/June 2002. A unique assemblage of data comprising more than 120 000 NaI(Tl) and 20

000 Ge AGS spectra, along with more than 750 laboratory gamma spectrometry analyses from 45 ground sites and some 120 in-situ observations, was achieved.

To ensure traceability an extensive programme of ground-based sampling and measurements was implemented. Due to the time scale required for laboratory gamma spectrometry analysis of soil core samples, a two stage approach, with pre-characterisation of calibration sites in November 2001 and further measurements of additional sites during the exercise, was adopted. In the first stage, three calibration sites were established in the vicinity of the exercise venue. Soil cores were collected from an expanding hexagonal pattern at each of these sites and divided into sections to determine the depth distribution of activity. During the exercise further ground-based work was undertaken. To maintain the objectivity of blind comparisons, 42 additional ground locations, covering the range of ^{137}Cs activity levels, were investigated during the exercise with 4 soil cores taken at each site together with dose-rate and in-situ measurements.

The core samples from both phases were dried, ground, homogenised and distributed to several laboratories for high-resolution gamma spectrometry. IAEA reference materials and common bulk samples from the calibration sites were provided to each laboratory to ensure traceability between the laboratories, and account for any discrepancies between them. There was good agreement between the different laboratories for measurements of the bulk samples. The average of results produced by each laboratory for the IAEA materials does agree with the recommended values, though there is considerable inter-laboratory variation. These results can thus be used to show traceability to IAEA reference materials for the soil analysis. Analysis of the soil samples from the measurement locations evaluated the mean activity concentrations for ^{40}K, ^{238}U and ^{232}Th and the activity per unit area and associated mean mass depth for ^{137}Cs.

In-situ gamma spectrometry and instrumental dose-rate measurements were made by all instruments on the centre point of each of the three calibration sites to allow comparisons between instruments, with the 42 additional sites being distributed amongst the teams. Initially, the in-situ data were submitted using a range of calibration assumptions, these were later recalculated to a common system; a uniform depth profile for ^{40}K, ^{238}U and ^{232}Th and an exponential profile with 8.5 g cm^{-2} relaxation mass for ^{137}Cs. For both ^{137}Cs and the natural series, activity concentrations were significantly underestimated compared to the soil core data, with significant improvement when normalised using data from the Inch Farm calibration site. The ^{137}Cs activity per unit area was also calculated with a relaxation mass depth determined from the soil core data, this improves the agreement between the soil cores and in-situ gamma spectrometry, though doesn’t account for all the differences implying that the soil cores are not representative of the field of view of the spectrometers. The instrumental dose-rates showed considerable variation on the calibration sites, and were consistently less than the dose-rates determined from the soil core and in-situ gamma spectrometry data. The dose-rates estimated from gamma spectrometry methods, traceable to IAEA reference materials, have been used for the ground to air comparisons.

For AGS measurements, 3 common areas were defined covering the range of environments in the region, with 9 adjacent composite areas covering an area of some 90 x 40 km. Each operational airborne team conducted measurements over each of the common areas and the three calibration sites, with 5 aircraft surveying the composite areas collaboratively. The analysis of the data for the common areas followed a pre-documented procedure. This consisted of initial descriptive analysis followed by further analysis on data after levelling using calibration site data, a procedure of the sort likely to be used in data assimilation for emergency response, and re-gridding onto a common spatial grid, allowing direct point-to-point comparisons.

Summary statistics show broad agreement over the three common areas, with mean ^{137}Cs activities having a slightly smaller range than dose-rates. Cumulative distributions show broadly similar general shapes, with differences in the lower tails close to limits of detection and some offsets. Flight line profiles also show broad similarity in the features identified. The differences that are observed can mostly be explained by calibration differences, particularly the depth profiles assumed for ^{137}Cs. After initial descriptive analyses, levelling was used to reduce the importance of diverse calibration assumptions, and the data re-gridded. Images of this data show good agreement, with a few notable differences. The ^{137}Cs inventory analysis shows differences of less than 25 % on Chernobyl contaminated terrestrial areas, with higher variations on lower activity areas and salt marshes. Investigation of shapes of radiometric features show that the salt marshes and lochs within moderately contaminated areas are well defined by all teams, with relatively minor differences. Regressions between each team and the mean reference data set generally show good fits, with slopes close to unity although the dose-rate data show some significantly non-zero intercepts.

Following distribution of the draft comparisons report, revised data sets were received from three teams. These revisions had little overall effect on the collective results, but were analysed and taken into account in the final conclusions. Four of the airborne teams also submitted data collected using Ge semiconductor detector systems, this data shows the same general patterns of ^{137}Cs distribution as the NaI(Tl) spectrometers in areas with activity concentrations above approximately 10 kBq m^{-2}, though for lower activity areas statistical uncertainties dominate unless the spectra are recorded with long integration times resulting in reduced spatial resolution.

Average ^{137}Cs activities and dose-rates in different environmental compartments for the airborne and ground-based methods have been determined, along with point wise regressions for the 42 ground sites. On the terrestrial environments there is good agreement between all methods. However, on the salt marshes both airborne and in-situ methods underestimate these quantities compared to the soil cores. Where the depth profile of activity is approximately that of the calibration assumptions, AGS and ground-based methods produce highly comparable results. These results have shown convincingly that AGS methods are capable of producing quantitative data which are consistent with ground-based observation while being spatially more numerous. In this respect the exercise results have fulfilled their validation aims.

The composite mapping area of some 90 x 40 km was surveyed within a three day period by 5 aircraft. The first maps of the whole area were produced within one day and published on the exercise website a few days later. The maps were finalised, and digital data transferred to UK and European data management systems within one week. The composite mapping results were presented at an international symposium ten days later. Thus it has been possible to demonstrate the speed and ease with which European AGS teams are able to work together and record compatible data over a variable set of environments. The effectiveness of simple levelling procedures for producing an effectively seamless set of mapped data has also been verified. The ability to gather, assemble and disseminate such data within only a few days shows the potential for cross-team cooperation of the sort that would be needed for mutual assistance or integrated European operations.

The spectral analysis workgroup surveyed and analysed current and future research needs across the European partnership through a questionnaire and workshop. In addition to windows-stripping methods, the Peak Isolation Method and Noise Adjusted Singular Value Deconvolution (NASVD) are used to analyse NaI(Tl) data, and an objective comparison of these methods is needed. The need for an exchange format for full spectral data sets was recognised, for research and data-exchange purposes, as no format for the bulk transfer of the very large numbers of spectra generated during airborne surveys existed. A European Radiometric and Spectrometry (ERS) format was defined within the workgroup and has been assessed and documented for future use. Several teams are using Ge detector systems in conjunction with NaI(Tl) systems, or are exploring the possibility of doing so. Future work is needed to develop new approaches spectral analysis of data sets from combined NaI(Tl) and Ge spectrometers.

The other platforms workgroup explored the key aspects of using Unmanned Aerial Vehicles (UAVs) for radiometric measurements, with a large part of the activities being to examine and document the potential roles of UAVs, particularly in the context of nuclear emergency response, the technical and regulatory requirements for operation of UAVs and characteristics of radiometric detection systems. It is clear that there are many potential scenarios where the use of fully robotic AGS capabilities would be significantly beneficial in minimising risk and hazard to personnel, including plume mapping and surveys of highly contaminated areas. Additionally, there is a potential use in conducting supplementary measurements of relatively small areas with high spatial resolution to complement other radiometric methods. Though common in military applications for surveillance and reconnaissance, civilian applications for UAVs are only gradually emerging. The main obstacle to civilian UAV use is aviation legislation, in particular in relation to airspace regulations and airworthiness certification.

Implications

The ECCOMAGS project has successfully conducted an international collaborative trial of the AGS method. It has clearly demonstrated the capability of the technique to rapidly map large areas and the comparability of dose-rate and activity measurements with ground-based methods. In terms of rate of data collection and area coverage it is in many ways superior to conventional methods, and clearly has a very important role to play in nuclear emergency response and environmental surveys.

The comparative analyses conducted on the exercise data sets have verified that the AGS technique is capable of producing data which are not only self-consistent, but which also compare favourably to conventional ground-based approaches. The data set collected does address the central validation aims of the exercise. On this basis a case can be made for validation of the AGS measurement protocols relative to ground-based methods, and it has been recommended that the possibility of utilising this work to initiate standardisation through national or European agencies should be pursued. The composite mapping task has demonstrated the ability of European AGS teams to cooperate in large scale mapping tasks on emergency time scales.

Variations between the measurements of common sites or samples by different laboratories, ground-based teams, and instruments show the value in regular inter-calibration trials to maintain the capability to consistently collect high-quality data. The very significant variations with dose-rate instruments, and considerable disagreement with dose-rate determined by spectrometric methods, in particular indicates the need for future work to investigate ways of using such instruments to produce quality data comparable to other methods.

The project also identified several areas where further development of the technique in a collaborative manner would be advantageous. These include methods for data analysis, including the use of a variety of complementary detector systems, and the potential of the use of unmanned aircraft for this sort of survey where contamination of the aircraft and exposure of operators is a potential concern. To further the ability of AGS teams to exchange data for collaborative research and survey tasks, a spectral data exchange format has been defined.