GIS supported calculations of ^{137}Cs deposition in Sweden based on precipitation data

S. Almgren[1], E. Nilsson[1], B. Erlandsson[2], M. Isaksson[1]

[1]Department of Radiation Physics, Göteborg University, Sweden

[2]Department of Nuclear Physics, Lund University, Sweden

Abstract: ^{137}Cs deposition maps were made using Kriging interpolation in a Geographical Information System (GIS). Quarterly values of ^{137}Cs deposition density per unit precipitation (Bq m^{-2} mm^{-1}) at three reference sites and quarterly precipitation at 62 weather stations distributed over Sweden were used in the calculations of Nuclear Weapons Fallout (NWF). The deposition density of ^{137}Cs, resulting from the Chernobyl accident, was calculated for western Sweden using precipitation data from 46 stations. The lowest levels of NWF ^{137}Cs deposition density were noted in the northeastern and eastern Sweden and the highest levels in the western parts of Sweden. The Chernobyl ^{137}Cs deposition density is highest along the coast in the selected area and the lowest in the southeastern part and along the middle. The sum of the calculated deposition density from NWF and Chernobyl in western Sweden was compared to accumulated activities in soil samples at 27 locations. Comparisons between the predicted values of this study show a good agreement with measured values.

Introduction

Nuclear weapons fallout (NWF) over Sweden from has occurred since the 1940s over Sweden, where most of this deposition can be attributed to tests carried out between 1962 and 1966 on Novaya Zemlya, although Chinese tests also made a contribution in the ´70s. The accumulated deposition density over Sweden from nuclear weapons tests is about 3 kBq/m^2: De Geer et al. (1978), and, in addition to this, the Chernobyl accident contributed with a deposition density varying from close to zero to well over 100 kBq/m^2, within a restricted area, SGAB (1986).

Several studies have shown that the variations in deposition density are closely related to the precipitation, e.g. Bergan, 2002; Schuller et al., 2004. The deposition of radioactive elements could therefore be estimated by relating the measured activity concentration in the precipitation (Bq L^{-1} = Bq m^{-2} mm^{-1}) at a reference site to the amount of precipitation in a geographical region (e.g. Isaksson et al., 2000; Wright et al., 1999). The point-estimates could then be interpolated to a deposition map using a Geographical information system (GIS). The development of reliable methods for predicting the spatial variation and amount of ^{137}Cs deposition following nuclear accidents or nuclear weapons explosions are of interest in e.g. emergency preparedness and by including weather forecasts from meteorological data sources a prediction of the effects of a release of radioactive elements to the atmosphere could be made. The aim of this study was to determine the deposition of ^{137}Cs due to fallout from nuclear weapons tests (NWF) over the whole area of Sweden and from the Chernobyl accident in a predefined area in the western part, visualize the results in deposition maps and compare the maps with measurements.

Material and methods

Nuclear Weapons Fallout: For the estimation of NWF three reference sites in Sweden (Kiruna, Grindsjön and Göteborg) were initially chosen since they represent areas with different mean quarterly precipitation rates and also since they had an almost complete data record of quarterly ^{137}Cs deposition density for the time period studied, 1962-1966. The period 1962-1966 was chosen since the major part of the radioactive debris was injected into the atmosphere during the periods 1952-1958 and 1961-1962 (UNSCEAR, 2000), and because no data was available prior to 1962. The deposition density per unit precipitation (Bq m^{-2} mm^{-1}) at the reference sites was found by dividing the quarterly deposition density by the quarterly precipitation. The quarterly precipitation during the years 1962-1966 at 61 weather stations, distributed over Sweden was provided by the Swedish Institute of Meteorology and Hydrology (SMHI), as well as the coordinates of the weather stations. Each reference site was then assumed to represent an area of Sweden with approximately the same quarterly mean precipitation as the reference site itself. Due to seasonal variations in the precipitation pattern these reference sites were used in different combinations to find the best way of accurately representing the deposition density over the Swedish territory. The quarterly ^{137}Cs deposition density at a weather station was found by multiplying the amount of precipitation with the deposition density per unit precipitation at the corresponding reference site for each quarter during the period 1962-1966. This was then used to calculate the integrated and cumulative deposition density for the whole period. Deposition maps were created with ordinary Kriging interpolation in the GIS software ArcView (ESRI, Environmental Systems Research Institute, Redlands, California.

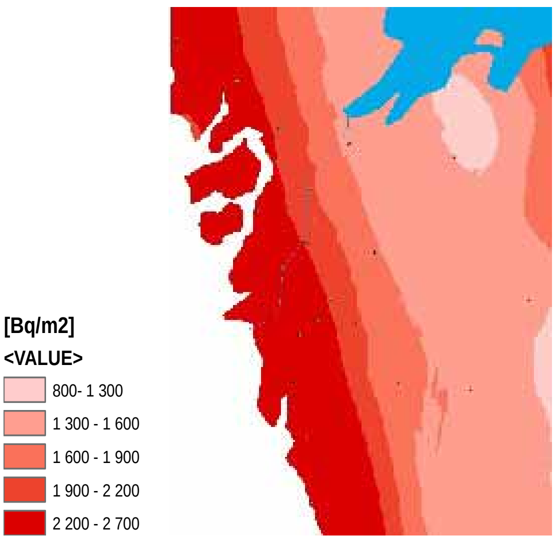
The Chernobyl fallout: This study has been concentrated to an area with a radius of approximately 120 kilometres with Göteborg in the centre. Earlier, 27 reference sites have been established for environmental monitoring, which gives the opportunity to compare the results of fallout estimations to measurements performed at those sites. In a similar way as for the NWF the ^{137}Cs deposition in the area was related to the precipitation. Göteborg was chosen to be the reference site because measurements of activity concentration in precipitation and deposited material were made at the time of the accident: Mattsson and Vesanen, (1988). The main part of the total ^{137}Cs deposition came in the rain that fell in Göteborg on the 8th of May, 1986. The activity concentration in the rain water decreased rapidly with the first millimetres and at a slower rate when the amount of rain increased, which can be well approximated by a double exponential function, Equation (1). After integration the total amount of deposited cesium is a function of the local precipitation according to

$$A = 2690 - 609e^{-x_{max}/0.34} - 2080e^{-x_{max}/5.07} \quad [\mathrm{Bq/m^2}] \qquad (1)$$

x_{max} is the total amount of rain. The parameters were obtained by fitting the double exponential to the data by Mattsson and Vesanen (1988). We assume that the main part of the Chernobyl fallout was wet deposited in the rainfall on the 8th of May and that equation 1 is valid in the whole region. A precipitation map for the 8th of May were derived by ordinary Kriging interpolation in a GIS with data provided by SMHI from 46 raingauge stations relatively well spread out in the region. Equation 1 was then applied to the precipitation layer in the GIS resulting in a deposition map of the area. The deposition layer could easily be merged with the ones from the NWF calculations thus representing the total integrated or cumulative ^{137}Cs deposition in western Sweden. The Chernobyl deposition map was compared with aerial measurements, SGAB (1986) and the total deposition, corrected for decay until 2003, with the accumulated activity in soil samples from the 27 sample locations.

Results and discussion

NWF: The deposition density of ^{137}Cs for each quarter was interpolated and summed to an integrated and a cumulative (decay corrected to 1994 and 1985, respectively) deposition density 1962-1966. The integrated deposition density can be seen in Figure 1b, where the mean is 1.853 kBq/m^2 (range: 1.416-2.695 kBq/m^2). In general, the lowest values of integrated ^{137}Cs deposition density are found in the northeast and east of Sweden where the northern area is an area with low precipitation. The highest values are found in the mountain areas in northern Sweden and in western Sweden. A comparison with the measured deposition each quarter at three sites, not used as reference sites, show good agreement.



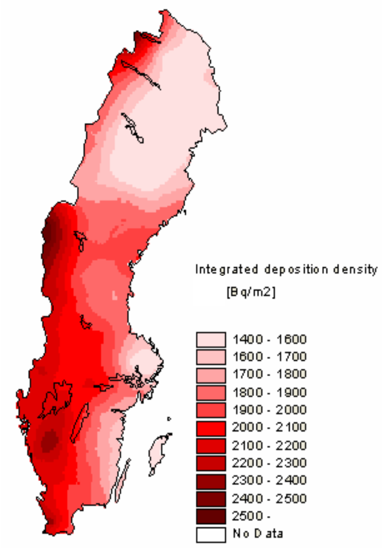


Figure 1a: Chernobyl fallout

1b: Integrated deposition density of ^{137}Cs due to NWF

The Chernobyl fallout: The mean value of the predicted deposition density over the integrated area of western Sweden is found to be 1.756 kBq/m^2 (range: 822-2.613 kBq/m^2). The highest values are found in the western parts along the coast and the lowest in an area between the coast and the lake Vänern, which can be seen in Figure 1a. The depositions from the two different sources are similar in the selected region. Calculated deposition from the Chernobyl accident was compared to aerial measurements: SGAB, 1986 and the mean ratio between calculated and measured deposition densities was 1.05±0.32. Excluding one site from the calculations because of large variations of neighbouring cells the comparison with aerial measurements yields a ratio of 0.996±0.13.

NWF+Chernobyl: The total deposition was compared to ^{137}Cs activities in soil samples and shows good agreement. The mean ratio between calculated and measured deposition densities is 1.28±0.62. If eight sites for soil sampling with large deviations are excluded the mean ratio of total calculated deposition and total accumulated activities measured in soil samples is 1.01±0.13. The predicted deposition from the precipitation are often overestimated compared to the soil samples. The soil was sampled down to a depth of about 15 cm for most of the sites, but at some only to 12 cm. At some places this might not be enough to cover the whole inventory. There can also be locally deviations in the precipitation pattern and much could have happen to the soil in the long time period since the deposition.

The method used represents a simplified model of the deposition. It would be interesting to study the influence of other parameters such as snow, humidity, topography etc. The grouping of the weather stations might also be different if natural barriers such as mountains and ridges also are considered. With knowledge of the dependence of the activity concentration in rain on the amount of precipitation and activity concentration in air it would be possible to predict the deposition based on measurements of the activity concentration in air and meterological forecasts.

Ackowledgement

This work was done with financial support from the Swedish radiation protection authority. (Project SSI P 1451.04)

References

Bergan, T.D. (2002). Radioactive fallout in Norway from atmospheric nuclear weapons tests. J Environ Radioact, 60, 189-208.

DeGeer, L.-E., Arntsing, R., Vintersved, I., Sisefsky, J., Jakobsson, S. & Engström, J.-Å. (1978). Particulate radioactivity, mainly from nuclear explosions, in air and precipitation in Sweden mid-year 1976 to mid-year 1977. FOA report C 40089-T2(A1) November 1978

M. Isaksson, B. Erlandsson and M-L. Linderson: Calculations of the deposition of ^{137}Cs from nuclear bomb tests and from the Chernobyl accident over the province of Skåne in the southern part of Sweden based on precipitation. J Environ Radioact 49 (2000) 97-112

S. Mattsson, R. Vesanen (1988), Patterns of Chernobyl fallout in relation to local weather conditions. Environment International, 14, 177-180

Schuller, P., Bunzl, K., Voigt, G., Ellies, A. and Castillo, A. (2004). Global fallout ^{137}Cs accumulation and vertical migration in selected soils from South Patagonia. J Environ Radioact 71 (2004) 43-60.

SGAB (1986). Map of Sweden showing fallout levels of ^{137}Cs after the Chernobyl accident, 1:200 000. Swedish Geological Company, Box 1424, S-75144 Uppsala, Sweden.

UNSCEAR, 2000. *Sources* and effects of ionizing radiation. Sources, vol. 1. Report to the General Assembly with scientific Annexes. United Nations Publications. United Nations Scientific Committee on the Effects of Atomic Radiation, New York.

S. M. Wrigth, B. J. Howard, P. Strand, T. Nylén and M.A.K. Sickel: Prediction of ^{137}Cs deposition from atmospheric nuclear weapons tests within the arctic, Environmental Pollution 104 (1999) 131-143