Computers & Geosciences 35 (2009) 1711–1721

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Real-time automatic interpolation of ambient gamma dose rates from the Dutch radioactivity monitoring network

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ARTICLE INFO

Article history:
Received 13 February 2008
Received in revised form
13 October 2008
Accepted 17 October 2008

Keywords:
Automatic interpolation
Kriging
Monitoring networks
Interoperability
Web services

ABSTRACT

Detection of radiological accidents and monitoring the spread of the contamination is of great importance. Following the Chernobyl accident many European countries have installed monitoring networks to perform this task. Real-time availability of automatically interpolated maps showing the spread of radioactivity during and after an accident would improve the capability of decision makers to accurately respond to a radiological accident. The objective of this paper is to present a real-time automatic interpolation system suited for natural background radioactivity. Interpolating natural background radiation allows us to better understand the natural variability, thus improving our ability to detect accidents. A real-time automatic interpolation system suited for natural background radioactivity presents a first step towards a system that can deal with radiological accidents. The interpolated maps are produced using a combination of universal kriging and an automatic variogram fitting procedure. The system provides a map of (1) the kriging prediction, (2) the kriging standard error and (3) the position of approximate prediction intervals relative to a threshold. The maps are presented through a Web Map Service (WMS) to ensure interoperability with existing Geographic Information Systems (GIS).

1. Introduction

Detection and monitoring of radiological accidents is of great importance. This has become clear after the Chernobyl accident in 1986. Possible radiological threats include releases from nuclear power plants, crashes of nuclear powered satellites, dirty bombs, releases from nuclear powered vessels and transport of radiological material. Many European countries have installed monitoring networks to detect radiological accidents. In the Netherlands the National Institute for Public Health and the Environment (RIVM) operates the National Radioactivity Monitoring Network (NRM).

In this paper we present a prototype system that provides real-time automatically interpolated maps of ambient gamma dose rate values from the NRM. Note that the monitoring stations from the NRM included in our analysis only measure total gamma dose rate and not a full gamma-ray spectrum. The prototype system is most suitable for mapping natural radioactivity data without major outliers. It represents a first step toward an automatic real-time interpolation system for emergency situations, when large outliers are to be expected. The goal of both the prototype system and the system for emergency situations is to improve the interpretation of variability in gamma dose rates measured by the NRM. Interpolated maps improve the interpretation of variability by providing a good overview and summary of the NRM data, making it easier to detect patterns and anomalies in the data. The interpolation algorithm not only provides a prediction but also an estimate of the prediction error, the *kriging standard error*. Under the assumption that the kriging error is normally distributed, approximate 95% prediction intervals can be calculated to indicate where predictions exceed thresholds with 95% confidence.

Output from the system is presented using a Service Oriented Architecture (SOA) to ensure that the system is platform independent, flexible and easy to integrate into existing applications. We use a Web Map Service (WMS) to distribute images of interpolated maps. WMS is a standard defined by the Open Geospatial Consortium.[1]

Examples of research into automatic interpolation include interpolation of meteorological data (Pardo-Igúzquiza et al., 2005), atmospheric pollution (Abraham and Comrie, 2004),

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[1] http://www.opengeospatial.org/standards/wms

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doi:10.1016/j.cageo.2008.10.011

seismic activity (Wald et al., 1999) and ionospheric activities (Stanislawska et al., 2002; Turley and Gardiner-Garden, 2006). Two large statistical exercises (EUR 20667 EN, 2003; Dubois and Galmarini, 2005; EUR 21595 EN, 2005) have dealt with the mapping of radioactivity in routine and emergency situations. The second exercise (EUR 21595 EN, 2005) focused on automatic interpolation. Results from all of these studies underline the fact that real-time automatic interpolation of environmental data—especially in case of an accident—is not an easy nor straightforward task (see also Brenning and Dubois, 2008).

2. Natural outdoor gamma radiation and spatial variability

Natural outdoor gamma radiation originates from cosmic rays and from the decay of radionuclides present in the air, on the ground surface (e.g. radon daughter products deposited during rain storms) or in the soil (e.g. ^{40}K). The measure of activity, the Becquerel (Bq), indicates the number of disintegrations per second of the radionuclide of a given sample. Outdoor radiation levels are usually expressed in terms of an ambient dose equivalent rate at 10 mm depth, $H^*(10)$ (International Commission on Radiation Units and Measurements, ICRU, 1993). $H^*(10)$ is commonly abbreviated to ambient dose rate, measured in nSv/h.

The average ambient dose rate for the period 1990–1994 in the Netherlands is between 55 and 115 nSv/h(Smetsers and Blaauboer, 1997). There are three major sources of natural background gamma radiation in the outdoor environment in the Netherlands (Smetsers and Blaauboer, 1997):

(1) *Cosmic gamma radiation* originates from outside the Earth's atmosphere and accounts for about 50% of the annual dose. This source is partly screened by the Earth's magnetic field and the atmosphere. The dose due to cosmic radiation depends on atmospheric pressure. Since the Netherlands spans just a few degrees latitude and has an almost constant atmospheric pressure, the cosmic radiation dose is nearly constant spatially.

(2) *Terrestrial gamma radiation* consists primarily of radiation from the natural decay chain of ^{232}Th, ^{235}U, ^{238}U and ^{40}K and accounts for about 50% of the annual dose. The amount of radionuclides present in the subsoil depends on soil type (Van Dongen and Stoute, 1985). In general, clay and loess contain more radionuclides than sand and peat and thus produce more terrestrial radiation. Fig. 1 shows a box-and-whisker plot of soil type versus terrestrial gamma dose rate. This figure was derived from a terrestrial gamma dose rate map made by Smetsers and Blaauboer (1996) and serves as an illustration of the effect of soil type on terrestrial radiation. Fig. 2 shows a simplified soil map of the Netherlands based on a 1:250.000 soil map (Steur et al., 1985). We aggregated the 13 soil types in this map to match the classes shown in Fig. 2. All sand types (e.g. sands rich in clay or sands rich in peat) were put into a single class. Similarly, all built-up areas, types of peat, types of marine clay and types of fluvial clay were aggregated into each of their respective classes for a total of five soil types.

(3) Radon (^{222}Rn, ^{220}Rn and their short-lived progeny) is an important source of natural radioactivity in air. The isotopes ^{222}Rn and ^{220}Rn originate from the ^{238}U and ^{232}Th series, respectively. Especially ^{222}Rn will be transported through the atmosphere after exhalation from the soil. Locally the radiation dose in air is correlated to the amounts of radioactivity of the ^{238}U and ^{232}Th series in the soil and thus to soil type. However, due to variation in exhalation because of changes in the groundwater table for instance and due to atmospheric transport of ^{222}Rn over large distances, the correlation of the ^{222}Rn concentration in air to soil type is less significant. Furthermore, the contribution to the radiation dose in air from ^{222}Rn and its progeny is small, but after precipitation events when significant amounts of progeny are deposited on the ground, significant temporary rises of dose rate occur that could easily double or triple the background radiation dose during an hour or more (Smetsers and Blaauboer, 1997).

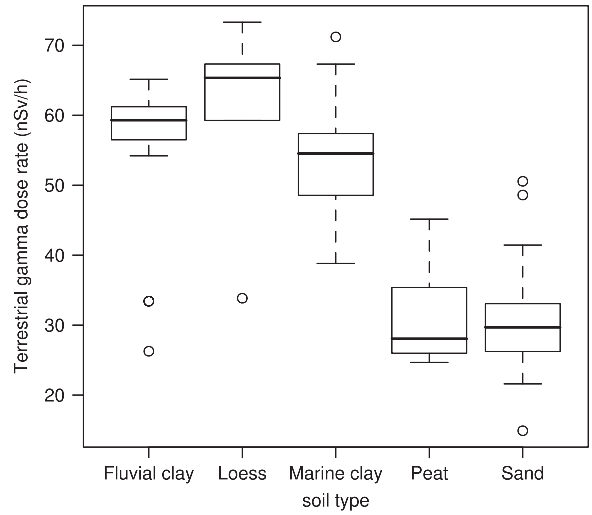

Fig. 1. Box-and-whisker plot (Tukey, 1977) of terrestrial radiation against soil type obtained from a terrestrial gamma dose rate map by Smetsers and Blaauboer (1996). Dots represent outliers in data.

3. The Dutch radioactivity monitoring network

The primary objective of the NRM (Twenhöfel et al., 2005) is to act as an early warning system in the event of an accidental radioactive release. To realise this objective a network of 153 ambient gamma dose rate monitoring stations has been set up. The network provides 10-min averaged values of the ambient gamma dose rate. Fig. 3 shows the locations of the monitoring stations. The network is designed to have a high probability of detecting a radioactive release. Some areas have an increased density of monitoring stations, for example the area around the nuclear power plant at Borsselle. The density is also higher close to country borders, especially near foreign nuclear power plants, to increase the probability of detecting any foreign releases. When a station reports a value exceeding 200 nSv/h (Twenhöfel et al., 2005), a warning is generated. The network automatically notifies an expert from the RIVM to validate the alarm and start emergency procedures if required. If an accident occurs, RIVM also has mobile measuring stations that can be deployed anywhere in the field.

4. Spatial interpolation

4.1. Universal kriging

Maps of ambient gamma dose rates were calculated by making predictions on a regular 1 km × 1 km grid using universal kriging (Chilès and Delfiner, 1999; Journel and Huijbregts, 1978). The main advantage of universal kriging is the ability to take into account