DATA ASSIMILATION OF MODEL PREDICTIONS OF LONG-TIME EVOLUTION OF CS-137 DEPOSITION ON TERRAIN

Radek Hofman and Petr Pecha

Department of Adaptive Systems
Institute of Information Theory and Automation
Academy of Sciences of the Czech Republic
Pod Vodárenskou věží 4, 182 08 Praha 8

1. INTRODUCTION

In case of an accidental release of radioactive pollutants into the living environment we would like to estimate (among many other quantities) the distribution of dose from groundshine due to deposition of ^{137}Cs on terrain and its time evolution in long-term horizon (tens of years). ^{137}Cs is in the long-time perspective important because of its long half-life of decay and also analysis after the Chernobyl disaster had shown that it is one of the most significant nuclide with regard to possible exposure of population.

In case of planning of long-time countermeasures concerning for example food bans we would also like to model the time development of this quantity, eg. how fast will radiation vanish due to radioactive and environmental decay. The main objective of this paper is to present methodology for improvement of reliability of the model predictions via advanced statistical techniques of assimilation of model results with observations incoming from terrain.

2. DATA ASSIMILATION

We employ all available information which will be available for this task. Let's suppose to have two different pieces of information from two different sources. Firstly, in case of an accident, there will be available some measurements on terrain, but they are usually sparse and we can't model the situation only upon these measurements. Let there be also available a numerical model of initial deposition of radionuclides on terrain which can be used for evaluation of an initial dose from groundshine. This prior deposition is provided by the atmospheric dispersion model (ADM, see [1]) based upon real meteorological conditions hourly provided by the Czech Hydro-Meteorological Institute. It is radiological situation on terrain when the radioactive plume has gone and we denote this moment in a scope of our assimilation process as the beginning t_0. This so called background field (the ADM output) on one hand provides valuable information and can give us a good estimate of the situation but on the other hand it could be more or less incorrect because of many uncertainties in modeling process (poor model quality, errors in inputs and so on). Via Kalman filter we are able to merge these two pieces of information and iteratively update first two moments of distribution of the analyzed quantity. We suppose to obtain qualitatively better information which will better describe the true situation on terrain and will be a good initial condition for prediction of further evolution of the true dose from groundshine.

Also Bayesian approach could be used but there are some problems relating to different character of supports of measurements and the numerical model.

2.1. The model

Due to environmental processes is ^{137}Cs deposited on terrain migrating into deeper layers of soil, other weathering mechanisms of decreasing could occur, for example run-off mechanisms due to rain. The activity of ^{137}Cs is not directly measured, we measure external gamma-dose rate and its time dependency. In the gamma-dose rates are included not only radioactive decay but also environmental effects. Relation between the dose rate in time t and initial ^{137}Cs deposition is expressed by the standard formula

$$D_g(t) = SD_k \cdot R(t) \cdot E(t) \cdot DF_g \cdot SF \qquad (1)$$

This work is part of the grant project GAČR No. 102/07/1596, which is funded by the Grant Agency of the Czech Republic.

where $D_g(t)$ is the dose rate from groundshine at time t after the radionuclide deposition on the ground in $Sv \cdot s^{-1}$. The term SD_k stands for the initial radionuclide deposition on the ground in $Bq \cdot m^{-2}$ (it is assumed that the deposition occurred at time $t = 0$). $R(t)$ and $E(t)$ are unitless factors taking into account the radioactive and environmental decay, respectively. Environmental decay takes into account the decrease of groundshine due to environmental processes, such as radionuclide migration deeper into the soil, weathering, leaching, etc. DF_g is the integrated dose-rate conversion factor for groundshine ($Sv \cdot s^{-1}\ per\ Bq \cdot m^{-2}$) and SF is the integrated shielding factor for groundshine, $SF = \sum_i f_i SF_i$ (f_i is the fraction of time spent in different places, indoor, outdoor etc. where SF_i is the shielding factor for each place).

Some of the ground exposure model parameters were determined empirically upon measurements and the parameter values depend on the local conditions of model application. Some of the model parameters are treated as random variables. Their distributions were determined from deposition of ^{137}Cs from the Chernobyl disaster, for details see [2]. This allows us to evaluate the propagation of uncertainty through the model and estimate its error covariance structure which is an input to assimilation process.

2.2. Two stage data assimilation process

We analyze the values of modeled quantity on a set of discrete points representing some spatial locations. The values of modeled quantity in these points represent the state vector. Kalman filter assimilation procedure ([3][4]) consists of two iteratively repeated steps. The first is called *time update* and in this step is expected value of state vector and its error covariance structure via the model extrapolated from time t to time $t+1$. The second step is called *data update* and in this step are extrapolated values for time $t+1$ corrected according to measurements incoming from terrain in time $t+1$. In this step is also evaluated new error covariance structure of the new estimate. The result of second step is called analysis and it enters assimilation procedure in the first step as a new initial condition for further prediction. We assume measurements to have smaller error than the model and so to improve the model output in terms of incorporating of the physical knowledge provided by the measurements. Initial error covariance structure of the state vector is given as sample covariance of a sample provided by multiple call of ADM in Monte-Carlo simulation. The errors of measurements are expert estimates of specialists from National Radiation Protection Institute of the Czech Republic. For purposes of comparison of measurements with modeled values was constructed an observation operator

3. CONCLUSION

Assimilation algorithm is implemented in HARP system which is a user friendly training, simulation and decision support system for the crisis management, see [5].

We are in cooperation with radiation protection specialists trying to acquire properly measured time series for testing purposes. Algorithm is still being tested on simulated measurements and the convergence to these measurements is being evaluated. The results will be demonstrated in the full paper and the oral presentation.

4. REFERENCES

[1] P. Pecha and R. Hofman, “Integration of data assimilation subsystem into environmental model of harmful substances propagation,” in *Harmo11 - 11th Internal Conf. Cambridge*, 2007, paper No. H11-069.

[2] T. Homma and T. Matsunaga, *OSCAAR Model - Description and Evaluation of Model Performance*, 2006.

[3] R. E. Kalman, “A new approach to linear filtering and prediction problems,” *Trans. ASME J. Basic Eng.*, vol. 82, pp. 35–45, March 1960.

[4] E. Kalnay, *Atmospheric modeling, data assimilation and predictability*, Cambridge Univ. Press, Cambridge, 2003.

[5] P. Pecha, R. Hofman, and E. Pechová, “Training simulator for analysis of environmental consequences of accidental radioactivity releases,” in *6th EUROSIM Congress on Modelling and Simulation, Ljubljana, Slovenia*, 2007, Paper ID: 240.

[6] A. C. Lorenc, “Analysis methods for numerical weather prediction,” *Quarterly Journal of the Royal Meteorological Society*, vol. 112, pp. 1177–1194, 1986.

[7] R. Hofman, “Assimilation scenario for long-term deposition of ^{137}Cs,” in *8th International PhD Workshop on Systems and Control a Young Generation Viewpoint, Balatonfred, Hungary*, 2007.