Assimilation techniques in consequence assessment of accidental radioactivity releases – the way for increase of reliability of predictions

Petr Pecha[1], Radek Hofman[1] and Petr Kuca[2]

[1] Institute of Information Theory and Automation, v.v.i., Dept. of Adaptive Systems, Czech Academy of Sciences, Prague, Czech Republic. [2] National Radiation Protection Institute, Prague, Czech Republic

Development of environmental system ***HARP*** for assessment of nuclear accident consequences continues in *Institute of Information Theory and Automation* within grant project of the Czech Grant Agency (2007-2009). Main objective of the project is **improvement of reliability of model predictions on basis of assimilation** of model results with observations incoming from field monitoring. The main objective of the development is advancing to modern statistical assimilation methods, but the way showed to be rather difficult. The problem complexity is increased when implementing statistical methods as can be demonstrated on application of standard recursive estimator algorithm of the Kalman filter. The walk process of time recursion includes chain of two steps: (a) - forecast step predicts values in the next time step, and (b) - during second step the incoming measurements are used to "correct" previous predictions. Thus, the assimilation procedure recalls additional specific demands on model analysis of harmful substances propagation into the living environment.

The main requirement consists in **transition from deterministic modelling to probabilistic approach**. The choice of environmental model ***HARP*** always represents a certain compromise between capability to include latest "art of modelling", precision of results and time of computing. Let us predict radioactivity deposition $D_n(i,k)$ on terrain of a certain radionuclide n. $D_n(i,k)$ stands for spatial field in all points (i,k) of calculation grid. Model uncertainties should be distinguished according to their origin. Uncertainties of input model parameters p_r (r=1, …, R) due to their stochastic nature, inaccurate determination of input constants etc. can be found in literature from expert elicitation studies. But even if the true values of all input parameters p_r^{true} are known, the resulting activity deposition $D_n(i,k)$ still remain uncertain in the sense:

$$DEP_n^{true}(i,k) = \boldsymbol{HARP}\,(p_1^{true}, p_2^{true}, \dots, p_j^{true}, \dots..) + \eta(i,k) \tag{1}$$

Where η represents model formulation error due to the model equations themselves and its insufficient parametrization of partial internal submodels (atmospheric dispersion, wash-out and dry deposition models, time evolution of environmental transport of activity in root zone etc.) that are introduced for description of real physical knowledge. Generally, η is interpreted as noise with zero mean and corresponding covariance matrix. This considerations have touched the problem of **demands issued by assimilation procedure towards capability of mathematical models**. The models should comprise profound analysis of uncertainty propagation (due to all causes of uncertainties) and generate detail model error covariance structure. Moreover, besides capability of step-wise time predictions, an inevitable condition for application of advanced statistical assimilation methods inheres in ability to predict time evolution of the model error covariance structure.

Choice of assimilation strategy is determined by the specific objectives of analysis:

Firstly, the **type of scenario** of radionuclide release and evolution phase of the accident should be differentiated. The most complicated topic seems to be online assimilation in early stage of accident when radioactive cloud is still spreading over the terrain. In Drews (2005) is presented a method for online estimation of release source term parameters based on radiation monitoring data from near-range areas provided that the detectors are optimally placed. The most valuable information for emergency management would consist in stepwise online improvement of predictions of situation in the affected areas potentially selected for effective introduction of urgent protective countermeasures. An approach used in the RODOS system to the online assimilation problem is summarized e.g. in Rojas-Palma (2003) or Astrup (2004). In latter phases of accident an attention is focused on long-term evolution of radioactivity deposited on terrain and its further transport through food chains towards human body (e.g. Gering (2004)). This subjects have its own specific requirements on assimilation inputs and target fields of predictions.

Secondly, a **quality of available input resources** entering assimilation procedure determines itself choice of embodied technique of objective analysis – Kalnay (2003). Hence, for inaccurate model giving poor informative predictions we should prefer classical interpolation methods taking into account only measured values having sufficiently dense coverage on terrain. Better model and adequate measurements can be blended using SCM (Successive Correction Method – application e.g. in Pecha (2007)). More detailed analysis of error model covariance structure and measurement errors allow introduction of constant statistical methods that can correct predictions optimally on basis of relations between model and measurement errors. An application of OI method (Optimal Interpolation – equivalent to update step of Kalman filter) for one specific scenario with local atmospheric precipitation is illustrated in Fig. 2 bellow. The most important result consists in correct preservation of proper physical knowledge after assimilation. An improvement of model with measured data when both are related to the end of radioactive cloud spreading (a few tens of hours after release start) is evident. Palette of assimilation techniques is crowned by advanced methods based on Bayesian approach, variational methods or a certain alternatives of Kalman filter techniques (Kalnay (2003)).

Thirdly, another important problem relates to **availability and accessability of measurements**, namely establishing a dialogue and cooperation with proper providers of data from radiation monitoring networks, solving interrelationship of measured data correspondence and conformance with generated model outputs (direct or indirect measurements), discriminate between modes of incoming observations (intermittent or continuous), accounting for measurement errors and density of measurement stations coverage on terrain etc. Provided that the “observations” are simulated by the same physical model (the procedure is sometimes called as “twin experiment”), we can examine convergence of algorithms of objective analysis methods to the artificially simulated measurements. In the poster part of presentation Pecha (2007) is shown an extension of minimisation technique to the segmented Gaussian plume model of atmospheric dispersion used in ***HARP*** environmental model and sufficiently fast convergence has been observed. As regards the availability of proper accidental data, we have no real usable files. For particular cases some subjective choices are used for illustrative purposes and algorithm tuning (e.g. the only one measurement in the middle of rain zone in Fig. 2). But now it is the time to consider more responsibly how to improve emergency preparedness trying to establish connection of models with real measurements in terrain. For this purposes close cooperation has been established with SUJB (State Office for Nuclear Safety) and SURO (transl. NRPI -

National Radiation Protection Institute) and possibility to extract radiation measurements for assimilation procedures is assessed. Dose rate monitoring from the Early Warning Network (EWN) of the Czech Radiation Monitoring Network is composed from Territorial Network (TN) and TeleDosemetric Systems (TDS) of NPP's, both operating continuously.

- TN consists of 54 measuring points transferring data into central ORACLE database each 10 minutes (16 stations) or 1 hour (38 stations) under normal resp. 30 minutes in emergency situation (switching automatically or on demand).
- TDS for both of the Czech NPPs consists of two circles – the inner circle positioned on the NPP fence (27 resp. 25 stations), the outer circle is formed of 8 resp. 7 measuring stations. Measured data are transferred into the central database every 4 minutes.

Spatial configuration of Czech EWN stations operated by responsible providers is in Fig. 1. We can conclude that online connection of assimilation subsystem to ORACLE server ensuring access to the relevant meteorological forecast data (in ALADIN format) and radiation measurements from the Czech Early Warning Network is realised. But other huge problems persist that are associated with source term estimation and measured doses from radionuclide mixtures and construction of observation operator used in assimilation scheme.

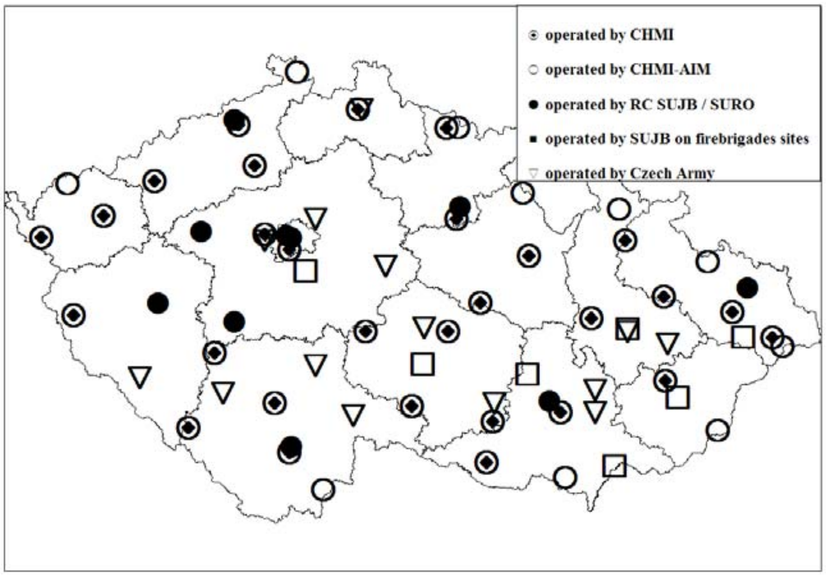

Figure 1. Configuration of the Czech Early Warning Network

In conclusion we shall present one illustrative example based on the first results of assimilation subsystem incorporated into the model ***HARP***. A simple scenario of straight-line spreading of radionuclide I-131 with total activity release 2.2 E+16 Bq from NPP Temelin is examined. Dispersion formulas for rural terrain are used. The radioactive cloud propagates in constant East direction and between kilometres 40 to 50 it penetrates through the local rain barrier having constant precipitation intensity 1 mm.h^{-1}. Let us assume only one input parameter of atmospheric dispersion model (ADM) having random character (otherwise, the number of the most important random parameters entering ADM model of ***HARP*** is standardly 13), concretely washout coefficient $\Lambda(s^{-1})$ controlling depletion of radioactivity from the plume and deposition rate of activity on terrain during rain. Let Λ has log-uniform distribution on interval $< 0.1 \cdot \Lambda^{nom}\, ; 10 \cdot \Lambda^{nom} >$ around its nominal value. Multiple generation (several thousands of the trials) of $D_{I\text{-}131}(i,k)$ fields for random realisations of Λ values enables estimate in the final stage the model error covariance matrix K^{Λ} pertaining to the only random parameter Λ. As Λ stands for local rain area, the **character of the uncertainty of Λ is also local**. Finally, let triangle icon denotes the only measured value fixed just in the middle of rain zone (km 45). When assimilate the "Model (rain)" with this one measurement using statistical method of OI (Optimal Interpolation) then physical knowledge is incorporated inside covariance matrix K^{Λ} and the knowledge is preserved properly (no influence in front of rain zone, anticipated decrease behind zone).

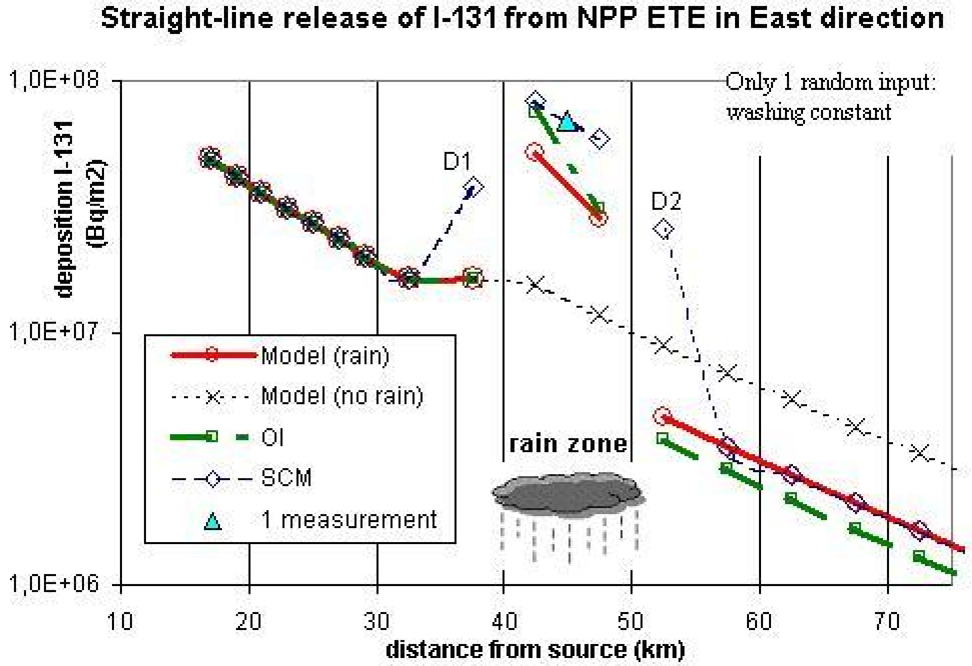

Figure 2. Illustrative example of significance of statistical approach to assimilation

Unlike this, non-statistical SCM (Successive Correction Method) is "blind" with regards to physical knowledge and its assimilated values in the points D1 and D2 in Fig. 2 are evidently wrong.

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