A SIMPLIFIED APPROACH FOR SOLUTION OF TIME UPDATE PROBLEM DURING TOXIC WASTE PLUME SPREADING IN ATMOSPHERE

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Introduction

Reliable and up to date prediction of radiological situation at near and medium distances from the source of pollution represents basic inevitable conditions for effective launching of urgent intervention operations targeted on consequence mitigation during emergency situations. But justifiability of Gaussian plume model application in medium range distances is questionable. A simplified solution offers segmented Gaussian plume model (SGPM) which can account stepwise for the time dynamics of the admixture release and hourly changes of meteorological conditions. The extension of modeling to meso–scale distances is facilitated by availability of the new quality of gridded spatial short–term meteorological forecasts. The Czech meteorological service provides 3–D data in ALADIN format for meso–scale domain 160 × 160 km around each nuclear power plant (NPP) in the Czech Republic. In the following text we are describing the SGPM application in meso–scale region up to 100 kilometers from the source taking into account the new gridded meteorological predictions. The comparison with former methodology is illustrated on two real meteorological situations: Transition of weather front with summer storm (June 25, 2008) and low–wind situation (August 17, 2008).

Advanced trends in risk assessment methodology

From global view the research effort should accept recent trends in risk assessment methodology insisting in transition from deterministic procedures to probabilistic approach. It enables generate more informative probabilistic answers on assessment questions. Corresponding analysis should involve uncertainties due to stochastic character of input data, insufficient description of real physical processes by parametrization, incomplete knowledge of sub–model parameters, uncertain release scenario, simplifications in computational procedure etc. Simulation of uncertainties propagation through the model brings data not only for the probabilistic assessment mentioned above but also for another main task of analysis called assimilation of model predictions with real measurements coming from terrain. Data assimilation represents the way from model to reality and can substantially improve precision of model predictions. Nevertheless, an inevitable prerequisite for any of the global tasks is availability of reasonable code for basic deterministic predictions of environmental pollution. The main problem of such analysis evidently inheres in necessary compromise between computer code speed and attained precision of the results.

Choice and development of environmental model HARP

We still use the traditional Gaussian dispersion scheme and introduce a certain modifications in order to extend the bounds of its applicability. Even simple, the Gaussian model is consistent with the random nature of turbulence, it is a solution of Fickian diffusion equation for constant K and u [2]. It is tuned to experimental data and offers fast basic estimation with minimum computation effort. This plays decisive role for analysis of uncertainty propagation through the model based on Monte Carlo modeling. Proved semi–empirical formulas are available for approximation of important effects [2] like:

- interaction of the plume with near-standing buildings
- momentum and buoyant plume rise during release
- power–law formula for estimation of wind speed changes with height
- depletion of the plume radioactivity due to removal processes of dry and wet deposition, dependency on physical–chemical forms of admixtures and land–use characteristics
- description of inversion situation, plume penetration of inversion, plume lofting above inversion layer
- approximate account for small changes in surface elevation, terrain roughness, land-use type etc.

Introduction of measures for meso–scale modeling

Synchronization of release dynamics with meteorological forecast Complicated scenario of release dynamics has to be synchronized with available meteorological forecasts. The total release interval is split into a certain number of equivalent one-hour intervals. Using assumption of activity conservation, corresponding one-hour release segment with constant release source strength is assigned to each interval. Each one-hour segment is modeled in its all subsequent hourly meteo-phases when stepwise segment movement is driven by meteorological forecast for the corresponding hours. The final solution is given by superposition of results of all segments in all their consecutive phases of movement. For such calculations the gridded meteorological forecast is inevitable.

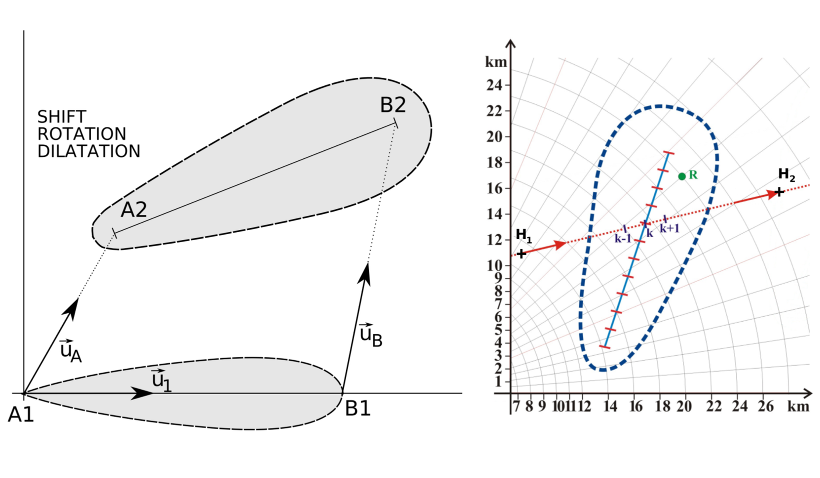

Figure 1. Stepwise simulation of 1–hour plume segment movement. *left:* Basic scheme – hourly time dependent and spatially dependent changes are accepted. *right:* Simulation of segment movement from hour H_1 to hour H_2 by sequence of elementary shifts k.

Construction of meteorological preprocessor for dispersion modeling Meteorological preprocessor is integrated into our environmental model HARP. Its main purpose is to convert spatial and temporal meteorological data provided by the Czech Hydrometeorological Institute (CHMU) into proper formats. Two kinds of short–term meteorological forecasts are generated and transmitted from CHMU to database centre of the State Office for Nuclear Safety: Simple point data for each NPP location and Gridded 2–D and 3–D forecasts in ALADIN format. The preprocessor includes wide options of effective procedures for extraction, interpolation and visualization of 2–D and 3–D data.

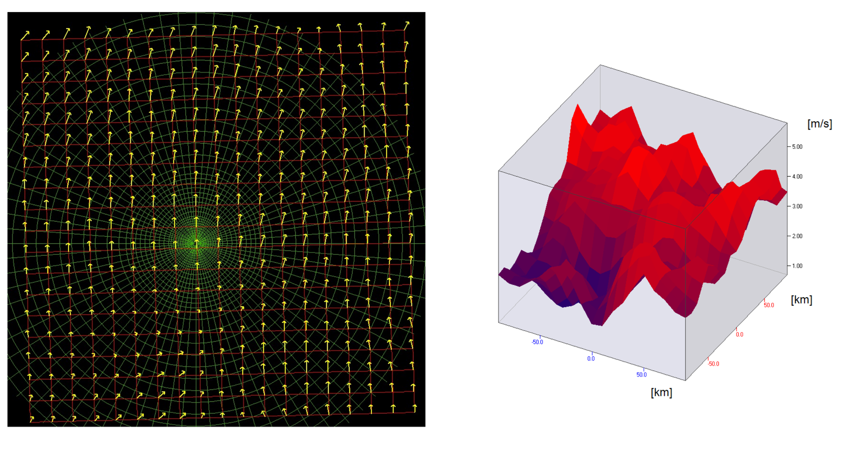

Figure 2. Meteorological preprocessor offers colorful visualization of gridded meteodata. *left:* Wind direction field. *right:* Wind magnitude field.

Accounting for local characteristics of accidental release scenario Spatial discrimination is introduced for other input fields such surface elevation and surface roughness, surface land–use characteristics, gridded demographical data and straightforward specification of local rain areas. Total movement of partial Gaussian segment from position H_1 to H_2 is modeled as a sequence of K partial elemental shifts k (see dashed contour in Figure 1, right), when input values conform with subregion k. Plume activity depletion factors during plume elemental shift $\Delta x^{k,\,k+1} = (x_{k+1} - x_k)$ (also respect local characteristics in each subregion k) account for three depletion mechanisms.

For *radioactive decay* (with radioactive decay constant λ)

$$\Delta f_R^{k\rightarrow k+1} = \exp\left[\frac{-\lambda \times \Delta x^{k,\,k+1}}{\bar{u}}\right], \qquad (1)$$

For *dry fallout* (with local deposition velocity v_g)

$$\Delta f_F^{k\rightarrow k+1} = 1 - \sqrt{2/\pi}\frac{v_g(k,k+1)}{\bar{u}\times\sigma_z(\bar{x}^{k,k+1})} \times \Delta x^{k,k+1} \exp\left[-\frac{H_{ef}^2(k,k+1)}{2\times\sigma_z^2(\bar{x}^{k,k+1})}\right] \qquad (2)$$

For *wet deposition* (with washout constant Λ depending on local rain in meso–scale sub–area k)

$$\Delta f_W^{k\rightarrow k+1} = \exp\left[-\Lambda(k,k+1)\times\frac{\Delta x^{k,k+1}}{\bar{u}}\right] \qquad (3)$$

Results for improved meso–scale modeling

Numerical calculation using environmental model HARP (complying with all improvements described above) were carried out in order to estimate significance of introduction of more realistic meteorological forecast on spatial 3–D grid around the source of possible pollution. The tests were accomplished for real meteorological situation from June 25, 2008 which has occurred in vicinity of 160 × 160 km around nuclear power plant Dukovany. Nice sunny day has been superseded in the evening by storm with intensive local rain and blasts of wind. The situation documents Table 1, which presents some part of short–term meteorological forecast for location of NPP Dukovany from hour 17.00 CET to 03.00 CET next day. The forecast was generated in CHMU on the basis of analysis procedure related to midnight (time stamp 20080625–0000 CET). Let us mention that the latest results for calm situation from August 17, 2008 (meteorological forecast with time stamp 20080817–1200 CET) are illustrated on bottom of Figure 4 (cases (c), (d)).

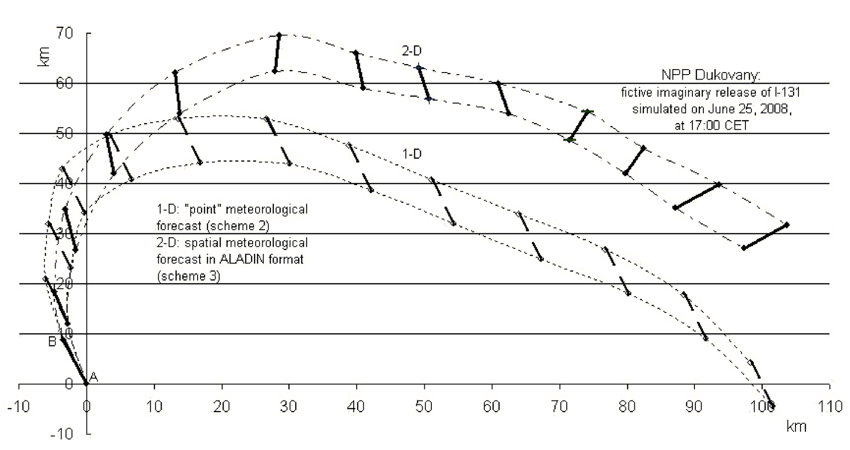

Figure 3. Abscissa AB illustrates trace of ^{131}I plume in the first hour of release. Its stepwise movement in the next hours is modeled alternatively using 1–D meteorological forecast or more realistic spatial forecast 2–D in ALADIN gridded format. Even if the advection is driven by wind speed in 10 meters, both trajectories differ noticeably.

Figure 3 demonstrates differences between trajectories constructed under assumption of 1–D or 2–D forecasts. More detailed comparison oriented on general consequence assessment can be concluded from the top of Figure 4 (cases (a), (b)). The results illustrate isolines of spatial distribution of time integrated near ground activity concentration in air $[Bq \times s \times m^{-3}]$. Parameters of scenarios enter the environmental model HARP and two alternative results are generated for meteorological conditions marked as 1–D (the results are in left part of Figure 4) and 2–D (right part of Figure 4). More realistically is considered effective height of the plume H_{ef}. We are generating proper local values of wind speed as a function of spatial coordinates (x, y) using power wind profile law and wind speed u_{10} in reference height 10 meters extracted from 2–D ALADIN data (provisionally - application of the advance function of meteo–preprocessor MP mentioned above is in progress). It is clear, that differences between two traces 1–D and 2–D from Figure 3 demonstrate significance of the new approach based on more precise input forecasts. The fact is still more noticeable in Figure 4 when comparing isolines on the left and right side of the picture. This is mainly due to consideration of the plume travel with $u(10, H_{ef}, x, y)$ in height greater then 10 meters. We can anticipate that significance of the new 2–D approach will increase for scenarios with large values of H_{ef} (high sources of release, large plume rise due to initial buoyancy and momentum flux of discharges).

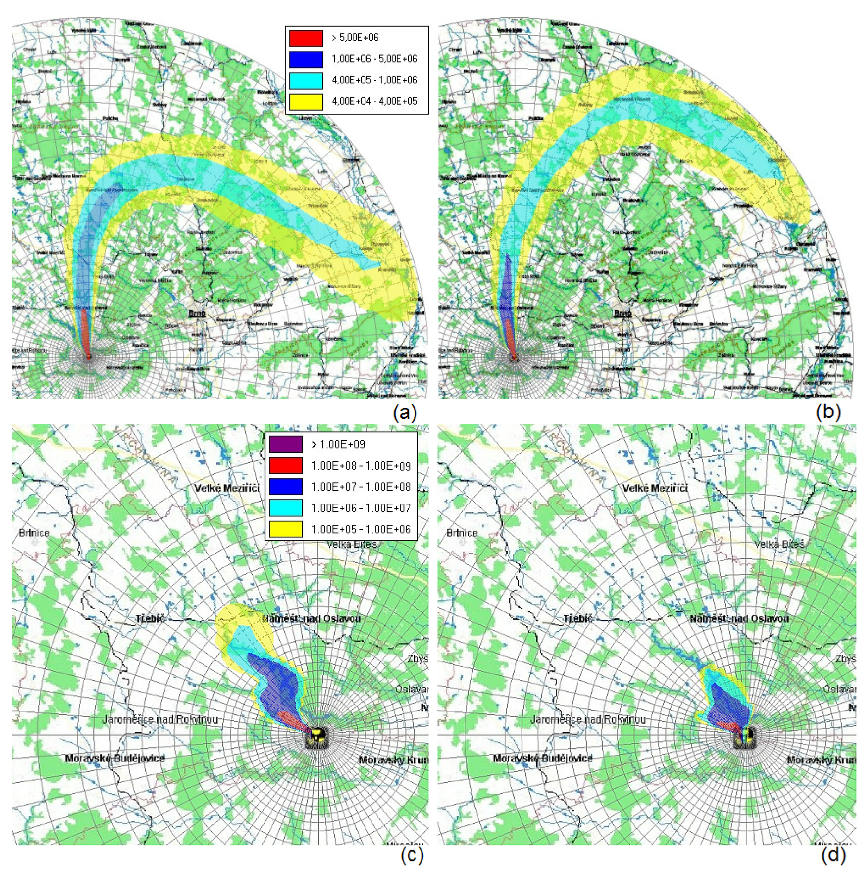

Figure 4. Time integral of activity concentration (TIC) of nuclide ^{131}I $[Bq \times s \times m^{-3}]$ in air in near ground level, the situation just after 11 hours from the release start. *Top:* Scenario with frontal weather change and summer storm (see Table 1, release start at 5pm on June 25, 2008). *Bottom:* Scenario during stable atmospheric stratification under low–wind conditions (release start at 8pm on August 17, 2008). *Comment:* Cases (a), (c) relate to simple point meteo–forecast and (b), (d) stand for more realistic gridded meteo–forecast.

Table 1. Short–term meteorological forecast for point NPP Dukovany ($49.137°N$; $16.263°E$).

date	June 25, 2008							June 26, 2008			
hour (CET)	17.00	18.00	19.00	20.00	21.00	22.00	23.00	00.00	01.00	02.00	03.00
wind direction [°]	162	176	182	196	222	254	279	298	299	301	301
wind speed in 10m $[m \times s^{-1}]$	2.3	2.7	3.5	3.0	2.5	3.0	3.4	3.6	4.3	4.4	4.5
Pasquill stability class	C	D	D	D	E	D	D	D	D	D	D
rain intensity $[mm \times hour^{-1}]$	0	0	0.93	0.05	0	0	0	0	0	0	0

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