



Influence of the diagnostic wind field model on the results of calculation of the microscale atmospheric dispersion in moderately complex terrain

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HIGHLIGHTS

- Microscale atmospheric dispersion was calculated for 7-months period.
- Results of calculations were compared with measurements available each 10 min.
- Using the diagnostic wind model in moderately complex terrain improved the results.

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ABSTRACT

The impact of diagnostic wind field model on the results of calculation of microscale atmospheric dispersion in moderately complex terrain conditions was investigated. The extensive radiological and meteorological data set collected at the site of the research reactor of the Chalk River Laboratories (CRL) in Canada had been compared with the results of calculations of the Local Scale Model Chain of the EU nuclear emergency response system JRODOS. The diagnostic wind field model based on divergence minimizing procedure and the atmospheric dispersion model RIMPUFF were used in calculations. Taking into account complex topography features with the use of diagnostic wind field model improved the results of calculations. For certain months, the level of improvement of the normalized mean squared error reached the factor of 2. For the whole simulation period (January–July, 2007) the level of improvement by taking into account terrain features with the diagnostic wind field model was about 9%. The use of diagnostic wind field model also significantly improved the fractional bias of the calculated results. Physical analysis of the selected cases of atmospheric dispersion at the CRL site had been performed.

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1. Introduction

Atmospheric dispersion models (ADMs) used in decision support systems dealing with atmospheric pollution usually receive input from meteorological pre-processors (MPPs), which act as an

interface between them and the incoming meteorological data. One of the most important tasks of the MPPs is to account for the influence of the terrain features unresolved by incoming numerical weather prediction data and/or the measurement network. Usually the core of the MPPs are the computationally efficient diagnostic wind field models (WFMs) which calculate the adjustments of the wind field to variable terrain topography using the divergence minimizing procedure or the linearized wind flow equations (both types of model were reviewed in [Finardi et al., 1998](#)). As it was reported in many studies (e.g. [Wang and Shaw, 2009](#); [Hu et al., 2010](#)) application of the diagnostic WFMs in complex terrain proved to result in reasonably accurate wind fields calculated with grid resolution of about 1 km. However the usefulness of such

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models for the microscale studies of atmospheric dispersion with the grid resolution reaching a few hundred meters and less is not clear since the physical background of such models is simplified. In particular, the latter factor has been noted by Brode and Anderson (2008) in their review of the widely used CALMET-CALPUFF modeling system (Scire, 2000). Only a few validation studies of diagnostic WFM on a microscale had been performed (Dyer and Astrup, 2012; Dyer, 2011; Burlando et al., 2007). Dyer and Astrup (2012) found that 'inverse square distance' interpolation of meteorological measurements was beneficial as compared to using linearized wind flow model in complex terrain. Burlando et al. (2007) confirmed the applicability of the wind flow model based on the divergence minimizing procedure for the modeling of a microscale wind distribution in complex terrain, but the atmospheric dispersion had not been considered.

The purpose of the present study is to use extensive and statistically representative data set of routine radiological and meteorological measurements taken at the site of Research Reactor of the Chalk River Laboratory (CRL) in Canada to quantify the relative benefits of the microscale atmospheric dispersion calculations based on the diagnostic WFM. These benefits are deduced from the comparison with the results based on the 'flat terrain' assumption. The diagnostic WFM deployed in the microscale atmospheric dispersion was based on the divergence minimizing procedure. In the forthcoming chapters we first present the results of validation of atmospheric dispersion models of the EU nuclear emergency response system JRODOS (Ievdin et al., 2010) using the data of experiments on atmospheric dispersion of tracer over flat terrain. Using these results as a basis, we choose the particular atmospheric dispersion model of the JRODOS for further investigations. Then we clarify the influence of divergence minimizing procedure on the results of calculations of radionuclides atmospheric dispersion following the routine releases at the site of CRL, characterized by the moderately complex terrain.

2. Short description of the JRODOS Local Scale Model Chain

The JRODOS is the recently developed redesigned (Java) version of the EU nuclear emergency response system RODOS (Ievdin et al., 2010). The Local-Scale Model Chain (LSMC) of the JRODOS atmospheric dispersion module consists of meteorological preprocessor (Andronopoulos et al., 2010) and three atmospheric dispersion models: ATSTEP (Päsler-Sauer, 2004), RIMPUFF (Thykie Nielsen et al., 1998) and DIPCOT (Andronopoulos et al., 2010).

Meteorological preprocessor interpolates/extrapolates horizontally and vertically the available measurements on the computational grid. Then MPP corrects the velocity field with the diagnostic WFM, which uses the divergence minimizing procedure (based on solving the Poisson's equation for Lagrangian multiplier), to take into account the influence of the topography features on the wind field. The Poisson's equation solved in WFM of JRODOS MPP depends on the single parameter $\alpha = \sigma_W^2 / \sigma_U^2$, where σ_U^2 , σ_W^2 are estimations of the root mean squared errors of the first guess estimations of the horizontal and vertical velocity components as calculated prior to application of WFM (the first guess estimation of the vertical velocity is usually set to zero). The physical meaning of α is also interpreted as 'adjustment coefficient' since it regulates the ratio of horizontal to vertical adjustment performed on the velocity components. As it is well known (e.g. Andronopoulos et al., 2010) smaller values of α result in more horizontal adjustment of the wind vector (i.e. air stream flows mostly around the sides of topography features), while as α increases the adjustment of the airflow in vertical direction is increased. Extensive literature review of different methods used to estimate that parameter in WFM is presented by (Ratto et al., 1994). The most appropriate value of α in

JRODOS MPP/WFM has been determined by Andronopoulos et al. (2010) performing a number of wind field calculation cases over idealized and real topographies (Andronopoulos and Bartzis, 2009). It has been established that a value of $\alpha \approx 1$ or slightly smaller could be used in all cases.

The LSMC includes three alternative atmospheric dispersion models. The most computationally efficient is the elongated puff model ATSTEP in which each puff is created in result of the release with finite duration and constant release rate. Hence, this model requires relatively small number of puffs. The growth of puffs in ATSTEP is defined by relationships taking into account stability categories. In the RIMPUFF model puffs are created in result of nearly instantaneous releases and the turbulent diffusion is accounted for by puff's growth. The default time interval between puffs in JRODOS RIMPUFF is 10 min. In the stochastic Lagrangian puff model DIPCOT puffs are transported by the mean and stochastic components of the wind field; hence to avoid non-physical non-homogeneities of concentration field it requires more puffs and more computational time than RIMPUFF. The default time interval between puffs in JRODOS DIPCOT is 10 s however for microscale applications presented in the next section it had to be reduced down to 1 s.

3. Intercomparison of the atmospheric dispersion models of the JRODOS for flat terrain conditions

Notwithstanding the fact, that all atmospheric dispersion models included in JRODOS were extensively verified using the measurement data, the broad comparison of those models, operating in the same modeling system under the same input conditions has not been performed. It shall be noted, that the work of Päsler-Sauer (2010), in which comparison was only qualitative, presents the only study of this kind. Therefore, in order to make an informed choice of the particular ADM, we have to first evaluate all three ADMs integrated in JRODOS using the data of flat terrain experiment on tracer dispersion which had been performed in 2004 by the Atomic Energy of Canada Limited at the site of Gentilly-2 (G2) Nuclear Power Plant (NPP). The G2 site is characterized by flat topography and the dominant land cover in the study region is a forest. The release of a tracer (SF6) had been performed with constant rate from the stack having height 37 m or from the roof of the nearby building located at 17.5 m above the ground. Experiment comprised of 17 trials. In each of the trial the concentrations had been measured and simulated at centerline of the plume at the distances 500 and 1000 m from the source. The available measurements included vertical profiles of velocity and temperature (at heights 10, 37, 48 m), measurements by mini sound radar (boundary layer height), micrometeorological measurements of momentum and sensible heat fluxes, and measurements of wind direction fluctuations for both horizontal and vertical wind components measured by 2 sonic anemometers located at heights 10 and 24 m.

Our simulations were performed with interactive mode of JRODOS operation and 'user-defined' meteorology which requires input of the observed velocity and stability category. The rich meteorological data base of the G2 experiment allowed for at least five options of calculating stability category. Therefore it was chosen to use the stability category which was in better correspondence with the observed Monin–Obukhov height.

The scatter plots of measured vs. calculated concentrations for all of three ADMs are shown at Fig. 1 together with statistical indicators of each model (normalized mean squared error $NMSE = \langle (C_o - C_m)^2 \rangle / (\langle C_o \rangle \langle C_m \rangle)$ and fractional bias $FB = 2 \langle (C_o - C_m) \rangle / (\langle C_o \rangle + \langle C_m \rangle)$ where triangle brackets denote arithmetic averaging and indices 'o' and 'm' stand for observed and calculated

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