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DISPERSION OF RADIOACTIVE AEROSOL PAST OBSTACLES

Vladimír Fuka [1] and Josef Brechler[1]

[1]Department of Meteorology and Environment Protection, Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic

Abstract: An experiment of dispersion of radioactive particulate matter after an explosion has been performed by the National Radiation Protection Institute of the Czech Republic. This experiment was set up to simulate an improvised radioactive dispersion device (RDD). Many pieces of various experimental equipment were used to measure aerosol concentration, deposited activity, total dose and basic meteorological conditions. In this contribution we perform a computer simulation of this experiment using our in-house CFD code. In this study we concentrated mainly on time histories of aerosol concentration in three positions, which were affected by an obstacle.

Key words: *RDD, aerosol dispersion, LES*

INTRODUCTION
The National Radiation Protection Institute (NRPI) of the Czech Republic performed a series of experiments of dispersion of radioactive tracer after an explosion (Prouza *et al.*, 2010). This explosion should have simulated a terrorist act using a radioactive dispersion device. An area of approx. 50 x 50 m was covered by paper detectors measuring deposited activity and several pieces of other equipment, namely Dusttraks (measuring PM10 concentration in time), cascade impactor (measuring average particle size distribution) and a small meteorological probe measuring wind speed and direction in 2 m, atmospheric pressure and temperature. Said experiments are also used by a Working group 9 – Urban areas of project EMRAS II under International Atomic Energy Agency.

NUMERICAL METHODS
The model uses a finite volume method on a staggered grid, where different variables use different control volumes to preserve pressure – velocity coupling. The time marching scheme is based on a fractional step (or pressure correction) method for incompressible Navier-Stokes equations. In this method momentum equations are solved first without the incompressibility constraint (continuity equation). In the next step the computed velocity field is corrected to be nondivergent and pressure for the next timestep is computed at the same time. For the spatial discretization of the (nonlinear) advection terms we use central difference scheme for momentum, because low numerical diffusion of the method is desirable. For the advection of pollutants this method is not appropriate, because it can lead to numerical instability and negative values can occur. Therefore we use a partial linear method with a slope limiter (van Leer, 1973), that preserves monotonicity (prevents creation of new extremes) of the solution.

Concerning the turbulent nature of the simulated flow in the atmosphere, the code utilizes large eddy simulation methodology. The subgrid stresses are computed using the classical Smagorinsky method and the dynamic Smagorinsky method (Smagorinsky, 1963; Germano *et al.*, 1991). The subgrid diffusion of scalar quantities is computed using the turbulent viscosity of momentum and a constant turbulent Schmidt number.

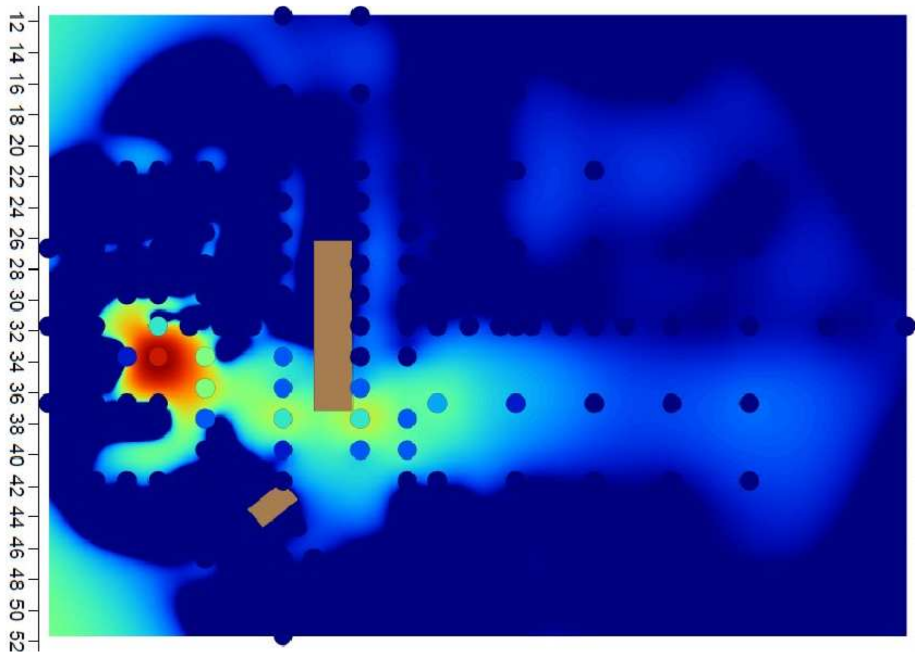

Figure 1. Experimental values of deposited activity (qualitatively, in log scale) and the layout of obstacles.

BOUNDARY CONDITIONS

The experiment was performed 21. 10. 2008 at the experimental site of NRPI. The computational area of interest has dimensions 60 x 50 m and the height for computation was 25 m. Two obstacles were placed downwind from the epicentre of the explosion. The first one was a bus covered with canvas to make it rectangular. The other one was a box with dimensions 1.5 x 3 x 3m placed to the right the bus when viewed in the direction of the wind. The ground at the experimental site was covered with small stones and the roughness length was roughly approximated as 1 cm. The layout is best seen in figure 1.

The meteorological conditions at the time of the experiment were not favourable. The wind speed was too low to be measured by the probe (minimum wind speed required is 1 m/s) and was estimated to be around 0.5 m/s at 2 m from a video of the dispersing cloud more or less in the direction of the axis of the experiment. The initial conditions of the cloud after the explosion were approximated as a half of a ball with radius 3 m, because we couldn't model the explosion itself. The position of the centre of the initial cloud was 2 meters in the direction of the wind. We also performed computation with the initial cloud shifted 2 meters to the right from the axis, because we had indications that the explosion was not fully aligned with the axis.

The boundary conditions at the inlet have to be prescribed correctly. We chose a computationally less demanding approach – generation of the turbulent inlet using random numbers. The other possibility would be direct computation of the incoming flow above a rough wall or resolved roughness elements. In this study we use a method by (Klein, Sadiki, Janicka, 2003) which uses filtration of the random fields. This is done because white noise random fluctuations would be damped very quickly by real and numerical diffusion. After filtration the turbulence has prescribed length scale and after additional transformation it has also prescribed correlations. In our implementation the user can supply profiles of mean velocity, friction velocity and relative values of individual stress tensor components.

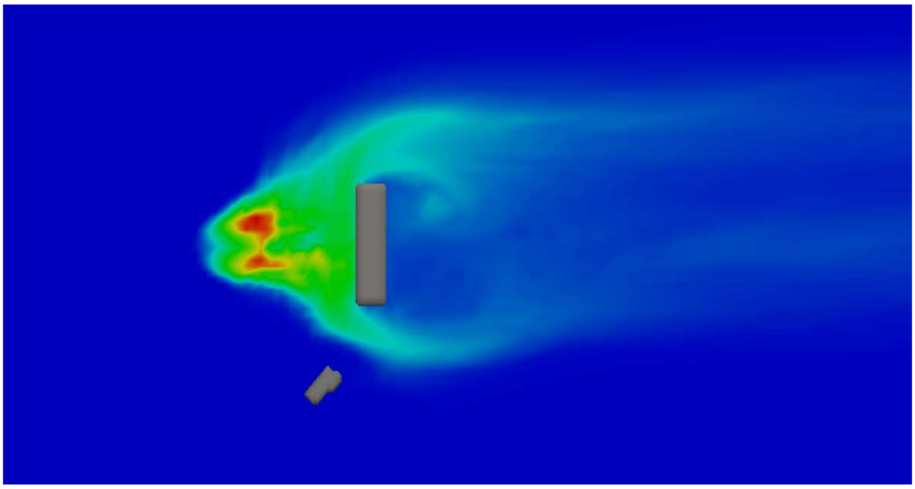

Figure 2. An example of time integrated concentrations of the scalar with centred initial concentrations (nondimensional)

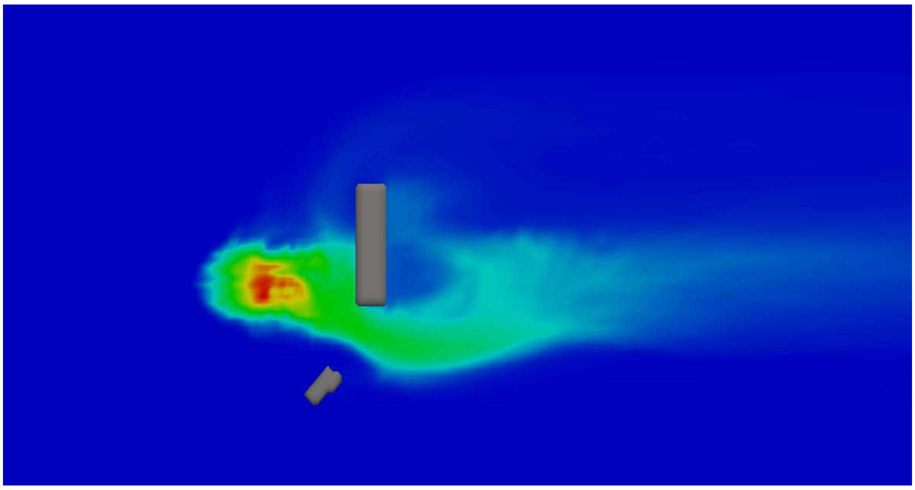

Figure 3. An example of time integrated concentrations of the scaler with shifted initial concentrations (nondimensional)

RESULTS

In this study we concentrate mainly on the time histories of aerosol concentrations in three detectors (Dusttraks) along the axis. The first detector was placed 11 m from the epicentre, i.e. between the explosion and the bus. The detectors no. 2 and 3 were placed behind the bus in the distance 18 m and 25 m from the epicentre. The measured concentrations are in fig.4. Notice the order of first signal in individual detectors. The first Dusttrak to detect the cloud was no. 2 (47 s after explosion), then no. 1 (t = 60 s) and the last one was no. 3 (t = 76 s).

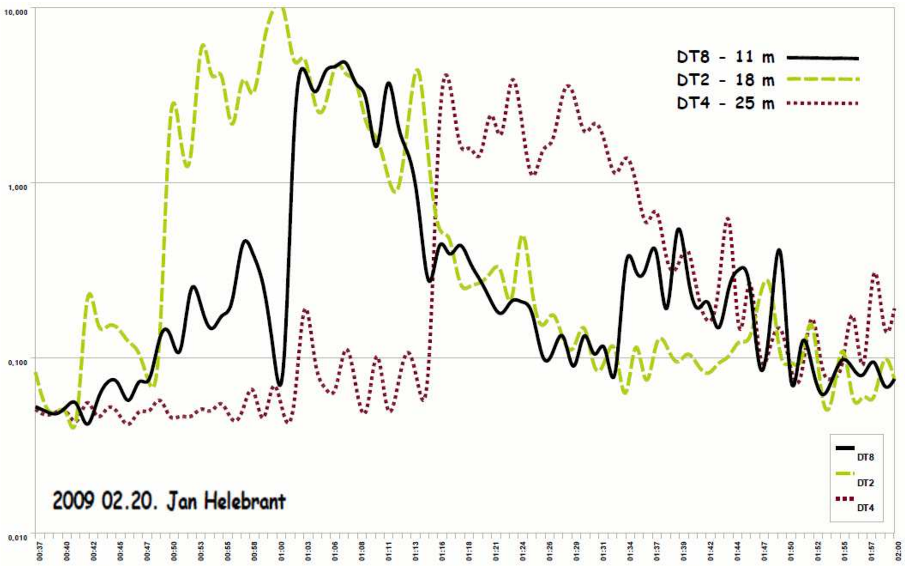

Figure 4. Experimental time histories of concentrations measured by the Dusttraks. Time axis runs from 37 s to 120s after explosion.

We performed 6 simulations of the dispersion with the same parameters for the described initial concentration with centre on the axis and 6 simulations with the initial cloud shifted to the right to find the sensitivity to the initial conditions, which are not known very precisely. For each initial condition 3 computations were performed using the Smagorinsky model and the other 3 using the dynamic model. There was no visible difference between these two models. The variability between individual computations was much greater. The time integrated concentrations for shifted initial cloud (fig. 3) were much closer to the measured deposition (fig. 1) than the results for the centered initial conditions (fig. 2). However, with the lack of the quantitative comparison and with insufficient wind measurements we cannot state whether the initial direction of the plume movement was more affected by the wind direction and turbulence or by the explosion itself.

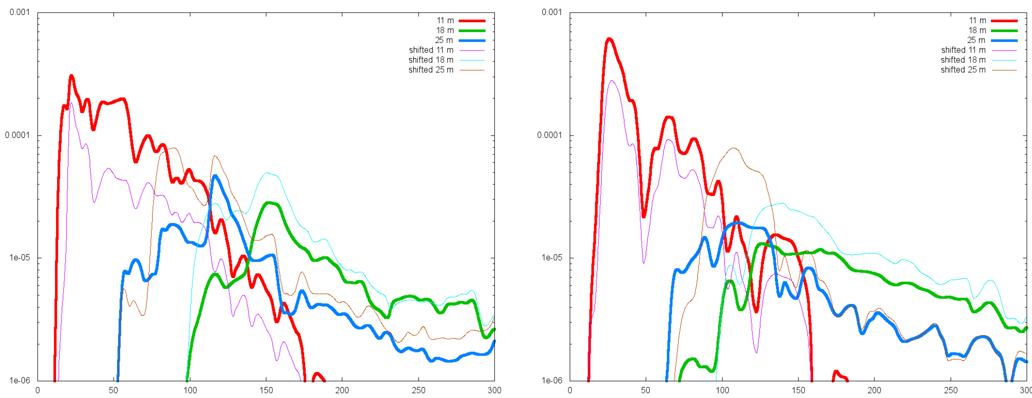

Figure 5. Time histories of concentrations two typical computations

Almost all of the computations agreed in the order of the signal in detectors in time. In all cases the first detector was detector no. 1 between the epicentre and the bus. The next detector to detect a signal in most of the computations was the detector no. 3. In two cases detectors 2 and 3 received concentration peaks at almost the same time. This is because detector number 2 was in the recirculation region. The variability between individual realisations of the same computation is substantial (fig. 6). The reason for different time behaviour of the experimental data and computation is not clear to us, because the results of the computation seem to be more intuitive. From other experiments made without obstacles (Prouza *et al.*, 2010) the Dusttraks time measurements seem to be reliable. One of the reasons could be underestimation of turbulence levels in the low wind situation combined with the sparse tree and shrub canopy that is placed approximately 100 m downwind of the experimental site and closely around it in other directions.

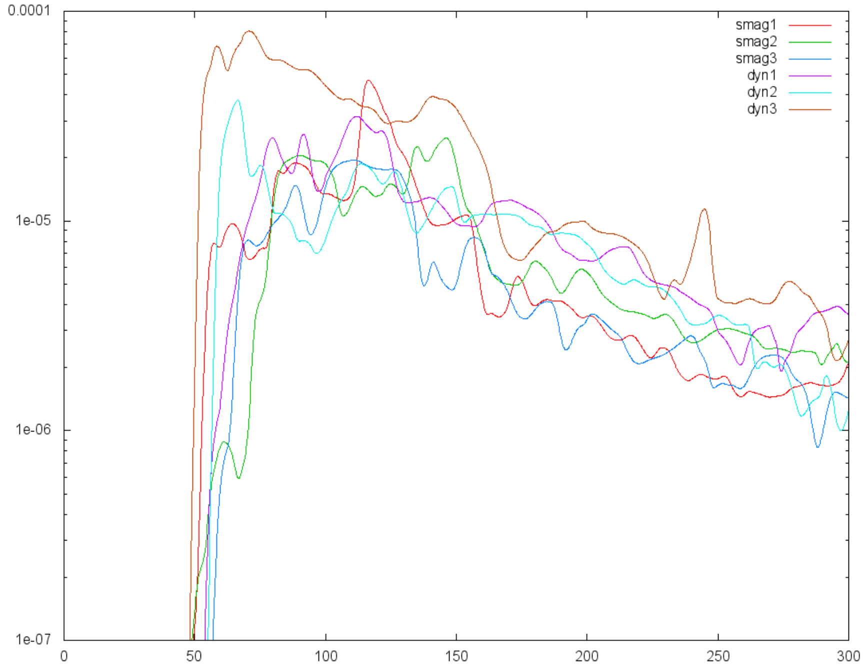

Figure 6. Variability between individual computations with the same parameters (detector at 25 m).

CONCLUSION

The experiments made by the National Radiation Protection Institute were repeated using CFD. The comparison was very basic and preliminary but revealed important disagreement between results of the computations and the experiment. We will continue in the computations. By now the code has become able to compute the deposition of particulate matter and we will make comparison of predicted activity for this and other experiments

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