Introduction
Numerical methods
Parameters for computation of the short-scale scenario
Results

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Introduction

Short scale scenario

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Introduction

- Our model is general-purpose high resolution code for Computational Fluid Dynamics.
- We have very limited experience in modelling of radioactive substances.
- The model uses a Large Eddy Simulation framework, which requires high resolution and has large demands on computational time.

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Large Eddy Simulation

- Filtered momentum equations

$$\frac{\partial \overline{u_i}}{\partial t} + \frac{\partial \overline{u_i}\,\overline{u_j}}{\partial x_j} = -\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial 2\nu \overline{S}_{ij}}{\partial x_j} + \frac{\partial \tau_{ij}}{\partial x_j} \qquad (1)$$

$$\tau_{ij} = \overline{u_i}\,\overline{u_j} - \overline{u_i u_j} \qquad (2)$$

- Continuity equation

$$\frac{\partial \overline{u_i}}{\partial x_i} = 0 \qquad (3)$$

This filtering is performed implicitly in our model.

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Smagorinsky model

Turbulent viscosity

$$\tau_{ij} = 2\nu_t \overline{S}_{ij} + \frac{1}{3}\tau_{ll}\delta_{ij} \tag{4}$$

Smagorinsky model

$$\nu_t = (C_S\bar{\Delta})^2 |\overline{S}| \tag{5}$$

$$|\overline{S}| = \sqrt{\overline{S}_{ij}\overline{S}_{ij}} \tag{6}$$

Too diffusive for most flows. Theoretical value $C_S \approx 0.2$ is too high in many cases.

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Vreman model

$$\nu_t = c\sqrt{\frac{B_\beta}{\alpha_{ij}\alpha_{ij}}} \tag{7}$$

where $\tag{8}$

$$\alpha_{ij} = \frac{\partial \overline{u}_j}{\partial x_i} \tag{9}$$

$$\beta_{ij} = \sum_m \Delta_m^2 \alpha_{mi}\alpha_{mj} \tag{10}$$

$$B_\beta = \beta_{11}\beta_{22} - \beta_{12}^2 + \beta_{22}\beta_{33} - \beta_{23}^2 + \beta_{33}\beta_{11} - \beta_{31}^2 \tag{11}$$

Gives zero ν_t for laminar flows with large strain rates unlike the Smagorinsky model. The constant c is also not a universal constant, but it's optimal value changes for different problems less than C_S.

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Other numerical methods

Projection (fractional step) method with second order
Runge-Kutta method for time discretization.

Finite volume spatial discretization on a staggered grid.

Second order central discretization for advective and diffusive
fluxes.

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Wall model

Wall model

Because of poor wall resolution is expected in atmospheric applications and we use aerodynamically rough walls a wall model must be used.

$$\nu + \nu_t = (u_\tau)^2 y/u \tag{12}$$

$$u^+ = \begin{cases} y^+ & \text{if } y^+ < y_0^+ \\ \frac{1}{0{,}41} \ln y^+ + 5{,}2 & \text{if } y^+ > y_0^+ \end{cases} \tag{13}$$

$$\text{or} \tag{14}$$

$$u^+ = \frac{1}{0{,}41} \ln(y/z_0) \tag{15}$$

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Dry deposition

Dry deposition

For dry deposition of particles we employ a semi-empirical scheme by Kharchenko (1997).

$$v_{\mathrm{d}} = f(\nu, d, D, z_0, u_*, \tau^+) \tag{16}$$

$$\text{where} \tag{17}$$

$$d = \text{particle diameter} \tag{18}$$

$$D = \text{coefficient of Brownian diffusion} \tag{19}$$

$$\tau^+ = \frac{u_{\mathrm{sed}}}{g} \frac{u_*^2}{\nu} \tag{20}$$

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Turbulent inflow

- On of difficult problems in LES is imposing inflow boundary conditions, that are turbulent and as realistic, as possible.

- One possibility is a separate computations of the incoming flow (e.g. a periodic boundary layer or channel), but it is very resource demanding.

- The other possibility is generation of the incoming field using random numbers.

- The generated flow has to have propper length scale and spectrum to contain the lower wavenumbers. White noise would be damped very quickly and turns out to be useless.

- Also correct correlations between velocity components are important.

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Turbulent inflow

- We employ a method proposed by Klein, Sadiki and Janicka (2003) in a more effective form by Xie and Castro (2008).
- First a random field U_i is generated with correct point to point and time statistics using filtering.
- The filter is constructed, so that the resulting field has prescribed autocorrelation function.
- Then this field is transformed using

$$u_i = \bar{u}_i + a_{ij}U_j, \qquad (21)$$

where a_{ij} is a function of Reynolds tensor.

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Turbulent inflow

- At this time our implementation requires uniform grid in y and z.
- We use the Reynolds tensor components reported in literature for neutral boundary layer scaled by the friction velocity (i.e. $\sigma_u/u_*, \sigma_v/u_*, \sigma_w/u_*$).
- The mean wind and stress profiles can be prescribed by the user.

Parameters I.

- The grid is always uniform, although generally the code is capable of nonuniform grid, some of the methods can be used only for uniform grid (for now at least).

- Two domains for computation: up to 50 m and up to 2000 m (both with some additional buffer zone) These were 2 separate computations and therefore there is a discontinuity in the results.

- None of the two tests had favourable wind speed and directions. Values used for computations were avereaged from the measurement: 2.3 m/s with 30 degrees to the right and 0.4 m/s in the direction of the main axis respectively.

- The reference height for the wind was 2 m.

Parameters II.

- We used 4 separate classes of particle sizes that were treated independently each with fixed diameter and initial percentage.

|	
$0.2\mu m$	10%
$1\mu m$	13%
$6\mu m$	64%
$20\mu m$	13%

Parameters III.

- The incoming flow had logaritmic profile. The turbulent stresses were computed using roughness length 10 cm.
- The roughness length for the ground surface was 1 cm.

Results

- The main feature that is common to all our computations is much weaker decay of deposite activity with distance than measured (in other scenarios with released data).

- This could be changed by allowing more larger particles in the initial cloud but that changes the maximum values. We would like to know opinions and results of other modellers.

- Also the 2 km run was at rather coarse resolution of 12.5 m.

Example result
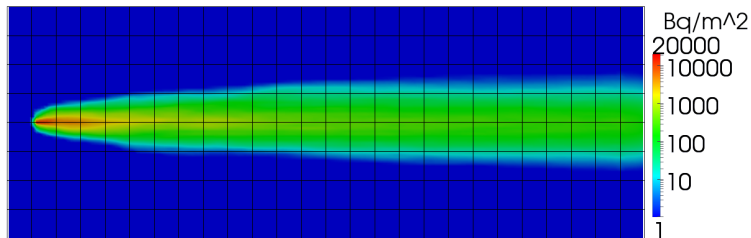
Deposition of activity T3 (grid lines every 100 m, aligned to the wind direction)

Percentiles of contaminated area

The percentiles of the contaminated area (only up to 2 km):

	test3	test4
50 %	3.95 ha	3.25 ha
75 %	12.2 ha	11.1 ha
95 %	25.9 ha	25.8 ha

Our model does not compute γ dose rates and we would appreciate any help how to do that.