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EXTENDED ABSTRACT

MODISAFE – Modelling of urban dispersion of buoyant gases

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Introduction

MODISAFE (MODellIng of Sources and Agent FatE) is a collaboration between the Swedish Defence Research Agency (FOI), the Norwegian Defence Research Establishment (FFI), the French Direction générale de l'armement (DGA), the GB Health and Safety Executive (HSE), the French Institut national de l'environnement industriel et des risques (INERIS) and the University of Surrey. The overall aim is to improve our understanding of source characteristics, loss processes and agent fate. The project has three technical topics: evaporation from porous and non-porous substances, deposition and re-suspension, and buoyant gas dispersion in urban environments.

Releases of toxic or explosive gases in an urban environment (either by accidents or by ill will) may constitute a threat and can potentially affect people's health in a negative way. Several gases have a density which differs from that of air, leading to negative or positive buoyancy. Furthermore, thermal effects (for example due to fire) associated with the release can also lead to a buoyant release.

MODISAFE includes a work package on the study of the transport of buoyant gases in an urban environment by means of wind tunnel experiments and numerical modelling. This presentation focuses on the numerical modelling work.

Numerical modelling

The environment for the study is a part of Oslo city, with full scale dimensions of 2 by 1 km^2. A model scaled by approximately 1:300 to about 6.7 by 3.3 m^2, was created and used in the atmospheric wind tunnel at the University of Surrey [1].

Positively buoyant gases are simulated by helium-air mixtures and negatively buoyant gases by carbon dioxide-air mixtures. In addition, a few experiments with neutral gas were conducted as a reference case. The gas was released from a circular source with a diameter of 5 cm located at an intersection. Table 1 lists the characteristics for the different releases and figure 1 shows the urban environment.

Test number	**Source type**	**Density ratio**	**Volumetric release rate (l/min)**
1	Neutral	1	15
9	Light	0.7	7.5
10	Light	0.38	18
11	Dense	1.52	20
12	Dense	1.26	20

Table 1 The release characteristics. The density ratio is the ratio of the density of the gas to that of air.

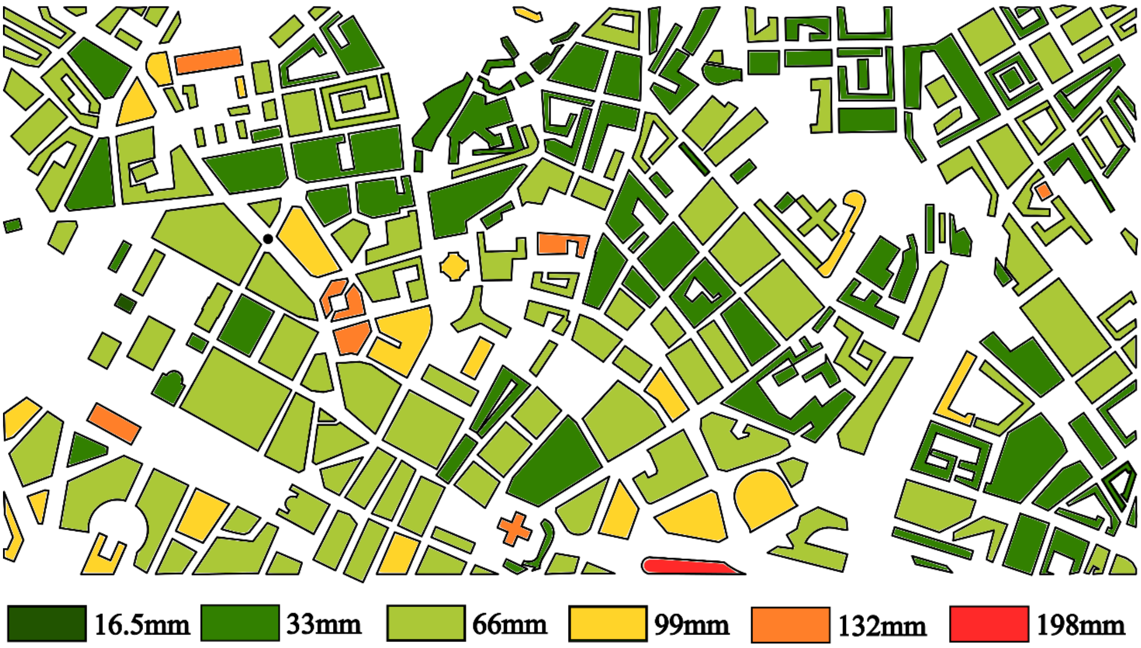


Figure 1 The geometry for the study. The colours indicated the building height (in wind tunnel dimensions). The location of the source is indicated by the black circle.

Two research groups at FFI and DGA respectively have simulated the experimental cases using different CFD models.

Model scale simulations using LES

Large Eddy Simulations, using the module buoyantReactingFoam of OpenFOAM-10, have been conducted at wind tunnel scale. A representation of the geometry and a computational mesh was created using the blockMesh and snappyHexMesh utilities. The grid resolution on the building walls are about 3 mm, which corresponds to a resolution of 1 meter in full scale. The resolution around the source is of the same size, while the resolution is increased further away to a maximum resolution of 20 cm. The computation mesh has a total of about 20 million computational cells.

First a precursor simulation of a 5-meter-long part of the windtunnel, including the roughness elements upwind the urban geometry, but excluding the urban geometry, was conducted. This simulation had symmetry boundary conditions on the side and top walls, no slip conditions on the ground and roughness elements, and cyclic conditions on the inlet and outlet planes. The instantaneous velocity profile between two rows of roughness elements were saved with a time resolution of 20 Hz.

The gas release simulations also had symmetry boundary conditions on the side and top walls and no-slip on the ground, the roughness elements and the buildings. The wind inlet boundary conditions are the time series from the precursor simulation. The boundary condition for the gas source is the volumetric release of the helium-air, air, or carbon dioxide-air mixtures (according to Table 1).

Atmospheric scale simulation with RANS.

Simulations of the atmospheric scale geometry is conducted with the Atmospheric Module of Code Saturne v6 using the RANS k-ε turbulence model. The length scale for this simulation is a factor of about 300 larger that for the wind tunnel experiments and the OpenFOAM LES.

A mesh with about 35 million cells is constructed using the snappyHexMesh utility of OpenFOAM over a domain of 4307 meter in length, 1064 meter spanwise and 180 meter in height (a little smaller in the vertical direction and shorter in the streamwise direction than the upscaled wind tunnel dimensions). The mesh is refined in several boxes near the source, ground and buildings.

The boundary condition for the inlet wind is based on a fit to the experimental wind profile. A surface roughness of 0.26 m was used to fit the neutral wind profile. The area for the source is 15.15 meters in these upscaled simulations.

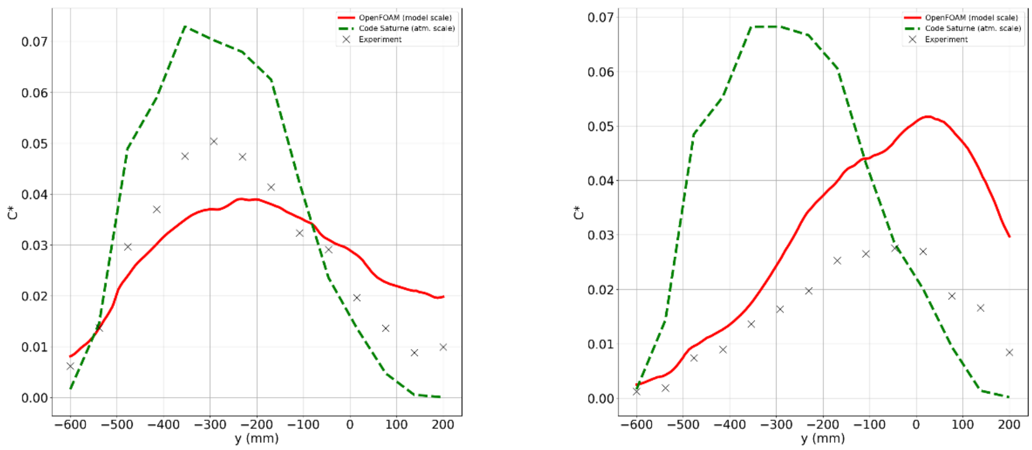
Results

The concentration results are given in dimensionless variable:

$$C^* = CU_{ref}A/Q$$

The reference wind speed is U_{ref} = 1 m/s and 17.4 m/s in wind tunnel and atmospheric scale respectively, the source area is A = 1.96 m^2 and 179 m^2 in wind tunnel and atmospheric scale. The release rate, Q, varies between the different releases. The volumetric rates for the wind tunnel are given in table 1.

Figure 2 shows the lateral dimensionless concentration profiles at height 80 mm (right above the building height) at 1400 mm downwind the source. The experimental measurements are fairly well reproduced by both the numerical approaches, although the wind tunnel scale LES show a better comparison. This trend is also evident at the other locations where measurements are taken (not shown in the abstract). At some locations the agreement between the wind tunnel scale LES with experiments are substantially better than the atmospheric scale RANS.



Neutral gas

Bouyant (light) gas

Figure 2 *Lateral concentration profiles right above the building height 1400 mm (in wind tunnel coordinates) downwind the source. (The source is at y = 0).*

Figure 3 shows concentration contours in a plane perpendicular to the mean wind direction 634 mm downwind the source for experiment 1 (neutral gas), experiment 10 (light gas) and experiment 11 (dense gas) from the OpenFOAM LES. The neutral gas is predominantly channeled toward one side. While for the dense gas release, the transport is bifurcated, leading to a dispersion pattern as if there were two sources. The light gas release is on the other hand lifted above the buildings and transported downwind.

Concluding remarks

Release and transport of neutral, buoyant and dense gases have been simulated by LES (in wind tunnel scale) and RANS (in atmospheric scale), and the results compared with wind tunnel measurements. In general good agreement is found, especially between the wind tunnel scale LES and the experiments. Different dispersion patterns is clearly seen in the different cases due to the density differences.

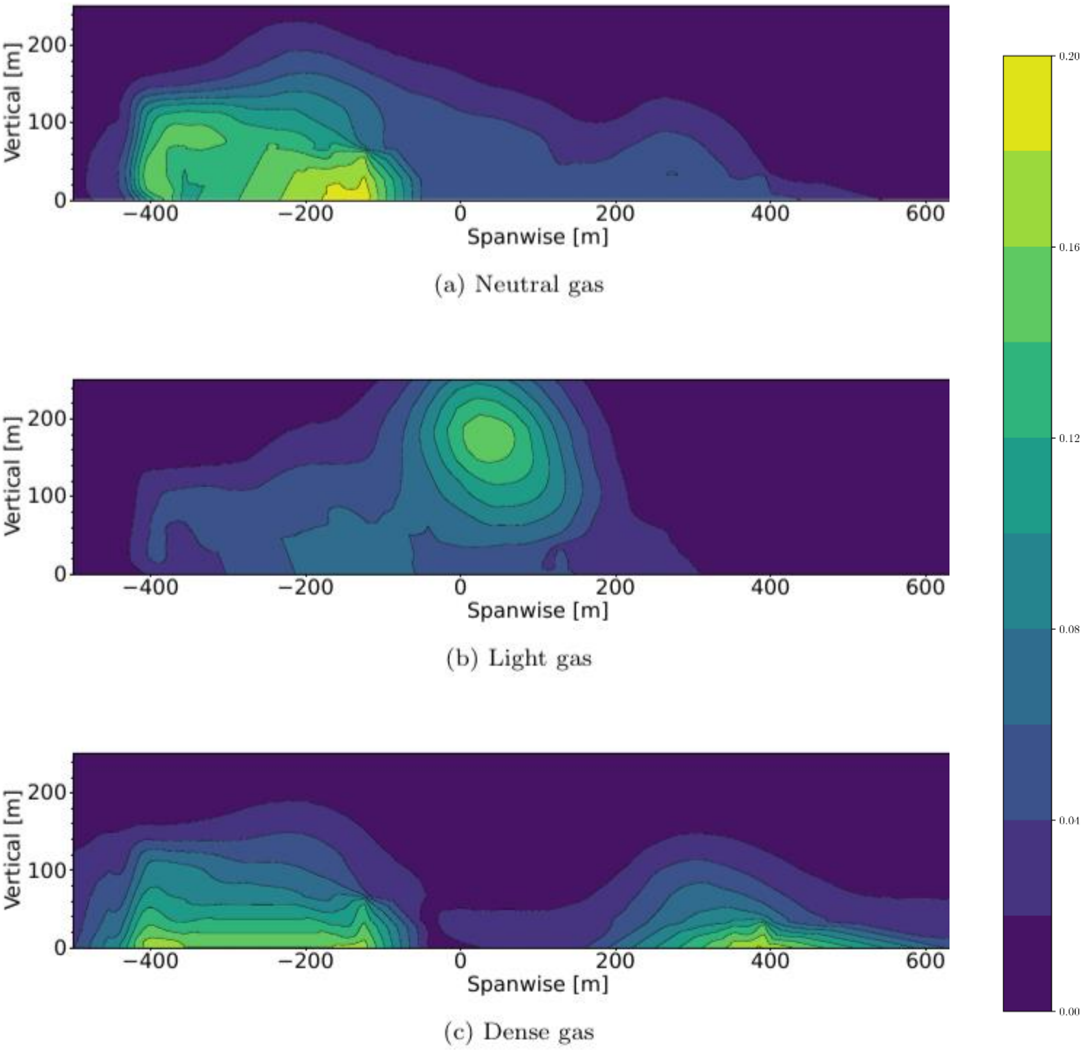


Figure 3 *Contours of the concentration in a plane perpendicular to the mean wind direction 634 mm downwind the source for neutral gas release (experiment number 1), light gas release (experiment 10) and dense gas release (experiment 11)).*

REFERENCES

[1] MODISAFE – Experimental studies of urban dispersion of buoyant gases, Charles Deebank, these proceedings.