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MODITIC WIND TUNNEL EXPERIMENTS NEUTRAL AND HEAVY GAS SIMULATION USING RANS

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Abstract: Wind tunnel experiments with heavy gas release in the vicinity of an urban like complex geometry is modelled and simulated with two different codes and turbulence models. The results are compared to the MODITIC wind tunnel data. The results show that both models capture the main features of the flow: turbulence levels and flow directions are mainly in line with the findings from the experiment. The comparison of the neutral release shows for both models that they can capture the turbulent transport.
The heavy gas release though, indicates that the buoyant effects are only partially captured.

Key words: *RANS, Saturne, PHOENICS, neutral gas release, heavy gas release*

INTRODUCTION

Wind tunnel experiments with heavy gas release in the vicinity of an urban like complex geometry gives a well-defined scenario and well established data with statistical confidence. This can be used for validation and comparison of models aiming to mimic the flow within such geometries. Though the dataset holds several scenarios with neutral and heavy gas release, with and without simulated trees, here only a few of these are used.

The building scenario (Robins et al, 2016) can be described as a market square surrounded by buildings and beyond that a line of buildings in two directions. Two alleys are also part of the scenario. Three source locations are used: the market square and upwind on two locations laterally displaced. The source is either neutrally buoyant or buoyant with a relative density to the ambient with 1.5.
Two different RANS models with different solvers are used. RANS1 is the code Saturne v4.0 developed by EDF. It uses a k-ε linear model together with an atmospheric module developed at EDF.
RANS2 is PHOENICS, which was developed by CHAM and uses the MMK-model.
In addition to concentration plots, the comparison between experiment and model results also uses a user-oriented measure of effectiveness (MOE) and statistical parameters such as fraction of prediction within a factor of 2 (FAC2) (see Warner et al).

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The heavy gas release though, indicates that the buoyant effects are only partially captured.
An improvement would consist in using low-Reynolds models such as kω–sst and more refined meshes in stratified regions to better capture the boundary layer and the dense plume edge gradients.
It would be also worth investigate algebraic flux models to better capture anisotropic turbulent viscosity, or damping factors in isotropic turbulent viscosity as a function of local Ri number.

RANS MODELLING

Code Saturne:

The atmospheric module in Code Saturne with dry atmosphere was activated. It uses a high Reynolds k-ε turbulent model with linear production (corrects the known flaw of the standard k-ε model which overestimates the turbulence level in case of strong velocity gradients) and an adapted rough wall law to atmospheric MO theory. It relies on works by Musson-Genon [1] and Geylen [2] to reconstruct turbulent fluxes and mean profiles from two-points vertical measurements (taken from the inlet profile) to be used as boundary layer profiles. The meteorological profile is read from a met file with the possibility to vary in time (one entry per date/time). It contains mean velocity, turbulent kinetic energy and dissipation rate, temperature and humidity as a function of altitude z. This module can a priori handle neutral, slightly stable and unstable atmospheres dry or wet (adiabatic profile modified). The turbulent production gravity term is included in the k-ε equations ($G=1/\rho\ (\mu_t/\sigma_t)\ \nabla\rho .\ g$). A "scalable wall law" instead of a log law is used in well meshed cases (y+ < 10).

Code PHOENICS.

PHOENICS is a general purpose CFD-code that allows for easy implementation of boundary conditions and grid generation for this case. Boundary conditions are set according to the measured values from the wind tunnel for wind speed and turbulence for the approaching flow. The MMK model differs from the standard high Reynolds k-ε turbulent model in that the eddy viscosity coefficient is limited in strong shear by multiplication with the ratio of the vorticity and strain parameters [3]. The same turbulent production gravity term as in Saturne is included.

HEAVY GAS RELEASE FLAT SURFACE

The flat surface dispersion case is limiting for dense gas release as it is always encountered in the other more complex cases upstream of the building area.

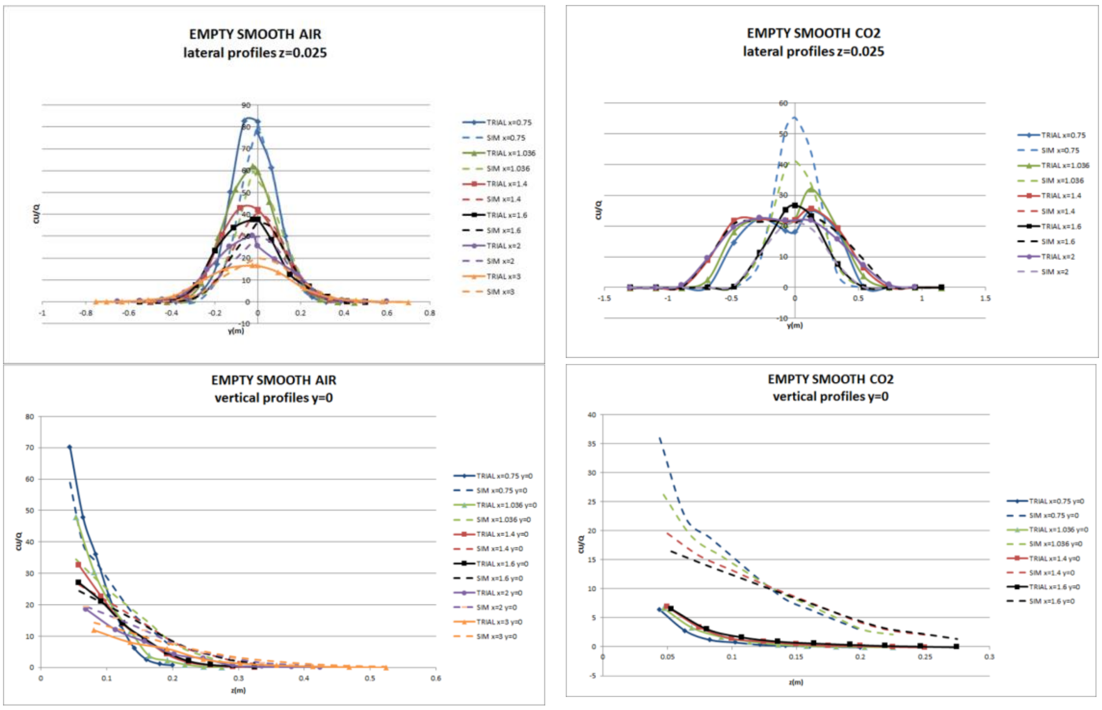

Figure 1. Normalized concentration for AIR (left) and CO_2 (right) on Flat Surface with Code Saturne

On flat surface, Air release (passive gas, left Figure 1) normalized concentrations close to the floor are rather well reproduced, whether CO2 (dense gas, right Figure 1) release concentrations are clearly overestimated with a factor 2 in magnitude and half width. The 2 peaks feature is missed. The neutral case is similar with RANS2 but the dense gas release in the smooth case is seen in Figure 2.

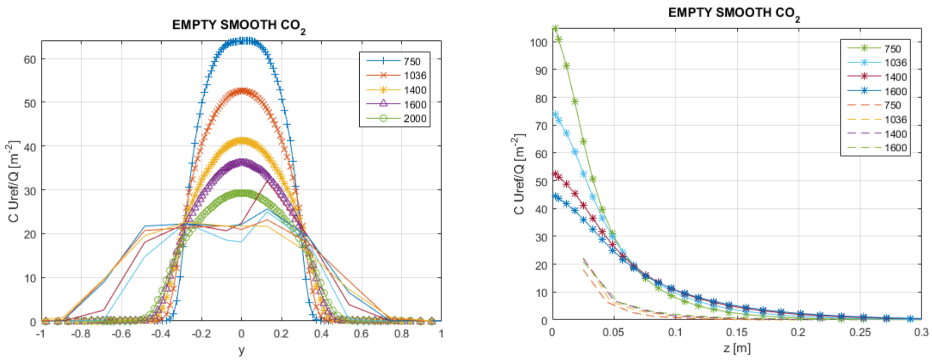

Figure 2. RANS2 sing the MMK model cannot resolve the broadening of the plume in the way the experiment elucidates (left pane), but the right pane show that the gas is vertically dispersed in a way the experiment do not show. It is not clear if the concentration close to the floor was higher than the simulation but it is likely to assume that. Thus the density also is higher and maintained close to the surface.

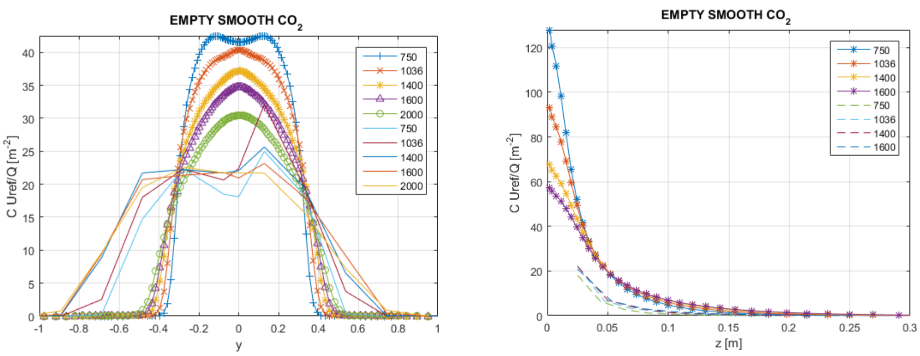

Figure 3. A minor correction of the MMK model is investigated in RANS2. By changing the Prandtl number in the GB formulation from unity to 0.714 a minor improvement is seen. The effect of the density gradient is increased. Still the left pane show unaltered broadening but a decrease of concentration levels and a double peak has emerged. The right panel indicate higher concentration close to the surface but the concentration levels are a factor of from the measured values.

In Figures 1, 2 and 3 the behaviour of the different turbulence models is seen. The AIR case for RANS2 is similar to RANS and is not reproduced. Figure 3 show that an increase in the production term from buoyancy will improve the concentration profile but does not change the broadening to a visual degree.

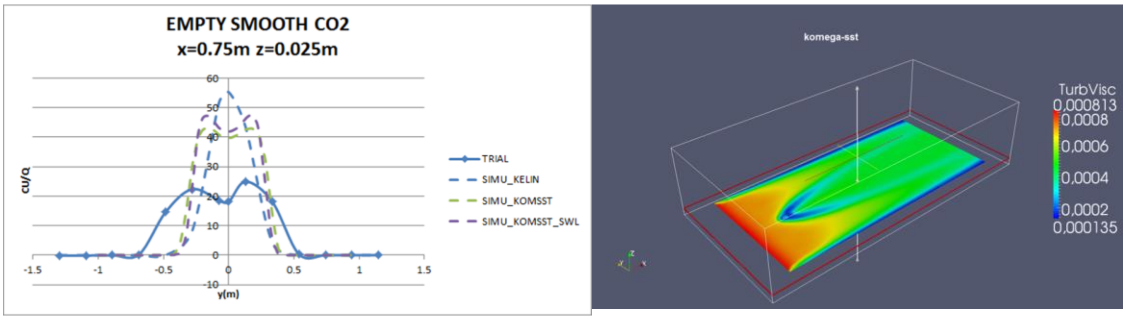

Figure 4. Normalized concentration close to the ground, effect of turbulence model. The left pane show the same pattern as Figure 3 that a modified turbulence model will improve the concentration profile but still cannot simulate the broadening of the plume.

One reason appears to be the use of a high Re turbulence model: we see a slight improvement going from k-ε-linear (Left pane in Figure , dashed blue) to kω–sst models (dashed purple and green), capturing the peaks and lowering the magnitude. The effect of the sharp density gradient is not well resolved by the RANS models studied and does not allow the slumping motion from the dense gas to develop. Further improvement is to be sought in anisotropic viscosity model (Figure , right) and mesh refinement in density gradient region.

HEAVY GAS RELEASE COMPLEX ARRAY

This semi-complex idealized urban area increases the flow patterns and the turbulent field complexity, hence the following dispersion.

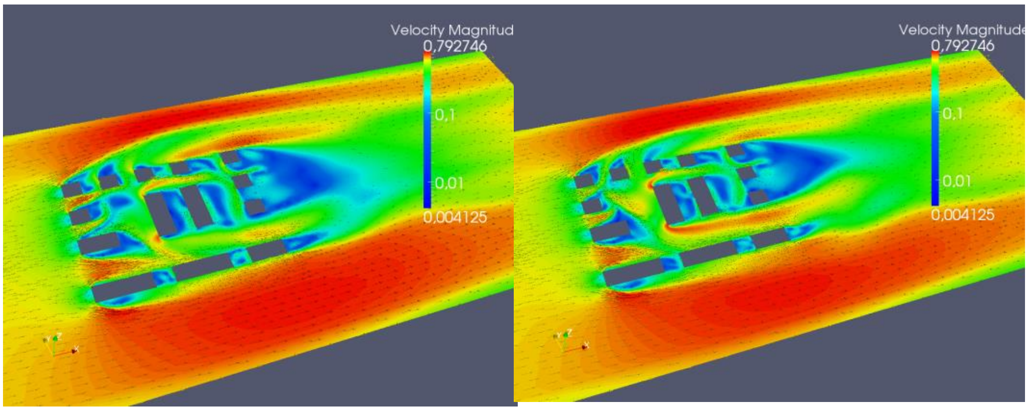

Figure 5. Velocity contours for AIR (left) and CO_2 (right) for complex array case with Code Saturne

We see a rather strong effect of the vertical dense gas release in the source vicinity, with a stronger wind speed in the lower street canyon (Figure 5).

Sensors are placed after the array on cross lines at x=0.8m, 1.0m, 1.5m, 3.0m, 3.0m

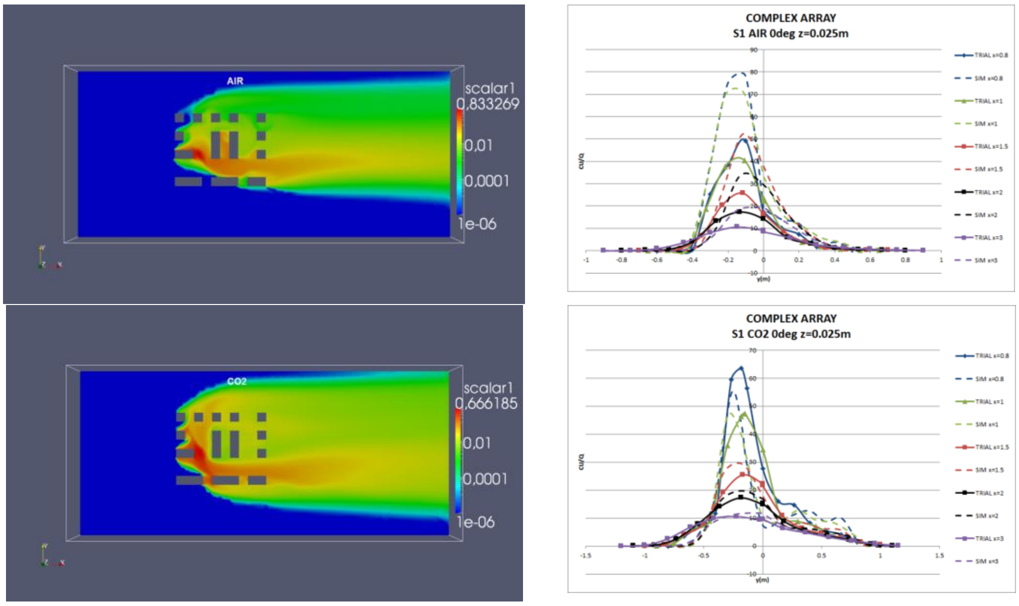

Figure 6. Mass Fraction contours for AIR (top) and CO2 (bottom) and cross wind profiles close to the ground for the 0° orientated array

The Air release results (mass fraction here in Figure 6, top) close to the ground show an overestimation, indicating that the non-stationary mixing turbulent process is under-rated. A slight orientation shift between simulation and experiment may also explain part of the difference. CO2 simulation results (Figure 6, bottom) are this time very close to the observations. Gravitational effects are less critical where strong mixing within building mixing layers occurs.

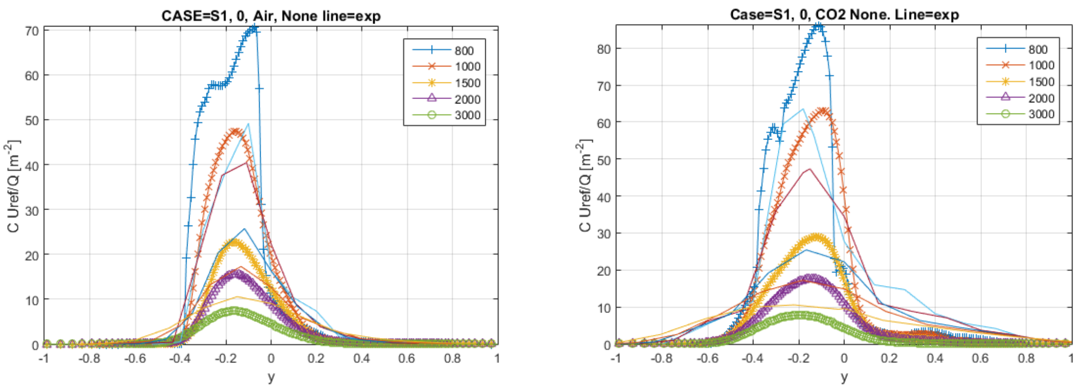

Figure 7. Measurements in the wind tunnel is compared with simulations with the RANS2 model. The lines with symbols are simulations, and the solid lines wind tunnel measurements. In the left pane the release is a neutrally buoyant gas and in the right pane the release is with heavy gas, (CO_2). The left pane (Air) shows an overprediction of concentration closer to the array but an under prediction farther away. The right pane (CO_2) show the same pattern in concentration but misses also to explain the broadening of the plume caused by the heavy gas effects.

CONCLUSIONS

As long as the source is surrounded by buildings, AIR as well as CO_2 (dense) gas release are well reproduced by RANS and RANS2 models tested here in terms of wind speed and concentration (see Figures 5 to 7). This is confirmed in the Paris Case RANS results (not shown here), see (Robins et al, 2016) for reference. The RANS k-ε-linear does perform a bit better for the complex array case than the MMK-model used in RANS2. The CO_2 flat case is more problematic since it reveals the shortcomings of RANS models in this context: high Re turbulence models overestimate the turbulent viscosity, the gravity terms in the $k\varepsilon$ equations is probably not sufficiently resolved by too rough a mesh at the plume edge (where high density gradients happen). Finally the dependence of turbulent viscosity with plume Ri number to further reduce it would be worth to study.

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