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APPLICABILITY OF GAUSSIAN DISPERSION MODELS FOR ACCIDENTAL RELEASES IN URBAN ENVIRONMENT – RESULTS OF THE "MICHELSTADT" TEST CASE IN COST ACTION ES1006

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Abstract: Dispersion modelling of accidental release cases in urban environment is presently developed to great detail using CFD and LES models. Comprehensive data sets are developed during the recent years for evaluation of such models. Still, the first practical issue at accidental releases is to run fast a model and to get fast idea of the area under danger. Using Gaussian models is fast, but not precise. The application of Gaussian models strongly depends on the complexity of the meteorological input they require and the parametrization of the effects of a built-up area. Within a COST ACTION ES 1006, a number of Gaussian models were evaluated on wind-tunnel data along with CFD and LES models. In this paper, some of the results obtained with ALOHA, TRACE and AERMOD are presented and discussed.

Key words: Gaussian dispersion models, ALOHA, TRACE, AERMOD, wind-tunnel modelling

INTRODUCTION

One of the main research tasks of COST Action ES1006 is testing of available dispersion models in order to evaluate their applicability in real situations of accidental gas releases in urban environment. For that purpose, model inter-comparison as well as comparison against test data from wind-tunnel experiments is performed.

Because of the characteristics of the wind flow in urban conditions, such as recirculation and/or blowing through the street canyons, the influence of high buildings and the relatively higher overheating at the surface, the use of more complex models is necessary. When it comes to complexity however, some questions are to be taken under consideration:

- What computer resource does the chosen model demand? For emergency response, minimum time for processing the input data combined with maximum output resolution of the pollution field would be a decision for a part of the problem.
- Is the model adequate enough to handle, and to what degree could it represent, the situation of emergency: input/output issues – meteorology, number of sources and receptors, specifics of the pollutant etc.

When Gaussian models are applied for the "Michelstadt" experiment (Rakai and Franke, 2013), namely AERMOD, TRACE and ALOHA for the sake of emergency response, a very simplified output is achieved at minimum input requirements.

MICHELSTADT EXPERIMENT

The COST Action ES1006 "Evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built "environments" has chosen a wind tunnel data set of an idealized Central European city centre – Michelstadt. Two component LDV (Laser Doppler Velocimetry) measurements were carried out in the Environmental Wind Tunnel Laboratory of the University of Hamburg. The two available velocity components are the streamwise and lateral velocity component. The Michelstadt case is part of the CEDVAL-LES database (http://www.mi.unihamburg.de/Data-Sets.6339.0.html), which contains datasets for different validation purposes (Rakai and Franke, 2013).

ALOHA AND TRACE MODEL RUNS

The input requirements for ALOHA (Reynolds, 1992) and TRACE (Safer TRACE, 2012) for the “Michelstadt” experiment are shown in the following table:

Table 1. Used input for ALOHA and TRACE

Input for the ALOHA and TRACE emergency dispersion models, full scale	
Source input – continuous release	
Type of pollutant	Ethane
Source IDs	S2, S4, S5
Source locations (x, y, z)[m]	All at (0.0, 0.0, 0.0)(Thoman et al., 2006)
Source diameter [m] (TRACE only)	1.575
Source volume flow rate [$m^3 s^{-1}$] (ALOHA)	0.4
Source mass flow rate [kg s^{-1}] (TRACE)	0.5
Temperature of the source's exit gas T [K]	293.15
Source input – puff releases	
Pollutant release time [s]	29 (TRACE rounds it up to 30s, and ALOHA assumes that “puff” release lasts 60s)
Release quantity of tracer gas [kg]	10
Receptor input	
Discrete receptor locations	Taken from database and transformed to meet the source locations
Receptors flagpole height [m]	7.5m for TRACE and 0.0m for ALOHA
Receptor grid origin (x,y)[m]	Coincides with the source
Meteorological input	
Wind velocity at 9 m height [m s^{-1}]	2,7
Wind direction at 9 m height (deg)(adjusted to ALOHA and TRACE)	270.0 (sensitivity tests: -5°, +5° – counter-clockwise and clockwise rotation in relation to 0° direction accordingly)
Ambient temperature at 2m height [K]	293.15
Relative humidity [%]	50
Cloud cover (ALOHA)	10 tenths (overcast)
Surface roughness length [m]	1.0 (sensitivity tests in the 0.8 – 1.2 m interval show almost no change in output)
Pasquill stability class	D (Neutral)
Inversion height options	Set to "No inversion"

Neither ALOHA nor TRACE need vertical wind profiles for the meteorological input. The wind speed value of 2.7 m s^{-1} (at 9 m reference height, full scale) is taken from the vertical wind profile database, situated in Michelstadt domain at coordinates (-450, 112.5). This point is the most representative for the meteorological input, since it is within the domain, and the wind direction at that point is not directly influenced by any situated buildings in the vicinity (see the blue square on Fig. 1). Another advantage is, that the point is close to the S2 source (coordinates (-361.9, 125.1)).

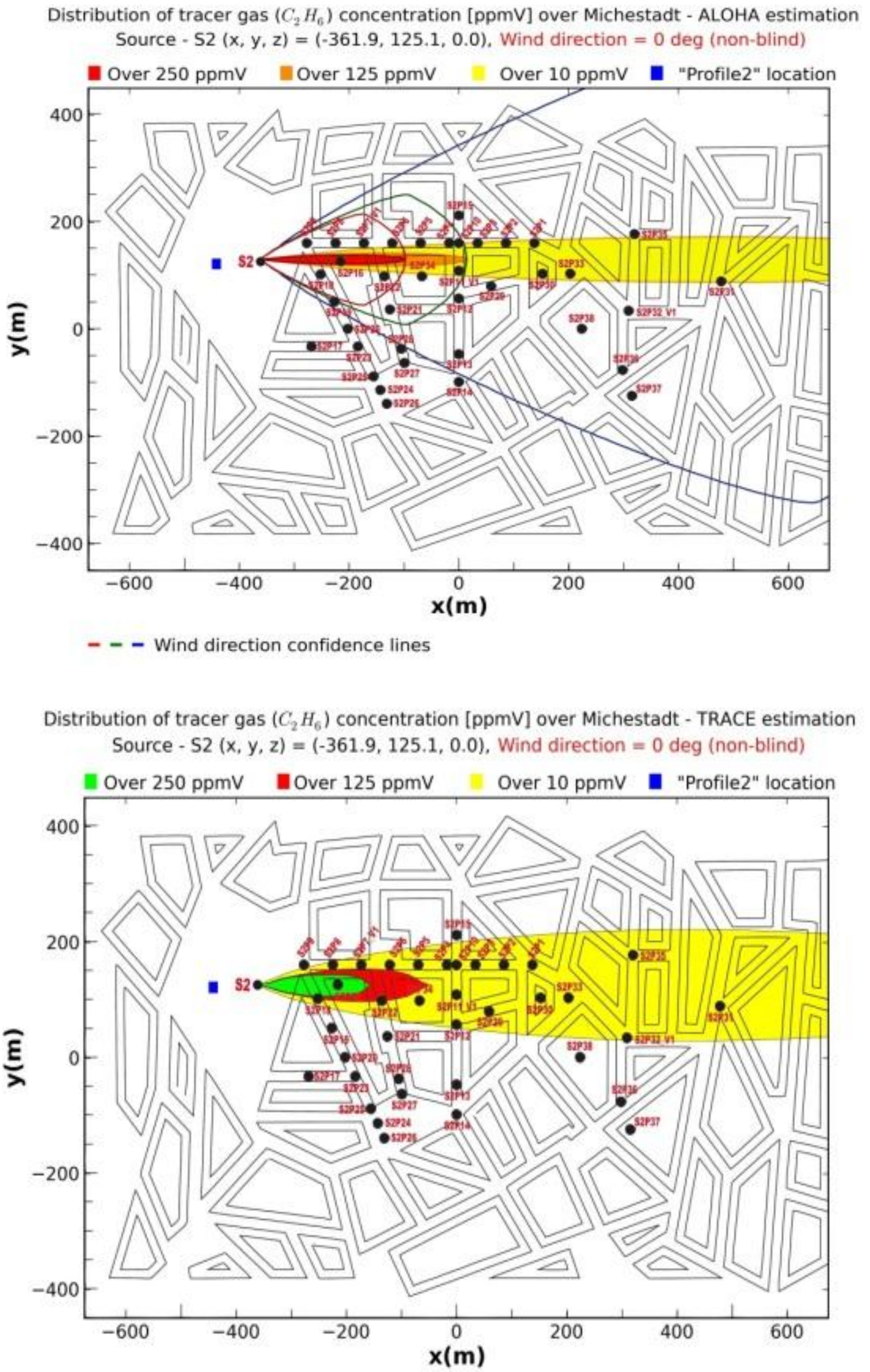

Figure 1. Distribution of the tracer gas concentration [ppmV] over Michelstadt – ALOHA (upper panel) and TRACE (lower panel) estimations

TRACE and ALOHA show similar sensitivity to wind direction, due to the relatively narrow plume simulated by both models. The best concentration predictions for continuous releases are observed when the wind flow direction is rotated -5 degrees (5 degrees counter-clockwise), which might be related to configuration of built-up area.

The tests with varying surface roughness (0.5, 0.8, 1.0 and 1.25 m) give negligible differences both with ALOHA and TRACE.

AERMOD RUNS

Being an integrated system, the AERMOD dispersion model is more complex (AERMOD, 2004). So, besides the sensitivity to flow direction, the sensitivity of AERMOD to surface roughness and friction velocity values were investigated. Changing the wind direction with -5 and -10 degrees (rotation counter-clockwise in relation to 0 deg direction) improved the prediction at the near source receptors for the case of source S2. Reducing the friction velocity by 71% ($u_* = 0.4$ m.s^{-1}) compared to the initial one ($u_{*0} = 0.566$ m.s^{-1}) improved the concentration prediction at the near source receptors and at some distant receptors (Fig. 2).

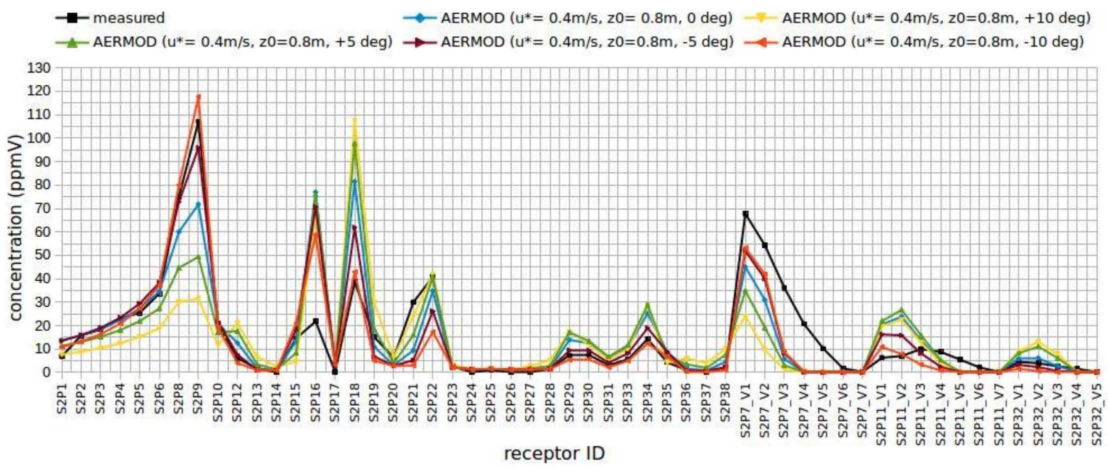

Figure 2. Comparison between measured and AERMOD's estimated concentrations – source S2, approach flow directions – -10^o, -5^o, 0^o, +5^o, +10^o, $u_* = 71\% u_{*0}$

An important disadvantage of the AERMOD dispersion model is the need of prepared in advance input data files concerning terrain complexity, meteorology, and source's type and location. Indeed, AERMOD is a regulatory model and not an emergency response one. So, in short, this means that in an emergency situation this model cannot be applied "on the run". Other issues are the lack of possibility of the AERMOD system to be applied for puff releases and graphical visualization. For graphical representation of the air pollution fields, a suitable graphical software is needed (ex. the air pollution field shown on Figure 3 is plotted with the Matplotlib open source package (Tosi, 2009). Nevertheless, the output results and the statistical analysis (Table 3) show, that it is worth applying this model whenever possible – even for post-emergency evaluation of the air pollution. Furthermore, both ALOHA and TRACE do not take terrain complexity into account, while AERMOD does. In this case, AERMOD is used with terrain option set to FLAT, and the need of terrain data input for AERMOD drops out.

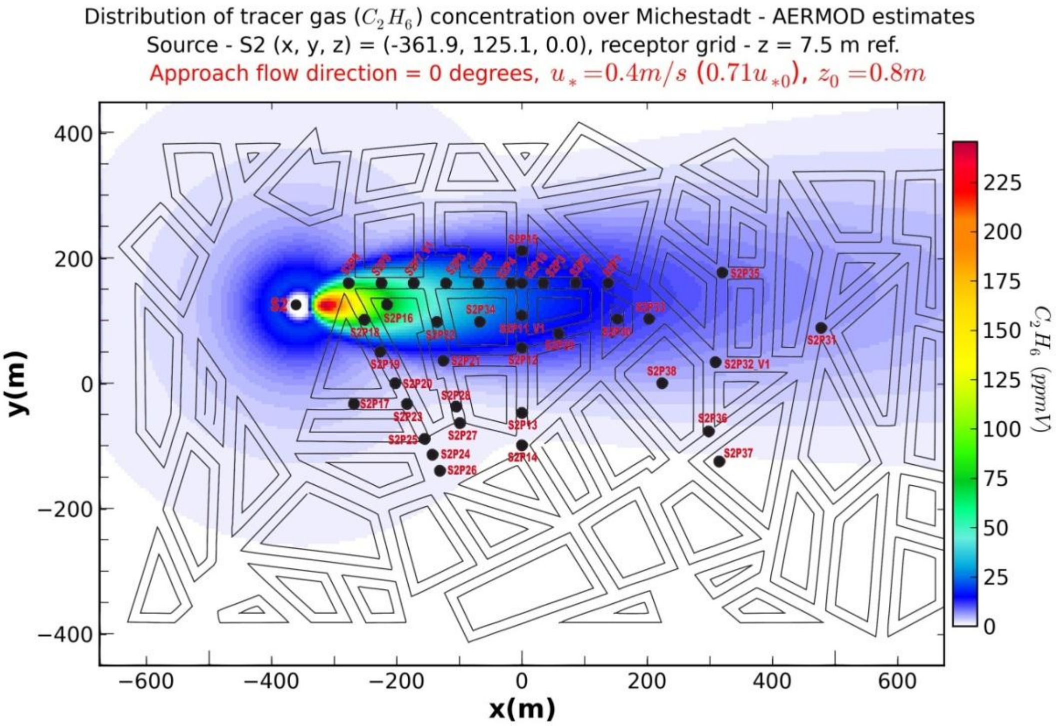

Figure 3. Distribution of the tracer gas concentration [ppmV] - AERMOD estimates

Table 3. AERMOD sensitivity tests statistical comparison for source S2

The following statistical performance measures are used: **FB** – Fractional bias, $FB = (\overline{C_o} - \overline{C_p})/0.5(\overline{C_o} + \overline{C_p})$, where $\overline{C_o}$ is the mean observed concentration, and $\overline{C_p}$ – the mean predicted concentration; **R** – Correlation coefficient, $R = (C_o - \overline{C_o})(C_p - \overline{C_p})/\sigma_{C_o}\sigma_{C_p}$, where σ_{C_o} and σ_{C_p} are the standard deviations over the C_o and C_p sets accordingly; **NMSE** – Normalized mean square error, $NMSE = \overline{(C_o - C_p)^2}/\overline{C_o}\ \overline{C_p}$.

S2(0°), u_* = 0.4 m s^{-1} (71% u_{*0})				**S2(+5°), u_* = 0.4 m s^{-1} (71% u_{*0})**			
z_0[m]	**FB**	**R**	**NMSE**	**z_0[m]**	**FB**	**R**	**NMSE**
0.50	-0.06	0.74	1.01	0.50	-0.03	0.56	1.05
0.80	0.01	0.77	0.88	0.80	0.04	0.62	0.91
1.00	0.05	0.79	0.85	1.00	0.08	0.65	0.87
1.25	0.11	0.80	0.84	1.25	0.13	0.67	0.86
1.50	0.14	0.81	0.85	1.50	0.16	0.69	0.86
S2(-5°), u_* = 0.4 m s^{-1} (71% u_{*0})				**S2(-10°), u_* = 0.4 m s^{-1} (71% u_{*0})**			
z_0[m]	**FB**	**R**	**NMSE**	**z_0[m]**	**FB**	**R**	**NMSE**
0.50	-0.02	0.86	1.05	0.50	0.09	0.90	1.18
0.80	0.05	0.87	0.92	0.80	0.16	0.91	1.02
1.00	0.10	0.88	0.89	1.00	0.20	0.91	0.98

Table 3. AERMOD sensitivity tests statistical comparison for source S2

1.25	0.15	0.88	0.87	1.25	0.24	0.91	0.96
1.50	0.19	0.88	0.88	1.50	0.28	0.91	0.97

CONCLUDING REMARKS

The use of Gaussian dispersion models for accidental releases in urban environment gives a quick, but not precise picture of the air pollution distribution. The real distribution of air pollutant concentrations between the buildings of a certain urban area is more complex due to accumulation of pollutants at some areas or protection by obstacles and so no pollution at other places.

ACKNOWLEDGEMENTS

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