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# WIND TUNNEL MEASUREMENTS OF ACCIDENTAL GAS RELEASES IN A SIMPLIFIED URBAN ENVIRONMENT

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**Abstract**: Rescue services apply numerical models in emergency situations involving accidental gas releases in urban environments. These models are often validated according to air quality standards. However in case of emergency situations the required information is very different from the results of an air quality study. Probabilities of high concentrations for various time periods, and characteristics of puff dispersion are important information for rescue services. Wind tunnel measurements were carried out to create a validation dataset for emergency response tools. The urban geometry was represented by the 1:225 model of the idealized city structure, Michelstadt. Continuous and puff release dispersions were investigated. The results show that the prediction of the mean concentration field is not enough to provide the necessary information for emergency response.

***Key words:*** *wind tunnel, validation, emergency response, urban dispersion, accidental release*

## INTRODUCTION

The flow field in an urban environment is influenced by the building structure (Britter and Hanna, 2003). The dispersion of gases in the urban canopy layer is governed by the flow field. Information about the dispersion of an accidental gas release is crucial for rescue services.

Numerical models are often applied to predict the concentration distribution of gas release. Resolving turbulence in an urban flow field requires unfeasible spatial and temporal resolution. Therefore the numerical models used by rescue forces are based on assumptions. The quality of these assumptions is quantified through validation. Validation is the comparison of the results from numerical simulation to a statistically representative dataset with known uncertainty. Validation dataset can be the result of field tests (e.g. Allwine et al., 2004 and Martin et al., 2010) or wind tunnel measurements (eg. .Harms et al., 2011).

In the past, the majority of the numerical models were validated according to air quality requirements. The most important parameter for air quality studies is the mean concentration resulting from continuous releases. Air quality is usually investigated in a larger district or in a whole city.

An air quality model is not necessarily applicable for emergency response. An accidental release can have effects in various scales. Most cases however have local scale impact. Characteristics of puff releases (such as arrival time, dosage, duration, etc.) are crucial information for rescue services. The information of the mean concentration resulting from continuous releases is not enough in an emergency situation. Information about expected high concentrations should be determined reliably by the numerical models.

The boundary conditions of accidental releases in an urban environment can vary. Differences in building structure, wind direction, release duration, density of the gas, thermal stratification, etc. all result in different boundary conditions. Numerical models should be tested against these different scenarios before application. One validation dataset usually does not include all of the different scenarios. However with a combination of different datasets, sufficient model validation can be achieved. In the frame of the COST Action ES1006, emergency response tools are evaluated and validated against several datasets. This paper describes the first validation test case.

## EXPERIMENTAL SETUP

Flow and dispersion measurements were carried out in the “WOTAN” boundary-layer wind tunnel in Hamburg. The test section of the wind tunnel is 18 m long and 4 m wide. The urban geometry was represented by a 1:225 scale model of “Michelstadt” (Fig.1). The design of the idealized model resembles a structure typical for cities in Central-Europe (Bastigkeit, 2011). The flow field inside and around the model is described by Hertwig et al. (2012).

2D Laser Doppler Anemometer and fast Flame Ionization Detector (FID) measured the velocity and the concentration. Both techniques provide results with high temporal resolution. The point sources mounted into the ground plates emitted ethane tracer gas. A bypass configuration ensured the release stability and repeatability. The speed of the release was one order of magnitude lower than the wind speed at source-height to model passive emission. The sources operated in continuous and short-term (puff release) mode.

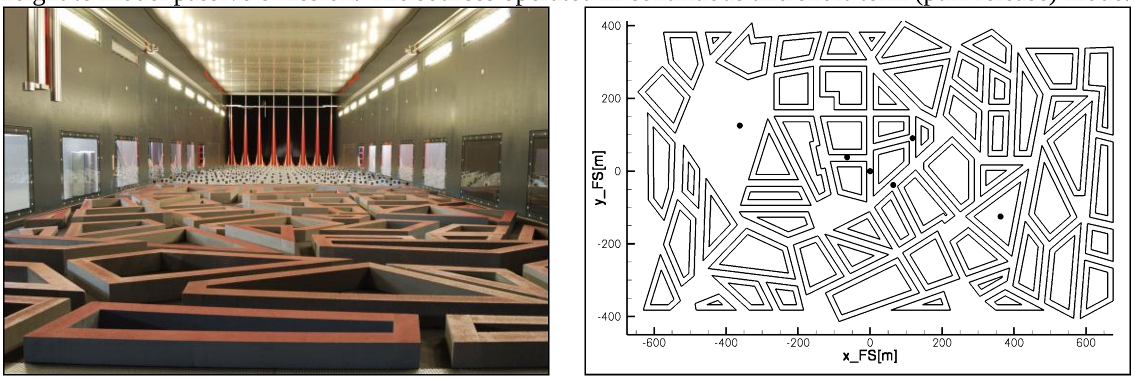


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**Figure 1.** Model of Michelstadt in the wind tunnel (a). Layout of the model (b).

Six source locations and two wind directions ensured a diversity of test cases. Continuous release dispersion was measured at 352 locations and puff dispersion was measured at 41 locations. The representativeness of the measurements was ensured by the length of the continuous releases and the number of puffs released. Repeated measurements give information about the uncertainty of the results.

The source locations were selected to provide different scenarios of releases (Fig 1.b). There are sources located in street canyons parallel and perpendicular to the approach flow, in an open terrain, in intersections and in a courtyard.

The measurement locations were chosen based on discussions with numerical modelers. Fig. 2 shows the measurement points for S2 source for continuous release. Street canyon profiles were measured close to the source. There are locations (e.g. inner courtyards, intersections, building edges) chosen to pose as challenge for the numerical models. At several locations, an attempt was made to detect the edge of the affected area. Therefore points, where no concentration could be measured were also included in the dataset. In emergency situations, the concentration field within the urban canopy layer is of most importance. Therefore most measurements were carried out at half-building height.

## RESULTS

In previous validation exercises (e.g. Schatzmann, et al., 2010) the average concentration from continuous release measurements served as the basis of comparison. However, in emergency situations extreme values for different time intervals are important information. Therefore the numerical models should be validated for these statistics as well.

The measured concentration time series were converted to full scale and evaluated. The distribution of the measured concentration values are plotted in Fig. 3 for two measurement locations. The shape of the distribution is different at each measurement point. Therefore the mean value alone is not representative of the whole concentration distribution. In the Michelstadt dataset, the statistics are calculated for 15 s, 10 min, 30 min and 1 h intervals. The maximum concentration, 5$^{th}$, 95$^{th}$ and 99$^{th}$ percentiles are given in the dataset.

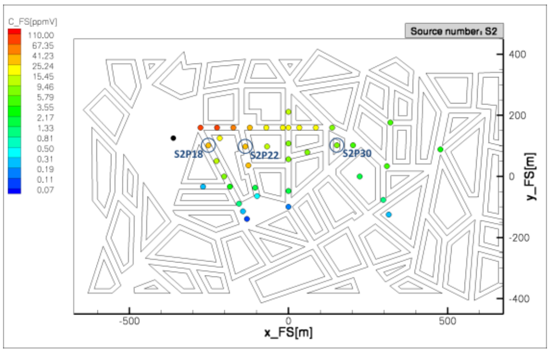


**Figure 2.** Results of the continuous release measurements from S2 source.

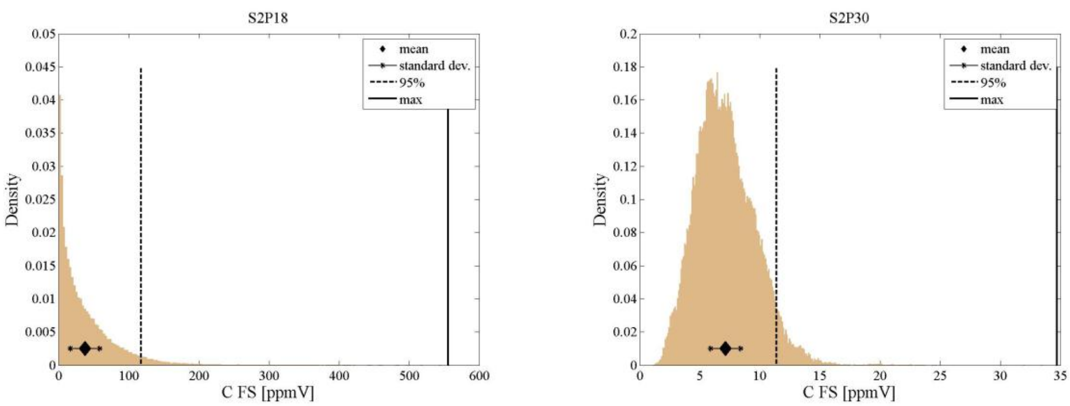


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**Figure 3.** Concentration distributions of continuous release measurements for locations S2P18 (a) and S2P30 (b).

Puff parameters were derived from the concentration time series resulting from the puff measurements. Dosage-based criterion was applied to evaluate the characteristic times of the puffs (Berbekar et al., 2015, Harms, 2010). The evaluation resulted in 8 parameters altogether for each puff measurement: dosage, peak concentration, peak time, arrival time, leaving time, duration, ascent time and descent time. The 15-s-average peak concentration and peak time were also determined. At least 300 puff releases were measured at each measurement location to ensure statistical representativeness. The parameters were determined for each release. Therefore, the result is a distribution of each puff parameter for each measurement location. These distributions were statistically analyzed. The 5$^{th}$ and 95$^{th}$ percentile, mean, median and skewness of the distributions were evaluated. The modes of fitted normal and gamma probability density functions (PDF) are also given in the dataset (Fig. 4). As Fig. 4 shows, the distribution of the results is wide. Even for the 15-s-averaged parameters, the range can be as large as the mean value itself. Therefore one puff realization is not enough, a smooth and reproducible distribution is needed to produce representative results.

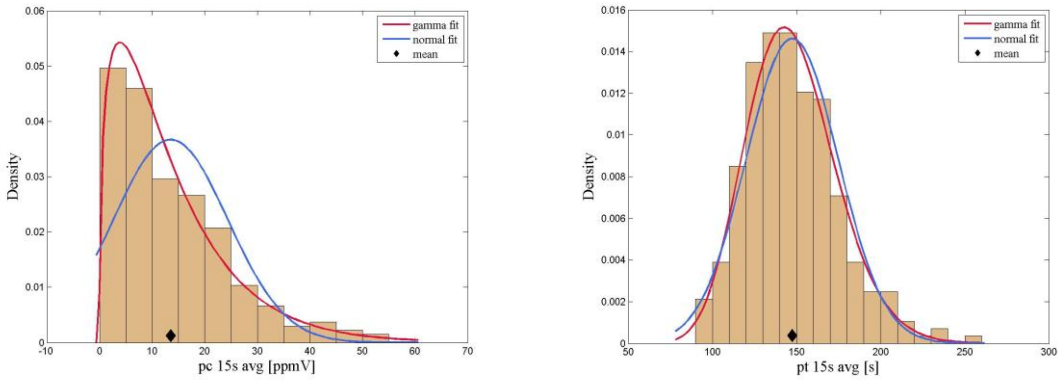


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**Figure 4.** Probability density of the peak concentration (a) and peak time (b) of the 15-s-averaged puff release dispersion time series for measurement point S2P22.

## CONCLUSION

According to Britter and Schatzmann (2007) to validate a numerical model, the variables relevant to the model purposes should be compared. Therefore validation according to air quality guidelines is not necessarily eligible for emergency situations. The information of the mean concentration field resulting from a continuous release is often not enough for the rescue services. Characteristics of puff dispersion and the probability of high concentrations are crucial information during an emergency situation.

Wind tunnel measurements were carried out to serve as basis for the validation of models applied in emergency situations in urban environments. To provide a diversity of test cases two wind directions, six source locations and numerous measurement points were selected. Concentration time series were recorded with high temporal resolution. The length of the continuous releases and the ensemble size of the puff releases were chosen to yield in a smooth and reproducible distribution of the results at each measurement location. This ensures the statistical representativeness of the results.

For the continuous release case the $5^{th}$, $95^{th}$ and $99^{th}$ percentiles and the maximum of the concentration distribution is provided for each measurement location. The statistics are given for 15 s, 10 min, 30 min and 1 h intervals.

For the puff releases, the distributions of the dosage-based puff parameters are given for each measurement location. From these distributions, the $5^{th}$ and $95^{th}$ percentile, mean, median and skewness are calculated. Moreover, a normal and a gamma PDFs are fitted to each distribution.

The distributions of the results are different at each measurement location. Therefore if a model is applied to predict higher concentrations and characteristics related to puff dispersion, validation of the mean concentration field is not enough.

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**REFERENCES**


Allwine, K J, M J Leach, L W Stockham, J S Shinn, R P Hosker, J F Bowers, and C J Pace, 2004: Overview of Joint Urban – An Atmospheric Dispersion Study in Oklahoma City. In *Symposium on Planning, Nowcasting, and Forecasting in the Urban Zone, Seattle, WA*

Bastigkeit, I., 2011: Erzeugung von Validierungsdaten für wirbelauflösende mikroskalige Strömungs- und Ausbreitungsmodelle. Ph.D. Thesis (in German). University of Hamburg, Germany

Berbekar, E., F. Harms, B. Leitl, 2015: Dosage-based parameters for characterization of puff dispersion results. *Journal of Hazardous Materials* 283, 178-185.

Britter, R, and M Schatzmann, 2007: Model Evaluation Guidance and Protocol Document. COST Office, Brussels

Britter, R. E., and S. R. Hanna, 2003: Flow and Dispersion in Urban Areas. *Annual Review of Fluid Mechanics* 35 (1), 469–496.

Harms, F., 2010: Systematische Windkanaluntersuchungen Zur Charakterisierung Instationärer Ausbreitungsprozesse Einzelner Gaswolken in Urbanen Rauigkeitsstrukturen. Ph.D. Thesis (in German). University of Hamburg, Germany

Harms, F., B. Leitl, M. Schatzmann, G. Patnaik, 2011: Validating LES-based flow and dispersion models. *Journal of Wind Engineering and Industrial Aerodynamics* 99, 289–295.

Hertwig, D., G. C. Efthimiou, J. G. Bartzis, and B. Leitl, 2012: CFD-RANS Model Validation of Turbulent Flow in a Semi-idealized Urban Canopy. *Journal of Wind Engineering and Industrial Aerodynamics* 111, 61–72.

Martin, D., C.S. Price, I.R. White, G. Nickless, K.F. Petersson, R.E. Britter, A.G. Robins, S. E. Belcher, J. F. Barlow, M. Neophytou, S. J. Arnold, A. S. Tomlin, R. J. Smalley and D. E. Shallcross, 2010: Urban Tracer Dispersion Experiments During the Second DAPPLE Field Campaign in London 2004. *Atmospheric Environment* 44 (25), 3043–3052.

Schatzmann, M, HR Olesen, and J Franke, 2010: COST 732 Model Evaluation Case Studies: Approach and Results. COST Office, Brussels