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Sensitivity of puff characteristics to maximum-concentration-based definition of departure time

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ABSTRACT

During a hazardous situation, its dangerousness has to be estimated. An important category of such situations is the one in which hazardous gas clouds are released into the atmosphere. The gas clouds are described by their characteristics at exposed locations. But their values are usually dependent on the parameters utilized in their definitions. Hence, the aim of this paper is to examine how the choice of parameter value in a definition of departure time can affect its value. Moreover, it evaluates how this change influences other characteristics which utilize the departure time in their definitions. To study these situations, wind-tunnel experiments of short-duration gas releases were conducted. The ground-level releases of ethane were performed on a model of an idealised urban canopy. The model was composed of houses with pitched roofs organised into closed courtyards. Concentrations were measured by a fast flame ionisation detector. The experiments were repeated about 400 times at each measurement position to get statistically representative datasets. In the analysis, two departure time definitions, based on a detected maximum concentration with various parameters, were utilized. Moreover, other derived puff characteristics were computed. The results showed that when a suitable range of parameters is used, the differences in mean departure times are significant. In contrast, some other characteristics which use puff departure times in their definitions (e.g. mean dosage) are usually not significantly different.

1. Introduction

Environmental disasters are unfortunately inseparable from the history of humankind. In the past, such disasters were mostly caused by earthquakes, volcanic eruptions or tsunamis (e.g., Kozák and Čermák, 2010). One example is the destruction of Pompeii by the Vesuvius explosive eruption in 79 AD (e.g., Luongo et al., 2003). Nowadays, environmental disasters are often connected with human activities (e.g., Chernobyl accident - Pollanen et al., 1997; Kuwaiti oil fires - Husain, 1994). Moreover, the number of deaths and damage is increasing, as suggested by Alexander (1999). An important category of human-caused disasters is the one in which radioactive or toxic material is released into the atmosphere (e.g., accidents in the Fukushima Daiichi Nuclear Power Plant in Japan - Chino et al., 2011; Bhopal Union Carbide in India - Varma and Varma, 2005; Flix in Spain - Marco et al., 1998). After the detection of such a disaster, emergency services need to estimate its evolution over time and also its consequences for the environment and people's health. For such purposes, models are utilized (e.g., HotSpot - Homann and Aluzzi, 2014). These models should give the most accurate results as possible. Hence, they have to be correctly developed. During the development, simulations of such incidents are utilized to validate the models. These simulations are usually performed using physical modelling (e.g., Santiago et al., 2007) or field experiments (e.g., Chan and Leach, 2007).

The results of experiments simulating short-term releases of toxic materials – both from field and laboratory campaigns – are usually concentration time series recorded at individual exposed locations (e.g., Chaloupecká et al., 2017). These data have to be analysed to assess the evaluation of the incident. The results of this analysis are characteristics describing release at the given location (e.g., arrival and departure time of toxic material, ascent time period of concentrations, descent time period of concentrations, dosage). An overview of frequently used characteristics is given e.g. by Zhou and Hanna (2007). Most of these variables are dependent on a determination of the times at which the material gets to and leaves the monitored location. Unfortunately, these times are very difficult to determine. This difficulty is mainly caused by the noise of the detector utilized for concentration measurements, the residue of tracer gas or dust particles sucked into the detector, as suggested by Chaloupecká et al. (2017). Hence, many definitions exist for how to determine them. Chaloupecká et al. (2017) utilized four

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different types of definitions of arrival time of material on one dataset and suggested the best option for the automatic usage. While the determination of the arrival time is definitely crucial for emergency services, the precise determination of departure time seems not to be as important at first glance. One reason is that the determination of the ending of the evacuation and the return of people to the exposed regions can be inspected by the direct measurements utilizing detectors at the exposed locations (e.g., Mitchell et al., 2005). The predicted departure time is therefore only a helpful tool, which should estimate the time when firefighters and the army can perform direct measurements at the exposed locations. On the other hand, the value of the departure time enters into the definitions of other variables - e.g. dosage or high percentiles of concentrations. Such variables help to evaluate the hazardous effects of the emergency incident (e.g, Efthimiou et al., 2016; Yee and Chan, 1997).

The aim of this paper is to estimate how slight changes in a method of determination of departure time affects its values and the other derived puff characteristics. The main question we would like to answer is: Is a precise determination of puff departure time important for the evaluation of hazardous effects of an emergency situation, or not? To answer this question, we utilized a definition of departure time based on the last detection of a concrete percentage of maximum concentration in a concentration time series (e.g. Zhou and Hanna, 2007) with various values of percentages in the algorithm. During the analysis, it was seen that this method shows false long departure times in cases where a background signal is noisy (a higher concentration is observed one or more times). Hence, we modified the method to be resistant to this phenomenon. The modified method also utilizes the information of the recorded maximum concentration as the first one. But the difference is that it looks at a difference of local maxima of concentrations during a specific time interval instead of looking at only one value of concentration. This method trades on the fact that concentration levels after a gas cloud departure exhibit almost no change or the change is very slow over time. In contrast, concentration levels change over time much more during the presence of a gas cloud. Investigating the concentration level is aggravated by intermittency, when we detect in a short time interval transitions between high and almost zero concentration values. Therefore, local maxima are utilized in the method. Connecting these local maxima with lines, we create an envelope curve around the concentration time series. Using these envelope data, we can investigate from which time changes in the concentration level almost stop and we set this point in time as the departure time of a gas cloud.

2. Materials and methods

2.1. Experimental set-up

The experiments were conducted in an open, low-speed wind tunnel specialised in boundary layer modelling. The boundary layer utilized in the experiments had a scale of 1:400 and a neutral stratification. The modelled boundary layer characteristics agree with the recommendations of VDI (2000) for flows found in cities (Grimmond and Oke, 1999; Britter and Hanna, 2003). More details about the wind tunnel and the boundary layer can be found in Chaloupecká et al. (2017). In the experiments, a model of an idealised city to the scale of 1:400 was used (Fig. 1). The model consisted of 63 mm high and 38 mm wide houses with pitched roofs. The height of the roofs constituted 13 mm of the height of houses. The houses were organised into 150 mm × 300 mm courtyards (outer dimensions) placed 50 mm from each other. A short-duration, ground-level point gas source with a circular orifice of 4 mm in radius was used in the experiments. Tracer gas discharges of 1 s set on a timer relay, which operated an electromagnetic valve, were utilized in the experiments. Pure ethane was used as the tracer gas. The placement of the source and measurement positions of concentrations within the model is displayed in Fig. 2. The measurement positions were set in the street parallel to the incoming flow (parallel street) and to three streets transverse to the incoming flow (transverse streets). The concentration time series were measured with a fast flame ionisation detector (FFID) at a human breathing zone. The detector response time was measured by a flick test (HFR400 User Guide). The flick test showed that the response time is better than 6 ms (see Chaloupecká et al., 2017 for more details). During the experiments, data were sampled at 1000 Hz rate and smoothed to 6 ms averages.

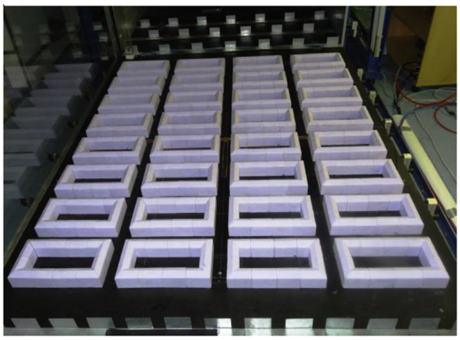

Fig. 1. Model of an idealised urban canopy placed in the wind tunnel.

2.2. Data analysis

In the paper, the results are presented in dimensionless forms. The following relations as found in VDI (2000) were used to recalculate the variables into a dimensionless form:

- for coordinates

$$x^* = \frac{x}{H},\ y^* = \frac{y}{H}. \tag{1}$$

In this relation, H stands for the characteristic height (the height of the modelled houses 63 mm), x and y are horizontal coordinates.

- for concentrations

$$C^* = \frac{CU_{ref}H^2}{Q}. \tag{2}$$

In this relation, U_{ref} stands for the reference speed (measured at the middle height of the wind tunnel), H is the characteristic height and Q is the source intensity. This relation is valid for a point source (VDI, 2000). Tests of independence of dimensionless concentration values on Reynolds number and on source intensity were conducted to set appropriate experimental conditions.

- for time

$$t^* = \frac{tU_{ref}}{H}. \tag{3}$$

In this relation, U_{ref} stands for the reference speed, and H is the characteristic height.

The uncertainty of the instruments used can be seen in Table 1. The experiments were repeated under the same experimental set-up around 400 times to get statistically representative ensembles. Each concentration time series was analysed to obtain puff characteristics (e.g. departure time, dosage). From these values, the ensemble statistics (e.g. mean values, interquartile ranges) were computed. The procedure is depicted in Fig. 3. The uncertainties of the ensemble statistics were computed with the help of an approach based on bootstrapping. We utilized Percentile Bootstrap Confidence Intervals based on 10,000 bootstrap samples (e.g., Davison and Kinkley, 1999; Good, 2005, 2006; Hesterberg et al., 2003). The uncertainties are depicted by error bars in the Figures in the article. They represent 95% confidence intervals. Lincoln University (2014) defines a confidence interval as an interval

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