Experimental study of atmospheric 3D dispersion of a passive tracer in urban environment: comparison with Briggs urban model

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Abstract

FluSAP 2010, a part of a large federative research program Vegdud (2010–2013) funded by the French National Research Agency, is an experimental campaign aiming to improve our knowledge on the dispersion of a plume in heterogeneous urban zones. For this, the French Institute for Radiological Protection and Nuclear Safety (IRSN) conducted an experimental campaign in the city of Nantes (France) to study atmospheric dispersion. A gas tracer SF_6 was released in the atmosphere and measured at different altitudes (from 1 to 100 m) by using a mast and a small tethered balloon. This allows determining the plume vertical dispersion in an urban area as a function of atmospheric turbulence. A sampling system was also used at ground (1 m height) in order to evaluate the plume horizontal dispersion. All these systems were placed at a distance from the emission point between 20 and 1150 m: 30 SF_6 emissions were performed between May 18 and May 27, 2010.

High compatibility was found between experimental horizontal and vertical widths of the plume and Briggs urban model for the stability class B, C and D according to Pasquill classification. However, this compatibility was only confirmed for small distances from the source (till 370 m). For higher distances from the source, it is hard to draw significant conclusions.
Keywords: atmospheric dispersion, experimental campaign, urban zone, Briggs urban model.

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1 Introduction

Chronic or accidental releases of radioactive contaminants in the environment could be transported to humans by the atmosphere, by fresh water, by marine water and by ground water. In case of accidental release the atmosphere present the faster way for the radionuclide to be transported to human. In fact, the radionuclide velocity in the atmosphere is higher than in other area (Crabol [2]). It is thus important to well understand and to predict the atmospheric dispersion of these contaminants. Several operational models could be recommended such as the models of Doury [3], Pasquill [4], ADMS (CERC [5]) and Briggs [6]. However, it is a difficult challenge to reduce the uncertainty of these models to obtain accurate predictions. Experimental database takes into account many environmental parameters (rural, urban, marine …) and the micrometeorology is necessary for increasing the model accuracy and for their validation.

In this paper we compare experimental measurements of ATC (Atmospheric Transport Coefficient) and horizontal and vertical standard deviation of a gas tracer SF_6 with a Gaussian model: Briggs urban model. The Briggs urban model predicts the ATC and the standard deviation of horizontal and vertical dispersion of a plume, defined from experimental campaigns held in St. Louis in 1962 (McElroy and Pooler [7]).

2 Experimental campaign

IRSN performed a number of releases at different distances from the sampling systems. The release location was chosen depending on the wind direction in order to have the sampling horizontal and vertical systems perpendicular to the axe of air direction. Figure 1 shows the studied area in the city of Nantes (west of

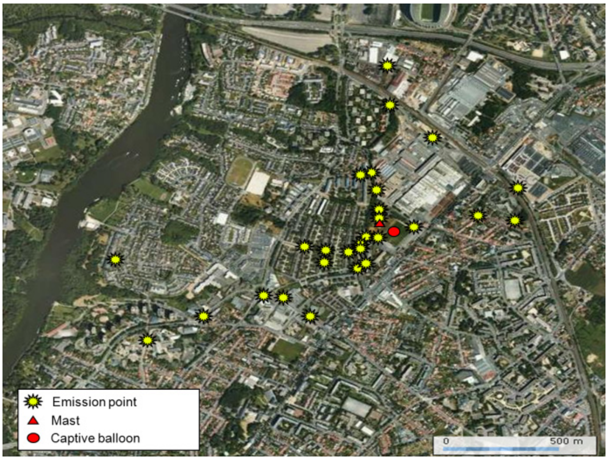

Figure 1: Location of mast/ balloon and releases point.

France). The distance from the emission point to the sampling system varied between 20 and 1150 m. Total number of emissions was 30 and exploitable ones was 25 (the five non exploitable emissions was due to the change of the wind direction during the measurements).

2.1 Atmospheric tracer release

As a gas tracer, the SF_6 (sulphur hexafluoride) was chosen because it is a passive and anthropogenic gas. In addition, SF_6 could be detected at low concentrations (50 ppt). That is the reason why other authors have also chosen the SF_6 as a gas tracer for their experimental campaigns (Connan *et al*. [8], Finn *et al*. [9], Hanna and Baja [10], Britter *et al.* [11]). The release duration was 10 to 20 min for a flow rate from 0.1 to 5.9 g s^{-1}. An SF_6 cylinder (Messer SA, France) was used and was connected to a mass flowmeter (Sierra 820) calibrated for SF_6 gas. The system was installed into a car and the release was made through a tube fixed at the top of the car (1.5 m). A fan was placed near the release point to help the dispersion of the gas. In order to have a constant release rate an operator monitored the flow rate during the entire length of each release.

2.2 Sampling system and meteorological measurements

To measure the SF_6 concentration in the air at different altitude air sampling was performed using automated system composed mainly of a pump and a flow meter (DIAPEG). The samples are made in bags made of Tedlar bag of 1 l. The sampling time was 10 to 30 min. The bags were inflated from different altitude by using a mast: 6 sampling levels between 1 and 27 m; or by using a balloon: 6 sampling levels between 1 and 100 meter. The release point was chosen

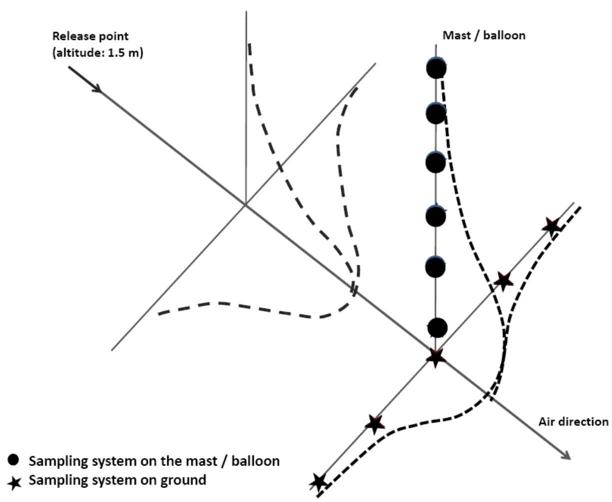

Figure 2: Position of horizontal and vertical sampling systems depending on the wind direction.

according to the wind direction in order to have the mast/ balloon in the wind axis direction. Other sampling systems were placed horizontally perpendicular to the axe of the wind (Figure 2). The location of each sampling device was determined by using a GPS. To calculate the SF_6 concentration, a gas chromatography system was used. For more information on the chromatography system the reader can check (Connan *et al.* [8]).

At the top of the mast (27 m height) an ultrasonic anemometer (Metek, USA1) was used to give the meteorological information: wind direction and velocity. These data allowed the calculation of turbulence parameters: friction velocity u∗, kinematic heat flux H, Monin–Obukhov length LMO. The LMO was used to obtain the stability class according to Pasquill classification.

3 Briggs urban model

Briggs urban model is Gaussian plume atmospheric dispersion model and requires a short calculation time Briggs G.A. [6, 12]. Briggs urban model is used to predict the Atmospheric Transfer Coefficients ATC (see section below) and the vertical and horizontal dispersion of a plume.
Standard deviation calculated with Briggs urban model depends on the distance of measurements and stability conditions.

The equation of the standard deviation considering rural/urban area has been determined from experimental campaigns (equation (1)):

$$\sigma_{y,z} = a_{y,z} x (1 + b_{y,z} x)^{c_{y,z}} \qquad (1)$$

y and *z* indicated respectively the horizontal and the vertical standard deviation, *x* is the distance to the release, *a, b* and *c* depend on the stability conditions as given by the Pasquill model and on the area (rural or urban).

4 Experimental data

The Atmospheric Transfer Coefficients (ATC) could be calculated by using the measurements of SF_6 and is defined by equation (2):

$$ATC = \frac{\int_{t_0}^{t_1} X(M,t).dt}{\int_{t_0'}^{t_1'} q(t).dt} \qquad (2)$$

where X(M,t) is the SF_6 concentration (ppb), q(t) is the SF_6 release rate in $m^3.\ s^{-1}$, t_0 and t_1 are the start and finish times of the measurement and t'_0 and t'_1 are the start and finish times of source emission in seconds.

The horizontal and vertical standard deviations of the plume dispersion is obtained by fitting a Gaussian curve respectively to the experimental data of the ATC with respect to the distance perpendicular to the axe of the wind direction and by fitting a Gaussian curve to the ATC with respect to the altitude. The horizontal and vertical standard deviations are then deduced from the fitted Gaussian curves Maro *et al.* [13].

Figure 3 and 4 show an example for the horizontal and vertical profiles of ATC respectively with fitted Gaussian curves.

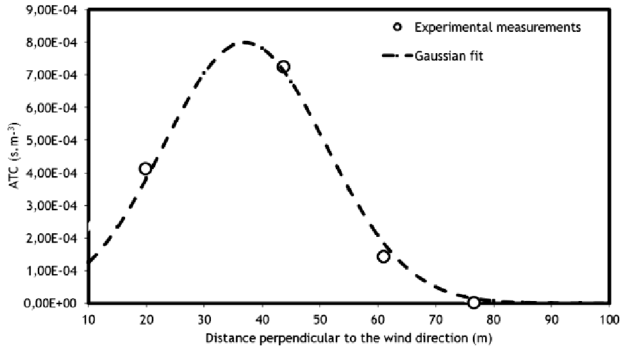

Figure 3: ATC (m.s^{-3}) with respect to the distance perpendicular to the wind direction experimental measurements and fitted Gaussian curve.

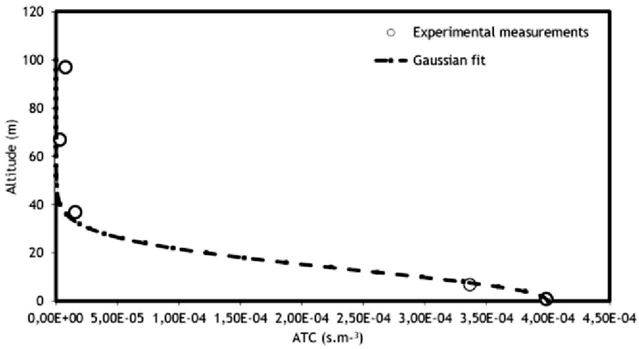

Figure 4: ATC (m.s^{-3}) with respect to altitude (m): experimental measurements and fitted Gaussian curve.

Table 1 shows the horizontal and vertical standard deviation and the maximal horizontal ATC calculated with equation (2) for each experiment (different distances from release point), for stability class B according to Pasquill classification.

For high distances, fitting a Gaussian curve was not possible so the standard deviation (horizontal/vertical) could not been obtained this will be discussed in the next section.

Table 1: Experimental ATC ($s.m^{-3}$), σ_y (m) and σ_z (m) deduced for each release for a stability class B according to Pasquill classification.

Date	Distance from release (m)	Stability class	ATC ($s.m^{-3}$)	σ_y (m)	σ_z (m)
18/05/11	170	B	4.43×10^{-5}	54	
19/05/11	20	B	8.73×10^{-4}	5	5
19/05/11	43	B	5.50×10^{-4}	18	43
20/05/11	130	B	2.36×10^{-5}	40	130

Table 2 shows the horizontal and vertical standard deviation and the maximal horizontal ATC calculated with equation 2 for each experiment (different distances from release point, for stability class C according to Pasquill classification.

Table 2: Experimental horizontal ATC ($s.m^{-3}$), σ_y (m) and σ_z (m) deduced for each release for a stability class C according to Pasquill classification.

Date	Distance from release (m)	Stability class	ATC ($s.m^{-3}$)	σ_y (m)	σ_z (m)
25/05/11	200	C	7.72×10^{-5}	32	35
25/05/11	230	C	2.56×10^{-5}	42	
25/05/11	120	C	4.25×10^{-4}	28	20
26/05/11	320	C	1.75×10^{-6}	58	50
26/05/11	130	C	7.86×10^{-5}	35	34

Table 3: Experimental horizontal ATC ($s.m^{-3}$), σ_y (m) and σ_z (m) deduced for each release for a stability class D according to Pasquill classification.

Date	Distance from release (m)	Stability class	ATC ($s.m^{-3}$)	σ_y (m)	σ_z (m)
26/05/11	330	D	4.92×10^{-5}	50	
26/05/11	154	D	1.40×10^{-4}	24	20
27/05/11	40	D	7.25×10^{-4}	12	10
27/05/11	124	D	0.90×10^{-4}	18	
27/05/11	367	D	1.52×10^{-5}	59	45

Table 3 shows the horizontal and vertical standard deviation and the maximal horizontal ATC calculated with equation 2 for each experiment (different distance from release point), for stability class D according to Pasquill classification.

5 Results

5.1 Comparison of standard deviations (horizontal / vertical) between experimental measurements and calculated with Briggs urban model.

Figure 5 shows a comparison between horizontal standard deviation σ_y (m) obtained with the experimental measurements and those calculated with Briggs urban model as function of distance from release point for the three stability class B, C and D according to Pasquill classification. Good coherence for the stability conditions B, C and D appears. For distances higher than 370 m, the horizontal standard deviation could not been obtained because fitting a Gaussian curve was not possible. This is due to the fact that the distance between two horizontal sampling systems was fixed to 20 m during the experiments so when the release point is far from sampling systems the measured concentrations of SF_6 have shown slight differences between each other.

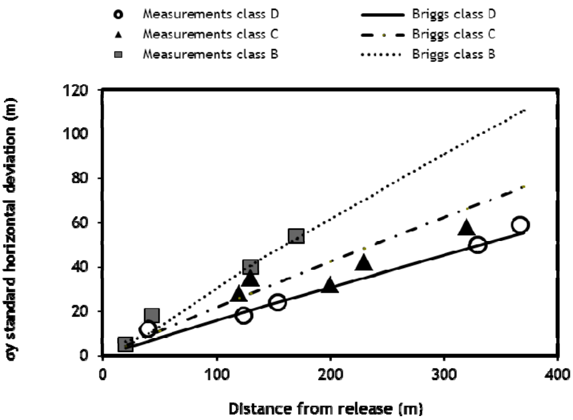

Figure 5: Horizontal standard deviation σ_y (m) deduced from experimental measurements compared to σ_y (m) calculated with Briggs urban model, for the different stability class according to Pasquill classification (B, C and D) as function of distance from release point.

Figure 6 shows a comparison between vertical standard deviation σ_z (m) obtained with the experimental measurements and those calculated with Briggs urban model as function of distance of release point for the three stability class B, C and D according to Pasquill classification. Good coherence for the stability conditions B, C and D appears. However, the vertical standard deviation as the horizontal one could not been obtained for higher distances than 370 m because the vertical sampling system was not high enough when the release point was far. In fact, the obtained ATC values have shown slight differences between each other so fitting a Gaussian curve was not possible in these cases.

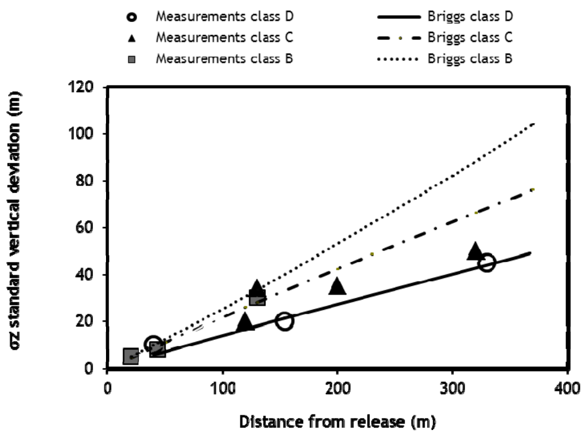

Figure 6: Vertical standard deviation σ_z (m) deduced from experimental measurements compared to σ_z (m) calculated with Briggs urban model, for the different stability class according to Pasquill classification (B, C and D) as function of distance from release point.

5.2 Comparison of horizontal ATC between experimental measurements and calculated with Briggs urban model

Figure 7 compares the ATC ($m.s^{-3}$) maximal obtained with the Gaussian curves fitted to experimental measurements for the three stability class B, C and D and calculated with Briggs urban model with respect to the distance from the release point. Trend curves added for each stability class show that in case of class B and C for atmospheric conditions the ATC decreases faster than for class D when the distance from the release point increases. No obvious difference could be confirmed between ATC trend curves for class C and class D.

The comparison between the trend curves obtained from experimental measurements shown in Figure 6 for the three stability class B, C and D with the Briggs urban model is shown in Figure 7. At small distances the curves obtained with the Briggs urban model converge quicker than the one obtained with experimental measurements. No difference is detected between class B and C with experimental measurements contrary to Briggs model were ATC decreases faster for class B. More measurements are needed at high distances to confirm or invalidate the non-difference between ATC with respect to the distance to the release point between class B and class C.

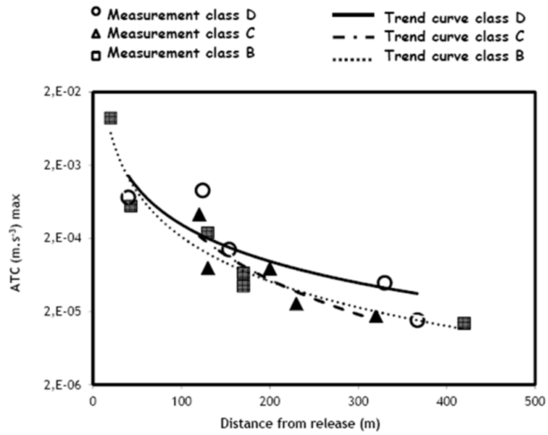

Figure 7: ATC (m.s^{-3}) maximal with respect to the distance from release point (m) for the three stability class B, C and D according to Pasquill classification.

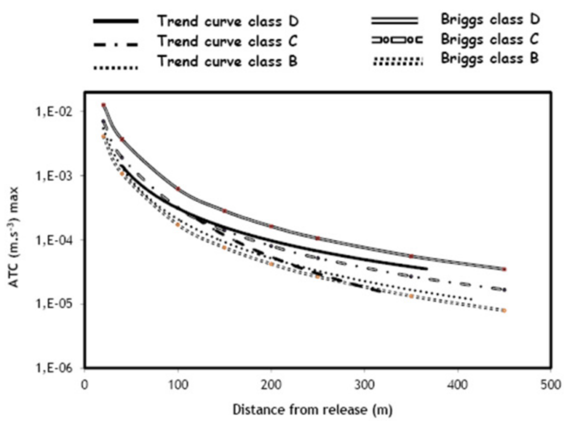

Figure 8: Comparison between trend curves of ATC (m.s^{-3}) max obtained from experimental measurements with Briggs urban model with respect to the distance from released point for the three stability class B, C and D according to Pasquill classification.

6 Conclusion

The experimental work in the city of Nantes helped preparing a data base that could be used to reduce the uncertainty for any 3D dispersion model in urban area. In this paper we compared our results: ATC max (s.m^{-3}), σ_y (m) and σ_z (m) with the values predicted with Briggs urban model.

In terms of horizontal standard deviation σ_y (m), a good agreement was found between experimental results and Briggs urban model for the three stability class

B, C and D according to Pasquill classification. However this agreement was only verified for distances between release point and sampling systems that did not accede 370 m. In fact the distance between two horizontal sampling systems was fixed to 20 m so when the release point was far from sampling systems the panache is expected to get larger. To detect a Gaussian form of the curve the more we get farer from the source the more sampling systems should be away from each other. This point will be taking into account during the next experimental campaign that takes place in the same city (Nantes) in June 2012.

In terms of vertical standard deviation σ_z (m), a good agreement was found between experimental results and Briggs urban model for the three stability class B, C and D according to Pasquill classification. However this agreement was only verified for distances between release point and sampling systems that did not accede 370 m. In fact the vertical sampling systems were not high enough and were not separated enough to detect a significant differences between measurements. This point will be also taking into account during the next experimental campaign that takes place in the same city (Nantes) in June 2012.

In terms of ATC, the comparison between the trend curves obtained from experimental measurements of the maximal ATC with respect to the distance from release point for the three stability class B, C and D with the Briggs urban model showed that Briggs urban model overestimate slightly the converge of the curves between the stability classes at small distances from the release point. No difference is detected between class B and C with experimental measurements contrary to Briggs model were ATC decreases faster for class B. More measurements are needed at high distances to confirm or invalidate the non-difference between ATC with respect to the distance to the release point between class B and class C.

Finally in case of accidental reject we recommend the Briggs urban model to estimate the horizontal and vertical standard deviation of the plume for distances that do not accede 370 m.

More experiment in the future will be held to evaluate the efficiency of Briggs urban model at higher distances. Also new experiments will be conducted to obtain better qualification of the plume widths principally as a function of roughness. Finally new experiments will be done in strong stability conditions.

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